Integrated remote sensing and GIS approaches for land degradation neutrality (LDN) assessment in the agricultural area

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Abstract. Healthy soils sustain humans. Yet these essential land resources are often overlooked and threatened by human activities. Such changes lead to an unbalanced state of soil functions. The land degradation neutrality (LDN) concept has been developed to serve the sustainable development goals (SDGs), in particular goal No.15. Our goal was to move an idea from LDN concept to reality. We assessed the LDN status of the agricultural area in Saraburi Province, Thailand by using three indicators: (i) land use/land cover (LULC) change, (ii) land productivity (LP) change, and (iii) soil organic carbon (SOC) change. The indicator datasets recorded in 2017 and 2020 were used to investigate the land resource changes. LULC and NDVI metrics were obtained using Landsat 8 satellite images and areas were classified into agricultural and non-agricultural uses. For the SOC stocks, 78 agricultural soil samples were collected from the top 30cm by the Land Development Regional Office 1 (Pathum Thani) in 2017 and by the research team in 2020. The standard procedure used for the SOC laboratory analysis was the Walkley–Black method. The LDN status was estimated by integration of results of the three indicators based on a "one out, all out" system. Over three years, the study metrics indicated that net loss occurred in LULC covering the area of 46.99 km\textsuperscript{2} and SOC stocks declined at an average of 0.02%. However, the NDVI obtained from the estimate did not show a difference in the three-year period. This research highlighted alarming signs of soil degradation in the agricultural economics zone. Negative changes occurred in two of the three indicators which showed a tendency towards the degradation of soil capital in the long run. Counterbalancing measures to achieve equivalent losses and gains should be implemented as quickly as possible.

1. Introduction

Without soil it is impossible for life to survive on earth and it is a foundation to perform a range of ecosystem functions. Healthy soils sustain living organisms, but land resources are often overlooked and threatened by human activities. A conversion of healthy land resources to unfavorable conditions alter soil's physical and bio-chemical properties. Such changes include soil structure degradation and loss of nutrients and consequently lead to an unbalanced state of soil functions [1].

The land degradation neutrality (LDN) concept, therefore, has drawn international attention as a universal framework to maintain and enhance land-based natural capital in response to the sustainable
development goals (SDGs). The concept of LDN was first raised at the Rio +20 conference of the United Nations, and the initiative grew out of the concept of Zero Net Land Degradation. In 2015 the twelfth Conference of Parties (COP 12) of the United Nations Convention to Combat Desertification adopted the achievement of LDN in goal 15 of the Sustainable Development Goals (SDGs) with the direction to: “Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.” Target 15.3 of this goal goes further in its ambitions to: “by 2030, combat desertification, and restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land-degradation neutral world” [2].

The goal of this work was to estimate the LDN status for the agricultural area in Saraburi Province, Thailand. The LDN status was assessed using three indicators consisting of land use/land cover (LULC) change, land productivity (LP) change, and soil organic carbon (SOC) change. The integration of LULC change, LP change, and SOC change based on a “one out, all out” system was used for the determination of land degradation.

2. Materials and methods

2.1. Study area

Saraburi Province, located in the central region of Thailand, has a total area of about 3.6 million km² and is divided into 13 districts (Figure 1). The majority of land use is agricultural with areas which account for 53% of the total region.

Figure 1. Study area and sample locations collected in 2020.

Saraburi plays a vital role in economic development in the country. While it has remained an outstanding agricultural provider, it has been designated as an investment promotion area. Its Gross Provincial Product (GPP) was ranked 9th in the country and is top of the list in the central region where the manufacturing sector has the highest value.

Soil resource in Saraburi Province, according to a scale of 1:25,000, can be classified into 39 soil series groups [3]. In general, clay and silty clay soils dominate in the study area and are recognized as poorly-drained soils. Mass agricultural crops such as rice, sugarcane, and corn are produced from Saraburi soils. Improper practices have been introduced to the land and have the potential to change the nature of the land resource [4].
2.2. Indicators and measures of LDN assessment
The three global indicators proposed by the UNCCD Secretariat encompass: LULC change, LP change, and SOC change [1,2]. The LDN status of the agricultural area in Saraburi Province was estimated by integration of the results of the three indicators based on a “one out, all out” principle whereby if one indicator shows significant negative change, LDN is not achieved [5]. It should be noted that using three indicators under certain circumstances may result in errors of “false positive” or “false negative” neutrality assessment. The local context and purposes within the agreed guidelines should be considered with sufficient justification.

2.2.1. Classification of land use/land cover (LULC) change. LULC metrics were obtained using Landsat 8 satellite images and were classified into agricultural and non-agricultural areas. The images were obtained from the United States Geological Survey (USGS) (https://www.usgs.gov) (Figure 2). Images were classified using classification (maximum likelihood classification) methods with ArcMap version 10.7 software to achieve five LCLU classes (Figure 4a). The green area is a combination of forest and agricultural classes of land use (Figure 4b). When the green area became more pronounced in the latter year, it implied that the LULC of the forest and agricultural area had increased and the land was not degraded. If the green area shrinks, the soil in that area may face soil degradation [2].

![Figure 2. Landsat 8 images obtained from the United States Geological Survey (USGS) in November 2017 and February 2020.](image)

2.2.2. Estimation of land productivity (LP) change. Land productivity change data analysis was performed using Landsat 8 satellite imagery to analyze net primary productivity (NPP). We chose images that contained minimal cloud to ensure the quality of the image analysis. The obtained Landsat 8 satellite images covered all the seasonal variations i.e., summer, rainy, and winter seasons. The normalized difference vegetation index (NDVI) data of 2017 and 2020 were averaged during each year across seasons. NDVI value was estimated with ArcMap version 10.7 software using image analysis methods. The NDVI was calculated using the following equation.

\[
\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}
\]  

(1)

where NDVI is Normalized Difference Vegetation Index, NIR is near-infrared regions, and RED is spectral reflectance measurements acquired in the red (visible) [6]. The NDVI change in the study area (NDVI_{a,b}) can be expressed as follows:
\[
\text{NDVI}_{\text{ch}} = \text{NDVI}_{2020} - \text{NDVI}_{2017}
\]

where \(\text{NDVI}_{\text{ch}}\) is the change in the vegetation index, \(\text{NDVI}_{2020}\) is the vegetation index value from 2020, and \(\text{NDVI}_{2017}\) is the vegetation index value from 2017.

2.2.3. Measurement of soil organic carbon (SOC) change. SOC change was performed by comparing the SOC content. For the SOC stocks, 78 agricultural soil samples were collected from the top 30cm by the Land Development Regional Office 1 (Pathum Thani) in 2017. In 2020, our research team collected soil samples at the collocated location or within a 200m radius. Soil organic matter was determined using the Walkley–Black method and converted to SOC by the relation between SOM and SOC using the van Bemmelen factor [7,8]:

\[
\text{SOC} = \frac{\text{SOM}}{1.724}
\]

where SOC is the percentage of carbon concentration in soil samples, and SOM is the percentage of organic matter in soil samples. The change in SOC contents were defined as follows:

\[
\text{SOC}_{\text{ch}} = \text{SOC}_{2020} - \text{SOC}_{2017}
\]

where \(\text{SOC}_{\text{ch}}\) is the mean value of change in of soil organic carbon content, \(\text{SOC}_{2020}\) is the mean value of soil organic carbon content measured in 2020, and \(\text{SOC}_{2017}\) is the mean value of soil organic carbon content analyzed in 2017.

2.2.4. LDN assessment procedural framework

![Figure 3. Land degradation neutrality (LDN) assessment proceeded framework.](image-url)
3. Results

3.1. Land use/land cover (LULC) change

The main land use type in Saraburi Province was agricultural in both periods (Table 1 and Figure 4). The agricultural area accounted for approximately half of the land area of the Saraburi Province and was mainly distributed in the region.

Table 1. The transfer of land use in Saraburi Province from 2017 to 2020.

| LULC classes     | 2017 km² | 2017 %  | 2020 km² | 2020 %  | Change km² |
|------------------|----------|---------|----------|---------|------------|
| Agriculture      | 2,139.55 | 61.39   | 2,237.75 | 64.21   | 98.20      |
| Forest           | 1,029.15 | 29.53   | 883.96   | 25.36   | -145.19    |
| Miscellaneous area | 19.11  | 0.55    | 19.01    | 0.55    | -0.09      |
| Urban            | 262.36   | 7.53    | 307.15   | 8.81    | 44.80      |
| Water resources  | 34.84    | 1.00    | 37.11    | 1.06    | 2.27       |
| Total            | 3,485    | 100.00  | 3,485    | 100.00  |            |

Table 1 shows a net loss occurred in the green areas (agriculture and forest) in a three-year period (2017–2020) at the average of -46.99 km². Within the green area, although the agricultural area increased the forest decreased. The declination of the green area was not only affected by forest reduction but also the expansion of the urban area should be taken into account.

Figure 4. Land use land cover (LULC) classes in Saraburi province, Thailand in 2017 and 2020 for different classification scheme as follows: (a) five classes (agriculture, forest, miscellaneous, urban, and water), (b) green areas and others.
3.2. Land productivity (LP) change
NDVI obtained by Landsat 8 satellite images did not show a difference over the three-year period (Table 2 and Figure 5).

Table 2. The transfer of NDVI average value in Saraburi Province from 2017 to 2020.

| District            | 2017 | 2020 | Change |
|---------------------|------|------|--------|
| Muang Saraburi      | 0.27 | 0.29 | 0.02   |
| Kengkoi             | 0.31 | 0.32 | 0.01   |
| NongKhae            | 0.29 | 0.28 | -0.01  |
| Wihan Daeng         | 0.31 | 0.31 | 0.00   |
| Nongseang           | 0.25 | 0.30 | 0.05   |
| Ban Mor             | 0.29 | 0.27 | -0.02  |
| Donput              | 0.22 | 0.23 | 0.01   |
| Nong Done           | 0.28 | 0.27 | -0.01  |
| Phraputthabath      | 0.25 | 0.28 | 0.03   |
| Sao Hai             | 0.24 | 0.28 | 0.04   |
| Muak Lek            | 0.30 | 0.32 | 0.02   |
| Wang Muang          | 0.28 | 0.29 | 0.01   |
| Cha Lerm Phra Kiet  | 0.26 | 0.28 | 0.02   |

Most areas in Saraburi Province showed a slight increase in the NDVI average value, with only three of the 13 districts where the NDVI average value had decreased.

Figure 5. NDVI map in 2017 and 2020 in Saraburi Province, Thailand.

3.3. Soil organic carbon (SOC) change
The comparison of SOC content between 2020 and 2017 from a total of 78 soil samples that were collected in the collocated sites showed a negative change with an average value of -0.02%. This decreasing trend was found in 39 paired soil samples which accounted for about half of the total samples.

3.4. Analysis of the LDN status
The LDN status was estimated by integrating the results of the three global indicators based on a "one out, all out" principle. In this study, two out of the three indicators – LULC and SOC changes – were
negative. As a consequence, the LDN status in Saraburi Province showed signs of land degradation at an early stage.

4. Discussion
To our knowledge, not many studies have been conducted to implement the LDN assessment from concept to reality. The study in Nigeria, for example, reviewed available spatial datasets and literature when analyzing indicators [5]. On the other hand, the study in Iran [9] and our study applied spatial data and empirical data to analyze the changes of the three indicators. There are still pros and cons to applying the different techniques. According to the real world, empirical sampling and spatial data extraction have the potential to show more accuracy than only reviewing an article. However, in the case of resource limitations such as human, money, and time, secondary data based on the review of several sources would offer proxy results for the study. The use of the three global indicators as proposed for the universal LDN application should be a minimum guideline. In this area, additional information to determine the LDN status could be improved by considering jarosite soil formation and by taking land erosion into account.

5. Conclusions
The present research showed alarming signs of soil degradation in the agricultural economics zone, as indicated by a net loss in LULC and SOC. In two of the three indicators negative changes have occurred showing a tendency towards the degradation of soil capital in the long run. Therefore, it is necessary to take measures to maintain agricultural soil; and counterbalancing measures to achieve equivalent losses and gains should be implemented as quickly as possible. However, the LDN status requires a longer period to improve its accurate assessment.

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