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Fuzzy Comprehensive Assessment of Typhoon Flood

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Abstract: - To reserve more volumes or to retain more water while flood is expected is always a dilemma for reservoir operators. The former consideration may land us in a trouble of drought if the flood is unanticipated small; however, the latter consideration may cause great downstream damage if the flood is unanticipated big. To make operation decision, four decision factors of typhoons are considered, and the comprehensive influences of each factor are analyzed by using fuzzy comprehensive assessment (FCA) method. Typhoon distance, path, intensity, and environmental condition at that time are the four decision factors. Instead of experiential judgments, fuzzy membership functions of each factor are actually calculated according to historical statistics. The concept of "flood storage grade" which discussed the "F-flood storage" is used to judge the initial operation water level of a reservoir before the flood. The way how fuzzy comprehensive assessment forecast upcoming floods is shown, and a real typhoon case, Aere, is taken as an example to demonstrate FCA of typhoon flood in this paper. Also, rainfalls of upcoming typhoon are forecasted form the proposed method. The final results are satisfactory, and it found that this FCA method is appropriate for typhoon assessment.

Key-Words: Typhoon flood, Flood control, Fuzzy comprehensive assessment, Flood storage, Rainfall forecast, Reservoir operation

1 Introduction

Forecasting typhoon rainfall has captured lots of attention in recent researches of Taiwan. Flood control is very critical in Taiwan since roughly 78% of its yearly rainfall concentrates in the summer and autumn, and the rain comes from typhoon mostly. Although the flood period is short, the discharge volume is high. Reservoir operators have to reserve space in advance for controlling the floods. Therefore, in order to predict the required reservoir volumes, capable of absorbing inflows parcels, reliable assessment of typhoon is necessary. The reserved volumes of reservoir could avoid or reduce the potential damage to the downstream area. However, keeping too much reserved volumes in reservoir may land us in a trouble of drought or wretched harvest. In terms of reservoir's security, the more volumes are kept, the less domestic water is maintained; nevertheless, in terms of saving water resource, the higher danger the reservoir might suffer.

It is a trade-off issue for reservoir management. Neither water resources nor reservoir safety should be ignored. This paper proposed a fuzzy comprehensive assessment (FCA) on flood control to help the reservoir operators to make the most optimal decision.

In 1965, Zadeh firstly proposed fuzzy set theory [15]. Mamdani [8] applied fuzzy control theories to steam engines in 1974 followed by Zimmermann [16] in 1978. More and more focuses were captured by fuzzy theory and its applications after 1980s ([1] [4]). In late of 1990s, there were plenty of researches using fuzzy theories. It was applied to various study fields in last decade. Since FCA can obtain judgment that evaluated and combined from several influence factors, it is usually applied to solve decision-making problems. For instance, Han [5] utilized fuzzy assessment to evaluate safety of pressure vessels. Tsaur [11] scored airline service quality by fuzzy multiple criteria decision-making, and define weights of each factor by AHP. Onkal [9] assessed Istanbul urban air quality using three fuzzy theories and compared with each other. In field of hydrology and water resources, fuzzy assessment is used mostly to evaluate water quality in river or reservoir [2] [7] [13]. Little attention was paid on reservoir operation and flood control problems that were analyzed in traditional way in the past [3] [14]. In 2002, Hasebe

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et al. [6] compared between reservoir operation using the fuzzy and neural network system both during flood and non-flood seasons. Fuzzy rule database are modeled and used to analyze reservoir operation problem. In this study, we attempted to apply FCA on flood assessment before it comes.

2 Methodology

In traditional mathematics or computer science, a crisp set is the most universal logic. The binary value, such as 0 or 1, true or false, was not replaced until fuzzy logic emerged. Fuzzy logic is derived from fuzzy set theory dealing with unclear or vague problems. It was introduced in 1965 by Zadeh and has been successfully applied universally in various fields. Setting a membership value between 0 and 1 could define linguistic form of imprecise concepts such as “very cold”, “not tall”, and “quite loud” in daily life. The membership functions transform crisp values to fuzzy values; crisp set to fuzzy set. A fuzzy set A has a membership function, μ_A, that can be written as: $\mu_A(x) \in [0,1]$.

Therefore, $\mu_A(x)$ is the degree of element x in fuzzy set A, and it connotes the degree to which element x belongs to fuzzy set A.

An assessment of an object, is often intangible and it may contain various and complex factors. The assessment is mostly described in language terms since a precise evaluation is so prejudiced and unsatisfactory. It requires a reliable method by which to evaluate and make decisions. An objective assessment approach, Fuzzy Comprehensive Assessment (FCA) based on fuzzy theory is applied in this paper to solve troublesome problems.

Let X is a universe of influence factors involved and Y is a universe of criteria. There are n factors and m criteria hypothetically, then

$$X = \{x_1, x_2, \ldots, x_n\} \tag{1}$$

$$Y = \{y_1, y_2, \ldots, y_m\} \tag{2}$$

X is called influence factor set, and Y is called criterion set. Let $R = \lfloor r_{ij} \rfloor$ that is defined as a mapping from factor set to criterion set through the Cartesian product ($R : X \times Y$) is a fuzzy relation matrix, where $i = 1,2,\ldots,n$ and $j = 1,2,\ldots,m$.

$$R = X \times Y = \left(r_{ij}\right)_{n\times m} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \tag{3}$$

If every factor has different contribution to the entire assessment, there will be a set of weight:

$$w = \{w_1, w_2, \ldots, w_n\},\ where \sum_i^n w_i = 1 \tag{4}$$

The final assessment, fuzzy vector, with considering criteria of all factors and their corresponding weights can be calculated as:

$$A = \begin{bmatrix} a_1 & a_2 & a_3 & a_4 \end{bmatrix} = w \circ R \tag{5}$$

In this paper, optimal reservoir operation is one of the complicated assessing problems. If we consider typhoon distance (r), typhoon path (p), typhoon intensity (i), and environmental situations (e) as the influence factors of forecasting typhoon floods, the factor set F for forecasting a typhoon flood can be written as:

$$F = \{ f_1(r), f_2(p), f_3(i), f_4(e)\} \tag{6}$$

In criterion set, C, it consists of several degrees that is set according to the membership function of each factor. We set five criterion degrees for four typhoon flood factors in this paper; Degree 1 (D1) denotes the slightest impact on flooding and D5 is the most serious degree, comparatively. Hence, criterion set C for forecasting a typhoon flood can be written as:

$$C = \{C_1(D1), C_2(D2), C_3(D3), C_4(D4), C_5(D5)\} \tag{7}$$

The triangular membership function for criterion set is selected, and it is figured as Fig. 1. The spans of each triangle are adjustable if necessary.

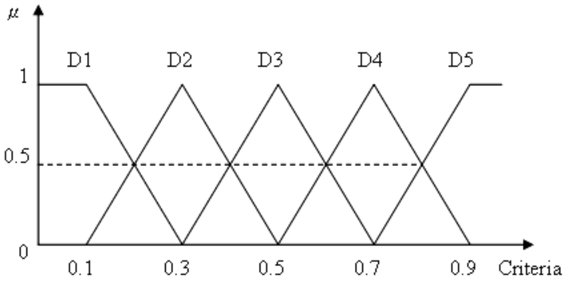

Fig.1 Membership function for criterion set

In flood assessment problem, the fuzzy relation matrix may be written as: (numbers are hypothetic)

$$R = \begin{array}{c|ccccc} & D1 & D2 & D3 & D4 & D5 \\ \hline \text{Distance} & 1 & 0 & 0 & 0 & 0 \\ \text{Path} & 0 & 0.5 & 0.5 & 0 & 0 \\ \text{Intensity} & 0 & 0 & 0.5 & 0.5 & 0 \\ \text{Environment} & 0 & 0 & 0 & 0.5 & 0.5 \end{array} \tag{8}$$

Since the fuzzy comprehensive assessment of a typhoon flood is not resulted from a single influence factor, each factor has its own contribution to a typhoon flood. The FCA result, fuzzy vector, can be calculated from formula (5). However, it is not enough for decision-makers to obtain a fuzzy vector matrix, and they need a readable and significant result. The defuzzificaiton method is required. In general cases, the weighted average method is frequently used in defuzzification since it is one of the more efficient computational methods [10]. Let the final assessment result is Z; the weighted average method is calculated as:

$$Z = \frac{\sum_{i=1}^{i=5} a_i z_i}{\sum_{i=1}^{i=5} a_i} \tag{9}$$

3 Typhoon flood assessing

3.1 Study Area

As the third largest reservoir in Taiwan, Shihmen was built in the middle of the Da-Han River. Work on the dam was begun in July 1956, and completed in June 1964, and the eight-year construction job cost NT 4.85 billions. The main facilities of Shihmen reservoir are listed in Table 1. Its location is in Taoyuan, Taiwan (shown in Fig. 2). It is significantly conducive to both water resource management and economic improvement in northern Taiwan. The residents in northern Taiwan could finally get rid of frequent flood disaster after the Shihmen reservoir was constructed. The watershed covers an area of 763.4 square kilometers, and its effective storage is 251 million cubic meters. It possesses functions of water supply, irrigation, hydraulic power generation, flood prevention, and sightseeing. With 3.4 million people involved, its water supply and irrigation area includes Taoyuan, Hsinchu, and part of Taipei.

As more and more electronic industry activity takes place in Taoyuan and Hsinchu, this area is becoming highly populous and crowded. Urbanization and industrialization make water resource very critical. Unfortunately, the ancient and hard-pressed Shihmen reservoir now is facing not only water supply crises but also soil depositing problem. The effective capacity of reservoir has declined over 24% since the construction. There is few works we can do to stop silt from watershed; it is hard to find a better location for building a new dam, not to mention the ecosystem issue. Therefore, a better water resource management and reservoir operation is an imperative task.

Table 1 Overview of Shihmen reservoir

Equipments	*Data*	*Unit*
Reservoir		
Watershed Area	763.4	Km^2
Submerged Area	8.0	Km^2
Full Water Level	245.0	M
Full Capacity	309.12	Million Stere
Effective Capacity	233.80	Million Stere
Low Water Level	195.0	M
Maximum Water Level	251.0	M
Maximum Probable Flood	14,500	M^3/s
Dam		
Dam Altitude	252.1	M
Dam Height	133.1	M
Dam Width	360.0	M
Dam Volume	706.0	Million Stere
Spillway (6)		
Designed Flood	10,900	M^3/s
Lowest Water Level	237.5	M
Maximum Drainage	11,400	M^3/s
Drainage Tunnel (2)		
Maximum Drainage	2100	M^3/s
Tunnel Altitude	220.0	M
Max Water Volumes for Power Generation	137.0	M^3/s
Total Power Generation	230.0	Million Kilowatt-hour per year
Shihmem Canal Volume	18.4	M^3/s

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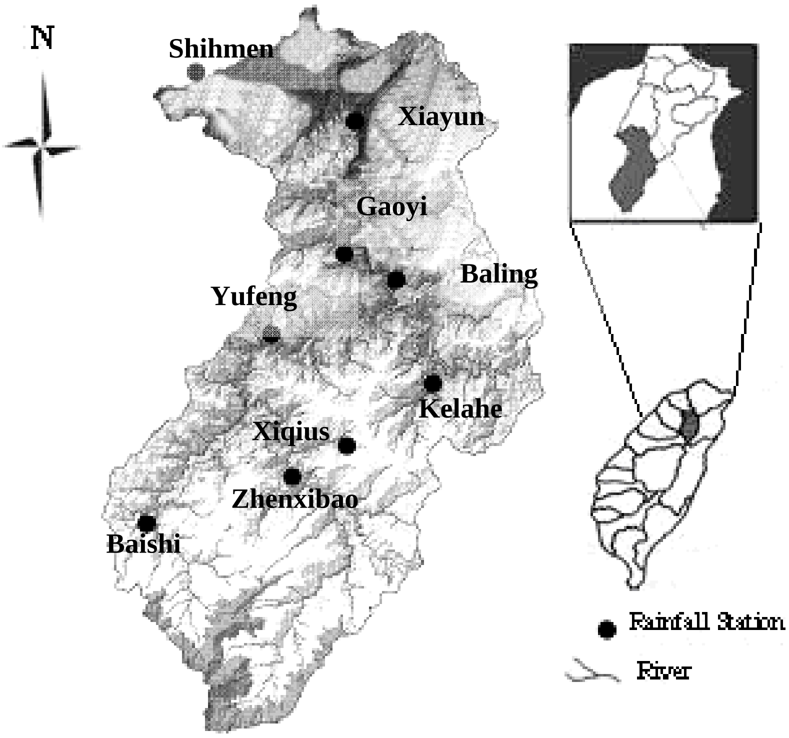

Fig.2 Watershed of Shihmen reservoir

3.2 Membership functions

The membership functions of influence factors are set and based on their specific properties. First, typhoon distance (r) is the shortest distance after a typhoon approach. Naturally, the shorter the distance, the heavier the rainfall will be. In the Shihmen case, we could judge it by the Central Weather Bureau's weather forecast. If we take the reservoir as the center of a circle as drawn in Fig.3, four kinds of radiuses are divided by distances: $\frac{1}{4}R_0$, $\frac{1}{2}R_0$, R_0, and $\frac{3}{2}R_0$, respectively. R_0 represents the typhoon storm radius. Fig. 1 can be redrawn as Fig. 4 for revealing distances with corresponding membership functions.

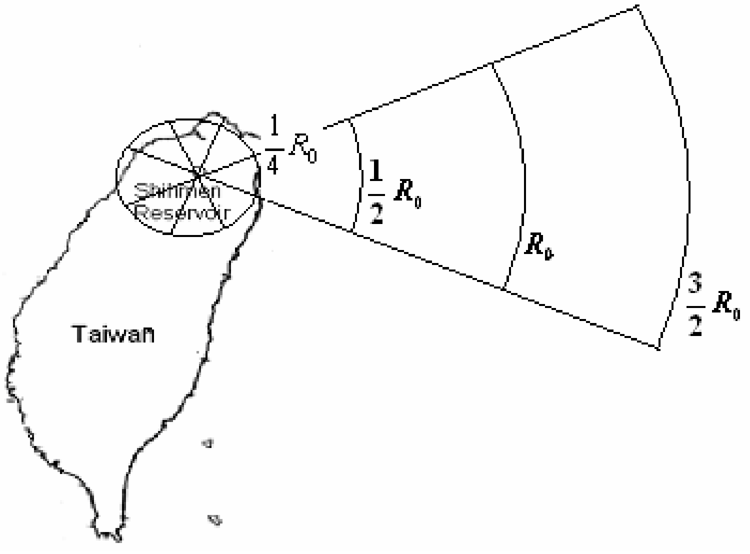

Fig.3 Typhoon distances classification

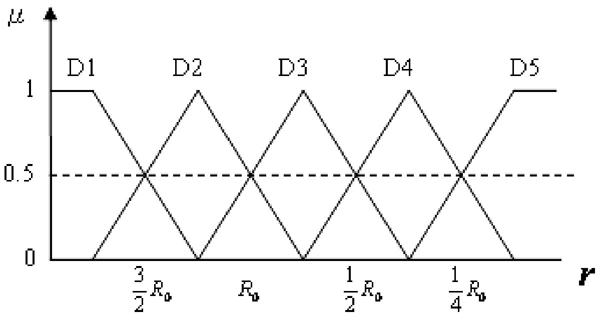

Fig.4 Typhoon distance membership function

The membership function of typhoon path (p), the second factor, needs to be defined. The Central Weather Bureau (CWB) is a government institution of meteorological research and forecasting in Taiwan. In accordance with CWB's classification, typhoon paths are divided into six path types as shown in Fig. 5[17]. There is still one path type left, the seventh type, which is also called the "other type" by CWB. This kind of typhoon invades Taiwan in an abnormal path. Each type of path will result in different rainfall possibilities and volumes.

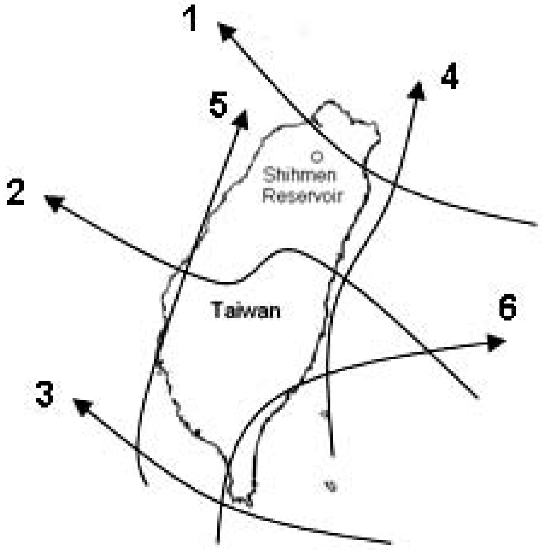

Fig.5 Six typhoon path types

To understand the typhoon path influence, observing historical data and compiling statistics are required. The data from typhoons that invaded or got passed (the eye did not land) the island from 1980 to 2002 are collected. During those years, there were a total of 111 typhoons that invaded Taiwan. CWB defined a 50 mm accumulative precipitation in 24 hours as heavy rain; a 130 mm accumulative precipitation in 24 hours as extremely heavy rain; a 200 mm accumulative precipitation in 24 hours as torrential rain, and a 350 mm accumulative precipitation in 24 hours as extremely torrential rain. If typhoon duration was temporarily disregarded, typhoon rainfalls could be graded into five situations according to the definition above. In collecting data, the number of typhoons with their own situations is counted and listed in path type order in Table 2. (All typhoon rainfalls listed here refer in particular to rainfall in the Shihmen reservoir watershed.)

Table 2 Rainfall statistics in six path types

	Under 49$_{\text{mm}}$	**Heavy Rain**	**Extremely Heavy Rain**	**Torrential Rain**	**Over 350$_{\text{mm}}$**	**Total**
Path1	0	3	1	8	4	16
Path2	1	5	5	1	1	13
Path3	13	11	6	2	0	32
Path4	8	7	5	6	1	27
Path5	3	3	2	0	0	8
Path6	3	3	2	0	0	8
Path7	0	3	1	1	2	7
Total	28	35	22	18	8	111

Obviously, the path1 and path7 typhoons have the highest flood possibilities, and path6 typhoons are comparatively safe for the reservoir. We could regard the five rainfall situations as five criteria in the criterion set. Over 350 mm of rainfall would be taken as D5 (the most dangerous degree), and torrential rain would be taken as D4, and so forth. To make it clear, the number of typhoons can be expressed in probability form. The probability ranges between 0 and 1, with the chance to fit in with the fuzzy number range. Therefore, typhoon path membership function is determined and listed in Table 3.

Table 3 Typhoon path membership function

	path1	**Path2**	**path3**	**path4**	**path5**	**path6**	**path7**
D1	0.00	0.08	0.41	0.30	0.38	0.38	0.00
D2	0.19	0.38	0.34	0.26	0.38	0.38	0.43
D3	0.06	0.38	0.19	0.19	0.25	0.25	0.14
D4	0.50	0.08	0.06	0.22	0.00	0.00	0.14
D5	0.25	0.08	0.00	0.04	0.00	0.00	0.29

Typhoon intensity membership function could be determined as well. It is much easier to analyze typhoon intensity due to the existing intensity scale. Unlike Saffir-Simpson Hurricane Scale, the typhoon intensity category in Taiwan is divided into four categories. The scale is ranked by the wind speed as Table 4 listed. The influence of a cyclone is also considered here because sometimes cyclones will turn into threatening light or middle typhoons in a couple days before approaching. The typhoon intensity membership functions are shown in Table 5.

Table 4 Typhoon intensity scale [17]

	Wind Speed Near Center			
Category	**m/s**	**Knots**	**Beaufort scale**	**Km/hr**
Cyclone	<17	<34	<8	<62
Light	17.2~32.6	34~63	8~11	62~117
Middle	32.7~50.9	64~99	12~15	118~183
Strong	51.0~66.9	100~130	16~17	184~240
Super	>67	>130	>17	0

Table 5 Typhoon intensity membership function

	Cyclone		**Light**		**Middle**		**Strong**		**Super**	
Criterion	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
D1	1	0.5	0	0	0	0	0	0	0	0
D2	0	0.5	1	0.5	0	0	0	0	0	0
D3	0	0	0	0.5	1	0.5	0	0	0	0
D4	0	0	0	0	0	0.5	1	0.5	0	0
D5	0	0	0	0	0	0	0	0.5	1	1

The last influence factor, the environmental situation, is decided by upstream watershed moisture. Also, it can be formulated by membership function. Moisture levels need to be defined first. For example, if it was very fair in the 3 days before a typhoon approached, the environmental situation should be defined as a very dry situation with a value of 0.1. Experimentally, the Shihmen reservoir requires about 72 hours for concentrated run-offs from its watershed. In theory, rainfall several days ago might make the watershed rather wet, and it will certainly increase reservoir inflows of the upcoming typhoon. Moisture levels can be obtained in the light of previous rainfall, and the environmental situation membership functions are listed in Table 6.

Table 6 Environmental situation membership function

	Moisture level **Dry** ⟵⟶ **Wet**									
Criterion	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
D1	1	0.5	0	0	0	0	0	0	0	0
D2	0	0.5	1	0.5	0	0	0	0	0	0
D3	0	0	0	0.5	1	0.5	0	0	0	0
D4	0	0	0	0	0	0.5	1	0.5	0	0
D5	0	0	0	0	0	0	0	0.5	1	1

After all factors and criterion sets are found, the fuzzy relation, R, can be obtained from formula (8).

4 Case study

To demonstrate the proposed method, a real typhoon case is required. In the summer of 2004, in the middle of August, a cyclone was strengthening and turning into a typhoon named Aere in the western Pacific Ocean. Several days later, Aere not only reached middle typhoon intensity but also got closer and closer to Taiwan; therefore, CWB issued its sea warning at 2 pm on August 23.

4.1 Typhoon Aere

With a radius of 200 km, Aere was centered 350 km southeast of Taipei, moving northwest at 12 kph. In Fig. 6, the dotted line and circle display the forecasting path and radius respectively. If Aere move forward as its path now, the typhoon eye will be quite close to the Taipei basin few days later. The distance from Aere to Shihmen reservoir will be only $\frac{1}{4}R_0$ or even less. According to Fig. 4, membership function of typhoon distance factor is $[0 \quad 0 \quad 0 \quad 0.5 \quad 0.5]$. It is obvious that Aere's path type is path1 (see Fig. 5), and the membership function of path1 (Table 3, matrix transpose) is $[0 \quad 0.19 \quad 0.06 \quad 0.5 \quad 0.25]$. With 120 kph wind speed near center, Aere was categorized as a middle intensity typhoon while sea warning was issued. As its present intensity, typhoon intensity membership function is $[0 \quad 0 \quad 1 \quad 0 \quad 0]$ (see Table 5). It was noted that it had already rained 136 mm of total precipitation for three days before the sea typhoon warning was issued, and groundwater level must have been high. In this wet environmental situation, upstream watershed moisture level is considered as 0.9 or 1 with membership function of $[0 \quad 0 \quad 0 \quad 0 \quad 1]$ (see Table 5). Therefore, fuzzy relation, R, can be obtained (see formula (8)) as follows:

$$R = \begin{array}{c} \\ \text{Distance} \\ \text{Path} \\ \text{Intensity} \\ \text{Environment} \end{array} \begin{array}{c} \begin{array}{ccccc} D1 & D2 & D3 & D4 & D5 \end{array} \\ \begin{bmatrix} 0 & 0 & 0 & 0.5 & 0.5 \\ 0 & 0.19 & 0.06 & 0.5 & 0.25 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \end{array} \quad (10)$$

Supposedly, the weights of each factor are allocated equally, that is, weight set w becomes

$[0.25 \quad 0.25 \quad 0.25 \quad 0.25]$. Consequently, FCA result was calculated by formula (5):

$$A = w \circ R$$
$$= [0.0000 \quad 0.0475 \quad 0.1400 \quad 0.3750 \quad 0.4375] \quad (11)$$

This FCA result gives final criterion of typhoon flood assessment, and we can say that each element of matrix A corresponds to its dangerous degree. For Aere, the highest element in A is D5 with 0.4375, and D4 is second highest with 0.3750. By definition of a criterion set, it is foreseeable that Aere would be a very dangerous typhoon with pouring rains.

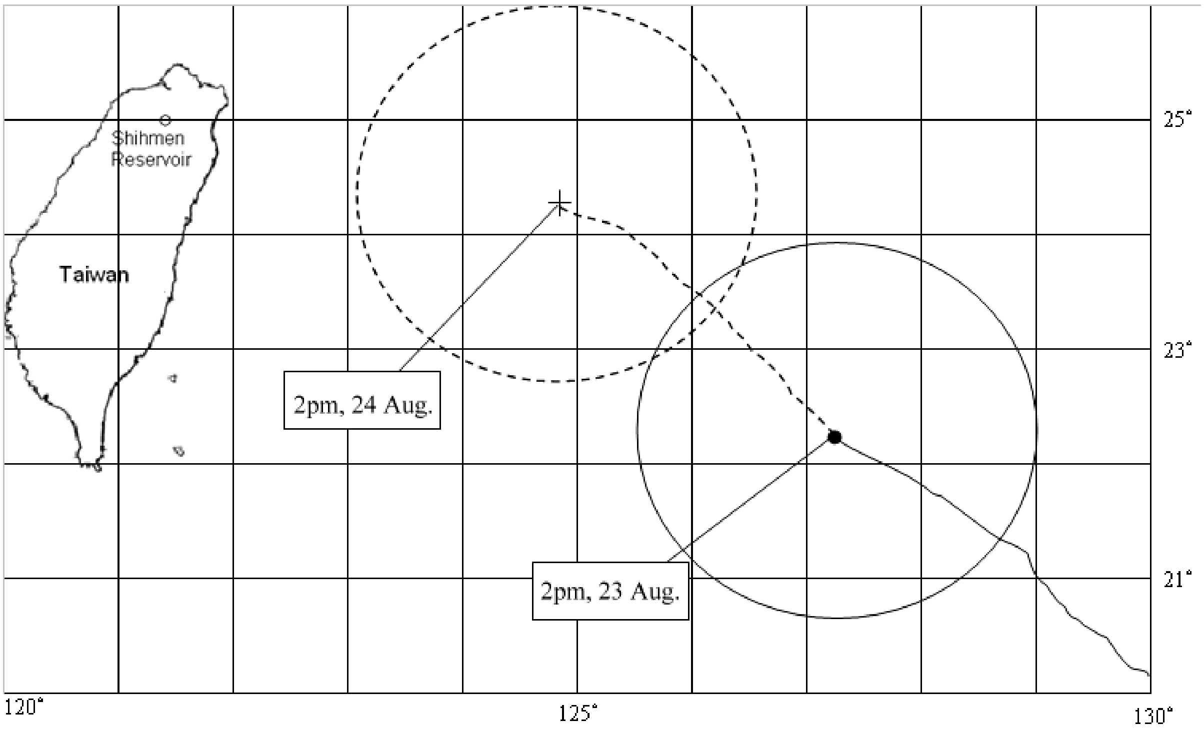

Fig. 6 Forecast figure of Aere typhoon

4.2 Defuzzification and forecasting result

The calculated matrix A in equation (11) is still not a clear assessment result. The defuzzification is required; the weighted average method of formula (9) is applied here. Let Z be the decision result, the weighted average method is formulated as:

$$Z = \frac{\sum_{i=1}^{i=5} a_i z_i}{\sum_{i=1}^{i=5} a_i} \quad (12)$$

in which z_i is criteria categories, and the suffix, i, is numbers of criterion set elements. A in equation (5) could be substituted for a_i in the equation (11), and z is calculated:

$$z = \frac{1\times 0 + 2\times 0.0475 + 3\times 0.14 + 4\times 0.375 + 5\times 0.4375}{0 + 0.0475 + 0.14 + 0.375 + 0.4375}$$
$$= 4.2 \quad (13)$$

The answer above is the final assessment. Typhoon Aere was taken as an example of forecasting floods by FCA because it is one of the most notorious typhoons in recent years. It brought extremely torrential rain to northern Taiwan and triggered the debris flow in the Hsinchu mountain area. The flood in Taoyuan filled Shihmen reservoir and greatly increased water turbidity, which resulted in two weeks water supply suspending. Aere caused 15 deaths; another 14 people were missing. There was over 1.8 billion NT dollars in losses to agriculture and related industries. Since Aere invaded Taiwan two years ago, we had already known what damage would result. It can be anticipated that the assessment by this method will be close to a dangerous degree, and the assessment result in equation (13), 4.2, seems answer the reality.

Additionally, the assessment result could approximately forecast typhoon precipitation since historical rainfall statistics are applied in the FCA method. By CWB's rainfall definitions mentioned above, five forecasting rainfall levels can be divided by rainfall definitions (see Table 7). In case of Aere,

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hence the value of 4.2 indicates that Aere would bring about 200 mm or more rainfall according to Table 7. Since Aere in reality did bring 519 mm during two days, the forecast rainfall is accurate. Finally, the flood assessment conclusions of the Aere typhoon are classed as "high danger" and over 200 mm of daily precipitation. From the results of this paper, reservoir operators can make a proper decision before Aere coming.

Table 7 Assessment classes and descriptions

Class	Dangerous level	Forecasting rainfall
D1	Safe	Under 49mm
D2	Low danger	50~129mm
D3	Middle danger	130~199mm
D4	High danger	200~349mm
D5	Very high danger	Over 350mm

5 Flood storage

How reservoir operators to make decision from the flood assessment results? In 1999, Wang and Cheng [12] divided the flood storage of reservoir into five grades: **F-1**, **F-2**, **F-3**, **F-4**, and **F-5** to correspond the fuzzy variable of assessment results with five linguistic variables: class I, class II, class III, class IV and class V. This flood storage grades offer water level for reservoir operating. The water level in reservoir of **F-1**, **F-2**, **F-3**, **F-4**, and **F-5** are introduced briefly as follow: [12]

F-1: In this case, flood is safe degree; meanwhile, the water level in reservoir should be highest for maintaining adequate water volume. The water level is set a maximum value of 240m.

F-2: $V_{F-2} = 0.4V_F$, where V_F is the reservoir total flood storage volume, and V_{F-2} is the unoccupied volume for controlling flood storage of the class II. In this case, the flood is still less threatening; hence the unoccupied volume is set $0.4V_F$.

F-3: $V_{F-3} = 0.6V_F$, where V_{F-3} is the unoccupied volume for controlling flood storage of the class III. The unoccupied volume is set $0.6V_F$ due to the normal danger degree of flood.

F-4: $V_{F-4} = 0.8V_F$, where V_{F-4} is the unoccupied volume for controlling flood storage of the class IV. In this case, the flood is dangerous and reservoir is recommended to leave volume of $0.8V_F$ unoccupied.

F-5: $V_{F-5} = 1.0V_F$, where V_{F-5} is suggested to set as V_F. Since the flood is very dangerous in this case, it would be better to leave total flood storage volume unoccupied for reservoir safety.

After flood storage is determined, reservoir operating water level can be obtained by regression. Take Shihmen reservoir for an example, the regression formulation of storage volumes and water level is expressed as:

$$V = 339.53(H-172.8)^3 + 21862.72(H-172.8)^2 + 169581.79(H-172.8) \quad (14)$$

V is storage volumes of Shihmen reservoir with unit of cubic meter, and H represents water level with unit of meter. Fig. 7 reveals the relation between reservoir volume and water level. From Fig. 7 and formula (14), flood storage can be switched to water level for operating.

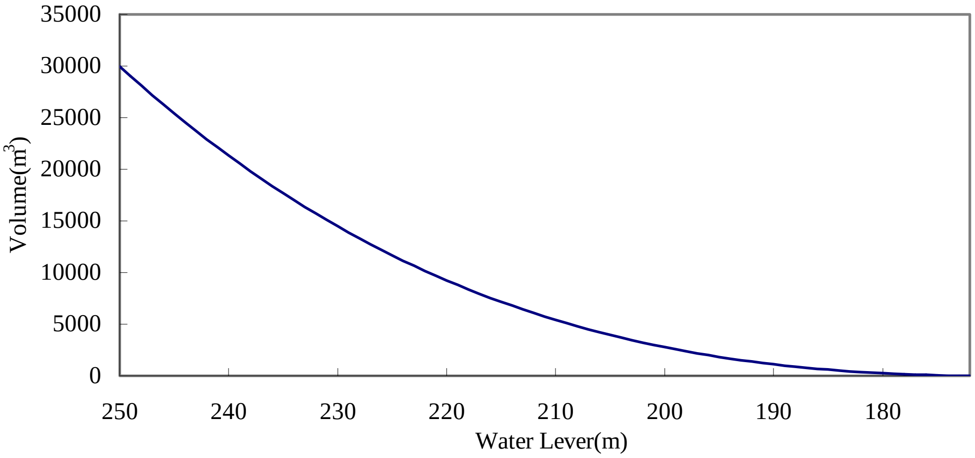

Fig. 7 The relation between volumes and water level in Shihmen reservoir

Additionally, Wang and Cheng [12] proposed a concept of "F-grade water level" during flood season (in Taiwan, from June to October) by using fuzzy statistics to decide initial water level to prevent flood. According to the property of every period, Table 8 lists proposed initial water level of F-grade flood storage in every period of June, July, August, September, and October, in which Jun.-1 is the first ten-day period of June, Jun.-2 is the middle ten-day of June, and others are expressed similarly. All the water levels of flood storage control cannot reach over 240 meters, which is the water level of **F-1** during the flood period.

In the aforementioned case, typhoon Aere, has assessment result $z = 4.2$ (see equation (13)). Aere developed in August, and its sea warning is issued during the last ten-day period of August. As a result of Table 8, Aere is classified between F-4 (water level: 226.5m) and F-5 (water level: 220.0m). Consequently, for preventing flood that Aere may cause, the reservoir operator is recommended to keep water level at 225.184m by interpolation calculation. This water level and its unoccupied storage volume appear to be appropriate for the reality.

Table 8 Water level (unit: m) of F-grade

	F-1	F-2	F-3	F-4	F-5
Jun.-1	240.0	239.1	236.2	232.8	229.1
Jun.-2	240.0	239.7	237.0	234.2	230.9
Jun.-3	240.0	239.5	236.7	233.7	230.2
Jul.-1	240.0	240.0	238.8	236.8	234.4
Jul.-2	240.0	239.5	236.8	233.8	230.3
Jul.-3	240.0	237.4	233.2	228.5	222.8
Aug.-1	240.0	236.7	231.9	226.8	220.0
Aug.-2	240.0	236.7	231.9	226.5	220.0
Aug.-3	240.0	236.7	231.9	226.5	220.0
Sep.-1	240.0	236.7	231.9	226.5	220.0
Sep.-2	240.0	236.7	231.9	226.5	220.0
Sep.-3	240.0	236.8	232.1	226.8	220.5
Oct.-1	240.0	237.9	234.1	229.6	224.5
Oct.-2	240.0	240.0	238.1	236.0	234.3
Oct.-3	240.0	240.0	240.0	238.8	237.1

6 Conclusions

Flood danger assessment of a typhoon is usually very complex and is confusing to analyze due to many related factors. Fuzzy comprehensive assessment (FCA) is proposed and applied to the assessment of typhoon flood danger in this paper. Typhoon distance, typhoon path, intensity, and environmental condition are considered as four factors herein. In accordance with historical typhoon statistics, four essential influence factors are analyzed and membership functions for the five-degree criterion set are defined. With fuzziness logic, the proposed method provides an accurate and objective assessment. In the sample case, satisfactory results and forecasting rainfall reveal that FCA is an appropriate technique for this issue. A more accurate forecasting of rainfall will definitely improve reservoir operators' decisions and greatly reduce the occurrence of flood disaster.

It is not necessary that the weights of each factor be allocated equally, but it depends on reality. In this paper, authentic typhoon forecasting reports with typhoon directions and path are very important.

Reservoir operation has its own existing rules. Take Shihmen for example, it is manipulated by a rule curve called M-5. It may not be an optimal rule for water resource management, but affirmatively safe for downstream area and reservoir itself. In the last part of this paper, a concept of "F-grade water level" during flood season is cited to offer a better water level of Shihmen reservoir when typhoon is coming. To consider both in flood control and water resource management, the proposed water level is a satisfactory water level decision. Any other reservoir can also set its specific grade flood storage and water level as Table 8 in this paper. Additionally, the proposed method based on FCA can also be applied to any other reservoir or different watershed as long as the specific membership function and fuzzy relation are rebuilt.

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