KSCE Journal of Civil Engineering (2009) 13(5):359-369
DOI 10.1007/s12205-009-0359-2

Water Engineering

www.springer.com/12205

The Spatial MCDA Approach for Evaluating Flood Damage Reduction Alternatives

Kwang-Suop Lim* and Dong-Ryul Lee**

Received September 3, 2008/Accepted April 2, 2009

Abstract

The conventional MCDA method helps in evaluating and ranking alternatives based upon criteria values associated with each of the alternatives, and upon the preferences of the various decision makers. However, analyses using conventional Multi-Criteria Decision Analysis (MCDA) techniques are often limited by the ability to capture the spatial variability of a region, which affects the decision-making information for floodplain management throughout the basin. The use of Geographic Information System (GIS) can give technical specialists and ultimate decision makers the possibility to represent in a spatially distributed fashion of the information needed in the decision making process. This study is focused on addressing questions pertaining to the methodology of floodplain analysis using GIS and spatial MCDA to evaluate flood damage reduction alternatives. These issues and the approaches used to address them have been outlined in the following points. This study presents a combined GIS with spatial MCDA. Thus, combining GIS and MCDA gives decision makers the capability with spatial analysis not to just use a single strategy for an entire geographical region but to determine if different strategies might have an advantage for the different spatial characteristics at different points in the floodplain. The issues will be examined in a case study of the Suyoung River Basin in Pusan, Korea.

Keywords: *MCDA, GIS, CP, SCP, spatial approach, flood damage*

1. Introduction

Selecting the best strategy from a number of potential alternatives in water resources planning and management is a complex decision making process. It may include conflicting quantitative and qualitative criteria and multiple decision makers. The decision-making process can benefit from the use of MCDA techniques because MCDA methods provide a documentation of the decision process. Conventional MCDA techniques have been used in the field of water resources in the past.

The purpose of this study is to identify, review, and evaluate the performance of MCDA techniques for integration with GIS. Even though there are a number of techniques which have been applied in many fields, this study will only consider the techniques that have been applied in floodplain decision-making problems. Two different methods for multi-criteria evaluation were selected to be integrated with GIS, Compromise Programming (CP) and Spatial Compromise Programming (SCP). This research has been examined in a case study of the Suyoung River Basin in Pusan, Korea.

The rest of the paper is organized as follows. Section 2 gives an in-depth literature review of pertinent topics such as MCDA, and GIS. In the section 3, the experimental design for case study will be explained. Section 4 describes comparisons of the spatial approach of MCDA used to evaluate candidate alternatives. The paper concludes with a conclusion and recommendation of the evaluation of the flood control alternatives using CP and SCP.

2. Methodology

2.1 Multi-Criteria Decision Analysis (MCDA) Technique

MCDA is the process of including multiple criteria in the objective function. MCDA is characterized by great methodological diversity with three main groups of techniques: (a) outranking techniques; (b) multi-attribute utility techniques; and (c) mathematical programming techniques (Goicoechea *et al*., 1982). Outranking techniques require pairwise or global comparisons among alternatives, which are not practical where the number of alternatives is large. Multi-attribute utility techniques rely on linear additive or simple multiplicative models for aggregating single or multiple criterion evaluations. They are not appropriate for the analysis of complex environmental systems (Tkach and Simonovic, 1997).

2.1.1 Compromise Programming (CP)

The CP developed by Zeleny (1973) is a mathematical programming method used in MCDA problems. CP has both a continuous and discrete form. Mathematical programming methods

*Member, Post-Doctor, Water Resources & Environment Research Dept., Korea Institute of Construction Technology, Goyang 411-712, Korea (Corresponding Author, E-mail: okaylim@gmail.com)

**Member, Research Fellow, Water Resources & Environment Research Dept., Korea Institute of Construction Technology, Goyang 411-712, Korea (E-mail: dryi@kict.re.kr)

are designed for continuous functions. In this research the discrete CP forms are used since they have a discrete set of alternatives. CP methods have been modified and improved for water resources decision-making problems because CP requires little additional input and the adjustments of only a few factors. The CP method can be used to identify the best compromise solution from a number of potential alternatives (Nirupama and Simonovic, 2002; Zeleny, 1973, 1974). The basic idea behind CP is the identification of an ideal solution as close as possible to the ideal point, which is possibly the only assumption made by CP about human preferences (Nirupama and Simonovic, 2002). The compromise solution can be determined by calculating the distance of each alternative from the ideal solution and selecting the alternative with the minimum distance as the compromise solution (Goicoechea *et al*., 1982). All alternatives are ranked according to their respective distance metric values. The alternative with the smallest distance metric is typically selected as the 'best compromise solution'. Eq. (1) is the formula used to compute the distance metric values (L_j) for a set of n criteria and m alternatives.

$$L_j = \left[\sum_{i=1}^{n} w_i^p \left| \frac{f_i^* - f_{i,j}}{f_i^* - f_i^{**}} \right|^P \right]^{1/P} \tag{1}$$

where L_j is the distance metric, w_i is the weight of the i^{th} criterion, $f_{i,j}$ is the value of the i^{th} criterion for alternative j, f_i^* is the most optimal value of the i^{th} criterion, f_i^{**} is the least optimal value of i^{th} criterion, p is a power parameter ($1 \le p \le \infty$), $i=1, ..., n$ criteria, and $j=1, ..., m$ alternatives.

In Eq. (1), each criterion is to be given a level of importance (weight), provided by the decision makers. The p value is used to represent the importance of the maximal deviation from the ideal point (Romero and Rehman, 2003).

However, as Nirupama and Simonovic (2002) show CP has weaknesses for application to floodplain management studies. The best alternative in the CP technique can be determined only for the entire geographical region. Thus, CP uses average or total impacts incurred across the entire region being considered, without accounting for spatial variation of the criteria values. Consequently, the alternative identified as the best for an entire region by a CP method may not be the best for all locations within that region (Nirupama and Simonovic, 2002). The point is that without accounting for spatial variation, the criteria values may inadvertently result in a considerable amount of missing information.

2.1.2 Spatial Compromise Programming (SCP)

The assumption of spatial homogeneity with the study area implicit in the CP method is clearly unrealistic. This assumption is clearly unrealistic in many decision situations because the evaluation criteria vary across space. In contrast to the conventional, non-spatial MCDA (CP), spatial multi-criteria analysis requires both data on criterion values and the geographical locations of alternatives. The data are processed using GIS and MCDA techniques to obtain information for making the decision (Malczewski, 1999).

The critical aspect of spatial MCDA is that it involves evaluation of geographical events based upon the criterion values and the decision maker's preferences with respect to a set of evaluation criteria. This implies that the results of the analysis depend not only on the geographical distribution of events but also on the value judgments involved in the decision-making process. Accordingly, two considerations are of critical importance for spatial MCDA:

- The GIS capability for considering the unique characteristics at all points.
- The MCDA capability for considering multiple-criteria in deciding upon the spatially variable best alternatives.

The role of integrated GIS and MCDA techniques is to support the decision maker by providing greater definition and discrimination in terms of the alternatives of decision-making. SCP (Tkach and Simonovic, 1997) was introduced to include the spatial variability in the criteria values associated with the various alternatives by combining CP with the GIS technology (Nirupama and Simonovic 2002; Tkach and Simonovic, 1997).

In this approach, an individual grid cell within the feature image represents each location within the region of interest, for which a distance metric is calculated. Criteria values associated with each of the alternatives are contained within sets of criteria images, which are georeferenced with the feature images of buildings, roads, agricultural fields etc. An important point to emphasize is the fact that spatial analysis with GIS makes it possible to discriminate and determine whether some alternatives are better in particular areas versus others. Eq. (1) will take the form of Eq. (2) when the computations are carried out on a cell-by-cell basis.

$$L_{j,x,y} = \left[\sum_{i=1}^{n} w_i^p \left| \frac{f_{i,x,y}^* - f_{i,j,x,y}}{f_{i,x,y}^* - f_{i,x,y}^{**}} \right|^P \right]^{1/p} \tag{2}$$

where $x=1, ..., a$ rows in the image, $y=1, ..., b$ columns in the image, a is the number of rows in the image, and b is the number of columns in the image.

2.2 Geographic Information System (GIS)

GIS is a system for capturing, storing, analyzing and managing data and associated attributes, which are spatially referenced to the earth. In the strictest sense, it is a computer system capable of integrating, storing, editing, analyzing, sharing, and displaying geographically referenced information. In a more generic sense, GIS is a tool that allows users to create interactive queries (user created searches), analyze the spatial information, edit data, maps, and present the results of all these operations (http://erg.usgs.gov /isb/pubs/gis_poster/index.html).

Presently, many GIS applications in water resources decision making are frequently used to make decisions related to the spatial variability of data from different research groups.

Because of the spatial nature of the required data (Tsihrintzis *et al*., 1996), GIS technology effectively facilitates the decision making process in water resources modeling. In addition, many of the GIS systems are equipped with a GUI, which increases the decision maker's comprehension of the spatial information that is involved in the problem being addressed. A GIS can offer an effective spatial data-handling tool that can enhance water resources modeling through interfaces with sophisticated models.

3. Application of the MCDA to Floodplain Management Problem

The purpose of the case study is to demonstrate how the spatial approach to MCDA might be applied to a specific river basin for flood management purpose. The flood water impacts occurring under the implementation of different protection alternatives are used to evaluate and rank the alternatives using both non-spatial CP and SCP techniques (Tkach and Simonovic, 1997).

3.1 Experimental Design

3.1.1 Suyoung River Basin (Physical and Hydrological Characteristics)

The target region for a demonstration application of the methodology was the Suyoung basin in Pusan Province where is located on the southeastern tip of South Korea (shown in Fig. 1). The entire study area covers an area of 199.65 km^2 and the population of this area is about 4 million people. The major reasons for flooding in the Suyoung River are typhoons and depression torrential storms. Moreover, this area has no facilities to release flood water. Relatively short river reaches and steep channel slopes also contribute to frequent flood disasters.

A typical typhoon storm case in the Suyoung basin is the 1991 Gladys flood event, during which rainfall occurred continuously for several days. The main cause of flood damage was the excessive rise in the water level of the Suyoung River. The highest water level was recorded at 10.6 m which is 1.1 m higher than the flood hazard water level. Levees were washed away and about 13,807 ha of farmlands were inundated. The estimated total property loss was about 7.5million US$ (MOCT, 2001). For the application of the developed methodology for evaluating flood damage reduction alternatives, the 1991 flood event and five different return periods were selected. Through a case study, the characteristic of the combined GIS-MCDA methodology is examined and compared.

3.1.2 Identifying Candidate Criteria for Evaluating Flood Protection Alternatives

The candidate alternatives are evaluated across five criteria for which the data exhibit a spatial variability and need the integration of mathematical procedures in order to make images of criteria maps. The first criterion used in the evaluation of the alternatives is *the floodwater depth* for the study region. An image is prepared in which each grid cell contains the water depth for all distinct geographic locations. This is accomplished by using a combination of flooded feature images, the water surface elevations as contained in the image, and the Digital Elevation Model (DEM) of the region of interest. For all flooded areas, as indicated by the flooded feature image, the ground surface elevations in the DEM are subtracted from the simulated

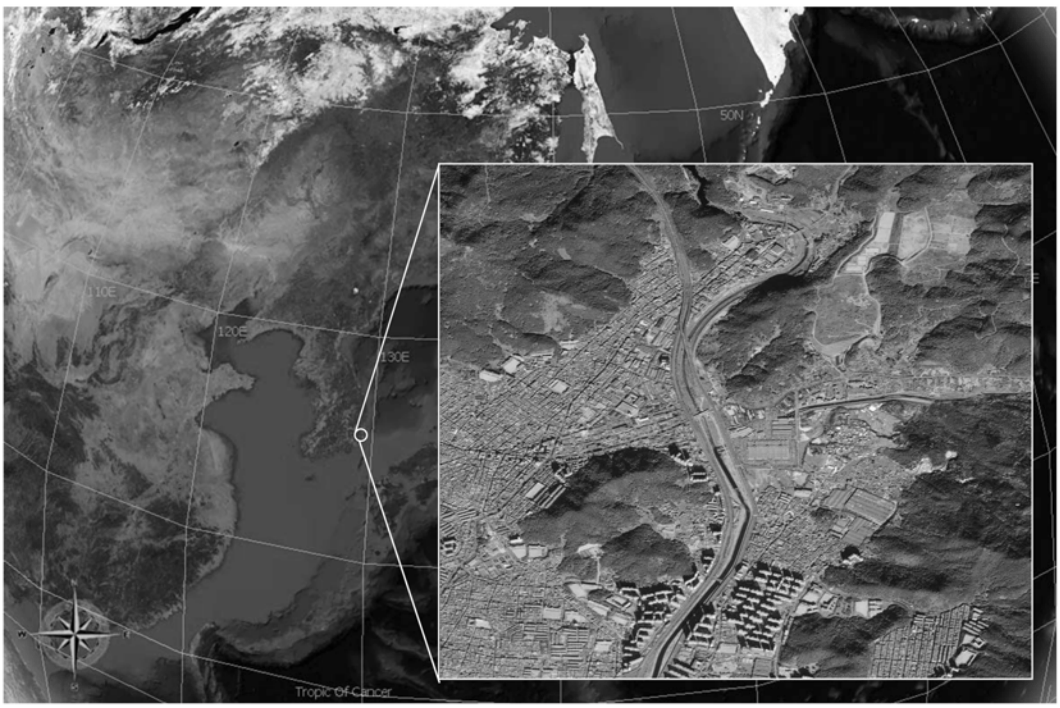


Fig. 1. Map Showing the Study Region (The Suyoung River in Korea)

water surface elevation. Grid cells in locations which were unaffected by floodwaters retain a value of zero or negative. In this way, an image containing the water depths for all flooded locations in the study region is produced for each floodplain alternative (Simonovic and Nirupama, 2005). An image of this criterion was prepared in which each grid cell contains the water depth. The second criterion is *the flood damage* under different return periods within the region of interest. Queensland (2002) commented that the relationship between the level of inundation by flood water and the resulting damage to buildings is influenced by the flooded depth of the buildings. Floodplain mapping predicts the extent and depth of flood water for varying levels of flood severity. These flood maps provide information regarding the locations of affected buildings, ground levels, and flood levels, all of which are required to calculate a damage estimate for buildings and roads. The third criterion is *the land use disruption* of the study area. Land use characteristics affect floods. Forested and heavily vegetated drainage basins generally produce floods of smaller peaks and longer durations than comparable bare basins. Urban and suburban developments can have profound effects on flooding. For this reason, land use will be employed as a different criterion from the flood damage. As

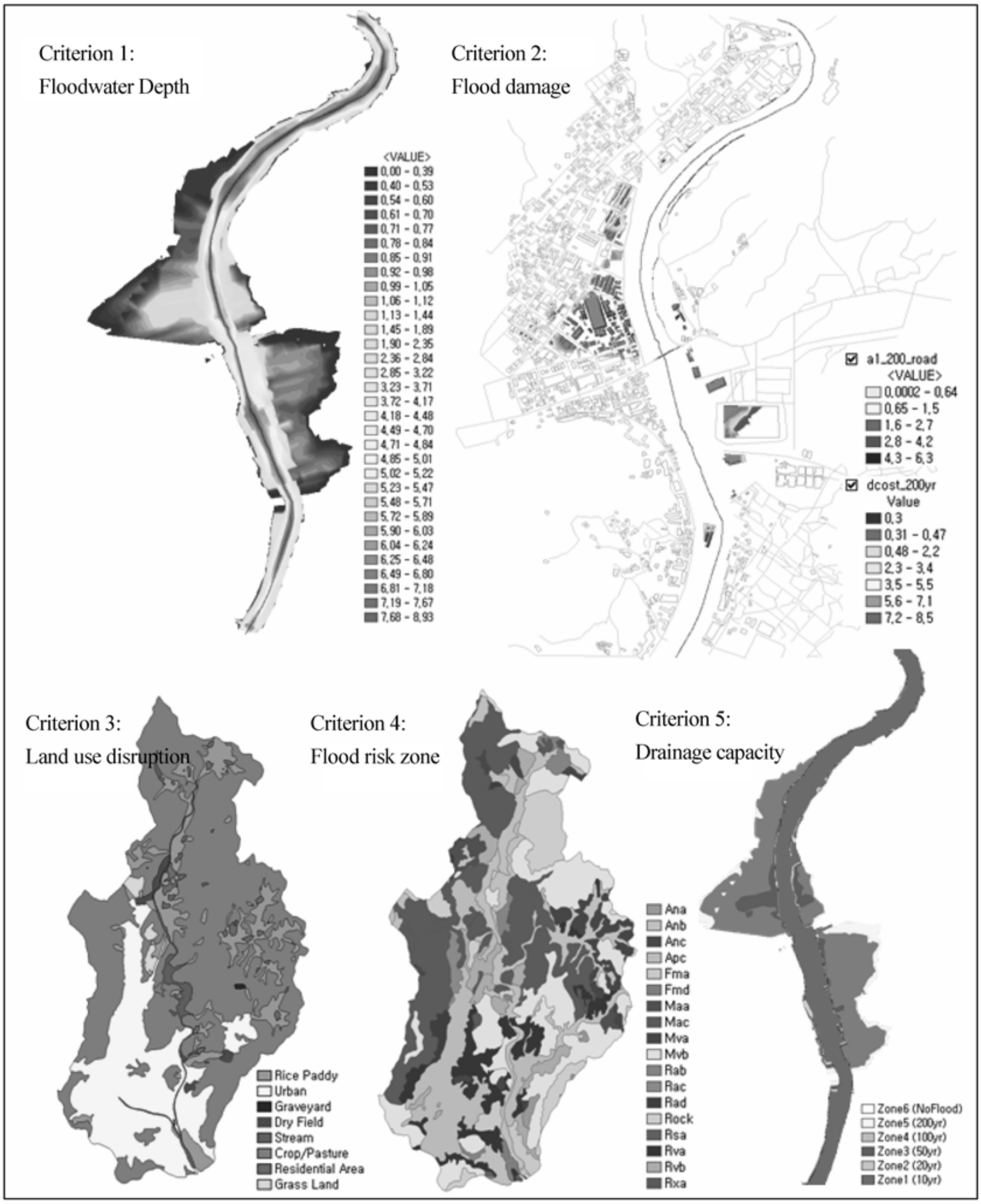


Fig. 2. Five Selected Criterion Maps

an example, if the flooded areas contain structures that may have a high population of people like housing, industrial buildings, or hospitals, they will have higher avoidance values than farmland. The land use disruption criterion also takes into account areas such as highways where disruption or interruption of service due to flooding would be particularly troublesome. This type of rating scale should be selected to fit the decision maker's desires and the characteristics of the flooding problem. The fourth criterion is *the risk of flooding under different return periods*. This criterion varies with different kinds of flood damage reduction alternatives. It is divided into six categories, Zone 1 through Zone 6. Zone 1 represents the area that is likely to flood with a 10-yr design flood. Zone 2 area will be submerged by a 20-yr design flood but not by a 10-yr flood (Zone 2 area = 20-yr inundation area – 10-yr inundation area). Similarly, in Zone 5 there is no flood damage for 10-yr, 20-yr, 50-yr, or 100-yr floods, but only for 200-yr floods. However, there is no flood damage in Zone 6 for any design flood event. The last criterion is *the drainage capacity*. Different types of soil have different capacities for retaining rainwater. If the soil in an area will not hold enough rainwater, flooding problems will ensue. For that reason, drainage capacity was chosen as the last criterion.

3.1.3 Defining the Flood Damage Reduction Alternatives and Weighting Sets

Flood control measures failed to contain the great Gladys flood of the summer of 1991, one of the worst in the Suyoung River Basin. Swelled by record summer rains, the Suyoung River area and many of its tributaries overflowed their banks, inundating an estimated 304 ha in late August. The raging floodwaters also inflicted major damage upon levees and floodways. The key concept of the Suyoung River Basin flood control planning is how to decrease the huge flood inflow from the upstream portions of the Suyoung River Basin during the flood season. As shown below, various alternatives have been derived to find the best way to reduce flood damage. The first alternative is *No Action* (Before 1991 Gladys Flood). This alternative is to leave the floodplain area as it is with no additional action. The second alternative is *Build a levee* (After 1991 Gladys Flood). After the 1991 Gladys flood event, one of the major communities (Banyeo-Dong) which had severe flood damage totaling around $1,500,000, built levees along the east side of the river. The third alternative is *Channelization plus levees*. Floods in the Suyoung River have demonstrated that levees alone do not provide sufficient protection against flooding on a large river, and other methods of flood control need to be implemented along the Suyoung River. The fourth alternative is *Pumping plus Levees*. For this study, four pump stations with a capacity of 3,800 m^3/min are installed along the upstream side of the Suyoung River. The last alternative is a *Combination of Channelization and Pumping plus Levees*. This alternative combines channelization with pumping for more effective flood control.

The preferences of decision makers are typically expressed in terms of the weights of relative importance assigned to the evaluation criteria under consideration. The derivation of weights is a central step of the evaluation and decision process. The weighting sets were chosen to give emphasis to specific criteria. For this study weighting set 1, has a large weight for criteria 1 and smaller, equal weights for the other criteria. In a similar manner, weighting set 2 favors the second criteria, and so forth. Weighting set 6 has the criteria equally weighted. Table 1 shows the weighting factors of the related criteria used in each of the six perspectives (District, 2002).

3.1.4 Hydraulic and Hydrologic Data Development

The purpose of this section is to apply, in a combined fashion, the latest hydrologic and hydraulic modeling tools and recently developed GIS software to the flooding problem in the Suyoung River Basin. The programs, the Hydrologic Engineering Centers Hydrologic Modeling System (HEC-HMS) and the Hydrologic Engineering Centers River Analysis System (HEC-RAS), allowed for the easy creation and transfer of modeling data sets relating to the Suyoung River. HEC-GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS using a GUI. The interface allows the preparation of geometric data for import into HEC-RAS and processes simulation results exported from HEC-RAS.

The overall methodology for hydraulic and hydrologic model used as a first step for this study is represented in Fig. 3. In step 1, computed flood frequency estimates are based on more than 25-years of annual peak-flow records, compiled from 1978 through 2005, from the Pusan weather station peak-flow data. Flood frequency estimates for the Suyoung River typically are presented as a set of peak flows and the associated recurrence intervals.

Table 1. Weightings of the Main Criteria Used in Each of the Six Perspectives

Criteria	Perspectives of main criteria out of a possible 100 points (weighting sets)					
	Emphasize Flood depth	Emphasize Flood damage	Emphasize Land use disruption	Emphasize Flood risk zone	Emphasize Drainage capacity	Balanced Emphasis
Flood depth	60	10	10	10	10	20
Flood damage	10	60	10	10	10	20
Land use disruption	10	10	60	10	10	20
Flood risk zone	10	10	10	60	10	20
Drainage capacity	10	10	10	10	60	20

After the interval of occurrence data was obtained, it was utilized as input data for the Suyoung River Basin hydrologic model. As a result of step 1, the HEC-HMS hydrologic model was developed. In step 2, the resulting peak flows from hydrographs generated by the hydrologic model were used as input to a HEC-RAS model created for a specific portion of the Suyoung River Basin. The hydraulic model was created in conjunction with the HEC-GeoRAS extension, using 5 m resolution DEM. HEC-GeoRAS was used to convert the resulting water surface elevations into specific digital floodplains. In the final step (step 3), these digital floodplains were combined with additional GIS data to evaluate flood damage reduction alternatives (Bedient and Huber, 2002).

3.2 The Application of the CP and SCP

Broadly speaking, decision-making is a sequence of processes. A multi-criteria decision problem usually involves selection of a number of alternatives to achieve an overall result based on the suitability of those alternatives against a set of criteria. The criteria will normally be weighted in terms of their importance to the decision maker, since criteria are rarely of equal importance. When a suitable process is applied to the problem, a rating of the alternatives can be formed into a rank, based on preferences (Kenevissi, 2007). MCDA problems involve a sequence of activities that are based upon the following steps: (1) start with a set of main criteria to be considered; (2) determine the relative importance of each criterion with respect to each other; (3) assign normalized importance weights; (4) select the alternatives to consider; (5) define a common rating scale and convert the scores for the alternatives into ratings; (6) use an MCDA technique to rank the alternatives; and (7) end with a recommendation based upon the ranking of each alternative (Traore *et al.*, 2007;

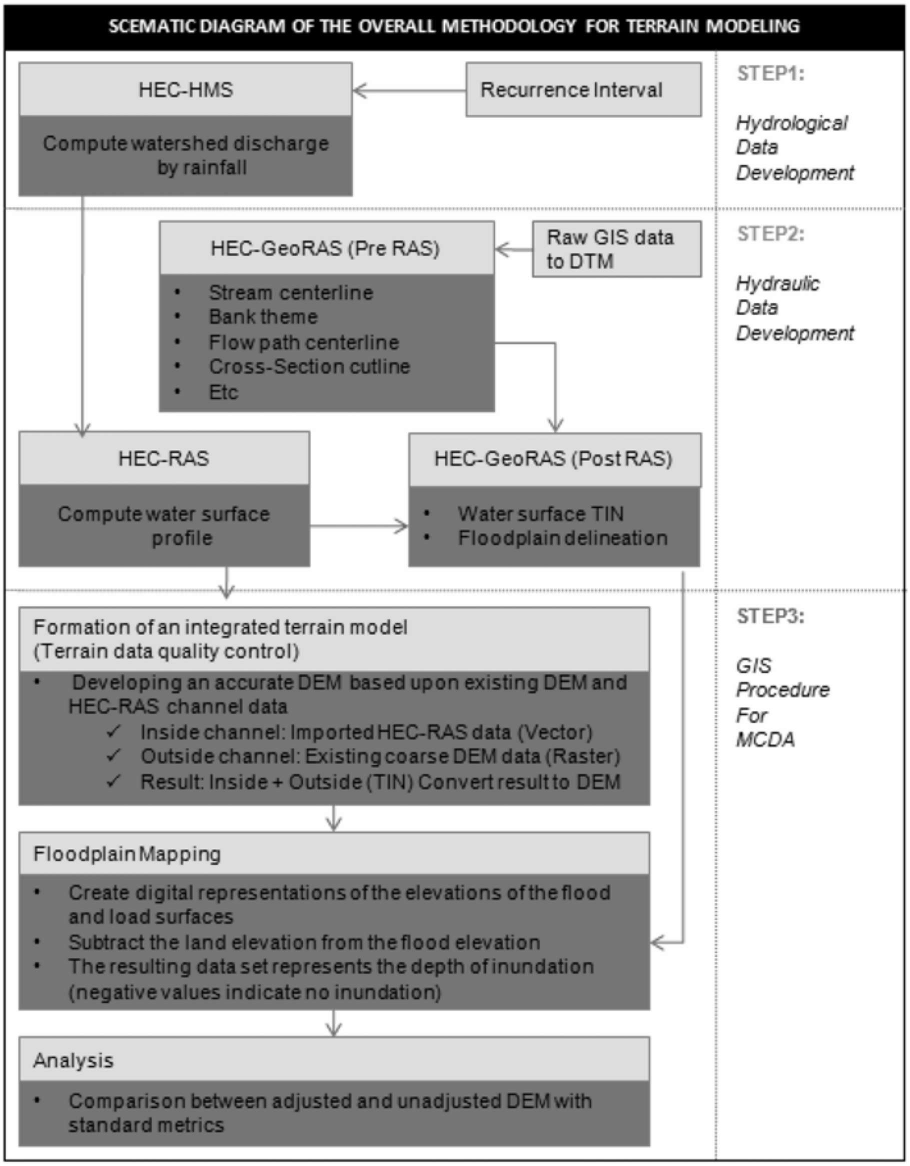


Fig. 3. Schematic Diagram of the Overall Methodology for Terrain Modeling

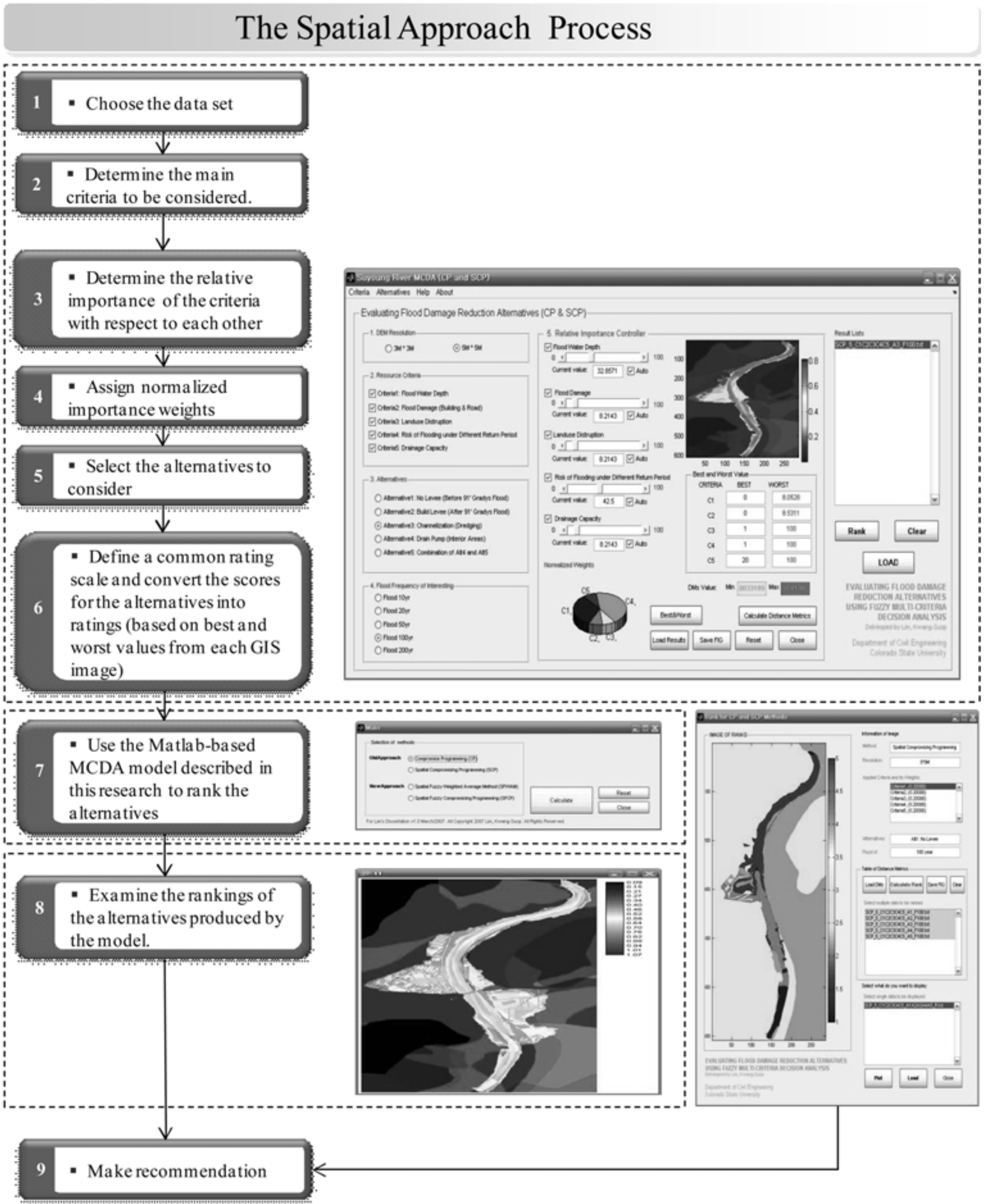


Fig. 4. The Framework for the Spatial Approach to MCDA

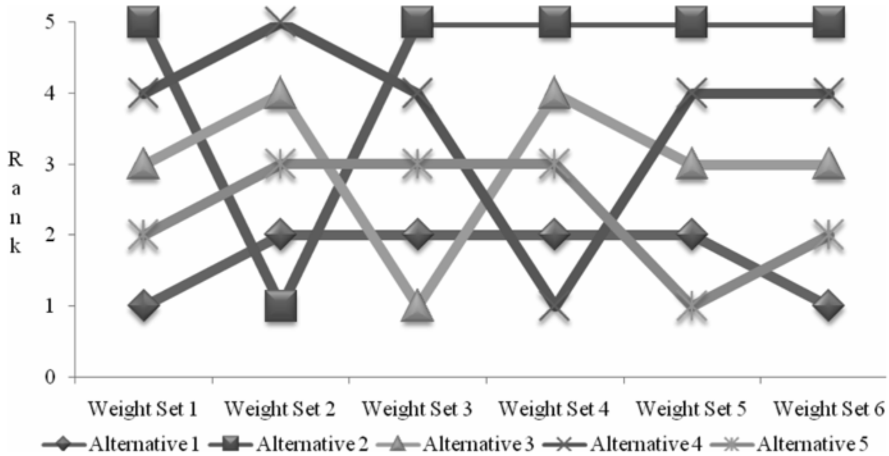
Malczewski, 1999; Simonovic, 2002; Tkach and Simonovic, 1997). Fig. 4 illustrates the framework for the spatial approach to MCDA as a part of this research. The CP and SCP methods use the exponent p value (in Eq. (1) and (2)) which is used to put increasing stress on the better rating values (Fontane, 2003). In this case study, a single value of 2 is used during the evaluation of all alternatives as the value of parameter p (Traore *et al.*, 2007; Nirupama and Simonovic 2002).

3.3 Results

MCDA methods described in section 2.1 were applied to evaluate various flood damage reduction alternatives. Performances of the alternatives were then compared according to the flowcharts in Fig. 4. First, the CP method was applied to evaluate the alternatives and then the SCP method was applied.

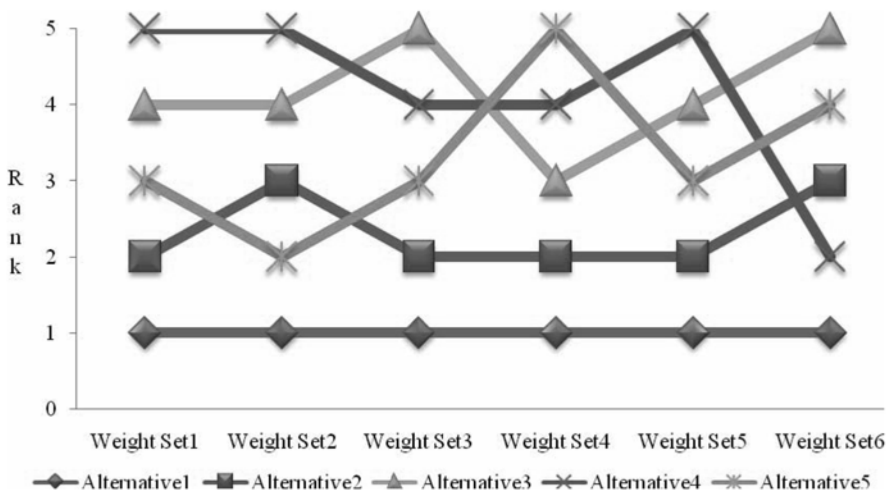
In first method, CP, the alternative having the smallest distance metric value is selected as the most appropriate for the entire Suyoung region. On the other hand, the alternative having the largest value of the distance metric is therefore determined to be the worst alternative (Tkach and Simonovic, 1997). Comparison of both the distance metric value and overall rankings for different weighting sets of all alternatives was performed following the flowcharts in Fig. 4 resulting in a ranking for each different weighting set. In Fig. 5, the graph (upper) and the table (lower) shows the overall final rankings for all six possible cases. This simple figure and table gives some valuable information in terms of the decision-making for evaluating floodplain alternatives in the Suyoung area. The results illustrate the problem with the spatial averaging used in the CP method.

As evident in Fig. 5, the best floodplain alternative determined for the entire geographical region by the CP technique, which uses average or total flood damage impact incurred across the entire region being considered (Nirupama and Simonovic, 2002), can be mis-leading. For example, when a criterion 1, flood depth, is emphasized, the CP method selects the No Levee option. This results from the metric being averaged over all cells in the basin. The averaging over the basin gives the impression that this is a good alternative.



Alt.	Weight Set 1	Weight Set 2	Weight Set 3	Weight Set 4	Weight Set 5	Weight Set 6	Average Ranking	Overall Ranking
No action	1st	2nd	2nd	2nd	2nd	1st	1.66	1st
Build a levee	5th	1st	5th	5th	5th	5th	4.33	5th
Channelization plus levees	3rd	4th	1st	4th	3rd	3rd	3.00	3rd
Plumping plus levees	4th	5th	4th	1st	4th	4th	3.66	4th
Combination of channelization and pumping plus levees	2nd	3rd	3rd	3rd	1st	2nd	2.33	2nd

Fig. 5. Overall Final Rankings for All Six Possible Cases of CP Method



Alternative	Weight Set 1	Weight Set 2	Weight Set 3	Weight Set 4	Weight Set 5	Weight Set 6	Average Ranking	Overall Ranking
No action	1st	1st	1st	1st	1st	1st	1.00	1st
Build a levee	2nd	3rd	2nd	2nd	2nd	3rd	2.33	2nd
Channelization plus levees	4th	4th	5th	3rd	4th	5th	4.16	4th
Plumping plus levees	5th	5th	4th	4th	5th	2nd	4.16	4th
Combination of channelization and pumping plus levees	3rd	2nd	3rd	5th	3rd	4th	3.33	3rd

Fig. 6. The Overall Final Rankings for All Six Possible Cases from SCP Method

Overall, it is obvious that the CP method is not suitable for considering and discriminating the best alternatives for every region of interest, since rankings of suitable alternatives for each specific grid cell considered in calculating the final ranking value cannot be obtained (Yalcin and Akyurek, 2004). The point is that the CP method does not allow the decision maker to consider the unique characteristics of each strategy at all points. The loss of spatial variability is one of the critical flaws of the CP method that needs to be addressed.

The main idea of the SCP method is to include the evaluation of spatial components throughout the whole basin. With this method, rather than selecting a single alternative for the whole region of interest, a distance metric is calculated for each location in the region (Nirupama and Simonovic, 2002). In addition, SCP may give decision makers the possibility to find more spatially distributed strategies.

Fig. 6 shows the overall final rankings for all six possible cases from SCP method. The preference order in the areas of interest would be:

Alternative 1 > Alternative 2 > Alternative 5 > Alternative 3 = Alternative 4

Many of the first-ranked alternatives appearing in the SCP results are Alternative 1 (No Levee). It is important to note the reason why Alternative 1 commands an overwhelming majority with respect to the other alternatives. This occurs because Alternative 1 includes non-flooded area. In other words, there was no action needed for flood protection. Alternative 1 is the only option available for non-flooding areas. Therefore, Alternative 1 will always command a high percentage of grid cells on any map that includes a fair amount of non-flooding area. Fig. 7 shows what might be more results in particular areas only between CP and SCP methods and better illustrate the richness of the SCP information compared to the CP information. In Fig. 7 (Left), the alternative produced by the CP method is the same for all locations within the interesting region 1 and region 2. Because the CP use average or total impacts incurred across the entire region being considered. But in Fig. 7 (Right) the distribution of the alternatives shows that for the region 1 alternative 4 is the best option for floodplain management but for the region 2 alternative 2 is the best choice to reduce flood impacts at that location. Straightforward application of the SCP is appropriate for problems which exhibit spatial variability in the criteria values.

Fig. 8 shows one of the example of the distance metric map resulting from the SCP method, for weighting set 1 and alternative 1. One can quickly notice that the SCP method is spatially variable. Since the SCP method produces a value for each grid cell of the area, spatial maps resulting from SCP show dramatic differences compared with the CP method. The ranking of alternatives in each weighting set in Fig. 9 shows significant differences between the strategies in the Suyoung area. Using this method, it is likely many more options will be selected. In other words, the SCP method gives decision makers the capability to use spatial analysis in more than a single strategy, for an entire

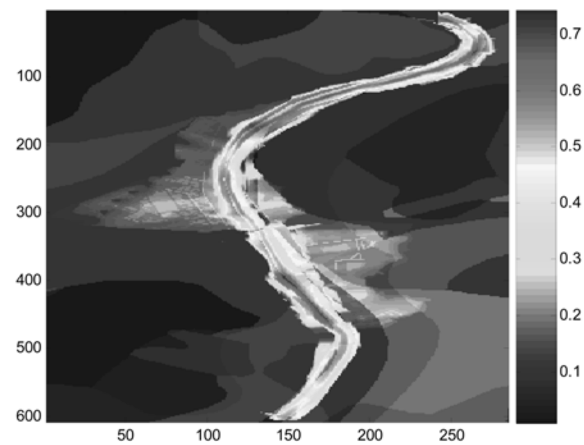


Fig. 8. Distance Metric Map Resulting from the SCP Method, for Weighting Set 1 and Alternative 1

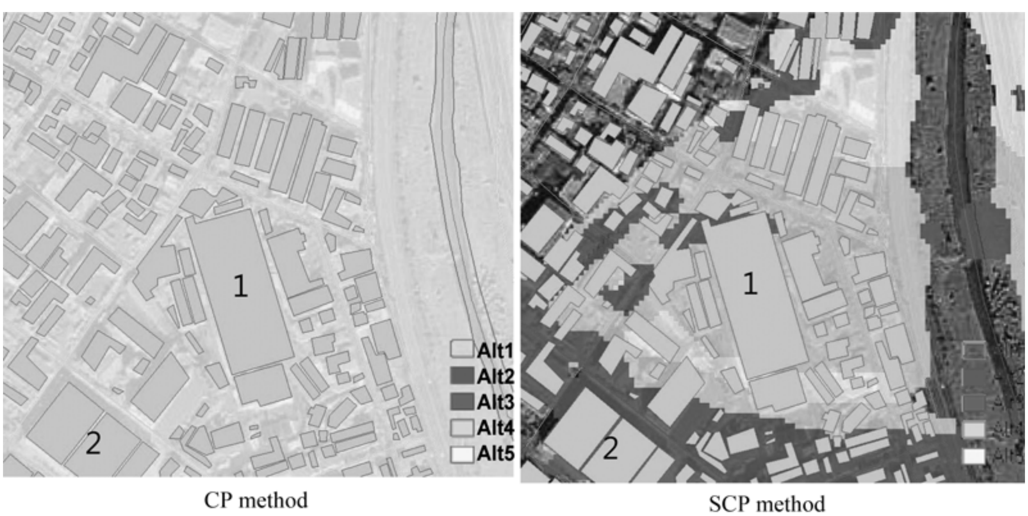


Fig. 7. Comparison of Ranking Map of the CP and SCP Method, for Weighting Set 6

geographical region and to determine the various alternatives. Different strategies might have an advantage since the different spatial characteristics highlight different points in the floodplain. For example, in flood prone areas, the flood impacts are typically not the same for all locations within the floodplain. The distribution of the flood impacts is a function of the implemented flood protection measures. Implementation of a particular alternative may reduce impacts produced by flooding at one particular

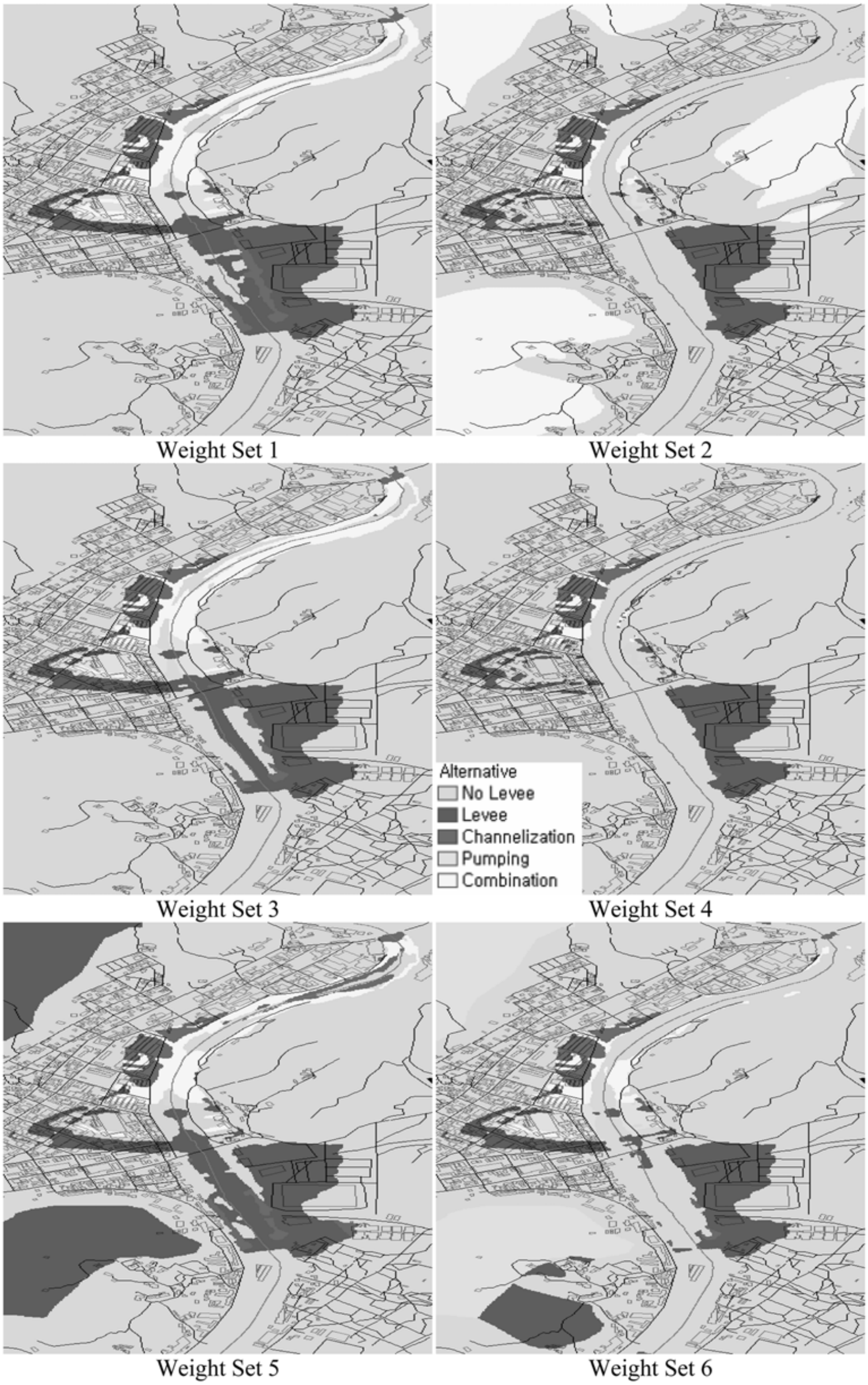


Fig. 9. Preferred Alternatives for Each Spatial Location Resulting from the SCP Method, for Weight Sets 1~6

location, while providing no protection at all for another. Thus different alternative to one particular location gives decision-makers to use the spatially diverse strategies to arrive at floodplain management recommendations.

When the ranked alternatives produced by both the SCP method and the CP method are compared, it is found that the SCP method provides decision makers the ability to have more definition, diversity and discrimination in terms of the best strategies for particular spatial locations. This occurs because SCP considers distance metric values spatially at each grid cell in the area, whereas the CP method calculates the average value of distance metrics throughout the whole region.

Overall, these comparisons seem to suggest the SCP method is a competitive method for evaluating floodplain alternatives. The SCP method gives abundant information allowing the decision maker to more accurately discriminate among the best alternatives under investigation.

4. Conclusions

Spatial comparison of floodplain management alternatives in a raster GIS environment is conceptualized as a multi criteria decision making problem. A spatial MCDA technique is developed by combining the conventional CP technique with GIS technology. Based upon the two selected MCDA approaches, differences in simulation results were evaluated and ranked non-spatially (CP) or spatially (SCP) in the region of interest for evaluation of flood damage reduction alternatives. For better comparison of the differences of simulated ranking maps, six weight sets were used individually for each result. Some of the findings from this work include: The CP method computed a single value per region for each of the alternatives. On the other hand, with the SCP method a distance metric per alternative was calculated for each impacted location within the region, which gives decision makers the capability with spatial analysis not to just use a single strategy for an entire geographical region but to determine if different strategies might have an advantage for the different spatial characteristics at different points in the floodplain. The performance of SCP provides the ability to have even more definition and discrimination in terms of the alternatives that might be best for particular spatial locations.

However, the CP and SCP approaches do not consider the effects of measurement error, inherent variability, instability, conceptual ambiguity, over-abstraction, or simple ignorance of important model parameters which have uncertainty, vagueness, or imprecision. Unfortunately, imprecision is inevitable in the decision-making process. Thus, it is necessary to find a new approach to reduce the effect of the imprecision on the results.

References

Bedient, P. B. and Huber, W. C. (2002). *Hydrology and floodplain analysis*, Prentice Hall, Upper Saddle River, NJ.

District, S. C. V. W. (2002). “Coyote watershed stream stewardship plan - Executive summary.” Santa Clara Valley Water District, URL: http://cf.valleywater.org/_wmi/Related_report/index.cfm.

Fontane, D. G. (2003). *Water resources systems analysis*, Class Lecture Note for CE546, Colorado State University, Fort Collins, CO.

Goicoechea, A., Hansen, D. R., and Duckstein, L. (1982). *Multiobjective decision analysis with engineering and business applications*, Wiley, New York, N. Y.

Kenevissi, F. (2007). *Multi-criteria decision making*, Newcastle Engineering Design Centre, Newcastle University Newcastle, UK.

Malczewski, J. (1999). *GIS and multi-criteria decision analysis*, J. Wiley & Sons, New York, N. Y.

MOCT. (2001). *The improvement method for economic of water control plan*, Ministry of Construction & Transportation, Korea (in Korean).

Nirupama and Simonovic, S. S. (2002). *A spatial fuzzy compromise approach for flood disaster management*, The Institute of Catastrophic Loss Reduction, London, Ontario.

Queensland, T. S. O. (2002). *Guidance on the assessment of tangible flood damages*, The State of Queensland (Dept. of Natural Resources and Mines); QNRM02081, Australia.

Romero, C. and Rehman, T. (2003). *Multiple criteria analysis for agricultural decisions*, Elsevier, Amsterdam, Boston.

Simonovic, S. P. and Bender, M. J. (1996). “Collaborative planning-support system: an approach for determining evaluation criteria.” *Journal of Hydrology*, Vol. 177, Issues 3-4, pp. 237-251.

Simonovic, S. S. (2002). *A spatial fuzzy compromise programming for management of natural disasters*, The Institute for Catastrophic Loss Reduction (ICLR), Paper Series No. 24, University of Western Ontario, London, Ontario.

Tkach, R. J. and Simonovic, S. P. (1997). “A new approach to multi-criteria decision making in water resources.” *Journal of Geographic Information and Decision Analysis*, Vol. 1, No. 1, pp. 25-44.

Traore, Z. N. and Fontane, D. G. (2007). “Managing drought impacts: Case study of Mali, Africa.” *Journal of Water Resources Planning and Management*, Vol. 133, No 4, pp. 300-308.

Tsihrintzis, V. A., Hamind, R., and Fuentes, H. R. (1996). “Use of Geographic Information System (GIS) in water resources: A review.” *Water Resources Management*, Vol. 10, pp. 251-277.

Yalcin, G. and Akyurek, Z. (2004). “Analysing flood vulnerable areas with multicriteria evaluation.” In: Geo-Imagery Bridging Continents, XXth ISPRS Congress, 12-23 July pp. 359-364.

Zeleny, M. (1973). “Compromise programming.” *Multiple Criteria Decision Making*, University of South Carolina Press, Columbia, pp. 262-301.

Zeleny, M. (1974). *Linear multiobjective programming*, Springer-Verlag, Berlin, New York, N. Y.