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Land Productivity: A Case Study on SDG 15.3.1 Sub-Indicator

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Abstract
Land Productivity is one of the main sub-indicators of Sustainable development goals (SDG 15.3.1) to acheive land degradation neutrality. In this study, the approach to evaluate land productivity was to assess the changes in the ecological productive capacity of the land. A case study was conducted on spatio-temporal change in the Land Productivity of Lalitpur Metropolitan City using time-series earth observation datasets. NDVI, a vegetation index, along with its derived products, the primary metrics: trend, state, and performance were examined. Furthermore, the analysis period was segmented into baseline and target periods correlating with the transition of the study area from a sub-metro to a metropolitan city. Through, several geo statistics and raster analyses, three metrics were combined, using the "one out all out approach", and observed a decline of 13.69% in land productivity during the baseline period and a further decline of 16.85% during the target period. Overall, Lalitpur Metropolitan City statistically achieved 30% of degraded land due to a decline in land productivity. The study highlights that the rate of land degradation has intensified, primarily due to the rapid urban expansion, particularly in the newly annexed areas. The findings of the study were that the vulnerability of land to degradation is due to population growth and accelerated urbanization. So, ecological restoration programs should be initiated with effective urban planning to support SDG 15.3.1.

Keywords
SDG 15.3.1, Land Productivity, NDVI, NPP

1. Introduction

The Sustainable Development Goal (SDG) is the global commitment to end poverty, protect the planet, and guarantee peace and prosperity for all by 2030. The 17 goals in total in the 2030 Agenda for Sustainable Development include SDG 15: 'Life on Land' [1], the SDG 15 commits to "protect, restore, and promote sustainable use of terrestrial ecosystems; sustainably manage forests; combat desertification; and halt and reverse land degradation and biodiversity loss". Each SDG encompasses specific targets, and the target for SDG 15 is to: "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought, and floods, and strive to achieve a land degradation-neutral world". There are several indicators to assess the progress of each SDG target.Inter-Agency Advisor Group of UNCCD and its key partner Food and Agriculture Organization (FAO) along with the Convention on Biological Diversity (CBD), United Nations Framework Convention on Climate Change (UNFCC), United Nations Environment Programme (UNEP), and United Nations Statistics Division (UNSD), developed and refined the methodology and data tools and options to calculate the SDG indicator 15.3.1 indicator [2]. The assessment for a land degradation-neutral world will be assessed using the indicator 15.3.1: "proportion of land that is degraded over the total land area" [3].

The methodology is universal, with the choice to select the most appropriate data sets. Land productivity, land cover, and soil organic carbon stocks are three sub-indicators that contribute to the evaluation of the SDG indicator 15.3.1 This study aims to compute the proportion of degraded land in Lalitpur Metropolitan City using sub-indicator land productivity. The primary source of food, fuel, and fiber that sustains biodiversity as well as human livelihoods is land. The biological productive capacity of these resources of land is known as land productivity. The decline in land productivity due to unsustainable land use management by human activities and natural processes reduces the productive capacity of land resources, diminishes ecosystem services, and leads to biodiversity loss. The negative trend in the state of land, resulting from human activities either directly or indirectly, that leads to sustained decline or depletion of at least one of the following: biological productivity, ecological integrity, or value to humans, is land degradation, defined by [4], which expands the scope to all regions, not just dry lands as defined by [5]. This study focuses on analyzing the spatio-temporal ecological productivity through time series data to determine whether its condition is in a state of decline or not. The depletion of ecological productivity leads to a long-term imbalance between the demand and supply of ecosystem goods and services [6]. Land degradation is a global ongoing environmental and socioeconomic issue [6] due to which the well-being of 3.2 billion people has been impacted and nearly one-quarter of the global land surface has reduced productivity [7]. The impact of land degradation can include the loss of food security, higher food prices, loss of biodiversity, and a degraded ecosystem [4].

Land degradation is not a simple process but is contextual. It can be influenced by spatial, temporal, economic, environmental, and cultural context [8], which makes the assessment of land degradation more intricate, encompassing a range of dynamic events. The complexity of land degradation processes should be addressed using a multidisciplinary approach [9]. The long-term decline in land productivity can be assessed by net primary productivity. Net primary productivity (NPP), an indicator of land degradation or improvement [4] NPP is the total energy captured by the plants minus their respiration, which translates into the rate of biomass accumulation [10]. The direct estimation of variable NPP is costly, very time-consuming, and out of the scope of this study. Also, the focus of the study is to determine whether land productivity is declining, increasing, or stable. The determination of relative change in land productivity will be unitless, not in terms of the magnitude of NPP in units.

The effective indirect measurement of NPP is deriving the productivity index from the remotely sensed images. The productivity index is an algorithm that computes the vegetation indices. One of the most popular and best alternatives to vegetation indices is the normalized difference vegetation index (NDVI) [11].The derived NDVI from satellite images has been used in many studies for monitoring vegetation cover, assessing changes, desertification, drought monitoring, and land degradation. The relation to the estimation of NPP from the NDVI was developed by [12]. Based on numerous studies mentioned by [13], there exists strong relationship between NDVI and NPP. Therefore, NDVI serve as a proxy for land degradation. Also, NDVI is related to the biophysical variables that control the vegetation and land/atmosphere fluxes like the leaf-area index, the fraction of photosynthetically active radiation absorbed by vegetation, and NPP found by [4]. However, this strong relationship between NDVI and NPP may not be applicable in those areas where vegetation growth requires a certain threshold of rainfall, especially in drylands [14]. Therefore, the climatic conditions should be considered because the relationship between the NDVI and precipitation can alter the results when mirroring the land degradation. [15] has classified the climatic conditions of Nepal, and the study area falls on the humid areas. In humid areas, NDVI serves as a proxy for land degradation that strongly correlates with vegetation dynamics [13].

1.1 Significance of the study

The overarching national aspiration of 'Prosperous Nepal, Happy Nepali', the 15th Development Plan (2019/20-2023/24) has mainstreamed the SDGs [16]. Due to a lack of data, technology, and resources on a national level [17], achieving the SDG 15.3.1 indicator has been challenging. The sub-indicators for SDG 15.3.1 comprised two specific metrics centered on forests and river rivulets [18]. However, land degradation isn't confined solely to forest cover and watershed regions; it can manifest across various land areas [4]. Land degradation is found to be consistent in the areas of active human activities, i.e., urban centers [19]. The advancement in technology, the increasing population, and unplanned human activities on land have gradually reduced land productivity and caused land cover changes caused by the growth of artificial areas. So, this study aims to identify degraded land in urban hub of Nepal and deduce the findings in the context of SDG.

The federal restructuring of the nation [20] has increased the urban areas, and so has the pace of urbanization in Nepal. The political decision of increment in urban areas has led to the beginning of the construction of new and unplanned urban structures [21]. The population residing in a metropolitan city is the highest among all. Lalitpur metropolitan city is the smallest metropolitan city in Nepal. Despite its recent declaration as a metropolitan city from a sub-metropolitan city, Lalitpur has captured attention in this study due to its ranking among the top four most populated areas [22].

1.2 Objective

The main objective of this study is

- to assess the portion of degraded land in the study area due to federal restructuring of the nation.
- to determine the trends in land productivity solely through remote sensing, without quantifying the magnitude of net primary productivity.

So, this study aims to address the questions about the changes in land productivity over time, the main influencing factors that help in declining the ecological productivity of land on one of the most urbanized cities of Nepal, Lalitpur Metropolitan City.

2. Methods and Materials

2.1 Study Area

The study area is Lalitpur Metropolitan City. Lalitpur metropolitan city (27.62- 27.69N, 85.29-85.36), located in the south-central part of Kathmandu Valley shares the characteristics with many other rapidly urbanizing cities. It is also considered as the fourth most populous city. The total area is 36.52 sq. km with, at an altitude ranging from 1,300 to 2,300 meters above sea level.

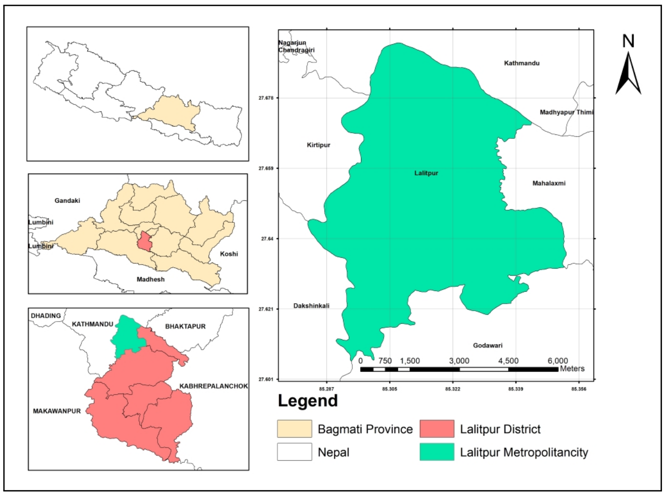

Figure 1: Study Area: Lalitpur Metropolitan City

In this study, land productivity is analysed using three metrics calculated from NDVI time series data: trend, state, and performance [2]. The analysis period for this study was taken from 2000 to 2021. This period is further broken down into baseline and target periods. Baseline period was taken from the year 2000-2017 and the target period was taken from the year 2018-2021. This study compares the loss in productivity in both periods. By setting the baseline period, the initial status of land productivity will be determined and with respect to which the status of land productivity in the target period can be compared. The data sets used in this study was Landsat 7 and 8 imagery provided by the U.S. Geological Survey, with 30m spatial resolution. These satellite images were directly accessed from the Google Earth engine. The overall methodology to compute the land productivity is shown in Figure 2.

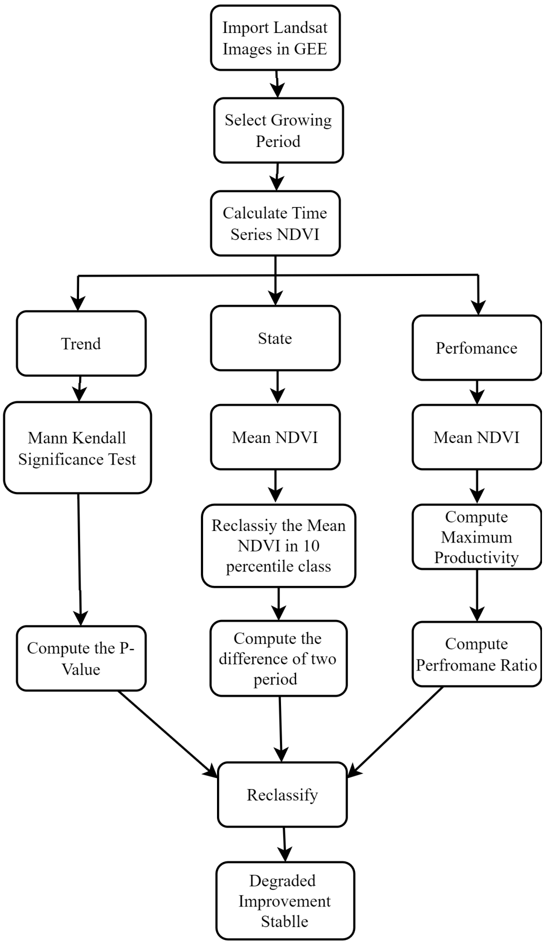

Figure 2: Research Methodology

The computation was done in the Google Earth Engine, a cloud-based platform, which involved handling a substantial volume of data. The data for the baseline period has total of 143 images and 41 images in the baseline period. Altogether, the analysis was performed in GEE using 184 images. Subsequently, the desired results of each measure of time-series NDVI were retrieved. The individual classification of each metrics were then amalgamated into a unified map using a raster calculator. The outcomes were then designed and exported into a map layout. The layout of map was created using QGIS.

The trend analysis is based on monotonic non-parametric tests to pinpoint significant long-term trends in NPP. However, this approach falls short in detecting short-term patterns of improvement or decline. So, the state captures the recent change in productivity by evaluating the long-term average against the latest period. The classification of degraded land follows the principle 'One Out All Out' [2]. The principle is that if any one of the pixels from the time series metrics of NDVI is identified as degraded, then that area is considered as degraded.

The analysis of productivity was focused on the vegetation growing season. In temperate regions, only by using NDVI time series data, it is easy to extract the distinct vegetation growing season [2]. The study area is situated in a temperate region [15]. Time series NDVI values of vegetation growing season, which was found to be spanned from the month of April to October were taken for the analysis. Similar to the study done by [23] the beginning of the vegetation growing season showed values of NDVI 0.22 and the end of the growing season showed 0.25.

2.2 Methods

2.2.1 Land Productivity: Trend

The trend is trajectory of land productivity over time. To test whether the set of NDVI values in each growing season of every year under analysis period, is significantly decreasing or increasing, at pixel level, a non parametric Mann-Kendall trend test was performed. It is the statistical method for determining the significance of the trend [24]. The Mann-Kendall statistic for the growth season is calculated as [25]. The Z score was computed of the trend test at a 95% confidence interval to determine trend significance. The probability of trend test value at p or below 0.05 was considered statistically significant trends [2]. The results were then classified based on the significant testing. Pixels with a p-value less than 0.05 were categorised as degraded and greater than 0.05 were classified as stable.

2.2.2 Land Productivity: State

The state compares recent changes in land productivity to historical observations within the same area. Firstly, the frequency distribution of time series NDVI values was computed. Then, the mean NDVI values of the baseline and target periods were computed. Then these mean NDVI values were assigned to each percentile class and reclassified into ten different classes. The difference in the class of target period and baseline period was computed. The class differences with values less than -2, greater than 2 and between -2 and 2 were classified as degraded, improvement, and stable, respectively [3].

2.2.3 Land Productivity: Performance

Performance compares the local productivity relative to other similar vegetation types in similar land cover types in the study area [26]. To test the performance, firstly, from the frequency distribution of time series NDVI values of analysis period, the mean value of NDVI of baseline and target period was computed. From the frequency distribution of time series NDVI values, the 90th percentile value was considered as maximum productivity as in [3] to avoid the probability of outliers in the data. Then, the ratio of observed mean NDVI values and maximum productivity was computed. The pixels whose ratio was less than 0.5 were classified as degraded areas, and those whose ratio was more than 0.5 were considered stable.

3. Results and Discussion

The results presented in this study is relative to the baseline period. The degraded land due to declining productivity of land in baseline period was 13.69%, and with respect to the baseline period, the degraded land in the target period was 16.85%. This makes the SDG 15.3.1 sub-indicator from 2000 to 2021 in Lalitpur Metropolitan City 30.54%, which means that 30.54% of land is degraded over the total area. The amount of degraded land in a 4-year span is higher than in a 17-year span. The status of each land degradation in each time series metric is discussed below in detail with its respective map.

3.1 Trend

The non-parametric trend test showed a significant declining trend of productivity at a confidence interval of 95% in both the baseline and target periods. Figures 3 and 4 illustrate a notable downward trend in productivity during both the baseline and target periods, covering an area of 0.43 sq km and 0.92 sq km, respectively. The decline in trend can be attributed to substantial changes in land cover within the area. Degraded land refers to areas that were previously croplands, grasslands, or barren regions but have now been converted into settlement areas during the target period.

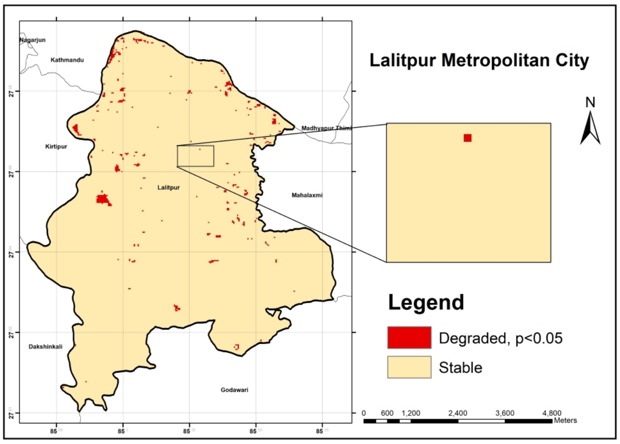

Figure 3: Trend: Baseline Period

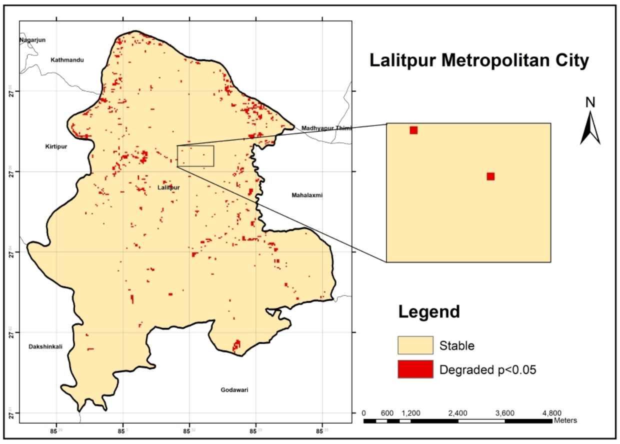

Figure 4: Trend : Target Period

Combining both trends from the baseline to target period, there is total decreasing trend of land productivity is 1.35 sq kms. The combined decreasing trend from baseline to target period is shown in Figure 5. The degraded pixel value was combined and then the total degraded areas was computed.

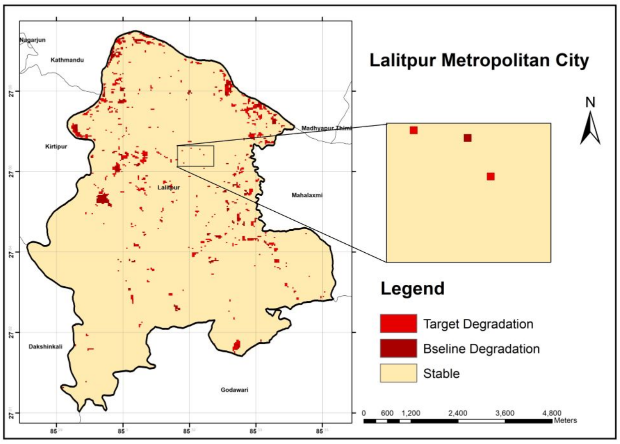

Figure 5: Trend : Baseline to Target Period

3.2 State

The state of land productivity in reference to the baseline period to target period was found to be area of 0.76 sq km. degraded, and the area 0.012 sq km was found to be improved in land productivity and remaining area shows no change. Figure 6 shows The state of productivity

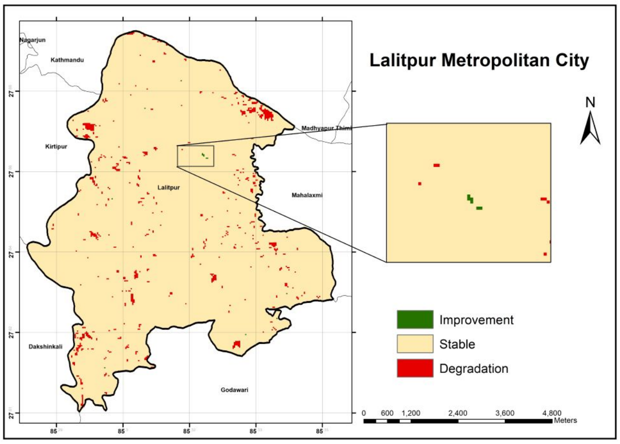

Figure 6: State: Baseline to Target Period

3.3 Performance

The land productivity performance ratio map of the baseline line and target period was generated. Figure 7 shows the productivity performance of the baseline period and Figure 8 shows of target period. Upon analysis, the areas exhibiting degraded portion were originally part of Lalitpur Municipality and is situated within the ring road.

Observation of Figure 7, and Figure 8, insights into the trajectory of land degradation in terms of its performance can be gained. From Figure 7, during the baseline period, the land performance deteriorated and the degraded area was found to be 4.57 sq km.

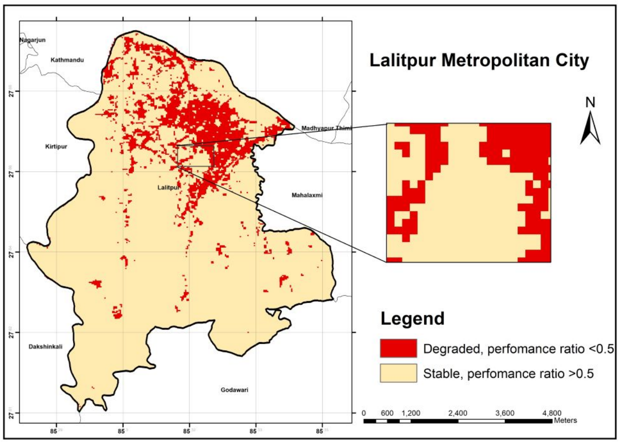

Figure 7: Performance: Baseline Period

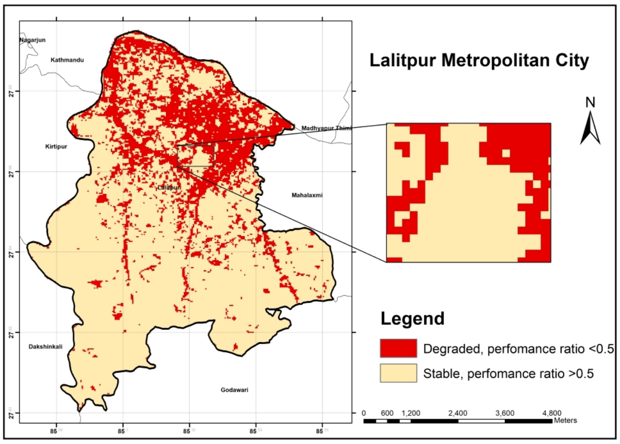

Figure 8: Performance: Target Period

Likewise, during the target period, the degradation in the productivity performance ratio was computed to be 4.47 sq km. When evaluating the entirety of the period spanning from baseline to target, the land's overall productivity performance experienced a degradation of 9.05 sq km. This is visually represented in Figure 9.

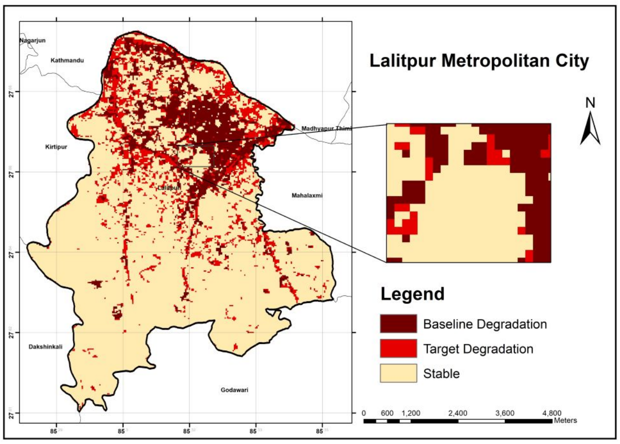

Figure 9: Performance: Baseline to Target Period

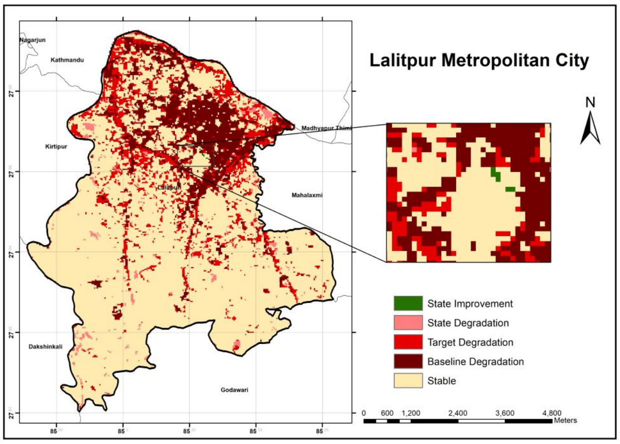

Figure 10: Land Productivity: Baseline to Target Degrdation

3.4 Land Productivity Degradation Metrics

The total degradation metrics of the land productivity were computed with the principle of the One Out All Out, approach. The resulting map illustrates the land productivity status throughout the analysis period from 2000 to 2021, as depicted in Figure 10. Combining all three degradation metrics, 11.15 sq km of study area was degraded from the 2000 to 2021. Also, Figure 11 and Figure 12 shows that in the baseline and target period, 5 sq km and 6.15 sq km land was degraded respectively. The pace of degradation was high in the target period as compared to the baseline period.

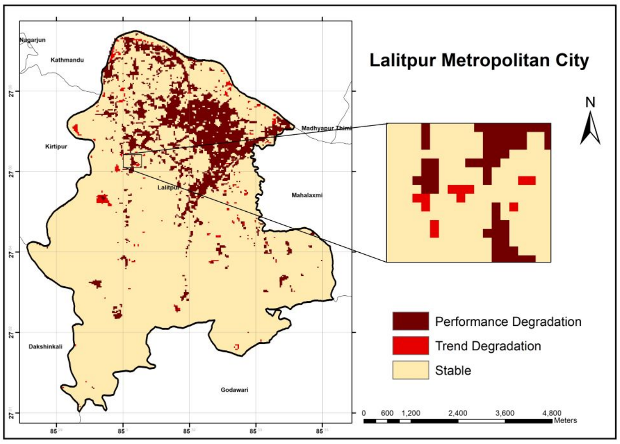

Figure 11: Land Productivity: Baseline Degrdation

The present Lalitpur Metropolitan City was established by amalgamating Lalitpur Sub Metropolitan City with three former Village Development Committees (VDCs): Bungamati, Sainbu, and Khokana. Previously, the Lalitpur Sub Metropolitan City was created through the merging of Lalitpur Municipality with three VDCs: Sunakothi, Dhapakhel, and Harisiddhi. During the baseline period, degradation was concentrated spatially in areas that were formerly part of Lalitpur Municipality. Following the declaration of metropolitan city status, the spread of degraded land is gradually extending towards the newly merged areas. The inclusion of road networks in the analysis indicates that a substantial portion of degraded land is located along newly constructed roads and inside ring road. Given that

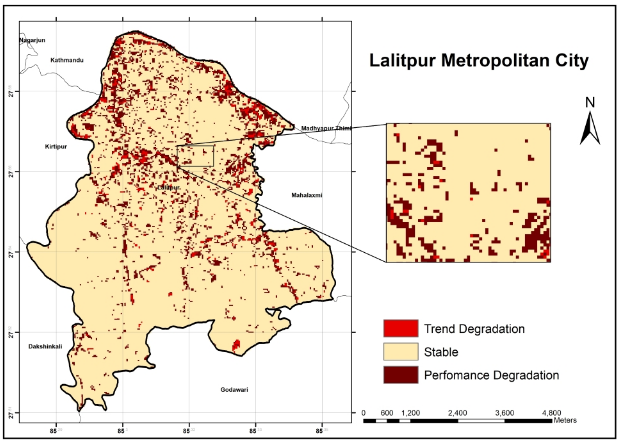

Figure 12: Land Productivity: Target Degrdation

municipalities serve as urban hubs in Nepal, there is a discernible reduction in land biological productivity concurrent with an increase in urban structures.

4. Conclusion

This study investigates the status of land degradation with the refined SDG 15.3.1 framework in Lalitpur Metropolitan City during 2000-2021. The proportion of degraded land is 0.3054 over the total area. The study area is experiencing serious land degradation due to population growth and rapid unplanned urbanization. The reason is the political decision on the federal restructuring of the nation which has led to the construction of new but unplanned urban structures. Also, the population residing in urban areas is increasing day by day. Key areas displaying degradation encompass locations with the construction of Lalitpur drainage planning plant, Money Plant Namuna Housing Society, Chyasal areas, Baghdol, construction of housing and apartments such as Civil Homes Dhapakhel and City Space, Bagmati corridor marga. Additionally, the conversion of cropland into barren land along the Bungamati River bank, the construction of greenhouses in cropland and Chwakampa marga contribute to the recent decline in land productivity compared to historical observations.

5. Recommendations

The study provided a general overview of the state of land productivity from the perspective of sustainable development. At present, initiating ecological restoration programs at the local level is of utmost importance to address ongoing land degradation issues. Strategies, policies, and programs at the national and local levels need to be formulated to achieve sustainable development goals. The study suggests integrating the framework into Nepal's Sustainable Development Goals Progress Assessment Report for a comprehensive evaluation of SDG 15.3.1 across all areas, extending beyond forests and rivulets. Integration ideas could address challenges related to data availability. Furthermore, the framework employed in this study can serve as a reference to conduct a thorough analysis of the impact of the metropolitan city on the land productivity of adjacent municipalities and scaling up nationwide. Moreover, this research paves the way for exploring additional sub-indicators such as land cover and soil organic carbon stocks to comprehensively assess the SDG 15.3.1 indicator. The framework utilized in this study for estimating degraded land could offer valuable case studies applicable to humid regions worldwide.

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