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Assessment of Land Productivity Dynamics in Relation to Land Degradation Using NDVI in Egypt

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ABSTRACT

The present study is concerned with the identification and assessment of the trends of Land Productivity Dynamics (LPD) in Egypt, during the 2000 - 2019 period as well as identifying drivers and hotspots of land degradation aiming at realizing the promotion of the land's sustainable development and degradation neutrality. The study is based on remotely sensed images (SPOT Vegetation NDVI) aggregated / composited to observation every 10 days at a spatial resolution of 30 m calculated by the Joint Research Centre. Results showed that trends of the net LPD for each of the degraded land cover categories were 0.4%, accounting for about 11415 sq. km (1.14% of Egypt's land area). On the other hand, the increasing trend of LP has been attained for both of the shrubs and grassland together with croplands, accounting for around 2077 and 10921 sq. km respectively representing together about 1.3 % of the country's land area. During the study period, mismanagement of soils and water resources has been the chief reasons for the changes in LP. Worthy mentioning, that RS, NDVI and GIS are considered essential tools for LPD monitoring and assessment.

Keywords: Land productivity dynamics; Land degradation; Remote Sensing; GIS; Egypt.

INTRODUCTION

Egypt, located in North-Eastern Corner of Africa, is under hyper arid and arid climatic conditions, having an area of about one million km^2, (Map 1). The domain Egyptian land is desert occupying almost about 93% of the total area, while the cropland area is only around 4.2% (mainly the Nile delta and flood plain) (Yossif, 2019). This unbalanced distribution, accompanied with overpopulation, causes serious economic problems associated with food scarcity and continuous loss of crop land (Abo El Ghar *et al*., 2004).

Since 1980's the governmental authorities have set about re-distributing the population as well as the industrial activities in desert areas; aiming at realizing self-sufficiency in food production through the extension of cultivated land (1.2% / year) and optimizing the production of already agricultural land (Springborg, 1979).

Land productivity is the total above-ground net primary productivity (NPP) defined as the energy fixed by plants minus their respiration (Millennium Ecosystem Assessment, 2005). Land productivity indicates the health, function and services of the ecosystem, therefore, maintaining and enhancing the productivity of agro-ecosystems in a sustainable manner ensure minimizing the degradation of natural ecosystems.

Land productivity is estimated by means of Earth observations of Net Primary Productivity (NPP) in terms of weight/area/time period (e.g., kg/ha/year; also referred to as Annual NPP or ANPP) based on the known correlations between the fraction of Absorbed Photosynthetically Active Radiation (fAPAR) and plant growth vigor and biomass. According to Sims, *et al*. (2017) the Normalized Difference Vegetation Index (NDVI) is the most common used index as a proxy for land productivity.

Dynamic of land productivity points to land degradation when significant loss of desirable services occurs (UNCCD, 2013). In this concern, three land-based indicators (trends in land cover, trends in land productivity and trends in carbon stocks above and below ground) were adopted for monitoring the progress toward acquiring Land Degradation Neutrality (LDN) targets. According to UNCCD (2016), land degradation is generated when land productivity or SOC show significant negative trends or negative land cover change occurs or a negative change occurs in another nationally relevant indicator.

Land productivity trends as indicator estimates the overall above-ground vegetation biomass productivity resulting from all land components and their interactions. It is not conceptually the same as, nor necessarily directly relates to, agricultural income per unit area unit or "land productivity" as used in conventional agricultural terminology. A retrospective assessment of land productivity trends, coupled with an analysis of the driving forces behind these trends, is an essential step in terms of understanding current conditions of land degradation, revealing anomalies and identifying degraded areas. Such an assessment will provide an informed evidence base for making decisions about potential interventions and prioritizing efforts in areas where degradation is taking place.

Many countries have already conducted assessments of the status and trends of land degradation using a variety of different approaches (e.g. Land Degradation Assessment in Dry lands (LADA), carried out by the FAO) and

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implemented some form of land evaluation for the assessment of the land potential.

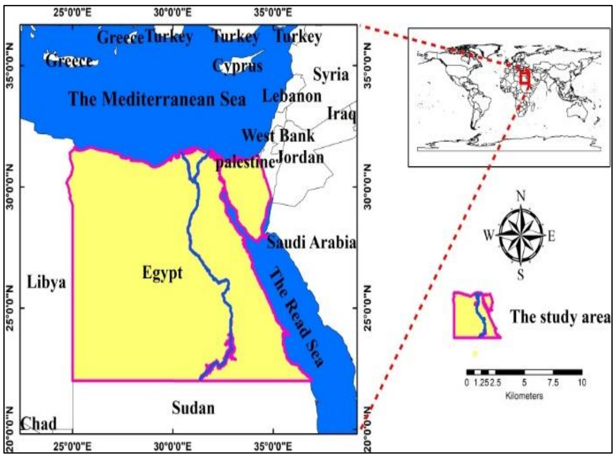
In tropical and sub-tropical desert, changes in land productivity result mainly due to agricultural intensification together with the harsh climatic conditions. Therefore, the need for monitoring land degradation and assessing its severity at any given time becomes vital particularly in establishing national land use policy, implementing land reclamation program and avoiding any land deterioration.

The multi-temporal remote sensing data can play an important role in monitoring and analyzing land productivity changes. Remote sensing has also the capability of capturing such changes, extracting the change information from satellite data requires effective and automated change detection techniques (Roy *et al*., 2002).

Digital change monitoring is the process of determining and/or describing changes in land productivity and land cover based on co-registered multi-temporal remote sensing data. The basic premise in using remote sensing data for change monitoring, is that the process can identify change between two or more dates that is uncharacteristic of normal variation.

Extensive research, using satellite imagery for mapping and monitoring land productivity, has been conducted over the last three decades, mostly with NDVI. There are three metrics can be calculated from the remotely-sensed estimates of land productivity (Trend, State, and Performance) and can facilitate the assessment of land degradation. Potential land degradation is identified where productivity may be increasing over time (trend) but remains low relative to the historical range of productivity levels for that location over time (state) or compared to other regions of similar NPP potential (performance), (Sims, *et al*., 2017).

The present investigation aims at classifying, mapping, assessing and identifying the trends of land productivity dynamics in quantity, occurred in Egypt during the period from 2000 to 2019, as well as identifying drivers and hotspots of land degradation based on NDVI data, GIS facilities and ground truth.



Map 1. Location of the study area (Egypt).

MATERIALS AND METHODS

In order to classify, map, assess and identify trends of land productivity dynamics in quantity occurred in Egypt during the period from 2000 to 2019 as well as identify hotspots and drivers of land productivity dynamics, the following methodology has been applied.

- Land Productivity Dynamics (LPD) dataset for Egypt (Table 1) was derived from a 20-year time series (2000 to 2019) of SPOT Vegetation NDVI images aggregated/composited to observation every 10 days at a spatial resolution of 300 m that calculated by the Joint Research Centre (JRC, 2019) to be used in the current study.
- The general file specifications of the LPD dataset used were GCS-WGS-1984 of Coordinate system and cell size (X, Y) of 300m; SPOT Vegetation LPD dataset at a spatial resolution of 300 m was converted in order for integration with the land cover dataset, at 30 m resolution.
- The LPD dataset were classified according to Joint Research Centre (JRC, 2015) into 5 qualitative classes of persistent land productivity trajectories over the above-mentioned time period i.e. 1) declining productivity, 2) moderate decline, 3) stressed, 4) stable , and 5) increasing productivity, in addition to class of no data and mapped, (Map 2). These qualitative classes do not directly correspond to a quantitative measure [e.g. t/ha of Net Primary Production (NPP) or Gross Primary Production (GPP)] of lost or gained biomass productivity, nevertheless there is an indirect relationship. The 5 classes are rather a qualitative combined measure of the intensity and persistence of negative or positive trends and changes of the photo-synthetically active vegetation cover over the observed period.
- The LPD dataset is disaggregated by the 6 main land cover categories as classified by Yossif (2019) as agro forest, crop land, shrubs - grasslands - sparsely vegetated areas, wetlands, artificial areas and bare lands, i.e. the statistical distribution of the 5 LPD classes within each of the 6 land cover categories was extracted.
- For the identification of degraded areas, the LPD dataset classified as LPD classes 1) declining, 2) moderate decline, and 3) stressed are considered.
- The LPD dataset used in the current study contained no data pixels representing areas affected by regular formation, i.e. water bodies, wetlands, artificial land and bare land.
- Cross-tabulation analysis between LPD data set and land cover classes data was carried out using the CROSSTAB module of Arc GIS software.
- Ground information collected during the year 2019 for the purpose of supervised classification and classification accuracy assessment were used.
- ERDAS Imagine v.16.5 (ERDAS Inc., 2018), ArcGIS v.10.5 (ESRI, 2017) and Trends.Earth plugin in QGIS v.3.10.3 (GIS Geography, 2020) software were used as the main GIS packages for analyzing, processing, mapping and measuring the areas of each land productivity category.
- Finally, validations of the methods applied were made using possibly comparable data sets at national and sub-national level.

RESULTS AND DISCUSSION

A- Assessing net land productivity status and trends over the period 2000 to 2019

Data presented in Table (1) and demonstrated in map (2) show that the net LPD in trends (sq. km) for the six land cover categories which have remained unchanged during the period from 2000 to 2019, ranged from “declining, moderate decline, stressed, stable and increasing” meaning that increasing in land productivity can be pointed out as improving and vise versa.

With regard to cropland, the total land area has increased from 33989.3 km^2 (representing about 3.4 % of the total area) in the year 2000 to 42066.2 km^2 (4.2 %) in the year 2019, indicating very slight positive expansion by around 0.8 % in the desert areas. The net LPD trends, on the other hand, areas were 2.3 % declining; 3.1 % moderate decline; 4.4 % stressed; 43.7 % stable and 32.1 % increasing trend in terms of the total cropland area remained unchanged.

Concerning the class "shrubs, grasslands and sparsely vegetated lands" the total area of which decreased from 15088.6 km^2 (1.5%) in 2000 to 14252.7 km^2 (1.4%) in 2019, pointing out negative change of about -0.1% of the total area of the country. The areas of net LPD trend for shrubs, grasslands and sparsely vegetated lands were disaggregated into 5 classes i.e. declining, moderately decline, stressed, stable and increasing trend with 18.5 %, 18.1 %, 18.4 %, 20.2 % and 14.6 % respectively from 2000 to 2019.

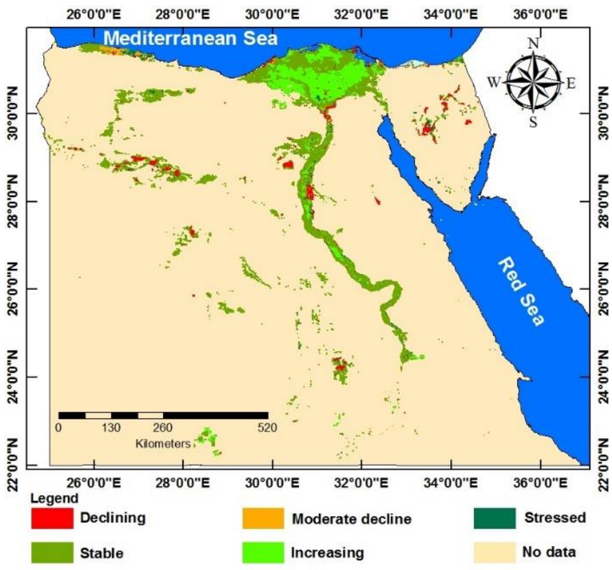
In connection with the "agro-forest" the total area of which accounted for 4.5 km^2 (0.0004%) in 2000 and 5.1 km^2 (0.001%) in 2019 with a gain of 0.6 km^2 of the total area of Egypt. The LPD trends were 5 % stressed; 58.9 % stable and 30.8 % had increasing trend.

On the other hand, wetland area increased from 9563.4 km^2 (1 %) in 2000 to 10514.6 km^2 (1.1%) in 2019 with a change of 951.2 km^2 representing around 0.1 % of the total area of the country. The areas of net LPD trend of wetlands were distributed in 5 classes as 1.0 % declining trend, 0.4 % moderated decline, 1.0 % stressed, 5.0 % stable and 0.7 % increasing trend during the period from 2000 to 2019.

Table 1. Estimates of LPD trends areas within each land cover class during the period from 2000 to 2019 of Egypt.

Land cover class	LC area in 2000		LC area in 2019		Net area change (2000-2019)		Net land productivity dynamics (2000-2019 sq. km)											
							Declining		Moderate decline		Stable but stressed		Stable not stressed		Increasing		No data	
	(sq. km)	%	(sq. km)	%	(sq. km)	%	(sq. km)	%	(sq. km)	%	(sq. km)	%	(sq. km)	%	(sq. km)	%	(sq. km)	%
Agro-forest areas	4.5	0.0004	5.1	0.001	0.6	0.0	0.0	0.0	0.0	0.0	0.2	5.0	2.6	58.9	1.4	30.8	0.2	5.3
Shrubs, grasslands and sparsely vegetated areas	15,088.6	1.5	14,252.7	1.4	-835.8	-0.1	2,642.6	18.5	2,578.2	18.1	2,623.1	18.4	2,877.3	20.2	2,077.7	14.6	1,453.8	10.2
Croplands	33,989.3	3.4	42,066.2	4.2	8,076.8	0.8	778.9	2.3	1,060.0	3.1	1,498.1	4.4	14,847.7	43.7	10,921.0	32.1	4,883.8	14.4
Wetlands	9,563.4	1.0	10,514.6	1.1	951.2	0.1	97.0	1.0	36.8	0.4	100.2	1.0	475.2	5.0	66.3	0.7	8,788.0	91.9
Artificial areas	1,466.0	0.1	3,486.4	0.3	2,020.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,466.0	100.0
Bare lands	940,476.0	93.99	929,552.4	92.97	-10,923.5	-1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	929,552.4	100.0
Total land	1,000,587.7		999,877.4		-710.4	-0.1	3,518.4	0.4	3,675.0	0.4	4,221.6	0.4	18,202.7	1.8	13,066.4	1.3	946,144.1	94.6
Water bodies	9,412.4	0.9	10,122.7	1.0	710.4	0.1												
Total country	1010000	100	1010000	100	0	0												

Artificial areas increased from 1466 km^2 (0.1%) in 2000 to 3486.4 km^2 (0.3%) in 2019 with gain of 0.2% of the total area of Egypt. The net LPD of artificial areas and bare lands had no data in the NDVI dataset used in the study.



Map 2. Land Productivity Dynamics (LPD) trends classification during the period from 2000 to 2019 of Egypt.

As a general view of the net Land Productivity Dynamics dataset of Egypt, the "declining" class represents 0.4 % of the total land area. Nevertheless, this value increased under intensive farming system. Also, the "moderate decline" class represents 0.4 % of the total land area of Egypt. Both classes are vulnerable to land degradation process with different magnitudes. The class "Stable but stressed" represents 0.4 % of the total land area of Egypt. According to the values of areas for trends 1 and 2, a high probability of recently active land degradation processes occurred. The values of areas for class 3 also indicated persistent strong inter-annual variations in land productivity and also the beginning of instability in land conditions.

In connection with "stable not stressed" class, the net LPD has been estimated at 1.8 % of the total land area of Egypt. Whereas the class "increasing" was only 1.3 % of the total land area of Egypt. An areas of no data in net LPD with an average of 94.6 % of the total land area categories of Egypt that are mostly attributed to bare land and artificial areas or missing pixels.

Land productivity dynamics trend classes presented in map (2) identify areas, where biomass activity is lessening, where the main land use patterns that are affected by productivity decline were illustrated as red-colored dots.

In figure (1) the graph visually represents trends in Net LPD according to combinations of land cover in 2000 and 2019. It shows the intensity and persistence of negative or positive alterations of land productivity in unchanged land cover categories.

Table (2) summarizes the change in land productivity identified in Egypt during the period from 2000 to 2019 in terms of the stable, improved and degraded lands. It was indicated that the land area with improved land cover became 13066.4 km^2 (1.3 %), land area without change (stable) was 18202.7 km^2 (1.8 %) and degraded land in productivity came to 11415 km^2 (1.14 %) of the total land of Egypt, considering that the inner water bodies occupy an area of 10122.7 km^2 (1 %) in 2019.

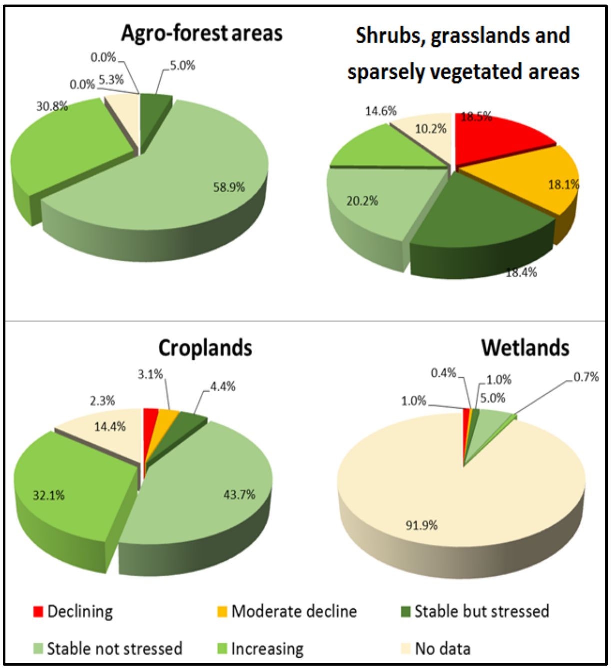


Figure 1. LPD dynamics trends areas in percentage within each land cover class during the period from 2000 to 2019 of Egypt.

Table 2. Summary of change in land productivity during the period from 2000 to 2019 of Egypt's area.

	Area km^2	Area %
Total Egypt's area	1010000	100
Total land area	999877	99
Total Water bodies	10122.7	1**
Land area with improved productivity	13066.4	1.3*
Land area with stable productivity	18202.7	1.8*
Land area with degraded productivity	11415	1.14*
Land area with no data productivity	957192.9	95.7

*** The area percentage is calculated according to the total land area in Egypt**
**** The area percentage is calculated according to the total of Egypt's area**

The results revealed the importance of integrating remote sensing and GIS in the study of land productivity trends since it provides essential information about the nature and spatial distribution of land productivity dynamics trends.

B- Identifying drivers beyond land productivity dynamics

Based on the field observation together with the quantitative information resulted from Land Productivity Dynamics (LPD) dataset, it is indicated that the trends of land productivity in Egypt during the period from 2000 to 2019 can be ascribed to some factors related to climate change , soil properties and anthropogenic impact.

The intensity of such drivers actually varies depending on the differences between the different agro-ecological zones. According to table (1) and figure (1), the changes of the net land productivity of each category of land cover, the absolute values of declining in productivity were found varying in terms of land use pattern. On basis of the magnitude of production declination, the different land cover types could be arranged as follow; "shrubs, grasslands and sparsely vegetated areas" > "crop land" > "wet land" > "bare lands > artificial area.

Noteworthy mentioning that a remarkable deterioration has been recorded for about 3421.5 sq. km covered by both of the grassland and shrubs together with croplands. The case that can be rendered to drivers ; namely overgrazing, fuel wood collection, over-abstraction of groundwater, wind and water erosion and improper soil and water management. This agro-ecological zone mostly represented in the Eastern and the Western desert, Inland Saini and less frequent in the Nile Valley and Delta.

Regarding the croplands, mainly in the Nile Valley and Delta zone, data obtained show that, this agro-ecological zone occupies the second level within the declining category, where it is negatively affected mainly by the urbanization and bad maintenance of drainage and irrigation framework. On the other hand, croplands in North Western Coastal region suffer from sea water intrusion, shallow water table and salinization.

Concerning the Western Desert (East Oweinat, Tushka, Darb El-Arabian areas), the main direct drivers of land cover change and land degradation are climate conditions, wind erosion and deposition, over-abstraction of the groundwater, and improper management of soil.

With regard to the Inland Sinai and the Eastern Desert, the direct drivers of land productivity lessening are those related to the climatic conditions, flash floods and improper soil management.

In general, improper water and soil management is regarded as the mainly frequent cause of for land degradation in the most of the agro-ecological zones. It's the main drivers for water logging that with poor drainage system may trigger salinization and / or alkalinization.

Noteworthy indicating that, urban sprawl and wind erosion aggravated the loss of vegetation cover and removal of fertile topsoil, leading to desertification.

C- Hotspots

Based on the results of the Land Productivity Dynamics (LPD) dataset and field observation, data in table (1), and map (2); the hotspots in each agro-ecological zone have been identified i.e.

The North coastal zone: El Hamam area, Borg Al Arab, Mersa Matrouh, Abis and El Tina mud flat;

The Nile Delta and Valley: Kafr El Sheikh, Bani Sweif, and Sohag Governorates;

The Western desert: El Fayum Governorate, El Baharia Oasis, El Farafra Oasis, New Valley Governorate and lake Naser area;

The Eastern desert and inland Sinai Peninsula: Hurghada, Sharm El Shekh, El Arish, El Qantara East, Halieb, Shalatien and Abu Ramad tri-angle.

These hotspots, representing degraded lands, are considered as priorities to find out the possible means of remediation, bioremediation and land reclamation to improve their soil health and raise the waste land output.

CONCLUSION

The present study indicates that Egypt has diverse land productivity trends i.e. declining (0.4%), moderate decline (0.4%), stressed (0.4%), stable (1.8%) and increasing (1.3%)" for the 6 land cover categories from the total Egypt's land area. The greatest decline in land productivity is reflected on the surface covered by both of the grassland and shrubs together with croplands (3421.5 sq. km). Likewise, the surface covered by shrubs, grasslands and sparsely vegetated areas and croplands occupy the highest percentage of the moderate decline, stable but stressed and stable not stressed classes of Net LPD. Consequently, these areas will take priority in designing an intervention plan and carrying out its activities for achievement LDN. The main drivers of land productivity change and land degradation in Egypt are ascribed to the improper management of soil and water, salinization, water logging, urbanization and sand dunes encroachment. Thus, such challenges need to be seriously studied, through multi-dimensional fields including socio-economy, in order to preserve the newly reclaimed land and increase food production. Utilizing vegetation indices (NDVI) in classifying and mapping of land productivity in areas of densely vegetated soils provided promising results.

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تقييم ديناميكية إنتاجية الأرض وعلاقتها بتدهور الأراضى باستخدام دليل التباين الطبيعى للغطاء الخضرى فى مصر

طاهر مصطفى حامد يوسف*

قسم البيدولوجى – شعبة مصادر المياه والأراضى الصحراوية – مركز بحوث الصحراء

تتناول هذه الدراسة تحديد وتقييم اتجاهات ديناميكية إنتاجية الأراضي (LPD) في مصر ، خلال الفترة 2000 - 2019 ، وكذلك تحديد مناطق تدهور الأراضي والعوامل المسببة لها بهدف تحقيق التنمية المستدامة وتحييد تدهورها. وتعتمد الدراسة على بيانات دليل التغير الطبيعى للغطاء الخضرى الناتج من صور القمر الصناعى الفرنسى (SPOT Vegetation NDVI) التي تم تجميعها / تركيبها للمراقبة كل 10 أيام بدقة مكانية تبلغ 30 متر والمنتجة بواسطة مركز الأبحاث المشترك JRC. أظهرت النتائج أن الأتجاهات الديناميكية لإنتاجية الأرض الصافية LPD لكل مستويات التدهور من فئات الغطاء الأرضي المتدهورة بلغت 0.4 ٪ ، وهو ما يمثل حوالي 11415 كيلومتر مربع بما يعادل 1.14 ٪ من مساحة الأراضي في مصر). ومن ناحية أخرى فيما يتعلق بالأتجاه المتزايد لأنتاجية الأرض LP فقد زادت مساحة أراضى الشجيرات والأعشاب بمقدار 2077 كيلومتر مربع وبمقدار 10921 كيلو متر مربع لمساحة الأراضي الزراعية ، والذى يمثلان نحو 1.3٪ من مساحة أراضي البلاد. وخلال فترة الدراسة ، كان سوء إدارة التربة والموارد المائية يشكل السبب الرئيسى وراء تدهور انتاجية الأراضى LP. والجدير بالذكر أن الدراسة بينت أن إستخدام بيانات مؤشر التغير الطبيعى للغطاء الخضر NDVI المستخرج من صور الأقمار الصناعية يعد من الأساليب والتقنيات ذات الكفاءة العالية والسريعة فى رصد وتقييم التغيرات فى إنتاجية الأرض وصفيا وتساعد متخذى القرارات فى مكافحة تدهور الأراضى ووضع البرامج والخطط التنموية المستدامة.