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Integration of Delphi Technique and Analytical Hierarchy Process Method in Assessment the Groundwater Potential Influence Criteria: A Case Study of the Ba River Basin

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Abstract. Water is a boon for all living beings over the world and groundwater is considered one of the indispensable natural sources of potable water. It is necessary to assess and predict the groundwater potential to provide insights for decision-makers for proper planning and management of groundwater. The occurrence of groundwater depends on hydrological, ecological, climate, geological, and physiographical criteria. The purpose of the present study is to choose and attribute scores to all various factors that affected groundwater prospects in the Ba river basin. Firstly, the Delphi method was applied in the expert-based survey to choose six parameters that are considered as influencing factors, namely, lineament density, rainfall, slope, land cover, drainage density, and geology. Then, the weights for the various factors were generated using the Analytic Hierarchy Process (AHP) approach which allows the pairwise comparison of criteria influencing the potential areas. The consistency analyses show that the findings were consistent with a previous study. The consistency and sensitivity analyses showed that the obtained results were coherent, providing the weight vector of the achievable criteria that affect the groundwater prospect in the study area. The study reveals that lineament density and slope are criteria affecting the most prominent groundwater occurrence with 35.1% and 20.1%, respectively. However, the influence of other factors (rainfall, land cover, drainage density, and geology) is not visible. These criteria are assigned to the small weights and do not have a significant influence on the groundwater potential. The study results provide baseline information, which needs to be taken into account to control and manage groundwater potentiality.

Keywords: Ba river basin, AHP method, Delphi technology, Groundwater, Groundwater potential

1. Introduction

Water covers approximately 71% of the Earth's surface. However, there is a serious shortage of freshwater for drinking, agriculture, industries, and other purposes because 97% of the water on the earth is found in the oceans and seas, about 2% of water is in glaciers in the polar region, and remaining 1% is found in some forms of stream channels and groundwater [1]. The main sources of freshwater are only stream channels and groundwater. According to Ahmadi et al. (2021), groundwater potential supplies almost 30% of freshwater globally, and in general, 65% of groundwater is used for agricultural irrigation, 25% as drinking water, and the remaining 10% is utilized as industrial water [2]. Therefore, groundwater, which is stored in the subsurface geological formations, is one of the Nations' most important natural resources. In Vietnam, groundwater provides the water supply for more than half of Viet Nam's population. More than one-third of the urban population is dependent on groundwater, and almost two-thirds of the rural population [3]. It serves as a natural source for domestic, industrial, and agricultural uses and other developmental initiatives. With exponential growth in population and industrialization, overexploitation of groundwater has been made in many regions, which has contributed to subsequent declination in the groundwater level. Today, many areas around the world are facing a possibility of water scarcity, and shortly, the freshwater sources will depend more on available groundwater resources. The ever-increasing requirement of freshwater for meeting human demands and developments has imposed immense pressure on this limited freshwater resource. Hence, the management of freshwater is very significant to prevent severe water scarcity in arid and semi-arid regions [4] because groundwater remains the ultimate freshwater resource while sources of surface water have been depleted.

The occurrence, distribution, and availability of groundwater are dependent on the various natural and anthropogenic factors. Climate change severely affects the parameters influencing groundwater recharge. Hence, it is necessary to identify and understand which criteria cause groundwater level degradation and what the consequences can be. Different scientists have utilized various parameters for studying groundwater prospects such as Geomorphology, Lineament, Geology, Groundwater Depth, Drainage

Density, Soil, Land use/ Landover, Rainfall, slope, Distance from River, Fault Density, Lithology, Stream Frequency, Relief Ratio, Soil Depth, etc. [5-10]. However, it is rare to combine all criteria because of the non-availability of data. Hence, a sincere evaluation of these factors can give a clear understanding of the groundwater prospect of an area. In addition, assessment of these elements develops a general knowledge concerning the importance of every criterion for groundwater potential in different regions around the world [8]. This proves that determining the dominant influencing factors of groundwater recharge potential and assessing their important information of this rare natural source is indispensability. In other words, it is necessary to identify the major factors affecting groundwater recharge and how to quantify these factors. Using the Delphi-AHP method to survey critical parameters affecting groundwater occurrence and assess their importance in declining groundwater levels has been extensively utilized in groundwater potentiality relevant research.

According to Keeney et al. (2001), although sometimes the reliability of the results obtained from a Delphi method may increase some controversy because of the inappropriate design and study execution, such as shortcomings of the survey instrument, poor choice of experts, weak bias control, unreliable analyses, and limited feedback during the research [11], this approach remains a particularly useful option for the situation when objective data are unapproachable, there is a lack of empirical evidence, or experimental study is not realistic or dishonest [12]. The present study intends to detect prominent factors resulting in the degradation of groundwater level using a Delphi method. It also employs the AHP technique to determine the significance of the criteria in comparison with each other. The combined Delphi-AHP approach is also used in the detection of flood influence criteria in an ungauged basin in Brazil [13], in the identification of factors affecting flood hazard in Lam river basin [14] or in determining the weight of each index used to identify the flood-prone areas of Angkor, Cambodia [15] and the flood hazard ptential zone of Nghe An and Ha Tinh province, Vietnam [16] . It is worth saying that the AHP approach is successfully used for solving various problems in groundwater management worldwide [5-10]. This technique is assessed as an effective tool in the determination of the relative importance weight for each hierarchy element [5-10, 13, 15]. With the ability to handle both qualitative and quantitative data as well as the flexibility of the model, the AHP is considered as a powerful tool in calculating the weights of each factor using pairwise comparison matrix basis of judgment formation to support in generating groundwater potentiality maps with a good degree of accuracy. This study has two research objectives: (1) identify the essential factors affecting groundwater occurrence; (2) determine the perceived relative importance of these criteria. To achieve the objectives, this study employed both Delphi and analytic hierarchy process techniques. Delphi can generate new, valuable and reasonable ideas from the respondents, free from group intervention, and strengthening the research validity by enabling a heterogeneity of panelists to contribute without the restriction of geographical distance. AHP is a mathematical technique for pairwise comparisons of multi-criteria, providing relative weights based on the importance of each parameter. It is believed that the results of this study may be considered as a great database for planning and management for groundwater in the study area.

2. Research area

The Ba river basin is the largest river in central Vietnam with a $14x10^3$ km^2 drainage area, 390 km length and the river density is about 0.22 km/km^2 [17]. The Ba river basin is located in the central region of Vietnam and has an L-shaped shape. The study area lies approximately between $12^0$35'N to $14^0$38' N latitude and $108^0$00'E to $109^0$55' E longitude. The study area belongs to the administrative boundaries of 20 districts and one city of the three provinces in Central Highlands including Kon Tum, Gia Lai, Daklak, and the Southern Central coastal province of Phu Yen. The highland part of the Ba River drainage basin lies mainly on the central highlands of Vietnam, which includes series of contiguous plateaus with an average elevation of about 800m [18].

The rainfall increases from low to high regions and distributes unevenly in parts of the basin. Annually, the area receives a mean rainfall of 1740 mm. Along the river valley, there is a quite small rainfall, especially in Cheo Reo and Phu Tuc areas where the average annual rainfall does not exceed 1300 mm, meanwhile, the average annual rainfall can reach around 3000 mm upstream of Ba river and Hinh river. The air temperature increases gradually from north to south, from west to east, and from high to low region. The average annual temperature in the uplands is 21.5 – 23.5^{o}C, in the midland region is 25 - 26^{o}C, and in the downstream area is 21 – 26^{o}C. In the Ba river basin, air humidity is closely related to air temperature and precipitation. In the rainy season, the humidity can reach 80 - 90% but this value is only from 70 - 80% in the dry season months. The lowest air humidity can even be as low as 15-20% [18].

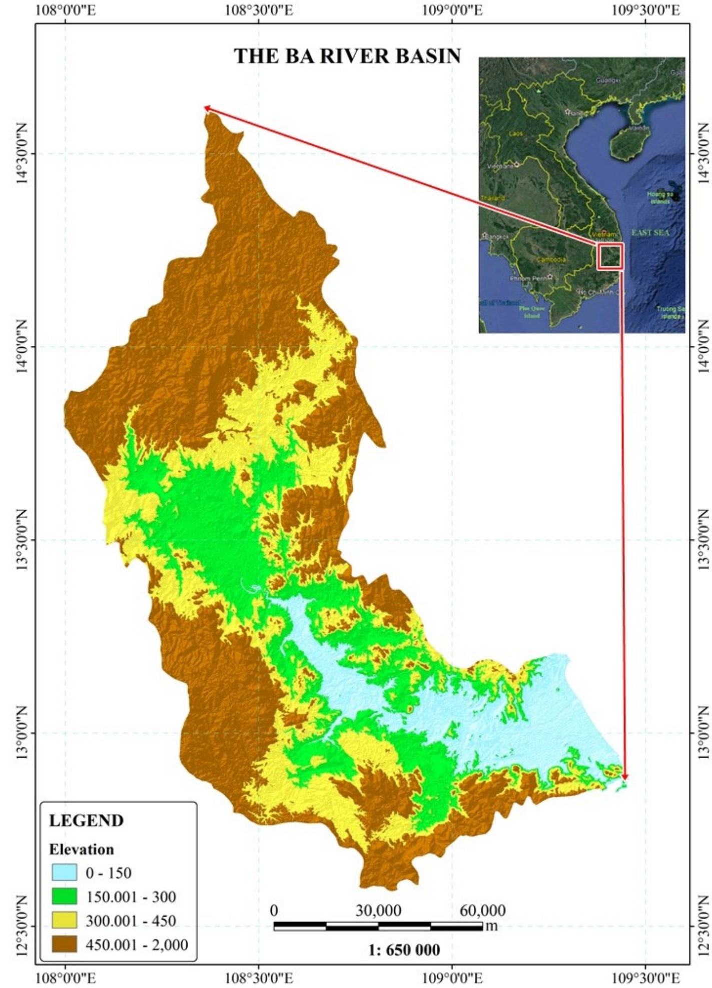

Fig. 1. Ba river basin

3. Methodology and Data

3.1 Methodology

The occurrence and movement of groundwater in an area are governed by several factors such as lithology, geological structures, soil, lineament features, slope, drainage pattern, geomorphology, land use/land cover, etc., and the interrelationship between these factors [19]**.** These can be divided into three following groups:

Group 1: physical geography factors, for example, lineament features, geological structures rainfall, slope, elevation, drainage density, geomorphology, etc.

Group 2: socio-economy factors, for example, land use, land cover, population density, etc.

Group 3: infrastructure factors, for example, irrigation facilities, reservoirs, etc.

In the groundwater potential zone determination studies, many factors related to groundwater storage based on geologic, hydrologic, hydrogeological, meteorological, and terrain features were used as decision criteria for analyzing groundwater potentiality. According to Yıldırım (2021), selecting the criteria influencing groundwater storage potential depends on the conditions of the region and available data [20]. This paper applies the Delphi method to determine the main factors affecting groundwater occurrence and uses the AHP approach to determine the weights of these main criteria. The combination of Delphi and AHP can determine weight values and increase the objectivity and accuracy of indicators and their relevant variables [21]. The model for the selection of parameters influencing the groundwater potential and assessment of their importance consisted of three stages: (1) identification of the criteria to be used in the model for evaluating the level of influence using the Delphi technique, b) AHP computation, and c) evaluation of alternatives to determine the final ranking. AHP was applied to give weights and to find the importance degree of each criterion. In the third stage, a ranking of alternatives was done. Fig. 2 shows a flow chart of the study

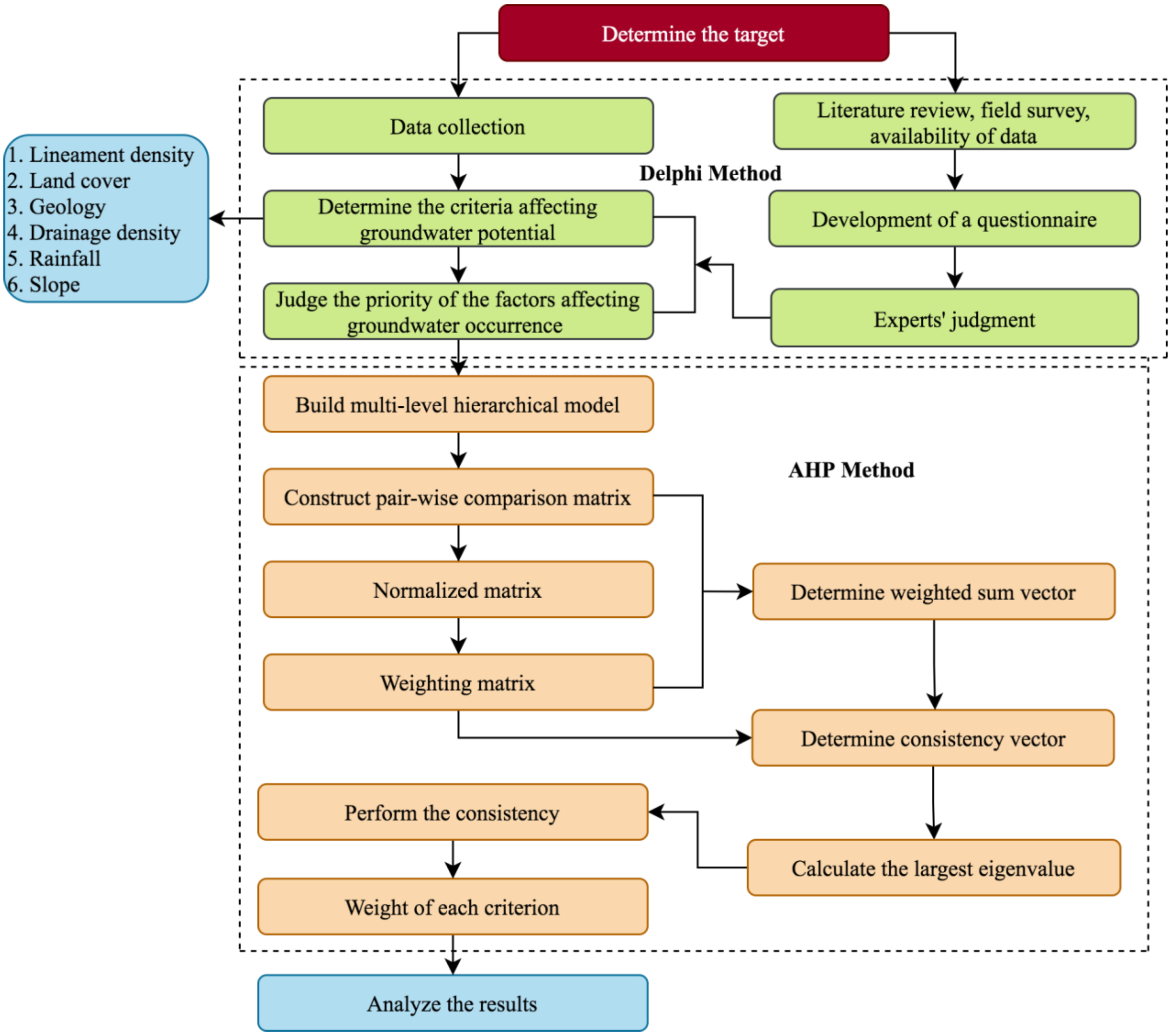

Fig. 2. Flow chart of the study

3.1.1 Delphi method

The Delphi technique was first developed by RAND Corporation in the United States in the 1950s. This technique has been depicted as a method well-suited for consensus-building through the utilization of a series of questionnaires distributed using multiple iteration processes to collect data from a panel of selected experts [22]. It is considered as a qualitative, long-range forecasting approach by some or a mixture of both qualitative and quantitative techniques by some others [23]. This method has been used in a variety of applications, such as planning, environmental impact assessment, social policy, flood hazard, and public health. The wide use of this technique has led to significant deviations from the original technique and the creation of a family of Delphi- related processes [24]. However, the Delphi technique has not yet been widely used in the determination of groundwater potentiality. Since this method is an iterative process designed to achieve consensus among a group of experts on a particular topic, the Delphi approach is the most effective means of querying experts to identify factors causing groundwater decline and depletion. The Delphi method comprises the following steps [25]:

(1) Design the questionnaire and select the experts

(2) Perform the first-round survey of anonymous experts
(3) During the first round survey, provide the experts with the opinion of the others

(4) According to the survey of the first round, request that each expert answer again the first round problem while observing whether new solutions are proposed or different perspectives are set forth.

(5) Synthesize expert opinion and reach a consensus

(6) Repeat steps (3) and (4) until a uniform result is achieved for a particular topic [25].

According to Song et al., the principle of selecting the questionnaire respondents is that they are expected to be professionals with the following qualifications: (1) Relevant education background; [26] (2) Practical experience and abundant expertise in geomorphology, geology, geography, hydrology, water resources, geomatics, soil, environment, metrological; Having been in the relevant fields for a long time and relevant qualification.

3.1.2 AHP method

AHP approach, developed by Saaty (1980), has been studied extensively and used in several applications for many years [27]. The wide AHP applicability is because of its simplicity, ease of use, and great flexibility. The AHP methodology primarily consists of (1) structure the decision into objectives and alternatives; (2) measure objectives and alternatives using pairwise comparison; (3) synthesize objectives; and (4) exploit subjective inputs to reach a prioritized list of alternatives [28].

In the first stage, the assessment criteria were identified and finalized by the Delphi method. Next, the decision hierarchy was created with the main criteria and alternatives. In this stage, the objective was at the first level, criteria at the second, and then ranking of alternatives at the third level of the hierarchy. In the generation of hierarchical structures, it should be noted that human perception is limited. According to George Miller, people can generally deal with seven facts at once, plus or minus two [29]. Therefore, in the AHP approach, several criteria at a given hierarchical level as well as the number of hierarchical levels themselves, for a given study issue should range from 5 to 9 criteria. The number of factors outside that range will lead to an unreliable evaluation. This study mentioned six factors as the main causative parameters for the groundwater decline which are related to the first group, physical geography.

Tab. 1. Fundamental scale of Saaty

Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one over another
5	Strong importance	Experience and judgment strongly favor one over another
7	Very strong importance	Activities are strongly favored and their dominance is demonstrated in practice
9	Extreme importance	Importance of one over another affirmed on the highest possible order
2, 4, 6, 8	Intermediate values	Used to represent a compromise between the priorities listed above

The elements used in groundwater potential assessment would be weighted using AHP in the next step. For this, a pairwise comparison matrix was created to calculate the factors' weights and determine their rankings. To determine the values of the parameters of pairwise comparison matrices A, let $C_1, C_2, \ldots, C_n$ denote the set of elements, while a_{ij} represents a quantified judgment on a pair of elements Ci and Cj. The relative importance of the two elements is rated using a Saaty's scale with the values are presented in Table 1 [27]. This yields an nxn matrix A as follows:

$$A = [a_{ij}] = \begin{array}{c} C_1 \\ C_2 \\ \dots \\ C_n \end{array} \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \quad (1)$$

where, $a_{ii} = 1$; $a_{ji} = \frac{1}{a_{ij}}$; $a_{ij} \neq 0$; i, j = 1, 2, 3,… , n. In matrix A, the problem becomes assigning to the n elements $C_1, C_2,…, C_n$ a set of numerical weights $W_1, W_2,…, W_n$ that reflect the recorded judgments.

The relative weights are given by the right eigenvector w corresponding to the largest eigenvalue max (λ) as in Equation (2).

$$A_w = \lambda_{max} * w \quad (2)$$

The consistency measures used for the eigenvector method in the AHP is the consistent index (CI) proposed by Saaty (1980). The expressions for this measure are:

$$CI = (\lambda_{max} - n) / (n - 1) \quad (3)$$

where λ_{max} is the largest eigenvalue derived from the paired comparison matrix, n is the number of criteria or sub-criteria.

For calculating the consistency ratio (CR), the following equation was applied:

$$CR = CI / IR \quad (4)$$

RI is the random consistency index that is shown in Table 2.

If the value of consistency ratio is equal to 10% or smaller (CR <= 0.1), the inconsistency is acceptable. If the consistency ratio exceeds 10% (CR> 0.), it is necessary to revise the subjective judgment to locate the cause of the inconsistency and correct it [30].

Tab. 2. Random Index (RI) used to compute consistency ratios (CR)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3.2 Data

A judgment from an experienced individual and his/her thorough understanding can be a reliable information source to provide opinions. Furthermore, to avoid bias, it is necessary to utilize more than one expert [31]. The Delphi-AHP model's primary data were obtained via expert Choice Matrix and were given to 50 specialists with experience in groundwater management from various agencies or departments in Vietnam and other countries. The study conducts two rounds and the second one is four months away from the first round. The main purpose of the survey was to determine the opinion of scholars for their priorities on likely affect groundwater potential, which occurs in the Ba river basin. Table 3 shows the survey respondents by expertise in eight fields.

Tab. 3. The survey respondents by expertise.

No.	Expertise	Number	Percentage
1	Hydrology	6	12%
2	Water resources	8	16%
3	Geology	7	14%
4	Soil	6	12%
5	Environment	5	10%
6	Geography	8	16%
7	Metrological	5	10%
8	Geodesy	5	10%
Total		50	100%

4. Results and discussion

4.1 Questionnaire survey

The questionnaire survey was established in Vietnamese and English language with clear and easy to understand questions. The questionnaire elicits the respondents' viewpoint about the criteria affecting groundwater occurrence in the Ba river basin, their influence degree as well importance. The main content of these questionnaires focuses on 2 following key objectives: First, based on the profound knowledge and experience, the experts selected groundwater potentiality impacts parameters in the Ba river basin. The answer for each question was divided into main five degrees: (1) Very Little Probability; (2) Little Probability; (3) Average Probability; (4) High Probability; (5) Very High Probability. Second, the experts were expected to rank the factors chose from the first question by comparing two elements at a time using a pair-wise comparison matrix based on Saaty's fundamental scale of judgment.

The validity of the questionnaire related to the groundwater potential was then confirmed by returned results from 10 experts in water resources, hydrology, and soil. The review of the questionnaire helped us to correct unclear questions to ensure that respondents understood the questions and give consensus opinions on the groundwater impacts criteria. In this research, experts are selected following the principle: (1) have more than five years of experience in the field related to groundwater; (2) were interested and willing to participate in our study; and (3) have no direct conflict of interest with this study. Through a literature review of scientist publications, we chose some experts who are appropriate to contribute their judgment to this study. As a result, 50 academics with research interests match the objectives of the current study who were invited to take part in the study. We sent an email, had a face-to-face, and made a phone call to introduce the study area, the criteria as well as the implications of each criterion affecting groundwater occurrence and distribution to the contributors.

Tab. 4. Evaluation of the criteria discussed in the last round

No.	Criteria	Concepts raised in the survey	Evaluation
1	Rainfall	The rainfall controls the groundwater recharge of a region	This factor is appropriate to be used in the study. Data is available from rain gauge stations distributed around the Ba river basin.
2	Slope	This parameter affects the speed and flow of water	This parameter is considered suitable for the study. It might be acquired through a Digital Elevation Model (DEM), which is available for the research region.
3	Drainage density	Drainage density is an inverse function of permeability and it indicates the runoff and infiltration of the specific region.	This alternative was judged meet to be applied in the study. It might be accomplished through the river network, a DEM, or topographic map in the Ba river basin
4	Lineament Density	This criterion shows rainfall penetration into the ground as well as controls the movement and storage of the groundwater	This criterion was appropriated essential for this study. It might be resolved using a DEM or topographic map which is gettable in the study area.
5	Land use	This factor impacts runoff, evapotranspiration, and soil infiltration rate, water retention, soil protection capacity, the interrelationship between surface runoff, and groundwater.	This is a necessary criterion and it should be used in the study. It may be achieved by using a current land use map or satellite image.
6	Geology	This element influences the nature of flow, erosion, and sediment transportation	This is a necessary criterion and it should be used in the study. It may be achieved by using a geological map

50 questionnaires were then sent to experts on hydrology, geology, meteorology, water resources, environment, geodesy, soil, and geography from the government offices, academia, university in Vietnam, and foreign. The distribution of the questionnaire to experts who are located in different regions and various

fields leads to reduce the bias in assessing the alternative groundwater potential criteria [32]. In this study, we sent multiple questionnaires in many different rounds to the experts with a request to appreciate and choose factors that can contribute to forming groundwater. The experts and scholars were required to rate the importance of the proposed factors, and the numbers 1–9 were employed to illustrate the importance of the indexes. The larger the number is, the more important it is. For example, the number 9 means that it is very important while number 1 reveals that it is very not important).

In the first Delphi survey, there were 45 returned questionnaires (meet 90% responses). From the results of the first survey, 5 out of the 25 indicators were excluded from the scale for the following reasons. First, some factors were not entirely related to the groundwater potential. Second, some criteria overlapped or have similar properties. In addition, the panelists' comments suggested that some attributes were not understood or explicitly presented. Consequently, 20 criteria were measured in the second survey. To ensure the validity of the Delphi method, only respondents who participated in the first survey were invited to join the remaining survey rounds. After multiple rounds of information feedback, almost all experts think that many important parameters influence groundwater generation, but six of them are the most preferred alternatives in creating these resources including rainfall, slope, drainage density, lineament density, land cover, and geology. Table 4 shown experts' opinions in the evaluation of the selected criteria affecting groundwater potential in the final round to give final decisions.

Tab. 5. The summarized results the priority of the factors affecting groundwater potential.

No.	Pairwise Comparison Factors	Average Mark	No.	Pairwise Comparison Factors	Average Mark
1	Lineament Density and slope	2	19	Geology and Lineament Density	-3
2	Lineament Density and rainfall	2	20	Geology and Slope	-2
3	Lineament Density and Geology	3	21	Geology and Rainfall	-2
4	Lineament Density and Drainage Density	5	22	Geology and Drainage Density	2
5	Lineament Density and Land use	7	23	Geology and Land use	7
6	Lineament Density and Lineament Density	1	24	Geology and Geology	1
7	Slope and Lineament Density	-2	25	Drainage Density and Lineament Density	-5
8	Slope and Rainfall	1	26	Drainage Density and Slope	-3
9	Slope and Geology	2	27	Drainage Density and Rainfall	-2
10	Slope and Drainage Density	3	28	Drainage Density and Geology	-2
11	Slope and Land use	5	29	Drainage Density and Land use	7
12	Slope and Slope	1	30	Drainage Density and Drainage Density	1
13	Rainfall and Lineament Density	-2	31	Land use and Lineament Density	-7
14	Rainfall and Slope	1	32	Land use and Slope	-5
15	Rainfall and Geology	2	33	Land use and Rainfall	-5
16	Rainfall and Drainage Density	2	34	Land use and Geology	-7
17	Rainfall and Land use	5	35	Land use and Drainage Density	-7
18	Rainfall and Rainfall	1	36	Land use and Land use	1

4.2 Determination of the weights of criteria affecting groundwater potential

The AHP aimed to weight each indicator in this study after determining six factors influencing groundwater potential by the Delphi method. The decision-makers show preferences or priority for each element in comparison to other factors. The study used six main factors in relation to creating groundwater, thus decision-makers prepare to get relative importance in each level of hierarchy through 6*(6-1) comparisons. The results of the average evaluation of the priority of the criteria influencing groundwater occurrence are listed in Tab. 5.

The final pairwise comparison matrix is presented in Tab. 6 by the 6 x 6 matrix, where diagonal factors are equal to 1. The values of each row are compared with each column to show the relative importance to achieve a rating score. For example, lineament density is significantly more important from land use and thus assigned the value 7. The row describes the importance of the land use, hence the row has the inverse value of the pairwise comparison (e.g. 1/7 for lineament density). The score matrix was then normalized to obtain the corresponding weight of each criterion. The weight of each factor was calculated by taking the average value of the corresponding row in the normalized matrix.

Tab. 6. Pairwise comparison matrix for six factors influencing Groundwater potential

Factors	Lineament Density	Slope	Rainfall	Geology	Drainage Density	Land use
Lineament Density	1	2	2	3	5	7
Slope	1/2	1	1	2	3	5
Rainfall	1/2	1	1	2	2	5
Geology	1/3	1/2	1/2	1	2	7
Drainage Density	1/5	1/3	1/2	1/2	1	7
Land use	1/7	1/5	1/5	1/7	1/7	1

Each factor was weighted by the AHP method. The higher the weight was, the more important the indicator was [33]. In the first-rank indicators, the weight of the "lineament density" was 35.1%, followed by a "slope" of 20.1%. More details were shown in Table 7. This revealed that the experts regarded the lineament density and slope as the most frequent impact of groundwater occurrence compared with the other factors. The overall result of AHP analysis (Tab. 8) shows that the consistency ratio (CR) is 0.05, which is much lower than the threshold value of 0.1 and this also indicates a high level of consistency in the pair-wise judgments. Hence, the weights (Tab. 7) are acceptable.

Tab. 7. The weight of influential criteria.

Parameters	Weight
Lineament density	0.351
Slope	0.201
Rainfall	0.186
Geology	0.134
Drainage density	0.096
Land use	0.030

Tab. 8. Parameters of AHP.

Parameters	Value
Eigenvalue of a matrix (λ_{max})	6.31
The number of criterion (n)	6
Consistency index (CI)	0.062
Random index (RI)	1.24
Consistency ratio (CR)	0.05

However, our obtained results have some limitations. First, it was challenging to develop a set of criteria affecting groundwater potential that apply to all various areas in the world. Most experts came from Vietnam, and the included literature was only in Vietnamese and English. Second, AHP scores were calculated subjectively by experts, and the weights were mainly based on the judgment of the experts' experience [34], without objective data to prove. Next, experts' opinions might not have been adequately included. These factors set mainly considered literature and expert's experience, without consultation of residents living in areas of shortage and depletion of groundwater. Finally, although details of the survey were described fully in the questionnaire, experts might vary in their understanding of the questionnaire because the survey was mainly conducted by mail instead of face-to-face. To reduce the limitation of identifying criteria affecting groundwater potential and assessing their influence level, face-to-face meetings with experts should be increased. In particular, it is necessary to collect opinions from people living in the study area. These ideas will be a useful information channel to contribute to better results.

5. Conclusion

The current study developed the set of criteria affecting groundwater occurrence in the Ba river basin.

This study was conducted in three rounds. There are 50 experts of eight relevant fields with different ages and years of experience in groundwater management to participate in the Delphi study. Six factors including lineament density, rainfall, slope, land cover, drainage density, and geology were selected as indicators for the groundwater potentiality assessment. Furthermore, each indicator was weighted and ranked and had an acceptable consistency ratio based on the AHP approach. The obtained results revealed that the lineament density is the main criterion of creating groundwater with the highest weight of 0.351 was assigned while the lowest weight of 0.03 to the land use.

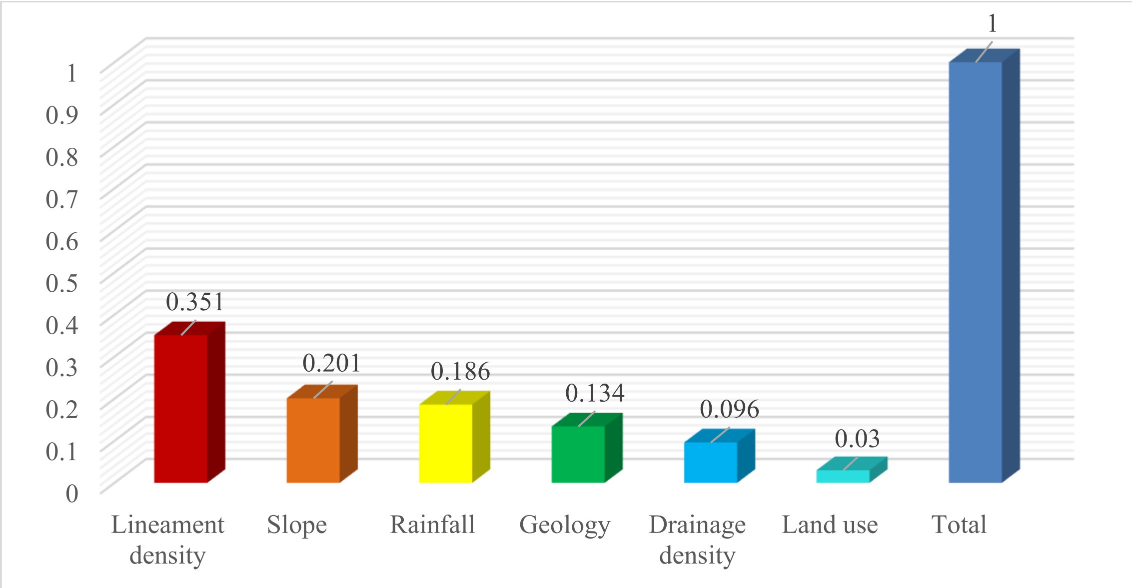

Fig. 3. The weight of criteria affecting groundwater potential in Ba river basin

Although there are some limitations, it can be confirmed that a combined AHP-Delphi method provides a powerful tool for decision-making procedures in groundwater potential analysis. This study describes that the Delphi method is a useful tool for querying and achieving consensus among a group of experts on the major factors affecting groundwater formation. The AHP method was found useful in transforming the preference of all participants regarding each determining factor into a numerical scale. Such scale was then aggregated to produce a numeric indicator that can use to prioritize factors causing groundwater shortage and depletion of groundwater in the study area. Finally, we conclude that the Delphi-AHP method is beneficial to define significant criteria that can impact groundwater generation. In the future, further research is necessary to investigate the applicability of established criteria and the generalizability of these results to other studies.

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