The Development of a Methodology for Improving Consideration of Imprecision using GIS and Spatial Fuzzy MCDA

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1. Introduction

In this study meets the objective of the development of a methodology for improving consideration of imprecision using GIS and spatial fuzzy MCDA. The methodology was developed and applied as a GIS-based MCDA interactive model designed to give end-users a convenient tool for floodplain management. The developed model was programmed in Matlab software. The target region for a demonstration application of the methodology was the Suyoung River Basin in Korea. The 1991 Gladys flood event and five different return periods were used as a case study to demonstrate the proposed methodology of evaluation of various flood protection alternatives.

2. GIS and MCDA

The advantage having spatial data is that it allows the consideration of the unique characteristics at every location. The GIS provides the possibility to develop more spatially distributed information. Ultimately decision makers will typically select a single flood water management alternative (such as levees or a combination of levees and channelization) for the entire project region. The selected alternative will be more successful in minimizing flood impacts at some spatial locations than others. If the information developed is lumped over the entire floodplain, then the details of the information are lost.

3. Methodology

GIS spatial analysis techniques may introduce problems unique to the technology during the data integration and analysis process. Moreover, floodplain management problems tend to be complex and multi-faceted, requiring an MCDA approach. MCDA allows decision makers to consider multiple-criteria in deciding on the best alternatives. The combinations of spatial and multi-criteria provide the ability to have even more definition and discrimination in terms of the alternatives that might be best for particular spatial locations. Again, more discrimination is taken to mean more information and this is considered highly desirable.

The proposed approach involves integrating a hydraulic model’s terrain data with lower accuracy DEM for flood maps, implementation of deterministic MCDA techniques, and implementing a combination of GIS and fuzzy MCDA into floodplain decision making. Spatial Fuzzy Weighted Average Method (SFWAM) for multi-criteria evaluation was selected to be integrated with GIS.

3.1. Study Area

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. The entire study area covers an area of 199.7 ㎢ and the population of this area is about 4 million people. For the application of the developed methodology for evaluating flood damage reduction alternatives, the 1991 Gladys flood event and five different return periods were selected.

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. Various alternatives have been derived to find the best way to reduce flood damage (Fig 2).

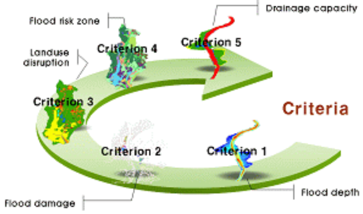

Figure 1. Criteria

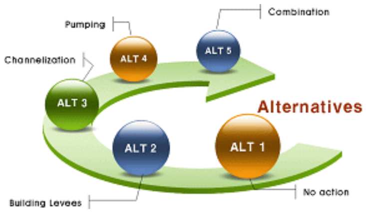

Figure 2. Alternatives

3.2. Fuzzy and SFWAM Method

Considering the literature available on MCDA techniques, it was realized that there is a need to develop a methodology that combines the three important issues, since time and space play an important role in flood management. Specifically, these are the GIS capabilities for finding more spatially distributed strategies, the MCDA capabilities for considering multiple-criteria in deciding on best alternatives, and the fuzzy capabilities for lessening the effect of the imprecision on the answer. The SFWAM was introduced to include these three objectives. Fuzzification has been proposed to account for the vagueness in the entire process of decision-making.

4. Cost of Uniformity

The overall sum (or the average) of the distance metrics for all spatial locations represents a lower bound or baseline against which options can be compared. If a single alternative is selected for the entire region, then the average of the distance metrics for all spatial locations will increase. The increase in this average represents a "cost of uniformity" for that alternative. Comparing these "costs of uniformity" for each of the alternatives can give an indication of the relative order of the alternatives in terms of their average scores.

To assist the comparison of the average scores for the alternatives, the increase in average scores was scaled from zero to one, where one corresponds to the largest increase in average score. An example of the calculation of the "cost of uniformity" is shown in Figures 3(left) and 4(left). It is apparent from these figures that selecting Alternative 5 as the entire basin alternative has the smallest increase in the "cost of uniformity." Compared to the baseline condition, selection of Alternative 5 results in an increase of 6% of the average score. If Alternative 4 is applied everywhere, the overall average score increases by 17%. By comparing these increases to the values for selecting the other alternatives (Alternative 3 = 25%, Alternative 2 = 36% and Alternative 1 = 100%) decision makers can see that alternatives 5 and 4 would clearly be the preferred options.

There might be situations where the selection of the alternative might be influenced most heavily by a particular region in the floodplain. To illustrate this situation the Geumsa area in the upstream portion of the Suyoung River Basin was selected as an important area that might influence the selection of the preferred alternative. The Geumsa area is an urban area with government buildings and hospitals. The "cost of uniformity" calculations were made for the Geumsa area only and the results are shown in Figures 3(right) and 4(right). For this particular region only Alternative 5 still has the smallest increase in the "cost of uniformity" and the second choice is still Alternative 4. However, the relative increase in the "cost of uniformity" was larger (Alternative 5 = 47% and Alternative 4 = 55%). This is an indication of the large amount of diversity of the optimal alternative for individual location in this region.

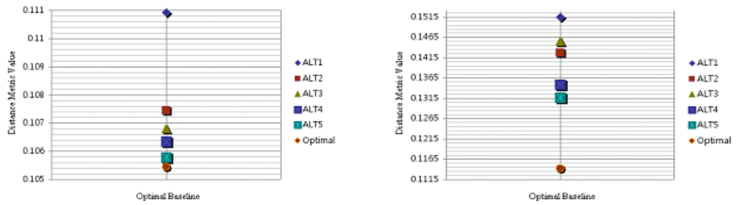

Figure 3. The cost of uniformity for each of the alternatives for the entire basin and the Geumsa area

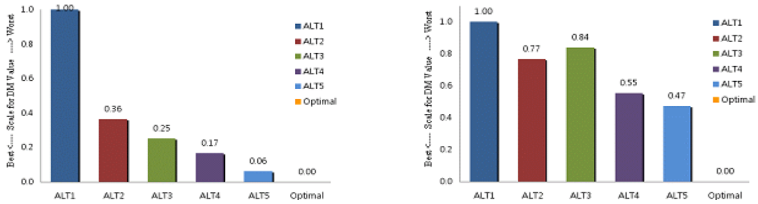

Figure 4. Scaling the total distance metric for the entire basin and the Geumsa area

5. Results

This study shows examples of how the details of the analysis might be synthesized so that the final decision maker can make a more informed decision. Specific key contributions made by this research include the following:

"Proposed the development of a "cost of uniformity" metric that allows decision makers to compute the impact of selecting a single alternative for the entire floodplain. This metric represents the increase in the average distance metric value as compared to the spatially diverse solution from the MCDA and GIS analysis.

6. References

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

[2] Gale, T. (2006). "Encylcopedia of Management." S. Neil, ed., International Directory of Business Biographies - F-L.

[3] Lim, K.-S. (2008). "Methodology for evaluating flood damage reduction alternatives using a GIS-based MCDA interactive model," Colorado State University, Fort Collins.

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