

DEVELOPMENT OF A SPATIAL MULTI-CRITERIA DECISION TOOL WITHIN A SPATIAL DECISION SUPPORT SYSTEM FOR WATER RESOURCES PLANNING

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ABSTRACT

Problems involving the process of integrated water resources management (IWRM) such as finding the best solution on water allocation and conflict resolution are of significant challenges especially in case of the changing environment. This might be a challenging problem because of technical, economic, social, environmental as well as political aspects that may be in contrast with each other. Recently, development of information technology has improved the application of specific tools to be used through the complex process of an IWRM. Geographic Information Systems (GIS) and Multi-Criteria Decision- Making techniques (MCDM) are two common tools that could be employed to solve water resources problems. This paper presents a spatial MCDM (SMCDM) which is used within a GIS-based Spatial Decision Support System (SDSS) for the purpose of water resources planning and management. The algorithmic process of the developed SMCDM and its role as an important module of a new developed spatial decision support system is discussed. SDSS integrates various modules of the water resources system and the spatial multi-criteria decision analysis within a single system. Thus, the system is found to be very effective and user-friendly to provide proper feedbacks for an integrated water resources management process of a river basin. The developed SMCDM model is useful for screening and prioritization of water resources alternatives through different conditions. An example of applying the developed system in Karkheh river basin in Iran is presented.

1 INTRODUCTION

Decision making is one of the most significant challenges in the field of water resources and environmental engineering because of either the complexity around a problem or the unpredicted impacts of a decision. This challenge might be a result of multidisciplinary problems, which may put some contrasting objectives in a competition that no compromising is allowed. To overcome this challenge, new technologies have presented powerful tools to increase efficiency and accuracy of decision makers as well

as to accelerate their response in facing with the real world problems. Decision Support Systems (DSSs) are one the most efficient tools, which their abilities have been proved in the enormous engineering contexts.

Geographical Information System (GIS) and Multi-Criteria Decision Making (MCDM) are currently the two most common decision support tools employed to solve spatial decision-making problems. GIS has very limited capability of incorporating the decision maker's preferences into the process of solving a problem. MCDM, which deals mainly with analyzing decision problems and evaluating the alternatives based on a decision maker's values and preferences, lacks the capability of handling spatial data (Eldrandaly, 2005). The necessity of incorporating spatial data into the decision making process, has raised a specific technique of MCDM which is known as spatial multi-criteria decision making (SMCDM). Applied developed SMCDM models usually benefit from GIS to process the spatial analysis, facilitating the decision making process.

The concept of SMCDM has made it popular to be used through the integrated water resources management (IWRM) process. Meanwhile, GIS tools are very helpful in dealing with the components of a water resources system such as watershed modelling (Malczewski, 1999). Therefore, the combination of GIS and SMCDM not only helps dealing with the making proper decisions, but also could tend to develop a powerful spatial decision support system. This paper presents a new SMCDM model, which has been specifically developed as a module of a spatial decision support system.

2 SMCDM AND SPATIAL DECISION SUPPORT SYSTEM

The goal of water resources development plans is to gain outputs with minimum impacts and maximum benefits. The aim of using MCDM analysis in water resources planning is to choose the best or the most preferred alternatives and/or rank the alternatives in a descending order of preferences. In the conventional methods of spatial multi-criteria decision making, the alternatives consist of different partition of a region as shown in Figure 1. In this approach, the attributes of each partition remains constant through the decision making process. Examples of application of this conventional approach could be found in land planning (Keisler and Sundell, 1997); land siting (Kao and Lin, 1996); mapping natural hazards (Wadge et al. 1993); and Forest planning (Mendoza and Sprouse, 1989).

In the developed system of this study, alternatives include the network of water resources sinks, and sources, and the links between them as well as the scenarios affecting the operation of the system. Examples of the alternatives are: changes in the withdrawal from the surface and ground water; constructing new surface reservoir and hydropower plant projects; hydropower generation; and water allocation to different consumptive and non-consumptive use. All of these alternatives are supported by the developed spatial decision support system (SDSS), which is called SIMAB, to analyze their attributes over the basin. The structure of the SMCDM developed in this study is presented in Figure 2. In this new approach of SMCDM process, different attributes at each partition may be changed as a function of the associated alternatives.

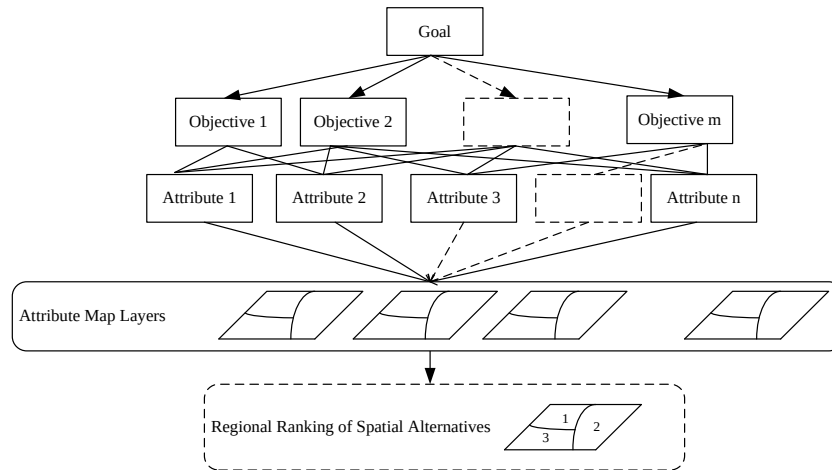


Figure 1. The conventional algorithm of a spatial multicriteria decision making (Malczewski, 1999)

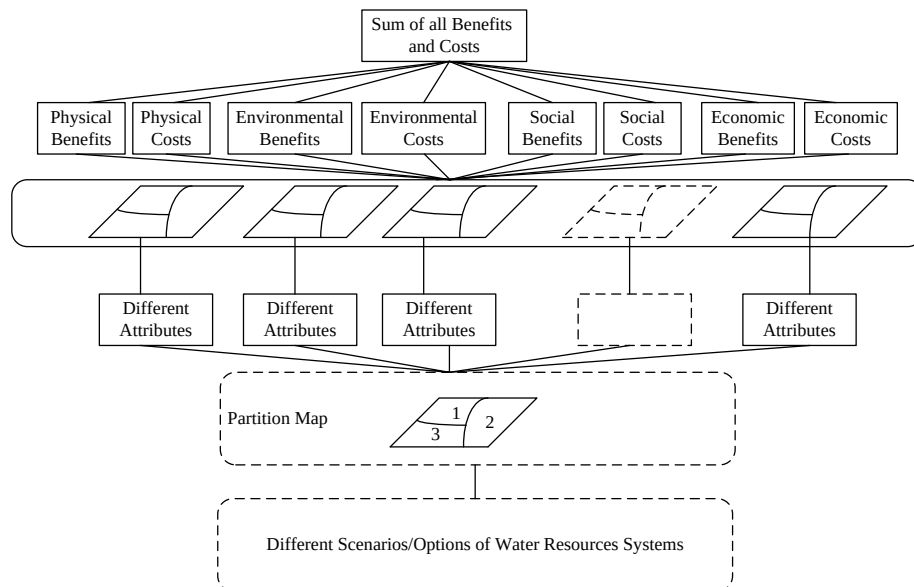


Figure 2. The proposed algorithm of the SMCDM in this study

In a general definition, the architecture of DSS is consisted of three components namely Data Base, Model Base, and Graphical User Interface (GUI). The developed SMCDM module is related to all these three components by the architecture shown in Figure 3. Decision Support Systems are usually developed for a certain groups of decision makers. This needs a specific design such that the decision maker could define new alternatives, using the models embedded in the system.

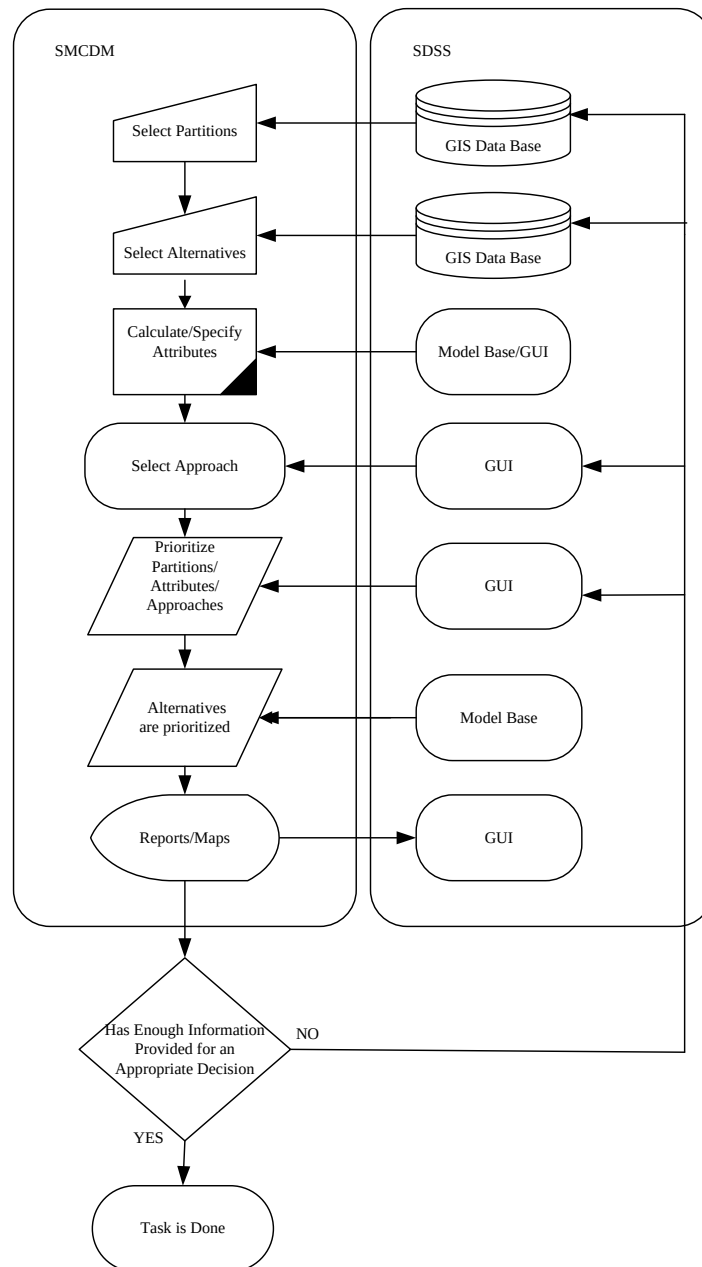


Figure 3. The schematic of the relation between different steps of SMCDM and different components of SDSS

The algorithmic procedure of the developed SMCDM of this research is presented as

follows.

Step 1: Select a Partition Map

In this step the partition map of a basin is selected. The partitions may include natural or political borders such as the borders of sub-basins, provinces, and countries, which lay in a basin. The aim of defining this partition map is to integrate indicators within the selected partitions as well as analyzing the benefits and the impacts of each option in those partitions of the basin. It helps analysing the impacts and benefits of each option in a regional manner.

Step 2: Define the Options/Alternatives

In this step, the user defines specific options/alternatives to be considered through the SMCDM process. As mentioned earlier, options may be consisted of different topologies of water resources systems, which could be different alternatives of a water resources development plan.

Step 3: Calculate the Indicators

In this step, the system calculates the pre-defined indicators for each option at each partition. The indicators are either calculated by the models already existed in SIMAB SDSS or specified by the user where no specific models exist calculate an indicator. The designed Graphical User Interface (GUI) for this step is shown in Figure 4. Examples of the indicators are:

- Volume of allocated water to the urban demands
- Volume of allocated water to the industrial demands
- Volume of allocated water to the agricultural demands
- Volume of allocated water to the Environmental needs
- Hydropower Generation
- Economic net benefit of water allocation
- Changes in groundwater volume
- Water quality in certain nodes
- Technical construction issues, and
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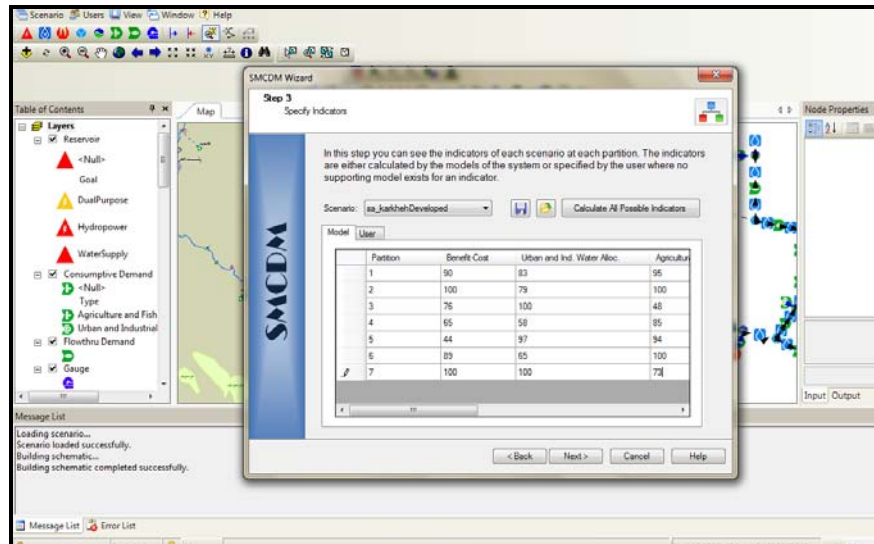


Figure 4. the GUI developed for step 3 of the algorithmic procedure of SMCDM

Step 4: Prioritize the partitions and attributes

In this step the indicators as well as the partitions are weighted by the social, environmental, economic, and physical viewpoints in two aspects of impacts and benefits of different options as shown in Figure 5.

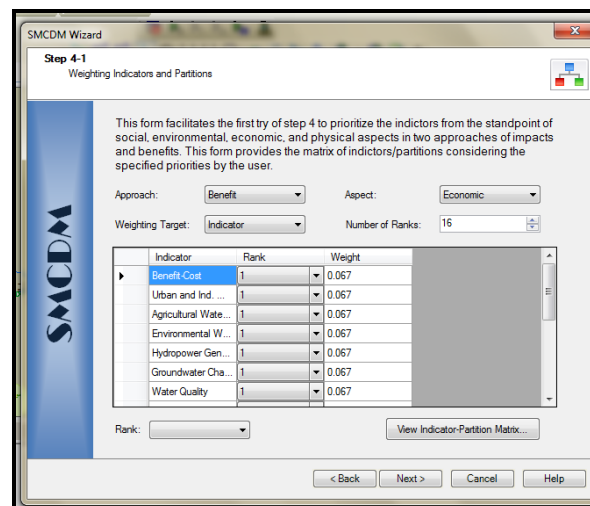


Figure 5. The GUI developed for step 4 of the algorithmic procedure of SMCDM

Step 5: Calculate the Scores of each Option

In this step the scores of different options are calculated based on the selected viewpoints and aspects. It is also possible to calculate the scores by overall viewpoints based on the weights specified by the user in the previous step. The final results are provided by the ranking of the options based on the impacts and benefits they might have in different partitions. The result is also shown as the affected partitions of the basin in a map generated by SIMAB SDSS (Figure 6).

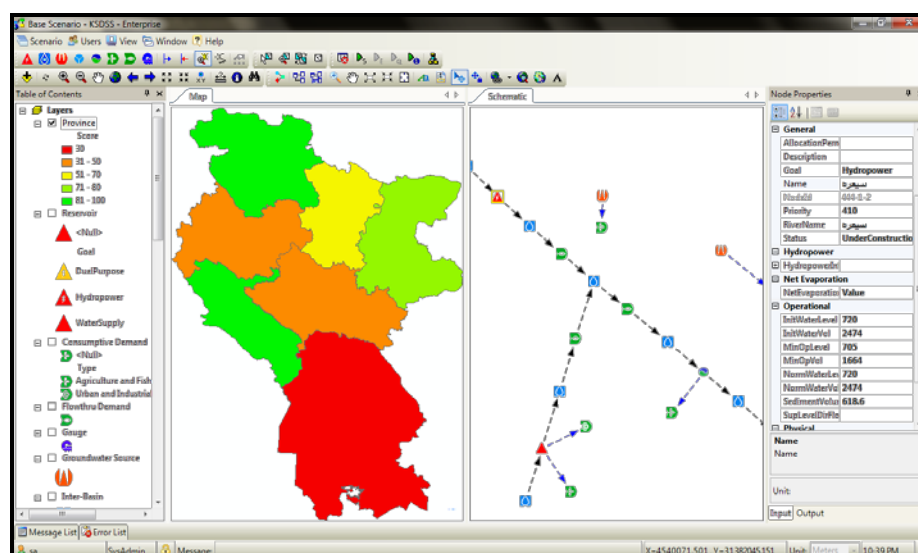


Figure 6. An example of providing the map of affected partitions associated with a specific option

3 CASE STUDY

Karkheh river basin is located in the western part of Iran. Karkheh dam is the largest surface reservoir in the basin. Furthermore, 20 reservoirs are being studied in the basin with the goal of hydropower generation and agricultural development. The complexity of water resources topology in Karkheh basin makes it necessary to develop a multi-criteria decision making process in a spatial manner to investigate the water resources development projects concerning an integrated water resources management approach. There are different questions regarding to the structural water resources development in the basin including: decision about the construction of a surface reservoir; size of the infrastructures; decision about the water transfer to the basin; and the main purpose of construction a water structure (say power generation and/or agricultural development). The questions are increased in case of dealing with the non-structural development of the basin including water demand management; economic valuing of water; mitigating water disasters, etc. Dealing with those questions needs the

use of a multi-criteria decision analysis to screen and prioritize different structural and non-structural alternatives of development.

The map of the basin is shown in Figure 7. Furthermore, an example of prioritizing the basin from the social aspect is shown in this figure. The figure shows different levels of water stress through the cities of the basin. It might help to make proper decisions of water allocation in the basin regarding the social impacts point of view.

Table 1 shows different criteria, which are used to analyse different development alternatives/projects in *Karkheh* basin.

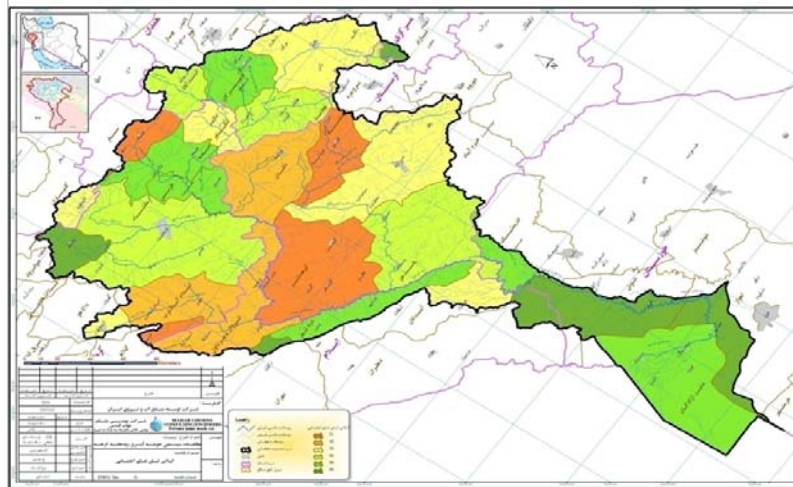


Figure 7. Map of the basin and the regional weighting according to the social water stress over the basin.

Table 1. The criteria used in the SMCDM of *Karkheh* basin

Economic Aspect		Social Aspect			Technical Aspect		Water Resources Aspect					Environmental Aspect				
Net annual benefit	Capital investment	Number of households need to be re-settled	Water stress on the stakeholders	Social welfare	Agricultural development	Construction technology	Uncertainty in design parameters	Construction time period	Water need allocation	Water demand allocation	Flood loss	Hydropower generation	Agricultural Development	Drought management	Changes in water temperature and salinity downstream of the reservoirs	Potential of Eutrophication

As an example of using the SMCDM system in the basin, the results of deciding about the construction of *Tang-e-Mashoure* dam on the *Kashkan* River is presented. Actually, the dam, if constructed, might be considered as an agricultural dam, a hydropower dam; or a multipurpose reservoir. This must be decided along with the other development projects in the basin considering the cumulative impacts and benefits of the topology of water resources system with and without the alternatives of the under-studying dam. After the application of 5 steps of the SMCDM described in the previous section, the scores of different possible alternatives are obtained as shown in Table 2. The greater score is associated with the greater preference. As it is demonstrated by the table, the construction of *Tang-e-Mashoure* dam as a hydropower dam is preferred among the others.

Table 2. The results of prioritizing the alternatives of Tange-Mashore dam

Alternatives	Score	Priority
Multipurpose dam (hydropower and agriculture)	6.6	2
Hydropower dam	7.4	1
Agricultural dam	6.1	4
Construction ignored	6.2	3

4 CONCLUSION

SIMAB SDSS integrates various modules of a water resources system and a spatial multi-criteria decision making tool within a standalone system. Thus, the system is found to be very effective and user-friendly to provide proper information for an integrated water resources management process in a river basin scale. The developed SMCDM model is useful for prioritizing water resources options through different approaches and aspects. The integration of different analytical models in GIS is found to be useful for analysing the impacts and the benefits of different scenarios over the entire basin. Furthermore, the system enables users to imply their points of view through social, economic, environmental, and physical aspects. Indicators such as the amount of urban and industrial water allocation, the amount of agricultural water allocation, hydropower generation, changes in the groundwater resources, net economic benefit and many other indicators are automatically analyzed by the use of SMCDM module of SIMAB SDSS either as a benefit or an impact of a water resources option.

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