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Support System Based Advanced Process Resolving Models for Water Management in Arid Environment

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Abstract: The availability of water may vary greatly with time and place as this variability causes serious problems in water management (e.g., not enough or too much, drought or flood, polluted surface and ground water, etc). These problems are complex and require a combination of diverse expertise in many related disciplines to effectively solve them. Moreover, the volume of data collected for these problems is growing rapidly and sophisticated means to optimise this volume in a consistent and economical procedure are essential. This paper presents an advanced methodology for developing an innovative system that can provides efficient solutions for water management that satisfy today's water demands. This developed methodology will take into account all the relevant aspects of water management (e.g., water pollution control, extensive use, flood risk management and preventive measures, river basin management, spatial and environmental planning, etc). This system is based on the use of dynamic optimisation and geo-information technologies for providing future water use scenarios and real-time monitoring of the impact of the water pollution problems and minimise their effects.

Key words: Water management • Decision support system • Arid environment • Dynamic optimisation

INTRODUCTION

Water is the most important element of the earth that directly impacts the human being and its surroundings (socio-economic activities, climate change, energy use, natural resources, atmosphere, soil, etc). The availability of water may vary greatly from time to time and place to place and this variability causes serious problems in water management (e.g., not enough or too much, drought or flood, polluted surface and ground water, etc). These problems are complex and require a combination of diverse expertise in many related disciplines to effectively solve them. The research described here will effectively support an existing programme called 'LATIS' which has been developed by the Department of the Geography, Ghent University, for water and flood management at Flanders Hydraulics Research [1] and [2]. Hence, the main objective is the development of the improved methodology to optimise the functionality of the existing model using robotic and innovative procedures based on the ideas of artificial intelligence. This methodology will take into account all the relevant aspects of water management, e.g., water pollution control, flood risk management, land-use, river basin management, urban development at all levels (local, regional and national), monitoring and forecasting overflows, spatial and environmental planning, early warning, simulation and optimisation procedures, etc. For example in case of flood management, this research will generate knowledge contributing to the design of effective response actions that maximise the urban flood protection and safety measures.

This paper is effectively link into wider strategic aims of bringing together innovative methods based on knowledge and technology in many scientific disciplines (e.g., geo-information technology, dynamic optimization, advanced computer simulation procedures, multidisciplinary mathematical modelling, spatial and environmental planning, urban development, etc). It presents an advanced methodology for developing an innovative system that can provides efficient solution for water management that satisfy today's water demands, extensive use and water pollution control, etc. This system is based on the use of dynamic optimisation and geo-information technology for providing future water use scenarios, real-time monitoring of the impact of the water pollution problems and minimise their effects.

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This user-friendly system will combine the observational data with innovative data analysis in order to improve environmental impact assessments on water quality. Also, it will give the synthesize result of monitoring data from different sources, models, data analysis and will allows rapid, reproducible and consistent assessments of water availability for the studied area. This will support planning, location and design of water resource schemes by providing access to a wide range of data collected at an investigated region. Section 2 presents the current status of water resources management in Syria and explains the seven principal basins that divide Syria hydrologically, while Section 3 describes the proposed dynamic model of the decision support system for integrated water resources management in arid and semi-arid countries, in general and in Syria, in particular. Also, it illustrates the implementation of the developed model using geo-information and dynamic optimisation that identifies optimal water use scenarios. Section 4 discusses the rules of the proposed decision system and its central database for providing a holistic approach to water resources management that seeks to consider the complex relationships between resources and users. The paper concludes the suggested criteria for major needs for efficiently using of water resources in arid and semi-arid countries.

The Water Resources Management System (Iwrms) in Syria: While the water situation is severe, good management of water resources is highly important to support and establish sustainable water supplies and to prevent deteriorating water quality. Therefore, an advanced support system based on integrated water resources management is needed to ensure the coordinated development and management of water and wastewater reuse, land and related resources to optimize economic and social welfare without compromising the sustainability of environmental systems [3]. This system requires a combination of diverse expertise to develop national water policies and to effectively create multidisciplinary approaches that can provide quickly optimal solutions that base the demand for and allocation of water resources. Cost-effective solutions for water use and reuse has become an important issue to augment water supplies in areas of drought and limited water resources [4].

In Syria, the total estimated water use volume is about 15 billion m3, with the Euphrates and Orontes basins accounting for about 50% and 20% respectively. As shown in Table 1, the water balance in most basins has been in shortage and this will affect the large urban areas especially in big cites as Aleppo and Damascus. Syria is hydrologically divided into 7 principal basins: Barada and Awaj Basin, Yarmouk Basin, Assi Basin, Coastal Basin, Tigris and Khabour Basin, Euphrates Basin and Badia Basin. The water resources originating in side the boundaries of Syria are estimated to be 9700 MCM per year on the average, while the renewable water resources originating inside the Syrian territories amount to 9929 MCM per year [5]. Syria will almost utilize all national and international shared water resources in most water basins. Therefore, it becomes very important to stop the unwise usage of the water by applying new technologies, policy and measures: supply increase (e.g., containing dam construction), demand decrease (e.g., application of water saving technology) and pollution control (e.g., waster water treatment).

Figure 1 depicts the stages of the proposed institutional system to support innovative technologies for integrating and managing all the utilized water resources in Syria. These stages are based on: 1) water resources management (e.g., programs for recycling and reuse of water, water supply augmentation programs), 2) water resources development (e.g., program and policies for watershed, programs for flood control), 3) water use programs and policies for managing

Table 1: Water Availability and Uses, Units: Million m^3/year (Sources: Syria, Irrigation Sector Report No. 22602-SYR, August, 2001)

	Irrigation		Domestic		Industrial		Total use of renewable water resources
Basin	Volume	Share %	Volume	Share %	Volume	Share %	Volume
Yarmouk	360	82	70	16	10	2	440
Aleppo	780	68	280	24	90	8	1,150
Orontis	2,230	82	230	8	270	10	2,730
Barada/Awaj	920	68	390	29	40	3	1,350
Coast	960	86	120	11	40	4	1,120
Steppe	340	87	40	10	10	3	390
Euphrates	7,160	95	250	3	110	1	7,520
Total	12,750	87	1,390	9	570	4	14,700

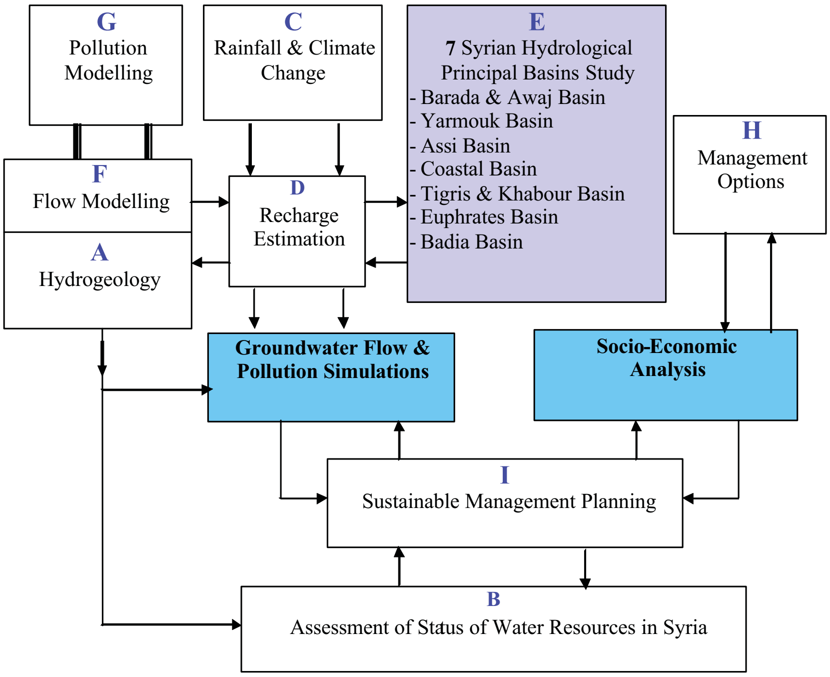

Fig. 1: The proposed support system for IWRM in Syria

other water uses (industrial, municipal, agricultural), 4) monitoring information management and dissemination (e.g., functional hydrological and hydro-meteorological networks, monitoring and reporting on the impacts of IWRM reforms), 5) capacity building and enabling environment (e.g., assessment of water sector capacity buildings needs, linkage of IWRM to other economic sectors).

The Dynamic Model of the Decision Support System: It is envisioned that the main component of the conceptual framework for water management is a decision support system [6]. Therefore, within the concept of dynamic optimisation, the above water problems can be regarded as non-differentiable and Multi-objective Optimisation Problems (MOPs). These problems involve multiple, conflicting objectives in a highly complex search domain. Moreover, the volume of data collected for these problems is growing rapidly and sophisticated means to optimise this volume in a consistent and economical procedure are essential. Therefore, robotic algorithms are required to deal simultaneously with several types of processes which are concerned with the unpredictable environment of these problems [7]. These algorithms can provide a degree of functionality for spatial representation and flexibility suitable for quickly creating real-time optimal solutions that account for the uncertainty present in the changing environment of these problems which can be formulated in a design model as shown in following equation:

$$Model_{MOP} = optimize: f(x) = \{f_1(x), f_2(x), .., f_n(x)\}$$
$$subject\ to\ x = (x_1, x_2, .., x_n) \in X$$

Where $f_i(x)$ is the model that consists of i^{th} objective functions to be optimised, x is a set of variables (i.e., decision parameters) and X is the search domain. The term "optimise" means finding the ideal solution in which each objective function corresponds to the best possible value by considering the partial fulfilment of each of the objects. More specifically, this solution is optimal in a way such that no other solutions in the search domain are superior to it when all objectives are considered in the model. The main innovative aspect of the developed model is the integration of the state of the art geographical and environmental data collection and data management tools with simulation and decision tools for water management. This will allow the modeller to develop a precise and unambiguous specification that can strongly help in estimating the impacts of an actual development process of the presented design. Therefore, it is almost impossible even for an experienced and higher-level designer to find an optimal design by the current

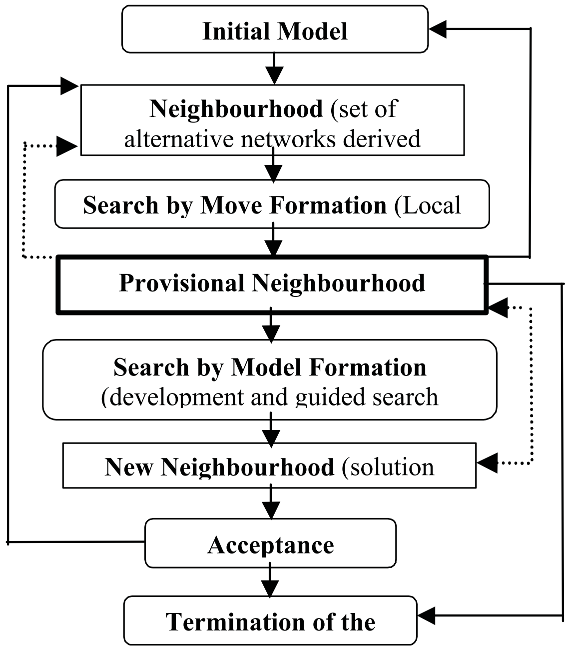

Fig. 2: The general framework for metaheuristic algorithms

Initialization Stage (Inputs)
- Define the model objectives;
- Create the information matrix;
- Set the number of ants;
- Set the control parameters;
- Set a tabu list for each ant;
- Set the iteration counter;

Construction & Selection Strategy
- Build up the best possible model design;
- Select the next potential design;
- Add the selected model to the tabu list;
- Empty the tabu list when the best model is found.

Pheromone Updating Stage
- Apply pheromone updating rules.
- Update the iteration counter

Termination Stage (Outputs)
- The maximum number of iterations;
- Declare the best model design;
- Stop.

Fig. 3: The general outlines for the ant colony procedure

used methods which do not provide spatial representation to the whole situation and lack the ability to select 'interesting' contingencies for which to optimise. Once such designs are obtained, the technical-user will be able to select an acceptable design by trading off the competing objectives against each other and with further considerations. The final design of the model should be robust (i.e., performs well over a wide range of environment conditions), sustainable (i.e., not only optimal under current condition, but also considering predicted changes) and flexible (i.e., allows easy adaptation after the environment has changed) [8].

Metaheuristic Techniques: The use of complex functions to produce further evaluations for the model requires flexible and power search algorithms that do not need mathematical constraints on the form of the objective functions. Metaheuristic algorithms (which are based on the ideas of artificial intelligence) potentially have these capabilities to produce set of high quality real-time designs that can model more closely and easily the monitoring parameters [9]. Metaheuristics can provide instantaneous comparisons of the achieved results of different developed designs using several procedures such as convergence, diversity and complexity analysis, etc. Figure 2 depicts main framework of metaheuristic techniques that can be implemented in the processing stages of the proposed model.

The well-known optimisation metaheuristics that have been successfully applied to optimise real-life applications are: simulated annealing, tabu search, ant colony optimization and genetic algorithm [10-12]. These metaheuristics are inspired, respectively, by the physical annealing process, the proper use of memory structures, the observation of real ant colonies and the Darwinian evolutionary process. For example in case of ant colony algorithm, which is inspired by the foraging behaviour of ant colonies, has been successfully applied to optimise monitoring network problem by using a colony of artificial ants that behaves as cooperative agents in a mathematical space where they are allowed to search and iteratively construct good designs in order to find the optimal network. Figure 3 outlines the structure of the ant colony algorithm to search for the best model design following two stages: *construction stage* using heuristic information with an adaptive memory to repeatedly construct good design and *pheromone updating stage* in which the amount of deposited pheromone is the mechanism by which ants communicate to share information about good monitoring network [11].

Geo-information Technology: As shown in Figure 4, the developed model utilizes the strengths of the *geo-information technologies* (Geographic Information Systems GISs, Remote Sensing RS, Global Navigation Satellite Systems GNSS, Internet, etc) in providing and

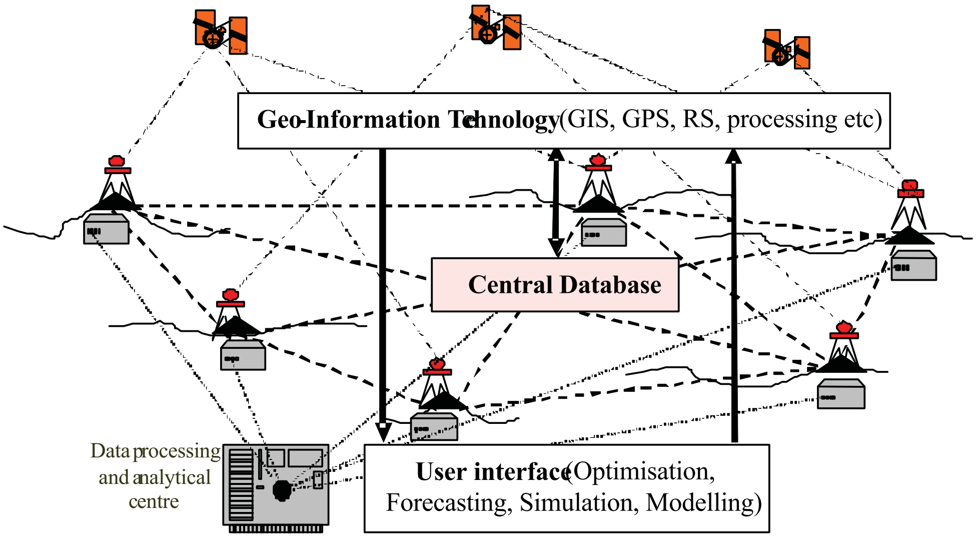

Fig. 4: The real-time model and its database structure

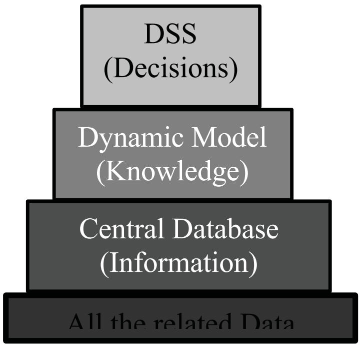

Fig. 5: Structure of the dynamical model of the decision support system

representing spatial data and *dynamic optimisation* in analysing and representing temporal processes. It is well known that throughout the world the use of the GNSS applications is dramatically increasing and this demands optimising the accuracy of the measurements provided by these systems. The Global Positioning System (GPS), the GLObal NAvigation Satellite System (GLONASS) and the Eurpoean Satellite Navigation (Galileo) are the most widely known satellite systems. They provide the user with a 24-hour highly accurate three-dimensional position, velocity and timing system at almost any global location [13]. Satellite imagery, which is in digital format, allows for the acquisition of environmental data, land occupation patterns and features over large areas. The main limitations of satellite images are cloud cover and resolution. Some of these problems may be circumvented using GNSSs. GISs facilitate the integration of quantitative water determination and control data with data obtained from maps, aerial photos, satellite images and satellite navigation systems [14].

The Rules of Dss and its Central Database: The model will be connected to a database (as shown in Figure 5), that combine environmental and geophysical data from earth observation, satellite positioning systems, in-situ sensors and geo-referenced information with advanced computer simulation and graphical visualisation methods. This should provide extra powerful functionality to sufficiently tailor the model to specific needs and optimise the environmental modelling and prediction of both the behaviour of the individual components and their interaction through the spatial representation of the physical, chemical and biological process taking place with the environmental system. The database will provide the following internet-based services: quickly locate and ensure data availability where and when needed; the detailed description of contents and limitations of the data; and present the data in different formats (maps, graphs, pictures, videos, etc.). In addition, the database will be designed to be searchable by data type, data holder/owner, location, etc. For example in case of flood management, the database will be used in three modes: planning and design for flood protection; real-time flood emergency; and flood recovery. Metaheuristics can successfully handle a mix of continuous and discrete parameters as well as selecting individual components from database. This will support the developed model to effectively optimise the water management over the other existing methods by:

- Providing access through a multiple-level web-based interface to a wide range of data types collected at investigated region in real-time. The user interface includes a module for computer simulation of different scenarios, a tool for managing simulation results, communication tools, etc. This will help the efficiency and optimize the stream gages locations and their operations for flood predictions (including early warning and cost-benefit analysis).
- Combining the observational data with innovative data analysis to improve forecasting and risk assessment and analysis and providing a clear physical representation of the processes involved that can define risk zones and emergency scenarios (which is one of the main limitations in the existing model of LATIS program) [4]. For example, values of water depth, velocity and their combination and the flood time are visualized in a global map, can provide a useful tool for emergency management and for determining protective measures against floods. This will support: human interface and allow the technical-user to interact with the current representation of the design, enhance the user's understandings and make it quicker for information to be reached on time and react to the warnings, etc.
- Developing advanced computational methods for collecting, processing, generating the data necessary for the fast and accurate simulation of different flood situations and the 3D visualization of the numerical results. This will: a) give the synthesize results of monitoring data from different sources, models, data analysis, etc, b) support evaluating the effect of alternative response scenarios by optimising the information overload (i.e., how to filter information and still get the right information to the right people at the right time) and c) assist in establishing the social, economic and environmental goals for managing water use and other related problems (e.g., floods).

CONCLUSION

As described in the paper, water management is becoming more and more important in the sustainable water development. The proposed research constitutes a crucial step in water management by elucidating how artificial intelligence and geo-information technology could be efficiently introduced in the design process of solving water problems by creating dynamic optimisation methods that potentially reduce the effects of these problems. With comparison to using metaheuristic methods to optimise other real-life applications, these methods can potentially provide vital information that is quicker, better and at lower cost more than existing methods [15]. Another innovative direction of the research will show how a novel approach parallelisation and hybridisation of metaheuristics coupled with local search procedures can effectively; simplify handling data, minimize the execution time and facilitate the design modelling approach based on simulation and optimisation process [16]. Furthermore, a sensitivity analysis using anticipatory process will be performed in order to handle robustness and simulate an appropriate behaviour of the design parameters in real-time [17]. Therefore, the main purpose of the research is to develop new methodology for effectively optimising the use of these technologies coupled with long-term sustainable development strategy for integrated water resources management in Syria.

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