Soil evaluation using GIS and remote sensing techniques: a case study Wadi Al-kuf Northeast of Libya

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ABSTRACT

Land evaluation is the first step toward the good agricultural management. Wadi Al-kuf is one of the promising areas for agricultural production in Northeast Libya. The agriculture activities in the Wadi Al-kuf catchment are traditional and inherited. Therefore, the current study aims to assess land resources in wadi Al-kuf, and to evaluate crop suitability maps using integration among soil data, remote sensing data, and GIS. For this purpose, thirty-one soil samples were collected from the study area to represent the main geomorphological units. Topographic maps, fieldwork notes and a Digital Elevation Model (DEM) were used to create the geomorphological map. The study area has been categorized into nine major geomorphological classes i.e. Alluvial fans, high alluvial plain, high table land, low alluvial plain, low table land, medium alluvial plain, mid-table land, Wadi, and Wadi outlet. The result of land capability showed that 19.92% of the total area is classified as "Very High", 31.55% as "High", 11.94% as "Fair"; 24.15% as "Poor"; 12.41% as "Very Poor". The main capability limitations are soil erosion risks and rockiness. 'Also, the results indicated that the most suitable crops in the study area are wheat, barley, sorghum, and alfalfa, (as field crops); Potato, tomato, watermelon (as annual crops), Citrus, olive, apple, grape, and fig (as perennial crops).

Keyword: Land capacity; land suitability; GIS; remote sensing; Wadi Al-Kuf.

INTRODUCTION

Recently, reliance on modern technologies in the management of land resources has become very important, and this requires obtaining accurate information about the soil types in large areas, in addition to information about land uses, as well as human behaviour for the use of resources. Land quality assessment is related to many factors such as climate, natural and chemical soil characteristics, and water availability and quality. These factors determine the priorities for the optimal use of land (Rossiter, 2005). FAO (1985) Shows that the assessment of the sustainability of soils is also related to biological and environmental conditions and the quality of the infrastructure in addition to the socio-economic conditions as well as the availability of surface freshwater resources are considered one of the factors that ensure agricultural sustainability. Agricultural sustainability also depends on the integration of environmental systems, as the balance between sustainability factors is very important to withstand and adapt to natural conditions, human practices, and climate fluctuations (Rossiter, 2005).

Soil is the source of food in the ecosystem, and therefore the negative change in its properties affects the food in terms of quantity and quality. Therefore, it is necessary to improve its quality, preserve it, and maintain it from various degradation factors (Blum, 1993; De Groot *et al.*, 2002; European Commission, 2006). Land evaluation methodologies explain the factors that reduce soil productivity, the inappropriate practices for land uses, and the obstacles that limit productivity (De la Rosa *et al.*, 2004). Relying on the use of computers in soil assessment has become very important as environmental, social, and economic factors can be integrated along with vital factors within the soil assessment system to predict future changes in soil characteristics and the degree of their reflection on accurate agricultural management. Although the use of automatic systems for assessing soils is very important because it is characterized by speed and accuracy, the cost may be one of the most important obstacles in poor rural communities.

Computerized systems differ based on their purpose, use, and data required. There are many systems for soil assessment such as Agricultural Planning Toolkit (APT), Comprehensive Resource Inventory and Evaluation System (CRIES). The Automated Land Evaluation System (ALES) has been developed under the Egyptian conditions and Microcomputer (Kalogirou, 2002 and Elaalem, 2010). The ALES system is a framework for assessing soils in arid and semi-arid regions, and users can benefit from it in building their own expert system. The Micro LEIS system aims to show an interactive evaluation model of the soil which can be achieved the optimum land use, in addition to achieving the optimal crop production under different soil and different climates conditions, as it is suitable for the soils of the Mediterranean regions and forest lands (De la Rosa *et al.,* 2004). There are also many advanced technologies that have spread recently to monitor environmental changes and their disturbances. The use of remote sensing provided many privileges, which facilitated the monitoring of the changes on the earth's surface, where satellite images are characterized by covering a large area that allows easy environmental monitoring due to the large temporal and spatial coverage. In addition, the Google platform also provided software to integrate with satellite images directly through the Google Earth Engine, to study various environmental phenomena such as land degradation and desertification, land cover change, land use, and urban sprawl (Zurqani, *et al.* 2018; Zurqani *et al.* 2019).

The classification of crop suitability of the soils aims to promote and achieve the greatest production of the lands, as it shows the degree of productivity in the soil. It also explains the best use and the factors that hinder production and thus can be addressed early (Sys *et al*., 1991). The assessment of crop suitability relay on several factors considering the various environmental variables such as topography, climate, and natural vegetation, where the inputs and variables are integrated together as influencing factors (Steiner *et al*., 2000 and Zhang *et al*., 2011).

The means of remote sensing provide a lot of important information about natural resources, which can be utilized or stored until it is retrieved in different ways. It can also be used as a basis for geospatial planning depending on geographic information systems, through which phenomena can be understood and analyzed spatially, where at the same time it is possible to plan resource management and monitor it at different levels of agroecosystems (Patel *et al*., 2002). Besides, remote sensing systems can provide unique information and data about soil properties and surface or subsurface layers, for example, can monitor and estimate spectral reflections of different materials, as well as predict moisture levels in the soil (Abdel-Fattah *et al*., 2021). Moreover, remote sensing gives an important coverage in soil mapping as well as classification of land cover features (Said *et al*., 2020). Satellite images are an important source of geospatial information, and therefore relying on them directly benefits agricultural management decisions and decision support systems (Mohamed *et al*.,2020).

The main objective of the present work was to assess land resources in the Al-kuf basin in northeast Libya, and to evaluate crop suitability maps using Applied System for Land and Evaluation (ASLE) Arid software and (GIS).

MATERIALS AND METHODS

The study area

The study area was in Al Jabal Al Akhdar region northeast Libya (Fig. 1). It is characterized by complex terrain and its geomorphology (Fig. 2(a)) with geographical coordinates between latitudes 32.293° and 32.43 ° north, and longitudes 21.241° and 22.422° east. It occupies an area of ≈ 3632.76 km^2. The altitudes of the study area vary from 0 to 876 m from the mean sea level (Fig. 2(b)) (El-Barasi and Saaed, 2013). The climate in Al Jabal Al Akhdar region is classified as the subtropical Mediterranean. In addition, the average annual temperature is ≈ 20.2 °C and fluctuated between 1°C (WMO, 2021) and 41°C (Fig. 2(c)) (Mallon and Antelopes, 2021). The climate is also characterized by heavy rainfall in the cold winter and drought in the dry summer with large quantities of rain estimated annually between 250 mm and 650 mm (Fig. 2(d)) (Megahed *et al*., 2021).

The highest rainfall intensity is observed in the northeast part of the study area and becomes lowers as one move northerly, southerly, and easterly (Allan *et al*., 1973; El-Barasi and Saaed, 2013). High evaporation rates varied in a range of 1530 – 1710 mm/year in the northern regions and rise whenever one moves a headed to the south (El-Barasi and Saaed, 2013; Ali, 1995). Finally, the relative humidity varied in a range of 66–72% in the northern regions and rise whenever one moves from the southwest to the northeast of the study area.

Soil Classification

Based on climatic data, the soil temperature and moisture regime of the studied area were defined and classified for Interpreting Soil Surveys *as thermic* and *torric* respectively. This was done on basis of the sixth edition of the Keys to Taxonomy System (USDA 2014). Soils were mapped under two soil orders, Aridisols and Entisols.

Soil survey and field work

A semi detailed soil survey was carried out as a one profile pit and was dug to represent each major soil type, since the soils have been identified as benchmark soils. Thirty-one soil profiles were observed, and the morphological features were outlined according to the FAO guidelines (FAO, 2006).

Sampling and analytical procedure

Soil samples were collected from different locations in the study area as shown in (Fig. 1). This was done once during the summer of 2020. Firstly, soil samples were also collected from surface with different depth in clean glass bottles that were labeled with different numbers. The soil samples were chemically and physical analyzed in laboratory of soil analysis at Faculty of Agriculture, Tanta University. The following chemical parameters such as, salinity, EC, pH level, major cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}), major anions CO_3^{2-}, HCO_3^{-}, Cl^{-}, and SO_4^{2-}), $CaCO_3$, Gypsum, organic matter OM and Physical such as soil texture (sand, silt, and clay) (USDA 2004 and Bandyopadhyay 2007).

Land evaluation

Land capability

Land capability was assessed using the Automated Land Evaluation System (ASLE) Arid mapping model to predict the general land use capability for a broad series of possible agricultural usage. This model was integrated with the ArcGIS software package to calculate the final soil capability index and its suitability classes for specific crops (Ismail *et al*., 2001). The Agro-ecological indicators were assessed based on the changes in soil characteristics, relief, soil, erosion, bioclimatic deficit. The land capability evaluations were divided into different classes and orders as follows: - 1) excellent (S1), 2) good (S2), 3) moderate (S3) and 4) marginal or null (N). In addition, these classes were divided into different sub-classes depending on the limitation factors: slope (t), soil texture (i), erosion risks(r) and bioclimatic deficit (b). Tables 1 and 2 exhibit the soils classifications belong to orders S1, S2, S3 and N.

Land suitability model (Arid mapping model)

The rating of land suitability classification index was assessed using the ASLE model. In addition, the soil suitability of a soil component (unit) was also assessed through the maximum limitation method where the suitability is decided upon the most limiting factor of soil properties. Tables 3 exhibits the rating of land suitability classification index that belongs to orders S1, S2, S3, S4, and S5.

RESULTS AND DISCUSSION

Geomorphologic features

Table 4 and Fig. 2(a) showed the geomorphological units of Wadi Al-kuf as follow: Alluvial fans, High alluvial plains, High table land, Low alluvial plain, Low table land, moderately alluvial plain, moderately table land, and Wadi outlet. High alluvial plains represented the biggest unit of the study area that represented about 24 % of the total area. In addition, the low table land covered about 18% of the total area. On the other hand, Alluvial fans and Wadi outlet represent the smallest areas as they covered about 2.3 and 0.3 % respectively.

Land evaluation

The purpose of soil evaluation is to identify the potential of the soil to produce crops depending on the soil's physical and chemical properties in addition to other factors, taking into account the lack of resources required to ensure the achievement of agricultural sustainability. The ALES- It has been developed under the conditions of arid and semi-arid regions and can provide a suitable solution for the management of those regions (Ismail *et al*.,2001).

Land capability

According to ASLE model the soils of Wadi Al-kuf it was used to evaluate the lands of the region, which includes many bio-diversities such as pastures and irrigated fields. The outputs of the model were linked using geographic information systems in the form of layers within the databases, which include soil properties.

Table 5 and Fig.3 represent the land capability classes for Wadi Al-kuf. The results revealed that S2 is the dominant class in Wadi Al-kuf which covers about 31.6 of the total area. Meanwhile, S4 and S5 covered about 24.2%and 12.4% respectively. It's clear that the area has several limitation factors with soil depth less than 50 cm. These results are consistent with that published by Stewart and Nielsen (1990). Meanwhile, results for the slope and calcium carbonate are agreed with that published by Nwer *et al*., (2021). In addition, S1 covered about 19.9 % of the total area. This class is characterized by low limitation factors. These results indicated that these soils are suitable for most crops.

Land suitability

The ALES model interactively runs to compare the values of soils properties with levels of generalizability to each soil suitability class. The results showed a reasonable suitability degree of studied soils. Meanwhile and based on analysis of factors affecting productivity, the model predicate that the suitability crops were classified into 12 traditional types as: wheat, barely, sorghum, alfalfa, citrus, olive, apple, grape, fig, potato, tomato, and watermelon. Table (6) summarizes the model outcomes for crops suitability of the study area.

The following steps are summarizing the most application of the model.

The diagnostic criteria of factors of effective soil are depth (p), texture (t), carbonate content (c), salinity (s), sodium saturation (a), degree of profile development (g), and drainage (d) (Ismail *et al.*, 2001).

The weighted average value of each soil characteristic (V) of the profile calculated by multiplying the sum of (Vi) for each horizon thickness by the horizon (ti) for crop suitability classification run was calculated of wheat (W), maize (M), potato (P), and sugar-beet (S); alfalfa (A) and peach (Pe), citrus fruits (C) and olive (O) as perennials, (Fig. 4 - 15). The spatial analysis function in ArcGIS 10.1 was used to create thematic layers of the most constrained factors. The soil suitability and its classes with selected crops are presented in Table 6. Land suitability varied from "high suitable" (S1), moderate suitable (S2) and moderate to low suitability (S3) in addition, the limitation of each crop due to one or more of limitation factors such as soil texture, salinity, drainage, depth, sodicity, and $CaCO_3$ content Nwer *et al.*, (2021).

The results revealed that about 52 % of the total area is highly suitable for wheat and barley, which agrees with that published by FAO, (2020). More than 60% of the area is suitable for Sorghum, Alfalfa, and Fig. This pattern is consistent with Elaalem, (2012). The results showed that about 88 % of the study area is suitable for watermelon. Furthermore, the results showed a variation of suitability from high to moderate low for potatoes and tomatoes with few limitations. In addition, the results showed that about 21% of the study areas are changed from moderate to low suitability for the apple crop, while the rest of the area has many limitations for apples and olives (Nwer *et al.*, 2013).

CONCLUSION

Land suitability evaluation can help in achieving sustainable crop production for agricultural development in the Wadi Al-Kuf, northeast Libya. The ALES-arid model and Geographic Information System (GIS) software were more effective tools in assessing land capability and its suitability in arid and semi-arid regions for agricultural development. The most of studied soils were classified into two capability classes, C2 (good) with C3 and C4 (poor) according to the ALES-Arid model outcomes. The predominant limiting factors of soil capability were soil texture, cations exchange capacity, hydraulic conductivity, and fertility. However, these limitations can be improved through appropriate management practices. It was found that the soils characteristics of the study area are varied in its suitability index among high suitability (S1) and marginal suitability (S4). The obtained results play a fundamental role in determining the most suitable crops in the study area. Meanwhile, the land evaluation assists decision makers in the sustainable management for agricultural resources. The obtained results also play a major role in revealing the most suitable crops in Wadi Al-Kuf and help us for decision making in the management of agricultural resources.

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Table 1: Land capability classes and degree using the **ASLE** Arid mapping model.

Land capability orders and classes		
Orders	Classes	Degree
	S1	Excellent
S	S2	Good
	S3	Moderate
N	NS1	Marginal or Null

Table 2: Agro-ecological evaluation of land capability subclasses of the ASLE Arid mapping model

Land capability subclasses		Limitation factor
Slope	(t)	Slope
		Useful depth
		Texture class
Soil	(i)	Stoniness and rockiness
		Drainage class
		Salinity
		Soil erodibility
Erosion risks	(r)	Slope gradient
		Vegetation density
Bioclimatic deficit	(b)	Aridity degree
		Frost risks

Table 3: Rating the land suitability classification index based on the **ASLE** Arid mapping model.

Class	Description	Rating (%)
S1	Soils with optimum suitability	> 80
S2	soils with high suitability	< 80 > 60
S3	soils with moderate suitability	< 60 > 40
S4	soils with marginal suitability	< 40 > 20
S5	soils with no suitability	< 20 >10

Table 4: Geomorphic and mapping units and their area and percentages of the total area.

Geomorphologic unit	Mapping unit	Area (ha)	Total area%
Alluvial fans	AF	02231.6	02.3
High alluvial plain	HAP	23212.1	24.2
High table land	HTL	11932.3	12.4
Low alluvial plain	LAP	09748.5	10.2
Low table land	LTL	18005.8	18.7
moderately alluvial plain	MAP	10087.7	10.5
moderately table land	MTL	11475.8	11.9
Wadi	W	09111.1	09.5
Wadi outlet	WO	00289.5	00.3
Total		96094.2	100.0

Table 5. Land capability classification for the Wadi Al-kuf

Capability classes	Area/ Fadden	Area/hectare	Area%

S1	45574.6	19149.0	19.9
S2	72173.5	30325.0	31.6
S3	27312.9	11476.0	11.9
S4	55244.6	23212.0	24.2
S5	28398.2	11932.0	12.4
Total	228703.8	96094.2	100.0

Table 6: Crop suitability of the study area.

Crops	Suitability Classes	Area (Hectare)	Area (Feddan)	Area (%)
Wheat	NS2	43111.1	102645.5	44.9
	S1	289.5	689.2	0.3
	S2	52693.6	125461.0	54.8
Barely	NS1	11932.3	28410.3	12.4
	S1	10037.9	23899.8	10.5
	S2	40824.2	97200.5	42.5
	S3	33299.7	79285.1	34.7
Sorghum	NS1	29088.0	69257.2	30.3
	NS2	5229.8	12451.8	5.4
	S1	36332.7	86506.4	37.8
	S2	25443.7	60580.2	26.5
Alfalfa	NS1	27116.8	64563.8	28.2
	S1	10037.9	23899.8	10.4
	S2	35727.4	85065.2	37.2
	S3	23212.1	55266.8	24.2
Citrus	NS1	18005.8	42870.8	18.7
	NS2	23408.1	55733.6	24.4
	S2	44592.6	106172.9	46.4
	S3	10087.7	24018.3	10.5
Olive	NS1	51549.3	122736.4	53.6
	S2	44544.9	106059.3	46.4
Apple	NS1	74761.3	178003.2	77.8
	S2	289.5	689.2	0.3
	S3	21043.4	50103.3	21.9
Grape	NS1	33023.4	78627.2	34.3
	S2	63070.7	150168.5	65.6
Fig	NS1	20586.8	49016.3	21.4
	NS2	10087.7	24018.3	10.5
	S1	35192.1	83790.8	36.6
	S2	30227.5	71970.3	31.5
Potato	S1	46776.5	111372.6	48.7
	S2	49317.7	117423.0	51.3
Tomato	S1	39386.3	93776.9	41.0
	S2	33495.8	79751.8	34.9
	S3	23212.1	55266.8	24.2
Watermelon	NS1	2231.6	5313.3	2.3
	S1	289.5	689.2	0.3
	S2	84462.0	201100.1	87.9
	S3	9111.1	21693.0	9.5

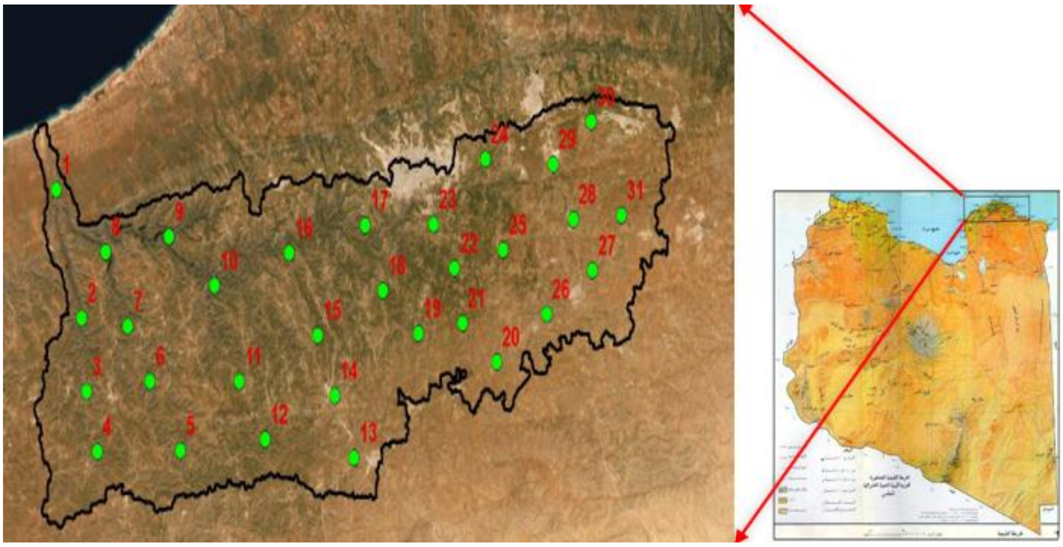

Figure 1: Location of the study area in Al-Jabal Al-Akhdar region northeast Libya.

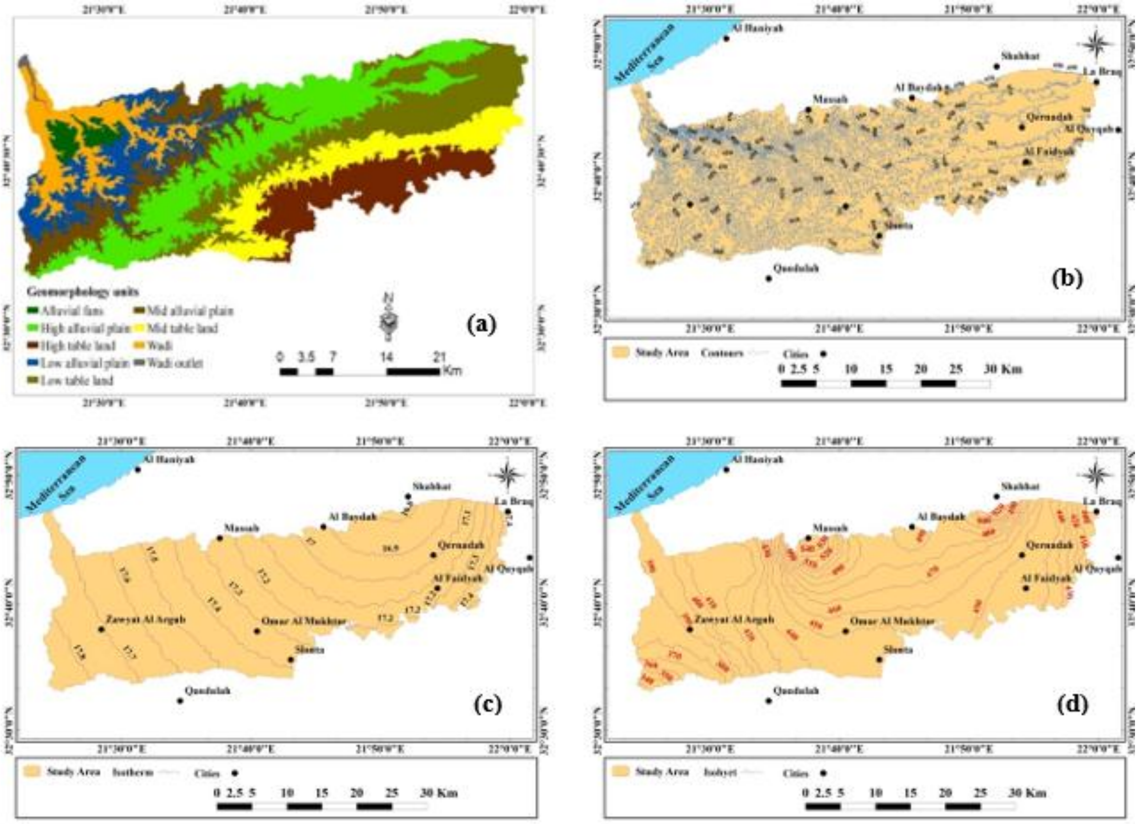

Figure 2: Geomorphology map of the study area (a); Altitude contour lines (b); Temperature contour (c) and Rain contour lines.

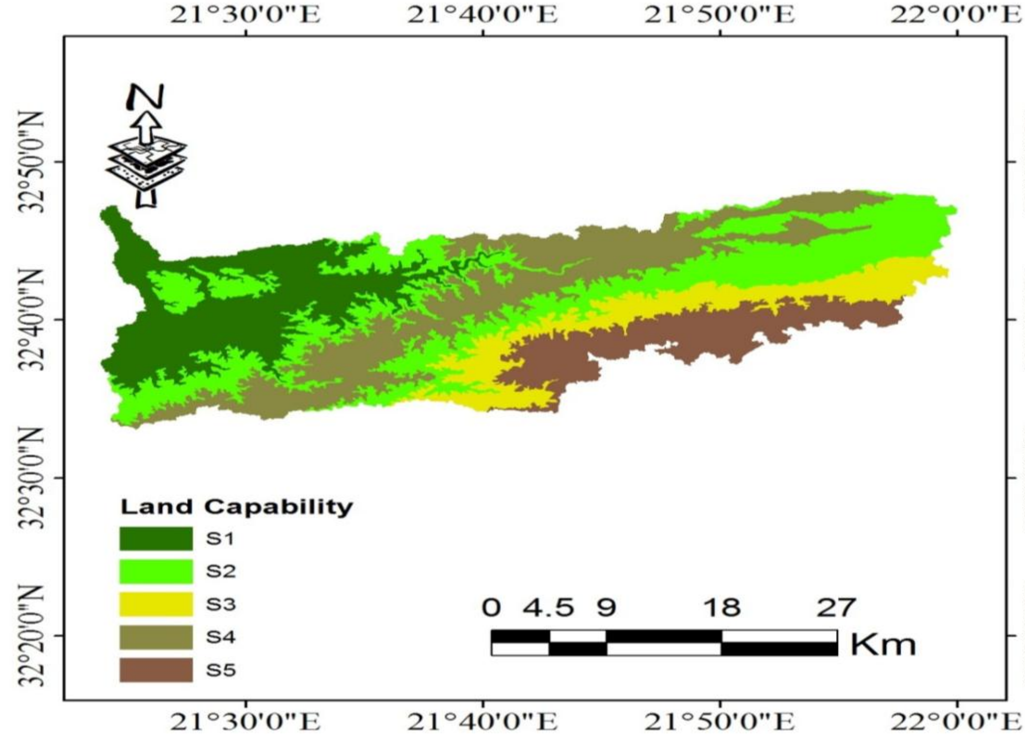

Figure 3: Land capability classes of Wadi Al-Kuf.

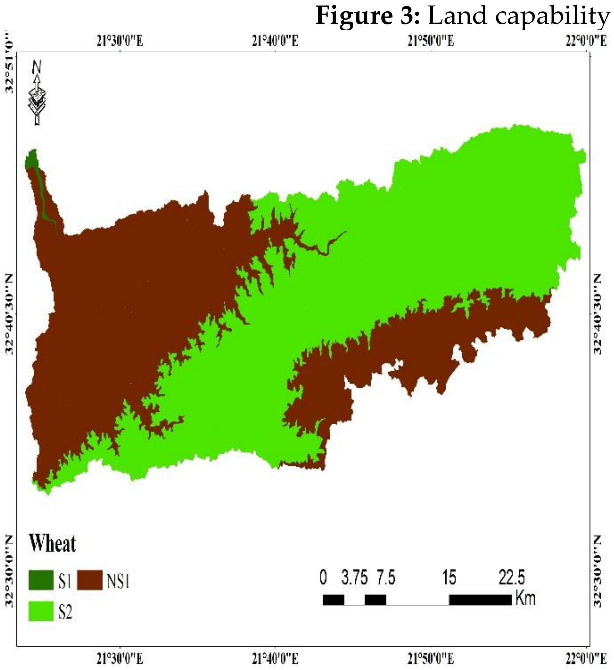

Figure 4: Land suitability map for Wheat.

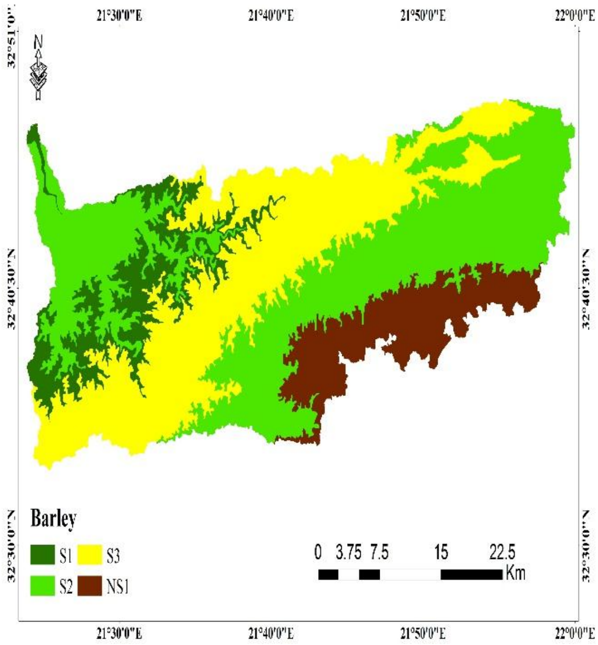

Figure 5: Land suitability map for Barley.

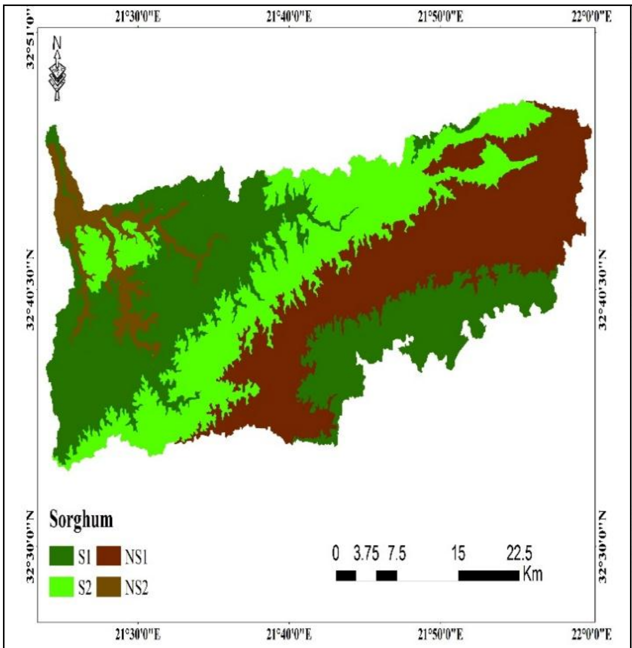

Figure 6: Land suitability map for Sorghum.

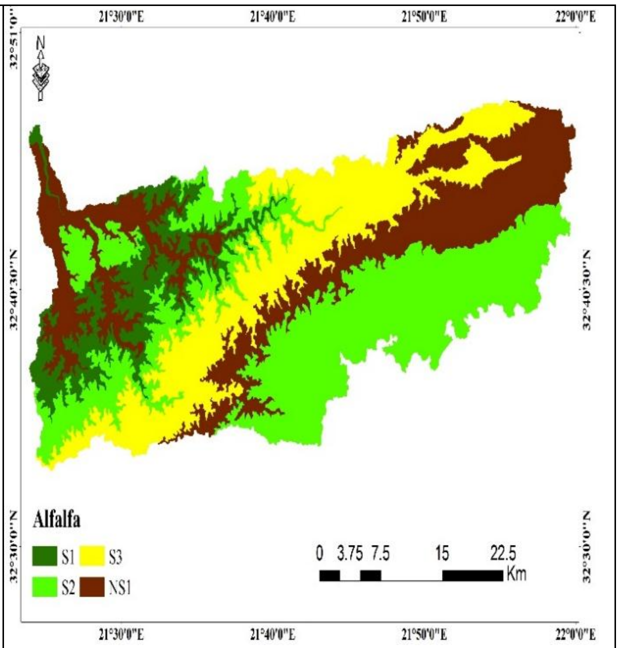

Figure 7: Land suitability map for Alfalfa.

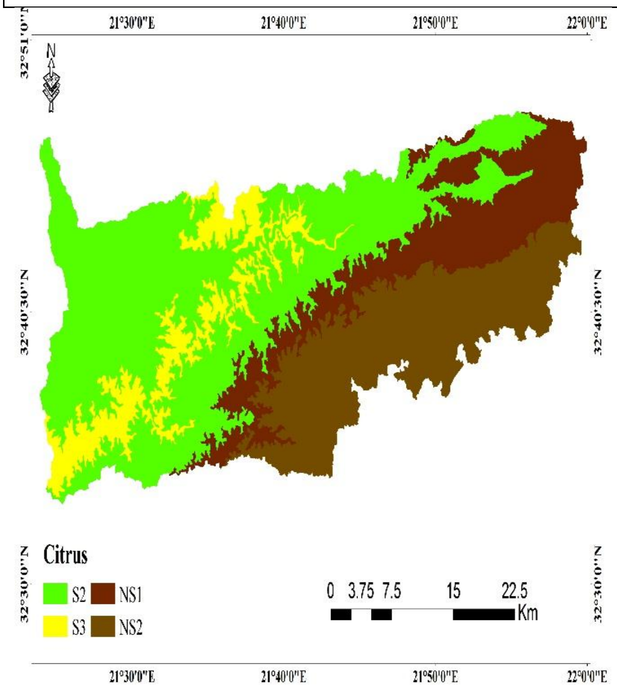

Figure 8: Land suitability map for Citrus.

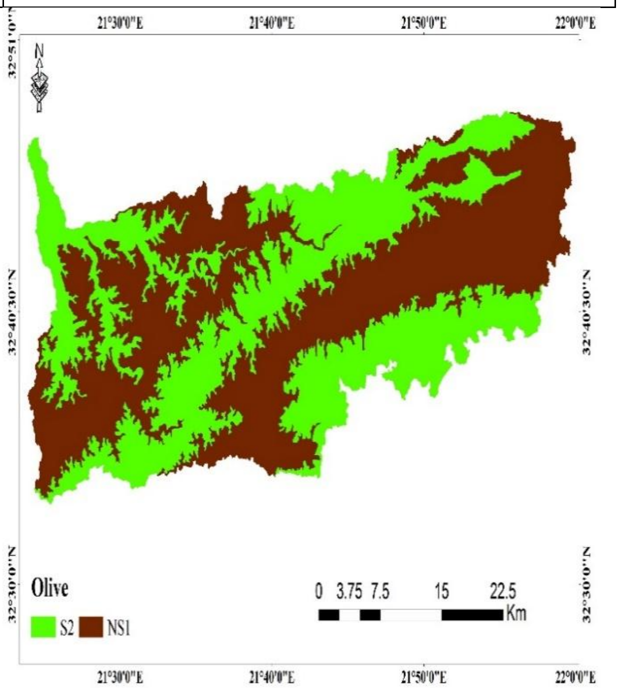

Figure 9: Land suitability map for Olives.

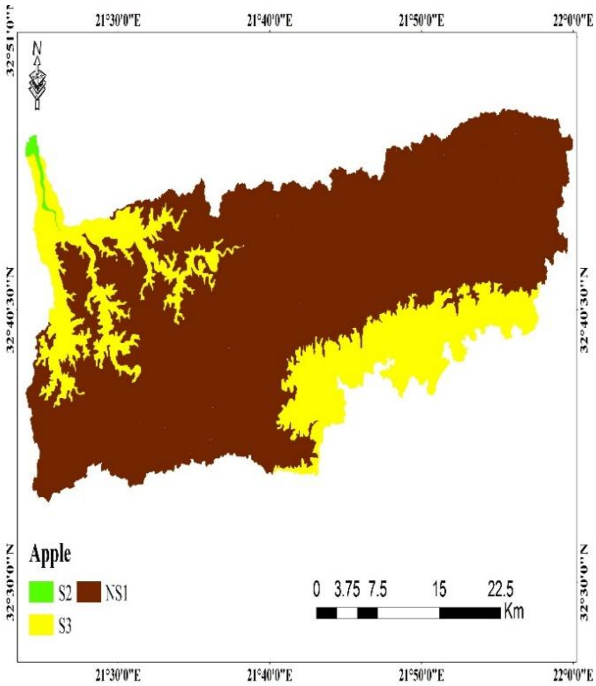

Figure 10: Land suitability map for Apple.

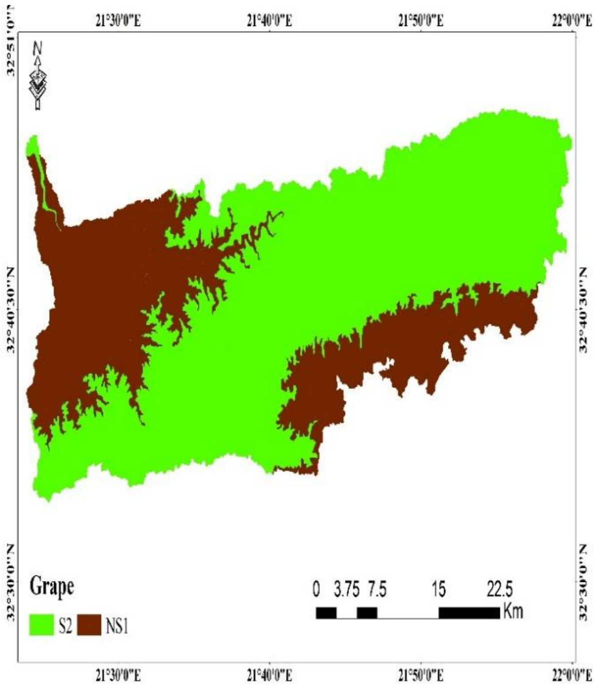

Figure 11: Land suitability map for Grapes.

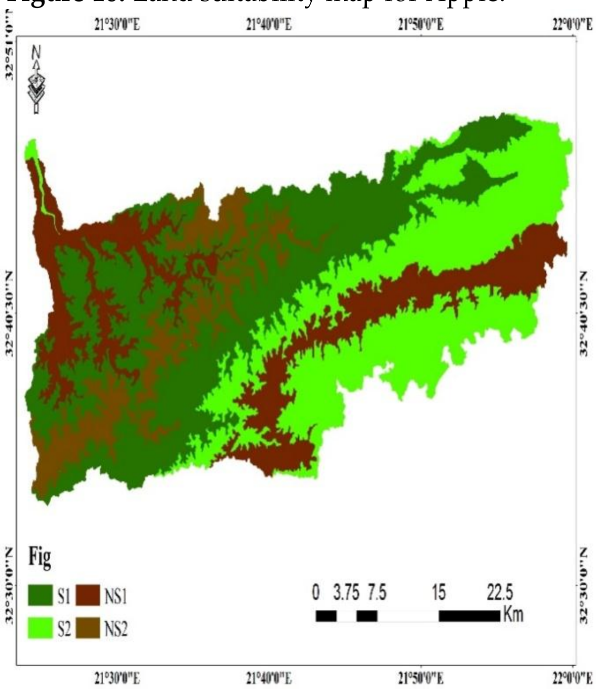

Figure 12: Land suitability map for Fig**.**

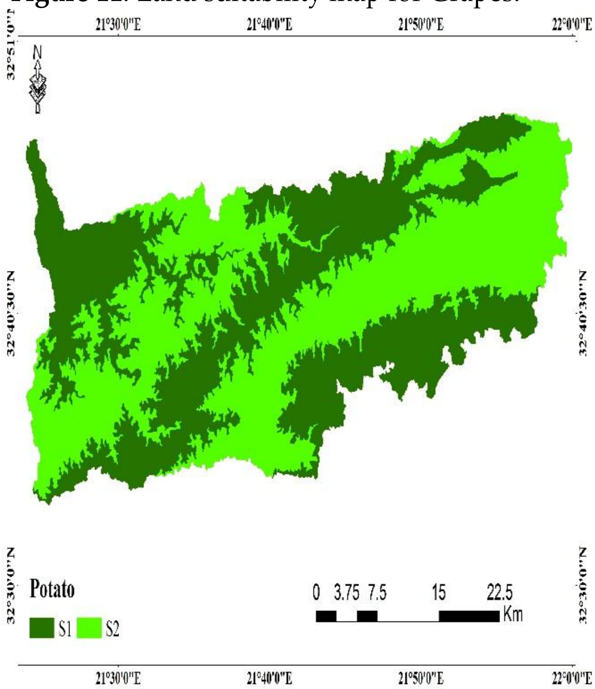

Figure 13: Land suitability map for Potato.

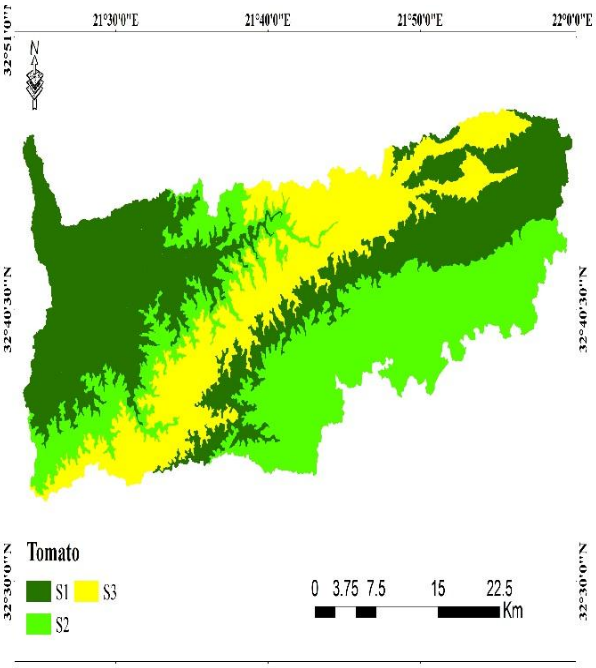

Figure 14: Land suitability map for Tomato.

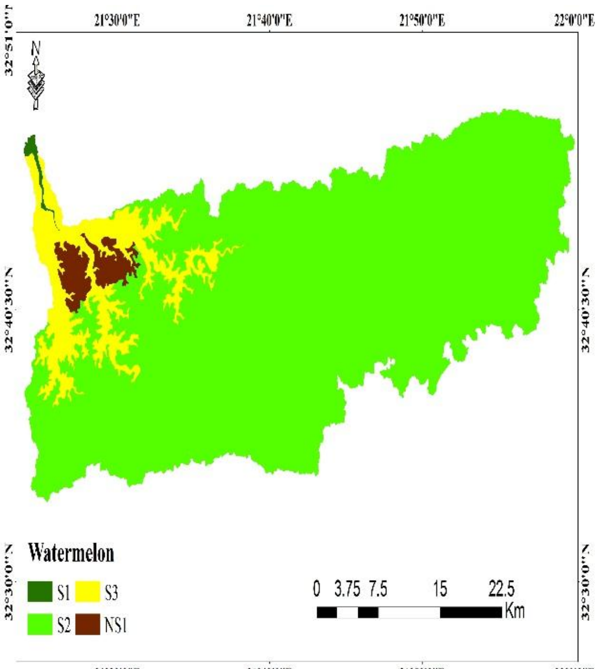

Figure 15: Land suitability map for Watermelon.

تقييم التربة باستخدام تقنيات نظم المعلومات الجغرافية والاستشعار عن بعد: دراسة حالة وادي الكوف شمال شرق ليبيا

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الملخص العربي

إن تقييم الأرض هو الخطوة الأولى للإدارة الزراعية السليمة، ويعتبر وادي الكوف من المناطق الواعدة للإنتاج الزراعي في منطقة شمال شرق ليبيا حيث تعتمد الأنشطة الزراعية في هذه المنطقة على الأساليب التقليدية الموروثة. لذلك، تهدف هذه الدراسة إلى تقييم الموارد الأرضية في منطقة وادي الكوف، اعتماداً على خرائط الملائمة المحصولية باستخدام التكامل بين بيانات التربة، وبيانات الاستشعار عن بعد ونظم المعلومات الجغرافية. ولتحقيق الغرض من الدراسة تم جمع 31 عينة تربة من منطقة الدراسة لتمثيل الوحدات الجيومورفولوجية الرئيسية، ومن خلال الدراسة تم إنتاج الخريطة الجيومورفولوجية اعتمادا على الخرائط الطبوغرافية، والوصف الحقلي ونموذج الارتفاع الرقمي (DEM)، وتم تصنيف منطقة الدراسة إلى تسعة وحدات جيومورفولوجية رئيسية، وهي المراوح الرسوبية، والسهول الروسوبية العالية، المسطبات المرتفعة، والسهول الرسوبية المنخفضة، والمسطبات المنخفضة، والسهول الرسوبية المتوسطة، المسطبات المتوسطة الارتفاع، الأودية، ومخارج الوادي. أظهرت نتائج الدراسة أن الأراضي التي تمتاز بالقدرة الإنتاجية العالية جدا تمثل 19.92٪ من المساحة الكلية للمنطقة، 31.55٪ تميزت بقدرة إنتاجية عالية، 11.94٪ قدرة إنتاجية متوسطة، 24.15٪ أراضي ضعيفة القدرة الإنتاجية، بينما حوالي 12.41٪ صنفت على أنها ضعيفة جدا في القدرة الإنتاجية. وتتمثل المحددات الأساسية للإنتاجية في مخاطر تآكل التربة ووجود طبقات من الصخور الصماء في الطبقات تحت السطحية. كما أوضحت النتائج أن أنسب المحاصيل في منطقة الدراسة هي القمح والشعير والذرة الرفيعة والبرسيم (محاصيل حقلية)، البطاطس والطماطم والبطيخ (محاصيل حولية) والموالح والزيتون والتفاح والعنب والتين (محاصيل معمرة).

الكلمات الاسترشادية: قدرة الأراض الإنتاجية، ملائمة الأرض للمحاصيل، نظم المعلومات الجغرافية، الاسشتعار عن بعد، وادي الكوف.