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Prioritization of water management under climate change and urbanization using multi-criteria decision making methods

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Abstract

This paper quantifies the transformed effectiveness of alternatives for watershed management caused by climate change and urbanization and prioritizes five options using multi-criteria decision making techniques. The climate change scenarios (A1B and A2) were obtained by using a statistical downscaling model (SDSM), and the urbanization scenario by surveying the existing urban planning. The flow and biochemical oxygen demand (BOD) concentration duration curves were derived, and the numbers of days required to satisfy the environmental flow requirement and the target BOD concentration were counted using the Hydrological Simulation Program-Fortran (HSPF) model. In addition, five feasible alternatives were prioritized by using multi-criteria decision making techniques, based on the driving force-pressure-state-impact-response (DPSIR) framework and cost component. Finally, a sensitivity analysis approach for MCDM methods was conducted to reduce the uncertainty of weights. The result indicates that the most sensitive decision criterion is cost, followed by criteria response, driving force, impact, state and pressure in that order. Since it is certain that the importance of cost component is over 0.127, use of the groundwater collected by subway stations will be the most preferred alternative in this application.

1 Introduction

An increasing consensus supports that climate change and urbanization should be considered in making environment management decisions. Clearly, many of the decisions made in the past have either had only short-term consequences or have only been weakly climate sensitive. Yet, the majority of the environment management decisions come with long-term commitments, and they are often very sensitive to climate and land use. Examples of such decisions can be risk management strategies, infrastructure development for water management. These decisions such as flood mitigation plans have consequences over periods of 50–200 yr. These kinds of decisions are also

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Step three is to quantitatively analyze the effectiveness of all the alternatives by all the climate change and urbanization scenarios using the HSPF model. HSPF can simulate the hydrologic and associated water quality processes on pervious and imperious land surface and in streams and well-mixed impoundments. The water quantity and quality targets for all sub-watersheds were collected from Lee and Chung (2007b) and Chung et al. (2011b); they were calculated by considering the stream flow seasonal variability and the fish habitat suitability at this step. The duration curves of flow and BOD concentration of all the sub-watersheds were identified and the numbers of days required to satisfy the target stream flow and BOD concentration were counted.

Step four is to prioritize five alternatives reflecting the future climate change and urbanization. Multi-criteria decision making techniques include a simple additive weighting method and ELECTRE II (Elimination and Choice Translating Reality). For the rational consideration of social and economic factors, all criteria were selected from the DPSIR framework which uses a cause-effect relationship. Since the weighting values evaluation is a time-consuming process, this study developed some feasible scenarios for weighting values.

The final step is to do a sensitivity analysis of MCDM methods. In this application, this study determined how critical each criterion is by performing a sensitivity analysis on the weights of the criteria.

2.2 DPSIR framework

DPSIR stands for Driving force-Pressure-State-Impact-Response; the components of an analytical framework that links the socioeconomic factors (driving force) forcing anthropogenic activities (pressure), the resulting environmental conditions (state), the environmental consequences resulting from these conditions (impact) and finally, the measurers taken into improve the environmental state (response) (Skoulikidis, 2009).

2.3 Additive Value Function (AVF)

The AVF method is a simplified version of a multi-attribute utility function (MAUF). In MAUF method, the risk attitude of the decision-maker can be incorporated through a concave (risk averse) or a convex (risk seeker) utility curve. The way scores are normalized in the AVF method makes it an MAUF method for a decision-maker that has a risk-neutral or risk-adverse attitude (Clemen, 1997). Each score (s_{ij}) in the matrix is replaced with a value v_{ij} according to Eq. (1):

$$v_{ij} = \frac{s_{ij} - s_{i-}}{s_{i+} - s_{i-}} \quad (1)$$

where s_{ij} is the impact of an scenario (j) with respect to a criterion (i); s_{i-} is the worst score of the criterion (i) with respect to all scenarios i ; and s_{i+} is the “best” score of the criterion (i) with respect to all scenarios i . All scores in the payoff matrix are scaled between the values of 0.0 and 1.0. An overall value index (V_j) for each scenario is calculated as shown in Eq. (2):

$$V_j = \sum_{i=1}^n w_i v_{ij} \quad (2)$$

where w_i is the relative weight assigned to criterion (i) and n is the total number of criteria.

2.4 Electre II

ELECTRE II is an improved version of ELECTRE family that produces a ranking of alternatives rather than indicating the most preferred. It outranks based on alternatives that are preferred with respect to most of the criteria and that do not drastically fail with respect to any one or more criteria. The first attribute is expressed by the “concordance” index and the second by the “discordance” index. Alternative A outranks

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alternative B if both concordance and discordance indices are satisfied. The concordance index $C(A,B)$ measures the strength of support in the information given for the hypothesis that A is at least as good as B. The discordance index $D(A,B)$ measures the strength of evidence against this hypothesis. $C(A,B)$ can be calculated as shown in Eq. (3).

$$C(A,B) = \frac{w^+ + w^-}{w^+ + w^- + w^-} \quad (3)$$

where w^+ is the sum of the weights of all criteria where A is better than B; w^- is the opposite case, i.e. the sum of the weights of the criteria where B is better than A; and w^- is the indifferent cases. $D(A,B)$ can be calculated as shown in Eq. (4).

$$D(A,B) = \max(v_{iB} - v_{iA}) \quad (4)$$

where v_{iB} is the value function of the impact of alternative B with respect to criterion (i) and v_{iA} is the value function of the impact of alternative A to outrank B, $C(A,B)$ has to be greater than $D(A,B)$, and both of $C(A,B)$ and $D(A,B)$ should be higher than a present threshold value ρ and lower than a preset threshold value q , respectively. Moreover, w^+ has to be greater than w^- .

2.5 Sensitivity analysis approach for MCDM methods

There must be three assumptions for the sensitivity analysis to criteria of MCDM methods as follows (Triantaphyllou, 2000):

Assumption (1) Let $\delta_{k,i,j}$ (for $1 \leq i < j \leq m$ and $1 \leq k \leq n$) denote the minimum change in the current weight w_k of criterion c_k such that the ranking of alternatives A_i and A_j will be reversed. Next $\delta_{k,i,j}^l$ is defined as follows:

$$\delta_{k,i,j}^l = \delta_{k,i,j} \times \frac{100}{w_k} \text{ for any } 1 \leq i < j \leq m \text{ and } 1 \leq k \leq n. \quad (5)$$

That is, the parameter $\delta_{k,i,j}^l$ expresses changes in relative terms.

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Assumption (2)

- The Percent-Top critical criterion is the criterion which corresponds to the smallest $\left| \delta'_{k,1,j} \right|$ (for $1 \leq j \leq m$ and $1 \leq k \leq n$) value.
- The Percent-Any critical criterion is the criterion which corresponds to the smallest $\left| \delta'_{k,i,j} \right|$ (for $1 \leq i < j \leq m$ and $1 \leq k \leq n$) value.

Assumption (3) The criticality degree of criterion c_k denotes as D'_k is the smallest percent amount by which the current value of w_k must change, such that the existing ranking of the alternatives will change. That is, D'_k can be calculated as follows:

$$D'_k = \min_{1 \leq i < j \leq m} \left\{ \left| \delta'_{k,i,j} \right| \right\}, \text{ for all } n \geq k \geq 1 \quad (6)$$

The sensitivity coefficient of criterion c_k denotes as $\text{sens}(c_k)$, is the reciprocal of its criticality degree. That is, $\text{sens}(c_k)$ can be calculated as follows:

$$\text{sens}(c_k) = \frac{1}{D'_k}, \text{ for all } n \geq k \geq 1. \quad (7)$$

If the criticality degree is impossible to change any alternative rank with any weight change, then the coefficient is set to be equal to zero.

For this case, it is assumed that a decision maker used AVF and wishes to alter the existing ranking of the two alternatives A_i and A_j by modifying only the current weight w_k of criterion c_k . If $P_j \geq P_i$, Triantaphyllou (2000) showed the minimum quantity $\delta_{k,i,j}$, needed to reverse the current ranking of the two alternatives A_i and A_j , should satisfy the following relation:

$$\delta_{k,i,j} < \frac{(P_j - P_i)}{(a_{kj} - a_{ki})}, \text{ if } a_{ki} > a_{kj}, \text{ or } \delta_{k,i,j} > \frac{(P_j - P_i)}{(a_{kj} - a_{ki})}, \text{ if } a_{ki} < a_{kj}. \quad (8)$$

Furthermore, Eq. (10) should also be satisfied for the new weight w_k^* (Eq. 9) to be feasible:

$$w_k^* = w_k - \delta_{k,i,j} \quad (9)$$

$$\begin{aligned} w_k^* &\geq 0 \quad \text{or} \\ w_k - \delta_{k,i,j} &\geq 0 \quad \text{or} \\ w_k &\geq \delta_{k,i,j} \end{aligned} \quad (10)$$

5 At this step, $w_j^* \leq 1$ is not required.

The quantity, $\delta_{k,i,j}^l$, by which the current weight w_k of criterion c_k needs to be modified so that the ranking of the alternatives A_j and A_i will be reversed, must be satisfied as follows:

$$\delta_{k,i,j}^l < \frac{(P_j - P_i)}{(a_{kj} - a_{ki})} \times \frac{100}{w_k}, \text{ if } a_{ki} > a_{kj}, \text{ or } \delta_{k,i,j}^l > \frac{(P_j - P_i)}{(a_{kj} - a_{ki})} \times \frac{100}{w_k}, \text{ if } a_{ki} < a_{kj}. \quad (11)$$

10 Furthermore, Eq. (12) should also be satisfied for the value of $\delta_{k,i,j}^l$ to be feasible:

$$\frac{(P_j - P_i)}{(a_{kj} - a_{ki})} \leq w_k. \quad (12)$$

3 Description of the selected watershed

15 The Suamcheon (SA), Ojeoncheon (OJ) and Dorimcheon (DR) streams are branches of the Anyangcheon which is the first-order tributary of the Han River (Fig. 2); this study selected three sub-watersheds because the Anyangcheon watershed located in the central Korea near Seoul, has been observed to have serious problems in the quantity as well as the quality of water. The length of the Anyangcheon River is 32.38 km; it drains the watershed area of 287 km² that contains 3.88 million people (population

density of $\sim 13\,500$ persons km^{-2}). The watershed land cover consists of 43 % urban area, 40 % forest, and 13 % agricultural fields (as of 2000).

The channel lengths of the OJ, SA and DR are 2.85 km, 5.50 km, and 14.20 km and the areas of OJ, SA, and DR watershed are 4.26 km^2 , 8.07 km^2 , and 40.96 km^2 , respectively. OJ is located in the upstream region of the Anyangcheon, SA in the middle-stream, and DR in the downstream region as shown in Fig. 2. The urban area ratios in 2000 were 11.4 %, 25.4 %, and 62.3 %, respectively. The populations were 26 370 for OJ, 49 960 for SA and 982 804 for DR.

Chung and Lee (2009) showed that approximately 40.5 % (OJ), 43.5 % (SA) and 70.3 % (DR) of the precipitation input to the study watersheds is discharged as direct runoff, and approximately 11.3 % (OJ), 9.4 % (SA), and 1.8 % (DR) of the precipitation is discharged as base-flow. Also, modeling studies were conducted to analyze the BOD concentration, which has estimated to be approximately 13.3 mg l^{-1} (OJ), 10.1 mg l^{-1} (SA), and 20.5 mg l^{-1} (DR) and the daily load to be 68.9 kg day^{-1} ($59.0 \text{ kg ha yr}^{-1}$, OJ), 68.4 kg day^{-1} ($30.9 \text{ kg ha yr}^{-1}$, SA), and $292.8 \text{ kg day}^{-1}$ ($25.7 \text{ kg ha}^{-1} \text{ yr}^{-1}$, DR) (Chung and Lee, 2009). Chung et al. (2011c) showed that the temperatures of the Anyangcheon watershed (1964–2008) have a strong increasing trend using the Mann-Kendall trend test.

4 Results

4.1 Alternatives for watershed management

This study used the five alternatives for OJ, SA and DR that Chung and Lee (2009) have developed for integrated watershed management. Their detailed descriptions are as follows:

- Alt 1 (OJ): redevelopment of the existing reservoir (capacity: $55\,000 \text{ m}^3$, outflow: 0.01 cms) (A_1)

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- Alt 2 (SA): reuse of treated waste water effluent (discharge quantity: $11\,000\text{ m}^3\text{ d}^{-1}$ and discharge concentration: 4.7 mg l^{-1} of BOD)(A_2)
- Alt 3 (DR): use of the groundwater collected by subway (17703 m^3) and construction of a small waste water treatment plant (capacity: $12\,540\text{ m}^3\text{ day}^{-1}$ and discharge concentration: 5.0 mg l^{-1} of BOD) (A_3)
- Alt 4 (DR): use of groundwater collected by subway (A_4)
- Alt 5 (DR): construction of a small waste water treatment plant (A_5)

The initials in all parentheses refer to the name of the watershed where each alternative is proposed to be set up.

4.2 Future scenarios for climate change and urbanization

This study used the downscaled precipitation and temperature data from Chung et al. (2011c) which used CGCM3 to develop some future climate change scenarios (A1B and A2). The SDSM indicated (forecasted) that the annual average temperatures would increase by $1.8^\circ\text{C} \sim 2.4^\circ\text{C}$ under A1B and by $2.7^\circ\text{C} \sim 4.3^\circ\text{C}$ under A2 during the period 2010–2100. The increased values were not biased to particular seasons. In addition, the annual average precipitations would increase by $90 \sim 440\text{ mm}$ under A1B and by $360 \sim 500\text{ mm}$ under A2, during the period 2010 ~ 2100. The total rainfall during the summer increases and the amount of rainfall in the remaining months decreases. That is, the flood control and the water supply would become increasingly difficult (Chung et al., 2011c).

The Anyangcheon watershed has been urbanized rapidly over the past 40 years regardless of previous urban planning. The urban area ratio increased from 16.7% in 1975 to 43.2% in 2000. In addition, three studied watersheds OJ, SA, and DR have been urbanized from 2.5% to 11.4%, and 4.5% to 25.4%, and 25.7% to 60.3%, respectively, over the last 25 yr. The urban area ratio is still on the increase through political connections and economic demands.

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The existing urban planning reports forecasted the future urban area ratios of OJ, SA, and DR individually to be as follows: OJ (25%), SA (60%), and DR (no more urbanization). When the impervious area was added to the watershed, new urban areas were developed adjacent to the existing city. Although new cities can be developed in the upstream region or without any consideration for the old cities, this study assumed homogeneity for urban growth.

4.3 Hydrological analyses

In this study, HSPF was formulated to simulate the flowrate and BOD loads of the Anyangcheon watershed, including OJ, SA and DR. Because the three study-watersheds (OJ, SA, and DR) have no monitoring data, HSPF was constructed at the Anyangcheon watershed which includes OJ, SA, and DR. Therefore, this study used the HSPF model constructed by Chung et al. (2011b). It has shown the detailed HSPF formulation process and described the periods of performance, the model efficiencies, and the RMSEs that resulted from the calibration and validation.

The hydrological output was examined in terms of the flow and BOD concentration duration curves which is useful in quantifying the stream flow quantity and quality variability. This study adopted all the criteria from Hejazi and Moglen (2008), which are the 90, 95, and 99 percentile values for water quantity during the dry period. Three criteria were selected to assess the water quality, i.e. the 1, 10, and 30 percentile values of the daily average pollutant concentrations.

It is probably true that the anticipated effectiveness of all the alternatives for watershed management, which was estimated at the design process, will be changed if climate change is not considered. Definitely, land use change would pose the same problem for water resources/watershed planning. Therefore, this study analyzed the differences of simulated results between water resources/watershed planning with and without climate change impacts. In these analyses, it is assumed that land use change will come up with climate change. So, climate change scenarios were projected to the planned land use scenarios. In other words, we compared two scenarios: one

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scenario for the present climate and land use conditions and the other scenario for the forecasted climate change and planned land use change conditions. The ratios of effectiveness changed to low flow and ave. BOD concentration were analyzed as shown in Table 1.

As a result, the effectiveness of all the alternatives to water quantity and quality decreased, and A2 scenario showed more severe reduction than A1B. Alt 3 showed the largest reduction of water quantity effectiveness at A1B scenario, while Alt 5 at A2. On the other hand, Alt 5 was analyzed to show the largest reduction of water quality effectiveness at both A1B and A2 scenarios.

Since the watersheds proposed in Alt 1 and Alt 2 will be planned to be urbanized, the expected changes in the ratio of alternative effectiveness due to urbanization are calculated, and the results are shown in Table 2. In general, the changed effectiveness to quantity showed a much larger increase than that to quality. In addition, the effectiveness will decrease because of climate change.

In the case of the numbers of days required to satisfy the target water quantity and quality, four alternatives among five showed that the effectiveness of both water quantity and quality decreased because of climate changes. On the other hand, the analysis of Alt 2 showed that the effectiveness of water quantity and quality is increased because of climate changes.

When compared to the OJ, and SA results, the combination of construction of small waste water treatment plant and use of groundwater collected by subway station showed high effectiveness but was more sensitive to climate change. The effectiveness of SA was by far the greater than that of OJ and DR. In addition, the alternative having large improvements of hydrological cycles shows a larger decrease in effectiveness due to climate change as shown in Tables 1, 2, and 3. Finally, the impacts of the present watershed management plans may change in the near future since the possibilities of urbanization and climate changes are increasing. The scale and capacity of the alternatives should be expanded considering the impacts of climate changes and urbanization.

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4.4 Prioritization of alternatives using multi-criteria decision making techniques

New decision making for future water management should consider social and economic factors. Based on the DPSIR framework, as shown in Sect. 2.4, the criteria for alternative ranking were selected as shown in Fig. 3. This study modified all the criteria of Chung and Lee (2009). Fourteen criteria were including components of water quantity and quality. All values of Driving force (c_1), and Pressure (c_2) for five alternatives were collected and aggregated from statistical data and GIS analyses, as shown in Table 4. All values of State (c_3), Impact (c_4) and Response (c_5) were derived by analyzing the simulation results of HSPF, as shown in Table 5. Since the cost (c_6) must be considered for sustainable management, all costs were estimated, as shown in Table 6.

The rankings of five alternatives were analyzed as shown in Table 7. Since the cost is a crucial management component for water resources, two scenarios with and without cost were compared. In addition, since the weighting values of all criteria can be assumed differently by every decision maker, this study used some weighting scenarios agreed by five experts. From the discussion, six sets of weighting values were derived as follows:

(WSc 1) (Without cost) All random values

(WSc 2) (Without cost) Response > Impact > State > Pressure > Driving force

(WSc 3) (Without cost) Driving force = Pressure = 0, State = 0.1, Impact = 0.3, and Response = 6

(WSc 4) (With cost) all random values

(WSc 5) (With cost) Cost = Response > Impact > State = Cost > Pressure > Driving force

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(WSc 6) (With cost) Driving force=Pressure = 0.05, State = 0.1, Impact = 0.15, Response = 0.25, and Cost = 0.4

Five experts working for water resources/watershed planning agreed that WSc 6 is the most reasonable and universal scenario.

As a result, the cost component changed the ranking, largely. With cost, Alts 2 and 5 showed high prioritization, but Alt 3 showed the opposite results. WScs 1, 2, and 3 showed the same result. That is, weighting values have no impacts on prioritization of these five alternatives if cost is not considered.

For the consideration of the uncertainty of MCDM techniques, ELECTRE II was added to this decision making problem, as shown in Table 7. Since ELECTRE II showed no different result except WSc 6, only the result of WSc 6 was presented. When ELECTRE II is used, Alt 4 showed a totally different prioritization because of high environmental efficiency. For the final decision, two MCDM results must be considered.

4.5 Sensitivity analyses to six criteria

If the base scenario is assumed to be WSc6 with AVF, the relation $P_5 > P_2 > P_3 > P_1 > P_4$ holds, and as a result, the most preferred alternative is A_5 . It can be observed now that according to the weights of the six criteria, criterion cost (c_6) appears to be the most important one. Using Eq. (8), all possible values $\delta_{k,i,j}$ for reversing the current ranks are calculated as shown in Table 8. The minimum change $\delta_{6,1,4}$ is needed to alter the current weight w_6 in order that the current ranking of the two alternatives A_1 and A_4 will be reversed.

Using Eq. (5), all possible weighting values $\delta'_{k,i,j}$ for reversing the current ranking were calculated as shown in Table 9. It can be observed that the negative changes in Table 8 indicate increases of weighting values, while positive changes indicate decreases. The highlighted numbers in both tables indicate the minimum critical changes.

The PT critical criterion can be found by looking for the smallest relative value of all rows which are related to alternative A_5 (i.e. the best alternative) in Table 10. The

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smallest such percentage (i.e. 13.0%) corresponds to criterion c_6 when the pair of alternatives A_3 and A_5 is considered. For criterion c_6 a reduction of its current weight by 68.3% will make A_3 the most preferred alternative, and A_5 will not be the best alternative any more.

The PA critical criterion can be found by looking for the smallest relative $\delta'_{k,i,j}$ value in the entire Table 10. Such smallest value is $\delta'_{6,1,4}=7.5\%$, and it corresponds to criterion c_6 again. Therefore, the PA critical criterion is c_6 . Finally, as Triantaphyllou (2000) mentioned, it is a coincidence that both definitions of the most critical criterion indicate the same criterion in this application.

The criticality degrees and sensitivity coefficients of the six criteria were calculated by using Eqs. (6) and (7) as shown in Table 11. As a result, the most sensitive decision criterion is c_6 , followed by the criteria c_5 , c_1 , c_4 , c_3 and c_2 in that order. Therefore, the ranking trajectories of five alternatives to criterion c_6 were derived as shown in Fig. 4. If $c_6 > 0.127$, A_5 is the most preferred. Since it is definitely certain that the importance of cost component is over 0.127, A_5 will be the most preferred alternative in this application. From Table 8 and Fig. 4, it can be seen that A_5 dominates over A_1 and A_2 . That is, it is impossible to make alternatives A_1 and A_2 more preferred than alternative A_5 by changing the weights of the criteria.

5 Conclusions

Numerous studies have analyzed management plans by means of monitoring and hydrologic modelling (Tripathi et al., 2005; Abaci and Papanicolaou, 2009; Hess et al., 2010), but few considered the impacts of both climate change and urbanization. This study derived the analysis results of five alternatives for integrated watershed management under urbanization and climate change scenarios. The climate change scenario was obtained by using the SDSM model, and the urbanization scenario by using the existing urban planning. The alternatives for the Anyangcheon watershed consist of reusing waste water treatment plant effluent and redeveloping the existing reservoir,

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construction of a small waste water treatment plant and use of groundwater collected by subway stations. The Flow and BOD concentration duration curves were derived using the HSPF model.

Therefore, this study analyzed the differences of simulated results between with and without climate change impacts. In these analyses, it is assumed that land use change will come up with climate change. So, the climate change scenarios were projected to the planned land use scenarios by comparing the present climate and land use conditions with the forecasted climate change and planned land use change conditions.

The results of this study show that the low flows (Q99, Q95, Q90) and BOD concentrations (C30, C10, C1) are very sensitive to the alternatives. Although urbanization distorts the hydrological cycle, effective alternatives can reduce its damage. The climate change reduces the effect of the alternatives on low flow and water quality, while urbanization increases the effectiveness in general. Also climate change affects the effect of the alternatives on water quality more than on water quantity, but urbanization causes the effect on low flow to increase. The impacts of A2 are greater than those of A1B. The numbers of days required to satisfy the target instreamflow and BOD concentration are also sensitive to urbanization. In addition, the alternative having large improvements of hydrological cycles shows a larger decrease in the effectiveness of the alternatives because of the climate change and the urbanization.

Finally, prioritization of water management options must include climate change and urbanization impacts since the anticipated effectiveness of all alternatives for watershed management, which was estimated at the design process, is more likely to be changed if climate change and urbanization are not considered. All the criteria were selected from DPSIR framework. Moreover, since the cost is a crucial management component for water resources, two scenarios of with and without cost were compared.

An analysis of social and economic components, and uncertainty of weighting values and MCDM techniques for decision making revealed that the most sensitive decision criterion is cost, followed by the criteria response, driving force, impact, state and pressure in that order. Since it is definitely certain that the importance of cost component is

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over 0.127, Alt 5 is found to be the most preferred alternative in this application. These results led us to conclude that climate change and urbanization should be considered simultaneously in water resource management and planning. Lastly, the cost must be included in the real design along with the sensitivity analyses of weighting values of all criteria.

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References

- Abaci, O. and Papanicolaou, A. N. T.: Long-term effects of management practices on water-driven soil erosion in an intense agricultural sub-watershed, *Monitoring and Modeling, Hydrol. Process.*, 23, 2818–2837, 2009.
- Al-Juaidi, A. E., Kaluarachchi, J. J., and Kim, U.: Multi-criteria decision analysis of treated wastewater use for agriculture in water deficit regions, *J. Am. Water Resour. As.*, 46, 395–411, 2010.
- Bae, D.-H., Jung, I.-W., and Chang, H.: Regional impacts of climate change on water resources in Korea by using a high resolution scenario, *Climatic Research*, 35, 213–226, 2007.
- Bicknell, B. R., Imhoff, J. C., Kittle Jr, J. L., Jobses, T. H., and Donigian, A. S.: Hydrologic Simulation Program-Fortran (HSPF) User's Manual for Version 12. US Environmental Protection Agency, National Exposure Research Laboratory, Athens, GA, 2001.
- Caldeira, K., Jain, A. K., and Hoddert, M. I.: Climate sensitivity uncertainty and the need for energy without CO₂ emission, *Science*, 299, 2052–2054, 2003.
- Carter, T. R., La Rovere, E. L., Jones, R. N., Leemas, R., Mearns, L. O., Nakicenovic, N., Pittock, A. B., Semenov, S. M., and Skea, J.: *Developing and Applying Scenarios in: IPCC Climate Change 2001: Impacts, Adaptation, and Vulnerability*, Cambridge University Press, Cambridge, 145–190, 2001.

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framework, *Sci. Total Environ.*, 407, 2501–2516, 2009.

Smith, J. B.: Setting priorities for adapting to climate change, *Global Environmental Change*, 7, 251–264, 1997.

Sulis, M., Marrocu, M., and Paniconi, C.: Conjunctive use of a hydrological model and a multi-criteria decision support system for a case study on the Caia catchment, Portugal, *J. Hydrol. Eng.*, 14, 141–152, 2009.

Triantaphyllou, E. and Sanchez, A.: A sensitivity analysis approach for some deterministic multi-criteria decision-making methods, *Decision Sci.*, 28, 151–194, 1997.

Tripathi, M. P., Panda, R. K., and Raghuwanshi, N. S.: Development of effective management plan for critical subwatersheds using SWAT model, *Hydrol. Process.*, 19, 809–826, 2005.

Van Lenthe, J., Hendrickx, L., Biesiot, W., and Vlek, C.: A decision-analytic approach to the integrated assessment of climate change, *Risk Decision and Policy*, 2, 213–234, 1997.

Wilby, R. L., Dawson, C. W., and Barrow, E. M.: SDSM – A decision support tool for the assessment of regional climate change impacts, *Environ. Modell. Softw.*, 17, 147–159, 2002.

Yin, Y.: Designing an Integrated Approach for Evaluating Adaptation Options to Reduce Climate Change Vulnerability in the Georgia Basin, Climate Change Action Fund, Adaptation Liaison Office, 2001.

Yin, Y. and Cohen, S.: Identifying regional policy concerns associated with global climate change, *Global Environmental Change*, 4, 245–260, 1994.

Yohe, G.: Uncertainty, Climate Change and the Economic Value of Information – An Economic Methodology for Evaluating the Timing and Relative Efficacy of Alternative Response to Climate Change with Application to Protecting Developed Property from Greenhouse Induced Sea-level Rise, *Policy Sci.*, 24, 245–269, 1996.

Yohe, G., Andronova, N., and Schlesinger, M.: Climate –To hedge or not against an uncertain climate, *Science*, 306, 416–417, 2004.

Zardari, N. H., Cordero, I., and Sharma, A.: An objective multiattribute analysis approach for allocation of scarce irrigation water resources, *J. Am. Water Resour. As.*, 46, 412–428, 2010.

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Table 1. Changed ratio of alternative effectiveness due to climate change.

Alternative	Scenario	Quantity	Quality
Alt 1	P→A1B	-3.2%	-7.8%
	P→A2	-10.7%	-14.1%
Alt 2	P→A1B	-6.8%	-9.5%
	P→A2	-10.1%	-10.4%
Alt 3	P→A1B	-10.8%	-13.8%
	P→A2	-13.6%	-25.2%
Alt 4	P→A1B	-10.7%	-14.5%
	P→A2	-13.6%	-27.5%
Alt 5	P→A1B	-10.4%	-15.0%
	P→A2	-13.8%	-29.8%

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Table 2. Changed ratio of alternative effectiveness due to urbanization.

Alternative	<i>P</i>		A1B		A2	
	Quantity	Quality	Quantity	Quality	Quantity	Quality
Alt 1	13.2 %	2.4 %	13.4 %	0.9 %	7.6 %	2.8 %
Alt 2	40.9 %	−12.8 %	37.6 %	0.8 %	37.3 %	1.3 %

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Table 3. Number of days required satisfying target water quantity and quality.

Alternative	Quantity			Quality		
	<i>P</i>	A1B	A2	<i>P</i>	A1B	A2
No Alt	88.5	109.3	107.9	170.0	176.9	175.6
Alt 1	97.7	119.0	118.3	231.6	234.0	236.9
Rate	10.5 %	8.8 %	9.6 %	36.2 %	32.3 %	34.9 %
No Alt	109.0	132.6	130.6	32.3	25.4	28.3
Alt 2	218.8	244.4	241.6	259.1	261.6	261.9
Rate	100.7 %	84.2 %	85 %	701.3 %	931.1 %	825.3 %
No Alt	138.6	69.4	67.4	46.7	28.7	28.8
Alt 3	278.1	122.3	122.2	268.8	104.9	105.2
Rate	100.7 %	76.3 %	81.3 %	475.5 %	265.1 %	264.9 %
Alt 4	254.0	115.9	116.0	153.3	65.6	63.8
Rate	83.3 %	67.1 %	72.0 %	228.2 %	128.4 %	121.3 %
Alt 5	219.0	101.2	101.0	102.8	47.7	46.6
Rate	58.0 %	45.9 %	49.8 %	120.1 %	66.1 %	61.7 %

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Table 4. Values of driving force and pressure.

Criteria	Alt 1	Alt 2	Alt 3, 4, 5
<i>D1</i>	26 370	49 960	982 804
<i>D2</i>	6190	6191	23 602
<i>P1</i>	7.7	18.9	62.3
<i>P2</i>	70.1	1	53.2
<i>P3</i>	0.16	0.23	0.11
<i>P4</i>	26.1	9.9	59.3

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Table 5. Values of state, impact and response.

	Present					A1B					A2				
	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
<i>S1</i>	0.35	0.41	0.36	0.36	0.36	0.37	0.43	0.40	0.40	0.40	0.35	0.44	0.43	0.43	0.43
<i>S2</i>	8.52	10.75	23.17	23.17	23.17	8.90	10.58	22.62	22.62	22.62	8.87	10.34	21.08	21.08	21.08
<i>I1</i>	93.4	135.3	138.6	138.6	138.6	114.4	159.0	69.4	69.4	69.4	105.4	157.5	67.4	67.4	67.4
<i>I2</i>	189.7	160.2	46.7	46.7	46.7	196.3	147.3	28.7	28.7	28.7	195.5	146.2	28.8	28.8	28.8
<i>R1</i>	11.2	67.6	100.7	83.3	58.0	9.9	60.9	76.3	67.1	45.9	18.7	60.4	81.3	72.0	49.8
<i>R2</i>	36.4	265.8	339.9	198.3	139.7	35.2	253.7	303.2	177.1	125.1	44.2	245.1	293.6	171.4	120.4
<i>R3</i>	30.3	79.4	475.5	228.2	120.1	25.7	95.9	265.1	128.4	66.1	29.0	98.1	264.9	121.3	61.7
<i>R4</i>	7.7	26.3	45.6	40.0	36.6	5.8	24.1	39.3	34.2	31.1	4.1	23.2	34.1	29.0	25.7

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Table 6. Costs of all alternatives.

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
Cost (10^6 won)	1000	400	9110	8700	410

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Table 7. Prioritization of five alternatives.

Scenario	Weights	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5
Without Cost	WSc1 Random number; AVF	5	4	1	2	3
	WSc2 $R > I > S > P > D$; AVF	5	4	1	2	3
	WSc3 $D = P = 0, S = 0.1, I = 0.3, R = 0.6$; AVF	5	4	1	2	3
With	WSc4 Random number; AVF	3	2	4	5	1
	WSc5 $R > I > S > P > D$; AVF	3	2	4	5	1
	WSc6 $D : P : S : I : R : C = 0.05 : 0.05 : 0.1 : 0.15 : 0.25 : 0.4$; AVF	4	2	3	5	1
	WSc6 $D : P : S : I : R : C = 0.05 : 0.05 : 0.1 : 0.15 : 0.25 : 0.4$ ELECTRE II	3	N/A	3	2	1

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Table 8. All possible $\delta_{k,i,j}$ values (absolute change in criteria weights).

Pair of Alternatives		Criterion					
Driving force		Pressure	State	Impact	Response	Cost	
A1	A2	N/F	-0.747	N/F	N/F	N/F	N/F
A1	A3	0.035	N/F	N/F	0.053	0.035	-0.034
A1	A4	-0.030	-0.104	-0.095	-0.045	-0.044	0.030
A1	A5	N/F	N/F	N/F	N/F	N/F	N/F
A2	A3	-0.135	-0.261	-0.380	-0.196	-0.331	0.120
A2	A4	-0.202	-0.388	-0.565	-0.291	N/F	0.187
A2	A5	N/F	N/F	N/F	N/F	N/F	N/F
A3	A4	N/F	N/F	N/F	N/F	0.189	N/F
A3	A5	N/F	N/F	N/F	N/F	-0.536	0.273
A4	A5	N/F	N/F	N/F	N/F	N/F	0.348
Number of feasible δ values		4	4	3	4	5	6

Note: N/F stands for Non-Feasible. That is, the corresponding value $\delta_{k,i,j}$ does not satisfy condition Eq. (10).

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Table 9. All possible weighting values w_k (absolute change in criteria weights).

Pair of Alternatives		Criterion					
Driving force		Pressure	State	Impact	Response	Cost	
A1	A2	N/F	0.797	N/F	N/F	N/F	N/F
A1	A3	0.015	N/F	N/F	0.097	0.215	0.434
A1	A4	0.080	0.154	0.195	0.195	0.294	0.370
A1	A5	N/F	N/F	N/F	N/F	N/F	N/F
A2	A3	0.185	0.311	0.480	0.346	0.581	0.280
A2	A4	0.252	0.438	0.665	0.441	N/F	0.213
A2	A5	N/F	N/F	N/F	N/F	N/F	N/F
A3	A4	N/F	N/F	N/F	N/F	0.061	N/F
A3	A5	N/F	N/F	N/F	N/F	0.786	0.127
A4	A5	N/F	N/F	N/F	N/F	N/F	0.052

Note: N/F stands for Non-Feasible. That is, the corresponding value $\delta_{k,i,j}$ does not satisfy condition Eq. (10).



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Table 10. All possible $\delta_{k,i,j}^l$ values (percent change in criteria weights).

Pair of Alternatives		Criterion					
		Pressure	State	Impact	Response	Cost	
A1	A2	N/F	-1493.3	N/F	N/F	N/F	N/F
A1	A3	71.0	248.3	113.1	53.4	13.8	108.5
A1	A4	-59.6	-208.7	-95.1	-44.9	-17.5	92.5
A1	A5	N/F	N/F	N/F	N/F	N/F	N/F
A2	A3	-271.0	-521.6	-379.6	-195.7	-132.3	70.1
A2	A4	-403.4	-776.6	-565.2	-291.4	N/F	53.3
A2	A5	N/F	N/F	N/F	N/F	N/F	N/F
A3	A4	N/F	N/F	N/F	N/F	75.6	N/F
A3	A5	N/F	N/F	N/F	N/F	-214.2	31.8
A4	A5	N/F	N/F	N/F	N/F	N/F	13.1

Note: N/F stands for Non-Feasible. That is, the corresponding value $\delta_{k,i,j}$ does not satisfy condition Eq. (10).

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Table 11. Criticality degrees D'_k and sensitivity coefficients $\text{sens}(c_k)$ of the six criteria.

Category	c_1	c_2	c_3	c_4	c_5	c_6
Criticality Degree	30.0	308.0	195.0	97.0	24.4	7.5
Sensitivity Coefficient	0.033	0.003	0.005	0.010	0.041	0.133

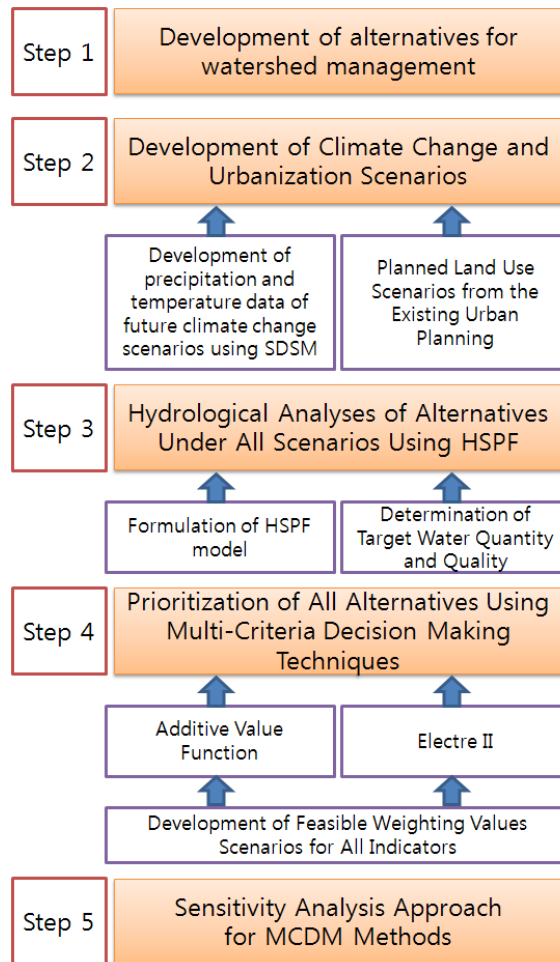


Fig. 1. Procedure of this study.

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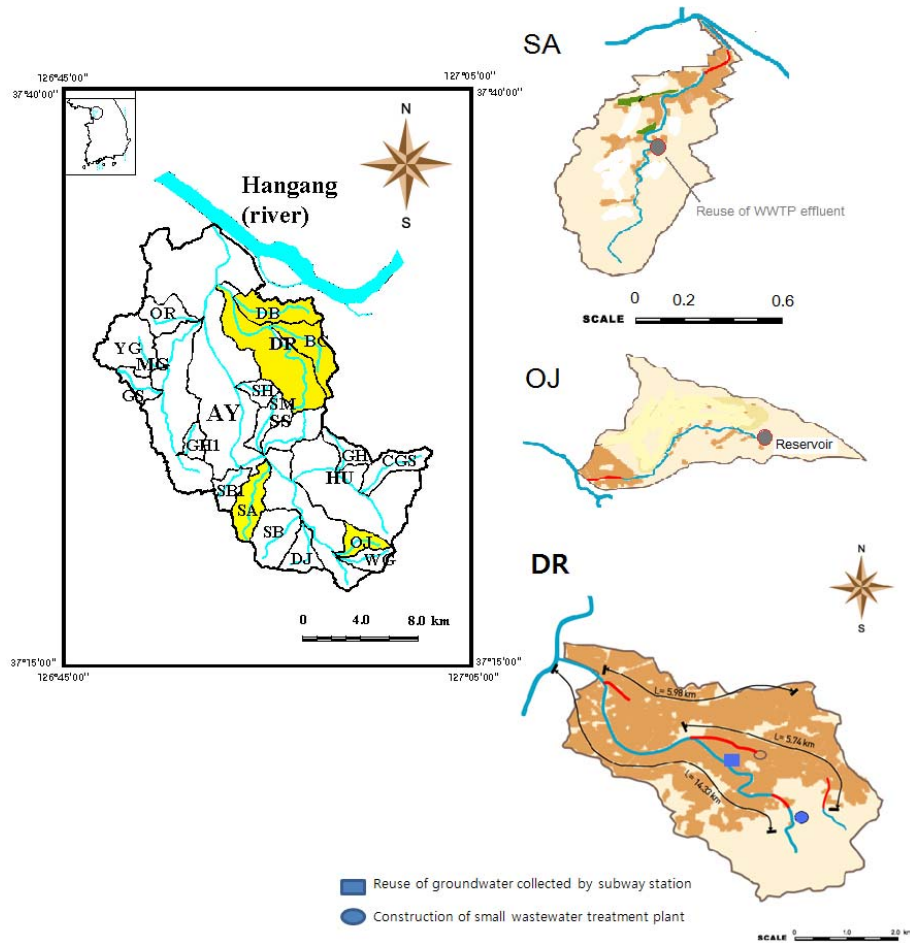
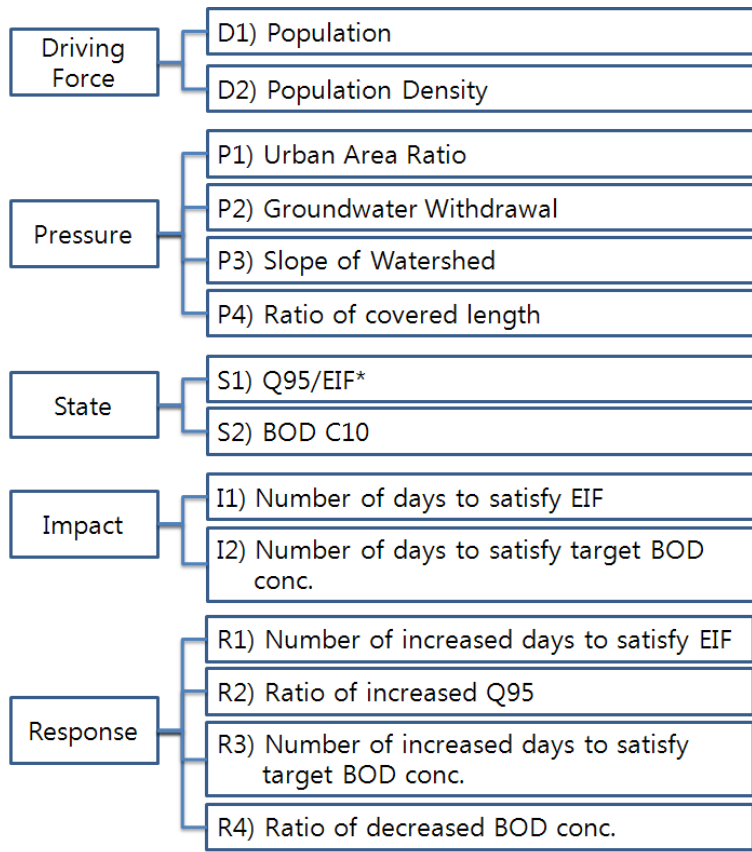


Fig. 2. Map of the study watershed.

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* EIF: Environmental Instream Flow

Fig. 3. Evaluation criteria based on DPSIR framework.

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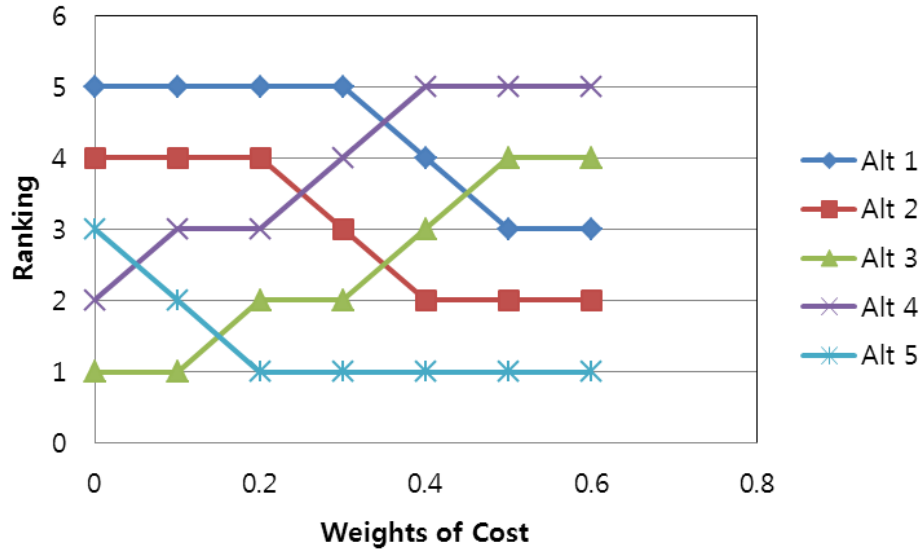


Fig. 4. Ranking trajectories of all alternatives to weights of cost.

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