UNIVERSITI PUTRA MALAYSIA

A SPATIAL DECISION SUPPORT SYSTEM FRAMEWORK FOR OPTIMIZATION OF CROPPING PATTERN AND WATER RESOURCES ALLOCATION AT PASARGARD PLAINS, FARS PROVINCE, IRAN

MOHAMMAD MEHDI GHASEMI

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By

MOHAMMAD MEHDI GHASEMI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

June 2014

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DEDICATIONS

This thesis is dedicated to:

*my **father** and **mother** for their endless love, support and encouragement.*

*my wife **Farzaneh** who had played many important role along the journey.*

*my daughters **Mahdis** & **Parmis** who are a source of inspiration for me throughout my life.*

Abstract of thesis presented to the Senate of University Putra Malaysia in fulfillment of the requirements for the degree of Doctor of Philosophy

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June 2014

Chairman: **Professor Ir. Lee Teang Shui, PhD**

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In recent years, optimization models have been extensively used to address water management issues by means of proposing appropriate cropping patterns and water allocation rules. However, in spite of their significance these models often consider the land as an entirety and fail to account for the variation of many contributing factors, including the ownership and fragmentation of lands and resources, or other unique characteristics that each farm may have. Moreover, the applicability of the present models can be limited due to the absence of inclusive frameworks in which the decision-maker could input his/her knowledge of the problem, properly model the hydrological and economic processes, test various scenarios, and arrive at judicious decisions. In the present study, a Spatial Decision Support System (SDSS) framework was developed to tackle the above-mentioned problems and was used to propose optimal decisions for agricultural lands of the Pasargad plain in central Iran as a case study. In this modular SDSS, the multi-purpose cadaster data help to form a spatial farm database in which the various characteristics of each farm are included. A unit response matrix groundwater model was coupled with a modified version of Genetic Algorithm (GA) in order to optimize cropping patterns and water allocation decisions. The proposed GA-based optimization model—namely Piece-Wise Genetic Algorithm (PWGA)—was capable of proposing optimal cropping patterns, deficit irrigation rules, and conjunctive use decisions for each farm, and to tackle the large number of decision variables involved. Furthermore, the Policy Analysis Matrix (PAM) was used as a module to limit the number of possible cropping decisions based on social and economic analyses. Meteorological data were also incorporated into the framework using an evapotranspiration module. Various scenarios were defined with regards to allowable water drawdown, water prices, and climatic conditions, and the associated optimal results for the case study are obtained from the SDSS. In this regards, the results acquired when considering the study area as a plain entirety are compared with those obtained from farm-based decision support. The results indicated that the use of lump models is problematic due to its tendency to overestimate the resulting net benefits, whereas the incorporation of cadastre-driven data into the optimization framework contributes to providing decisions that are more realistic. More importantly, the obtained decisions from SDSS—in the forms of maps and written reports—are detailed enough to be directly advised to farm-owners. Furthermore, the consistency of the PAM results with those of the optimization model confirms the suitability of employing PAM-based codes for refinement of the choice of crops. The use of a modular decision support framework in which each of the modules could work independently has also enabled the users of SDSS to employ the system selectively and adapt it according to their needs.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SATU RANGKAKERJA SISTEM SOKONGAN KEPUTUSAN SPATIAL BAGI PENGOPTIMUMAN CORAK TANAMAN DAN AGIHAN AIR DI DATARAN PASARGARD, MUKIM FARS, IRAN

Oleh

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Sejak kebelakangan ini, terdapat banyak model pengoptimuman digunakan untuk menyelesaikan isu pengurusan air melalui cadangan corak tanaman yang sesuai serta peraturan pengedaran air. Walau bagaimanapun kebanyakan model tersebut mengambilkira tanah pada keseluruhannya dan gagal merangkumi banyak faktor termasuk pemilikan dan pembahagian tanah dan sumber atau mengambikira ciri ciri berbeza setiap keping tanah. Tambahan pula, kegunaan model tersedia mungkin terhad kerana ketiadaan rangkakerja yang menyeluruh dimana pembuat keputusan boleh memasukkan pengetahuan sendiri mengenai masalah, memodelkan proses proses hidrologi dan ekonomi, ujian pelbagai senario semoga mencapai keputusan terbaik. Dalam kajian ini, satu Sistem Sokongan Keputusan Spatial (SDSS) telah dibangunkan untuk menangani masalah tersebut dan juga telah diguna untuk mencadangkan keputusan optimum bagi tanah pertanian yang terletak di Satah Pasargard di Tengah Iran, sebagai kes kajian. Dalam modula SDSS, data kadastera pelbagai-fungsi boleh menghasilkan pangkalan data ladang spatial dimana pelbagai ciri setiap ladang dipastikan. Sebuah model matriks respon unit air bawah-tanah telah dikait kepada satu versi Algoritma Genetik (GA) terubahsuai untuk mengoptimumkan corak tanaman dan keputusan pengedaran air. Model pengoptimuman berdasar GA yang dicadangkan – ia itu bernama Algoritma Genetik Berbahagian (PWAGA) – boleh mencadang corak tanaman optimum, hukum-peraturan pengairan berkurangan, dan keputusan kegunaan bagi setiap keping tanah, serta mengatasi perubah keputusan yang banyak. Matriks Polisi Analisa (PAM)

boleh diguna sebagai modula untuk menghadkan nombor keputusan corak berkemungkinan berdasarkan analisa sosial dan ekonomik. Data meteorologi juga dimasukkan ke dalam rangkakerja mengunakan modula penyejatpeluhan. Pelbagai senario didefinasikan berkaitan susutan aras-air dibenarkan, harga air dan keadaan iklim, dan keputusan optimum untuk kes kajian didapati daripada SDSS. Keputusan yang diperolehi bagi kawasan kajian dianggap sebagai berintegrasi-penuh dibandingkan dengan hasil berdasarkan keputusan system sokongan berasaskan ladang. Keputusan menunjukkan bahawa model bercorak tergumpal menaksirkan melebihi amaun keuntungan berseh yang dijangkakan, dan dengan kemasukan data berkadastera ke dalam jangkakerja pengoptimuman boleh memberi keputusan yang lebih realistik. Kekonsistenan keputusan PAM dengan hasil model pengoptimuman memastikan kesesuaian pendekatan ini untuk pilihan tanaman terperinci. Kegunaan rangkakerja sokongan keputusan modula dimana setiap modul dapat berfungi tak bersandar dapat membenarkan pengguna SDSS menggunakan sistem terpilih dan mengikut keperluan masing masing.

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I certify that an Examination Committee has met on 19 June 2014 to conduct the final examination of Mohammad Mehdi Ghasemi on his Ph.D. thesis entitled "A Spatial Decision Support System Framework For Optimization of Cropping Pattern and Water Resources Allocation At Pasargad Plains, Fars Province, Iran" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

APERI	Agricultural Planning and Economic Research Institute
ANN	Artificial Neural Network
CAD	Computer-aided design
CI	Computational Intelligence
CIF	Costs, Insurance, and Freight
DP	Dynamic Programming
DRC	Domestic Resource Cost
EA	Evolutionary Algorithm
EPC	Efficient Protection Coefficient
ESRI	Environmental Systems Research Institute
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
FDP	Fuzzy Dynamic Programming
FGP	Fuzzy Goal Programming
FOB	Free On Board
GA	Genetic Algorithm
GIS	Geographic Information System
GMS	Groundwater Modeling System
LP	Linear Programming
MCM	Million Cubic Meters
NLP	Non-Linear Programming
NSGA	Non-dominated Sorting Genetic Algorithm
OER	Official Exchange Rate
PAM	Policy Analysis Matrix
PM	Penman-Monteith xixreference crop evapotranspiration method
PMWIN	Processing Modflow for Windows
PPP	Purchasing Power Parity
PSO	Particle Swarm Optimization
PWGA	Piece-Wise Genetic Algorithm
RSBT	Rubinstein Sequential Bargaining Theory
SA	Search Algorithm

SDP	Stochastic Dynamic Programming
SDSS	Spatial Decision Support System
SER	Shadow Exchange Rate
SGA	Sequential Genetic Algorithm
URM	Unit Response Matrix
YCRT	Young Conflict Resolution Theory
3-D	3-Dimentional

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CHAPTER 1

INTRODUCTION

1.1 Background

Water management policies should consider hydrological cycles, surface and groundwater resources and atmospheric conditions as their fundamental basis. Their function in structural planning should be capable of achieving their long-term objectives and strategies such as monitoring large scale economical and land logistical plans. While it should make the organization of inter-sectional relations more probable, assessment of different water planning policies from directorship and large scale economical viewpoint will become more relevant. Therefore, a proper solution to those problems facing management of water resources is to bring them all together through an integral system in order to correct managing regulations.

Iran is located in an arid to semi-arid region of the world. About 93.5% of its fresh water is allocated for agriculture, out of which 80% is supplied through groundwater. Therefore, it is obviously concluded that groundwater is the key element for sustainable agriculture in Iran. In recent years, many fertile and agricultural plains suffered from 0.5 to more than 15 m water table drawdown and many wells have dried up.

Water management consists of planning, strategic management and tactical management. Management is defined as “a process of making and implementing decisions about obtaining and using an organization’s resources in order to achieve agreed organizational objectives”.

Cropping pattern is one of the most important design and performance parameters in irrigation management that is in direct relationship with water use efficiency and optimal allocation of soil and water resources (Montazar & Rahimikob, 2008).

Generally, Decision Support Systems are computer-based systems facilitating the decision making process, and aid the decision makers in dealing with water resource problems through proper temporal and spatial allocation of the water resources. Considering the fact that spatial data comprises more than 90 percent of water resources data, it is obvious that decision support systems with spatial capabilities are suitable variants of such computer-based decision-making tools.

1.2 Statement of Problem

Iran, with an annual precipitation of approximately 240 mm/year (less than one-third of the global average) is situated in an arid and semi-arid geographical region of the world (Karimi & Hayati, 2005). The biggest consumer of water in Iran is the agriculture sector as shown in Figure 1.1 (Iran Water Resources Management Corporation, 2012).

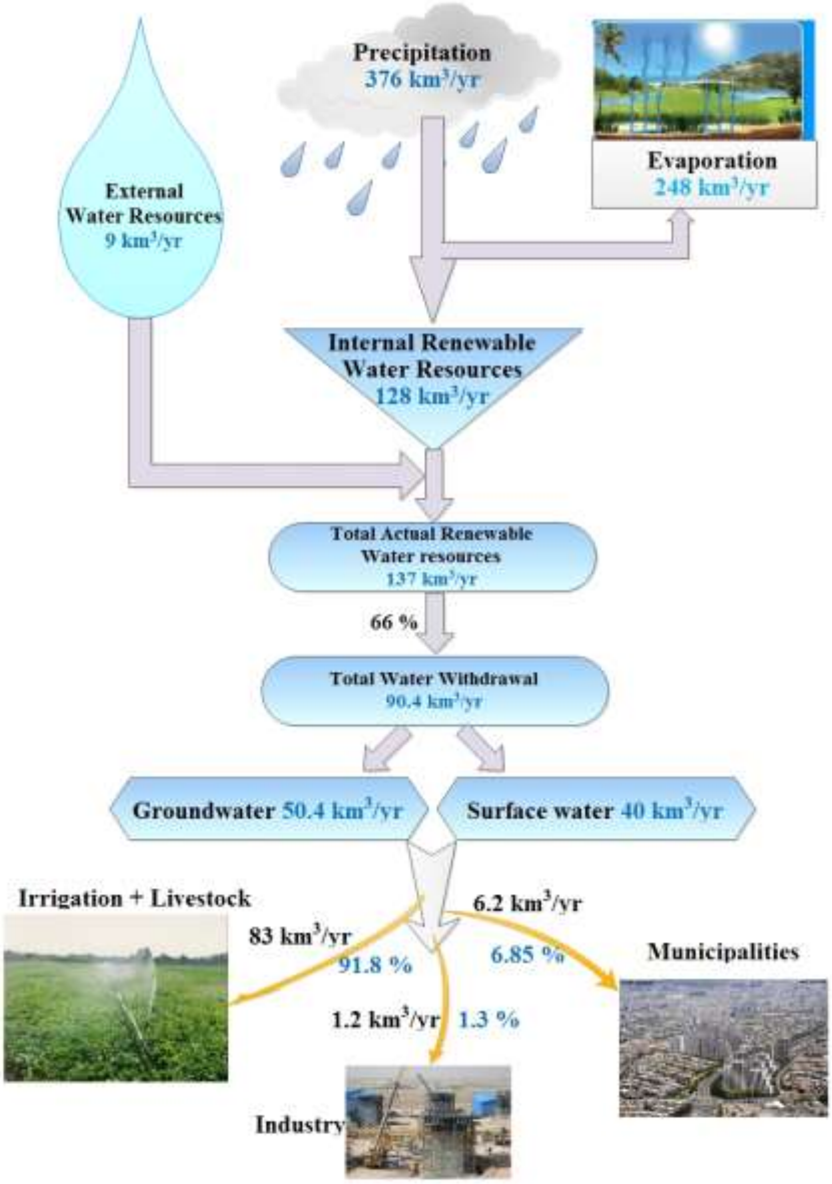

Figure 1.1 Summary of annual water budget in Iran.

Globally, on average, the agricultural sector is responsible for 70% of the freshwater consumption, while in Iran it is almost 92%.

Since there is no central scheme for water management in Iran, the solution that can compensate this with proper agricultural water demand management, and one of its appropriate ideas is to determine suitable cropping pattern based on the optimal water resources consumption. Such a pattern should be capable of increasing the economical yield through least water demand.

Fars province, with an area of about 121000 km^2 (7.5% of the country's total surface area) and with a population of more than 6 million is one of the more important agricultural zones in Iran. Regarding the groundwater, the latest estimations show that an average of 13369 million m^3 of water enters the groundwater annually, of which almost 13069 million m^3 is consumed. Illegal withdrawal of groundwater should also be added to this value (The Adhoc Committee Of Drought And Agricultural Water Crisis, 2008). As a result, high risk is encountered with Fars province ground water resources. In Fars, the main way to provide agricultural lands with water is to make use of groundwater resources (about 83% of water consumed by this sector). These numbers reveal the fact that Fars is facing a crisis regarding its depleting groundwater resources. Besides, water usage efficiency in the agricultural sector is considerably low. Currently, agricultural products of the country weigh around 65 million tons, and the associated agricultural water consumption is almost 85 billion m^3 per year. Therefore, water use efficiency is about 0.7 kg per cubic meter of water (Keshavarzi & Sadeghzadeh, 2001), whereas in developed countries this amount is about 2.8-3 kg/m^3 (Jin & Young, 2001).

Fars Drought and Agricultural Lands Water Crisis Committee (2008), suggests nine guidelines to confront probable water shortages. These include:

1. Training and development of practical research.
2. Organizing and controlling illegal wells.
3. Covering or changing the path of irrigating channels.
4. Land leveling and avoiding land fragmentation.
5. Irrigation planning management for farmlands and orchards.
6. Application of modern irrigation methods (Pressurized Irrigation).
7. Watershed management and preservation of natural resources.
8. Artificial recharge to balance the groundwater resources discharge and recharge.
9. Preparing and producing proper cropping patterns' requirements.

These guidelines could be briefly summarized into taking advantage of water resources management practices, increasing the water use efficiency, and government-regulated water consumption policies.

A cropping pattern could only be regarded as optimal when comparative advantage of agricultural production, in addition to economical and technical justifications fully support its employment in a specific area. In fact, other guidelines may only result in better preservation of water resources or improve the efficiency of their application.

However, cost-effective cultivations should be sought through cropping patterns which are not only suitable in terms of handling of water resources, but also can justify economic issues as well. This point of view in critical plains where there are cropping patterns along with non-cultivation plans can affect the whole stability of water resources. Adjustment of cropping pattern and water allocation becomes more important in view of the fact that currently farmers and stakeholders of these regions exploit the water resources in a competing manner instead of making environmentally-sound and sustainable decisions to optimize the withdrawal of water resources. As a result, the region is expected to face water resources crises in the near future (Hayati, 2006).

As regards the improvements in cropping pattern and water consumption policies, in spite of the availability of valuable data from variety of resources, an inclusive framework for integration of and extraction of information and policies from these data is yet to be developed. Furthermore, the existing computerized approaches to the improvement of cropping pattern and water consumption policies often suffer from inaccuracies and simplistic assumptions on many levels. Thus, providing an inclusive framework for integrating data from variety of resources and approaching the problem from multiple aspects could be beneficial. The applicability of this system would be conditional upon its modeling accuracy, level of simplifications, and user-friendliness.

1.3 Objectives

The main purpose of this research is to develop a computerized framework for decision-making on cropping patterns and water allocation rules, while taking advantage of spatial farm data for improving modeling accuracy and framework usability. To this end, a spatial decision support system (SDSS) framework is developed for evaluation of optimal cropping patterns within a regime of conjunctive optimal use of surface and groundwater resources in the Mobarakabad District of Pasargad County in Fars province, Iran. The most specific features included are:

1. Simulation of groundwater in the case study zone and estimation of tolerance limit of groundwater discharge and its fluctuation.
2. Optimization of cropping pattern with respect to available water resources (ground water and surface water) and presenting spatial allocation of cropping for each landlord (detailed cropping pattern).
3. Mapping the cropping pattern and making comparisons with the current cropping pattern of the area in terms of irrigation water usage and benefits.
4. Establishing the most suitable computational environment in terms of computational performance, reliability, ease of use, user-friendliness, and so on.

1.4 Scope of Work

In this research, the three main components should be considered in detail: (1) water resources, (2) water use, and (3) spatial decision support system for allocating water resources to different agriculture users. The first component includes prediction or estimation of future or existing water resources. The second component includes all consumers of water such as crops and their relevant items, and the third includes simulation model, optimization model, knowledge, and decision criteria. Data for these main components are as follows for case study area:

1. Collecting Mobarakabad basin data (arable area, gross command area, soil type, and topography).
2. Collecting soil parameters for each paddock (depth, dry air and saturated water content, field capacity, wilting point, and infiltration rate).
3. Collecting crop data (cropping pattern, planting date, crop base period, crop coefficients at different growth stages and nutrient requirement by each crop).
4. Collecting hydro-meteorological data (rainfall, evaporation and deep percolation losses, infiltration loss from rainfall, discharge rate from tube wells, reference evapotranspiration, which is a function of temperature, humidity, radiation, daily sunshine hours, wind velocity, and crop resistances).
5. Collecting Management practice data (irrigation system efficiency, Water application efficiency, Fertilizer and labor availability, and current market price of production).
6. Collecting economic data (plants price, irrigation water price, cultivation cost, irrigation water cost, interest rate, future crops price).
7. Collecting groundwater and water resource data (Regional hydro geologic reports, previous investigations of aquifer and/or surface waters. Available information on groundwater use, including purpose, quantities, and future projections, Boring log data, Cone penetrometer log data, Monitoring well data, Production well data, Well construction characteristics, Geophysical data, Geologic, hydrologic, and topographic maps, cross sections of study area and aerial photographs).
8. Reorganizing data gaps in each step of procedure, and presenting related methods for derivation.
9. Reorganizing all detailed components of the case study area as an example for modeling.
10. Collecting expert knowledge about agriculture, cropping pattern, water resources and environment taking into consideration their interaction in the case study area.
11. Selecting the compatible version of Geographic Information System (GIS) software.
12. Selecting and providing groundwater simulation model.
13. Choosing the best optimization method based on objective functions and constrains.
14. Choosing one of the optimization methods for farm-based irrigation water optimization.

1.5 Significance of study

To date, several whole-farm socioeconomic optimization models have been developed to deal with lump planning issues in the agriculture sector. However, these models cannot be used to devise appropriate, separate farm management strategies for irrigated agriculture, because of the complexity and diversity of hydrological processes across a given area (Khan et al., 2008). Nevertheless, based on the spatial farm database that was proposed and implemented for Passargad city by Ghasemi et al. (2010), it is possible to guide farm managers on which crop to plant and how much area to allocate for each type of crop in order to achieve the maximum benefits (Ghasemi et al., 2010). This study provides a spatial decision support system by which the decision-makers could appropriately model areas of interest, and arrive at optimal cropping pattern and water allocation decisions for each of the farms. The key innovations presented in this thesis include:

(1) Previous studies have typically dealt with the whole area as an entirety to be planted, and usually fail to support each of the individual farms with optimal farm-specific decisions. However, in the present study, the developed SDSS has the ability to support explicit cropping patterns and detailed 10-day conjunctive use decisions for each of the farms separately.

(2) The objective function and constraints of the optimization model—which are known to serve as the core of the cropping pattern optimization frameworks—will redefine in this study, in order to function properly in such a detailed spatial decision support system.

(3) The proposed SDSS will provide a framework in which the valuable cadaster data could improve the process of decision-making by contributing to finding optimal cropping patterns and water allocation rules. That is, the proposed SDSS will design as a stand-alone extension of organization Spatial Data Infrastructures (SDI).

(4) An evolutionary algorithm will develop to solve the optimization model and arrive at decisions for each farm. The algorithm will be able to tackle the large number of variables involved in SDSS framework by taking advantage of special chromosome and operator structures. In addition, a stall-handling mechanism will be used in order to improve the convergence of the algorithm.

(5) With modeling of groundwater, it is possible to determine the effects of withdrawal on the water table and storage, which could help farmers and experts in making better decisions regarding the exploitation of valuable groundwater resources systems. The use of such modeling tools may improve water resources planning to avoid the "tragedy of the commons" that may arise when individuals interact with open-ended resources with incomplete knowledge of the system (Reeves & Zellner, 2010). To this end, a groundwater model will incorporate in the decision-support framework that works closely with optimization model.

(6) A Unit Response Matrix (URM) approach to groundwater modeling will employ in order to minimize the computational costs associated with the

coupling of an iterative-based optimization model with a precise and accurate groundwater model.

(7) The indicators acquired from Policy Analysis Matrix (PAM) of the cropping activities will be used in the framework, in order to incorporate social and economic analyses in the process of decision-making. the use of such indicators has not been explored so far in the realm of cropping patterns and water allocation optimization.

(8) All of the functionalities of the SDSS (including the above-mentioned ones) will develop in a modular manner, in a way that the modules may work independently and will connect to each other using mediatory files/variables. Therefore, the decision-maker is able to work with the SDSS selectively and may only use his/her required modules at a time. Moreover, this would allow the later modifications and extensions of the SDSS to be developed more easily and with more flexibility.

(9) The issue of proper planning for using water resources by means of organizing the agricultural activities appears to be more important in arid and semi-arid parts of the globe. In this vein, the proposed SDSS will implement to study Mobarakabad village, located in the central part of Iran, where the limited amounts of precipitation in addition to extensive use of groundwater resources have contributed to several problems.

(10) Nevertheless, the flexibility of the approaches used, in addition to the utilization of data import and model setting tools, will make it possible to use the proposed SDSS framework in a wide range of conjunctive use problems, where the cropping pattern should be determined and the surface and groundwater resources should be optimally allocated to a certain number of agricultural fields with known characteristics.

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