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| Research Article

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Remote Sensing and GIS Soil Moisture Index Evaluation for Iraqi Land Management

Maha Adnan Meteab*[1]
[1]Department of Architecture and Construction Engineering, Technical Engineering College of Kirkuk, Northern Technical University, Kirkuk, 36001, Iraq
* Correspondence: mahaadnan3@ntu.edu.iq

Abstract: Soil moisture is important for appraising land and water resources, particularly in arid and semi-arid countries like Iraq where climate unpredictability and water shortages continue to threaten sustainability. This research evaluates the Soil Moisture Index (SMI) using remotely sensed surface soil moisture data and Geographic Information Systems (GIS) in Iraq from 2016 to 2020 to improve sustainable land management. AMSR2/GCOM-W1 daily surface soil moisture content was processed and evaluated for a variety of observation sites around the nation with different climatic circumstances. The Soil Moisture Index (SMI) was created and confirmed 17 using a normalized min–max technique to classify soil moisture levels from Very Dry to Very Wet and consistent geographically and temporally. Results show significant spatio-temporal heterogeneity in SM dynamics, with Very Dry and Dry conditions dominating 2016 and 2018, indicating widespread SM stress and high drought susceptibility, while Moderate to Moist SMI classes indicate episodic hydrological recovery in 2020. However, the recurrence of drier and Very Dry conditions at many sites throughout this research reveals persistent soil moisture deficiencies throughout Iraq.

Keywords: GIS, SMI, Soil Type, Sustainability, Iraq

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INTRODUCTION

Soil moisture is one of the important hydrologic variables that play a decisive role in the global water cycle, albeit with small storage volume [1]. Accurate estimation of soil moisture is critical to agricultural drought monitoring, vegetation growth and water resources management [2]. Contemporary climate change is causing severe weather that can be more extreme [3–5], posing substantial threats to agriculture with increased flood and drought risk [6]. Long-lasting and severe droughts have occurred in multiple areas world-wide [7–9], causing significant socioeconomic damage, particularly during the agriculture growing period. Therefore, accurately monitoring the water level is necessary to estimate water needs and crop drought stress and provide early warning of agricultural drought to prevent a decline in crop yield. Soil moisture is an important indicator of subsurface water content and can be correlated with agricultural drought conditions using either observations or model simulations.

Land degradation and climate variability are increasingly becoming challenges to sustainable land management in arid and semi-arid areas [10]. Soil water is central in the control of land-atmosphere interactions, plant output, hydrology and resilience of an ecosystem [11]. Soil moisture being a major part of the water cycle on earth has a significant effect on agricultural growth, evapotranspiration, infiltration, and runoff generation, and thus is a crucial indicator to agricultural sustainability and environmental management aspect [12]. In countries like Iraq, where the climatic conditions are characterized by low rain, high rates of evapotranspiration, and frequent cases of droughts, dynamism of soil moisture is important in the sustainability of land and water resources in the long term. Iraq is typified by various physiographic and climatic features which include slightly humid mountains in the north to arid and hyper arid terrain in the central and southern regions respectively.

During the past decades, there have been growing pressure on land resources in the country as a result of population increase, agricultural activities, mismanagement of water and climate change [13]. Reduced flowing rivers, changes in the distribution of precipitation, and increased temperatures have also added to the shortages of soil moisture, which have contributed to land degradation, low agricultural output, and drought susceptibility [14]. As a result, there is an increased demand of reliable, spatially explicit tools that can be used to monitor the soil moisture conditions across large spatial and long periods to help in implementing sustainable land management strategies [15].

Conventional soil moisture observation is based on at-point measurements [16], which are precise at the point scale but are not dense, expensive, and can be inadequate to measure spatial variations at regional or national scales [17]. In Iraq, ground-based observations of long-term soil moisture are especially scarce which limits the overall evaluation of soil water [18]. Remote sensing has also become a viable alternative to large scale soil moisture monitoring due to the provision of consistent, repeatable, and spatially continuous measurements. Passive microwave remote sensing, especially, has been shown to be useful in estimating surface soil moisture since the method is sensitive to soil dielectric properties, and the method is able to work in most weather conditions [19].

One of the most popular indices that are used to measure the conditions of soil water is the SMI, especially in drought and agricultural researches [20]. The SMI converts absolute soil moisture into a dimensionless index indicating extreme values of dry and wet soils by normalizing the values of soil moisture under specified dry and wet conditions of reference [21]. This normalization can be used to compare spatial and temporal data and place soil moisture conditions in meaningful categories like Very Dry, Dry, Moderate, Moist and Very Wet. These classes give a ready-to-use model to determine the availability of soil water and determine the regions that are stressed by moisture shortage [22].

This study aim to assess the Soil Moisture Index (SMI) of an extent area in Iraq using remotely sensed surface soil moisture data merged with Geographic Information Systems (GIS) for sustainable land management during the years 2016–2020. In particular, the study aims to extract SMI values from AMSR2/GCOM-W1 satellite observations using a normalized min-max approach; arrange soil moisture conditions into standardized qualitative classes; and investigate the areal and temporal patterns of (soil) moisture over representative sites across Pakistan. Along with looking towards interannual variations in soil water availability and also towards dryland areas with consistent moisture stress versus episodic recovery, the study aims to assess the utility and applicability of GIS-based SMI analysis as an effective, scalable and cost-effective method for drought assessment, agricultural planning as well as water resource management in data-poor arid semi-arid regions like Iraq.

METHOD

The methodological framework of this research was aimed to measure the soil moisture conditions and the effects of these conditions on sustainable land management in Iraq with the help of a GIS-based Soil Moisture Index (SMI).

Study Area

The study area is Iraq. The topographic map of study area prepared using GIS data source and GIS mapping tool. Figure 1 represents the topographic map of Iraq.

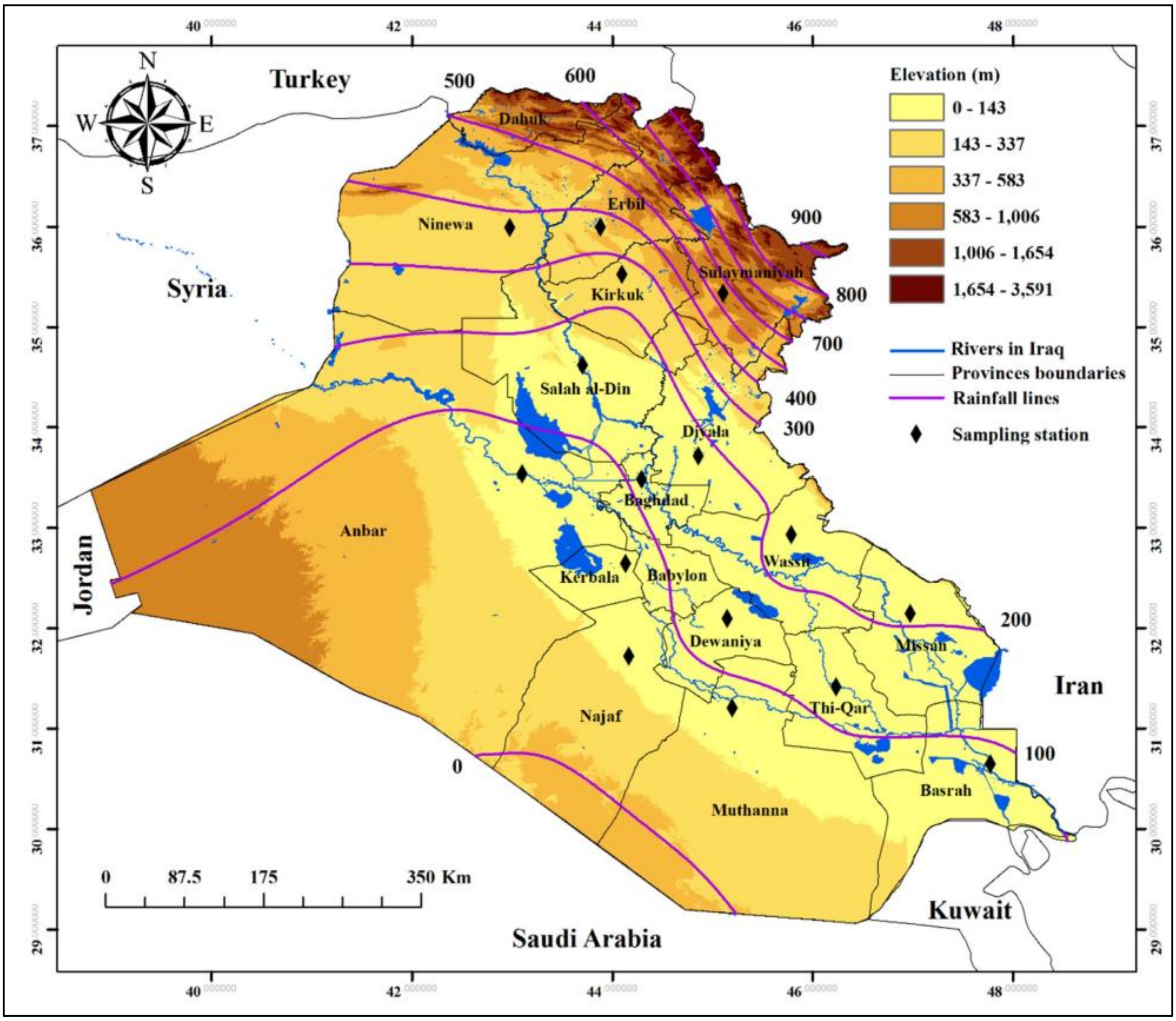

Figure 1. The topographic map of Iraq.

Remotely Sensed Data Source

The data on the surface soil moisture came out of the Advanced Microwave Scanning Radiometer 2 (AMSR2) on the Global Change Observation Mission -Water (GCOM-W1) satellite. In particular, this study employed the product of Surface Soil Moisture C1-band (Day, Daily). The data set offers near-surface estimations of soil moisture daily based on passive microwave measurements and are ideal to be used in monitoring regions because of their sensitivity to water content in the soil and the fact that they can penetrate clouds. The AMSR2 soil moisture product is a volumetric surface soil moisture condition and has found extensive use in drought monitoring, hydrological and land surface analysis, especially in data deficient areas like the Middle East. The chosen dataset guarantees the comparison of the time and space of various years.

Data Processing and GIS Mapping

The obtained remotely sensed soil moisture data were calculated and analyzed in a Geographic Information System (GIS). The processes involved in the preprocessing involved spatial crosslinking, reprojection to a common coordinate reference system, and extraction of soil moisture values of the chosen observation points scattered throughout Iraq. The points were selected to depict different conditions of the environment and land surface. The daily AMSR2 surface soil moisture layers were used to extract soil moisture values in each of the 7 years chosen (2016, 2018, and 2020). These represents 10 years SMI differences in the study area. The values extracted were put into structured database to enable them to compare the values in time and calculate indices. The spatial data were handled with the use of GIS tools that have attributes information attached to them and further index analysis is supported. Figure 2 represents selected points of soil moisture data.

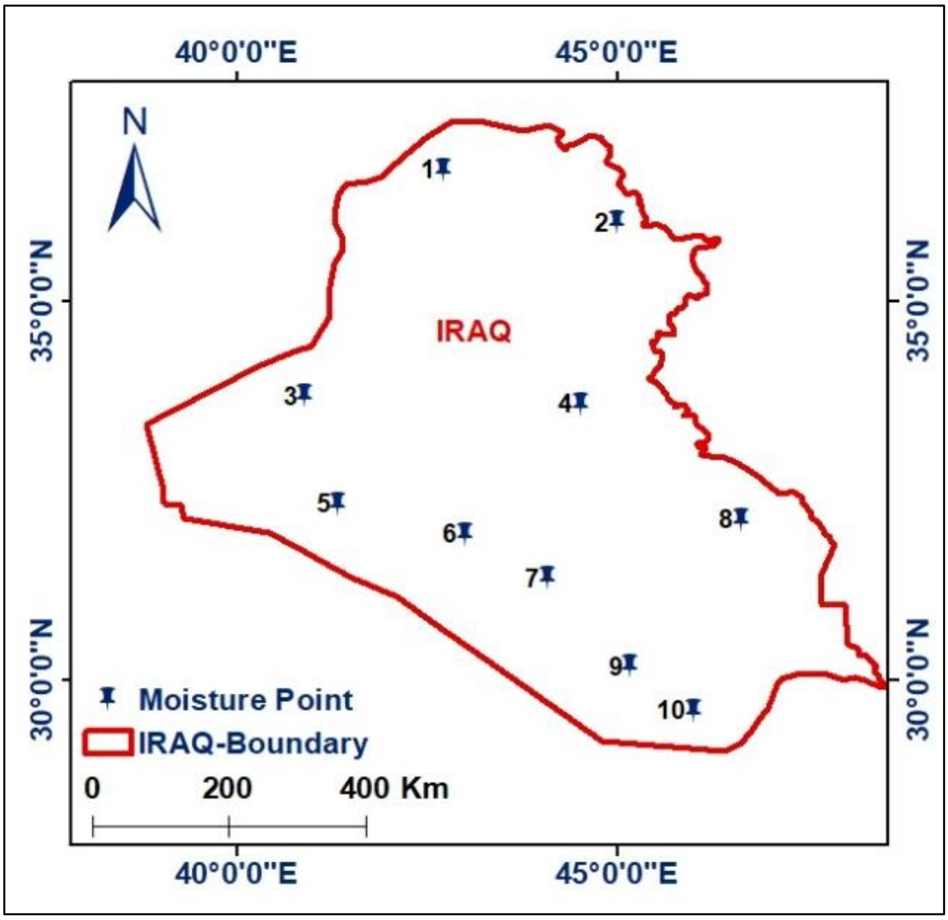

Figure 2. Selected points of soil moisture data in Iraq.

SMI Calculation and Evaluation

The computation of SMI is founded on the fact that high crop yields are linked to high moisture content in the soil. To calculate the SMI, a normalized min max method was selected so that the result can be used to define the soil moisture condition as Very Dry, Dry, Moderate, Moist, and Very Wet, based on Table 1 which represents SMI Standards. The equation used to determine the SMI was the following:

$$SMI = \frac{\theta - \theta min}{\theta max - \theta min} \quad (1)$$

where, θ, is soil moisture. While, θmin, is minimom value of soil moisture, and θmax, is the maximum value which were fixed at 5 and 45 per cent respectively.

Application of fixed physical thresholds will suit regional scale studies where detailed soil hydraulic properties will be unavailable uniformly. The soil moisture conditions were further categorized into qualitative moisture types after SMI calculation to enable the interpretation and sustainability evaluation. The classification scheme has been developed on the basis of the frequently used SMI thresholds and adjusted to represent arid and semi-arid environmental conditions. This classification can be used to determine soil moisture stress, transitional, and favorable moisture availability. All the obtained soil moisture measurements were given individual moisture types according to their calculated SMI values.

Table 1. SMI Standards [13].

Grade	Type	Standard
1	Very dry	0<Index<0.2
2	Dry	0.2≤Index <0.4
3	Moderate	0.4<Index <0.6

4	Moist	0.6<Index <0.8
5	Very wet	0.8<Index≤1

RESULT AND DISCUSSION

SMI Temporal Analysis Results (2016–2020)

The same scale of SMI of all the years of study was used to analyze the change of the soil moisture situation over time. Tables (2-7) represent the SMI statistics results for the years 2016, 2018, and 2020, respectively. Figure 3 shows SMI Map of Iraq in the years (2016-20250).

Table 2. SMI statistics results for the year 2016.

No.	Soil Moisture %	SMI 2016	Type
1	35	0.86	Very Wet
2	38	0.94	Very Wet
3	10	0.14	Very Dry
4	6	0.03	Very Dry
5	20	0.43	Moderate
6	10	0.14	Very Dry
7	8	0.09	Very Dry
8	6	0.03	Very Dry
9	7	0.06	Very Dry
10	6	0.03	Very Dry

Table 3. SMI statistics results of the year 2018.

No.	Soil Moisture %	SMI 2018	Type
1	20	0.43	Very Dry
2	39	0.97	Very Wet
3	7	0.06	Very Dry
4	6	0.03	Very Dry
5	10	0.14	Very Dry
6	6	0.03	Very Dry
7	8	0.09	Very Dry
8	20	0.43	Moderate
9	10	0.14	Very Dry
10	6	0.03	Very Dry

Table 4. SMI statistics results of the year 2020.

No.	Soil Moisture %	SMI 2020	Type
1	30	0.71	Moist
2	39	0.97	Very Wet
3	10	0.14	Very Dry
4	7	0.06	Very Dry
5	30	0.71	Moist
6	10	0.14	Very Dry
7	25	0.57	Moderate
8	20	0.43	Moderate
9	25	0.57	Moderate
10	10	0.14	Very Dry

Based on results, most of the observation points in the years 2016 and 2018 were typified by a prevalence of Very Dry conditions, which implies that there was a lot of stress in the soil moisture. Conversely, there were higher cases of the conditions of Moderate and Moist in 2020, indicating better availability of soil water in a number of areas.

Relevance to Sustainability Discussion.

AMSR2 remote sensing databases are found to be effectively integrated into the framework of SMI analysis based on GIS to supply a strong and scalable framework of monitoring the dynamics of soil moisture in Iraq. The methodology will be useful in managing the land, drought, and water resource planning in a sustainable way whereby the crude tests in soil moisture will be converted into standard indices and interpretable moisture types. This is particularly effective in regions where ground measurements of soil moisture are limited and offers a relatively cheap and reproducible long-term observation of the environment.

CONCLUSION

This study shows that integrating remotely sensed AMSR2/GCOM-W1 surface soil moisture data with a GIS-based Soil Moisture Index (SMI) framework is a reliable and effective method for evaluating soil moisture conditions and supporting sustainable land management in Iraq from 2016 to 2020. The normalized min–max SMI transformed raw soil moisture data into a standardized and interpretable index, allowing consistent geographical and temporal comparisons across varied climatic and physiographic circumstances.

Soil moisture levels varied greatly between years, with 2016 and 2018 dominated by Very Dry and Dry SMI classifications, suggesting significant soil water stress and drought risk throughout broad sections of the nation. At various monitoring locations in 2020, Moderate to Moist SMI readings indicated episodic soil water availability recovery. However, Very Dry conditions at many places during the research period demonstrate Iraq's chronic soil moisture shortage and the long-term issues of climate unpredictability, low precipitation, and water resource demands.

In a data-scarce setting, predefined regional threshold values for minimum and maximum soil moisture normalized satellite-derived data, enabling meaningful evaluation without site-specific soil hydraulic parameters. The SMI categories give a realistic and decision-oriented framework for recognizing moisture stress, transitional situations, and relative moisture adequacy.

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