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Research Article
Prioritization of Factors Impacting on Water Security using Analytic Hierarchy Process Method

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Abstract

Background and Objective: Water Source Security (WSS) is one of the key challenges for many countries due to climate change, limited water supply and growing water demand. The objective of this study was to find out the important factors which influence the security of water sources in the mainstream of the “Da” River, Vietnam. **Materials and Methods:** In this study, three groups of factors affecting WSS were considered including, (1) Policies and mechanisms factors, (2) Water demand factors and (3) Natural factors. Fuzzy analytic hierarchy process method was applied to quantify the factors which influence WSS. The input data were collected by means of face-to-face interviews with water resources experts. **Results:** The results show that the group of natural factors were the most affecting group to water security, followed by the group of mechanism and policy factors and group of water demand factors. **Conclusion:** This study has found out the most affecting group to WSS using the fuzzy AHP approach. The results obtained from this study may serve as a reference for policy makers in water resources management.

Key words: Analytic hierarchy process, water source security, water resources management, fuzzy numbers, “Da” river, factors

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Water Source Security (WSS) poses one of the biggest challenges of the 21st century. Water security is defined as the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies[1]. Due to changing climate, limited water supply and growing water demand, humanity faces the prospect of uncertain future water supplies[2-4]. It was estimated that the world would face a 40% shortfall of water supply in the next 15 years[5]. This shows that the assurance of water source is becoming an urgent and pressing issue for many countries.

Many studies have looked at different aspects of WSS[1-4,6-13]. However, a limitted studies has investigated the WSS in Vietnam, especially the studies on risks of water insecurity in the river basin[14].

Now a days, Vietnam is facing a major challenge of WSS due to the uneven distribution of water sources, environmental pollution and declining water source in both quantity and quality and a strong reliance on external water sources. In addition, under the impact of industrialization, modernization, population pressure, urbanization, rising food demand, the shrinking of agricultural land and watershed forests are happening in a complex way, which has made the security of water supply in some places seriously threatened[14]. To overcome this situation, systematic and consistent measures must be taken throughout the river basin with a view of water resources management, water decrease management. Meanwhile, Vietnam does not have a legal tool with sanctions strong enough to protect and guarantee water supply security, sustainable development, environmental protection, ecosystems.

Fuzzy Analytic Hierarchy Process (AHP) is one of the most widely used tools for multiple criteria decision-making. Recent applications of fuzzy AHP methods are found[15-24]. Among the existing AHP approaches, the extent analysis method proposed by Chang[25] is a commonly used approach that is highly cited and has wide applications.

The objective of this study was to apply the fuzzy AHP technique proposed by Chang[25] to determine the important factors affecting WSS in Vietnam.

MATERIALS AND METHODS

Fuzzy sets theory: This study reviews some basic notions and definitions of fuzzy sets and fuzzy numbers as follows[26,27]:

Definition 1: A real fuzzy number A is described as any fuzzy subset of the real line R with membership function f_A that can be generally be defined as:

(a) f_A is a continuous mapping from R to the closed interval $[0, \varpi]$, $0 \leq \varpi \leq 1$
(b) $f_A(x) = 0$, for all $x \in (-\infty, a]$
(c) f_A is strictly increasing on $[a, b]$
(d) $f_A(x) = \varpi$, for all $x \in [b, c]$
(e) f_A is strictly decreasing on $[c, d]$
(f) $f_A(x) = 0$, for all $x \in (d, \infty]$

where, a, b, c and d are real numbers. Unless elsewhere specified, it is assumed that A is convex and bounded (i.e. $-\infty < a, d < \infty$).

Definition 2: The fuzzy number $A = [a, b, c, d, \varpi]$ is a trapezoidal fuzzy number if its membership function is given by:

$$f_A(x) = \begin{cases} f_A^L(X) & a \leq x \leq b \\ \varpi & b \leq x \leq c \\ f_A^R(X) & c \leq x \leq d \\ 0 & \text{otherwise} \end{cases}$$

where, $f_A^L: [a, b] \rightarrow [0, \varpi]$ and $f_A^R: [c, d] \rightarrow [0, \varpi]$ are two continuous mappings from the real line R to the closed interval $[0, \varpi]$. If $\varpi = 1$, then A is a normal fuzzy number, otherwise, it is said to be a non-normal fuzzy number. If $f_A^L(x)$ and $f_A^R(x)$ are both linear, then A is referred to as a trapezoidal fuzzy number and is usually denoted by $A = (a, b, c, d, \varpi)$ or simply $A = (a, b, c, d)$ if $\varpi = 1$. In particular, when $b = c$, the trapezoidal fuzzy number is reduced to a triangular fuzzy number and can be denoted by $A = (a, b, c, d, \varpi)$ or $A = (a, b, d)$ if $\varpi = 1$. So, triangular fuzzy numbers are special cases of trapezoidal fuzzy numbers.

Fuzzy analytic hierarchy process methodology: This study adopted the extent analysis method proposed by Chang[25] due to its computational simplicity. The extent analysis method is briefly discussed as follows.

Let $X = \{x_1, x_2, ..., x_n\}$ be an object set and $U = \{u_1, u_2, ..., u_m\}$ be a goal set. According to Chang[25], each object is taken and an extent analysis for each goal (g_i) is performed, respectively. Therefore, the m extent analysis values for each object are obtained as:

$$M_{g_i}^1, M_{g_i}^2, ..., M_{g_i}^n, i = 1, 2, ..., n$$

where, $M_{g_i}^j\ (j = 1, 2, ..., m)$ are triangular fuzzy numbers (TFNs).

Assume that $M_{g_i}^j$ are the values of extent analysis of the ith object for m goals. The value of fuzzy synthetic extent S_i is defined as[25]:

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right]^{-1} \quad (1)$$

where,

$$\sum_{j=1}^{m} M_{g_i}^j = \left[\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right], j = 1, 2, ...m, i = 1, 2, ...n$$

Let $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ be two TFNs, whereby the degree of possibility of $M_1 \geq M_2$ is defined as follows[25]:

$$V(M_1 \geq M_2) = \sup_{x \geq y}\left[\min(\mu_{M_1}(x), \mu_{M_2}(x))\right] \quad (2)$$

The membership degree of possibility is expressed as[25]:

$$V(M_1 \geq M_2) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) = \begin{cases} 1 & \text{if } m_1 \geq m_2 \\ 0 & \text{if } l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases} \quad (3)$$

where, d is the ordinate of the highest intersection point of two membership functions $\mu_{M1}(x)$ and $\mu_{M2}(x)$, as shown in Fig. 1.

The degree of possibility for a convex fuzzy number to be greater than *k* convex fuzzy numbers is defined as[25]:

$$V(M \geq M_1, M_2, ..., M_k) = \min V(M \geq M_i), i = 1, 2, ..., k \quad (4)$$

The weight vector is given by Chang[25]:

$$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^T \quad (5)$$

where,

$$A_i (i = 1, 2, ..., n), d'(A_i) = \min V(S_i \geq S_k), \ k = 1, 2, ..., n, \ k \neq i \quad (6)$$

Via normalization, we obtain the weight vectors as[25]:

$$W = (d(A_1), d(A_2), ..., d(A_n))^T \quad (7)$$

where, W is a non-fuzzy number.

In this present case, Chang[25] method is applied to determine the level of impact of factors on WSS. We adopt a "Likert Scale" of fuzzy numbers starting from 1-9 to transform the linguistic values into TFNs, as shown in Table 1.

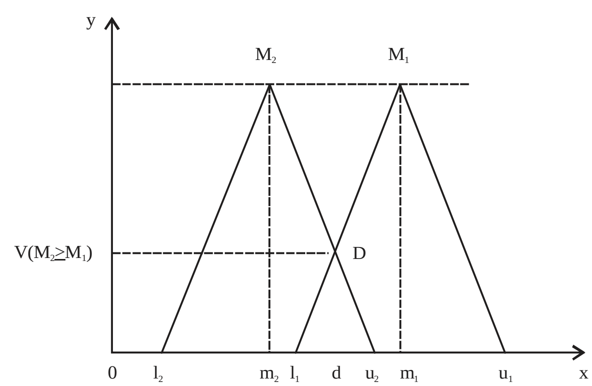

Fig. 1: Comparison of two fuzzy numbers

Table 1: Triangular fuzzy conversation scale

Linguistic values	Triangular fuzzy numbers	Reciprocal triangular fuzzy scale
Unimportant (U)	(1, 1, 1)	(1, 1, 1)
Between U and SL	(1, 2, 3)	(1/3, 1/2, 1)
Slightly important (SL)	(2, 3, 4)	(1/4, 1/3, 1/2)
Between SL and MI	(3, 4, 5)	(1/5, 1/4, 1/3)
Moderately important (MI)	(4, 5, 6)	(1/6, 1/5, 1/4)
Between MI and SI	(5, 6, 7)	(1/7, 1/6, 1/5)
Seriously important (SI)	(6, 7, 8)	(1/8, 1/7, 1/6)
Between SI and VSI	(7, 8, 9)	(1/9, 1/8, 1/7)
Very seriously important (VSI)	(8, 9, 9)	(1/9, 1/9, 1/8)

RESULTS

Analysis results of mainstream in da river:

Background of Da River: Da River is the largest tributary of the Red River, originating from Van Nam Province-China and flowing into Vietnam in Muong Te (Lai Chau), making the confluence with the Red River in Phu Tho. Da River valley is 52,500 km^2 with the length of 910 km. The section in the territory of Vietnam covers an area of 26,800 km^2 and 540 km in length.

The river flows across the north-western provinces of Vietnam including Lai Chau, Dien Bien, Son La, Hoa Binh and Phu Tho. The rivers and streams in the Da River basin have narrow valley and the river beds are being seriously dug up, with many rapids. The average altitude of the river valley is 1,130 m, particularly the section in the territory of Vietnam is 965 m. Beside the mainstream, Da River has six river branches including Nam Po, Nam Na, Nam Muc, Nam Mu, Nam Sap and Nam Bu.

The river has a high discharge, providing 31% of the water for the Red River and the river is the great hydropower resource for Vietnam's power industry. Along Da River, a lot of reservoirs have been built to serve the power generation, downstream flood control and enhancing the downstream flow during the dry season for irrigation and water supply. These hydroelectric power plants include "Hoa Binh", "Son La" and "Lai Chau" province. The river basin has the great resource potential with various types of rare minerals, typical ecosystems including biological sources with high biodiversity level.

Analysis result: Based on the literature review and discusion with water resource experts, three groups of risk factors causing loss of water supply security are defined as: (1) Policies and mechanisms (awareness of local people on protecting water resource is still low-PM1, lack of uniformity in policies on water resources protection-PM2, risks from Da River upstream-PM3, lack of compliance with the legislation on protecting water resources of people and business households-PM4). (2) The demand for using (the process of operating China's upstream reservoirs-DM1, increasing the demand for Da River water for industrial production-DM2, domestic waste water from local people and business households-DM3, construction of hydropower dams-DM4, toxic chemicals in agricultural production-DM5). (3) Natural factors (landslide-NF1, climate change, such as flood, drought-NF2, reducing vegetation cover-NF3, topographical and geomorphic factors causing difficulties in water supply drainage and storage-NF4, surface water scarcity-NF5).

In this study, the analytic hierarchy process was used to determine the level of impact (risk) of factor group of level 1 and level 2, which cause loss of WSS as shown in Fig. 2.

Calculation procedure is implemented according to the steps below:

Determining the comparative relationship between pairs of factors: Based on the results of the survey of 50 water resources experts, the average comparison values between the factor pairs of level 1 and 2 are presented in Table 2-5. Particularly, Table 2 shows the average comparative values between factor groups of level 1 using the likert scale in Table 1 and survey from 50 experts. Table 2 indicates that in factor groups of level 1, the average comparative values of the factors PM, NF are larger than the factors DM and PM, DM, respectivly. In Table 3, for the demand factors group: The average comparative values of DM1 is larger than DM3, DM2

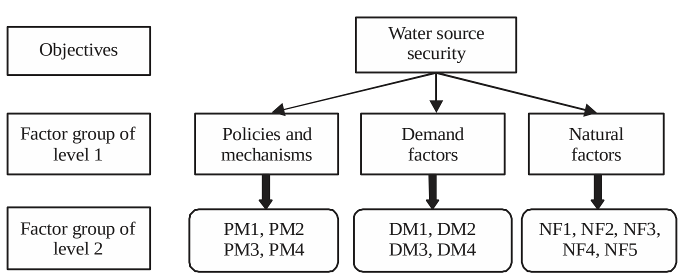

Fig. 2: Analytic hierarchy process for determining the importance weight of factors

Table 2: Average comparative value between factor groups of level 1

Factors	PM	NF	DM
PM	(1, 1, 1)	(0.16, 0.24, 0.45)	(1.36, 2.5, 3.13)
NF	(2.2, 4.2, 6.2)	(1, 1, 1)	(1, 2.14, 2.78)
DM	(0.32, 0.4, 0.73)	(0.36, 0.47, 1)	(1, 1, 1)

PM: Policies and mechanisms, NF: Natural factors, DM: Demand factors

Table 3: Average comparative values of demand factors

Factors	DM1	DM2	DM3	DM4	DM5
DM1	(1, 1, 1)	(0.29, 0.45, 1)	(1.8, 2.6, 3.4)	(0.29, 0.45, 1)	(0.16, 0.24, 0.45)
DM2	(1, 2.2, 3.4)	(1, 1, 1)	(1, 2.2, 3.4)	(1.8, 2.6, 3.4)	(0.29, 0.38, 0.56)
DM3	(0.29, 0.38, 0.56)	(0.29, 0.45, 1)	(1, 1, 1)	(0.24, 0.38, 1)	(0.24, 0.38, 1)
DM4	(1, 2.2, 3.4)	(0.29, 0.38, 0.56)	(1, 2.6, 4.2)	(1, 1, 1)	(0.29, 0.38, 0.56)
DM5	(2.2, 4.2, 6.2)	(1.8, 2.6, 3.4)	(1, 2.6, 4.2)	(1.8, 2.6, 3.4)	(1, 1, 1)

Table 4: Average comparative values of policies and mechanisms

Factors	PM1	PM2	PM3	PM4
PM1	(1, 1, 1)	(1, 2.2, 3.4)	(1.8, 2.6, 3.4)	(0.1, 0.24, 0.45)
PM2	(0.29, 0.45, 1)	(1, 1, 1)	(0.29, 0.45, 1)	(0.29, 0.38, 0.56)
PM3	(0.29, 0.38, 0.56)	(1, 2.2, 3.4)	(1, 1, 1)	(0.24, 0.38, 1)
PM4	(2.2, 4.2, 10.33)	(1.8, 2.6, 3.4)	(1, 2.6, 4.2)	(1, 1, 1)

Table 5: Average comparative values of natural factors

Factors	NF1	NF2	NF3	NF4	NF5
NF1	(1, 1, 1)	(0.15, 0.22, 0.38)	(1.8, 2.6, 3.4)	(0.56, 0.71, 1)	(0.16, 0.24, 0.45)
NF2	(2.6, 4.6, 6.6)	(1, 1, 1)	(1.8, 3.8, 5.8)	(1.8, 2.6, 3.4)	(0.17, 0.26, 0.56)
NF3	(0.29, 0.38, 0.56)	(0.17, 0.26, 0.56)	(1, 1, 1)	(0.24, 0.38, 1)	(0.29, 0.45, 1)
NF4	(1, 1.4, 1.8)	(0.29, 0.38, 0.56)	(1, 2.6, 4.2)	(1, 1, 1)	(0.29, 0.38, 0.56)
NF5	(2.2, 4.2, 6.2)	(1.8, 3.8, 5.8)	(1, 2.6, 4.2)	(1, 2.2, 3.4)	(1, 1, 1)

Table 6: Aggregate values of factors of level 1 and 2

TT	Factors	Aggregate values
1	PM	(0.146, 0.289, 0.545)
2	NF	(0.243, 0.567, 1.187)
3	DM	(0.097, 0.144, 0.325)
4	DM1	(0.069, 0.134, 0.31)
5	DM2	(0.1, 0.237, 0.532)
6	DM3	(0.04, 0.074, 0.206)
7	DM4	(0.07, 0.186, 0.439)
8	DM5	(0.153, 0.368, 0.824)
9	PM1	(0.106, 0.266, 0.577)
10	PM2	(0.051, 0.101, 0.248)
11	PM3	(0.069, 0.175, 0.416)
12	PM4	(0.163, 0.458, 1.323)
13	NF1	(0.066, 0.122, 0.255)
14	NF2	(0.133, 0.314, 0.71)
15	NF3	(0.036, 0.064, 0.168)
16	NF4	(0.065, 0.148, 0.332)
17	NF5	(0.14, 0.353, 0.811)

Table 7: Possibility of comparative relationship between the factor groups of level 1

Factors	Possibility values	Factors	Possibility values	Factors	Possibility values
$V(S_{PM}>=S_{NF})$	0.520	$V(S_{NF}>=S_{PM})$	1.00	$V(S_{DM}>=S_{PM})$	0.554
$V(S_{PM}>=S_{DM})$	1.000	$V(S_{NF}>=S_{DM})$	1.00	$V(S_{DM}>=S_{NF})$	0.163

is larger than DM1 and DM4, DM4 is larger than DM3 and DM5 is larger than DM1-4. Table 4 shows that the average comparative values of PM1 is larger than PM2 and PM3, PM3 is larger than PM2, PM4 is larger than PM1-3. For the natural factors group, the results in Table 5 indicate that the average comparative values of NF1 is larger than NF3, NF2 is larger than NF1, 3-4, NF4 is larger than NF1, 3, NF5 is larger than NF1-4.

Calculating the aggregate value for each factor: Using equations 1 and 2, the aggregate values of each factor are presented in Table 6.

Calculating the posibility of comparative relation between 2 fuzzy numbers: Table 7-10 indicate the posibility of comparative relation between two fuzzy numbers using Eq. 3 and 4. From Table 7, we can see that the possibilities of natural factors are better than policies and mechanisms, policies and mechanisms are better than demand factors, natural factors are better than demand factors are 100%. In Table 8, the factor PM1 is better than the factors PM2 and PM3 with the possibilities of 100%, the factor PM3 is better than the factors PM2 and PM4 with the possibilities of 100%, the factor PM4 is better than

Table 8: Possibility of comparative relationship between the factors group of level 2-mechanisms and policies

Factors	Possibility values	Factors	Possibility values	Factors	Possibility values	Factors	Possibility values
$V(S_{PM1}>=S_{PM2})$	1.000	$V(S_{PM2}>=S_{PM1})$	0.463	$V(S_{PM3}>=S_{PM1})$	0.773	$V(S_{PM4}>=S_{PM1})$	1.000
$V(S_{PM1}>=S_{PM3})$	1.000	$V(S_{PM2}>=S_{PM3})$	0.709	$V(S_{PM3}>=S_{PM2})$	1.000	$V(S_{PM4}>=S_{PM2})$	1.000
$V(S_{PM1}>=S_{PM4})$	0.683	$V(S_{PM2}>=S_{PM4})$	0.192	$V(S_{PM3}>=S_{PM4})$	1.000	$V(S_{PM4}>=S_{PM3})$	1.000

Table 9: Possibility of comparative relationship between the factor group of level 2-use demand

Factors	Possibility values	Factors	Possibility values	Factors	Possibility values	Factors	Possibility values	Factors	Possibility values
$V(S_{DM1}>=S_{DM2})$	0.671	$V(S_{DM2}>=S_{DM1})$	1.000	$V(S_{DM3}>=S_{DM1})$	0.693	$V(S_{DM4}>=S_{DM1})$	1.000	$V(S_{DM5}>=S_{DM1})$	1.000
$V(S_{DM1}>=S_{DM3})$	1.000	$V(S_{DM2}>=S_{DM3})$	1.000	$V(S_{DM3}>=S_{DM2})$	0.394	$V(S_{DM4}>=S_{DM2})$	0.869	$V(S_{DM5}>=S_{DM2})$	1.000
$V(S_{DM1}>=S_{DM4})$	0.823	$V(S_{DM2}>=S_{DM4})$	1.000	$V(S_{DM3}>=S_{DM4})$	1.000	$V(S_{DM4}>=S_{DM3})$	1.000	$V(S_{DM5}>=S_{DM3})$	1.000
$V(S_{DM1}>=S_{DM5})$	0.403	$V(S_{DM2}>=S_{DM5})$	0.744	$V(S_{DM3}>=S_{DM5})$	0.548	$V(S_{DM4}>=S_{DM5})$	1.000	$V(S_{DM5}>=S_{DM4})$	1.000

Table 10: Possibility of comparative relationship between the factor group of level 2-natural elements

Factors	Possibility values	Factors	Possibility values	Factors	Possibility values	Factors	Possibility values	Factors	Possibility values
$V(S_{NF1}>=S_{NF2})$	0.391	$V(S_{NF2}>=S_{NF1})$	1.000	$V(S_{NF3}>=S_{NF1})$	0.637	$V(S_{NF4}>=S_{NF1})$	1.000	$V(S_{NF5}>=S_{NF1})$	1.000
$V(S_{NF1}>=S_{NF3})$	1.000	$V(S_{NF2}>=S_{NF3})$	1.000	$V(S_{NF3}>=S_{NF2})$	0.125	$V(S_{NF4}>=S_{NF2})$	0.546	$V(S_{NF5}>=S_{NF2})$	1.000
$V(S_{NF1}>=S_{NF4})$	0.882	$V(S_{NF2}>=S_{NF4})$	1.000	$V(S_{NF3}>=S_{NF4})$	1.000	$V(S_{NF4}>=S_{NF3})$	1.000	$V(S_{NF5}>=S_{NF3})$	1.000
$V(S_{NF1}>=S_{NF5})$	0.333	$V(S_{NF2}>=S_{NF5})$	0.936	$V(S_{NF3}>=S_{NF5})$	0.553	$V(S_{NF4}>=S_{NF5})$	1.000	$V(S_{NF5}>=S_{NF4})$	1.000

Table 11: Possibility of one-factor relationship that is better than the other factors

Factors	Possibility values
W_{PM}	0.309
W_{DM}	0.097
W_{NF}	0.594
W_{PM1}	0.258
W_{PM2}	0.073
W_{PM3}	0.292
W_{PM4}	0.378
W_{DM1}	0.118
W_{DM2}	0.218
W_{DM3}	0.116
W_{DM4}	0.255
W_{DM5}	0.293
W_{NF1}	0.113
W_{NF2}	0.318
W_{NF3}	0.043
W_{NF4}	0.186
W_{NF5}	0.340

Table 12: Risk level of factors influencing the security of water sources

Factors	Risk levels
W_{PM}	0.309
W_{DM}	0.097
W_{NF}	0.594
W_{PM1}	0.258
W_{PM2}	0.073
W_{PM3}	0.292
W_{PM4}	0.378
W_{DM1}	0.118
W_{DM2}	0.218
W_{DM3}	0.116
W_{DM4}	0.255
W_{DM5}	0.293
W_{NF1}	0.113
W_{NF2}	0.318
W_{NF3}	0.043
W_{NF4}	0.186
W_{NF5}	0.340

the factors PM1, PM2 and PM3 also with the possibilities of 100%. Table 9 shows that the possibilities of one factor is better than other factors between DM1 and DM3, DM2 and DM1-3, DM3 and DM4, DM4 and DM1,3,5, DM5 and DM1-4 are highest in the demand factors. In Table 10, the possibility that NF1 is better than NF2 is 100%, the possibility that NF2 is better than NF1, 2, 4 is 100%, the possibility that NF3 is better than NF4 is 100%, the possibility that NF4 is better than NF1, 3, 5 is 100% and the possibility that NF5 is better than NF1-4 is 100%.

Calculating the possibility of the one-factor relationship better than the other factors: Using Table 7-10 and Eq. 5 and 6, it is possible to determine the possibility of one-factor relationship which is better than the other factor as shown in the Table 11.

Determining the risk level of factors: The risk level of the factor groups is determined based on the Table 11 and Eq. 7. Table 12 presents the risk level of the factors.

DISCUSSION

The present study applies fuzzy AHP method to determine the important factors which influence the security of water sources in the mainstream of the "Da". The findings of this study should be of interest to both researchers and policy makers in order to manage the water resource[1,2,6]. The results of the Table 12 show that the risk affecting the WSS from the natural factor group is the highest, followed by the mechanism and policy factor group and the use demand factor group. This results are almost the same in the case of China as mentioned by Wang *et al.*[8] and Jiang[10]. Specifically, in the natural factor group such as climate change and dependence on natural water sources are identified as the highest levels of impact on WSS in the region. They are followed by groundwater and natural water levels as well as herbage covering deterioration. In Vietnam, more than 60% of surface water discharge comes from outside the country and the Mekong and "Da" rivers (also called "Hong" river) are projected to be inundated because of climate change, a one-meter rise in sea level would cost Vietnam 5% of its land[28]. Cosslett *et al.*[29] also indicated that climate change and extreme weather events have the strongest impacts in WSS in Mekong delta.

For the policy and mechanism factor group: the greatest risk affecting the WSS is the lack of mechanisms and policies on coordination with China in the use of Da River's water and the people's bad awareness in the water source protection, followed by the lack of uniformity in water source protection policy and lack of local government management in water use, chemicals for agricultural production. Asian Development Bank (ADB)[30] indicated that urban centers in many countries in Asia and the Pacific still fall short of the vision of water underpinning vibrant, livable cities and towns. And in most regions, only a small portion of wastewater is collected through an improved sanitation method (i.e. Vietnam is 10%, the Philippines is 4% and Indonesia is 1%).

In the use demand factor groups: The greatest risk of WSS in the area is due to the construction of hydropower dams, followed by toxic chemicals in agricultural production, the increase in the use demand of Da River's water for industrial production and the lack of clean domestic water and domestic wastewater of local residents and business households[14].

CONCLUSION

The research applies the hierarchical analysis method to determine the level of impact of factors on WSS. The results of analysis show that the greatest risk group affecting the WSS is the natural factor group, followed by the mechanism and policy factor group and use demand factor group. The results obtained from this study may serve as a reference for policy makers in water resources management.

SIGNIFICANCE STATEMENTS

In this study, the fuzzy Analytic Hierarchy Process (AHP) technique was applied to quantify the factors which influence WSS. This study discovers that the climate change and dependence on natural water sources factor in group of natural factors have the highest effect to WSS, followed by the group of mechanism and policy factors and group of water demand factors. This study will help policy makers in order to recommend a legal tool in order to protect and guarantee water supply security in Vietnam. Thus, a new polices or law on WSS may be developed.

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