Kuwait J. Sci. **42 (2)** pp. 250-260, 2015

Assessment of soil moisture through field measurements and AMSR-E remote sensing data analysis over Kuwait desert

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ABSTRACT

Field measurements of volumetric soil moisture were conducted 24 times between April 2011 and September 2013 in KISR (Kuwait Institute of Scientific Research) protected site (Sulaibiya) at 16 specific locations over an area of 50 sq. km. The soil moisture varied from 0.11 m^3 m^{-3} in the wet season to less than 0.01 m^3 m^{-3} in the dry season. Another study was conducted in this paper using remote sensing data of soil moisture (NASA product) from the Advanced Microwave Scanning Radiometer (AMSR-E) on the Earth Observing System (EOS) Aqua satellite. AMSR-E instrument provides Volumetric Soil Moisture (VSM), brightness temperatures and Vegetation Water Content (VWC) during nine years from 2003 to 2011 all over the land mass of the Earth. The AMSR-E derived monthly averaged soil moisture over the Kuwait study area was found to vary between 0.08 m^3 m^{-3} in the wet season to less than 0.06 m^3 m^{-3} in the dry season. There are some indications of general seasonal trends of soil moisture variations. More analysis and interpretation of the results are presented in this paper.

Keywords: AMSR-E; satellite remote sensing; volumetric soil moisture.

INTRODUCTION

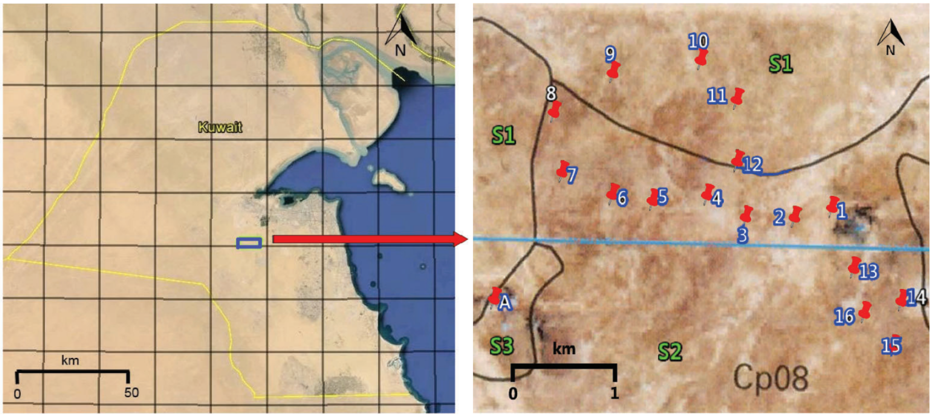
Soil moisture parameter is considered important for several applications. These applications include climate change, water resources, dust storms, human health, defense, and renewable energy (Entekhabi *et al*., 2014). In general few studies have been conducted in arid regions to measure soil moisture from both field campaigns and satellite remote sensing (Diouf & Lambin, 2001; Al Jassar & Rao, 2010 ; Kuolin *et al*., 2012).Variations of soil moisture in arid regions occur due to both environmental and structural causes. Environmental causes such as temperature, humidity and precipitation have an impact on soil moisture and are based on temporal changes due to season. The structural causes of soil moisture variation are due to spatial factors such as topography, soil type and texture. Extensive field work was conducted at the Sulaibiya protected site in order to quantify soil moisture variation spatially and temporally.

The climate of Kuwait is arid with hot to very hot dry summers and cool to mild rainy winters (Halwagy & Halwagy, 1974). There are generally four seasons in Kuwait: winter, spring, summer and autumn. Sub-seasons are periods of distinct weather, such as frequent dust storms, thunderstorms, or persistent winds. Winter, from December to mid-February, is the wettest and coldest season and is characterized by north-westerly winds. Spring begins in mid-February and generally lasts through May. During this season, southeasterly winds (Suhaili) bring warm to hot weather, and the Sarrayat (local thunderstorm) is common. Summer starts towards the end of May and lasts to the beginning of November. During June and July, north-westerly winds may develop, generating extensive dust storms. Autumn occurs during the month of November and is characterized by winds switching from the south-east to the north-west. Clouds with some rain are common. The maximum temperature can be as high as 50°C, while a minimum of – 4°C was recorded at Kuwait International Airport on 20 January 1964 (Halwagy & Halwagy, 1974). Mean annual temperatures are 37°C for July and 14°C for January. The mean annual rainfall average is around 120mm and can reach up to 200mm.

Previous work on the field measurements of soil moisture over Kuwait desert were conducted in years 2000, and 2005 (Al Jassar *et al*., 2006; Al Jassar & Rao, 2010). In this paper we describe the field work conducted between April 2011 and September 2013 at the Sulaibiya protected site along with an assessment of AMSR-E soil moisture data. Although, KISR site with an area of 50 sq. km is much smaller in comparison to the averaged AMSR-E grids over Kuwait, a general indication of the seasonal trend of soil moisture may be obtained.

FIELD WORK

Field work was conducted in KISR protected site located at Sulaibiya. It extends 10 km in West-East direction and 4 km in South-North directions centered at Latitude 29.2° and Longitude 47.7°. Soil samples were collected from the numbered locations shown in Figure 1.



Legend	
S1	Typic Torripsamments
S2	Calcic Petrocalcids
S3	Typic Petrocalcids

Fig. 1. Soil moisture survey locations (KISR Site). The AMSR-E 25-km grid is superimposed on the left image. The soil classification map is overlaid on the right image.

Fig. 2. Collecting soil samples

Fig. 3. KISR field

Photos of the field and soil moisture sample collection are shown in Figure 2 and Figure 3. The major soil types in this area are Typic Torripsamments, Calcic Petrocalcids and Typic Petrocalcids. A map of the soil types in the KISR protected site is shown in Figure 1. The objective of the field experiments is to determine temporal and spatial variations of soil moisture across the KISR protected site using thermo-gravimetric techniques.

Estimation of top and bottom soil moisture

Several field trips have been conducted over the KISR protected area (Sulaibiya), to collect soil samples from different locations (Figure 1). The soil moisture has been measured at two depths – 0 to 10 cm and 10 to 20 cm, using the thermo-gravimetric method in which samples were weighed first and then dried in an oven at 105°C for 48 hours. The average top soil moisture (0-10 cm) at the KISR recorded on 7th, April 2011 was 0.032 m^3 m^{-3} with a standard deviation of spatial variation of 0.0152 m^3 m^{-3}. The average bottom soil moisture (10-20cm) at the KISR site recorded on 7th, April 2011 was 0.0269 m^3 m^{-3} with a standard deviation of spatial variation of 0.0158 m^3 m^{-3}. Apart from this, temporal variation of soil moisture at the KISR site was also studied. Figure 4 shows the average top volumetric soil moisture for all the 16 locations, during the period from December 2012 to September 2013.

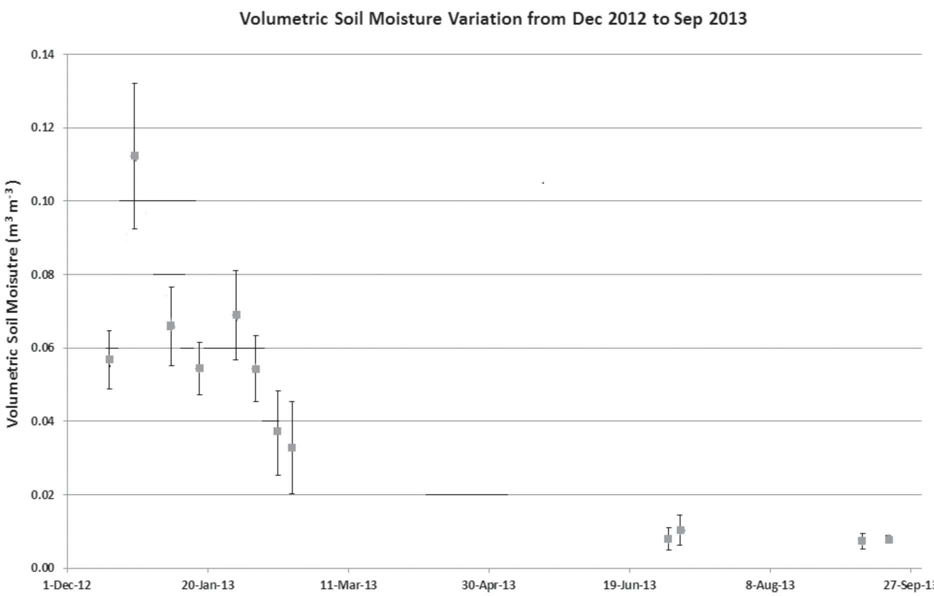


Fig. 4. Temporal and spatial variation of VSM at KISR site (Dec 2012 to Sep 2013). Each date represents VSM of 16 locations

The vertical bars in Figure 4 represent the spatial variation of soil moisture of the 16 locations. It can be seen that the spatial variation is generally higher during the wet season (December-February) and low values in the dry season (June- September). The spatial variation reaches a maximum of 0.02 m^3 m^{-3} in December, averages 0.011 m^3 m^{-3} in February and decreases down to 0.009 m^3 m^{-3} in September. This can be attributed to the fact that there is greater variation of soil moisture spatially during the wet season (Nov-Feb) due to precipitation, whereas during the dry season the spatial distribution of moisture is relatively steady.

Measurement of sub surface soil moisture down to a depth of 1.2 m

Two steel pipes of length 1.2 m were fabricated. They were used to obtain core of soil samples up to a depth of 1.2 m. For this analysis, two points within a few feet of each other inside the KISR site are selected at the location labeled A in Figure 1 with co-ordinates 29.169920°N, 47.690105°E.

The pipes have been hammered down to a depth of 1.2 m and it was pulled out to take out the samples at different depths. Figure 5 shows the different depths at which the sample has been taken and its corresponding volumetric soil moisture at that depth, dated 22nd Jan 2012. It is evident from the graph that soil moisture decreases first and then increases with depth. However, except for the deepest point, the two profiles follow a generally similar trend.

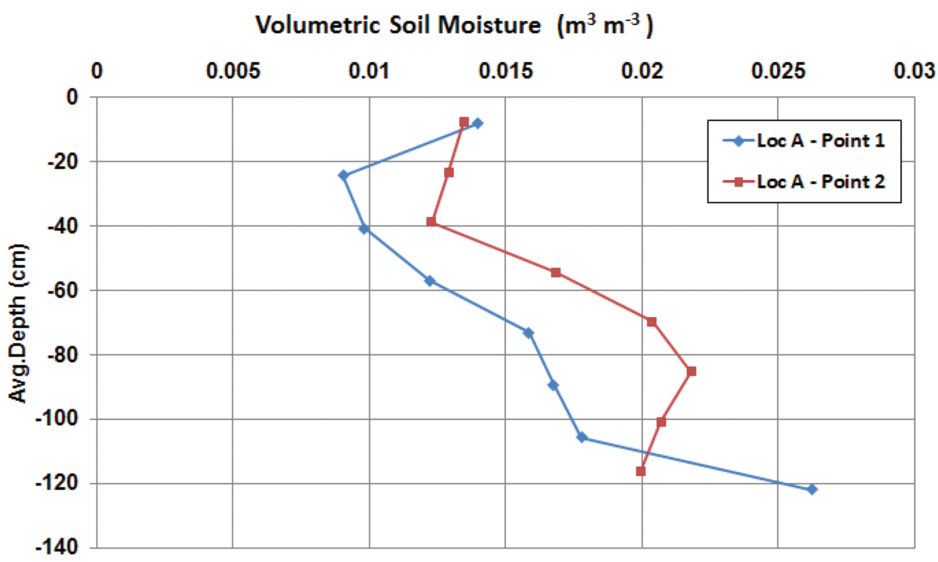


Fig. 5. Volumetric sub-surface soil moisture (22 Jan 2012)

AMSR-E L3 DATA DESCRIPTION

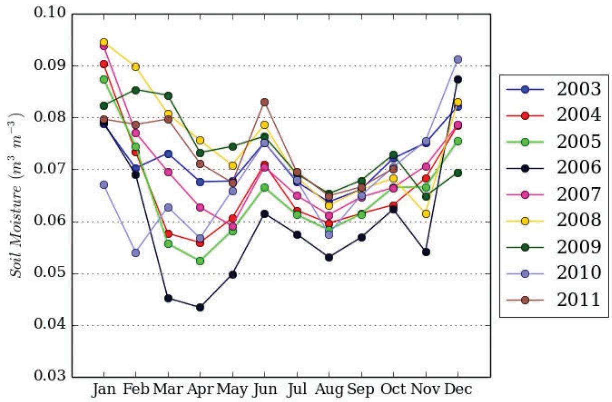
The AMSR-E Level 3 dataset contains daily measurements of surface VSM and vegetation/roughness water content, interpretive information, as well as brightness temperatures. It also includes ancillary data like time, geo-location, and quality assessment. Input brightness temperature data, corresponding to 56 km mean spatial resolution, are resampled to a global cylindrical 25 km Equal-Area Scalable Earth Grid (EASE-Grid) cell spacing (Njoku, 2004). The accuracy of the AMSR-E soil moisture product is 0.06 m^3 m^{-3}. Data are stored in HDF-EOS format, and are available from 19 June 2002 to 2011 via FTP (NSIDC, 2013). Daily level-3 ascending pass (1.30 pm local time) and descending pass (1.30 am local time) data were obtained over the study region for the period from 2003 to 2011. Monthly averages were computed for the study region pixels after avoiding dates with null data.

AMSR-E VOLUMETRIC SOIL MOISTURE DATA

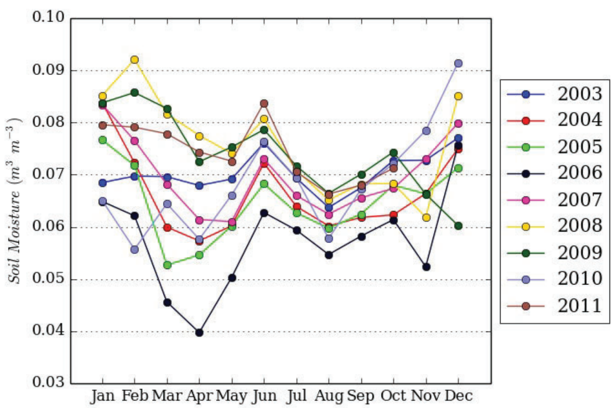
A simple model for the retrieval of soil moisture over Kuwait from Nimbus-7 SMMR brightness temperatures data at two bands (6.6 GHz H polarization and 36 GHz V polarization) was developed previously (Al Jassar & Rao, 2006). However, due to the presence of RFI (Radio Frequency Interference) in the 6.6 GHz band, we have not used this model and have opted to use AMSR-E VSM data for the current study. At launch AMSR-E soil moisture retrieval algorithm used by NASA was based on iterative inversion of the forward model using 6.9, 10.7 and 18.7 GHz V & H (6 channels) to estimate 3 parameters (VSM, VWC and LST) (Njoku & Li, 1999; Njoku *et al*., 2003). A post-launch detection of RFI in the 6.9 GHz channels led to the development of a new algorithm using the 10.7 GHz polarization index as the primary measurement observable. This algorithm has been used for main duration of AMSR-E data processing (Njoku & Chan, 2006). The AMSR-E soil moisture data used for analysis in the current paper is based on this algorithm. However, 10.7 GHz polarization ratio was found to lack sensitivity to the soil moisture signal and the algorithm was biased in many regions. A variety of alternate algorithms for AMSR-E soil moisture retrieval have been proposed and published (Mladenova *et al*., 2014).

ANALYSIS OF SOIL MOISTURE FROM AMSR-E OVER KUWAIT DESERT

The Kuwait study region for the AMSR-E analysis lies between latitude 29.14 °N and 29.61°N and longitudes 46.96 °E and 47.52 °E. Figure 6 shows the results for Kuwait region (a) VSM distribution ascending pass (1.30 pm local time) (b) VSM distribution descending pass for the years 2003-2011 (1.30 am local time). Generally, Kuwait receives scant rain during the months November-February. Subsequently, the soil loses moisture during the rest of the period. However, Figure 6(a) and Figure 6(b) show an increase of VSM of about 0.009 m^3 m^{-3} in the month of June consistently for all the years.



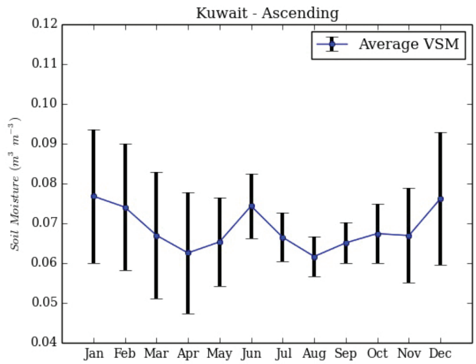
(a)



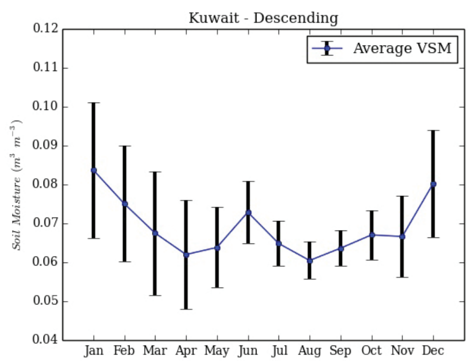
(b)

Fig. 6. AMSR-E VSM from 2003 to 2011. (a) VSM distribution - ascending pass (1.30 pm local time) (b) VSM distribution – descending pass (1.30 am local time)

The same is reflected in Figure 7(a) and Figure 7(b), which is an average of all the years. However, this trend is within the error of 0.06 m^3 m^{-3} in the AMSR-E soil moisture. This needs to be investigated further. The standard deviation of VSM ranges from 0.004 m^3 m^{-3} in September to 0.017 m^3 m^{-3} in January. There gradual trend of decreasing standard deviation during the dry season and increase during the wet season. This is comparable to results obtained over the KISR site, where a decreasing trend of standard deviation was also seen.



(a)



(b)

Fig. 7. Monthly average VSM (a) Ascending pass (1.30 pm local time)
(b) Average VSM distribution from 2003-2011(1.30 am local time)

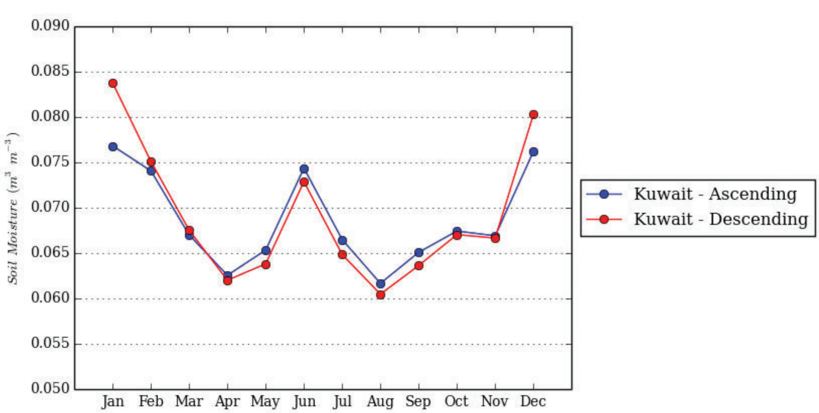


Fig. 8. Monthly average VSM trend – Both ascending and descending passes from 2003 to 2011.

Figure 8 shows the combined graph of ascending and descending pass monthly averaged VSM. As expected, the VSM of the descending pass is higher for the months from December to March. The months from April to November exhibit higher ascending pass VSM than descending. Although this is unexpected, the differences are small and it is within the VSM retrieval accuracy of 0.06 m^3 m^{-3}.

DISCUSSION OF THE RESULTS AND CONCLUSIONS

Field soil moisture measurements in the KISR protected site indicate a seasonal trend in the soil moisture measurements. The highest soil moisture is seen in December during the wet season (0.11 m^3 m^{-3}) followed by a gradual reducing trend with September exhibiting the lowest soil moisture of 0.01 m^3 m^{-3}. Monthly average VSM of Kuwait study region retrieved from AMSR-E data from 2003 to 2011 also shows the seasonal effect in the sense, during December/January, the moisture is high (0.08 m^3 m^{-3} in January) during the wet season and low (0.06 m^3 m^{-3} in August) during the dry season. AMSR-E soil moisture data of the Kuwait study region exhibits higher standard deviation during the wet season and gradual decrease in standard deviation during the summer. A similar trend is also seen from a study of the KISR soil moisture data, where a larger spatial variation is seen during the wet season and lower spatial variation during the dry season. As explained earlier, this can be attributed to non-uniform precipitation, variations of soil type and macroscopic topography, which leads to spatial variation of soil moisture. Comparison of different years VSM data of Kuwait study region shows a gradual variation. The VSM increases by 0.009 m^3 m^{-3} in the month of June. This is a slight increase of soil moisture and it is within the retrieval error of 0.06 m^3 m^{-3} of AMSR-E VSM data. Further study must be done on the evaluation and assessment of VSM data from AMSR-E.

ACKNOWLEDGEMENTS

The authors are thankful to Kuwait Foundation for the Advancement of Science (KFAS) for funding this work under grant number 2010440103. Also, the authors are grateful to Kuwait University under whose aegis the work was completed. We are grateful to KISR for providing access to the KISR test site in Sulaibiya, throughout the duration of the project. We would like to thank Dr. Sameera Sayed Omar (KISR) for providing soil maps. Also, we would like to thank Mr. Waleed Roy for the logistical support while working at the KISR test site. The authors appreciate the assistance extended by Mr. Nevil Jose and Mr. Mohamed Shuaib Ansari.

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Submitted **:** 02/04/2014

Revised **:** 14/08/2014

Accepted **:** 25/09/2014

تقييم رطوبة التربة من خلال القياسات الحقلية وتحليل بيانات الاستشعار عن بعد (AMSR-E) لصحراء الكويت

*** هالة خالد الجسار ، كوتاراو**

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خلاصة

أجريت القياسات الميدانية لرطوبة التربة 24 مرة ما بين أبريل 2011 وسبتمبر 2013 في محمةي الصليبية التابعة لمعهد الكويت للأبحاث العلمية، وذلك في 16 موقع على مساحة 50 كيلومتر مربع. ومن القياسات الميدانية وجدنا النسبة الحجمي لرطوبة التربة تختلف من 0.11 م3/ م3 في موسم الأمطار إلى أقل من 0.01 م3/م3 في موسم الجفاف. وأجرينا دراسة أخرى في هذه الورقة، وذلك باستخدام بيانات لجهاز الاستشعار (AMSR-E) المحمول على نظام مراقبة الأرض (EOS) والمسمى بالقمر الصناعي اكوا (Aqua). ولقد رصد جهاز (AMSR-E) النسبة الحجمية لرطوبة التربة والحرارة الطيفية والمحتوى المائي للنباتات خلال تسع سنوات من 2003 إلى 2011 للكتلة اليابسة من الكرة الأرضية. ومن هذه البيانات وجدنا أن المتوسط الشهري لنسبة الرطوبة تتفاوت بين 0.08م3/م3 في موسم الأمطار إلى 0.06 م3/م3 في موسم الجفاف. وتظهر هذه الدراسة على وجود تغيرات موسمية لنسبة الرطوبة في التربة. ونستعرض في هذه الورقة المزيد من التحليل والتفسير لهذه النتائج.