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Influence of Anthropogenic Activities on Spatio-Temporal Land Use Change in the Tungu–Nithi Sub-Catchment, Tharaka Nithi County, Kenya

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Abstract

Anthropogenic activities significantly modify the River Tungu and Nithi sub-catchment, influencing biodiversity and ecological balance. This prompts a need for a thorough understanding of their effects for effective conservation efforts. This study aims to map the influence of anthropogenic activities on land use change by integrating remote sensing with non-parametric statistical tests within the Tungu-Nithi sub-watershed. This research employs the meta-ecosystem perspective theory as its conceptual basis and utilizes mixed-methods research design. The results showed that vegetation cover and settlements increased by 19.1% and 6.7%, respectively. Conversely, there was a decrease in bare land, road networks, river area, and other land uses by 6.0%, 12.5%, 2.2%, and 5.8%, respectively. The chi-square test revealed a significant influence of anthropogenic factors on land use change, with a p-value of 0.001. The government needs to develop an integrated land use plan and strengthen collaboration to raise public awareness and encourage sustainable land use practices through environmental education.

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Abstrak

Aktivitas antropogenik telah memodifikasi sub-daerah aliran sungai (DAS) Tungu dan Nithi, memengaruhi keanekaragaman hayati dan keseimbangan ekologis. Hal ini mendorong perlunya pemahaman menyeluruh tentang dampaknya untuk upaya konservasi efektif. Studi ini bertujuan memetakan pengaruh aktivitas antropogenik terhadap perubahan penggunaan lahan dengan mengintegrasikan penginderaan jauh dengan uji statistik non-parametrik di sub-DAS Tungu-Nithi. Teori perspektif meta-ekosistem digunakan sebagai dasar konseptual dan menerapkan desain metode campuran. Hasil menunjukkan bahwa tutupan vegetasi dan permukiman meningkat sebesar 19,1% dan 6,7%. Sebaliknya, terjadi penurunan lahan terbuka, jaringan jalan, luas sungai, dan penggunaan lahan lainnya sebesar 6,0%, 12,5%, 2,2%, dan 5,8%. Uji chi-square menunjukkan pengaruh signifikan aktivitas antropogenik terhadap perubahan penggunaan lahan dengan nilai p = 0,001. Pemerintah perlu mengembangkan rencana tata guna lahan terpadu dan memperkuat kerja sama untuk meningkatkan kesadaran masyarakat dan mendorong praktik tata guna lahan berkelanjutan melalui pendidikan lingkungan.

INTRODUCTION

River sub-catchments are vital parts of the global environment, offering essential services such as water supply, food production, transportation, and recreation (Tiwari et al., 2023). These systems function as integrated socio-ecological units where biophysical processes and human activities are closely interconnected, making them particularly sensitive to external pressures. However, these valuable sub-catchments face increasing threats from various human activities, including land use changes like rapid growth in crop farming, resource extraction such as gravel mining, infrastructure development, and water withdrawal (Zhou et al., 2024). The expansion of these activities often occurs without adequate planning or environmental safeguards, leading to the introduction of pollutants, habitat fragmentation, and altered flow patterns, which in turn cause significant impacts on the ecological balance and functioning of riverine systems (Mukherjee et al., 2020).

In Africa, the freshwater resources flowing through have been heavily polluted, particularly the River Bonsa Tarkwa Nsuaem, Ghana (Obiri-Yeboah et al., 2021). Activities like illegal mining, domestic water use in river systems, the release of untreated household and industrial waste into water bodies, and agricultural pollution contribute to the contamination of water bodies, thereby affecting water quality (Obiri-Yeboah et al., 2021). These pressures are compounded by weak enforcement of environmental regulations and limited institutional capacity in many developing regions. Water resources in the East African region are under pressure due to factors including soil erosion and siltation, destruction of water catchments, low compliance with water regulations, inefficient water use strategies, invasive species, uncontrolled ballast harvesting, and over-abstraction of water resources (Tramberend et al., 2021).

Kenya is experiencing a persistent water crisis caused by several factors, including infrastructural developments, crop farming, deforestation, mining, poor water management strategies, water contamination, and rapid population growth (Mwirigi et al., 2024). While issues such as deforestation, poor water management, and water contamination could potentially be addressed, the increasing frequency and intensity of droughts and floods are linked to ongoing climate change, which is expected to become more unpredictable in the future (Veldkamp et al. 2020). This is associated with the degradation of the river sub-catchment.

The Tungu–Nithi catchment has important ecological components, including water quality, soil, vegetation, and aquatic life, which have undergone significant changes over the last two decades due to anthropogenic activities. Located within a rapidly transforming socio-economic landscape, the catchment has become increasingly vulnerable to land use pressures driven by both subsistence and commercial activities. This study is aimed at mapping the influence of human-induced changes on land use patterns within the catchment, emphasizing the spatial and temporal dynamics. By analyzing the land use, the study provided insights into how human actions had influenced the ecological landscape of the catchment, highlighting the need for sustainable management practices to preserve biodiversity and ecological integrity (Abuyeka Tela & Masayi, 2023).

Satellite imagery evaluated how human activities had shaped land use dynamics between 2005-2025. This period captures critical phases of development, policy shifts, and population growth that are likely to have influenced landscape transformation. Land use changes track landscape transformation and anthropogenic pressures such as infrastructure development, crop farming, deforestation, and gravel extraction. The integration of satellite imagery has emerged as an effective tool for monitoring these changes, offering high-resolution images that allow for detailed temporal analysis. By complementing traditional methods such as ground survey and historical data analysis, satellite imagery enhances the accuracy and reliability of land use assessments (Awate & Nagne, 2025). As a result, remote sensing provides a robust basis for understanding long-term environmental change in data-scarce regions. This study focuses on the Tungu-Nithi Sub catchment, aiming to fill existing research gaps and provide insights into the spatial-temporal land use changes driven by anthropogenic activities.

Many studies focused on specific land use, such as agriculture, leaving a need for a comprehensive analysis that considers other land uses such as settlement, recreational activities, and gravel extraction. Such sectorspecific approaches often overlook cumulative and interactive effects on river systems. A study by Kirema (2020) on the effects of land use on the Thanantu River found that there was a water shortage within Tharaka Sub-county because of irrigation farming. Land use practices need to be regulated and managed, else they will harm the rivers. Therefore, this study aimed at mapping the influence of anthropogenic activities on spatial-temporal changes in land use, such as crop farming, infrastructure development, and gravel extraction within the Tungu-Nithi sub-catchment. This research reveals how human activities influence land use and ecosystems, informs watershed management strategies, promotes sustainable practices, and guides policymakers to enhance collaboration for environmental sustainability.

METHOD

Research Design

This study employed a mixed-method research design, utilizing remote sensing techniques and conventional statistical methods to explore the influence of anthropogenic activities on land-use change. Therefore, this study indirectly integrated qualitative and quantitative approaches to enable the translocation of data sources and increase the robustness of the findings in understanding human-environmental interactions. Combining land-use data obtained through remote sensing with socio-ecological data from household surveys at the regional level allows for a clearer understanding of the relationship between land use and ecosystem service benefits. Remote sensing information can represent landscape patterns and dynamics, while household survey data reflect community involvement in production systems, such as rice farming, and their perceptions of ecosystem service benefits. The integration of these two data sources provides a more comprehensive picture of the interaction between human activities and landscape structure in supporting household well-being (Zaehringer et al., 2017).

Study Location

The study was conducted in the Tungu-Nithi Sub-catchment, located in Mitheru Ward, Tharaka Nithi County, eastern Kenya (Figure 1). Tharaka Nithi County lies between latitudes 00° 07’S – 00°26’S and longitudes 37°19’E – 37° 46’E, and is bordered by Meru County to the north, Kitui County to the east, and Embu County to the south (Ogolla et al., 2019). Administratively, the county comprises five sub-counties: Meru South, Igambang’ombe, Maara, Tharaka North, and Tharaka South (KNBS, 2019). According to the 2019 national population census, Tharaka Nithi County had a population of 393,177 people and a total area of 2,609 km², indicating increasing demographic pressure on land and water resources (KNBS, 2019).

River Tungu and River Nithi are the main drainage systems within the sub-catchment. River Tungu originates from the slopes of Mount Kenya and flows through forested, agricultural, and rapidly urbanizing landscapes before joining River Nithi at Maringaniro in the Kamutiria area (Ogolla et al., 2019). The combined flow later joins the River Maara and drains into the Tana River. The rivers form administrative boundaries between Muthambi, Meru South, and Mitheru wards and are characterized by multiple tributaries that support riparian vegetation and aquatic ecosystems.

The Tungu–Nithi Sub-catchment experiences a bimodal rainfall regime, with long rains occurring between March and May and short rains between October and December. Mean annual rainfall ranges from approximately 1,500 to 2,800 mm, while temperatures range between 12°C and 30°C, with an average of 21°C (Ogolla et al., 2019). Rapid population growth, agricultural expansion, infrastructure development, and urbanization associated with Chuka University have intensified land use change and pressure on riparian zones, making the Tungu–Nithi Sub-catchment an appropriate case for examining the influence of anthropogenic activities on spatial–temporal land use dynamics (KNBS, 2019).

Type and Source of Data

Primary and secondary data were used in this study to understand the interactions between land-use change and human activities in the Tungu–Nithi Sub-catchment. This approach allows for the integration of spatial and non-spatial data to obtain a comprehensive picture of the environmental and social dynamics in the study area.

Primary data were obtained through questionnaires, checklists, field observations, and GPS survey points. Questionnaires were used to gather residents' perceptions of dominant anthropogenic activities such as

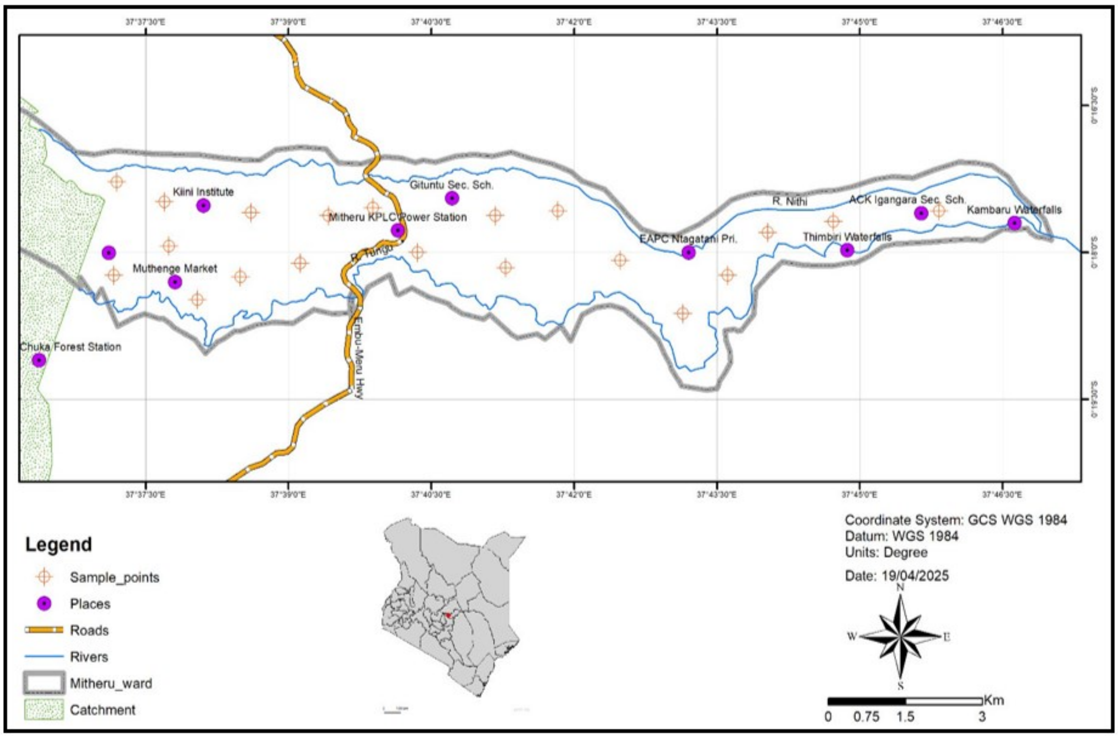

Figure 1. River Tungu-Nithi Sub-catchment

agriculture, gravel mining, infrastructure development, and settlements, as well as their perceived impacts on land use and river conditions. This data is crucial because it captures social dimensions and local experiences that cannot be captured through satellite imagery analysis (San et al., 2024). Checklists were used to systematically record observable land-use activities and environmental conditions within the Tungu–Nithi Sub-catchment, including riparian zone conditions, the presence of extraction activities, signs of erosion, and physical changes in the river as a form of field verification.

Secondary data consisted of Landsat satellite imagery and population census data. Landsat imagery was used to analyze spatial-temporal changes in land use, while population census data provided demographic context for the intensity of human activity in the study area. This integration of primary and secondary data enabled a more robust analysis of the relationship between anthropogenic pressures and land use change in the Tungu–Nithi sub-catchment. This integrative approach has been widely recommended in land use change studies because it enhances the validity of interpreting causal relationships between human activities and environmental change, particularly at sub-catchment and local scales (Geist & Lambin, 2002).

Population and Sample

The population is all individuals residing in a geographic area. The study population consisted of the residents of Mitheru Village in the Tungu–Nithi Sub-catchment. According to the 2019 national population census, Mitheru Village had a total population of 16,289 (KNBS, 2019). Mitheru Village was purposefully selected due to its rapid population growth between 2009 and 2019, which is associated with increased anthropogenic activities such as agricultural expansion, infrastructure development, gravel mining, and residential growth within the sub-catchment.

The sample size was determined from the total population using the Slovin formula (Yamane, 1973). This formula is considered appropriate for estimating representative samples where population variability is not fully known. The formula used to determine the sample size is equation 1:

$$n = \frac{N}{1 + Ne^2} \quad (1)$$

where n represents the sample size, N is the total population, and e is the margin of error. Assuming a margin of error of 0.05.

The calculation results indicate a sample size of 390,441. However, the final sample size was 390 respondents, rounded to the nearest whole number to facilitate field data collection.

In addition to household respondents, the sample included one local government water and sanitation officer and one official from NEMA to provide institutional perspectives relevant to land use and river management in the Tungu–Nithi sub-catchment.

Instrument Reliability

Instrument reliability testing was conducted to ensure that the questionnaire and observation sheets used in this study had an adequate level of consistency and stability in measuring the phenomena under study. Through a piloting phase, the instrument's content reliability was achieved, thereby increasing the research instrument's stability and reliability (Mugenda & Mugenda, 2003). This process aimed to ensure that each question item consistently represented the research variables and met the measurement objectives.

This study confirmed that the questionnaire and observation schedule produced consistent data when used in different locations under relatively similar environmental conditions. To evaluate this consistency, the researchers employed a test–retest reliability method by administering the questionnaire to the same group of respondents at two different measurement times, two weeks apart. The test–retest approach was chosen because it is widely used in social and environmental research to test the temporal stability and internal consistency of measurement instruments (William, 2024).

The results of the reliability testing showed a correlation coefficient of 0.85. This value exceeds the recommended minimum reliability threshold of 0.70; thus, the research instrument is considered to have a good level of reliability and is suitable for use in primary data collection (Cohen, 2013). Thus, the questionnaire and observation sheet used in this study are considered capable of producing consistent, stable, and reliable data in analyzing the influence of anthropogenic activities on land use change in the Tungu–Nithi Sub-catchment.

Data Collection

Data collection techniques in this study used a combination of social survey methods, field observations, and spatial data analysis in the Tungu–Nithi Sub-catchment. Primary data collection was conducted by distributing questionnaires to selected respondents in Mitheru Ward. The questionnaires were used to obtain data on community perceptions of dominant human activities, changes in land use over time, and perceived impacts on the condition of the Tungu and Nithi rivers. Questionnaires were administered face-to-face to increase response rates and ensure respondents understood the questions.

In addition to the questionnaires, checklists were used during field observations to systematically record observable physical environmental conditions and land use activities. The checklists covered aspects such as gravel mining, riparian agriculture, infrastructure development, riparian vegetation conditions, and signs of erosion and sedimentation. This technique served as ground truthing for the interpretation of satellite imagery. While other indicators, such as socioeconomic factors, are also important to consider, they were excluded due to limited data availability and the primary focus of this study on land use impacts.

Spatial data collection was conducted through GPS coordinate point acquisition to record the location of anthropogenic activities and key environmental features within the sub-catchment. These coordinated data were used to improve the accuracy of spatial analysis and support the land use classification process. Secondary data in the form of Landsat satellite imagery was obtained from official archives and selected for Landsat 7 ETM+ for 2005 and 2015, and Landsat 8 OLI/TIRS for 2025. All Landsat data have a spatial resolution of 30 meters and are freely downloaded from the United States Geological Survey (https://earthexplorer.usgs.gov/).

Data Analysis

Data analysis in this study integrated statistical analysis of questionnaire data and spatial analysis of land use changes. Questionnaire data were coded, entered into a spreadsheet, checked for completeness, and unnecessary data were removed before analysis. The eliminated data were then analyzed using SPSS version 26. This descriptive statistical analysis was used to describe respondents' perceptions of dominant anthropogenic activities and their perceived environmental impacts. The data were then organized into a contingency table, with rows representing observation years and columns representing land use categories. The chi-square test was also used to identify statistically significant differences in land use change between observation periods.

Spatial analysis was conducted using ArcGIS to classify and map land cover in 2005, 2015, and 2025. Changes in each land use class, including settlement, vegetation cover, water bodies (river), bare land, and gravel extraction areas, were quantified to identify spatial-temporal change patterns and trends. One of the core features of the Markov Chain model was used to analyze transition probabilities between land use classes and simulate land use change.

The land cover maps resulting from the classification process are then tested for accuracy using Overall Accuracy (OA), Kappa Index (K), User's Accuracy (UA), and Producer's Accuracy (PA). Overall Accuracy is used to indicate the overall percentage of correctly classified pixels compared to reference data. User's Accuracy measures the reliability of the classification results from the perspective of the map user, namely the likelihood that a class on the map accurately represents conditions on the ground. Meanwhile, PA indicates the classification model's ability to correctly identify land cover classes based on reference data, thus illustrating the level of omission errors. The K is used to measure the level of agreement between the land cover classification results and the reference data, considering the possibility of coincidence. The Kappa value provides a stronger indication of the reliability of the classification results than OA alone.

Land cover classification accuracy analysis was only conducted for the year 2025 because validated field reference data were only available for the current year, while the 2005 and 2015 imagery were not supported by comparable historical field data. Therefore, accuracy testing was not conducted for these years to avoid validation bias.

Although the accuracy analysis was only conducted for the year 2025, these results are considered to adequately represent the reliability of the classification method used, as the procedures, algorithms, and classification scheme were applied consistently throughout the analysis period. Kang et al. (2020) stated that land cover maps with consistent classification processes are an important foundation for global change research and provide comparable data across time periods. Therefore, the 2025 classification results can serve as a valid basis for interpreting land use change in the Tungu–Nithi Sub-watershed.

The results of the accuracy, statistical, and spatial analyses were then integrated to interpret the influence of human activities on land use change in the Tungu–Nithi Sub-watershed, allowing for a more comprehensive understanding of the spatial-temporal dynamics and anthropogenic pressures occurring in the study area.

RESULT AND DISCUSSION

The agreement between the land cover classification results and the reference data was assessed. The Kappa value provides a stronger indication of the reliability of the classification results than OA alone. Land cover classification accuracy analysis was only conducted for the year 2025 due to the availability of reliable reference data. The decipherable accuracy statistics showed that the overall accuracy of the LULC classification was 0.81, while the producer's accuracy and user's accuracy were 0.79 and 0.72, respectively. The Kappa coefficient index was 0.88. This high level of accuracy suggests that the classification results were reliable for subsequent spatial–temporal land use analysis. The relatively high accuracy observed was associated with the improved spatial resolution of the satellite imagery used, which enhanced the discrimination of different land use classes.

Satellite image analysis yielded the following land use maps: settlement, bare lands, roads, rivers, gravel extraction, and vegetation cover The area of each land use class is presented in Table 1.

Table 1. Spatial–Temporal Changes in Land Use within the Tungu–Nithi Sub-Catchment

Land Use Class	Land Use 2005		Land Use 2015		Land Use 2025		Percentage of Land Use Change
	ha	%	ha	%	ha	%	
Vegetation	4609.55	42.50	7092.20	65.30	6681.10	61.60	+19.10
Settlement	2027.12	18.69	2339.40	21.50	2853.50	26.30	+7.60
Bare land	1244.04	11.40	686.50	6.30	584.60	5.30	-6.08
Road Reserve	1883.95	17.30	515.10	4.70	523.80	4.80	-12.50
River	379.61	3.50	157.20	1.40	136.60	1.20	-2.24
Other	701.74	6.40	55.30	0.50	66.10	0.60	-5.80

Information in Table 1 shows an increase in vegetation cover from 42.50% in 2005 to 61.60% in 2025, indicating an overall increase of 19.10%. The increase in vegetation cover was associated with an increase in planted vegetation. The study established that farmers had planted cover crops such as nippier grass, grevillea, and eucalyptus trees, which contributed to increased vegetation cover and soil erosion control (Figure 2).

Figure 2. Agroforestry Practices within the Catchment area: a) Banana and Napier grass; b) Eucalyptus spp of trees; c) Tobacco nursery bed; d) Grevillea spp. trees

Information presented in Figure 1 shows the integration of trees into crop farming systems, which enhanced biodiversity within the watershed. Loss of native vegetation due to deforestation has led to the introduction of invasive vegetation species. Therefore, the observed increase in vegetation cover could largely be attributed to the expansion of planted vegetation rather than natural vegetation regeneration. These findings mirrored those of Kuyah et al. (2019), who showed that although increased crop farming may lead to deforestation and a reduction in natural vegetation cover, areas practicing agroforestry experienced an overall increase in vegetation cover. Similar observations were reported by Buruso et al. (2023).

The information presented in Table 1 also shows an increase in settlement area from 18.69% in 2005 to 26.30% in 2025, indicating an increase of 7.60% over the study period. This expansion reflects growing anthropogenic pressure within the watershed. The study established that the establishment of various institutions in the neighboring Karingani Ward of Chuka South Sub-County may have contributed to population growth in Mitheru Ward between 2005 and 2025. Increased population subsequently led to the expansion of settlement areas within the watershed (Annan et al., 2024). These results indicated that population growth increased the demand for housing and business structures such as hotels and hostels. This finding mirrors the study by Kimani (2021), which reported that population pressure resulted in the conversion of agricultural land into residential, industrial, and infrastructural uses within watershed areas.

The study further showed a percentage decrease of 6.08% in bare land between 2005 and 2025. The establishment of infrastructure such as bridges, hotels, and restaurants, as well as quarrying activities along the River Tungu and the River Nithi, resulted in the destruction of riverbanks and deterioration of the physical characteristics of water bodies (Figure 3).

Figure 3. Structures Constructed within River Tungu Nithi Watershed: a) Bridge along River Tungu; b) Hotel along River Nithi; c) Bridge Construction across Tungu River; and d) Gravel used in the Construction of a Bridge across Tungu River

The construction of bridges and hotels contributed to a decrease in road reserves and riparian land (Figure 3). This decrease may be attributed to the increasing demand for land for settlement, recreational activities, and crop farming to meet the needs of the growing population. Although land had been cleared for various human activities, such as settlement, invasive species, including grevillea, eucalyptus, nipper grass, and crops such as coffee, maize, tea, and beans, colonized the cleared areas, outcompeting natural vegetation and altering the landscape (Ruto et al., 2023). The proliferation of these species reduced bare land coverage as the land became increasingly vegetated. Cover crops such as nipper grass protected the soil from erosion, thereby reducing exposed bare surfaces. The application of fertilizers enhanced crop growth, further increasing vegetation cover and reducing bare land. However, increased fertilizer use may have contributed to watershed degradation by altering the physical and chemical characteristics of river water through surface runoff (Jo & Kwon, 2023). These findings disagreed with Sang et al. (2023), who reported that decreases in built-up areas, cropland, and bare land were associated with population increase.

The study further established a decrease of 12.54% in road reserves between 2005 and 2025 (Table 1). This decrease was associated with increased crop farming and infrastructural development, including roads, buildings, car washes, and recreational facilities, which led to the encroachment of protected land such as road reserves and riparian zones. This finding agrees with Kuusaana et al. (2022), who reported that human activities in watershed areas often result in the conversion of land initially designated for roads into agricultural, residential, or commercial uses.

Results presented in Table 1 also indicate a decrease of 2.24% in river coverage between 2005 and 2025. The study identified irrigation farming as a major activity along the watershed, particularly during dry seasons. Farmers were observed preparing tobacco nursery beds using water directly abstracted from the rivers (Figure 4a). In addition, some streams within the Tungu-Nithi sub-catchment were observed to have dried up due to over-abstraction (Figure 4b).

Figure 4: a) Drying stream; and b) Irrigation of Tobacco Nursery along River Tungu

Increased human activities along the rivers, particularly irrigation farming during dry seasons, may have contributed to the reduction of water sources (Figure 4). Over-abstraction of water for irrigation, construction activities, hotels, institutions, car washes, coffee and tea factories, and domestic use reduced river flow and water availability. Gravel extraction along riverbanks further reduced water retention capacity within the watershed. These results align with Pacheco & Sanches Fernandes (2020), who reported that deforestation and continuous irrigation farming reduced river flow and water availability in sub-catchments, especially during dry seasons. Similar findings were reported by Apoorva & Kundlas (2024), who found that over-extraction of water, deforestation, and agricultural land conversion resulted in habitat destruction.

The study also found a slight decrease of 5.86% in areas covered by other human activities, such as gravel extraction, between 2005 and 2025 (Table 1). This decrease may be attributed to stricter County Government by-laws regulating the use of public land, including feeder roads and riparian zones, which reduced encroachment. The decline in gravel extraction may also be linked to a shift toward other socio-economic activities such as crop farming and recreational activities. However, gravel extraction remained a significant economic activity within the sub-catchment due to increased demand for construction materials associated with expanding built-up areas. This finding agrees with Annan et al. (2024), who reported that population growth, economic activities, and policy decisions influence spatial-temporal land use changes within watersheds.

The spatial-temporal changes in land use within the Tungu-Nithi sub-catchment were further illustrated using land use choropleth maps for 2005, 2015, and 2025. In the maps, green represents vegetation cover, dark red indicates settlement areas, light brown denotes bare land, dark grey represents roads, blue indicates rivers, and bright blue represents other land uses. The results of the map are presented in Figures 5 to 7.

Based on the LULC map of 2005, vegetation occupied the largest area (4609.55 ha), followed by settlement 2027.12 ha, road reserves 1883.95 ha, bare lands 1244.04 ha, other land uses such as gravel extraction 701.74 ha, and rivers covered 379.61 ha of land (Figure 5). The dominance of natural vegetation cover could have been due to less human interference. The land use data revealed a landscape undergoing dynamic changes influenced by anthropogenic factors. The spatial distribution of different land cover types reflected the complex interaction between the Tungu-Nithi sub-catchment and human settlement patterns. However, given the encroachment by human activities such as settlement expansion and infrastructure development, this vegetative cover has been reduced significantly in subsequent periods. Settlements accounted for 2027.12 ha of land area, pointing to a significant human footprint within the watershed. The presence of road reserves, occupying 1883.95 ha, further supported the trend of infrastructural development. Although transportation networks

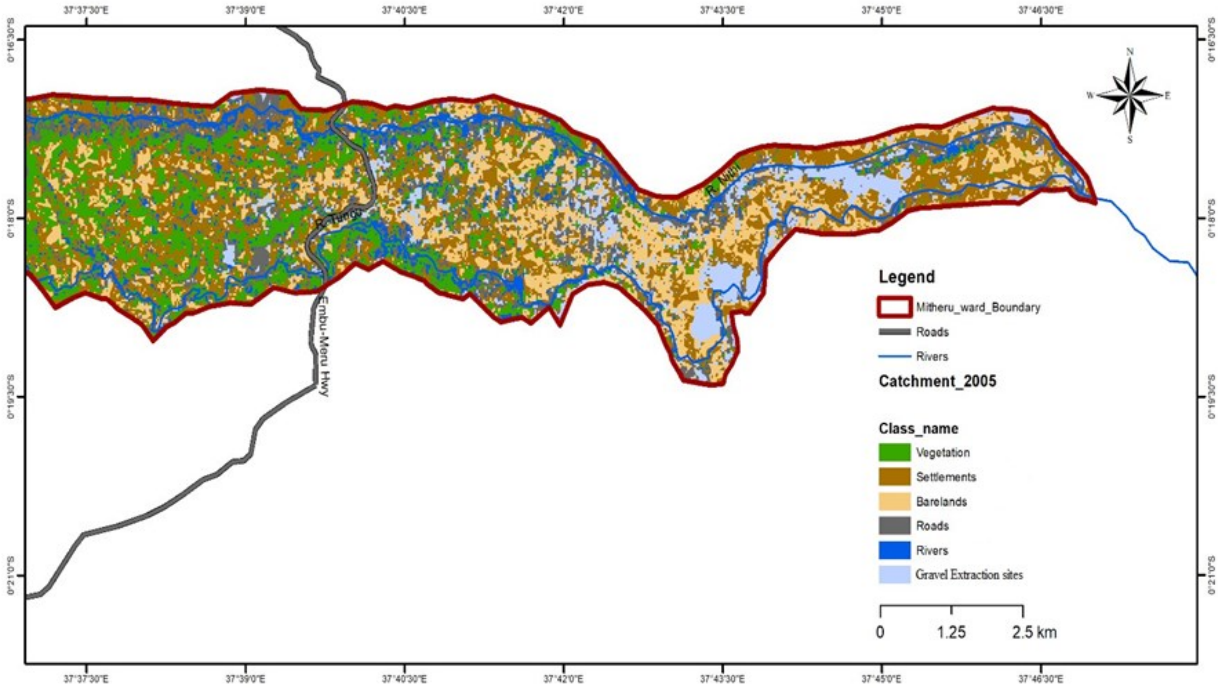

Figure 5. Land Use Map of Tungu-Nithi Catchment for 2005

were vital for economic growth, their expansion often fragmented the watershed, hence contributing to land degradation if not carefully planned. Bare land comprised 1244.04 ha of the area and may represent degraded or unproductive land. This could be due to overgrazing, deforestation, or past intensive land use. Such areas offered opportunities for land reclamation, afforestation, or other sustainable land use practices to restore ecological functionality. These study findings aligned with a study done by Toromo et al. (2020) on the effects of land use on the upper Turkwel watershed that changes in land use, especially the expansion of built-up areas, crop land, decrease in grass and forested areas, affected the ecosystem services within the sub catchment. Rivers covered 379.61 ha of the total area, underscoring the presence of significant surface water systems within the region. These water bodies are essential for both ecological functions and human use. However, their relatively low proportion reflected possible degradation from upstream activities such as sand harvesting, agriculture, or waste discharge (Yang et al., 2020). Gravel extraction sites, which occupied 6.4% indicated active resource extraction, likely for construction purposes. While these sites contributed to local economic development, uncontrolled or poorly regulated gravel mining can lead to severe land degradation, alteration of river courses, and loss of vegetation. The findings agreed with a study done by Ayab et al. (2024) that mining activities in Gwadabawa in Nigeria had led to a decrease in vegetation cover and increased bare soil and exploited areas. The findings also mirrored a study done by Bendixen et al. (2021) that sand, gravel, and crushed stones were the most mined materials on earth, but faced degradation, especially in watershed areas; therefore, it was important to identify sustainable mitigation measures to conserve and manage the reservoirs.

The result of Figure 6 indicated a significant increase of 2482.65 ha in vegetation cover between 2005 and 2015, and in the settlement area of 312.36 ha. The study also found that there was a decrease in bare lands (557.49 ha), roads (1368.76 ha), rivers (222.34 ha), and gravel extraction sites (695.27 ha). The increase in vegetation cover could have been due to the availability of water from the river Tungu and Nithi to carry out irrigation farming during the dry season or when rains are insufficient. The study also found that an increase in vegetation could have been due to the presence of diverse crops such as tea and coffee farming, which were perennial crops within the sub-catchment. These findings aligned with a study done by Waithaka et al. (2019) that increasing tea and coffee farming enhanced vegetation cover in a sub-catchment though the relationship

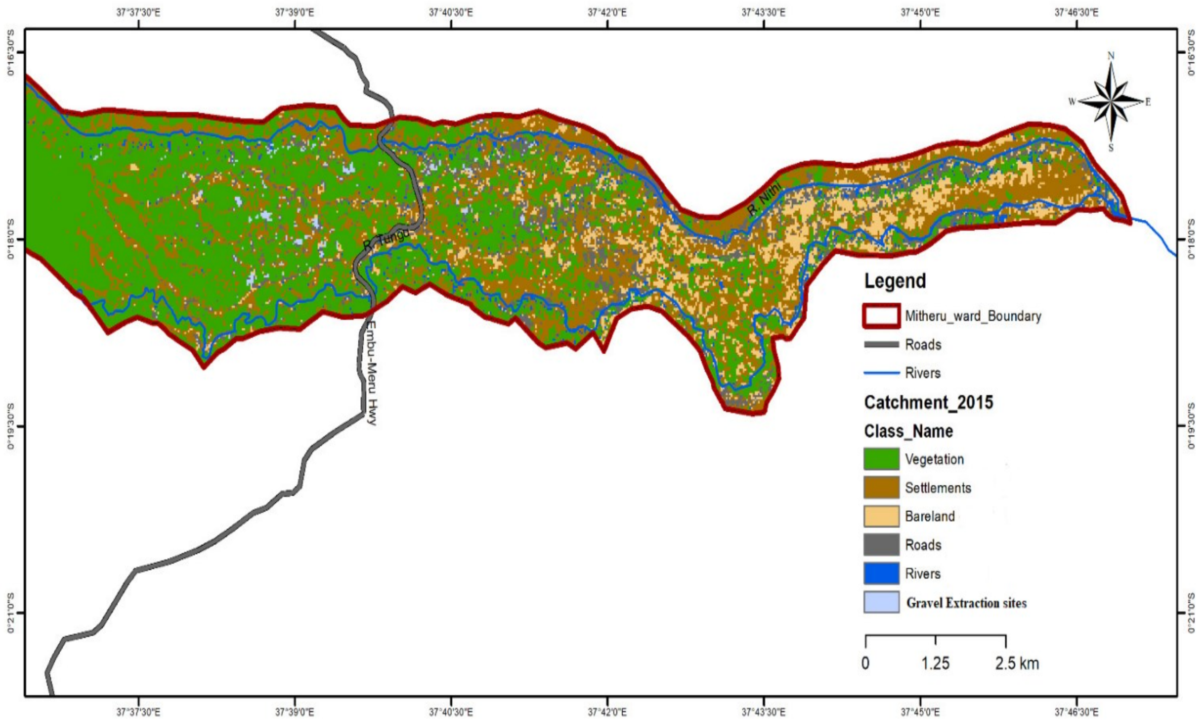

Figure 6. Land Use Map of Tungu-Nithi Catchment for 2015

is complex. The study identified that there was an increase (312.36 ha) in settlement area. This could have been due to the establishment of institutions, which had led to an increase in population within the sub-catchment. The study established that a high number of people could have led to the establishment of facilities such as hotels and restaurants to provide leisure activities to the residents. This could have led to the construction of recreational centers, hostels, businesses, and residential areas. These research results correspond with a study done by Toromo et al. (2020) that a growing population in a watershed directly resulted in increased human settlement. The study also found that as the population increased, there was a greater demand for housing, infrastructure, and crop land, which led to the expansion of settlement (Waithaka et al., 2019). The study also identified that the decrease in bare land, road area, river sources, and other land uses, such as gravel extraction sites, could have been due to increased crop farming. Residents were found to have shifted to crop farming to increase food productivity to cater to the growing population. A study done by Muche et al. (2024) also corresponded with the findings that a reduction in bare land, roads, and rivers sub-catchment areas was a result of increased crop farming. The research also concluded that the changes were seen to have enhanced soil fertility, improved water availability, and reduced soil erosion, hence creating more suitable conditions for agriculture. The results also aligned with a study done by Dynowski et al. (2019) that increased recreational activities encouraged settlement, which led to the development of infrastructure, though indirectly. His study also identified that the need for aesthetic structures created a need for buildings, roads, and campgrounds, which altered the sub-catchment's ecology.

The results presented in Figure 7 established that there was a decrease (411.06 ha) in vegetation cover between 2015 and 2025, as well as land covered by bare lands (101.95 ha) and rivers (20.61 ha). The study also noted that there was an increase in settlement area (514.1 ha), roads (8.67 ha), and other land use changes, such as gravel extraction sites (10.85 ha). The decrease in vegetation cover could have been due to increased deforestation. The study further established that there was demand for timber in the construction of hostels, business centres, and residential homes. The study found that this could have been due to high demand for timber, charcoal, and firewood. This could have contributed to a decrease in vegetation cover. These findings were supported by a study done by Tela et al. (2024) that deforestation clears forests is directly decreasing trees and plant life.

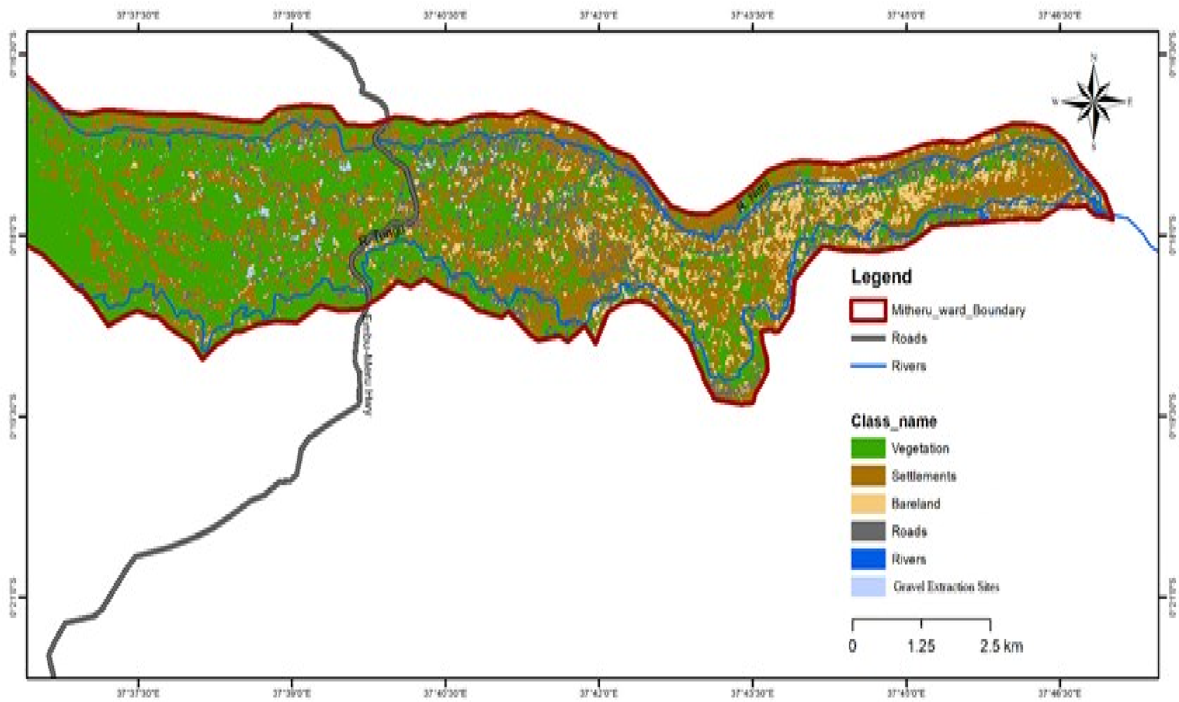

Figure 7. Land Use Map of Tungu-Nithi Catchment for 2025

This loss was found to have affected the watershed by altering water flow, increasing soil erosion, and influencing ecosystem health (Chen et al., 2020). The study further found that most of the bare lands had been developed, thus decrease in land coverage of bare lands. This was associated with an increase in settlement areas. An increase in gravel extraction sites could have also been due to an increase in settlement areas. This agrees with a study done by Buke et al. (2024) that gravel extraction is mainly for construction purposes. Gravel facilitates the expansion of settlement areas by supplying materials needed for building houses, roads, and other infrastructure.

To further determine if there was a significant influence of anthropogenic activities on spatial-temporal changes in land use within the Tungu-Nithi sub-catchment between 2005 and 2025, The Chi-square test of independence results showed a p-value of < 0.001, which was less than the 0.05 level of significance, hence rejecting the null hypothesis. This implied that anthropogenic activities had significantly influenced spatial-temporal land use changes in the Tungu-Nithi sub-catchment from 2005 to 2025. The results agreed with a study done by Nuissl & Siedentop (2021) that there was a significant association between specific types of anthropogenic activities and patterns of land use change: urban expansion, areas with higher rates of urbanization showed a significant increase in land converted from agricultural to urban uses. Industrial Development, Regions with industrial growth experienced notable land use changes, particularly in proximity to urban centers. Agricultural land use declines in agricultural land were statistically significant in areas experiencing rapid urban sprawl.

CONCLUSION

Spatial-temporal changes affected watershed dynamics. These changes significantly influenced hydrology, water quality, and ecosystem health. Changes in land use over time, such as settlement, vegetation, bare land, water sources, and others like gravel extraction and recreational establishments, altered watershed characteristics affecting runoff patterns and sediment transport. Anthropogenic activities modified vegetation cover and soil characteristics, influencing water retention, erosion rates, and rock structure. Infrastructure development created spatial barriers that disrupted natural water flow and altered sediment dynamics affecting the aquatic ecosystem. Understanding the relationship between spatial-temporal land use changes and the influence of anthropogenic activities was essential for developing adaptive management strategies that enhanced sub-catchment resilience and sustainability.

The study highlights the essential importance of effective land use policies and planning frameworks in alleviating the negative impacts of anthropogenic activities. Policymakers should prioritize integrated land use planning that harmonizes urban development with environmental conservation and agricultural sustainability. Additionally, further research is crucial to understand the long-term effects of these land use changes on ecosystems and communities. This research should focus on identifying adaptive strategies that can bolster resilience against ongoing urbanization and climate change.

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