Precision Irrigation Management through Conjunctive Use of Treated Wastewater and Groundwater in Oman

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Abstract. *Agriculture under arid environment is always become a challenge due to water scarcity and salinity problems. With average rainfall of 100 mm, agriculture in Oman is limited due to the arid climate and limited arable lands. More than 50 percent of the arable lands are located in the 300 km northern coastal belt of Al-Batinah region. In addition, country is facing severe problem of sea water intrusion into the groundwater aquifers due to undisciplined excessive groundwater (GW) abstraction for irrigation. Although farmers are allowed to use ground water with a quota system developed by the Ministry of Agriculture, groundwater over pumping has caused seawater intrusion and salinity issues in most arable lands. The main objective of this research is to find alternative options for minimizing the groundwater irrigation by developing a Decision Support System (DSS). The DSS could be used to optimize the precision management of conjunctive use of treated wastewater (TW) for irrigation. Oman follows guidelines available for the use of treated wastewater with two classes A and B both with tertiary treatments as per international standards. Class-A can be recommended for vegetables consumed raw while Class-B for after cooking. Current TW production in Muscat governorate along is over100,000 m^3/day and it is predicted to be four fold by 2025. Currently this volume is underutilized and some have to be dumped in sea. The developed DSS comprised of subsystems for data management, a model management, knowledge management and the user interface for easy use and interpretation of results. The date management was done under Excel domain, and the model management was through macro programming, linear programming (LP) optimization models including transportation algorithms all in Excel domain. A user interface was optional through either with excel or using Visual Basic. The results were based on two extreme scenarios; zero TW dumped 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. Using LP optimization, crop selections and rotation could be done while transportation algorithm could organized and predict best locations and capacities for treatment plants and the wastewater* *collection and transportation to farming areas via treatment plants. This type of DSS would be useful as a water management optimization and planning tool for managers and planners.*

Keywords*: Decision support, precision irrigation management, conjunction use, treated wastewater, ground water*

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, around 59 percent of the total arable lands are located in the northern coastal belt of Al-Batinah region (Alahakoon et al. 2013; MAF 2013; MAF 2014; MAF 2015). The country with average annual rainfall around 100 mm has limited natural freshwater resources, has been facing serious problems. Seawater desalination and use of GW are the main sources for drinking and agricultural purposes. Country is facing a problem with undisciplined excessive abstraction of GW for irrigation from aquifers (Al-Ajmi 2002; Mott MacDonald and MRMWR 2013a; Mott MacDonald and MRMWR 2013b); consequently the sinking of water table and seawater intrusion into the scarce GW reserves has been identified as main threats. Farmers are allowed to use GW with a quota system developed by the two ministries; Ministry of Agriculture and Fisheries, and Ministry of Water Resources (MAF 2013; MAF 2014; MAF 2015; Mott MacDonald and MRMWR 2013a; Mott MacDonald and MRMWR 2013b). However, GW over pumping has yet been undisciplined and in common practice among some farmers causing salinity increase along the farmlands coastal belt due to seawater intrusion (Alahakoon et al. 2013; Norman et al. 1998; Prathapar et al. 2005; Zekri 2008). There are problems associated with the crop selections and rotations as the farmers make own decisions without considering the water saving efforts. Some of the crops that have higher crop water demand are grown by using inefficient irrigation methods (Ensink et al. 2004; FAO 1998; FAO 2009; Somarathne and Ahmed 1999).
The researchers with the support of the relevant ministries have been looking for alternative options to minimize the irrigation water using GW (Alahakoon et al. 2013; Mott MacDonald and MRMWR 2013a; Mott MacDonald and MRMWR 2013b; Zekri 2008) and more efficient irrigation techniques (Alahakoon et al. 2013; Scardigno 2014; Zekri 2008) including precision irrigation (Alahakoon et al. 2013; Zekri 2008; Jayasuriya et al. 2014; Alahakoon et al. 2014). 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 million cubic meters (MCM) in 2013 (Alahakoon et al. 2013; Mott MacDonald and MRMWR 2013a; Mott MacDonald and MRMWR 2013b; Zekri 2008; Jayasuriya et al. 2018). Due to migration of people to cities, city expansions and industrial growth has created excess production of wastewater. As per the statistics, there is a steep growth rate of wastewater production. Current daily wastewater produce in Muscat governorate is 94,000 m^3 and predicted to be four fold in 2025 (Mott MacDonald and MRMWR 2013a; Mott MacDonald and MRMWR 2013b; Prathapar et al. 2005; Somarathne and Ahmed 1999; Jayasuriya et al. 2018). Wastewater treatment plants have been established around the city basis 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 (Abderahman et al. 2011; Al-Khamisi et al. 2011; Bedbabis et al. 2010; Berry et al. 2010; David and Williams 1979; Fluet et al. 2009; Haruvy 1997; Mohammed and Mazahareh 2003).

Rationale and Objectives

Effort of this research was to find solutions for Oman's three-facet problems of lowering of GW table (Al-Batinah GW deficit 315 MCM in 2013), increase in daily wastewater production (94,000 m^3/day in 2015) and how to handle excess TW after reuse (Mott MacDonald and MRMWR 2013a; Mott MacDonald and MRMWR 2013b; Prathapar et al. 2005; Zekri 2008; Jayasuriya et al. 2018). 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.
Main objective of the effort was to find alternative options for replacing the irrigation water used by over pumping GW (Alahakoon et al. 2013; Mott MacDonald and MRMWR 2013a; Mott MacDonald and MRMWR 2013b; Prathapar et al. 2005; Zekri 2008; Jayasuriya et al. 2018) with the assistance of a DSS. And the specific Objectives of the effort were; to see the feasibility of maximizing the use of TW replacing GW use for irrigation and to minimize the unused TW excess, to optimize the land use for different crop combinations and rotations with TW use while optimizing the farmers' profit, to optimize the TW distribution network; feasibility for locating STPs minimizing the transportation (TW) cost for farmers, and to develop a DSS for managers to conduct feasibility studies for better planning and management of TW use.

Main considerations taken into account in developing DSS

- 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 of DSS recommendations

- Acceptance by the society to use TW in agriculture and agro industry; farmers, consumers, managers and the scientists. Many sensitive issues on the sales, consumption of TW irrigated crop products which need to be addressed.
- Lack of 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.
- TW quality is not accepted for aquifer recharge. Further treatment facilities not available and costly. Therefore, significant quantity of TW produced has to be dumped in the ocean.

Methodology

An Excel and Visual Basic based DSS was developed to select options for conjunctive use of TW and 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 Figure 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.

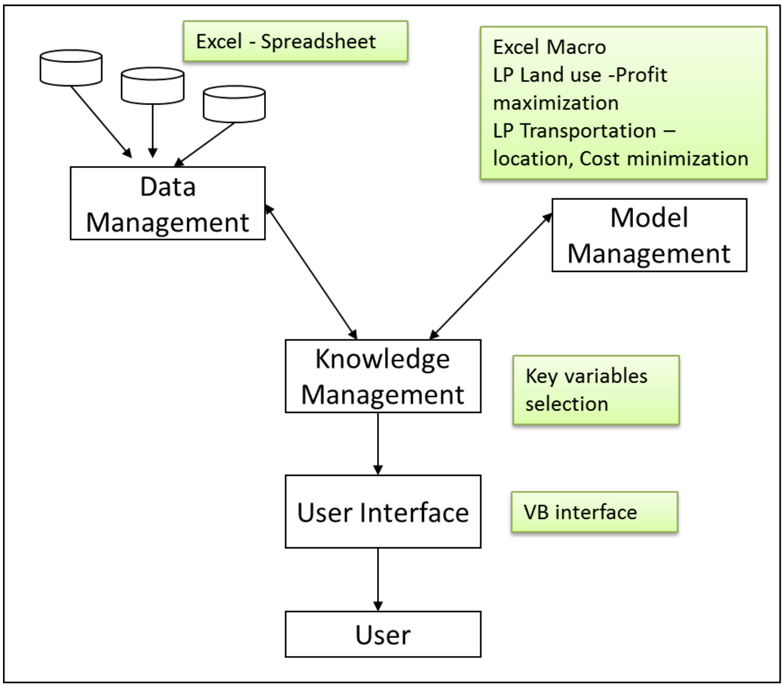

Fig. 1 The architecture used in developing the Decision Support System

Two critical threshold levels were considered in the analysis as in section 1.1 considering two scenarios as in Figure 2. Threshold levels are; 1. Zero excess TW and 2. Zero use of GW chosen based on the prevailing conditions in Oman.

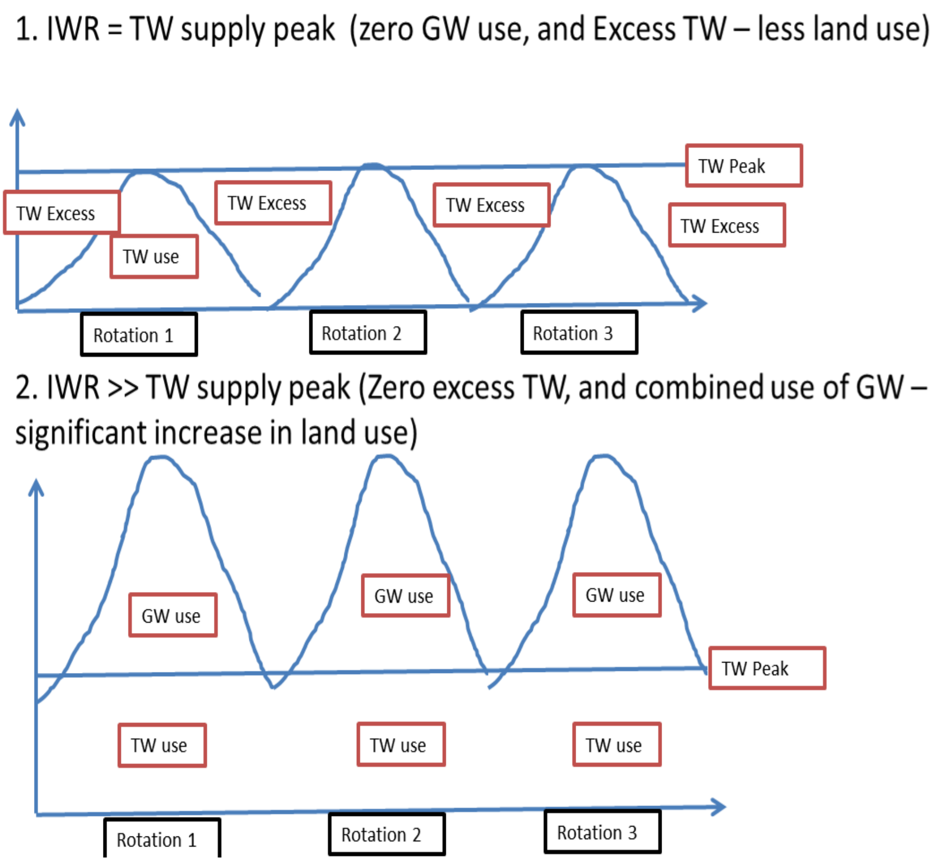

Fig. 2 The two extreme scenarios considered; (a) zero GW use and (b) zero TW excess

The main decision variable of the systems is the volume of daily produce of TW in MCM. In addition, there are other variables in the system applicable for different management modules (Figure 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 (Figure 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 graphical results obtained under given data and applied decision variables. Table in Figure 3 shows the three crop rotations and two extreme scenarios of zero excess TW and zero GW use. Extended portion of the table shows cost of excess TW or the opportunity cost. Left bottom section shows the cells for decisions variables used in the computations; daily TW production costs for TW and GW etc. 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.

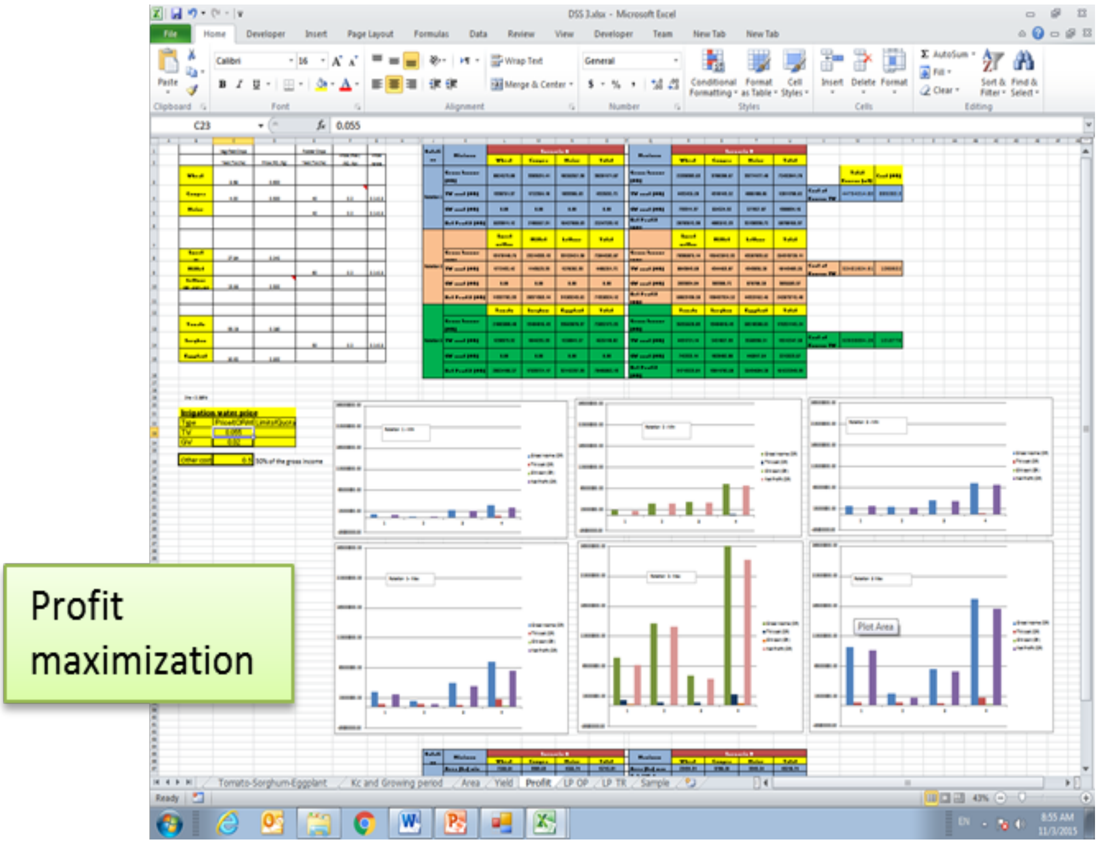

Fig. 3 A sample view of Excel-based DSS on farmer profit maximization condition

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.

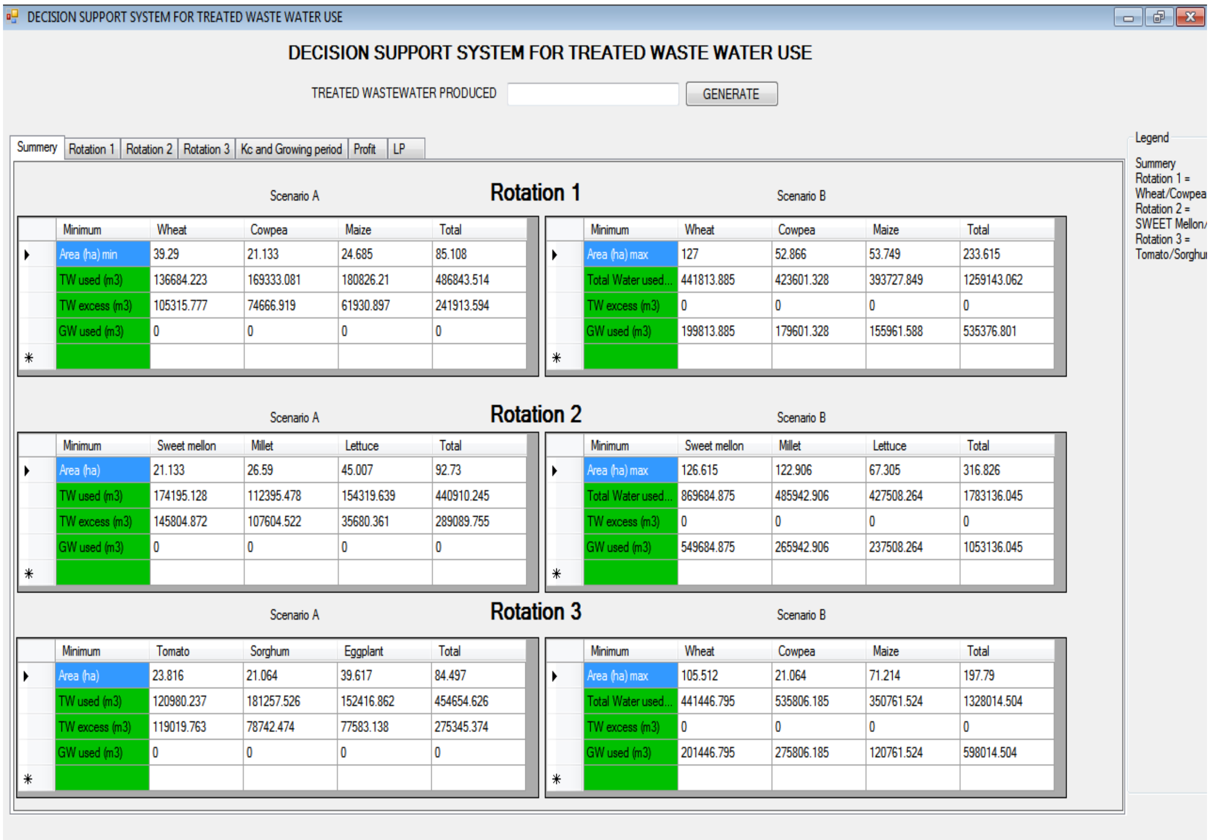

Fig. 4 A sample view of Visual-basic interface of the DSS on crop rotation optimization

Extended work completed

The developed DSS could be used to, conduct number of sensitivity analyses on the following;

- Sensitivity analysis on leaching fraction (4 conditions of salinity increase)
- Sensitivity analysis on farmer subsidy
- Sensitivity analysis on projected production of TW
- Sensitivity analysis on GW cost and excess of TW cost
- Sensitivity analysis on farmers' perspective.

Conclusions 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 basic DSS was 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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