# MULTICRITERIA DECISION MAKING FOR MULTIRESERVOIR WATER ALLOCATION DURING SHORTAGE : A CASE STUDY OF UPPER MUN BASIN

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## Abstract

**The objective of this study was to develop the methodology for water allocation during the water shortage in the multipurpose-multireservoir system. The water shortage of the multireservoir system was first identified. The water allocation alternatives taken into account the profitability, equity and reliability of the multireservoir system and allowing the stakeholders involved in diagnosis and making decision for the water allocation were developed. The Upper Mun basin was selected as a case for the study. The HEC-3 was used as a tool to simulate the multireservoir system by using 25 years of inflow data and using the selected dry, normal and wet years data for the study of the water shortage. The results of simulated annual water shortage in the driest year were 17.79% and 40.03% of the water demand, occurring during July - September and December - May respectively. The $\epsilon$ - constraint linear programming was used to generate 16 optimum alternatives. The alternatives were ranked by the Analytical Hierarchy Process (AHP) based on the three criteria as profitability, equity and reliability. The results indicated that the priority of water allocation criteria were ranked as profitability (41%), reliability (32.3%) and equity (26.7%). The first ranked alternative (29.38%) was the alternative which did not allow water shortage in the municipal and industrial sectors, the downstream requirements for the ecological system would lack water by 43.99% of demand (55.43 million cubic meters) and allow the yield for agriculture reducing to 56% of the maximum yield. Thus, the water allocation methodology developed in this study can help the priority setting in water allocation and define the most preferable alternative for the concerned stakeholders.**

**Keywords: Multicriteria, water allocation, water shortage, upper mun basin**

## Introduction

Water is an important natural resource for all lives both direct and indirect utilities. The amount of water changes all the time and this makes it difficult to predict correctly. Sometimes it cannot respond at the right amount and time to the demand causing water shortage and flooding.

Keller *et al.*, (1996) presented the

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Integrated Water Resources Management (IWRM) that considered the whole river basin area in order to use water more effectively and efficiently. This approach corresponds to the common water management practices in Thailand at present. Since most of the large scale water resource systems are the multipurpose type, they needs to study the behavior of the system from the management and operation point of view such as product potential water uses (Molden, 1997) and the effect of water uses on various purposes (Kite and Droogers, 1999) in order to develop the alternatives for the decision makers. Analytical Hierarchy Process (AHP) is one of the methodology for analysis and solving the water problems (Flug *et al.*, 2000; Schwartz, 2000).

Previously, Kongjun and Vudhivanich (2001) studied the status of water shortage in the Upper Mun river basin in order to develop the water allocation criteria. The purpose of this study was to analyse the alternatives for water allocation during shortage for the Upper Mun basin consequently the maximum benefit, equity and reliability were obtained.

## Materials and Methods

1. The monthly rainfall and reservoir inflow data for 25 years, from 1975 to 1999, the water demand for agriculture, municipal and industrial water supply, downstream water requirements to preserve the equilibrium of the ecological system in the river downstream of the reservoir and the water requirements at the river basin outlet, were collected. Identified the probability distribution function of the annual inflow in order to determine the dry, normal and wet years.
2. Simulation of the multireservoir system by using 25 years of the inflow data and by using the selected dry, normal and wet year data with HEC - 3 (Hydrologic Engineering Center, 1981) was performed in order to study the shortage of water in the whole river basin (Figure 1).
3. The alternatives for water allocation among water use sectors in dry years were generated by using ε-constraint technique (Goicoechea *et al.*, 1982)

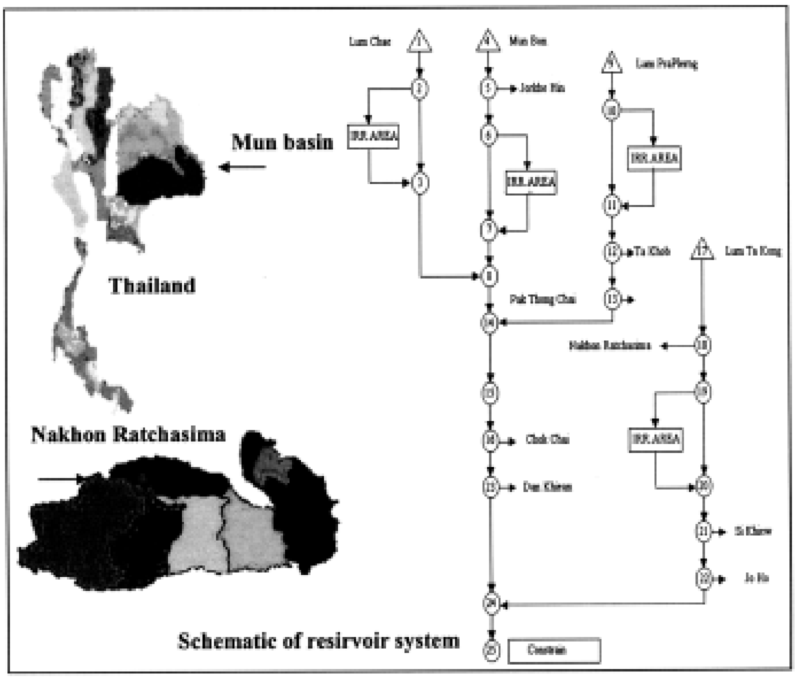
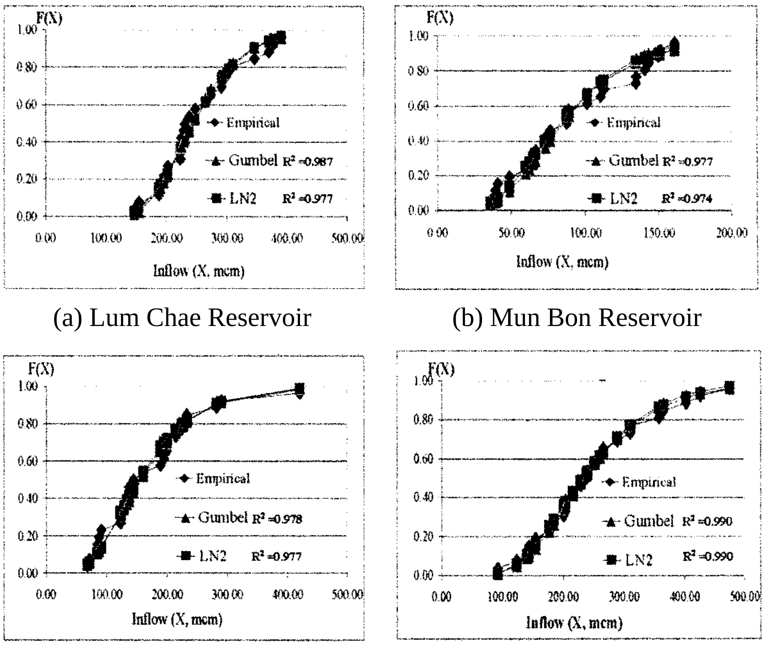



**Figure 1. Location of the research site and the entire basin map of Mun.**




(a) Lum Chae Reservoir (b) Mun Bon Reservoir

(c) Lum Phra Phloeng Reservoir (d) Lum Takong Reservoir

**Figure 2. Probability distribution function of the annual reservoir inflow.**

4. The selected the alternative was analysed and selected by the multicriteria decision making with AHP (Sahoo, 1998).

## Results and Discussion

### Identification of dry, normal and wet years by using probability distribution function

The 25 years (1975-1999) annual inflow of Lum Chae, Mun Bon, Lum Phra Phloeng and Lum Takhong reservoirs were used for the probability distribution analysis. The goodness of fit test by Smirnov-Kolmogorov at the significant level 5% showed that both Gumbel and Log Normal 2 parameters were fitted. Gumbel indicated a higher $R^2$, except Mun Bon reservoir as shown in Figure 2. Therefore, Gumbel distribution function was used for the analysis. If a probability of inflow was less than or equal 20% or $P(x \leq 0.20)$, it would be defined as a dry year. If a probability of inflow was more than or equal 80% or $P(x \geq 0.80)$, it would be defined as a wet year. If the probability was 20%-80% or $P(0.20 < x < 0.80)$, it would be a normal year. By this definition each reservoir has 6, 14 and 5 years of dry, normal and wet years. The occurrences of dry, normal and wet years of the 4 reservoirs were not different.

### Simulated 25 years average water shortage

The results of simulating the reservoir systems in the Upper Mun basin by using 25 years of inflow data and HEC-3, the water shortage characteristics of the Upper Mun basin were identified as follow:

1. In case the requirements at the river basin outlet were not considered, the simulated average annual water shortage over the whole basin was 14.88%, occurred during the dry spell in the rainy season (July-September) and in the dry season (December-May). The average annual water discharge volume at the river basin outlet was 151.37 million cubic meters (Table 1).

2. In case the water requirements at the river basin outlet were equivalent to the average minimum monthly flowing from the historical data (6.1 mcm), the average annual water shortage over the whole basin was 17.79% and

occurred at the same time as the first case. The average annual water discharge volume at the river basin outlet was 252.94 million cubic meters (Table 1).

According to the simulation results, when the water requirements at the river basin outlet were not considered, the discharge volume was lower than the lowest of the record (218.85 million cubic meters). This might have an effect on water users on the lower part of the river basin. To avoid this problem, the second case was selected. However, the water shortage in the Upper Mun basin increased about 2.91% per year. In the simulation, the boundary of a case study was in the particular multireservoir system irrigated area might cause the little amount of side flow. In order to add the side flow to return flow estimation, the model was calibrated by comparison with observed gauging discharge at the outlet but it was not shown in the paper.

**Simulated water shortage in the dry, normal and wet year.**

Based on the selected dry, normal and wet years using the nonexceedence probability of 20% and 80% as mentioned in the previous section and assuming the required minimum flow at the basin outlet of 73.2 mcm per year (or 6.1 mcm per month), the simulation results indicated that the water shortage occurred in dry and normal year. In the dry year, it was divided into extremely dry (Dry 1), dry (Dry 2) and slightly dry (Dry 3) according to the magnitude of water shortage of 40.03%, 24.56% and 28.61% respectively as shown in Table 2. In the normal year, it was divided into slightly normal (Normal 1), normal (Normal 2) and slightly wet (Normal 3) corresponding to 22.35%, 9.56% and 0.35% of water shortage as shown in Table 3. Especially, the agriculture sector had the most serious water shortage of 47.19%, municipal and industrial sector of 17.74% occuring in Nakhon Ratchasima municipality. Downstream requirements will have the water shortage of 15.64%.

According to the simulation result, the water shortage took place only in the dry and normal years. The dry year showed more serious shortage than did the normal year. There were 2 periods of water shortage which was the same as the 25 years data simulation. However, the duration of water shortage depends on the annual inflow in each year.

**Generation of water allocation alternatives**

The water shortage was occurred in the dry and normal years for all water use sectors, but there were different in the magnitude of water shortage. In fact, the effect of the water shortage on each water use sector was different even though the magnitude of water shortage was the same. Therefore, by the water allocation alternatives to various water use sectors needed to be developed by using the multiobjective

**Table 1. The average annual water shortage of the Upper Mun basin simulated by HEC-3 using 25 years of data.**

| Water users group | Requirement (mcm) | Shortage | | Duration | | Shortage | | Duration | |
|---|---|---|---|---|---|---|---|---|---|
| | | Volume (mcm) | % | Initiate | Terminate | Volume (mcm) | % | Initiate | Terminate |
| Agriculture | 754.81 | 129.30 | 17.13 | Jul.<br>Jan. | Sept.<br>Apr. | 160.83 | 21.31 | Jul.<br>Jan. | Sept.<br>Apr. |
| Municipal-Industrial | 35.55 | 1.04 | 2.93 | Dec. | Apr. | 1.04 | 2.93 | Dec. | Apr. |
| Ecology | 126.00 | 6.06 | 4.81 | Dec. | May | 7.88 | 6.26 | Dec. | May |
| Outlet | 73.20 | - | - | - | - | 6.31 | 8.62 | Apr. | May |
| Total | 989.56 | 136.40 | 14.88 | Jul.<br>Dec. | Sept.<br>May | 176.06 | 17.79 | Jul.<br>Dec. | Sept.<br>May |

optimization. The case of extremely dry year (Dry 1) was used in the analysis. The objective function of agricultural sector was to maximize the yield as follows.

$$\text{Max } z_1(x) = \sum_{i=1}^{m}\sum_{j=1}^{n} Y_{ij} \qquad (1)$$

where $Z_1(x)$ = agricultural objective; $Y_{ij} = Y_m[1-K_y(1-ET_a/ET_m)]$; $Y_{ij}$ = the actual yield; $Y_m$ = the maximum yield; $ET_a$ = actual evapotranspiration; $ET_m$ = maximum evapotranspiration; $K_y$ = the yield response factor; i = the number of reservoir; and j = the number of month. The municipal and industrial sector and the downstream requirements for the ecological balance would have the minimum shortage by using ε-constraint technique.

$$\text{Max } Z_2(x) = -\sum_{i=1}^{m}\sum_{j=1}^{n} (DM_{ij} - SM_{ij}) \qquad (2)$$

where $Z_2(x)$ = municipal and industrial objective; DM = municipal and industrial demand; and SM = municipal and industrial supply

$$\text{Max } Z_3(x) = -\sum_{i=1}^{m}\sum_{j=1}^{n} (DD_{ij} - SD_{ij}) \qquad (3)$$

where $Z_3(x)$ = downstream requirement objective; DD = downstream requirement demand; and SD = downstream requirement supply

There were 16 examples of alternatives as illustrated in Figure 3 and Table 4.

According to the trade-off among the 16 alternatives in the extremely dry year of inflow,

**Table 2. The annual water shortage of the Upper Mun basin in the dry years.**

| Water users group | Water requirement (mcm) | | | Inflow year | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Dry 1 | | Dry 2 | | Dry 3 | |
| | Dry 1 | Dry 2 | Dry 3 | Volume (mcm) | (%) | Volume (mcm) | (%) | Volume (mcm) | (%) |
| Agriculture | 761.76 | 708.80 | 807.06 | 359.51 | 47.19 | 211.29 | 29.81 | 264.90 | 32.82 |
| Municipal-Industrial | 35.55 | 35.55 | 35.55 | 0.79 | 2.22 | 3.15 | 8.87 | 6.31 | 17.74 |
| Ecology | 126.00 | 126.00 | 126.00 | 19.71 | 15.64 | 7.88 | 6.26 | 11.04 | 8.76 |
| Outlet | 73.20 | 73.20 | 73.20 | 18.92 | 25.85 | 9.46 | 12.93 | 15.77 | 21.54 |
| Total | 996.51 | 943.55 | 1,041.81 | 398.93 | 40.03 | 231.78 | 24.56 | 298.02 | 28.61 |

**Table 3. The annual water shortage of the Upper Mun basin in the normal years.**

| Water users group | Water requirement (mcm) | | | Inflow year | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Normal 1 | | Normal 2 | | Normal 3 | |
| | Normal 1 | Normal 2 | Normal 3 | /olume (mcm) | (%) | Volume (mcm) | (%) | Volume (mcm) | (%) |
| Agriculture | 787.00 | 754.81 | 679.14 | 223.91 | 28.45 | 88.30 | 11.70 | 0.00 | 0.00 |
| Municipal-Industrial | 35.55 | 35.55 | 35.55 | 0.00 | 0.00 | 3.15 | 8.87 | 0.00 | 0.00 |
| Ecology | 126.00 | 126.00 | 126.00 | 4.48 | 3.55 | 3.15 | 2.50 | 3.15 | 2.50 |
| Outlet | 73.20 | 73.20 | 73.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 1,021.75 | 989.56 | 913.89 | 228.39 | 22.35 | 94.60 | 9.56 | 3.15 | 0.35 |

the total product was between 49-60% or reduced 40-51%. This indicated that if at all wanted to have the total product of 60%, the municipal and industrial sectors would lack water 85.06%. The downstream requirements for the ecological system would lack water by 43.99% of demand (55.43 million cubic meters) or the water level in the river reduced from the normal depth (2.21 m) by 19.72% or the alternative was the total product reduced 49%, the municipal and industrial sectors and the downstream did not face any water shortage.

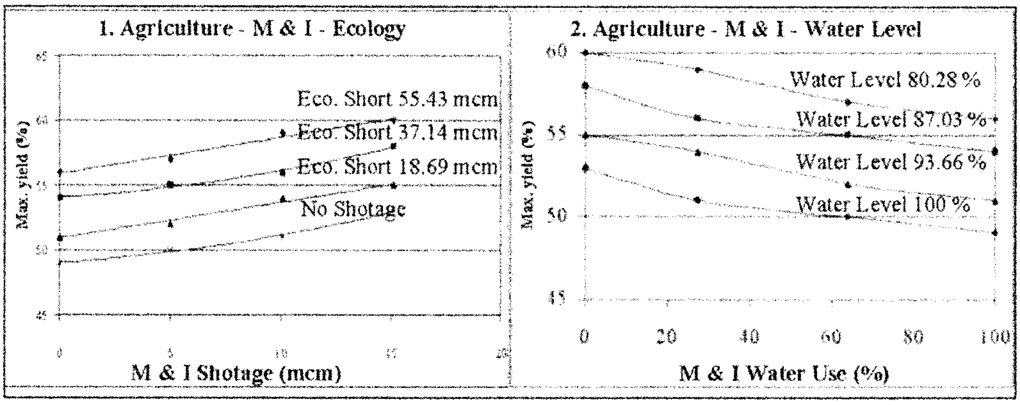



**Figure 3. Trade-off among allocation alternatives.**

**Table 4. Trade-off among water allocation alternatives.**

| Alternatives | Agriculture | | Municipal-Industrial | | Ecology | |
|---|---|---|---|---|---|---|
| | Max yield (%) | Yield depletion (%) | Min shortage (mcm) | Water use depletion (%) | Min shortage (mcm) | Water level depletion (%) |
| 1 | 60 | 40 | 30.24 | 85.06 | 55.43 | 19.72 |
| 2 | 59 | 41 | 20.16 | 56.71 | 55.43 | 19.72 |
| 3 | 57 | 43 | 10.08 | 28.35 | 55.43 | 19.72 |
| 4 | 56 | 44 | 0.00 | 0.00 | 55.43 | 19.72 |
| 5 | 58 | 42 | 30.24 | 85.06 | 37.14 | 12.97 |
| 6 | 56 | 44 | 20.16 | 56.71 | 37.14 | 12.97 |
| 7 | 55 | 45 | 10.08 | 28.35 | 37.14 | 12.97 |
| 8 | 54 | 46 | 0.00 | 0.00 | 37.14 | 12.97 |
| 9 | 55 | 45 | 30.24 | 85.06 | 18.69 | 6.34 |
| 10 | 54 | 46 | 20.16 | 56.71 | 18.69 | 6.34 |
| 11 | 52 | 48 | 10.08 | 28.35 | 18.69 | 6.34 |
| 12 | 51 | 49 | 0.00 | 0.00 | 18.69 | 6.34 |
| 13 | 53 | 47 | 30.24 | 85.06 | 0.00 | 0.00 |
| 14 | 51 | 49 | 20.16 | 56.71 | 0.00 | 0.00 |
| 15 | 50 | 50 | 10.08 | 28.35 | 0.00 | 0.00 |
| 16 | 49 | 51 | 0.00 | 0.00 | 0.00 | 0.00 |

**Analysis and selection of the alternatives by multicriteria decision making.**

There were 16 alternatives from the trade-off analysis for multicriteria decision making. The questionnaire was developed to ask 26 concerned stakeholders of the Upper Mun basin including the 10 water management administrators, 1 water management expert, 6 agriculturists, 2 representatives of municipal and industrial sectors, 6 district administrators (downstream requirements for ecology systems) and 1 researcher. Each respondent selected 4 alternatives based on the three criteria, i.e. profitability, equity and reliability. The analysis outcomes with the AHP found that the water allocation in the extremely dry year had an effect on profitability, reliability and equity 41%, 32.3% and 26.7% respectively. It was noticed that the attitude in the water allocation of the respondent when they were at the turning time, they would consider the profitability more important than the reliability and the equity (Table 5).

The first ranked alternative of 29.38% was the fourth alternative. This alternative satisfied 100% of demand for municipal and industrial sector, the downstream requirements for the ecological system would lack water by 43.99% of demand (55.43 million cubic meters) or the water level in the river reduced from the normal depth (2.21 m) by 19.72% and allowed the yield for agriculture reducing to 56% of the maximum yield. This alternative did not allow water shortage to the municipal and industrial sector and the downstream requirements (ecological balance) would use the water from return flow (Table 6).

According to the questionnaire, some stakeholders added 4 more alternatives which were 17$^{th}$, 18$^{th}$, 19$^{th}$ and 20$^{th}$. These alternatives maintained the water level in the river at the normal depth but resulted in water shortage in municipal and industrial sector by 5%, 7%, 15% and 20% of demand. Twelve alternatives were selected from the 16 alternatives that caused different water shortage.

## Conclusion

The water demand in the Upper Mun basin consisted of agricultural, municipal and industrial water supply, downstream ecological

**Table 5. Water allocation criterion developed by AHP (%).**

| Informant | Profitability | Equity | Reliability | Informant | Profitability | Equity | Reliability |
|---|---|---|---|---|---|---|---|
| 1 | 69.6 | 22.9 | 7.5 | 14 | 62.7 | 28.0 | 9.4 |
| 2 | 19.9 | 73.3 | 6.8 | 15 | 75.0 | 7.8 | 17.1 |
| 3 | 24.3 | 5.6 | 70.1 | 16 | 33.3 | 33.3 | 33.3 |
| 4 | 76.3 | 6.1 | 17.6 | 17 | 33.3 | 33.3 | 33.3 |
| 5 | 70.9 | 6.0 | 23.1 | 18 | 77.8 | 11.1 | 11.1 |
| 6 | 68.2 | 23.6 | 8.2 | 19 | 33.3 | 33.3 | 33.3 |
| 7 | 6.7 | 29.3 | 64.0 | 20 | 6.4 | 13.8 | 79.8 |
| 8 | 6.8 | 73.3 | 19.9 | 21 | 6.8 | 19.9 | 73.3 |
| 9 | 73.3 | 6.8 | 19.9 | 22 | 6.4 | 13.8 | 79.8 |
| 10 | 48.1 | 46.3 | 5.8 | 23 | 6.8 | 19.9 | 73.3 |
| 11 | 6.0 | 70.9 | 23.1 | 24 | 79.8 | 6.4 | 13.8 |
| 12 | 76.4 | 11.5 | 12.1 | 25 | 6.6 | 14.9 | 78.5 |
| 13 | 15.3 | 77.7 | 7.0 | 26 | 76.3 | 6.1 | 17.6 |
| Average | | | | | 41.0 | 26.7 | 32.3 |

requirements and water requirement at the outlet of the basin. The multireservoir system was simulated by HEC-3. In case the water requirements at the river basin outlet, the 25 years average water shortage of the whole basin was 17.79%, and 40.03% in the extremely dry year, occurring during the dry spell in the rainy season (July - September) and in the dry season (December - May). It was noticed that the capacity of 4 reservoirs in the Upper Mun basin was sufficient for demand in 1999 but occurrence of water shortage was caused by the amount of reservoir inflow in each year. In the future the economic development and expansion of community might increase the water demand. The new water resources development is now limited. To reduce these problems, one has to consider the demand side management. According to these situations, alternatives for water allocation among the water use sectors needed to be developed particularly the case of Dry 1. The result of the 16 alternatives from the trade-off analysis showed the total agricultural produce between 49-60% or the maximum yield was reduced by 40-51%. This showed that if one wanted to maintain the total produce of 60%, the municipal and industrial sector would lack water 85.06% and the downstream requirements for ecology system would lack water by 43.99% of demand (55.43 million cubic meters) or the water level in the river reduced from the normal depth (2.21 m) by 19.72%. If one wanted to have the total produce of 49%, there would not be shortage in the municipal and industrial sector and the downstream requirements. There were three decision criteria for the alternatives ranked by AHP, which were profitability, equity and reliability. It was found that the water allocation at the turning point or the extremely dry year (Dry 1) gave the priority weight for profitability, reliability and equity at 41%, 32.3% and 26.7% respectively. It was noticed that the attitude toward the water allocation of the respondents when they were at the turning time, they would consider the profitability more important than reliability and equity. The first ranked alternative of 29.38% was the alternative which did not allow water shortage to the municipal and industrial sector, the downstream requirements for the ecological system would lack water by 43.99% of demand (55.43 million cubic meters) and allows the yield for agriculture reducing to 56% of the maximum yield. Thus, the water allocation methodology developed in this study can help the priority setting in water allocation and define the most preferable alternative for the concerned stakeholders.

**Table 6. Overall water allocation criterion developed by AHP (%).**

| Alternatives | Overall | Priority |
|---|---|---|
| 2 | 0.37 | 16 |
| 3 | 5.78 | 5 |
| 4 | 29.38 | 1 |
| 6 | 1.30 | 10 |
| 7 | 4.67 | 6 |
| 8 | 24.49 | 2 |
| 10 | 2.75 | 7 |
| 11 | 2.74 | 8 |
| 12 | 14.47 | 3 |
| 14 | 1.19 | 11 |
| 15 | 0.63 | 14 |
| 16 | 8.36 | 4 |
| 17 | 1.57 | 9 |
| 18 | 1.11 | 12 |
| 19 | 0.70 | 13 |
| 20 | 0.46 | 15 |

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