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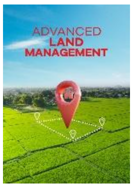

The assessment and management of soil fertility using GIS and remote sensing

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Abstract

Geoinformation technologies are deeply rooted in all spheres of human activity, including agriculture. The efficiency rate of agricultural areas can be remarkably increased by utilizing efficient agricultural production technology such as remote sensing and Geographic Information Systems (GIS). Analyzing soil data through GIS helps in agricultural planning and facilitates quick and appropriate decisions on soil fertility and land use management. GIS technologies make it possible to manage soil fertility and crop quality to the level of farms and even private subsidiary farms. Soil fertility assessment, field monitoring, yield forecasting, proper farming, soil fertility management include not only soil data collection and analysis, but also spatial information collection. With the help of global positioning systems (GPS), it is possible to accurately determine the location on the ground of each plot, as well as to follow the development of crops from sowing to harvesting, to detect moisture and nutrient deficiencies in time, and to identify plant diseases. A well-known example is the vegetation indices Normalized Difference Vegetation Index (NDVI) and Normalized Difference Red Edge Index (NDRE) which could be provided by the EOS Crop Monitoring Company to assess much information on soil fertility in agricultural areas. Vegetation indices provide data on crop growth and health and can be used to monitor crop development from sowing to harvesting, timely detection of moisture and nutrient deficiencies, and detection of plant diseases. Within agricultural fields, GIS technologies are effectively used to apply fertilizers to the soil at certain rates according to the condition of the site, as well as for the correct organization of irrigation. The study area is located in the Imishli district of the Central Aran economic region of the Republic of Azerbaijan, which is regarded as an important agriculture site in the region recognizing cotton and grain growing spots. Accordingly, a few well-known indices such as normalized difference vegetation index - NDVI, and normalized difference red edge – NDRE, were step-wisely applied in the assessment of soil fertility in the region by processing EOSDA LandViewer-derived high-resolution imagery inside the ArcGIS functionality. These indices could be used in agricultural planning, particularly soil fertilizers with some standards by the condition of the site, as well as for the proper organization of irrigation.

1. Introduction

Azerbaijan's population is growing and accordingly, the demand for food supply, particularly crop production is increasing [1]. Failure to provide reliable data on national food security remains a challenge for agriculturalists and researchers. In Azerbaijan, this problem can be solved by taking into account the multidimensional limiting factors of food security at the national level [2]. Climate change and urban population growth are also having a negative impact on Azerbaijan's food security. In particular, the country is going to face climate change consequences and water supply concerns and as a result food security [3,4]. In order to obtain the maximum quality yield, with the lowest labor inputs and production costs, the study of plant characteristics, the use of perfect methods of cultivation of crops is the main task of agricultural workers.

In order to ensure food security and increase agricultural production, when selecting a crop, it is particularly important to take into account the agroecological characteristics of the crop and the agroecological conditions of the region, for sustainable use of natural resources and increase their productivity, while it is also important to take into account the spatial and temporal dynamics of soil quality and fertility. Scientific methods of agriculture, such as nutrient management, tillage, irrigation, saline land reclamation, pest control, favorably affect the ecosystem, as well as the quality and fertility of soil [5].

To obtain information on various features of the Earth's surface, including vegetation, water, and agricultural-related features dissimilar satellite imageries could be used. These data with additional spatial provided data such as Global Positioning System (GPS) could be together analyzed inside any GIS platform in the assessment of farming activities. These data, together with climate data, have become important sources for crop yield forecasting, and soil fertility management, especially where crop production is likely to decline [6]. Remote sensing data obtained at the field level can supply detailed information on the variability of crop biophysical parameters related to yield, in large areas, they supply the capacity to check these parameters throughout their development cycle [7].

The basis for the use of spatial data in agriculture is the use of vegetation indices as an indicator compared to yields for deciding soil productivity and vegetation status. The potential productivity of agricultural land is estimated by biomass density in the case of limited soil data for plots [8]. Field productivity maps obtained with GIS using vegetation indices allow to remotely decide soil quality, and to find sites where individual differentiated fertilizer applications can be applied, The irrigation regime, allows researchers to move to the implementation of precision farming technologies, save costs, and improve soil condition [9].

The advent of high-resolution satellite sensors has reached a new level of advantage by providing higher spatial resolution to obtain the most accurate, reliable and timely data necessary to detect changes in land use, accurate agriculture, response to emergencies and social research among other applied fields. Being up-to-date with the evolving technologies, EOSDA LandViewer offers the option to purchase high-resolution satellite imagery from the world's leading providers online [10].

Decision makers need a clear and accurate quantification of the spatiotemporal variability of soil fertility and degradation for the formulation and implementation of national agricultural policies [11,12]. Advances in observatory systems such as EOSDA data of fine-to-fine spatio-temporal resolutions and process-based and data-driven modelling techniques have facilitated the collection, storage, analysis, visualisation and interpretation of non-spatial data for soil fertility indices. The issue of agricultural productivity and food security is still crucial, in particular, in areas of the Kur Chay River basin in recent years with water significant lack of water storage [13]. Therefore, our main objective was to quantify the spatial distribution in soil properties and accordingly to determine the changing soil fertility under intensive cultivation using ground facts and based on the recognized remotely sensed driven incises.

2. Study Area

The sample area is located in the northern part of the 'Imishla' district of the Republic of Azerbaijan, at coordinates 48°5'17,157", 39°59'20'536" with 3210 hectares part of the Kura-Araz plain Figure 1. On the territory, the average annual rainfall is 315 mm, and the average air temperature reaches - +14.10 C. The amplitude of the level of groundwater in rare cases is 1 m. In riverine zones and irrigated areas - 1.5-2.5 m [14,15].

Figure 1. Location of the study area on Google Earth.

Vegetation cover consists of desert and semi-desert, chalk-meadow, grassland, wetland, and forest plants, whereas human activity significantly impacts the formation of vegetation cover. As a result of the construction of irrigation systems, the area under cultivated plants has expanded, mainly cotton, cereals, and forage plants [16] with a secondary salinization domain. In the river spill zone, the Tugai Forst is a kind of biological oasis nearby of the Kury River deposit. The soil-forming rocks consist of diluvial pluvial, river alluvial, and ancient Caspian sediments.

3. Material and Method

The current case study data is first provided by the EOSDA Crop Monitoring Company, an online satellite-based precision agriculture platform for field monitoring created by EOS Data Analytics EOSDA [17]. It is a valid global site provider of AI-powered satellite imagery foundation of satellite analytics solutions in agriculture and forestry requests. Extended satellites include Sentinel-1, Sentinel-2, Landsat series (5-8), MODIS, NAIP, and CBERS-4 as data archives dating back 20 years. To get access to EOSDA documents any interested researcher needs to create an account by accessing the API page and the sidebar menu bars. Vegetation indices are one of the most important indicators in crop analytics. The main reason for using vegetation indices in remote sensing is the accuracy of the data and the possibility of remote monitoring of agricultural fields. The use of vegetation indices in software improves the quality of data analysis, provides access to different sources. Satellite images allow to cover large areas, reduce costs of field monitoring, provide regular images, get data analytics quickly, observe fields for the whole vegetation period, save time and resources, get access to more data. Vegetation indices are used to analyse the quality of crop condition, to identify problem areas.

Then, NDVI and NDRE indices, as numerical indicators, were imported to the ArcGIS-Pro setting developed by ESRI [18]. These indices are closely related to moisture, soil surface, and green vegetation, representing choice grain and cotton as the most occupied crop in the field under study [19]. Vegetation indices can be created in the ArcGIS Image Analysis window as a standardized representation of relative health and biomass density. In some cases, the application of NDVI to remote sensing satellite imagery yields acceptable results. It normalizes the difference between green leaf dispersion in the near-infrared and chlorophyll uptake. The NDVI is calculated using the Equation 1:

$$\mathrm{NDVI} = (\mathrm{NIR}-\mathrm{RED}) / (\mathrm{NIR}+\mathrm{RED}) \tag{1}$$

Where NIR is the light reflected in the near-infrared region of the spectrum and RED is the light reflected in the red range of the spectrum. The NDVI values are expressed in the range from -1 to 1. Negative NDVI values mainly show clouds, water surface, and close to zero bare surface. The general range of the NDVI value for green vegetation is 0.2 to 0.8.

Whereas the NDRE is regarded to be an index based on the measurement of chlorophyll in plants, calculated by a combination of the short infrared band (NIR) and the Red Edge band between the visible red and NIR, as Equation 2:

$$\mathrm{NDRE} = (\mathrm{NIR} - \mathrm{RedEdge})/(\mathrm{NIR} + \mathrm{RedEdge}) \tag{2}$$

This combination makes the NDRE extremely sensitive to the wavelengths of light reflected by the chlorophyll found in plants. The NDRE values of -1 to 0.2 show bare soil or developing crops, 0.2 to 0.6 can be interpreted as unhealthy or not yet mature, and 0.6 to 1 shows healthy, mature, maturing cultures. NDRE values below 0.3 are a sign of unhealthy or stressful vegetation cover.

4. Results

The main findings of the study are presented as follows:

4.1. General Outputs

In the first stage, the initial outputs show that more than 90% of the area is located from -7 to -12 m from sea level. The terrain features are mainly low slope and flat, gentle slope, moderate slope, strong slope, and steep, with an inclination of mostly 0 to 3^0 (Figure 2).

Also, the elevation areas of the subsided area are indicated in Table 1.

Table 1. Elevation areas of the field under study.

Elevation	Area (%)	Area (ha)
-7.50 – -3.50	3	90.83
-12,00 – - 7.50	92	2958.64
-18.50 – -12.00	5	168.16
Total	100	3217,63

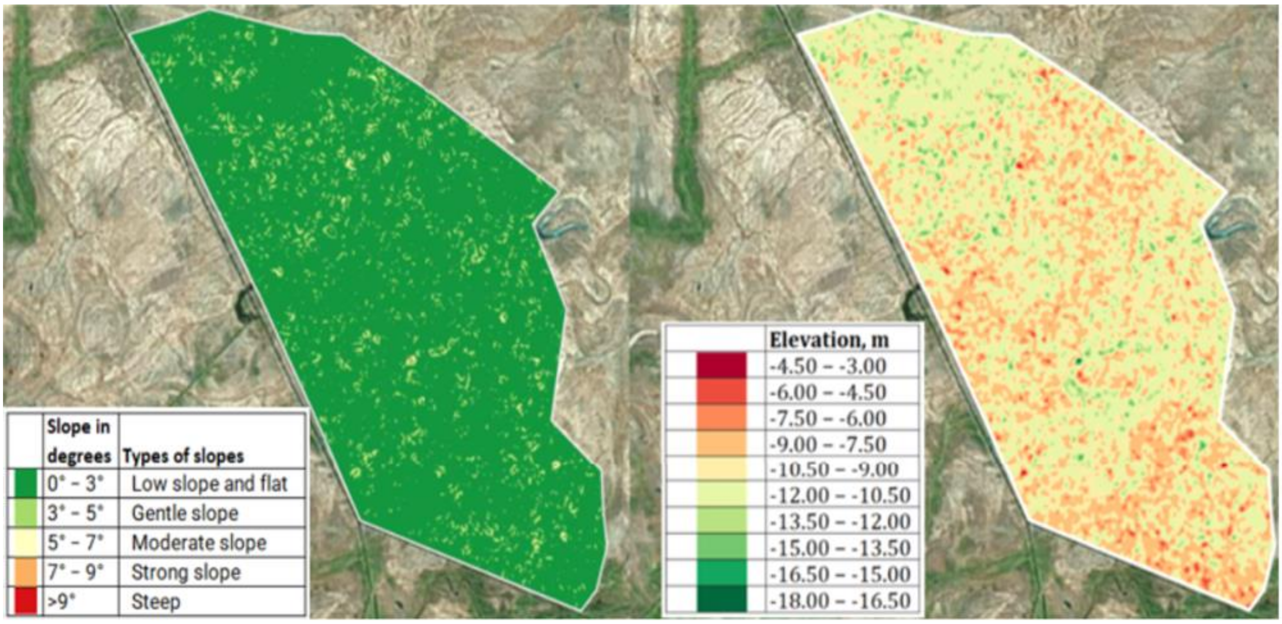

Figure 2. Slope and elevation map of study area.

As Figure 3a shows the highest area of vegetation is assigned to the fields of cotton and grain farming. A pivot irrigation system was fully implemented in the territory, nonetheless, the field was developed quite recently, as can be seen from the traditional soil map the area here is marked as winter pastures Figure 3b.

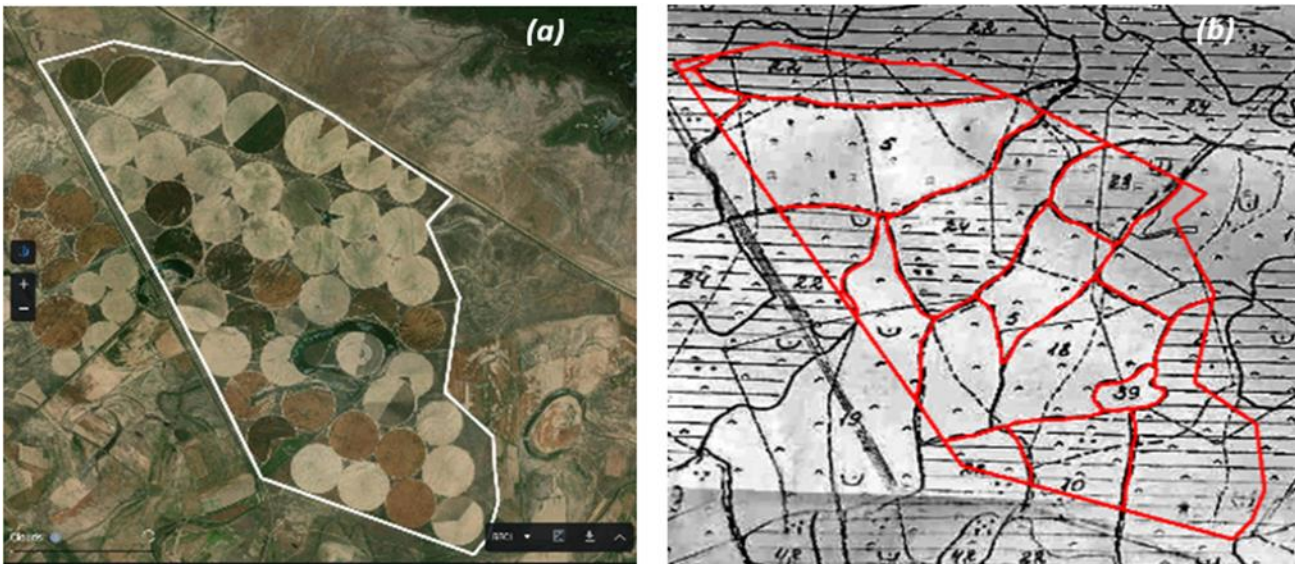

Figure 3. (a) The study area in the space image 2021-year, (b) The study area on the classic soil map.

At a simple glance, the study area is fully irrigated, and the cover consists mainly cropland, and herbaceous vegetation, but the boundaries of the fields consist of shrubs, ponds, and on the outskirts of water bodies grassy wetlands, which are illustrated by Figure 4a & 4b.

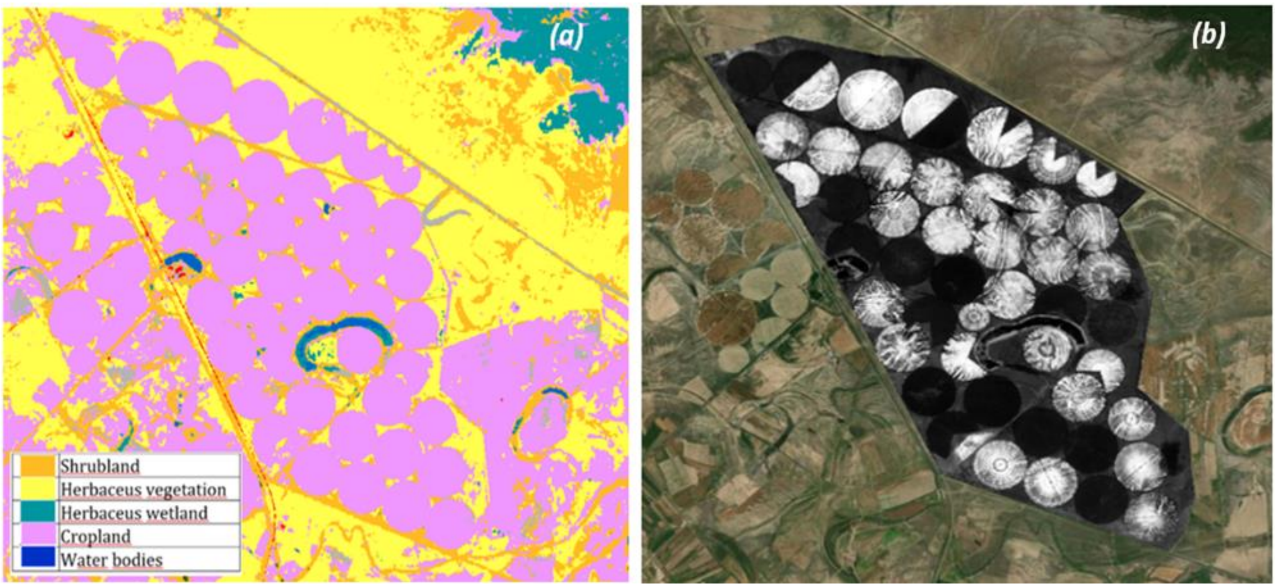

Figure 4. (a) Vegetation cover structure and (b) "Tiff" image of the examined field.

4.2. NDVI Outputs

The NDVI function requires correct input of the red and near-infrared bands, as it computes the differential reflection of the different bands. The order of the bands corresponding to red and infrared varies depending on the specific satellite sensor or source data. Choosing the wrong band order for the red and short infrared bands is calculated by the formula 1 leads to incorrect results. Using images during different vegetation periods, vegetation indices can be used to decide the loss of soil productivity, decide the limiting factors of fertility, and correctly plan land management. Further research is needed using spectral vegetation indices with different reference plants, for forecasting and monitoring soil productivity, Spectral indices can also be used under different environmental conditions and for different plant species. Throughout the study area, the results of the NDVI analysis sampled from June 2 and September 15, 2021, are shown in Figure 5.

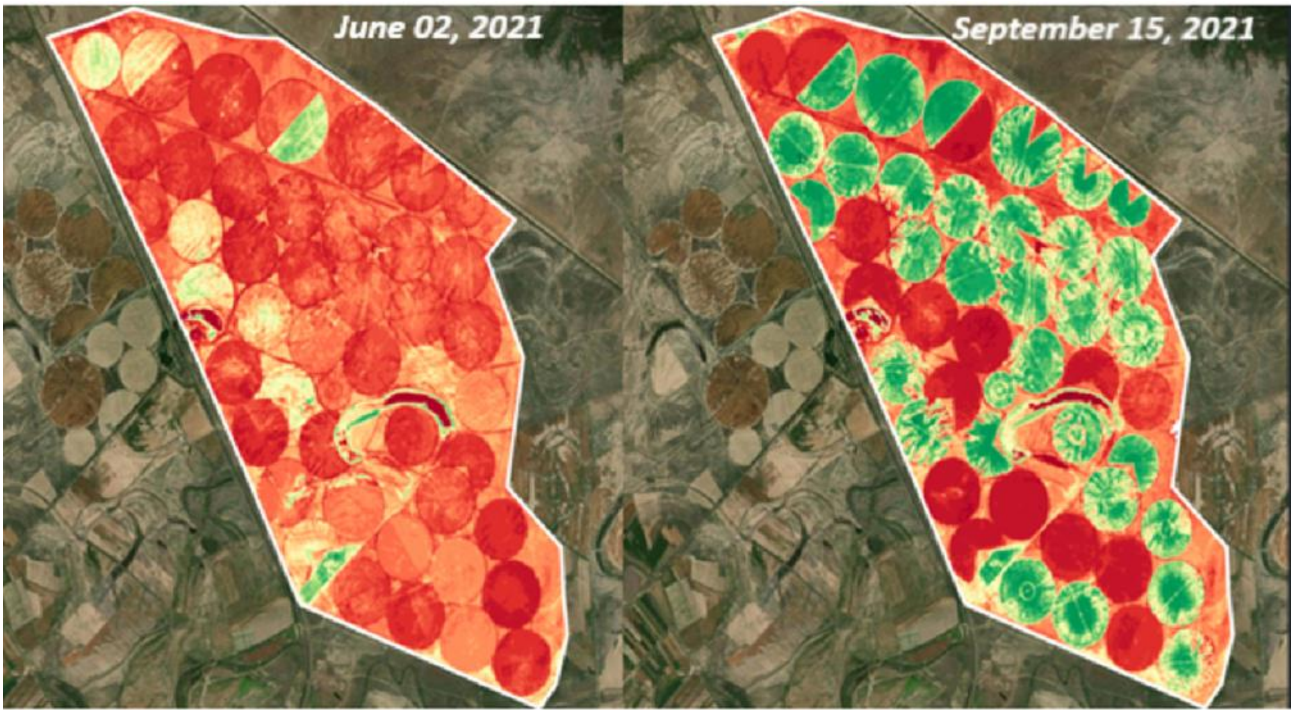

Figure 5. NDVI values for June 2, 2021, and September 15, 2021.

Meanwhile, areas of the field with too low NDVI indicate problems with pests or plants, and areas with abnormally high NDVI indicate a mixture of weeds. If at the beginning of June, the NDVI index of dense vegetation is 2.58%, within the study area, then in the first half of September it is 36.70%, temperate vegetation - 7.38%, 9.52%, respectively, rare vegetation 44.38%, 20.78%, open ground 45.66%, 32.93% (Table 2).

Table 2. NDVI values in early June and the first half of September 2021.

Vegetation Category	NDVI Classes	June 2 (%)	September 15 (%)
Dense vegetation	0.60 – 1.00	2.58	36.75
Moderate vegetation	0.40 – 0.60	7.39	9.52
Sparse vegetation	0.20 – 0.40	44.38	20.78
Open soil	-1.00 – 0.20	45.66	32.93
Total	0-100	100	100

The exact distribution of vegetation index values for two different time sampling spans (2nd June and 15th September) is shown in Figure 6. Accordingly, the area of sparse vegetation and open soil are not equal, respectively, 1422 hectares and 1463 hectares, Dense vegetation covers only 82 hectares, and during the harvest Dense vegetation reaches up to 1176 hectares.

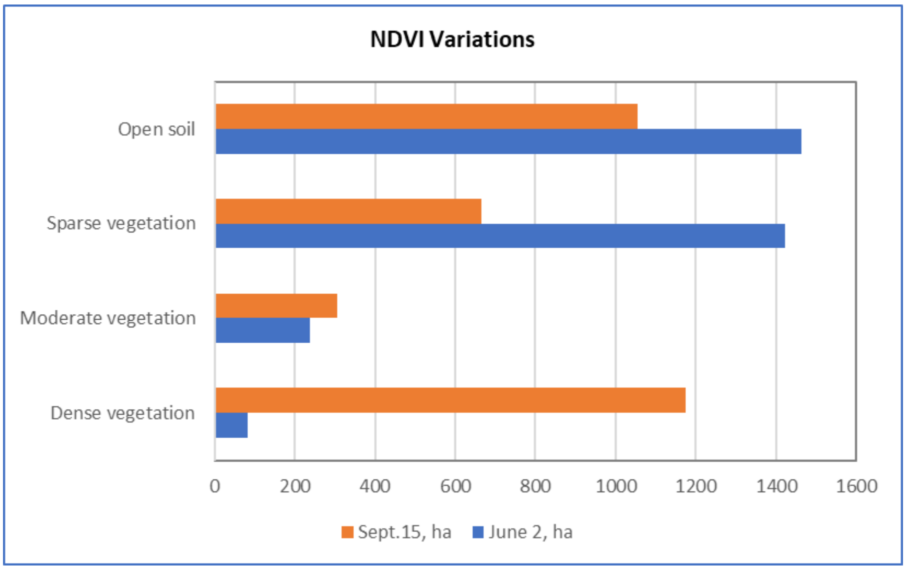

Figure 6. NDVI values on June 2, 2021, and September 15, 2021.

4.3. NDRE Creations

In the crop monitoring system and based on the NDRE results, the values of -1 to 0.2 show bare soil or developing crops 0.2 to 0.6 can be interpreted as unhealthy or not yet mature. Wille NDRE 0.6 to 1 decent, showing healthy, mature, and maturing cultures values below 0.3 are signs of unhealthy or stressful vegetation. On the other hand, low values show bare soil and young plants. Therefore, in the early stages of plant development and growth, it could be referred to other indices Figure 7.

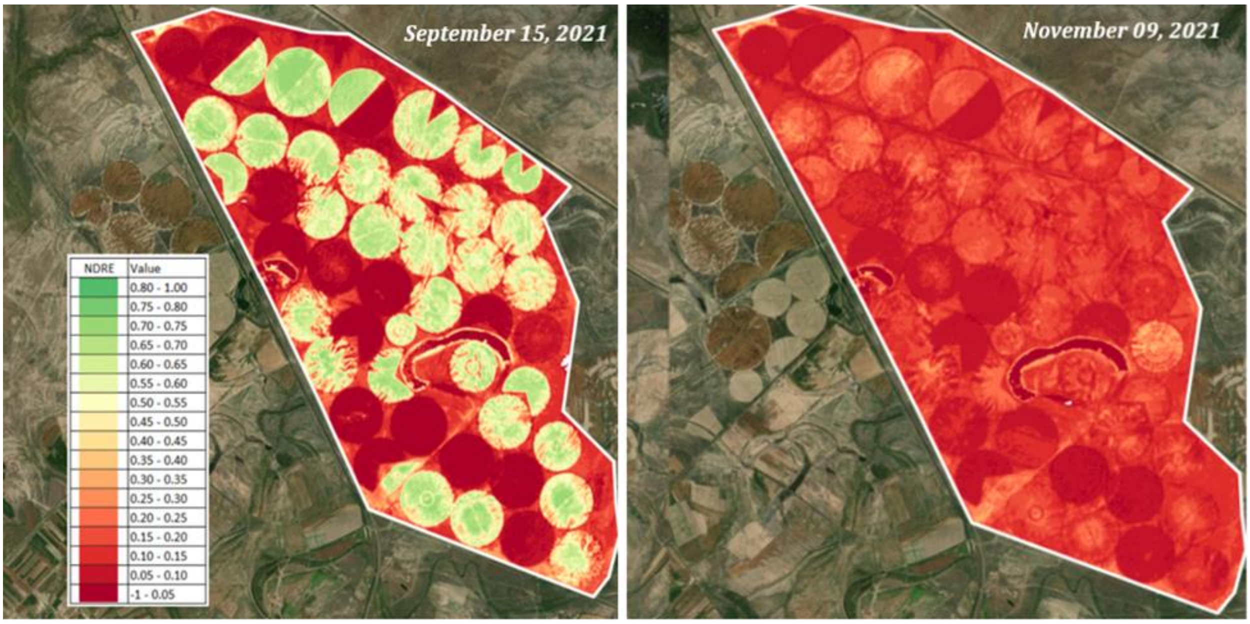

Figure 7. Alignment field NDRE, values for two time-spans.

Figure 8 indicates NDVI and NDRE indicators before (15 September) and after (09 November) harvesting stage inside the sample area.

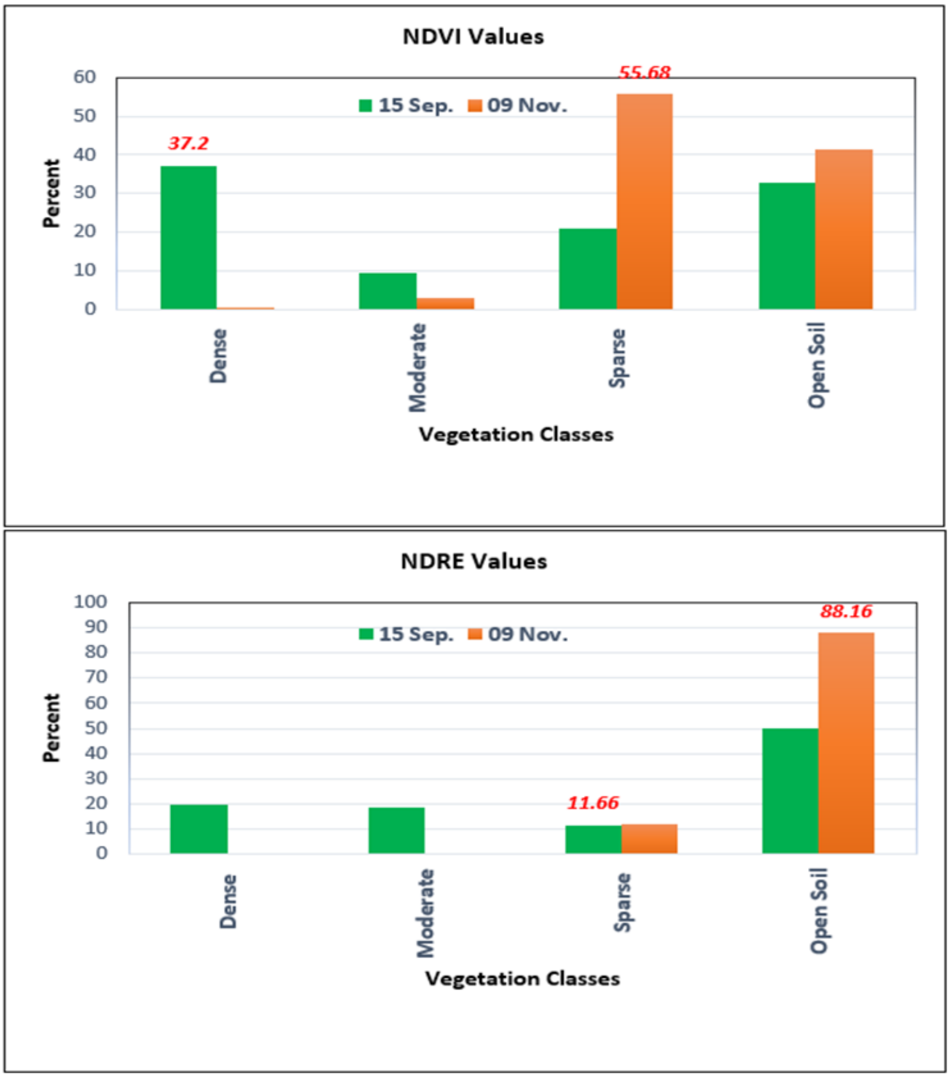

Figure 8. NDVI and NDRE indicators before and after the harvesting stage.

Comparing the values of the NDVI and NDRE indices shows that the results obtained are somewhat different from each other. Secondly, in the transition to the cold season, the greenness index is completely reduced, and this can be seen in both indices, despite the existing differences. More details on the vegetation indices are indicated in Table 3.

Table 3. NDVI and NDRE indicators before and after the harvesting stage.

Indices Vegetation Classes	Range (%)	NDVI		NDRE	
		15 September	09 November	15 September	09 November
Dense	0.60 – 1.00	37.2	0.2	19.8	0
Moderate	0.40 – 0.60	9.52	2.81	18.75	0.08
Sparse	0.20 – 0.40	20.78	55.68	11.66	11.77
Open soil	-1.00 – 0.20	32.93	41.42	49.79	88.16
Total	0-100	100	100	100	100

4.5. Soil Assessment

An assessment of soil fertility was carried out in the ArcGIS setting based on diagnostic indicators in a closed 100-point system and an open scale, taking into account the coefficients for salinity, alkalinity, granulometric composition, irrigation, etc. Figure 9 illustrates a cartogram of soil bonnet inside the ArcGIS setting.. Each soil contour has attribute information - name, area, perimeter, coordinates and score - and each has additional information on agrochemical, agrophysical and environmental data.

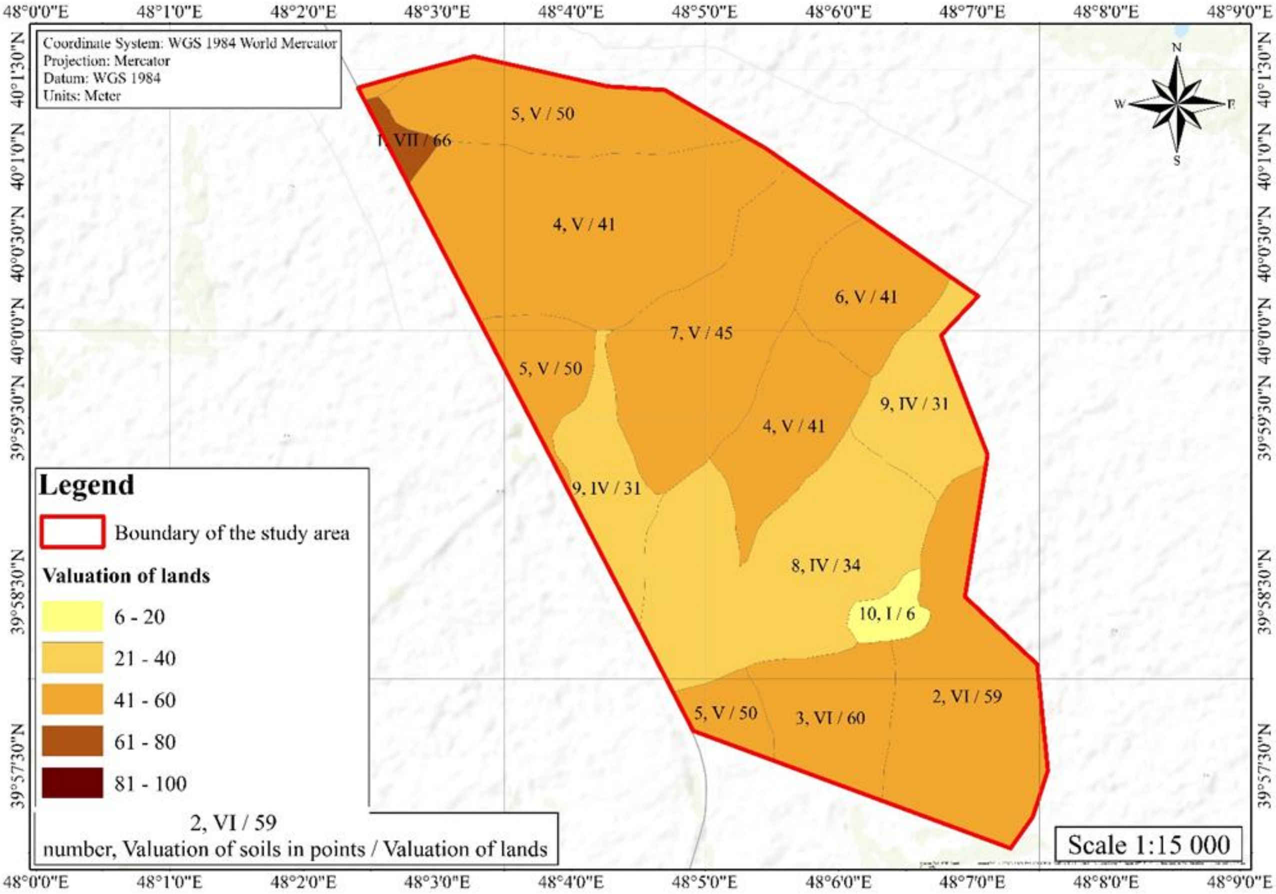

Figure 9. A cartogram of soil bonnet inside the ArcGIS setting.

Each soil contour has attribute information - name, area, perimeter, bonitet score, and each has results of agrochemical, agrophysical analyses. Table 4 shows part of the attribute table in ArcGIS settings, which includes soil contour numbers, soil names, area in hectares, soil score in points, soil score classes, and soil agro-productive group. This table is part of the soil assessment attribute table and includes more than 40 agrochemical and agrophysical soil parameters. Soil scores, soil evaluation classes and agro-productive soil groups were calculated from these data.

Table 4. Part of the attributes table of the soil assessment cartogram created in ArcGIS settings.

No	Name of the soil type and subtype	Area (ha)	Soil assessment in points	Soil assessment classes	Agricultural production group
10	Light loamy salt pans	2313	6	I	V
9	Light loamy slightly saline light meadow-gray soils	29454	31	IV	IV
8	Light loamy light meadow-gray soils	13208	34	IV	IV
6	Heavy loamy medium saline light meadow-gray soils	7777	41	V	III
4	Light loamy meadow-gray soils	6479	41	V	III
7	Medium loamy slightly saline light meadow-gray soils	46345	45	V	III
5	Heavy loamy slightly saline light meadow-gray soils	112369	50	V	III
2	Heavy loamy slightly saline meadow-gray soils	58676	59	VI	III
3	Medium loamy meadow-gray soils	14285	60	VI	III
1	Heavy loamy meadow-gray soils	56277	66	VII	II

5. Discussion

Satellite imaging is a powerful technology that can be used to improve soil fertility, by the processing of high-resolution images of the soil, vegetation covers, and other essential associated components. The advent of high-resolution satellite sensors has brought a new level of advantage by providing higher spatial resolution for the most accurate, reliable and timely data required for land use change detection and precision agriculture research, among other applied fields. Up-to-date with emerging technologies, EOSDA LandViewer offers the option to purchase high-resolution satellite imagery online from the world's leading providers [20]. Such driven information from advanced image analysis can then be used to develop soil-specific management plans for farmers and land managers to increase soil fertility and productivity. Several different index values have been used in agriculture to analyze crop health at certain growth stages, the presence of weeds, and crop moisture status. The use of remote sensing data offers the potential to improve the prediction of crop diseases and weeds [21]. Indices are also used to contrast the stronger chlorophyll absorption of red wavelengths with the higher reflectance of NIR wavelengths for NDVI and other indices to indicate chlorophyll content. Although NDRE is an index very similar to NDVI, its main difference lies in a more secure solution as it can detect changes in crop health at more advanced stages. This is because it uses red-edged light that can penetrate leaves much deeper than red light, used in the NDVI index.

From the spectral profiles of vegetation, it is clear that peak reflectance can be detected in the near-infrared wavelength range and the greatest absorption at red wavelengths due to the presence of chlorophyll. Therefore, several indices have to be applied for assessing vegetation growth and vegetation cover based on the ratio of these two bands [22]. The NDVI is often used around the world to monitor drought, monitor and predict agricultural production, help predict fire hazard zones, and map desert intrusion. The NDVI is preferred for global vegetation monitoring because it helps compensate for changing lighting conditions, surface slope, aspect, and other extraneous factors [23]. However, NDVI was not designed to measure density beyond the shallow cover. As the plant continues to grow and more layers of leaves from under the canopy, measuring excessive green mass for NDVI becomes more challenging. For this reason, for crops in the middle and late stages of development, NDVI is better replaced by NDRE. At the end of the growing season, it is much more difficult for NDVIs to register subtle changes in the condition of certain crops with a large amount of foliage and it is better to switch to another index at the end of the season. NDRE, on the other hand, captures changes in the amount of chlorophyll not only in the upper part of the canopy but throughout the foliage. The vegetation cover may remain visible green on the surface but at the same time experience stress in the lower layers. In this case, the concentration of chlorophyll content will be the best indicator of the health of the crop. The crop here is at a late stage of growth, so it is green and dense. Several other indices can be applied in green cover assessment procedures.

6. Conclusion

Soil fertility assessment helps in agricultural planning in making quick and right decisions for vegetation covers and management as follows:

- ✓ Within the limits of agricultural fields, ESO high-resolution imagery accompanying GIS technology could be used for the application of soil fertilizers with certain norms according to the condition of the site selected.
- ✓ The use of NDVI and NDRE indices makes it possible to find fields with dense, moderate, or rare vegetation at any time, so it is very useful to consider this index in the estimation and management of fertility.
- ✓ By comparing dissimilar indices, it is found that the NDRE index can make an important contribution to the country's agricultural production, not only by improving yield but introducing solutions in the recognition of vegetation class changes during growing seasons.
- ✓ Based on accurate final image processing spectral-based outputs, it is possible to save time and resources by providing farmers with accurate geolocations of problem areas of the field.
- ✓ In further research, it could address, more advanced Object-Based Image Analysis (OBIA), and Deep-learning methods to accurately assess and map vegetation covers and temporal-spatial changes.
- ✓ The overall results suggest that there is an urgent need to improve the institutional framework if the government of Azerbaijan sincerely wishes to have sustainable food security, as organizations control all other issues.

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Conflicts of interest

The authors declare no conflicts of interest.

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