. 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...

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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 16^{o} 22' and 32^{o} 14' North latitudes and 34^{o} 29' and 55^{o} 40' East longitudes, in an arid to semi-arid climate. The country has a low average annual precipitation ranges from 80 mm to 140 mm, with limited natural water resources. There are no lakes, rivers, or streams; consequently, the country is increasingly dependent on fossil groundwater resources, which receive very limited natural recharge, for intensive agriculture and mainly for irrigation that consumes about 85% of total water supply. This paper presents a 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 the 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, GPR, Soil Water Content, Crop Water Requirements Irrigation

1.0 INTRODUCTION

The Kingdom of Saudi Arabia (KSA), like many other countries in the Middle East, has a distinct and serious deficit in water. KSA lies 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), and it has diverse geography, the eastern part is rocky or sandy lowland up to the Arabian Gulf, in the western part, the land rises from the sea level to a peninsula-long mountain range called Jabal Al-Heijaz, beyond which lies the plateau of Nejed; whereas, the south-western region of KSA contains mountains with a height reach up to 3,000 m above the main sea level. Empty Quarter covers the southern part of the country (SGS, 2012). The Saudi population has 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). This 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% in 2000 (SCDSI, 2010).

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

1.1 Water Resources

The KSA is 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 a source for potable water supply. The current desalination plant capacity is about 1 billion Cubic meters per year. (SWCC, 2010), which supply about 37% of municipal water demands. The

KSA government supports the reuse of treated wastewater for agricultural and landscape irrigation, hence several 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 from both conventional and non-conventional resources in KSA are shown in **Table 1**, which summarized water resources sustainable yields and total water demand per sector in the year 2010. The table shows also the 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

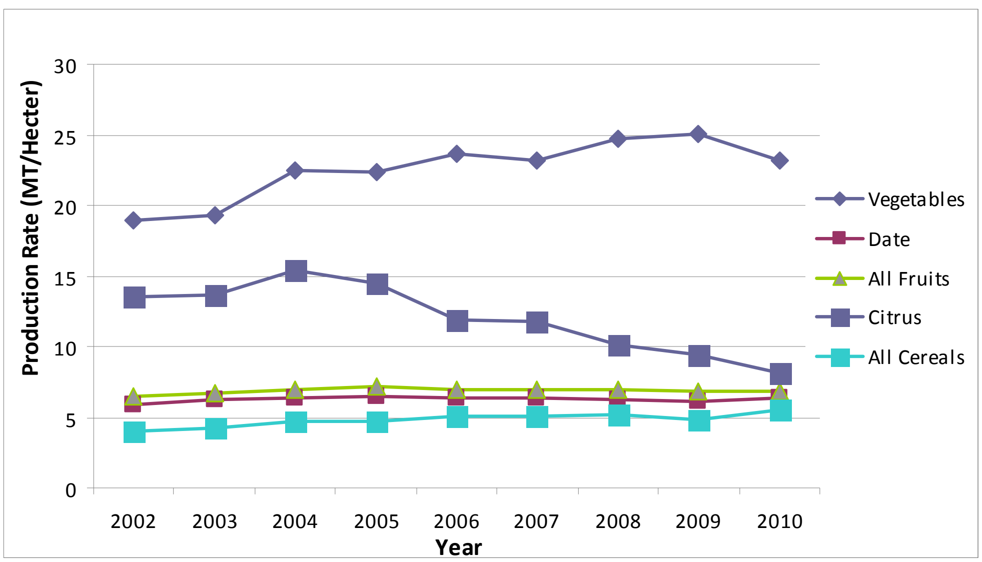
2.0 AGRICULTURE SECTOR IN SAUDI ARABIA

Agriculture is considered a main sector in KSA economy, 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 shown in **Table 3** (MOA, 2011), also the various crops productivity per unit area is shown in **Figure 2**. Agriculture sector is the main water consumer; about 80% of all water used by mankind is withdrawn towards irrigation usage, where 74 % is evaporated by crops (Sundquist, 2007). Protected irrigated agriculture is solely used for crop productions in KSA; however, agricultural water (mainly for irrigation) consume about 85% of the total water supplies from scarce groundwater resources as shown in **Table 1** (Al Zahrani 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%

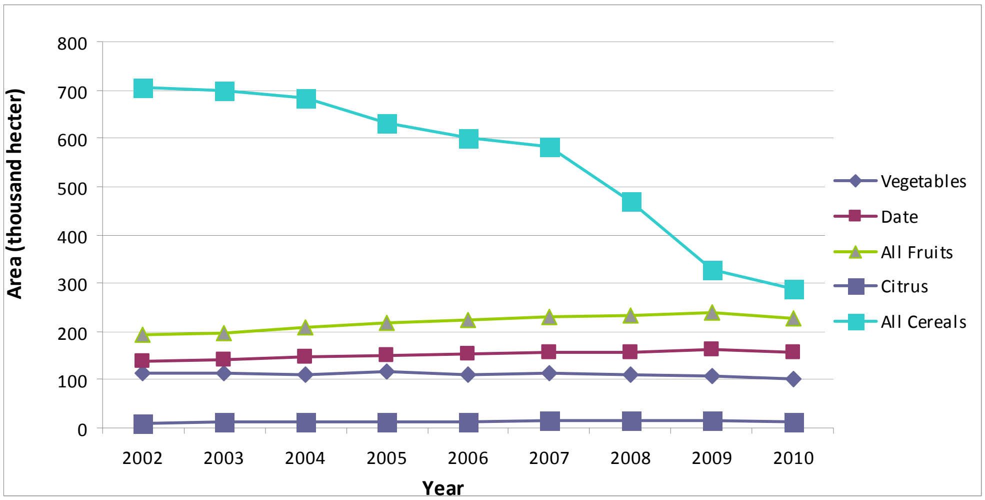
Source : (MOA , 2011)



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

The agricultural sector has been intensively supported during the period from 1974 to 2006 by Saudi government. The support program aimed to improve the livelihood and prosperity in rural communities. This 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 increase in irrigated agricultural area has resulted in the depletion of groundwater resources. KSA government has decided to re-structure the agricultural sector and reconsider the governmental support for cultivation of the high water demanding crops, such as wheat (Al-

Zahrani and Elhag, 2003; Al-Zahrani, 2010; Al-Zahrani and Baig, 2011). Accordingly, new programs and policies were enacted, headed toward maximizing the 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 policies and programs 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 cultivation. **Figure 3** shows the drastic decrease in total area cultivated with cereal crops within the last decade; as well as, **Figure 4** shows the substantial decrease in cereal crops production; on the contrary, the vegetable corps production is growing up.



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

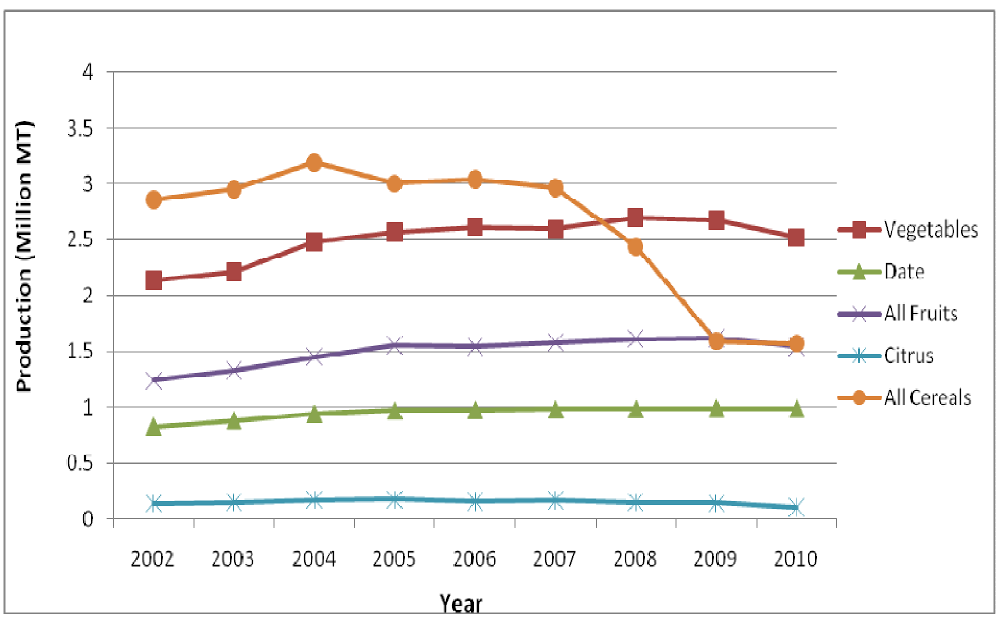


Figure 4: Total production of different crops in Saudi Arabia

As a result of implementing the new revised Saudi water policies, the total demand for irrigation water has been 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). Currently, the KSA government is planning to reduce the agricultural water usage on an annual diminishing rate of 3.7% during the period from 2010 to 2014 (MEP, 2010). The proposed project will help in achieving the KSA government objectives through presenting new approach and implementing a new technology transfer to increase irrigation efficiency.

3.0 SOIL WATER CONTENT

Irrigation is mainly applied to compensate the shortage in soil water content. In modern agricultural practices, monitoring the soil water content (SWC) is a crucial component for achieving high water use efficiency, minimizing water losses by inappropriate irrigation technique, optimizing crop quality and productivity. In addition to it is positive environmental impact through minimizing soil salinity. Beside soil water content, understanding of others vadose zone hydrological processes, such as evapotranspiration, surface runoff, and groundwater recharge rate is considered very important (Steelman et al., 2011). Several conventional methods to measure SWC 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. SWC depends on many parameters that are spatially and temporally variable such as soil type, vegetation cover, crop type, topography, and precipitation. Taking into account all these varialble factors, in collecting enough measurements for the account of the spatial variations of the vadose zone soil water contents is neither financially nor technically practical. The remote sensing technique can be used to estimate vadose zone water content over very large area but with very low resolution in the range of 100 meters 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. Whereas, using Ground Penetrating Radar (GPR) is more promising for estimating SWC at field scale. This technique has high 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 techniques for SWC measurement (Chanzy et al., 1996; Overmeeren et al., 1997; Grote et al., 2003; Grote et al., 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 Technology

GPR 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 is composed of the transmitter antenna, which sends radio waves through the soil (Reynolds, 1997; Dobriyal et al., 2012), and the receiver antenna which 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 does not require complicated calculations to generate three-dimensional views of the SWC (Do, 2003; USACE, 1995). The GPR is a fast and non-destructive soil investigating 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 estimate over larger areas (Huisman et al., 2001; Al-Shuhail, 2006; Adetunji et al., 2008; Dobriyal et al., 2012). The application of GPR techniques 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), and it has been successfully implemented in humid to semi humid climate for clay to silty clay soil. On the contrary, its applicability under arid to semiarid climate is not well investigated. Additional studies with a large set of soil textures are required (Grote et al., 2010) especially for silty sand to sandy soil. The applicability of GPR technology for intensive agriculture fields is not totally well investigated either. Further 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 Al-Shuhail & 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 techniques to measure SWC in arid to semiarid agricultural fields in the Eastern Province of Saudi Arabia, by 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 finaly 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 will conduct 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. Several field visits to different farms in the area will be conducted to select the target farms and crop types. the selection process will be based upon 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 be 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 according to pinpoint soil water contents testing results. Two TDR units will be used for simultaneous pin point samplings. At least three soil samples per farm will be collected and tested 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 measurement 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 a high value and benefit to Kingdom of Saudi Arabia and in particular to water sector. The project will contribute directly to promote and support the Kingdom economic, social, security, and sustainable development through localizing and applying an advanced technology in water management and conservation as the following:

- It will be a pioneer project for studying innovative methods for measuring SWC for both dominant KSA conditions and 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 consumer of water resources; therefore, developing a sustainable water management methods for to the KSA agriculture, and the endogenous dominant environmental conditions is critical to increase agricultural productivity, ensure more amount of water can be shared with other users; as well as, 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 pest infestation, 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, agricultural 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. Applying massive measures to bridge the gap between water supply and demand is not more an option in the Kingdom, it is a must. Therefore, 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 aimed 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 techniques will be introduced and applied to common agricultural crops in the target area. This technology transferred technique will play a major role in improving the irrigation efficiency and minimizing the agricultural water consumption and losses 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 soils. Furthermore, the applicability of GPR technology to arid to semiarid climate has never been studied yet. The potential for real-time efficient irrigation scheduling based on GPR soil water content measurement is hardly investigated in previous works. This fact highlight 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, agricultural engineers, geoscientists, farmers and agricultural companies working in KSA.

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