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RESEARCH PAPER

Development of a decision support system for precision management of conjunctive use of treated wastewater for irrigation in Oman

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تطوير نظام دعم القرار لإدارة دقيقة لاستخدام مياه الصرف الصحي المعالجة والمخلوطة بعمان

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ABSTRACT. This research aimed at finding alternative options for conjunctive use of treated wastewater (TW) with groundwater (GW) minimizing the irrigation water from aquifers in the Al-Batinah region with the assistance of a Decision Support System (DSS). Oman is facing a three-facet problem of lowering of GW table, wastewater over-production and excess TW. Approved guidelines for use of TW with tertiary treatments are of two classes: class-A (for vegetables consumed raw), class-B (after cooking). The developed DSS is comprised of four management subsystems: (1) data management in Excel, (2) model and knowledge management by macro programming in Excel, (3) with linear programming (LP) optimization models including transportation algorithms, and (4) user interface with Excel or Visual Basic (VB). The results are based on two extreme scenarios: zero TW excess, and zero GW used for irrigation. The DSS could predict water balance for number of crop rotations, and based on adjustable cost variables farmer profit margins could be created. Crop selections and rotation could be done using LP optimizations while transportation algorithm could organize best locations and capacities for treatment plants and the wastewater collection and transportation to farming areas via treatment plants. The developed DSS will be very useful as a water management, optimization and planning tool.

KEYWORDS: Decision support; precision irrigation management; conjunctive use; treated wastewater; groundwater.

الملخص: يهدف البحث لتحسين إدارة المياه الجوفية ومياه الصرف الصحي المعالجة عن طريق استخدام نظام دعم القرار. تواجة عمان ثلاث حقائق مائية وهي انخفاض مستوى المياه الجوفية والإنتاج الزائد لمياه الصرف الصحي المعالجة مع تزايد كمياتها مع مرور الزمن. يتكون نظام دعم القرار من إدارة الأعداد، الإدارة المعرفية للبرامج، الإدارة الخطية للبرامج المستخدمة واستخدام التداخل العددي في البرامج. اعتمدت النتائج على تصورين وهما الاستخدام الكلي للمياه المعالجة وعدم استخدام المياه الجوفية في الزراعة. تنبأ النظام بكميات المياه المطلوبة لعدة محاصيل منتجة أثناء السنة والذي يدعم ربح المزارع. من خلال النظام قد يكون هناك تنبوأت بنوعية المحاصيل وتدويرها مما يتناسب مع كمية المياه المنتجة والمنقولة. النظام الجديد سيكون مفيدا لإدارة المياه وعمل المخططات المستقبلية.

الكلمات المفتاحية: دعم اتخاذ القرار، إدارة الري الدقيق، الاستخدام المشترك، مياه الصرف الصحي المعالجة والمياه الجوفية

Introduction

As in any country or region with arid environment, water is scarce in Oman. Yet the agriculture is a common and traditional practice in Oman in which more than 50 percent of the arable lands are located in the northern coastal belt of Al-Batinah region (Alahakoon *et al.*, 2013; MAF, 2013; MAF, 2015). The country with average annual rainfall around 100 mm, has limited natural freshwater resources and has been facing the serious problem of seawater intrusion into the scarce GW reserves due to undisciplined excessive pumping of GW for irrigation from aquifers. Farmers are allowed to use GW with a quota system developed by the two ministries: the Ministry of Agriculture and Fisheries and the Ministry of Water Resources (MAF, 2013; Mott MacDonald and MRMWR, 2013a; Mott MacDonald and MRMWR, 2013b; MAF, 2014; MAF, 2015). However, GW over pumping has been undisciplined and is a common practice among some farmers causing seawater intrusion and salinity issues in the region with most arable lands (Norman et al., 1998; Prathapar et al., 2005; Zekri, 2008; Alahakoon et al., 2013). There are problems with the crop selections and rotations as the farmers make own decisions on that issue without considering the water saving efforts. Some of the crops that have higher crop to water demand are grown by using inefficient irrigation methods (FAO, 1998; FAO, 2010; Somarathna and Ahmed 1999; Ensink et al., 2004).

The researchers, with the support of the relevant ministries, have been looking for alternative options to minimize the use of irrigation water by over pumping of GW (Zekri, 2008; Alahakoon *et al.*, 2013; Mott MacDonald and MRMWR, 2013a; Mott MacDonald and MRMWR, 2013b) and more efficient irrigation techniques (Zekri, 2008; Alahakoon et al., 2013;

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Alessandra, 2014) including precision irrigation (Zekri, 2008; Alahakoon et al., 2013). A consistent deficit of GW has been experienced due to irrigation use, and annual deficit of GW in the agricultural region Al-Batinah along was 315×10^6 m^3 in 2013 (Zekri, 2008; Alahakoon et al., 2013; Mott MacDonald and MRMWR, 2013a; Mott MacDonald and MRMWR, 2013b). Due to people migration to cities, city expansions and industrial growth have created excess production of wastewater. As per the statistics, there is a steep growth rate of wastewater production. Current daily wastewater produced in Muscat governorate is 94 000 m^3 and predicted to be four fold in 2025 (Somaratna and Ahmed, 1999; Prathapar et al., 2005; Mott MacDonald and MRMWR, 2013a; Mott MacDonald and MRMWR, 2013b). Wastewater treatment plants have been established around the city with tertiary treatment levels, standard processes and quality; however there is not much effort made to use the water for consumable crop irrigation. Even after applying for various needs, there is a significant excess production of TW and handling this has become a challenge as there are restrictions for recharge (David and Williams, 1979; Berry et al., 1980; Harvey, 1997; Mohammad and Mazahareh, 2003; Fluet et al., 2009; Bedbabis et al., 2010; Abdelrahman et al., 2011; Al Khamis et al., 2011).

Rationale

The objective of this research was to find solutions for Oman's three-facet problems of lowering of GW table (Al-Batinah GW deficit 315×10^6 m^3 in 2013), increasing daily wastewater production (94 000 m^3/day in 2015) and how to handle excess TW after reuse (Prathapar et al., 2005; Zekri, 2008; Mott MacDonald and MRMWR, 2013a; Mott MacDonald and MRMWR, 2013b). The developed DSS can find potential solutions to all above-mentioned problems. A couple of key variables are kept in the system in order to maintain flexibility and adjustments. Following critical points and constraints were taken into consideration when developing the DSS for the use of TW for irrigation.

Points considered on development:

- It is important to find alternative options for replacing the irrigation water used by over pumping GW with the assistance of technology and planning.
- The seawater intrusion, soil salinity, land degradation hinder agricultural production.
- Use of TW for irrigation is one of the best options, and the cheapest option in Oman to save GW.

Constraints on implementation:

- Acceptance by society to use in agriculture and agro industry; farmers, consumers, managers and the scientists. Many sensitive issues, need to be addressed.
- No storage facilities at sewage treatment plants (STPs) to store bulk of TW exit from the plant, transportation network should be efficient with Just-In-Time basis or dump in somewhere (in the ocean).

Objectives

The main objective of the study was to find alternative options for replacing the irrigation water used by over pumping GW (Zekri, 2008; Alahakoon et al., 2013, Mott MacDonald and MRMWR, 2013a; Mott MacDonald and MRMWR, 2013b) with the assistance of a DSS. The specific objectives of the study were to see the feasibility of maximizing the use of TW replacing GW use for irrigation and to minimize the unused TW excess, optimize the land use for different crop combinations and rotations with TW use while optimizing the farmers' profit, optimize the TW distribution network; determine the feasibility for locating STPs minimizing transportation (TW) cost for farmers, and develop a DSS for managers to conduct feasibility studies for better planning and management of TW use.

Methodology

An Excel and Visual Basic based Decision Support System (DSS) was developed to select options for conjunctive use of treated waste water (WT) and ground water (GW) for irrigation in Oman. The developed system targeted managers and farmers as users and the system was with necessary simplicity and flexibility. The system architecture utilized is illustrated in (Fig. 1). It comprised of four management subsystems; data management in Excel, model and knowledge management by macro programming in Excel, with linear programming (LP) optimization models including transportation algorithms all in Excel, and user interface optional with Excel or VB mode. Graphical results could also be retrieved in the VB mode

Two critical threshold levels were considered in the

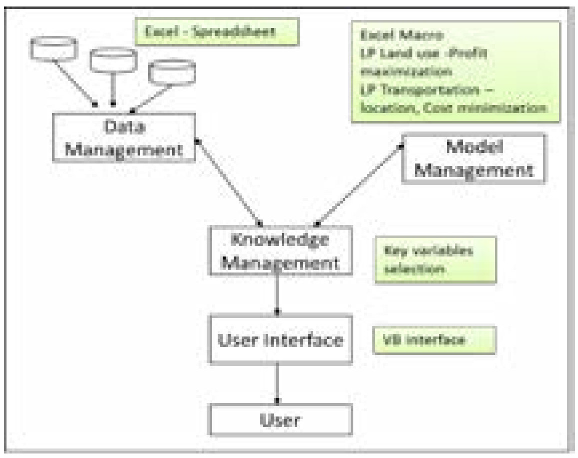

Figure 1. Architecture used in developing the Decision Support System.

analysis considering the two scenarios shown in (Fig. 2). Threshold levels were: (1) Zero excess TW and (2) Zero use of GW based on the prevailing conditions in Oman.

The main decision variable of the systems is the volume of daily production of TW in 10^6 m^3. In addition, there are other variables in the system applicable for different management modules (Fig. 1). As an example, for the cost analysis, prices of TW and GW (including transportation costs) are auxiliary variables. Once all the variables are entered, the results including graphical results will appear (Fig. 3). Crop and meteorological data are based on the experimental farming by the MOAF Oman.

Results

Figure 3 shows a sample view of Excel-based decision support system and results with graphics obtained under given data and applied decision variables. Table in (Fig. 3) shows the three crop rotations and two extreme scenarios of zero excess TW and zero GW use. Extended portion of the table shows the cost of excess TW or the opportunity cost. The bottom left section shows the cells for decisions variables used in the computations: daily TW production costs for TW and GW ,etc. The bottom area shows the cost analysis results in graphical form. Decision makers can observe the simulation results and select the appropriate crops and cropping enterprises leading to profit maximization while maintaining the optimum conjunctive use of TW and GW.

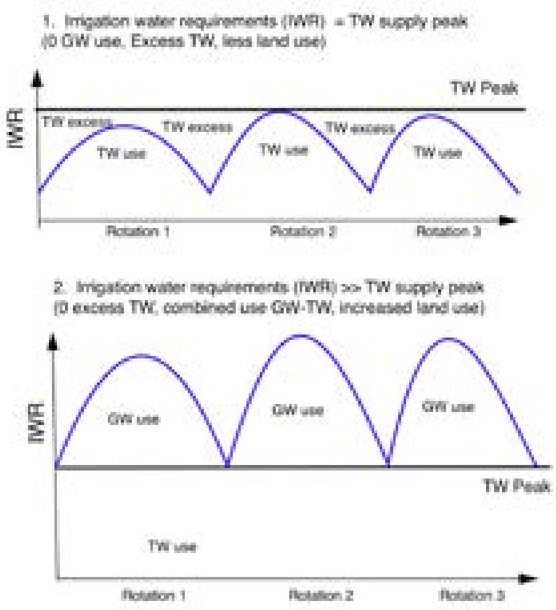

Figure 2. The two extreme scenario considered : (1) zero GW use, i.e. the peak of treated water production is considered as the peak of irrigation water requirements and (2) zero TW excess, the minimal requirements for the different crops is provided by treated water and additional GW is used when necessary.

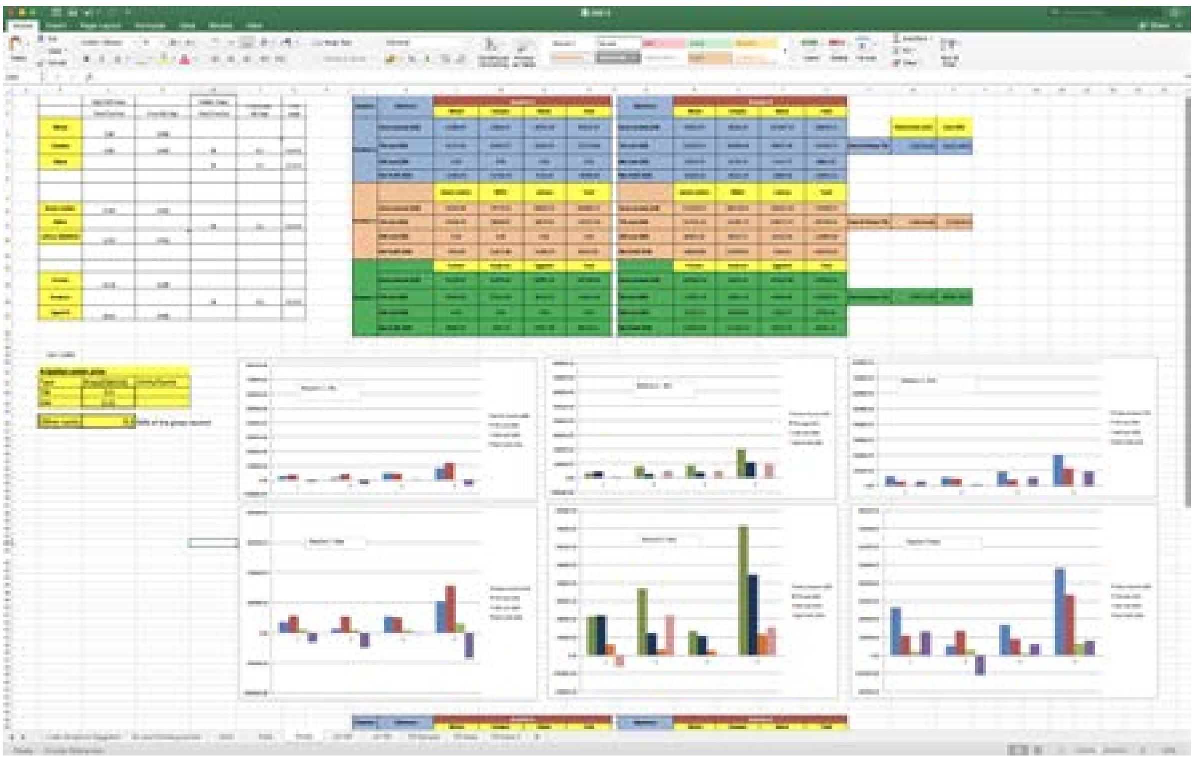

Figure 3. A sample view of Excel-based DSS on farmer profit maximization condition.

Figure 4. A sample view of Visual-basic interface of the DSS on crop rotation optimization.

Figure 4 shows a sample view of the VB interface window which provides the results in tabular form with cells having decision variables for adjustments. The upper row of the table shows option buttons (Summery, Rotations, Profits, LP, LP-Transportation etc.), through which corresponding programs could be executed in Excel and results could be obtained in the VB window. The cells in the upper rows provide the main decision variables for necessary adjustments and tables show the corresponding results. The graphical results (bar charts) obtained in Excel could also be retrieved in the VB mode. The system provided greater simplicity and flexibility, and with a short training the users will be able to operate the system.

Conclusion and recommendations

- The developed DSS could simulate best options with conjunctive use of TW and GW for scheduling seasonal irrigation in Oman.
- The developed DSS could simulate potential solutions for the Oman's three-facet problems; reduce the use of GW lowering the stress on GW table, maximize the use of TW without dumping in sea, and system could be used to plan the locations for treatment plants and two-way transportation network with quantities.
- The developed DSS is very simple, flexible and user-friendly. It can be further improved with extensions incorporating leaching fraction, soil/water salinity fractions etc.

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