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Soil productivity assessment of El-Fayoum depression, Egypt, using remote sensing and GIS

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Abstract

Soil productivity is a major concern in soil science. The current study was conducted to evaluate the productivity of soils in El-Fayoum Governorate of Egypt. The study area covers 228145 ha. It consists of eleven major geomorphic units: high old terraces (HOT), moderately high old terraces (MHOT), moderate old terraces (MOT), low old terraces (LOT), alkali flat (AF), overflow basin (OB), decantation basin (DB), high recent river terrace (HRT), moderate recent river terraces (MRT), low recent river terraces (LRT), and sand dunes (SD). 33 soil profiles representing the different geomorphological units were excavated in the study area. Requier land productivity index (RLPI) was used to classify soil productivity. About 83% of the total area are of excellent and good classes (I and II). Class III represents 12.1% of the total area, whereas 4.4 % are poor class IV. The remaining of the area (0.5 %) are of very poor class V.

Keywords: El-Fayoum governorate, Remote sensing and GIS, Soil productivity

Introduction

Soils which cover most of the earth's land are largely non-renewable resources (Blum, 2006 and Rashed, 2020). World's arable lands cover 3.2 billion hectares comprising a quarter of the total land area (Scherr, 1999 and Davis and Masten, 2003). Agriculture is the economic backbone of many countries, particularly the least developed (UNDP, 2007). Compared with population increase, land resource regeneration is slow.

Soil productivity is its capability to give production of crops as a result of efficient use of production factors related to its fertility (Singh and Dhillion, 2002 and Sokolowski, et al. 2020). Land degradation is the result of a mismatch between land use and land quality (Brady and Weil, 1999, Van Lynden and Kuhlman 2003, Barrow 2009, Tekwa et al., 2011 and Kumar et al. 2019). Increased food production helps to ensure long-term food security. Due to climate, raising agricultural production becomes a serious problem (Delgado and Lopez, 1998; Dengiz, 2007; Kokoye et al., 2013, Mirlotfi & Sargolzehi, 2013 and Vogel, et al. 2019). One of the causes of decreased food production is the decline in soil fertility (Debeljak et al., 2019). Human activity can have negative as well as positive effects on soil productivity (John et al., 2006 and Rashed et al.,2021). Each agricultural system has its own social pattern (Kirch, 1994). The impact of land productivity has been studied using an indicator of land suitability for agriculture (Ramankutty et al., 2002 and Zuo et al., 2019). Several attempts have been made to develop systems that produce a productivity index or rating using numerical or parametric methods (Delgado and Lopez, 1998 and Ouyang et al., 2019). Mueller et al. (2010) supported a simple indicator-based soil evaluation and classification based on existing and traditional techniques of assessing total soil productivity. The productivity index (PI) model is a measure employed as an algorithm. It is based on the idea that crop output is a function of root growth, including rooting depth, which is influenced by the soil environment (Lindstrom et al., 1992). It establishes a single scale for grading soils based on their suitability for crop cultivation (Ziblim et al., 2012).

The current study aims at: i} determining soil productivity of the EL-Fayoum depression based on soil properties, using remote sensing data; and (ii) obtaining a soil productivity map for the study area.

Materials and Methods:

Site description:

The study area was El-Fayoum depression where El-Fayoum Governorate exists.It covers an area of 228145 ha. It lies 90 km south of Cairo, between latitudes 29 º 10` and 29 º 30` N and longitudes 30 º 20` and 31 º 10` E (Figure 1).

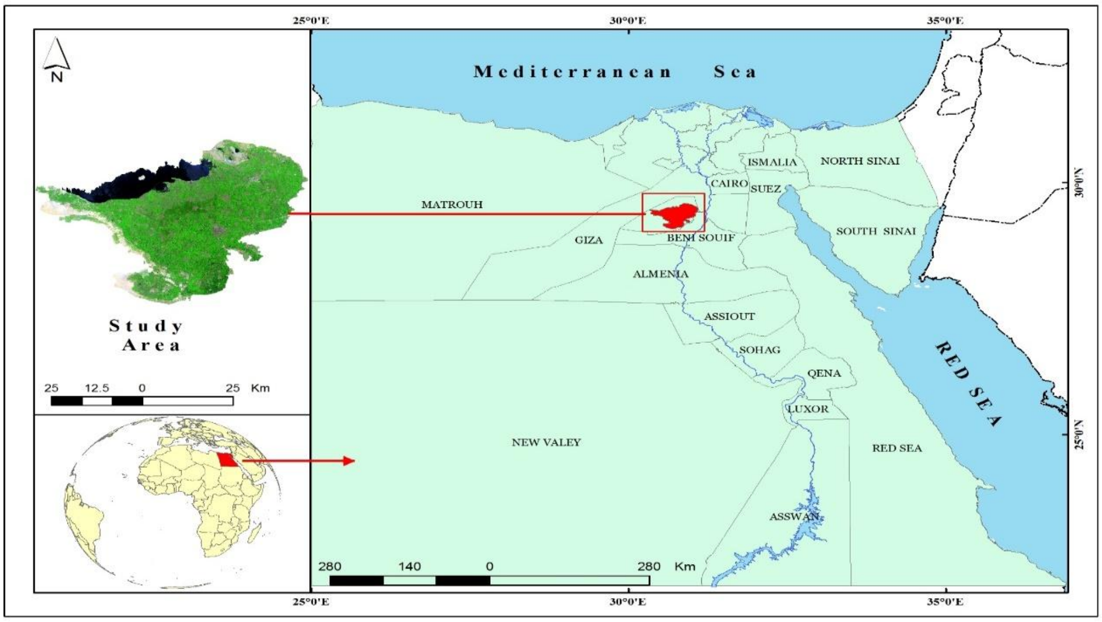

Fig 1: Location map of the studied area

Climate:

The climate is a typical desert one: arid with long hot rainless summer, mild winter with very low or no rainfall. Some rare and irregular storms may take place over scattered localities during winter. Average temperature range is 13.3 °C to 29.2 °C. Highest monthly temperature is 37.2 °C in July, and the lowest is 6.1 °C in January. Humidity varies from 41 % in May to 72 % in December and February. Figure 2 shows the climatic diagram of El-Fayoum.

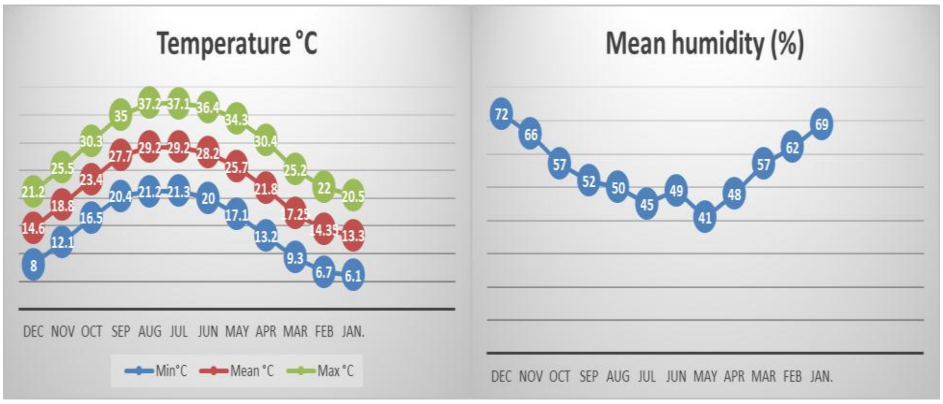

Fig 2: Climatological data of El-Fayoum station

Geology and geomorphology:

The oldest sediments were formed of Middle Eocene beds (Said 1962, Tamer 1968 and Metwaly et al. 2010), The Upper Eocene formations sandstone overlie the shale and limestone in the northern terraces overlooking El Fayoum depression (Qasr El Sagha). The Oligocene deposits underlie the Eocene ones (Hamad et al. 1983). El-Fayoum area is represented by three main geomorphologic forms:1- The flood plain which included recent river terraces (high, moderate and low) and basins (overflow and decantation basins), 2-lacustrine plain deposits which included old terraces (high, moderately high, moderate and low old terraces) and alkali flats, and 3- Aeolian deposits of sand dunes.

Water resources:

The main water resources and their suitability for irrigation in El Fayoum Governorate are as follows:

Fresh Nile water of Bahr Youssef canal is the main water source. It is one of the main branches of Ibrahimiya canal that takes water from the River Nile

Agriculture Drainage water :The most important sources of agricultural Drainage in wadi El Raiyan lake, Qaroune Lake and El-Wadi-drains

Mixed water :water of some main agriculture drains such as El-Tagen, Abu-Denkash and Tanhala, mixed with the Nile water. Also, drainage water mixed with sewage effluent, in El Batts drain, of which water is pumped into El Nokla irrigation canal and used for irrigation.

Satellite data processing:

Digital image processing of Landsat 8 satellite images dated to 2021 was executed using ENVI 5.3 software. Digital image processing included bad lines manipulation by filling gaps module using **Interactive Data Language** "IDL" language.Data calibration to radiance was according to Lillesand and Kiefer (2007).

Soil Taxonomy:

According to USDA (2014) and in view of the meteorology data of Egypt (EMA1996), the soil temperature regime of the studied area is 'thermic' and soil moisture regime is 'torric' and the soils are Aridisols and Entisols.

Field work:

A semi detailed soil survey was carried out in the study area. Thirty-three profile pits were dug and the morphological features were outlined according to the FAO (2006), and samples were taken for analysis.

Soil laboratory analyses:

Soil samples were analyzed for the followings according to (Black et al. 1965): Particle size distribution, Electric conductivity (EC), pH, exchangeable sodium percent, macro nutrients (NPK).

Soil productivity index:

Productivity potential of the representative soil profiles were assessed by applying the mathematical models proposed by Riquier et al. (1970)

Riquier Land Productivity Index (RLPI)

The Riquier Land Productivity Index (RLPI) was calculated for the study area's various mapping units using a model developed by Riquier et al. (1970) and based on the following equation:

$$RLPI = (H/100) \times (D/100) \times (P/100) \times (T/100) \times (S/100) \times (O/100) \times (A/100) \times (M/100) \times 100$$

where H is moisture availability, D is drainage, P is effective depth, T is texture/structure, S is soluble salts O is organic matter, A is cation exchange capacity/nature of clay, and M is mineral reserves.

Each factor is rated on a scale from 0 to 100, the actual percentages being multiplied by each other. The resultant is the index of productivity (between 0 and 100). The rating of the productivity and potentiality of the soil was done according to the grading system in Table 1.

Table 1. Class and rating limit of soil productivity (P) and potential soil productivity (P/) indices

P	P/	Rating	Class
1	I	65 – 100	Excellent
2	II	35 – 64	Good
3	III	20 – 34	Average
4	IV	08 – 19	Poor
5	V	00 – 07	Extremely poor or nil

Results and Discussion

Geomorphologic features and soils:

The geomorphic units were identified by analyzing the landscape extracted from satellite imagery with the aid of Digital Elevation Model (DEM). The geomorphology map (Figure 3) shows three main landscapes as follows:

1) Flood plain containing overflow basin (OVB), decantation basin (DEB), high recent river terraces (HRT), moderate recent river terraces (MRT), and low recent river Terraces (LRT). Taxonomy being *Vertic Torrifluvents, Typic Haplocalcids, Typic Torrifluvents, Typic Haplogypsids, Aquic Torriflvents and Typic Torripsamments.*

2) Lacustrine plain deposits with five landforms; high old terraces (HOT), moderately high old terraces (MHOT), moderate old terraces (MOT), low old terraces (LOT) and alkali flat (AF). Taxonomy being *Typic Torrifluvents, Aquic Torrifluvents, Vertic Torrifluvents, Typic Torripsamments, Typic Haplosalids and Aquic Torripsamments.*

3) Aeolian deposits including sand dunes (SD). In this unit, no profile pit was dug since the land was a loose sand dune. The obtained results are shown in Table 2.

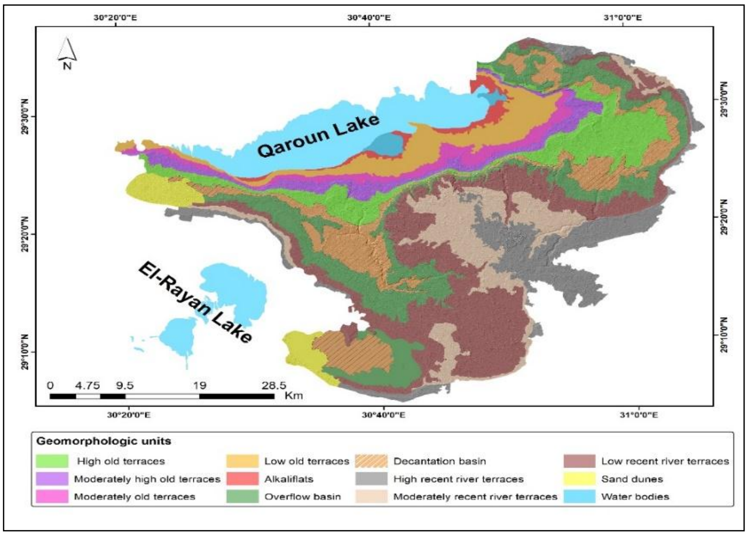

Fig. 3: Geomorphic map of El-Fayoum depression area

Table 2. Landforms and soils of the investigated area

Geomorphic unit	Landform	Profile No.	Soil Taxonomy
Old river terraces	**High**	7, 19, 25	Typic Torrifluvents
	Moderately high	3	Aquic Torrifluvents
		6, 12	Typic Torrivluvents
	Moderate	5, 11, 24	Typic Torrifluvents
	Low	4	Vertic Torrifluvents
		10	Aquic Torrifluvents
		23	Typic Torripsamments
	Alkali flats	9, 27	Typic Haplosalids
		26	Aquic Torripsamments
Basins	**Overflow basin**	1, 2	Typic Haplocalcids
		21	Typic Torrifluvents
		22	Vertic Torrifluvents
	Decantation basin	13, 20	Typic Torrifluvents
		28	Vertic Torrifluvents
Recent river terraces	**High**	16, 31, 32	Vertic Torrifluvents
		8	Typic Haplogypsids
	Moderatel	15, 30	Typic Torrivluvents
		17	Aquic Torriflvents
	Low	14	Vertic Torrifluvents
		18, 29	Typic Torrifluvents
		33	Typic Torripsamments

Soil productivity potentials:

In order to make agricultural policy decisions, accurate forecasts of future soil productivity are required. . The **Riquier Land Productivity Index (RLPI) of** Riquier et al. (1970), is a reliable system of land productivity assessment.

The results show that most of the study area (163784.6 ha; 83% of area) consists of excellent and good classes (classes I and II), while a smaller area of 23878.8 ha (12.1% of area) is of an "average" quality (class III), and a very small one of 8677.62 ha (4.4% of area) has a "low" grade (class IV). The remaining 965.61 ha (0.5% of area) has extremely low (class "V"). Therefore, more than two-thirds of El-Fayoum area are productive. Table 3 shows the Requier productivity index of the study area. Thus, classes of the area varey from “excellent” to “extremely poor to nil” due to different limiting factors (Table 6). Some of these limiting parameters are not correctable such as; soil depth and soil texture, while others like salinity and CEC that can be corrected. The parametric evaluation system of Riquier index is in Tables 3 to 5, and their map is in Figure 4.

Table 3: value of the factors of land productivity of the studied soils of the investigated area

Mapping unit	**Moisture availability**	**Drainage**	**Effective depth (cm)**	**Texture/ structure**	**Soluble salt concen-tration (dS/m)**	**Organic matter content (g/kg)**	**Cation exchange capacity (cmolc/kg)**	**Mineral reserves**
HOT	Rooting zone below wilting point for 3 to 5 months of the year	Well drained	150	Clay Loam	4.27	0.29	25	Minerals derived from sands, sandy material or ironstone
MHOT	Rooting zone below wilting point for 3 to 5 months of the year	Well drained	150	Clay Loam	3.18	0.25	23.6	Minerals derived from sands, sandy material or ironstone
MOT	Rooting zone below wilting point for 3 to 5 months of the year	Good drainage,	130	Clay Loam	3.12	0.23	22.85	Minerals derived from sands, sandy material or ironstone
LOT	Rooting zone below wilting point for 3 to 5 months of the year	Well drained	150	Sandy Clay Loam	3.39	0.24	26	Minerals derived from sands, sandy material or ironstone
AF	Rooting zone below wilting point for 3 to 5 months of the year	Soil flooded for 2 to 4 months of year	150	Loamy Sand	18.8	0.17	15.3	Sands, sandy materials or ironstone
OVB	Rooting zone below wilting point for 3	Well drained	120	Sandy Loam	3.44	0.14	12	Minerals derived from basic or

	to 5 months of the year							calcareous rocks
DEB	Rooting zone below wilting point for 3 to 5 months of the year	Well drained	150	Clay Loam	3.75	0.25	25.2	Minerals derived from sands, sandy material or ironstone
HRT	Rooting zone below wilting point for 3 to 5 months of the year	Well drained	150	Clay Loam	2.8	0.32	25.8	Minerals derived from sands, sandy material or ironstone
MRT	Rooting zone below wilting point for 3 to 5 months of the year	Total waterlogging of profile for 8 days to 2 months	100	Clay Loam	4	0.27	12.5	Minerals derived from basic or calcareous rocks
LRT	Rooting zone below wilting point for 3 to 5 months of the year	Well drained	150	Sandy Clay Loam	2.97	0.25	22.04	Minerals derived from basic or calcareous rocks

Note: HOT: High Old Terraces, MHOT: Moderate High Old Terraces, MOT: Moderate Old Terraces, LOT: Low Old Terraces, AF: Alkali Flats, OVB, Over Flow Basin, DEB: Decantation Basin, HRT: High River Terraces, MRT: Moderate River Terraces, LRT: Low River Terraces

Table 4. Soil characteristics of the investigated area

Mapping unit	Moisture availability (H)	Drainage (D)	Effective depth (P)	Texture/ structure (T)	Soluble salt concentration (S)	Organic matter content (O)	Cation exchange capacity (A)	mineral reserves (M)
HOT	H4c	D4	P6	T6b	S1	O3	A2	M2a
MHOT	H4c	D4	P6	T6b	S1	O3	A2	M2a
MOT	H4c	D3a	P6	T6b	S1	O3	A2	M2a
LOT	H4c	D4	P6	T5a	S1	O3	A2	M2a
AF	H4c	D1b	P6	T4b	S6	O2	A1	M3a
OVB	H4b	D4	P5	T4b	S1	O2	A1	M2c
DEB	H4c	D4	P6	T5b	S1	O3	A2	M2a
HRT	H4c	D4	P6	T6b	S1	O3	A2	M2a
MRT	H4c	D2a	P5	T6b	S1	O3	A1	M2c
LRT	H4c	D4	P6	T6b	S1	O3	A2	M2c

Table 5. Assessment of Requier Land Productivity Index of the study area

Mapping unit	Moisture availability (H)	Drainage (D)	Effective depth (P)	Texture/ structure (T)	Soluble salt concentration (S)	Organic matter content (O)	Cation exchange capacity (A)	mineral reserves (M)
HOT	100	100	100	90	100	90	95	90
MHOT	100	100	100	90	100	90	95	90
MOT	100	80	100	90	100	90	95	90
LOT	100	100	100	50	100	90	95	90
AF	100	10	100	50	5	80	90	95
OVB	90	100	100	50	100	90	90	100
DEB	100	100	100	80	100	100	95	90
HRT	100	100	100	90	100	100	95	90
MRT	100	40	100	90	100	90	90	100
LRT	100	100	100	90	100	100	95	100

Table 6. distribution of Requier Land Productivity Index of the study area

SLPI	**Grade**	**Class**	**Area (ha)**	**Area %**
65 - 100	I	**Excellent**	60304.5	30.6
35 - 64	II	**Good**	103480.1	52.45
20 - 34	III	**Average**	23878.8	12.1
8 - 19	**IV**	**Poor**	8677.62	4.4
0 - 7	**V**	**Extremely Poor**	965.61	0.5

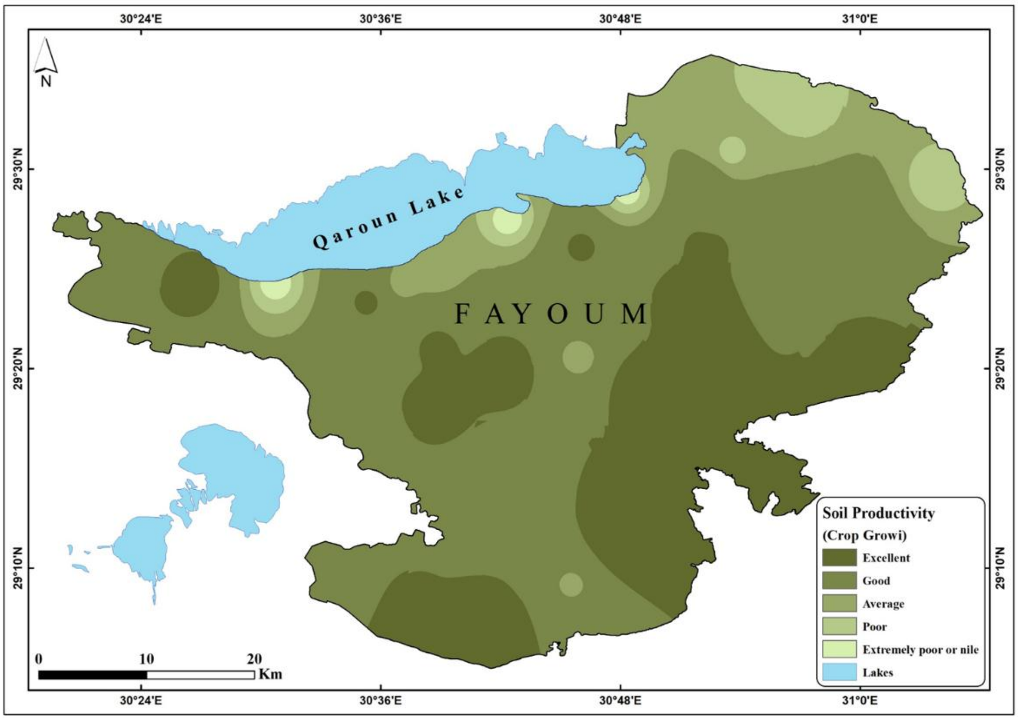

Fig. 4: Soil productivity map of study area

Conclusion

About 83% of El-Fayoum depression it is excellent and good classes (classes I and II), and 12.1% are "average" quality (class III). A very small one potion of 4.4% of area has a "low" grade (class IV). The remaining 0.5% has extremely low productivity (class "V"). Therefore, more than two-thirds of El-Fayoum area are productive. Some of the low-grade soils have limiting factors which are correctable like salinity and cation exchange capacity but others are non-correctable such as soil depth and soil texture.

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تقييم إنتاجية التربة بمنخفض الفيوم بمصر باستخدام الاستشعار عن بعد ونظم المعلومات الجغرافية

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[1] الهيئة القومية للاستشعار عن بعد وعلوم الفضاء ، القاهرة ، مصر .

[2]قسم الأراضي و المياه– كلية الزراعة– مشتهر– جامعة بنها– مصر .

تقييم إنتاجية التربة هو مصدر مهم في علوم التربة. أجريت الدراسة الحالية لتقييم إنتاجية التربة بمحافظة الفيوم بمصر. تغطي منطقة الدراسة حوالي 228145.2 هكتار. وتتكون من إحدى عشرة وحدة جيومورفولوجية رئيسية وهي: المدرجات القديمة المرتفعة (HOT)، المدرجات القديمة المرتفعة إلى حد ما (MHOT)، المدرجات القديمة المتوسطة (MOT) ، المدرجات القديمة المنخفضة (LOT) ، السبخات (AF) ، الاحواض الفيضية (OB) ، احواض الترسيب (DB) ، مصاطب نهرية حديثة مرتفعة (HRT) ، مصاطب نهرية حديثة متوسطة الارتفاع (MRT) ، مصاطب نهرية حديثة منخفضة الارتفاع (LRT) ، والكثبان الرملية (SD).

تم أخذ 33 قطاع تربة في منطقة الدراسة وتم تمثيل كل وحدة جيومورفولوجية بقطاع تربة واحد على الأقل باستثناء وحدة الكثبان الرملية بسبب صعوبة حفر قطاع تربة بها. استند مؤشر إنتاجية الأرض (LPI) إلى الأساليب البارامترية باستخدام نظم المعلومات الجغرافية. تم استخدام مؤشر إنتاجية الأراضي المطلوبة (RLPI) مع مراعاة معايير التربة والطبوغرافيا باستخدام صيغ محددة، وتصنيف الإنتاجية لكل وحدة خرائطية. وأظهرت النتائج أن حوالي 83٪ من المساحة الكلية تتكون من المؤشرين الممتاز والجيد (الفئة الأولى الفئة الثانية) من حيث الاستخدام الزراعي. يمثل المؤشر المتوسط (الفئة الثالثة) حوالي 12.1٪ من المساحة الكلية، بينما تمثل الفئة الرابعة الفقيرة في الانتاجية حوالي 4.4٪ من المساحة الكلية. أما باقي المساحة (0.5٪) فقد أظهرت قيم إنتاجية متدنية نتيجة الممارسات البشرية التي لا تلبي متطلبات الإنتاجية (الفئة الخامسة).