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Land Degradation and Urban Expansion in Nagarjun Municipality, Kathmandu, Nepal

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Abstract

Land degradation poses a serious global challenge with around 25% of world's land mass degraded badly affecting over 1.5 billion people worldwide. Urbanization plays fairly a significant role among major contributors as expanding cities tend to rapidly convert agricultural land into sprawling built-up areas. This study utilizes MEDALUS framework assessing land degradation vulnerability in Nagarjun Municipality situated within Kathmandu Valley of Nepal somewhat effectively. Four composite indices were calculated including Soil Quality Index by 1.318 and Vegetation Quality Index standing at 1.261. Values were combined rather haphazardly deriving an Environmental Sensitivity Area Index score of 1.566 pretty precisely it seems. This value puts area directly in critical degradation category exceeding severe vulnerability threshold of 1.37 pretty significantly in our time. Major contributing factors include steep slopes and shallow erosion-prone soils alongside unhappily insufficient vegetation coverage with merely 44% of land protected. Nagarjun has rapidly emerged as a swiftly rising suburban region within Kathmandu Valley at the same time. By 2018 it had backed 3477 businesses employing 11001 people and saw a rather quick spike in demand for housing. Rapid urban expansion alters land use pretty drastically and puts tremendous pressure on infrastructure heightening erosion risks significantly everywhere. High-risk zones should be prioritized for reforestation efforts and rigorous erosion control measures while land-use planning gets guided by robust data.

Keywords: *Land degradation, urbanization, soil erosion, MEDALUS methodology, Environmental Sensitivity Area Index (ESAI), Soil Quality Index (SQI), Vegetation Quality Index (VQI).*

Introduction

Land degradation, which refers to the decline in land productivity due to both natural and human-induced factors, is recognized as a serious worldwide concern. It is often associated with soil erosion, deforestation, loss of biodiversity, and depletion of water resources threatening both ecosystems and human livelihoods (UNCCD, 2020). Desertification is the consequence of a set of important degradation process in the especially in semi-arid and arid region (Kosmas et al., 1999). The rapid pace of contemporary urbanization is contributing significantly to this issue. As urban areas are expanding, they are replacing fertile agricultural land, forests, and wetlands, which in turn are causing habitat destruction, pollution, and a higher risk of environmental disasters. It is estimated that more than half of the global population is now residing in cities, and this proportion is expected to reach nearly 70% by 2050. As a result, there is growing competition between urban development and agricultural land use, which is contributing to soil sealing and accelerated erosion.

Nagarjun Municipality, located on the north-western edge of the Kathmandu Valley, is serving as a prime example of how urban expansion is interacting with environmental stress. The municipality is bounded by Kathmandu Metropolitan City and several rural municipalities, and it spans an area of approximately 29.8 square km with elevations ranging from about 1,300 meters to 2,782 meters above sea level (Municipal Profile of Nagarjun Municipality: Volume II/V). The region is characterized by steep terrain and a monsoonal climate, making it vulnerable to soil erosion and landslides. In the past, higher elevations were mainly covered by forests or used for terraced farming, while settlements were concentrated in the lower valleys. In recent years, there has been a noticeable increase in suburban housing and commercial development, which is transforming forested and agricultural land into built-up zones. These changes are contributing to intensified soil erosion, localized flooding, and reduced biodiversity.

This study investigates the overlooked interaction between urbanization and land degradation in Nagarjun Municipality using the MEDALUS framework. It assesses environmental vulnerability through key indices (SQI, VQI, CQI, MQI, ESAI) and analyzes urban expansion impacts. Findings aim to inform sustainable land management strategies and guide policy decisions balancing development with ecological resilience.

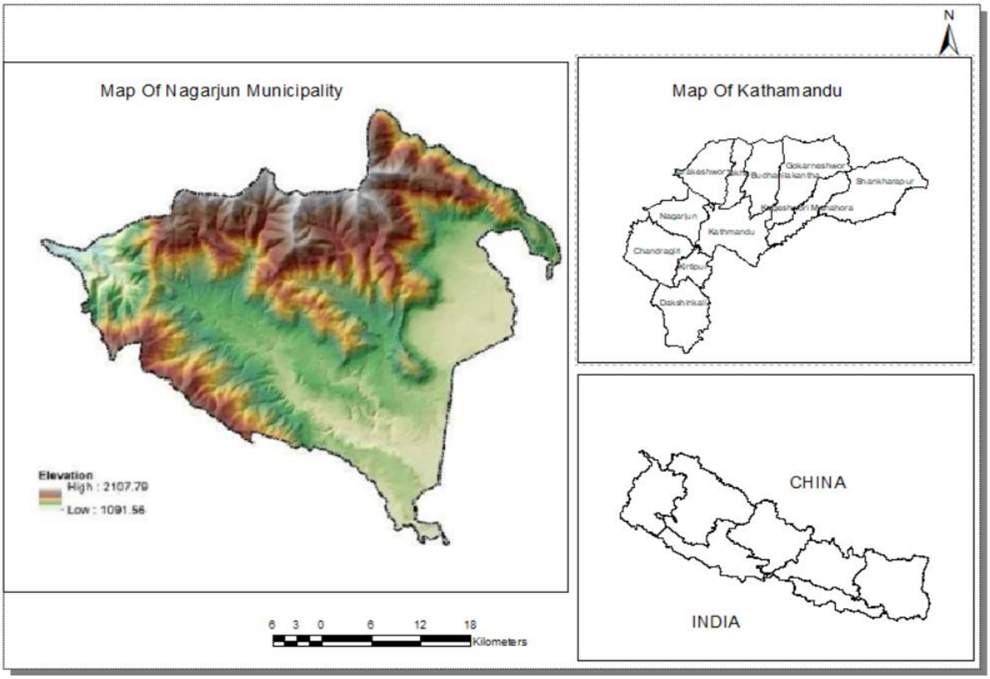
Methodology

Study Area and Site Characteristics

Nagarjun Municipality, located in Bagmati of Nepal, is composed of wards that were he study area, Nagarjun Municipality, is located between 85°12′ to 85°17′ east longitude and 27°40′ to 27°44′ north latitude. It was formed by merging five former village development committees and is known for its varied terrain, ranging from approximately 1,300 meters in the valley floors to 2,782 meters at the summit of Nagarjun Hill, which lies within the Shivapuri-Nagarjun National Park (Figure 1), characterized by steep ridges and deep gorges, and nearly one-third of the land is found to have slopes steeper than 18%, which is known to increase the speed of surface runoff significantly. On the upper slopes, dense temperate forests consisting mainly of oak (*Quercus*) and rhododendron species are present, while the lower slopes and terraced areas are used for growing subtropical crops such as rice, maize, and vegetables on inherited agricultural land.

Figure 1

Location Map of the Study Area



The region is characterized by steep ridges and shallow depression, and nearly one-third of the land is found to have slopes steeper than 18%, which is known to increase the speed of surface runoff significantly. The lower slopes and terraced areas are used for growing subtropical crops such as rice, maize, and vegetables on inherited agricultural land. Despite this, road development and construction activities are causing visible fragmentation. The area experiences a subtropical to temperate climate, where summers are typically warm with temperatures reaching up to 30°C, and winters remain relatively cool. Rainfall is abundant, ranging between 1,500 and 2,700 mm annually, with most of it falling from June to September. This rainfall pattern is responsible for creating alternating periods of wet and dry conditions, which often put stress on the soil. Given the steep terrain and seasonal climatic shifts, the region is naturally prone to erosion. When combined with increasing development pressure, there is a clear need for urgent assessment of land degradation risks in the area.

Methods and Materials

The study adopts a pragmatist research philosophy that integrates both positivist and interpretivist approaches. Quantitative geospatial and statistical methods represent the positivist side, while the interpretivist aspect involves the qualitative and quantitative analysis of secondary data. Satellite imagery from sources such as Landsat and Sentinel is used to monitor land cover dynamics, and GIS-based land use and land cover (LULC) maps are analyzed. Supplementary data are obtained from Nepal's Survey Department, the Nagarjun Municipality Profile (2076, Volume II/V), and various national environmental datasets, including land capability, soil, temperature, rainfall, and vegetation. Tools such as Google Earth Pro assist in processing and visualizing this information to evaluate environmental changes in the region.

Topography and soil characteristics

Topographical and soil features play a vital role in influencing soil vulnerability across Nagarjun. The area is characterized by varied terrain and is underlain mainly by sedimentary rocks, which are prone to weathering and result in sandy and silty loam soils. According to data carried out using the MEDALUS framework, soil samples from wards 1, 3, 5, 7, and 8 were examined to assess texture, depth, and drainage.

Soil texture is found to be a key factor in erosion susceptibility. Sandy loams, which are prevalent on steep slopes covering around 60% of the municipality, are less cohesive and retain minimal moisture. In contrast, the lower zones with loamy soils are able to hold more water. However, approximately 70% of soils in the study area are classified as shallow or very shallow, which restricts both root development and water retention. Field observations reveal that urban expansion and the neglect of traditional terrace farming are contributing to compaction and the loss of organic content, which further decreases fertility. Overall, the soil quality in Nagarjun is highly variable, with certain zones showing resilience while others face elevated degradation risks due to their physical and land-use characteristics.

Result and Discussion

This independently conducted study faced challenges such as limited historical data, difficult terrain, and low stakeholder engagement. Although predictive models may not reflect all socio-cultural complexities, the research offers meaningful insights into the dynamic relationship between urban growth and environmental sustainability. No conflicts of interest were reported.

Khanal et al., 2008 argues that Nepal is naturally prone to soil erosion, flooding, and landslides, as it is shaped by rugged topography, monsoon weather patterns, and tectonic activity. These natural risks are worsened by population growth, dependence on traditional energy sources, and inadequate land management practices. It is estimated that around 28.24% of Nepal's land is affected by desertification, with negative impacts on 36% of forests, 10% of farmland, and 37% of grazing areas. Between 1984 and 2003, about 1% of the total land area was damaged by natural disasters, and nearly 2% of forests were lost. While properly maintained terraces and forests are effective in reducing erosion, neglected lands are more likely to experience severe degradation. The restoration of over 4 million hectares of degraded land is considered essential for enhancing long-term ecological resilience.

According to Amaefuna et al. (2024), weak enforcement of urban planning laws and ineffective legal frameworks are responsible for accelerating land use changes, largely driven by increasing demand for space. As a result, land conflicts, ecological degradation, and major environmental transformations have become more common. Urban sprawl into wetlands and riverbanks has contributed to overcrowding, higher waste production, rising urban temperatures, and coastal degradation. To manage these impacts, there is a need to adopt energy-saving measures, encourage the development of green spaces, and engage communities in the planning process.

Despite growing environmental challenges, Nepal is yet to implement strong, targeted policies to combat desertification, land degradation, and drought. There is no comprehensive food security policy, and although the Land Use Council has approved a land use strategy, it is neither inclusive nor thorough. The imperative need for integrated policy frameworks focused on land use, rangeland management, soil protection, and watershed management are still largely unmet.

Land Degradation Vulnerability Assessment

This study makes use of the MEDALUS (Mediterranean Desertification and Land Use) methodology to conduct a comprehensive assessment of land degradation vulnerability. The Environmentally Sensitive Area Index (ESAI) is calculated as the geometric mean of four key sub-indices: Soil Quality Index (SQI), Vegetation Quality Index (VQI), Climate Quality Index (CQI), and Management Quality Index (MQI). This method is recognized as an effective approach for analyzing land degradation on a regional scale (Imbrenda et al., 2021). Through the integration of these indicators, it becomes possible for policymakers to formulate strategies aimed at sustainable land management and environmental protection.

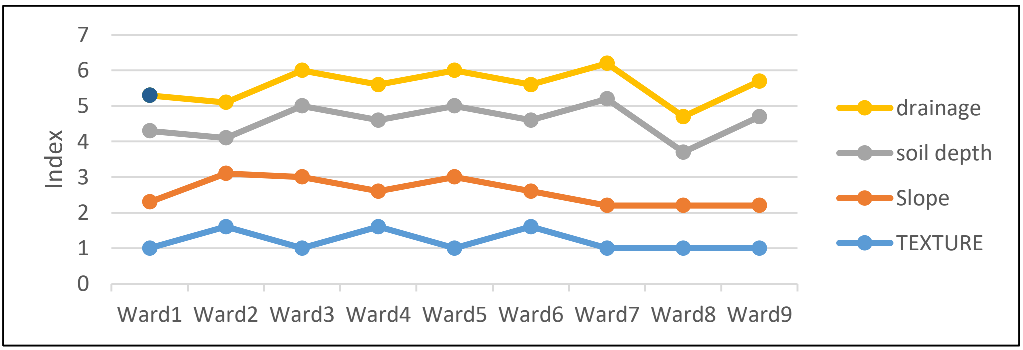
In this assessment, SQI was based on soil-related parameters such as texture, slope, depth, drainage, and parent material, although rock fragmentation could not be included due to limited time and lack of data. CQI was evaluated by considering climatic variables like mean rainfall, average temperature, and the aspect of slopes. VQI was developed using indicators such as vegetation cover, fire risk, erosion protection, and drought resistance. MQI was derived from data related to land use type, land use intensity, and relevant policy conditions. The area is observed to be under significant environmental stress, which includes accelerated soil erosion, rapid vegetation loss, and intense human-induced pressure on natural resources. Geological and soil characteristics are found to be major contributing factors. More than 60% of the municipality is covered by sandy loam or silty loam soils located on slopes greater than 10%. As these soils are mostly shallow around 70% of the area, they are poorly resistant to erosion. When this is combined with the steep slopes present in the region, it results in increased vulnerability due to heightened runoff and reduced soil stability.

SQI = (TEXTURE*SLOPE*SOIL DEPTH* DRAINAGE)1/4

By this formula Soil Quality index is calculated based on land use and soil data which is produced by survey department of Nepal.

Figure 2

Soil Quality Index Chart



Soil fertility

The average Soil Quality Index (SQI), around 1.318, by the soil quality table is indicative of moderately good soil conditions in certain areas (Kosmas et al., 1999). However, the eastern and southern fringes are marked by the most degraded soils, where organic matter is low and compaction is severe. These locations are also where unplanned development has been most intense. As a result, the soils are unable to retain water and nutrients effectively, which has been contributing to a significant decline in land productivity.

Land Use, Vegetation, and Climate Impacts

Land use in Nagarjun has been undergoing significant transformation, reflecting its shift from a primarily agrarian area to a peri-urban zone. Agricultural terraces that were once used for growing rice, maize, and vegetables are now being replaced by residential and commercial constructions. The initiation of the Comfort Housing project in the southern part was a major turning point, as it triggered a wave of housing developments and led to a noticeable increase in land prices. By 2018, there were 3,477 establishments recorded, employing around 11,001 individuals, which indicates how swiftly urbanization has been taking place. Farmland has become fragmented, while activities such as roadside quarrying and waste dumping have been disturbing soil stability. In contrast, the upper elevations are still covered with relatively healthy forests consisting of species like oak, khayer ,schima, and rhododendron, which are vital for slope protection. However, these forest margins are not entirely safe, as they are being affected by road construction and unauthorized grazing.

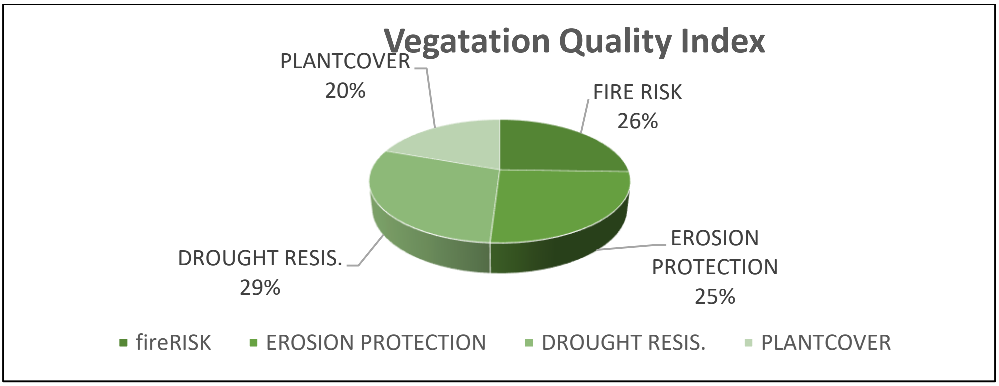
Vegetative cover is known to be an essential barrier against soil erosion. Based on satellite imagery and field observations, the Vegetation Quality Index (VQI) was calculated as the fourth root of four key parameters: fire occurrence, soil erosion control, drought tolerance, and canopy density.

$$\text{VGI} = (\text{fire risk}*\text{erosion protection}*\text{drought resistence}*\text{ plant cover})1/4 = 1.262$$

The obtained VQI was found to be 1.262, which is considered high (Figure 3). This outcome suggests that the municipality's vegetation cover has been high-quality by least amount wildfires and human clearance activities. Presently, only about 44% of the area is covered by dense vegetation, while the remaining land consists of exposed surfaces, urban developments, or sparsely vegetated plots that are not adequate to control erosion. Furthermore, regions affected by fire tend to have limited undergrowth, which slows down natural recovery.

Figure 3

Vegetation Quality index Chart



Climate factors are contributing to land degradation risks in Nagarjun. The Climate Quality Index (CQI) is 1.260, indicating moderate climatic stress. This index is based on rainfall distribution, temperature extremes, and aridity. The area is known for its strong seasonality there are intense monsoon rains in summer and very dry winters. Such imbalance in water availability is a major concern. During the monsoon, heavy rainfall causes high runoff, especially on bare slopes, while in winter, dry spells lead to soil cracking. Data from Kakani station (2,066 m) shows that monthly rainfall ranges from about 5 mm in winter to over 900 mm in summer, with temperatures varying between 0.3°C and 22.7°C. This climatic variability, combined with moderate vegetation cover, makes the land highly vulnerable to erosion and moisture stress.

The Bagnouls-Gaussen Aridity Index (BGI) is a simple tool used to measure the dryness or aridity of an area based on temperature and rainfall data. It helps assess how much moisture is available, using easily accessible weather records (Kosmas et al., 1999).

$$BGI = \sum_{i=1}^{n} (2Ti - Pi) * k$$

Where:

T = Average temperature of the month (°C)

P = Total precipitation (rainfall) for the month (mm)

k = A factor that determines whether the month is arid (k = 1 if dry, 0 if not)

CQI = (rainfall* aridity*aspect)1/3 = 1.260

Table 1

Climate Quality Index Table

Average Temperature (℃)	Average Rain Fall (cm)	BGI
20.3	9.32	31.28

Slope aspect includes NW, NE and SW, SE assigning indices 1and 2, respectively (figure 4). These slopes receive more direct sunlight, making them warmer and drier. They often lose moisture faster, which can affect soil quality and plant growth.

Management Quality (Anthropogenic Stress)

Rapid urbanization and population growth are increasing pressure on natural resources, landscapes, and ecosystems through construction, transportation, and industrial activities. These human-induced actions are referred to as anthropogenic stress, which is seen in problems like water depletion, air pollution, and reduced green spaces. The municipality's response to these issues is a sign of its ability to manage and reduce such stress. Solutions are being proposed, including the promotion of eco-friendly transport, better waste management, and the protection of biodiversity, so that a balance between development and nature is maintained. The Management Quality Index (MQI) is used to assess how effectively land is managed, as it is based on land use intensity and the implementation of environmental protection policies.

$$MQI = (\text{Land use intensity} * \text{Policy enforcement})\ ½ = 3.04$$

This formula combines the intensity of land use with how strictly environmental policies are enforced. Depending on the values of these factors, the resulting MQI can be categorized into different classes. Below is a simplified explanation of the assessment parameters used in land management, based on defined standard table.

Figure 4

Aspect Map of Nagarjun Municipality

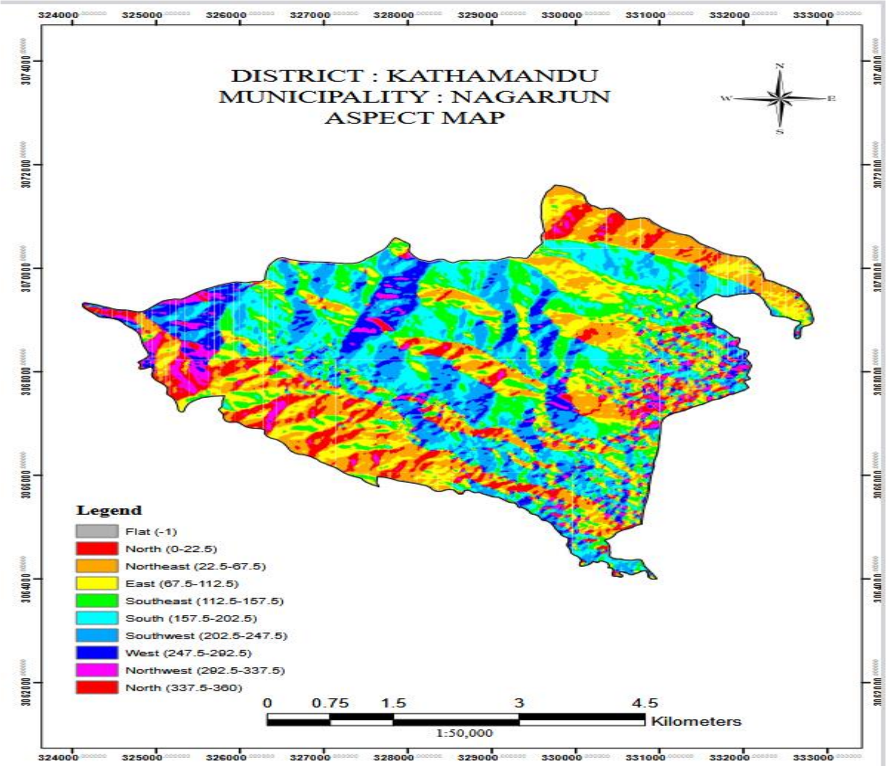


Table 2

Land use intensity

Cropland			Natural Areas			Mining Areas			Recreation Areas		
Land use intensity (Index)			Management Characteristics (Index)			Erosion control (Index) Measures			Visitor Ratio (Area/Population)		
Low	Medium	High	Low A/S=0	Moderate A/S<1	High A/S≥1	Low	Moderate	High	Low (Ratio is>1)	Medium (Ratio range bet^{n}1-2.5	High Ratio >2.5
1	1.5	2	1	1.2	2	1	1.5	2	1	1.5	2

Policy Enforcement

Degree of Protection:

High: Over 75% of the area is under protection (Index = 1)

Moderate: Protection covers 25–75% of the area (Index = 1.5)

Low: Less than 25% of the area is protected (Index = 2)

This index helps land managers evaluate how effective their practices are by combining land use intensity and policy enforcement levels. Understanding the MQI shows where improvements are necessary to support sustainable land management.

Land Degradation

The Environmentally Sensitive Areas Index (ESAI) serves as a simplified final measure to identify regions with different levels of vulnerability to land degradation. It is calculated by taking the geometric mean of four equally weighted sub-indices. Following the MEDALUS methodology (Kosmas et al., 1999), ESAI classifies areas into four categories that reflect the severity of land degradation (Basso et al., 2000; Lavado et al., 2009). This classification enables researchers and policymakers to systematically evaluate and prioritize regions that require intervention to combat land degradation. The algorithm offers a comprehensive approach to quantify soil quality and its susceptibility to degradation.

The ESAI is computed as:

$$ESAI= (SQI*CQI*VQI*MQI)^{1/4}$$

Based on standard classification, The ESAI values range from below 1.17 indicate “unaffected” conditions; values between 1.17–1.22 are “potentially affected”; those ranging from 1.23 – 1.37 are classified as “fragile”; and values above 1.37 signify “critical” degradation. As this result is well above the 1.37 threshold, Nagarjun Municipality is categorized within the “critical” degradation zone. With an ESAI value of 1.589, this region is in a critical state of land degradation. This suggests that severe environmental stress exists, with active processes such as soil erosion and declining vegetation cover negatively impacting the landscape. Therefore, urgent measures are required to prevent further deterioration and to promote sustainable land management.

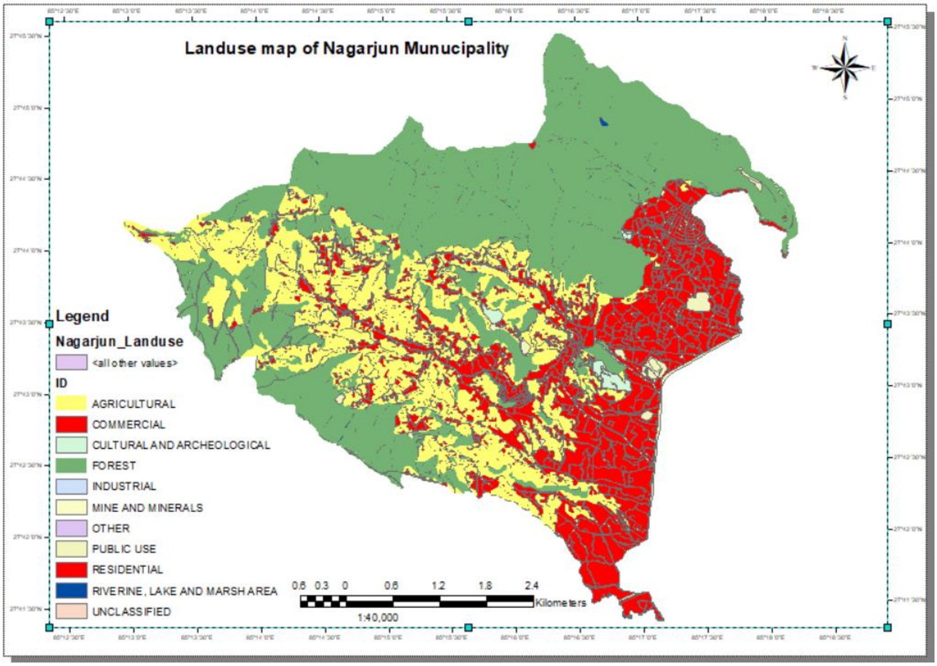
Urban Expansion

Urban expansion is known to intensify land degradation, yet significant gaps in knowledge remain regarding its wider effects. The question of whether current policies are effectively managing rapid urbanization remains open. If these gaps are not addressed, there is a risk that land resources crucial for both human livelihoods and environmental health will suffer irreversible damage. Meeting this challenge calls for evidence-based policymaking, sustainable land governance, and forward-looking urban planning to foster harmony between development needs and ecological preservation.

Nagarjun has experienced rapid peri-urban growth due to its closeness to Kathmandu, better road access, and availability of services, which have attracted both migrants and developers. The initial project by Comfort Housing in the southern area led to many developers following suit, resulting in a significant increase in housing construction and land prices. According to the National Economic Census of 2018, there were 3,477 establishments, including shops, factories, and service providers, employing 11,001 people. This rapid development has visibly transformed farmland and forests into built-up areas. Roads, parking spaces, and buildings now interrupt the once continuous rice terraces, causing the loss of cultivable land. Construction debris is sometimes disposed of on empty plots, introducing pollutants and further destabilizing the soil.

Figure 6

Land Use Map of Nagarjun Municipality

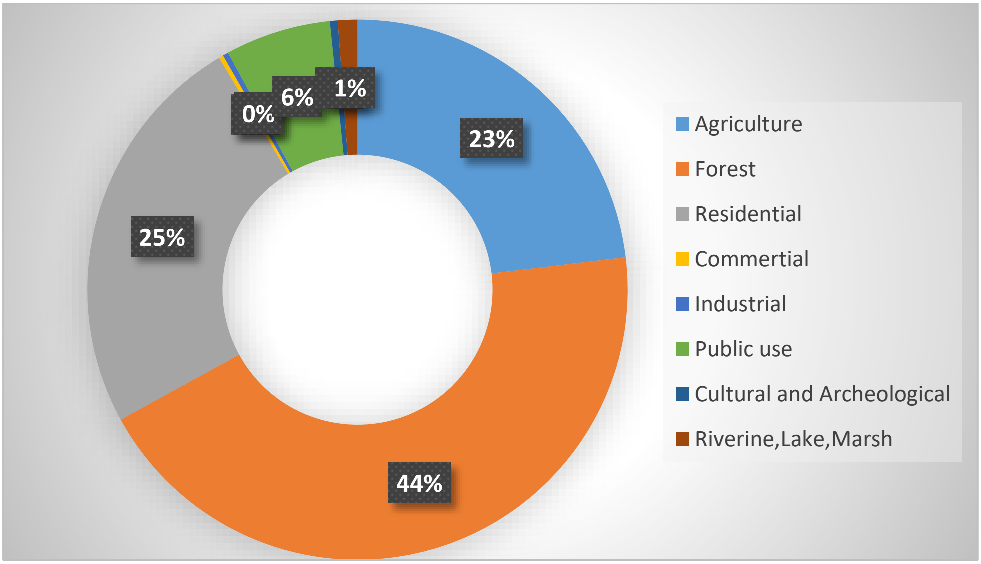


Source: Survey Department of Nepal, 2021

These urbanization trends have intensified land degradation. Paved areas prevent rainwater from soaking into the ground, which increases surface runoff and the risk of flooding. Additionally, sealing the surface reduces groundwater recharge, which can lower the base flow during dry seasons. As housing replaces terraced fields, the removal of traditional conservation features like contour walls and stone bunds leads to deeper erosion during heavy rains. For instance, many small landslides have been noted along new road cuts, directly caused by clearing vegetation for construction. Simultaneously, declining agricultural productivity near the peri-urban edge has pushed farmers to leave their fields and seek employment in the city, which perpetuates a cycle of rural land degradation driving further urban expansion.

Figure 6

Landuse Doughnut of Nagarjun Municipality



Source: Land use Map Survey Department of Nepal (FY 077/78)

Topographical and soil features play a vital role in influencing soil vulnerability across Nagarjun. The area is characterized by varied terrain and is underlain mainly by sedimentary rocks, which are prone to weathering and result in sandy and silty loam soils. Fieldwork using the MEDALUS framework shows that soil in Nagarjun Municipality is highly variable. Sandy loams on steep slopes are erosion-prone, while loamy soils in lower zones are more fertile. Around 70% of soils are shallow, limiting moisture retention and root growth. The overall Soil

Quality Index is 1.319, suggesting moderate quality, though urbanization and terrace abandonment are reducing fertility in vulnerable areas.

Conclusion

Nagarjun Municipality is undergoing significant land degradation, driven largely by rapid urban expansion. With an ESAI score of 1.589, the area falls into the "critical" vulnerability category. This circumstance arises from a combine of natural and human factors, as well as steep and erosion-prone slopes, frequent wildfires, and the high decline of vegetation cover, now limited to just 44% of the area. Human-induced pressures such as uncontrolled construction and unsustainable land use changes are intensifying soil erosion and disrupting natural water flow.

These local challenges reflect worldwide patterns. The urban growth in Nagarjuna acts both as a cause and effect of land degradation, creating a feedback loop that calls for integrated management approaches. As urban populations are projected to reach 70% of the global total by 2050, peri-urban areas are under growing pressure. The conversion of green spaces and farmland to build environments not only reduces carbon and water retention capacity but also elevates the risk of natural hazards like flooding and wildfires. In Nagarjuna, such transformations are already affecting ecosystem resilience.

Addressing these issues call for a multi-faceted approach: ongoing monitoring, targeted erosion control in the most vulnerable areas, integrated land-use planning supported by GIS and zoning tools to protect ecological assets, participatory planning and stronger enforcement of environmental regulations. Promoting public awareness and green infrastructure will also be key. Sustainable urban development hinges on informed planning, community engagement, and long-term environmental stewardship. There remain many aspects of this region that are not fully understood, and continued research could yield new insights and deeper understanding.

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