Assessing the applicability of Ground Penetrating Radar (GPR) Techniques for estimating soil water content and irrigation requirements in the Eastern Province of Saudi Arabia: A project methodology.

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Abstract: The Kingdom of Saudi Arabia (KSA) has distinct and serious water deficit problem. KSA lies between between 16° 22' and 32° 14' North latitudes and 34° 29' and 55° 40' East longitudes in an arid to semi-arid climate. The country has low average annual precipitation ranges from 80 mm to 140 mm, with limited natural water resources. There are no lakes, rivers, or streams. The country is increasingly dependent on fossil groundwater resources which receive very limited natural recharge for intensive irrigation. Irrigation consumes about 85% of total water supply. This paper presents review of the application of GPR technology to estimate soil water content (SWC), underlines and discusses promising methodology of a two-year research project (submitted by Al-Shuhail & Ouda, 2012) for funding by the King Abdulaziz City for Science and Technology – Saudi Arabia. GPR technique will be used to measure agricultural field SWC as an accurate, precise and alternative method to conventional measurements methods in the Eastern Province of Saudi Arabia. A new irrigation scheduling methods based on tested and modified GPR technique will be introduced and applied to common agricultural crops in the target area. This technology transferred technique will play major role in improving the irrigation efficiency and minimizing the agricultural water consumption.

Keywords: Saudi Arabia, Ground Penetrating Radar, Soil Water Content, Crop water requirements Irrigation

1.0 INTRODUCTION

The Kingdom of Saudi Arabia (KSA), like many other parts in the Middle East, has a distinct and serious deficit in water. KSA lies between between 16^{o} 22' and 32^{o} 14' North latitudes and 34^{o} 29' and 55^{o} 40' East longitudes as shown in **Figure 1**. The country total area is about 2 million square kilometres (SGS, 2012). KSA has diverse geography. The east part is rocky or sandy lowland up to the Arabian Gulf. In the west, the land rises from the sea level to a peninsula-long mountain range called Jabal Al-Heijaz, beyond which lies the plateau of Nejed. The south-western region of KSA has mountains as high as 3,000 m above the main sea level. Empty Quarter covers the southern part of the country (SGS, 2012). KSA population increased from about 7 million to about 27 million in the last 40 years with an annual population growth rate of 3.4% (SCDSI, 2010). The increase in population was also coupled with an increase in urbanization level where urban population has increased from about 50% of the total population in 1970 to about 80% of the total population in 2000 (SCDSI, 2010).

Figure 1: Kingdom of Saudi Arabia Location Map. Source: The Encyclopedia of the Earth

1.1 Water Resources

The Country characterized by an arid to semi-arid climate and low average annual precipitation ranges from 80 mm to 140 mm, with limited natural water resources; there are no lakes, rivers, or streams. Intermittent flash floods water is captured in 260 irrigation dams collecting an estimated 0.6 Billion m^3 per year (Ouda, 2013). Groundwater is the only reliable natural water source on the country. KSA utilized sea water desalination as source for potable water supply. The current desalination plant capacity is about 1 billion Cubic meters (SWCC, 2010), which satisfied about 37% of municipal water demand. KSA government supports the reuse of treated wastewater for agricultural and landscape irrigation. Saudi Municipalities have used treated wastewater extensively for street landscape and municipal parks irrigation. In 2010, about 240 million m^3/year of the treated wastewater have been used for landscape and crop irrigation across the country (MWE, 2012). Water sustainable yields form both conventional and non-conventional resources in Saudi Arabia are presented in **Table 1** summarized the 2010 water resources sustainable yields and total water demand per sector. The table shows a total water demand versus supply gap of about 11.5 Billion m^3 per year. This gap is typically covered by groundwater over abstraction and depletion.

Table 1: KSA Sustainable Water Resources Yields and Water Demand in the year 2010

Water Resource Sustainable Yields	Quantity (million m^3/year)
Groundwater	3,850
Surface water	1,300*
Total conventional Sources	*5,150*
Treated wastewater	240
Desalinated water	1,050
Total non-conventional sources	*1,290*
Total water resource yields	6,440
Water Demand Per Sector	
Domestic	2063
Industrial	800
Agricultural	15000
Total Water Demand	17,863
2010 Water Demand vs. Supply Gap	11,423

*annually variable depending on rainfall pattern

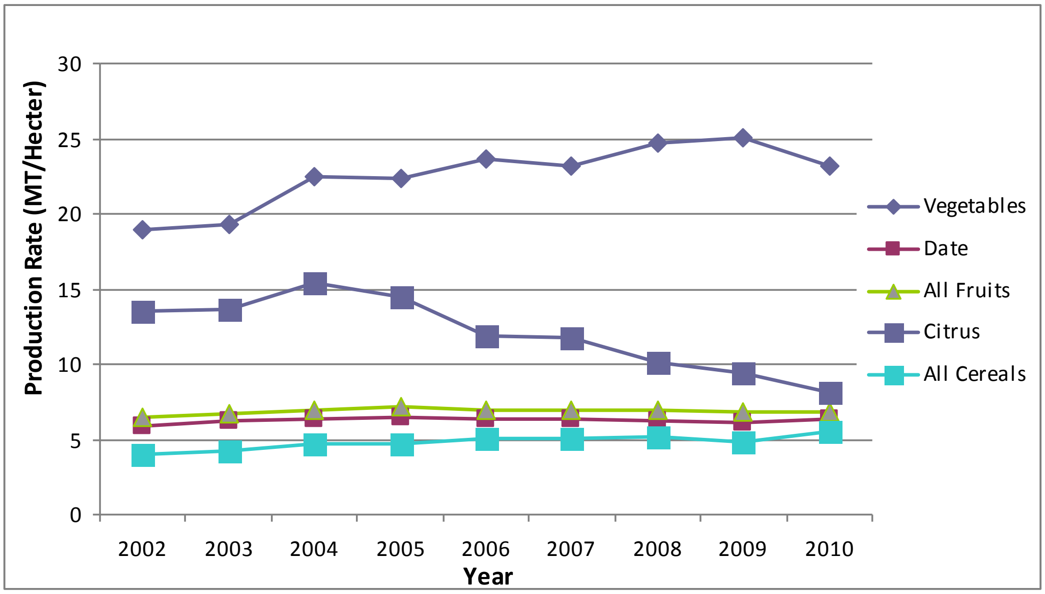
2.0 AGRICULTURE SECTOR IN SAUDI ARABIA

Agriculture is considered a main sector in KSA, it contributes directly in food availability and securing food resources, also it has a positive impact on job market and offering jobs for a wide range of people (Alam et al. 2011). In addition, to its good contribution in the gross domestic product (GDP), it offers self sufficiency ratio of different agricultural food products, reach up to 85 % - 60 % for vegetable and fruits, respectively as presented in **Table 3** (MOA , 2011). The productivity of various crops per unit area are presented in **Figure 2**. Agriculture sector is the main water consumer; about 80% of all water used by mankind is withdrawn towards irrigation uses, where 74 % is evaporated by crops (Sundquist B., 2007). Protected irrigated agriculture is solely used for crop productions in KSA, where, agricultural water used (mainly irrigation) about 85% of the total water supplies from scarce groundwater resources as shown in **Table 1**. (Al Zhrani et al., 2011; MEP 2005; World Bank, 2010).

Table 2 Self Sufficiency Ratio OF Different Agricultural Food Products For 2010

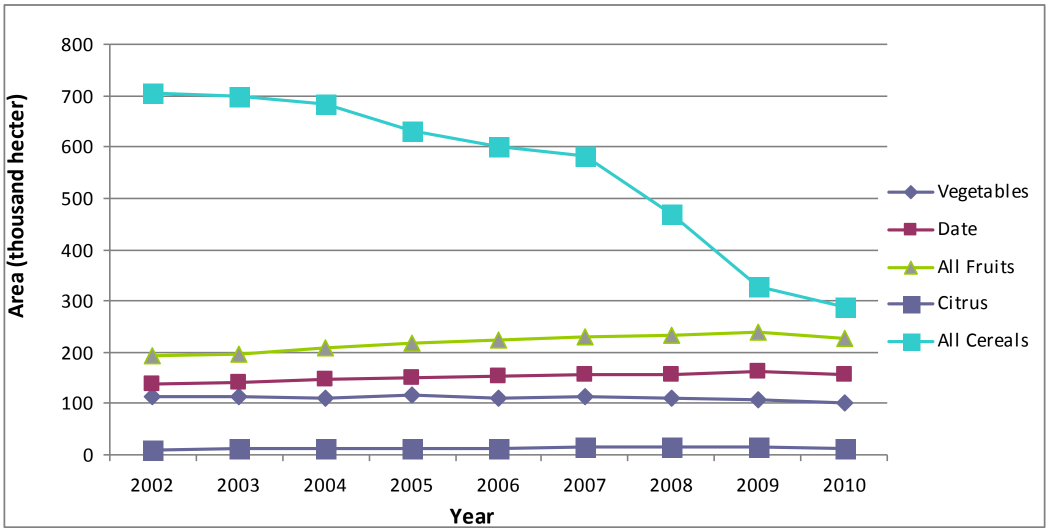
Crops	**Local Production**	**Net Imports**	**Available for Consumption**	**Sufficiency Ratio**
Vegetables total	**2521000**	**379633**	**2900633**	**86.90%**
Potatoes	399000	-104808	294192	135.60%
Cucumber	221000	-5712	215288	102.70%
Water Melons	339000	-59781	279219	121.40%
Melons	267000	9215	276215	96.70%
Tomato	492000	201869	693869	70.90%
Eggplant	61000	-3772	57228	106.60%
Okra	53000	0	53000	100.00%
Fruits total	**1549000**	**1127566**	**2676566**	**57.90%**
Grapes	139000	36782	175782	79.10%
Dates	992000	-73360	918640	108%
Citrus	105000	470807	575807	18.20%
Other Fruits	313000	693337	1006337	31.10%

Source : (MOA , 2011)



Figures 2: The productivity per unit area of different crops in Saudi Arabia

The agricultural sector has been intensively subsidized during the period from 1974 to 2006 by Saudi government. The subsidized program aimed to improve the standard of livings in rural communities. The program came with substantial increase of the cultivated area mainly for intensive irrigated crops such as wheat. The irrigated area increased from less than 400 thousands hectare (ha) in 1971 to about 1.62 million ha in 1992 (World Bank, 2005). The expanded irrigated agricultural has resulted in the depletion of groundwater resources. KSA government have decided to re-structure the agricultural sector including phase out its support to the cultivation of high water demanding crop such as wheat (Al-Zahrani, K. H. and E.A. Elhag, 2003; Khodran Hamadan Al-Zahrani, 2010; Al-Zahrani K. H.; Baig M. B., 2011). KSA has also set up programs and policies heading towards maximizing efficiency of irrigation water supply and arable land to produce high value crops such as fruits and vegetables. (MEP, 2005, Alabdulkader et al. 2012). The newly massive policy and program have reduced cultivated area from peak figure of about 1.63 million ha in 1992 to about 0.85 million ha in 2009 (FAO, 2009; MWE, 2012). The reduction was mainly in cereal crops cultivated area as shown in **Figure 3.** The total Saudi production of different crops is presented in **Figure 4**. The figure shows a substantial decrease of cereal crops productions in the last few years, where vegetable corp. production is growing.



Figures 3: The cultivated area of different crops in Saudi Arabia

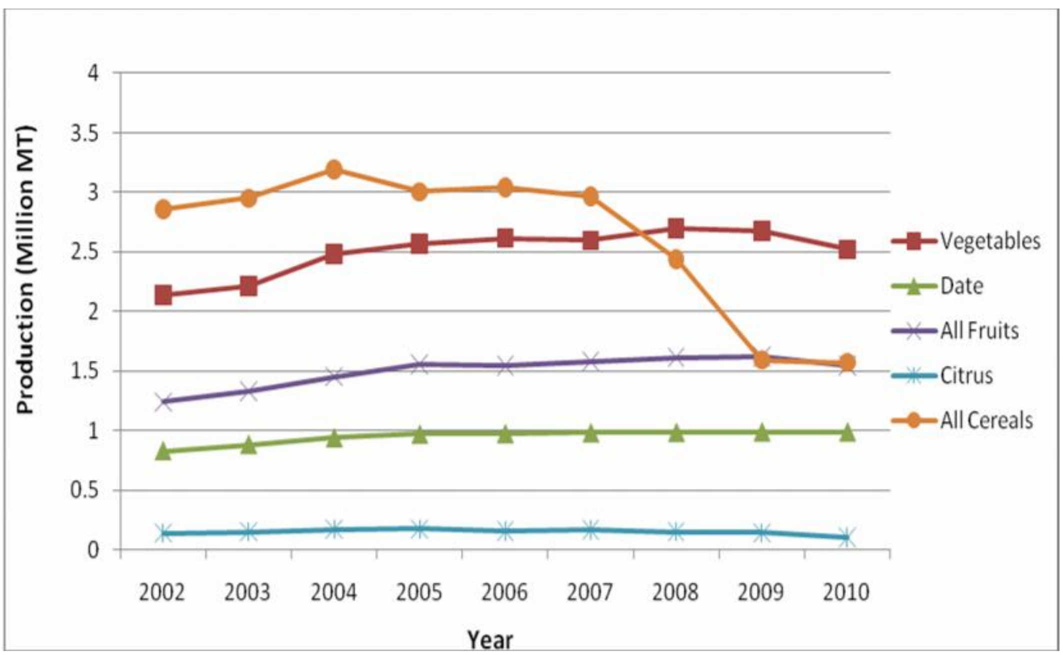


Figure 4: Total production of different crops in Saudi Arabia

The total irrigation water demand has decreased from the peak value of 18.5 billion m^3/year in 1990 to about 15 billion m^3/year in 2010 with an average annual diminishing rate of -1.05%

(World Bank, 2005; MWE, 2012). KSA government is planning to reduce the agricultural water demand on an annual diminishing rate of 3.7% during the period from 2010 to 2014 (MEP, 2010). The proposed project will help in achieving KSA government objectives through presenting new approach to increase irrigation efficiency.

3.0 SOIL WATER CONTENT

Irrigation is applied to compensate the shortage in soil water content. Monitoring soil water content is crucial component for achieving higher irrigation efficiency, optimizing crop quality as well as quantity, and minimizing soil salinity. Understanding vadose zone hydrological processes such as evapotranspiration, surface runoff, and groundwater recharge rate is also very important *(Steelman* et al. *2011).* Several conventional methods to measure soil water content are currently used; such as gravimetric sampling, neutron probe logging, time domain reflectometry (TDR), frequency domain reflectometry (FDR), tensiometers, gamma ray attenuation, capacitive sensors, gypsum block measurement, and pressure plate method. The soil water content depends on many parameters that are spatially and temporally variable such as soil type, vegetation cover, crop type, topography, and precipitation. Looking at all those variable factors, collecting enough measurements for the account of the spatial variations of the vadose zone soil water contents is neither financially nor technically practical. Remote sensing technique can be used to estimate vadose zone water content over very large area but with a very low resolution in the range of 100 meter and typically for the top 5cm of the vadose zone. Additionally, dense crop coverage limits the applicability of the remote sensing for vadose zone applications. On the other hand, Ground Penetrating Radar (GPR) is more promising technique for estimating soil water content at the field scale. This technique has the potential to determine soil water content with vertical resolution comparable to that of conventional pin point methods and with an extended spatial resolution, leading to a better estimation over field size area. Abundant research articles have documented the successful applications of GPR technique soil water content measurement (Chanzy et al., 1996; van Overmeeren et al., 1997; Grote et al., 2003, 2010; Galagedara et al. 2005; Lambot et al.; 2006; Weihermuller, et al. 2007; Brandford 2008; Giroux et al. 2010; Mint et al. 2011).

3.1 GROUND PENETRATING RADAR METHOD

Ground Penetrating Radar technology is based on the transmission and reflection of radio waves in the soil (Chanzy et al., 1996; Dobriyal et al., 2012). The GPR system sends radio waves through the soil *(Reynolds, 1997; Dobriyal et al., 2012)*. The GPR receiver detects the reflected radio waves, where the variation in radio wave velocity shows the electromagnetic properties of the subsurface soil (Du and Rummel, 1994). Radar antennas are manually or mechanically moved over the soil surface simultaneously assessing the subsurface SWC (Reynolds, 1997). The collected data do not need complicated calculations to generate three-dimensional views of the SWC (Do, 2003; USACE, 1995). The GPR is a fast and non-destructive method. It is capable to determine SWC with high vertical resolution comparable to that of conventional pin point methods and with an extended spatial resolution, leading to a better estimation over large areas (Huisman et al., 2001; Al-Shuhail, 2006; Adetunji et al., 2008; Dobriyal et al., 2012). The successful application of GPR technique for the estimation of SWC in the field scale in humid to semi-humid climate and for experimental purposes is well documented (Chanzy et al., 1996; van Overmeeren et al., 1997; Grote et al., 2003 and 2010; Galagedara et al., 2005; Lambot et al., 2006; Weihermuller et al., 2007; Brandford, 2008; Giroux et al., 2010; Mint et al., 2011). The GPR technology has been successfully implemented to determine SWC in humid to semi humid climate for clay to silty clay soil. Its applicability to arid to semiarid climate is not well investigated. Additional studies with a large set of soil textures are needed (Grote et al., 2010) especially for silty sand to sandy soil. The applicability of GPR technology for intensive agriculture fields is not well investigated either. Studies are needed to develop optimum GPR data acquisition and processing schemes for intensive agriculture fields. The potential for real-time efficient irrigation scheduling based on GPR soil water content estimation is hardly investigated in previous works.

This paper underlines and discusses the promising expected results of a two-year research project (submitted by Dr. Abdullatif A. Al-Shuhail & Dr. Omar Ouda, 2012) for funding by the King Abdulaziz City for Science and Technology – Saudi Arabia.

4. PROJECT METHODOLOGY

The project objectives are to assess the applicability and adaptability of the GPR technique to measure SWC in agricultural fields in the Eastern Province of Saudi Arabia, to design and implement various GPR data acquisition and processing schemes in order to identify the optimum scheme for GPR application for SWC in target agricultural areas, and to develop software codes to calculate SWC from processed GPR data and another for real-time efficient irrigation scheduling based on the calculated SWC. To achieve the stated objectives the project team willconduct a comprehensive literature review of recent applications of GPR technology and other vadose zone water content measurement technologies, especially for the GPR technology applicability to arid and semiarid climate will be conducted. A field visits to different farms in the area will be conducted to select the target farms and crop types. The farms will be selected based on a set of criteria including: location; crop type; soil type, topography, and farm sizes. Based on the intensive literature review various GPR data acquisition schemes (1-D, 2-D, or 3-D, monostatic or bistatic.) will be developed and implemented in the field. The GPR data will be processed using various processing workflows. The efficiency and accuracy of the implemented GPR data acquisition and processing schemes will be assessed and calibrated in light of pin-point soil water contents testing results. Two TDR units will be used for simultaneous pin point samplings. At least three soil samples will be collected and tested from each farm for physical and chemical properties including: SWC (based on gravitational method), soil texture, organic contents, salinity, phosphorus, and nitrogen contents. Finally the optimum GPR data acquisition and processing scheme for SWC determination in the studied agricultural fields and similar areas will be selected. A workflow for inverting SWC from processed GPR data starting from available workflows will be developed as a base for software code for SWC inversion from processed GPR measurements. The code will be tested on the GPR data acquired and processed through the optimum schemes. A workflow for real-time irrigation scheduling based on SWC values inverted from GPR measurements and software code for real-time irrigation scheduling based on SWC values inverted from GPR measurements.

5.0 EXPECTED RESULTS AND DISCUSSION

The results and outputs of this project expected to be of high value and benefit to Kingdom of Saudi Arabia and in particular to water sector. The project will contribute to the promotion and supporting the Kingdom economic, social, security, development through localizing and applying an advanced technology in the water conservation area as the following:

- It will be a pioneer project for studying innovative methods for measuring SWC not only for the KSA but for the globe, since the GPR technology applicability to arid-to-semiarid climate and for intensive agricultural field is not well investigated.
- Agriculture is a major user of water resources, developing sustainable management of water in agriculture specific to KSA endogenous dominant environmental conditions is critical to increase agricultural production, ensure water can be shared with other users and maintain the environmental and social benefits of water systems.
- Determine the optimum irrigation strategy and develop an irrigation scheduling to provide a positive impact to KSA agriculture industry. This includes, but not limited to, the following: decrease in pest proliferation, decrease in water use, and decrease in fertilizer use, decrease in energy cost, and decrease in pesticide use.
- A new technology will be transferred and introduced to KSA and in particular to the agricultural sector in Eastern Province aiming for optimizing and scheduling irrigation.
- A great opportunity will be offered for human capacity building. Three graduate students and a technician will be directly involved in various project activities, to learn and improve their capabilities and research skills.
- This project will serve as an end-user oriented project; all objects and activities will be planned and modified to fulfill the demands and needs of target end users and beneficiaries of this research project such as; water resources planning engineers, agriculture engineers, geoscientists, farmers and agricultural companies working in KSA.

6.0 CONCLUSION

The Kingdom of Saudi Arabia faces a serious water shortage problem where the current water demand is three folds the sustainable yields of both conventional and non-conventional water resources. Agriculture sector demand is about 85% of total water demand in the Kingdom. Apply massive measures to bridge the gap between water supply and demand is no more an option in the Kingdom, it is a must. In this direction, KSA is planning to decrease the agriculture water demand by 3.7% annually through increasing water irrigation efficiency and phasing out uneconomical crops such as cereal. This paper presents a research project towards increasing irrigation efficiency in Saudi Arabia. The project will review the applicability of GPR technology to estimate fields SWC in the Eastern Province of Saudi Arabia. A new irrigation scheduling methods based on tested and modified GPR technique will be introduced and applied to common agricultural crops in the target area. This technology transferred technique will play major role in improving the irrigation efficiency and minimizing the agricultural water consumption in the Kingdom. The project has high scientific merits. The literature review showed that the GPR technology applicability for intensive agriculture fields is not well investigated especially under silty sand to sandy soil conditions. The applicability of GPR technology to arid to semiarid climate has never been studied before. The potential for real-time efficient irrigation scheduling based on GPR soil water content estimation is hardly investigated in previous works. This reality shows the global scientific value of the proposed project.

This project will be implemented as an end-user oriented project; all objects and activities will be planned and modified to fulfill the demands and needs of target end users and beneficiaries of this research project such as; water resources planning engineers, agriculture engineers, geoscientists, farmers and agricultural companies working in KSA.

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