Providing decision support system in groundwater resources management for the purpose of sustainable development

Hamed Aliyari, Majid Kholghi, Sina Zahedi and Marzieh Momeni

ABSTRACT

Decision support system (DSS) for sustainable development is an efficient tool in managing aquifers, since an aquifer as a complex system is not a structural issue due to varied components. In this article, software entitled DSS-SMGW-01 is developed based on the so-called DSS to realize sustainable management of groundwater. This system includes a database, a simulation model, and a decision-making model controlled through a graphical user interface. This software controls exploitation of groundwater in managing subunits and integrated management of water resources and consumptions. Furthermore, management options are evaluated by the software according to aquifer sustainability and socio-economic indicators. In this system, WEAP-MODFLOW linked model (Water Evaluation and Planning system dynamically linked to the United States Geological Survey modular finite-difference groundwater flow model), Analytic Hierarchy method, and Simple Additive Weighting method are utilized for simulation of groundwater resources system, weighting indicators and prioritizing options, respectively. In order to evaluate efficiency of the exerted system, Qazvin plain data was used and 68 experts from different parts of water industry in Iran were consulted to have the best analysis on weighting the indicators. Consequently, the prepared system was found to be successful in designing and prioritizing the seven managing indices.

Key words | decision support system (DSS), environmental indicators, groundwater resources management, social-economic indicators, sustainable development, WEAP-MODFLOW

INTRODUCTION

The water crisis in Iran has turned into the most serious public concern through the recent decade. The severity of this problem has also aroused anxieties among officials, decision makers and environmental activists. Scarcity of water resources, over-exploitation of aquifers and increasing population are also major concerns, and have intensified the problem for water management officials and policy makers. In addition to these concerns, the variety of temporal and spatial information, the complex structure of aquifers and the necessity to have an integrated management for realizing sustainable development are the other main parameters that complicate the subject of ‘Making decision and managing groundwater resources’ (Jakeman et al. 2016). The above factors are serious enough to turn such an easy task into a pretty uncontrollable concern. A decision support system (DSS) has been developed to increase accuracy and simplicity of making decisions in the light of information technology (Pierce et al. 2016). The purpose of developing these systems is to support and direct decision-making groups towards determining the most appropriate choices (Janža 2013).

In the last two decades, different support systems have been invented to enable easier decision-making in the field of water resources and consumption, with the focus on groundwater. Doherty & Simmons (2013) proposed combined utilization of simulating, optimizing and decision-making...
based on systems analysis in integrated management of surface and ground water. They first designed options for an aquifer-river system and then chose the best option by using a mathematical model of surface and ground water.

Beddek et al. (2005) described the DSS for sustainable exploitation of water resources in Gnangara region, Australia. In this system, the Modular Three-Dimensional Finite-Difference Groundwater Flow (MODFLOW) 2000 model was utilized for aquifer simulation in order to optimize water consumption in agricultural production. For this purpose, it was required to simulate conditions for stabilizing groundwater levels to prevent seawater interference with fresh water. This was obtained by connecting economic surface and groundwater model (ESGM) to MODFLOW model via the Ventana Simulation System (VENSIM). Khelifi et al. (2006) developed a web-based DSS for the purpose of groundwater remediation project based on technical, environmental, and socio-economic indicators. In this system, Prometheus algorithm was utilized as a multi-criteria DSS to evaluate options.

Manos et al. (2009) proposed a spatial DSS entitled Water Map in order to reach sustainable development and protect environment in agricultural areas. The aim of this system was to optimize the amount of consumed water for production in agricultural areas by considering available water resources, environmental parameters, and a groundwater vulnerability (GV) map of the region. Then, different options designed for the region were modeled by local experts and decision makers. Prepared options were subsequently simulated using DSS while social, economic and environmental indicators were ultimately obtained for options as the final stage. In this system weighted goal programming was used as the decision-making process. The efficiency of the prepared model was studied in Sarigkiol basin in northwestern Greece. Additionally, Gholami et al. (2015) analyzed groundwater level fluctuations using dendrochronology in alluvial aquifers Guilan province, Iran. They estimated groundwater level using an artificial neural network (ANN) for the period from 1912 to 2013. The research discussed an accurate simulation of groundwater levels and claimed that the method could be used for drought evaluation and drought period prediction in water resources management. Moreover, Taormina et al. (2012) utilized the feed forward neural networks (FFNs) to assess the simulation practiced for hourly groundwater levels in the coastal aquifer system of the Venice lagoon. The results indicated that the developed FNN method could accurately reproduce groundwater depths of the shallow aquifer for several months. This method could also be used as a feasible alternative to physical-based models and was expected to be efficient for simulating responses of the aquifer under plausible future scenarios. This could also be applied to reconstruct long periods of missing observations providing past data for the influencing variables.

Wu et al. (2010) applied ANN to forecast rainfall time series using modular artificial neural networks (MANN) coupled with data-preprocessing techniques in Zhenshui river basins of China. The results demonstrated that advantages of MANN over other models were quite noticeable, particularly for daily rainfall forecasting. They approved that the proposed optimal rainfall forecasting model could be derived from MANN coupled with singular spectrum analysis (SSA). Wang et al. (2015) improved forecasting accuracy of annual runoff time series using the autoregressive integrated moving average (ARIMA) model coupled with the ensemble empirical mode decomposition (EEMD) in Biliuhe reservoir, China. The obtained results indicated that EEMD could effectively enhance forecasting accuracy and that the proposed EEMD-ARIMA model could significantly improve ARIMA time series approaches for annual runoff time series forecasting.

Chen et al. (2015) utilized population-based optimization algorithms to forecast downstream river flow using a hybrid neural network (HNN) model in Altamaha River Basin, Georgia state, USA. The results indicated that the differential evaluation (DE) algorithm and ant colony optimization (ACO) attained the best performance in generalization and forecasting. The DE and ACO algorithms are both favorable for searching parameters of the HNN model, including the recession coefficient and initial storage.

Chau & Wu (2010) applied a hybrid model coupled with SSA to forecast daily rainfall values in Zhenshui and Da’ninghe River Basins, China. The results illustrated that the hybrid support vector regression model performed the best and the SSA model also exhibited considerable accuracy in rainfall forecasting.

In general, applications like VENSIM, Modeling and Simulation System, River and Basin Simulation Model,
Water Evaluation and Planning System (WEAP), etc., are recognized as DSS systems that are commonly used for different issues and regions. Among them, water resources planning model of WEAP is one of the models with the ability to connect to the groundwater simulation model (MODFLOW and MODPATH) or MABIN model. The significance of such capability is to have an accurate estimation of infiltration depth used for simulating aquifers as well as the integrated management of ground and surface water. The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) with contribution of Federal Institute for Geosciences and Natural Resources of Germany (BGR) (Droubi et al. 2008) utilized a WEAP-MODFLOW linked model for evaluating different scenarios of groundwater extraction in some regions of the Middle East. In addition, Hadded et al. (2015) utilized WEAP-MODFLOW model as a DSS for managing an aquifer in southeast Tunisia. The designed model was specified for evaluating aquifer loss conditions and presenting an analytical overview from resources and water consumption systems of the region until 2030. A monthly period was considered for this research.

In this research, a DSS entitled SDGWM-DSS-01 in groundwater management was modeled with the aim of sustainable development.

MATERIALS AND METHODS

A review of DSS concepts and structures

The structure of a DSS includes three modules entitled database, model base and decision-making base. These three items are technically used in a main program (graphical user interface).

Figure 1 illustrates fundamental components of DSS along with the main program location as well as the process of using this system for attaining the most accurate decision.

DSS is recognized as a gadget to simplify management and planning process. Selecting, developing and utilizing gadgets like DSS are not enabled while goals, approaches, impressive and impressed elements and generally management pattern are not determined.

The utilized indicators for evaluating management options have been propounded as one of the most important issues. These indicators are defined based on conditions, purposes, programmable elements, available data, task accuracy, etc. The following items should be considered.

Determination and evaluation of utilized indicators in a system

The purpose of a prepared system is to manage groundwater resources to attain sustainable development. Access to sustainable development involves attaining environmental, economic and social sustainability. These indicators, therefore, have been utilized in order to evaluate management options in this system. In the current investigation, due to the complexities of socio-economic issues, their influences have been presented in three indicators. These indicators are estimated through calculating the products' revenue, cost of plans and comparing the condition of each option through available data of the region.

Table 1 specifies the utilized indicators in the system. These indicators have been chosen based on available data and simplicity of calculation.

According to Table 1, validation of environmental conditions can be performed by using aquifer sustainability indicators that are presented by The United Nations Educational, Scientific and Cultural Organization. Land and
water productivity are used in various references as standard indicators (FAO 2011). Calculation of Employment (EMP) indicator is considered as a linear function from revenue due to the impressive changes in factors.

The amount of consumed water, output, revenue, types of expenses, price of varied products and number of occupations are available along with cultivation patterns of farming and horticultural products in the studied region, according to the water years. Afterwards, different options can be defined through the changes exerted on the factors influencing the amount of consumed-water like changes of the area under cultivation, irrigation methods, cultivation patterns, deficit irrigation, and so on. In fact the conditions are defined in a form that the amount of production, income and expenses are simultaneously modified by changing the volume of consumed water in each option. Therefore, the extracted volume of different sub-regions of aquifer is determined for each option. Scales of area and amount of water, production costs of obtained cultivation pattern and earned income should be determined according to the available data in the database. Then, the six primary indicators are calculated and EMP indicators are estimated by development of proportionality between the occupation statistics and the conditions of extant income.

**Introducing calculation processes in the system**

In the provided system, both the simulating and decision-making processes are performed by developing middleware. In other words, in this investigation, a sub-structure is provided that enables an expert to perform designing process of options, calculation of relative weight of indicators and prioritization of options in an integrated structure. According to the utilized methods and tools in this system, this system has the capability to: integrate management of surface-water and groundwater; manage resources and consumptions; functioning in different regions and consider varied issues by applying changes in input data (different types of aquifer, water consumption management in agricultural, horticultural, green infrastructural parts, etc.); application of different scenarios in different time periods (by utilizing WEAP model) and the possibility of applying other models; connect to WEAP in the simulation part; save, modify, and update the collected and computed data in the database; and to utilize environmental, social, and economic indices for evaluating the options.

In the simulation module, the WEAP-MODFLOW linked model has been utilized. In the WEAP application, calculation is based on the water balance equation. In particular, the WEAP model can be developed using COM technology and network programming. Moreover, WEAP application has the ability to connect to the MODFLOW model for more accurate groundwater simulation (Sieber & Purkey 2015).

In the present system, the relative weight of indices is computed by the group analytic hierarchy process (GAHP). The computations of this process are performed by pairwise comparisons among indices, in order that the level of importance of two indices could be specified with respect to each other by assigning a number from one to

<table>
<thead>
<tr>
<th>Types</th>
<th>Indicators</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental indicators</td>
<td>Groundwater Decay Rate (GDR)</td>
<td>$\frac{2}{3}$ Multiplied to the averaged thickness of the aquifer (in meters) proportional to the averaged loss of aquifer (in meters) through a 5-year period</td>
</tr>
<tr>
<td></td>
<td>Groundwater Abstraction Development (GAD)</td>
<td>Ratio of the exploited water to the exploitable groundwater resources</td>
</tr>
<tr>
<td></td>
<td>Dependence on Groundwater (DG)</td>
<td>Ratio of total groundwater abstraction to the total abstraction of all other water resources</td>
</tr>
<tr>
<td></td>
<td>Groundwater Vulnerability (GV)</td>
<td>Ratio of the area of aquifer with high vulnerability (with shallow depth) to the total area of aquifer</td>
</tr>
<tr>
<td>Social-economic indicators</td>
<td>Land productivity (LP)</td>
<td>Ratio of the profit to cost, per each hectare</td>
</tr>
<tr>
<td></td>
<td>Water productivity (WP)</td>
<td>Net profit per unit volume of water (NBPD)</td>
</tr>
<tr>
<td></td>
<td>Employ (EMP) (employment)</td>
<td>Estimation for the value of employment in different options compared to statistics of the productions’ revenue as well as the available job positions</td>
</tr>
</tbody>
</table>
ten. If the importance of indicator (A) is five in comparison with indicator (B), the value of indicator (B) compared to indicator (A) is one-fifth (Saaty 2001). The implementation process of this method is embedded in the graphical user interface. The AHP method is included only in one table, since the aim is to determine the relative weight of indices (Figure 2).

In this process, experts complete their pairwise comparison matrix and the relative data is entered into the system. Then weighted geometric means of the computed pairwise comparison matrix are calculated and finally the relative weight of indices can be obtained based on an averaged matrix. It is noteworthy to say that varied values or weights determined by the experts can be referred to their different backgrounds and work experiences.

In addition, an index entitled Incompatibility Rate (CR) is calculated for each pairwise comparison matrix indicating the level of mathematical incompatibility among the comparisons of each individual. Therefore, for each expert, incompatibility rate of his/her comparisons is removed from computations by the system when the abovementioned incompatibility rate is above 0.1.

Moreover, the simple additive weighting method (SAW) has been utilized in order to evaluate options (Yilmaz & Harmancioglu 2010). The computations in this method are performed based on the decision matrix data. Rows of this matrix are the options and its columns are the value of indices (Table 2).

Normalizing the values of the decision matrix is the first computational step in a SAW process. Different methods have, so far, been proposed for normalizing the decision matrix, two of which are provided for users in the present software.

In the first method, normalized matrix is obtained by dividing each element of the decision matrix by the mean value of the column (Equation (1)).

\[ a_{ij}^N = \frac{a_{ij}}{(\sum_{i=1}^{m} a_{ij})/m} \quad i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n \quad (1) \]

In Equation (1), \( a_{ij} \) is the value related to the \( j^{th} \) index for the \( i^{th} \) option in the decision matrix and \( a_{ij}^N \) is the normalized value of the decision matrix. The denominator of this equation is the averaged value of the \( j^{th} \) column, while \( m \) and \( n \) are the determined number of options and indices,
respectively.

\[ a_{N}^{ij} = \frac{a_{e}^{ij}}{a_{e}} \quad i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n \] (2)

In Equation (2), the second manner of the normalized decision matrix has been presented. In this method, at first, an option is selected as the reference option, or the current status option, and then, each element belonging to an index is divided by the value of that index belonging to the reference option in order to obtain the normalized matrix. In this equation, parameter \( a_{e}^{ij} \) indicates the value of the decision matrix for reference matrix \( e \) and the \( j^{th} \) index. Other parameters are as in the previous paragraph.

In Equations (1) and (2), calculation is performed for the next column \((j + 1)\) after terminating computation of column \( j \). Then, the weight of each index is computed using Equation (1) after normalized decision matrix numbers. And finally, an index with the highest weight should be inserted in priority.

\[ W_{i} = \sum_{j=1}^{n} L_{j} \times a_{N}^{ij} \quad i = 1, 2, \ldots, m \] (3)

where \( L_{j} \) is the relative weight of the \( j^{th} \) index and \( W_{i} \) is the value of final weight of the \( i^{th} \) option. Other parameters are as above.

In the prepared system, after quantifying indicators and terminating computations, it is required that the user specifies the intended method as well as the reference option, then prioritizing options are performed by the system.

**Describing DSS-SMGW-01**

The DSS-SMGW-01 system is organized into two sections entitled professional view points and preparation/evaluation of options. The database of this system applies two database management systems entitled MS.Access and MS.Excel. This module of the middle-ware undertakes duty of summoning, saving and updating data. Simulation base of this system is the WEAP-MODFLOW linked model and also the decision-making process is performed by the developed model. Figure 3 illustrates a view of different modules of this system.

**Experts’ views or professional viewpoints**

In this section, importing the data relating to the experts, on one hand, and saving and summoning the data, on the other hand, are possible for the users, so that the relative weight of indices are calculated in the model based on the individual (AHP) or group (GAHP) views of the experts. In addition,
different conditions are evaluated by changing the importance of each expert in computing his/her view weight.

**Designing options and aquifer management**

According to the literature, preprocessing should comprise initially providing a groundwater simulation model (MODFLOW) as well as the water consumption and a resources system model (WEAP) for the study area, before utilizing DSS-SMGW-01. The output file of MODFLOW is subsequently summoned in the WEAP along with layers relating to network of aquifer. WEAP-MODFLOW linked model is calibrated, if necessary, and prepared for simulation of integrated surface and ground water system.

After the pre-processing phase, the prepared WEAP file is summoned in the system with an optional title and other calculating processes are performed automatically. Figure 4 illustrates framework of utilizing different modules in this system.

Since the water consumption from an aquifer depends on the amount of water demand and consumption, the management of this consumption amount would also be different for each subdivision.

In the current system, feasibility of dividing a region to different subdivisions is provided in pre-processing module using WEAP model. Also utilizing WEAP model has actualized the integrated management of water resources and consumption.

**Designing options conditions and model implantation**

In the prepared DSS, different options are designed by changing the water consumption value in agricultural and horticultural parts. Then the data for water demand and returning water to the aquifer are transferred to the WEAP-MODFLOW model for each sub-region after designing an option by the user and its verification by the system. Subsequently, simulated results of water level reduction are attained and all indices can be acquired for that option, after conducting the required calculations in the system.

The available data in Figure 5 include the area of each sub-region (area under cultivation for farming and horticultural products), prepared scenario in WEAP, the beginning and the latest years of management period, current demand values for each sub-region, the percentage of returning water to aquifer, and percentage of the utilized water from other resources. In addition,
other water consumption amounts are considered as constant values in the system. Due to the limitation in describing all items, the image of one of the system sections are presented for designed options (Figure 5). Figure 6 illustrates the window relating to the evaluation of cultivation patterns. What should be taken into account is that cultivation patterns are determined in the management years by the user, due to the intended time period. Then, the type of cultivation pattern is prepared for each management year by applying percentage change for each product. Moreover, the obtained revenue of product sales was calculated from basic information of the year 2011.

### Study area

The study area is located in a part of Qazvin province in the northwest of Tehran province and nearly 150 km away from Tehran city. The groundwater balance of the study area was obtained by a based study group of the Qazvin regional water authority using topographic, geological and groundwater maps. In Figure 7, the case study, surface water resources, modeling area and the area under irrigation are indicated. Moreover, this figure illustrates that besides groundwater resources, three rivers and one dam are also available as the water supply resources of this region.
Due to the flow path of main rivers in the region, the aquifer area was divided into four management subdivisions. These divisions are displayed in Figure 7 along with elements of water resources and consumptions system. Figure 8 illustrates five demand sites, groundwater and other resources nodes, as well as cells containing water wells and river flow. This figure is an image of the schematic module that is summoned in the WEAP model.

**Weighting the indicators**

In this section, viewpoints of 68 experts in the water industry have been prepared from different state departments by completing a questionnaire (pair wise comparison matrix). These results can be used for calculating relative weight of indices. Hence, the window relating to the relative weight of each expert and also the final weight of indices in group decision-making are displayed in Figure 9. As shown in this figure, the values of final weight are modified for each index by changing expert weights in GAHP method. In Figure 9, the weight of each expert is considered equal to his/her professional experience years.

Moreover, the last column of this matrix is the incompatibility rate (CR) of each expert demonstrating the rate of mathematical compatibility of expert viewpoints in completing pair wise comparisons. Therefore, the incompatible viewpoints of each expert should be ignored if their values exceeded 0.1. Locations and academic/career levels of the experts participating in the survey are presented in Figure 10.

After analyzing relative weights in different conditions of experts' background, it was determined that the index titled Groundwater Decay Rate (GDR) gained the highest weight score compared with other indices. Besides, Environmental indices relating to the aquifer sustainability gained higher weight score compared with socio-economic indices (Figure 11). It is noteworthy that the presence of experts with solid backgrounds in the water sector could affect the survey results.
The process of altering irrigation and deficit irrigation methods with cultivation patterns was followed to render evaluating options when several options were involved within the samples provided. Table 3 presents a package of designed options considered for evaluating the system. In this system, changes in construction and operational costs, irrigation efficiency and infiltration depth (water reflux to aquifer) occurred.
by altering the irrigation methods. In addition, cultivation patterns and deficit irrigation can have influences on water demand and product income. The cultivation patterns of different statistical years have been selected for designing these options. These information and data have been saved along with product prices and types of costs.

In Figure 12, the structure of cost estimation by the system can be observed for varied types of construction, as well as utilization of novel irrigation methods. Due to the different conditions, these costs include construction and operational costs.

**Providing decision matrix**

Decision matrix is obtained after performing options. Figures 13 and 14 illustrate the decision matrix and

<table>
<thead>
<tr>
<th>Option</th>
<th>Cultivation pattern</th>
<th>Previous irrigation method</th>
<th>Current irrigation method</th>
<th>Irrigation efficiency (%)</th>
<th>Water reflux to aquifer (%)</th>
<th>Deficit Irrigation</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>High consumption</td>
<td>Gravitational</td>
<td>Gravitational</td>
<td>30</td>
<td>25</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>Second</td>
<td>Profitable</td>
<td>Gravitational</td>
<td>Gravitational</td>
<td>30</td>
<td>25</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>Third</td>
<td>High consumption</td>
<td>Gravitational</td>
<td>Gravitational</td>
<td>30</td>
<td>15</td>
<td>30</td>
<td>–</td>
</tr>
<tr>
<td>Fourth</td>
<td>Profitable</td>
<td>Gravitational</td>
<td>Gravitational</td>
<td>30</td>
<td>15</td>
<td>30</td>
<td>–</td>
</tr>
<tr>
<td>Fifth</td>
<td>High consumption</td>
<td>Gravitational</td>
<td>High pressure</td>
<td>85</td>
<td>10</td>
<td>0</td>
<td>Construction and operational costs</td>
</tr>
<tr>
<td>Sixth</td>
<td>High consumption</td>
<td>Gravitational</td>
<td>High pressure</td>
<td>85</td>
<td>10</td>
<td>0</td>
<td>The commencement of utilizing high pressure system in the third year of time period</td>
</tr>
<tr>
<td>Seventh</td>
<td>High consumption</td>
<td>High pressure</td>
<td>High pressure</td>
<td>85</td>
<td>10</td>
<td>0</td>
<td>Only the maintenance cost</td>
</tr>
</tbody>
</table>

Figure 10 | Location (left figure) and academic/career levels (right figure) of the expert participating in the survey.

Figure 11 | Prepared relative weights.

Table 3 | Designed options for evaluating the system
the values relating to priority of the options. Available parameters are explained as follows: annual exploitation of aquifer in million cubic meters (GWO); average drop of groundwater level during time period management in meters; aquifer decay (GDR) in year; capability of groundwater abstraction development (GAD); dependence on groundwater (DG); GV; land productivity (LP); water productivity (NBPD); and employment (EMP).

In Figure 13, all values are obtained for all time periods except total aquifer extraction that was confirmed from annual average extraction from the aquifer.
RESULTS AND DISCUSSION

In Table 4, the results of all options are observed along with their priorities determined by arithmetic mean. This table illustrates that the GDR index, or aquifer lifetime, is decreased by increasing aquifer loss. The aquifer loss increment would decrease the GV index while the decrement of aquifer exploitation results in decreasing the GAD index (be optimized) (Table 4).

Moreover, Table 4 illustrates that the DG index is about 90% indicating that other water resources provide a portion of water demand.

Options 1 and 2 are the consumption options with the highest values, respectively, causing the highest groundwater level loss. In these two options, the GAD index is close to 1 and their GV index has the lowest values compared with other options. It is mentioned that an increase in exploitation of groundwater exerts the least influence on GV index and would have a direct or inverse relationship.

Table 4 | Results of the model for prepared options

<table>
<thead>
<tr>
<th>Rel. wt.</th>
<th>Alt. name</th>
<th>GWO (MCM/Year)</th>
<th>Ave. loss (m)</th>
<th>GDR</th>
<th>GAD</th>
<th>DG</th>
<th>GV</th>
<th>LP ($10^9$)</th>
<th>NBPD ($10^{12}$)</th>
<th>Emp/1,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.951</td>
<td>Alt. 1</td>
<td>1,923.354</td>
<td>21.96</td>
<td>3.036</td>
<td>0.962</td>
<td>0.938</td>
<td>0.003</td>
<td>14.082</td>
<td>1.567</td>
<td>127.829</td>
</tr>
<tr>
<td>0.854</td>
<td>Alt. 2</td>
<td>1,843.306</td>
<td>20.73</td>
<td>3.216</td>
<td>0.922</td>
<td>0.936</td>
<td>0.004</td>
<td>9.14</td>
<td>1.033</td>
<td>115.069</td>
</tr>
<tr>
<td>0.951</td>
<td>Alt. 3</td>
<td>1,380.504</td>
<td>16.03</td>
<td>4.159</td>
<td>0.69</td>
<td>0.916</td>
<td>0.006</td>
<td>11.543</td>
<td>1.835</td>
<td>104.781</td>
</tr>
<tr>
<td>0.891</td>
<td>Alt. 4</td>
<td>1,324.471</td>
<td>15.08</td>
<td>4.42</td>
<td>0.662</td>
<td>0.913</td>
<td>0.006</td>
<td>7.492</td>
<td>1.21</td>
<td>94.322</td>
</tr>
<tr>
<td>0.786</td>
<td>Alt. 5</td>
<td>1,320.188</td>
<td>16.08</td>
<td>4.145</td>
<td>0.66</td>
<td>0.913</td>
<td>0.006</td>
<td>1.49</td>
<td>0.249</td>
<td>127.829</td>
</tr>
<tr>
<td>1.791</td>
<td>Alt. 6</td>
<td>1,521.243</td>
<td>19.65</td>
<td>3.392</td>
<td>0.761</td>
<td>0.933</td>
<td>0.005</td>
<td>59.759</td>
<td>8.969</td>
<td>127.829</td>
</tr>
<tr>
<td>0.99</td>
<td>Alt. 7</td>
<td>1,320.188</td>
<td>16.08</td>
<td>4.145</td>
<td>0.66</td>
<td>0.913</td>
<td>0.006</td>
<td>12.181</td>
<td>2.033</td>
<td>127.829</td>
</tr>
</tbody>
</table>
One of the gadgets of this system is a graphics module that represents the changes in the utilized indices. In Figure 15, a sample of these changes can be observed. According to this diagram, higher groundwater exploitation resulted in a higher apparent groundwater level due to the regional conditions.

CONCLUSION

Varied parameters such as limited amount of groundwater resources, water demand increase, and conflict of interests have led to serious difficulties in decision-making conditions relating to sustainable groundwater management. Through the rapid development of information technology, applications such as DSS play an important role in estimating different management options and detecting appropriate solutions by spending lowest possible time and cost. In this paper, software entitled DSS-SMGW-01 is developed as the DSS for sustainable groundwater management. Due to the aim of achieving sustainable development and appropriate exploitation of groundwater resources for the sake of agricultural and horticultural benefits, seven indices (namely GDR, DG, GV, GAD, NBPD, LP, and EMP) are presented in this system in order to evaluate their influence on an aquifer and socio-economic conditions. Additionally, in this system, the WEAP-MODFLOW linked model, group analytic hierarchy method (GAHP), and SAW have been utilized in order to simulate groundwater resources system, weight indicators and prioritize options, respectively.

In this article, water resources of Qazvin plain have been modeled by utilizing WEAP-MODFLOW linked model and study area has been divided into four sub-regions. Management options have also been designed by graphical user interface based on the available data in the database. These options were prepared by changing agricultural and horticultural consumptions (cultivation pattern, irrigation method, deficit irrigation) while being independent from each other with regard to water consumption pattern in agricultural and horticultural sections.

Evaluation of DSS-SMGW-01 is carried out by investigating manual calculations of indices and comparing them with DSS results. Finally, the performance and limitations of the model in designing and evaluating different options can be realized through delivering logical results via the model.

One can state that this system would be able to function properly in other regions by changing database information. Moreover, some specific requirements, such as conversion of DSS to a GIS-based system for regional decision making, model independence to the WEAP application, and increased accuracy in determining and calculating...
socio-economic indices should be met in order to develop the system and enhance its performance.

REFERENCES


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