Original Research Article

Quantifying the Environmental Impact of Standard Gauge Railway (SGR) on Land Cover Changes along the Nairobi-Kiambu Corridor: A Geospatial and Field-Based Investigation

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ABSTRACT

Transport infrastructure development can have significant negative impacts on natural resources over time and space, making it crucial to undertake careful consideration to minimize damage to both natural and artificial features. The objective of this study was to assess the magnitude of the environmental impacts caused by the standard gauge railway (SGR) from Nairobi Terminus to Nachu station in Kiambu county. The study used a detailed GIS and remote sensing (RS) baseline environmental assessment to identify social and environmental impacts and proposed mitigation measures for the SGR project during and after implementation. The results show that there was a 3.6% increase in built-up areas along the SGR line, while grassland, forest, and cropland decreased by 2.5%, 2.6%, and 13%, respectively. The drivers of this change were mainly attributed to urbanization. Negative environmental effects of the SGR included encroachment on conservation areas, disruption of human settlement, and reduction of forest and vegetation cover. Noise and air pollution from SGR construction and operation affected wildlife, vegetation, and human settlements. To mitigate these negative impacts, this study recommends a number of measures including the wet-spraying of cement and wet drilling to reduce dust emissions during construction, frequent investigations of construction sites, afforestation, and GIS analysis to locate the most suitable SGR routes. Moreover. In conclusion, this study highlights the negative environmental impacts of the SGR project from Nairobi Terminus to Nachu station in Kiambu county. The results suggest that the project caused significant environmental degradation, particularly in terms of reduced forest and vegetation cover, and encroachment on conservation areas. The proposed mitigation measures can help reduce these negative impacts and minimize future damage caused by transport infrastructure development.

Keywords: Geographical Information System (GIS), Remote Sensing (RS), Standard Gauge Railway (SGR), land cover, environmental impacts.

1. INTRODUCTION

Transport infrastructure form an essential component of any built environment by enhancing the rapid movement of goods and services thereby promoting the production processes in any economy [1]. Many African governments are currently trying to get recognition for acquiring modern transport infrastructure. This is mainly achieved by inviting economic and logistic aid that enables them to meet their vision of attaining a level of development set out by the United Nations (UN). The massive increase in imports and exports, as well as people movement, puts a lot of pressure on African countries to develop efficient transportation infrastructure.

Kenya is no exception, with significant investment being made to improve its infrastructure network [2]. The Kenyan government constructed the standard gauge railway (SGR) line that connects Mombasa (at the Indian Ocean's coast) and Naivasha (in Rift Valley ca. 570 km from the Indian Ocean). The construction of this rail system began in 2013 and was completed in 2019. The project was expected to have a positive impact on the country's economic growth and total factor productivity. Regardless of the benefits, the environmental impact of SGR advancement cannot be overlooked.

According to [3,4] the rapid expansion of railway infrastructure can have a detrimental impact on the environment both directly, as an immediate effect of the infrastructure and its construction, or indirectly due to human activities after construction. The SGR is not an exception and there have been reports of negative ecosystem impacts of the SGR. In this case, disruption of movement and migration of wildlife, behavioral modification among species, bisections of basins and watersheds [5], and the physical disruption of the structure and compositions of ecosystems [6]. Similarly, there has been an increase in water, soil, and air pollution, grassland fires, and alteration of predator-prey relationship [7].

So far, research on the ecological impacts of transport infrastructure has focused mainly on roads, even though railway lines have similar ecological impacts on the environment. Additionally, the majority of these studies have been mainly done in developed countries and less in developing countries, particularly in sub-Saharan Africa [8,9]. This leaves a knowledge gap on the impact of the railway on the ecosystem. There is thus a need to understand how railway line impacts the environment to have effective mitigation measures, to contribute to planning and policy on future infrastructure projects, and finally to contribute to Kenya’s obligation to the international bodies on climate change mitigation [10]. Moreover, previous studies on SGR have been mostly socio-economic studies, for example, [6] conducted a reconnaissance study to access the ecological impacts of SGR. Likewise, Geographic Information System (GIS) studies done so far have focused on the open/sparse areas such as parks and rural regions. For example, [11] looked at the impact of SGR on the Nairobi National Park, while [7] looked at the landscape dynamics along the SGR.

To the best of our knowledge, this is the first comprehensive study that uses a holistic approach to analyze changes in land cover and the environmental impact of the Standard Gauge Railway (SGR), using spatial analysis methods and a household survey. In addition, no study has looked at the impact of SGR on urban and peri-urban region nor applying a hierarchical approach and examined the study area from two spatial levels. For direct impacts caused by the SGR track on the landscape, very-high-resolution multi-time imagery from Google Earth was used to on-screen digitize features of interest. For indirect impacts of the SGR development on the study region, medium resolution imagery (30 m) Landsat 8 OLI imagery was analyzed. This study, therefore, factored both micro and macro land cover change indicators to best capture the complexities of the change, and sought to provide a comprehensive spatial-temporal assessment of the impact of SGR on the land cover changes between the Nairobi Terminus to Nachu Station Kiambu County. Additionally, the study aimed at assessing the socio-economic impact of the SGR.

2. METHODOLOGY

2.1 Study area

The research was conducted on a stretch of Kenya's Phase IIA Standard Gauge Railway (SGR), which spans from the Nairobi Terminus in Syokimau to the SGR Nachu Station located in Kiambu County. A buffer zone measuring 2.5 km wide and covering 290 km^2 was computed to evaluate the changes in land cover within the study area (Fig. 1).

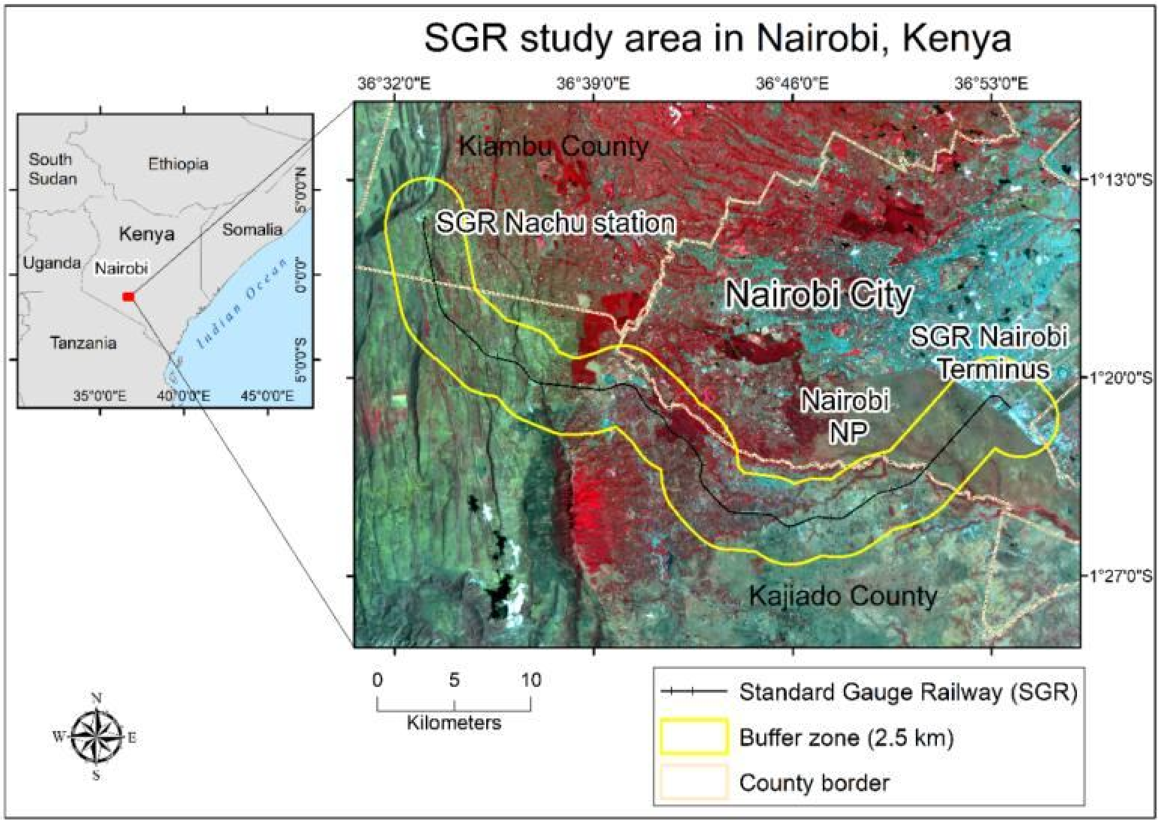

Fig. 1. False colour satellite image and SGR track with the study area buffer zone from Nairobi Terminus to Kiambu County

2.2 Environmental analysis

2.2.1 Remote sensing data

In this study, open and freely available satellite imagery from the Landsat 8 mission was utilized. The Landsat 8 platform is capable of collecting data across 11 spectral bands with spatial resolution ranging from 15 meters to 100 meters. A subset of visible and near-infrared wavelength bands from the Landsat 8 imagery was produced and used in this study.

2.2.2 Image processing

The study acquired four Landsat 8 Operational Land Imager (OLI) satellite images, which were cloud-free and obtained from the U.S. Geological Survey Earth Explorer web portal. The images were acquired on four different dates: 2016/03/28, 2017/01/10, 2018/01/29, and 2019/02/01. The images were first geometrically corrected, cropped to the study area (2.5 km buffer zone of SGR line), and projected to the UTM projection zone 37 south. Radiometric pre-processing was conducted using the RS-toolbox R package to correct for the atmospheric scattering of remote sensing radiation and to convert the raw Digital Number (DN) values to Top-of-Atmosphere (TOA) reflectance values. To analyze land cover change using the remotely sensed images, the individual bands of Landsat images were stacked, and a subset of visible and near-infrared wavelength bands (bands 1–6 and 7) was produced. The normalized Differential Vegetation Index (NDVI) was derived from the final image subset to analyze vegetation changes across the study area.

2.2.3 Supervised Land Cover classification

The Maximum Likelihood Classifier (MLC) in the ArcGIS software was employed in this study for the supervised classification of the remotely sensed images. Initially, training samples were created using the Image Classification toolbar and polygons representing various land cover classes were delineated based on visual interpretation using Google Earth. Next, geometrically and radiometrically pre-processed satellite images for each year under study were imported into ArcGIS for MLC classification. As there was high spectral variability in the study area, the best results were obtained by initially classifying 10 preliminary classes and subsequently merging them to obtain the desired 4 final land cover classes. The target land cover classes and their corresponding pixel values assigned from the classification are presented in Table 1.

Table 1: Designation of classified image pixels in land cover map

Pixel Value	Land Cover Class
10	Built-Up Areas
20	Grasslands / Rangelands
30	Forests and Wooded Areas
40	Croplands and Bare Fields

To evaluate the accuracy of the final classifications, ground truth data were obtained from high-resolution imagery. Stratified random sampling was used to generate assessment points, and Cohen's Kappa statistic and confusion matrices were used to quantify the accuracy [12].

2.2.4 Accuracy assessment

Land cover accuracy assessment reference points were generated through stratified random sampling, which creates sample points for each class based on the class size. These reference points were validated using high-resolution Google Earth imagery for ground truthing, and accuracy metrics were calculated from them. A confusion matrix, also called a contingency table, was used to visually represent the differences between the predicted and actual classes, quantifying the frequency of mislabeling. Cohen's Kappa statistic [12] was used to determine inter-rater agreement, indicating the level of agreement between the observed and actual classes. In this case, the classification and ground truth data were considered as two raters who classify N number of items into C mutually exclusive categories. Kappa takes into account the possibility of an agreement between the two raters occurring purely by chance, providing a more reliable metric to evaluate the accuracy of the classification. The equation 2 provides the formula for Kappa.

$$\kappa \equiv \frac{p_0 - p_e}{1 - p_e} = 1 - \frac{1 - p_0}{1 - p_e} \qquad \textbf{(Equation 1)}$$

Where;

p_0 Is the relative observed agreement among raters (accuracy)

p_e Is the hypothetical probability of chance agreement

The Kappa statistic is a measure of inter-rater agreement, which quantifies the degree of agreement between two raters, in this case, the classification and ground truth data. It ranges from 0 to 1, where 1 indicates complete agreement between the raters, and 0 indicates no agreement other than what would be expected by chance. In this study, both the confusion matrix and its associated Kappa statistic were generated for the 2019 land cover map, to assess the accuracy of the classification.

2.2.5 Land Cover Change analysis

The study utilized the post classification comparison technique to investigate land cover changes in the study area between 2016 and 2019. Specifically, changes between one-year epochs (2016 - 2017, 2017 - 2018, and 2018 - 2019) were examined. Additionally, the overall changes across the entire period were analyzed to determine the aggregate differences.

2.2.6 Normalized Difference Vegetation Index (NDVI) analysis

The study focused on analyzing the impact of changes on vegetation in the study area using the Normalized Difference Vegetation Index (NDVI) [13], which is widely used for assessing land cover changes and predicting future changes [14]. The NDVI was calculated for different years and used as a proxy for vegetation change over time. This index is calculated using the ratio of red and near-infrared bands, and its magnitude ranges from +1 to -1, providing an estimate of vegetation biomass by differentiating green vegetation from other surfaces. The formula used to calculate the NDVI is given by equation 1.

$$\boldsymbol{NDVI} = \frac{(\boldsymbol{NIR} - \boldsymbol{Re\ d})}{(\boldsymbol{NIR} + \boldsymbol{Re\ d})} \qquad \textbf{(Equation 2)}$$

2.2.7 Forest clearance and excavated areas analysis

The methodology used in this study involved the use of high-resolution satellite imagery from Google Earth to map the specific area of the Oloolua Forest that was cleared for the SGR railway track. Additionally, excavated areas that were created during the construction of the SGR track were also delineated using Google Earth. The forest clearance and excavated areas were then mapped and converted from Google Earth Keyhole Markup language format to vector shapefiles using ArcGIS. This enabled the researchers to accurately map the forest clearance and calculate the total acreage of the excavated areas.

2.2.8 Demolished houses analysis

High-resolution imagery analysis from Google Earth was conducted within a 2.5 km buffer zone to identify residential dwellings that were demolished to make way for the SGR railway track. The houses were categorized based on size, with big houses designed to accommodate four or more people, while small houses were designed to house two or fewer people. A map was then generated to visualize the impact of the SGR development on the residential areas and dwellings within the buffer zone.

2.3 Socio-economic analysis

2.3.1. Household Survey

To gather the perspectives of people living in the study area, a household survey was conducted using a semi-structured questionnaire. The survey was administered to 100 respondents, and the data collected was digitized to a database. Tables were then created to show the various effects of the SGR development on the people living in the area.

3 RESULTS

3.1 Land Cover classification

The results of land cover classification for the years 2016 - 2019 can be seen from the Fig. 2.

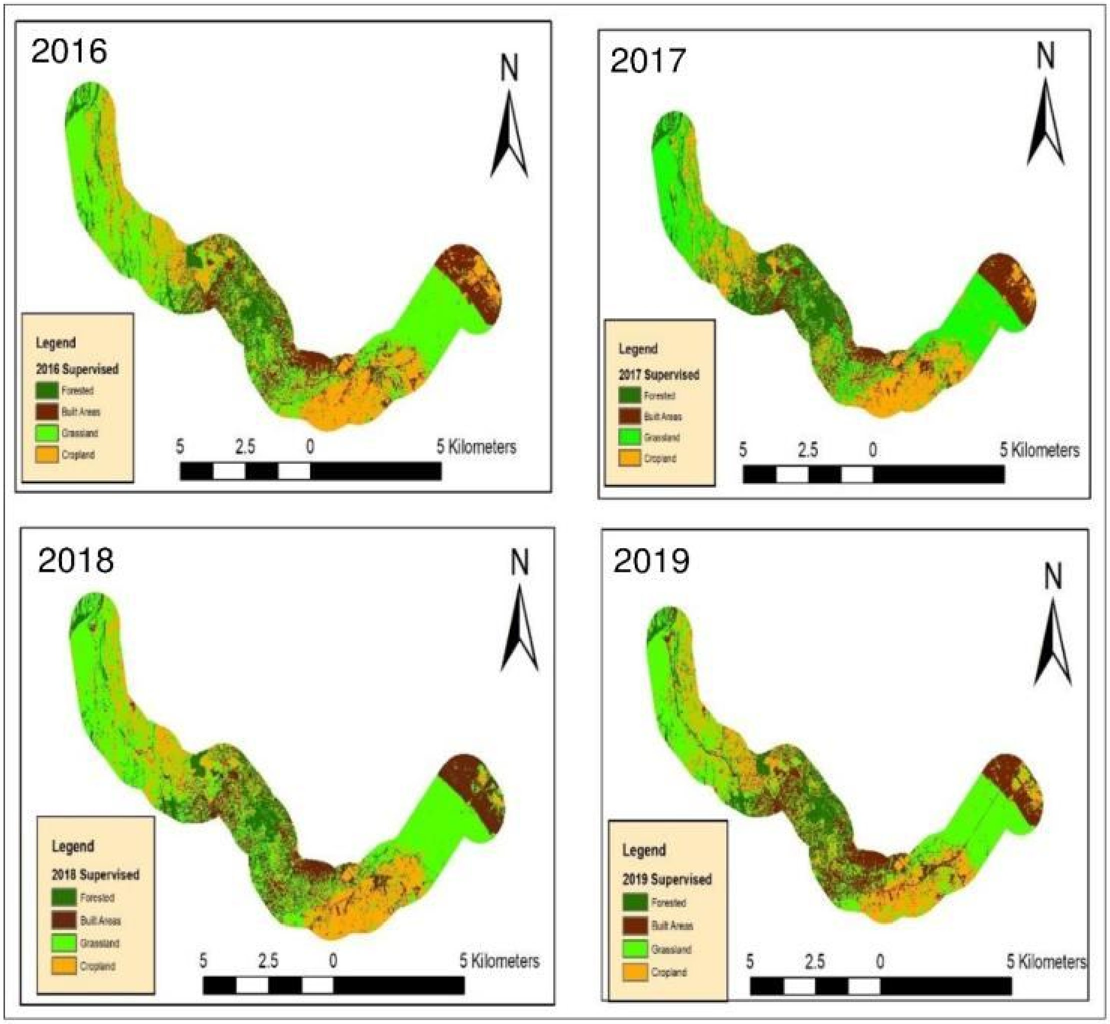

Fig. 2. Land cover change classification results for years 2016 - 2019

3.1 Accuracy assessment

Table 2 presents the confusion matrix of the 2019 land cover map. The rows of the matrix provide information on the type 1 errors, also referred to as 1 s user's accuracy. It reveals that urban areas and cropland exhibit the highest errors of commission, indicating a considerable number of pixels were incorrectly classified. This represents false positive pixels were classified into the wrong class. The columns of the confusion matrix provide information on type 2 errors, also referred to as producer's accuracy. It reveals that the forested and grassland classes exhibit the highest errors of omission, indicating that many pixels that should have been classified into these classes were left out. The Kappa statistic, which shows the overall accuracy of the classification, indicates that the method achieved an accuracy of approximately 82%.

Table 2: Confusion Matrix for 2019 Land Cover Map

Class	Urban	Grassland	Forested	Cropland	Total	U. Acc
Urban	7	3	0	1	11	0.636364
Grassland	0	20	0	0	20	1
Forested	0	0	10	0	10	1
Cropland	0	3	0	10	13	0.769231
Total	7	26	10	11	54	0
P. Acc	1	0.769231	1	0.909091	0	0.87037

3.2 Land Cover changes from 2016 - 2019

The objective of this study was to examine the changes that transpired in the study area between the years 2016 to 2019 so as to obtain a comprehensive understanding of the situation over the four-year span. The results of the overall change analysis across the four-year period are illustrated in Figures 3 and 4.

Based on the findings from the overall change analysis across the four-year period, it was observed that there was an increase in croplands and built areas by 26 sq. km (as shown in Fig. 3). However, it was also noted that croplands decreased by 38 sq. km, while urban areas reduced by only 10 sq. km. Moreover, there was an increase in grasslands by 30 sq. km, although it reduced by 34 sq. km. Forested areas had the least changes with an increase of 9 sq. km and a reduction of 12 sq. km.

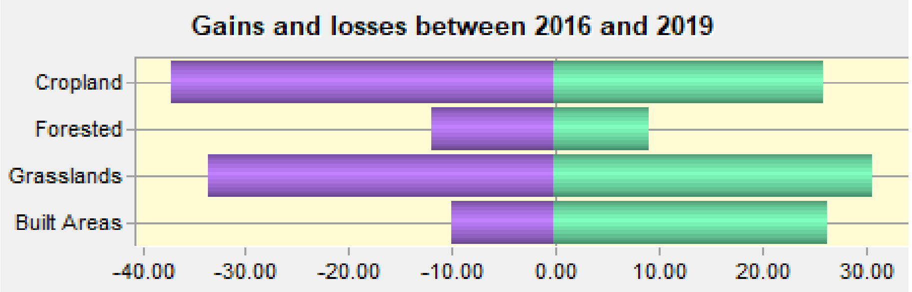

Fig. 3. Land cover classes gains and losses between 2016 and 2019

The results of the analysis indicate that only the built areas class had a net increase in acreage, with a gain of 17 sq. km as illustrated in Figure 4. On the other hand, cropland experienced the highest net loss, with a reduction of 11 sq. km. Similarly, grasslands and forested areas exhibited nearly identical net reductions of about 3 sq. km each, as shown in Figure 4.

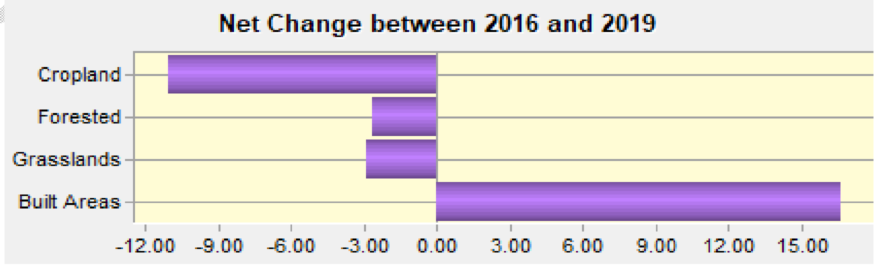

Fig. 4. Net land cover changes between 2016 and 2019 (in sq. km)

3.3 Mapping NDVI Normalized Difference Vegetation Index (NDVI)

Figure 5 displays the NDVI maps for the four-year period under study. Observations made from the 2016 and 2017 maps show that the SGR railway track was not yet clearly visible. However, in the 2018 map, the track becomes visible in the western region of the study area, running from the top left of the map to its central region. In the 2019 map, the SGR railway track is visible across the entire extent of the study area. Additionally, the tracks crossing Nairobi NP are distinguishable by their low NDVI values.

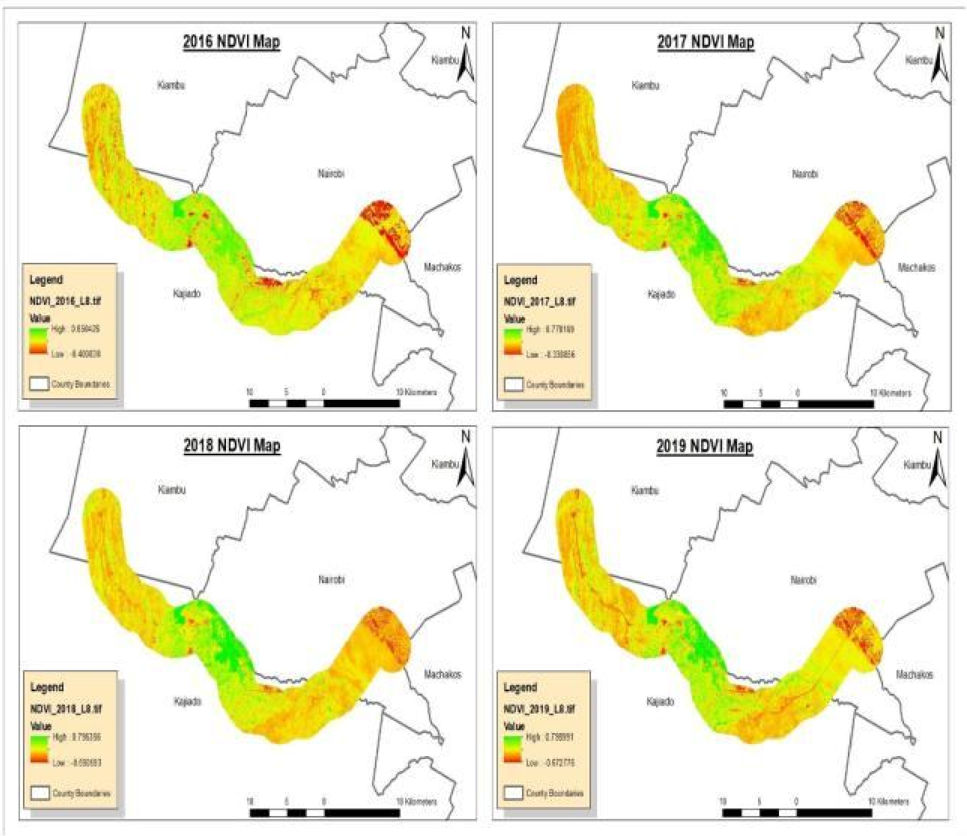

Fig. 5. Normalized Difference Vegetation Index maps for 2016 to 2019

Figure 6 presents a visual representation of the land cover change phases observed between 2017 and 2019 in the 2.5 km buffer zone of the SGR track. The NDVI images reveal that the working compounds, excavation sites, and land clearings associated with the SGR track construction were developed and expanded between 2017 and 2018. In the 2019 NDVI map, additional clearings in Oloolua Forest, the construction of railway stations, and bridge development can be observed throughout the Nairobi National Park. These findings suggest that the SGR track construction has resulted in significant land cover changes in the study area, highlighting the need for further environmental impact assessments and mitigation measures.

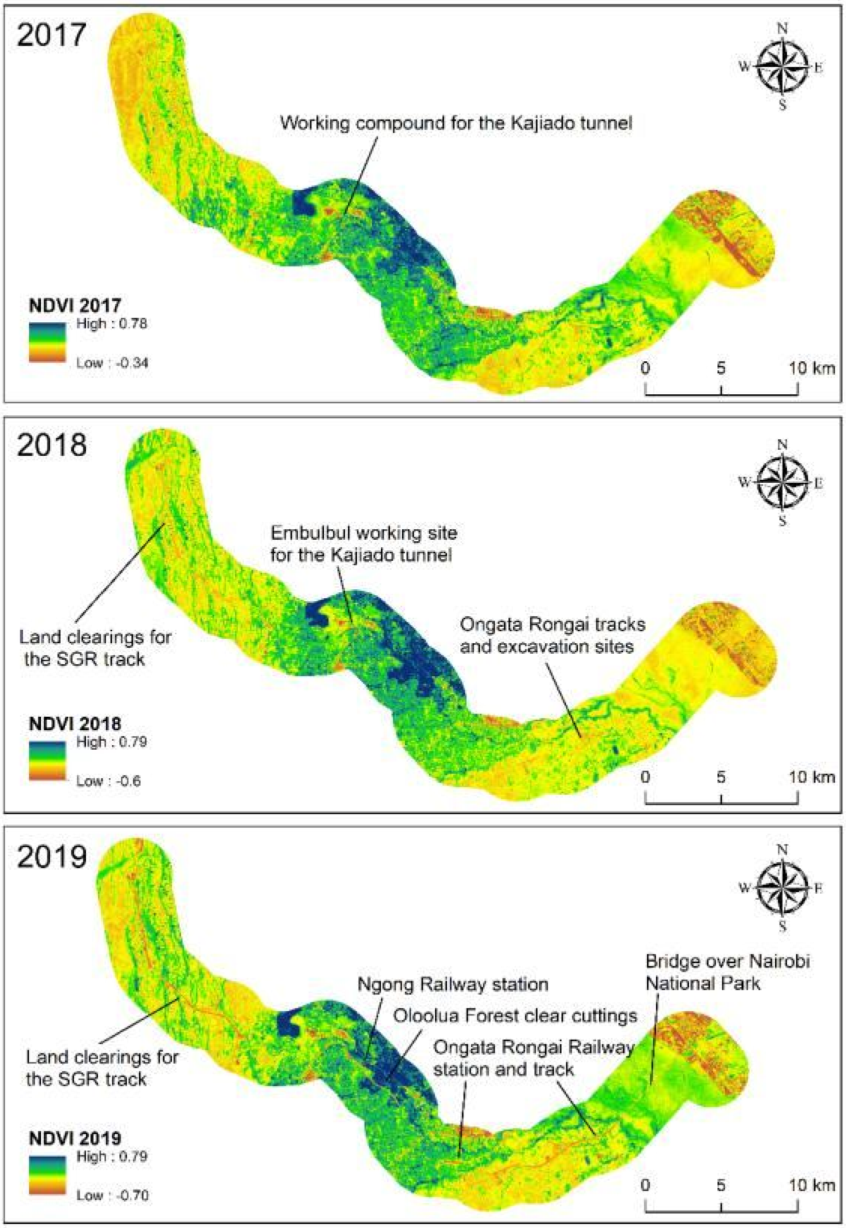

Fig. 6. NDVI based land cover change for 2016 to 2019

3.4 Forest clearance and excavation

Figure 7 provides a detailed view of the forest clearance areas within Oloolua Forest. The analysis reveals that approximately 0.173 sq. km of pristine forest was cleared along the railway track. Prior to the clearance, the forested area measured 6.76 sq. km which was reduced to 6.58 sq. km, resulting in a 2.56% loss of forest cover.

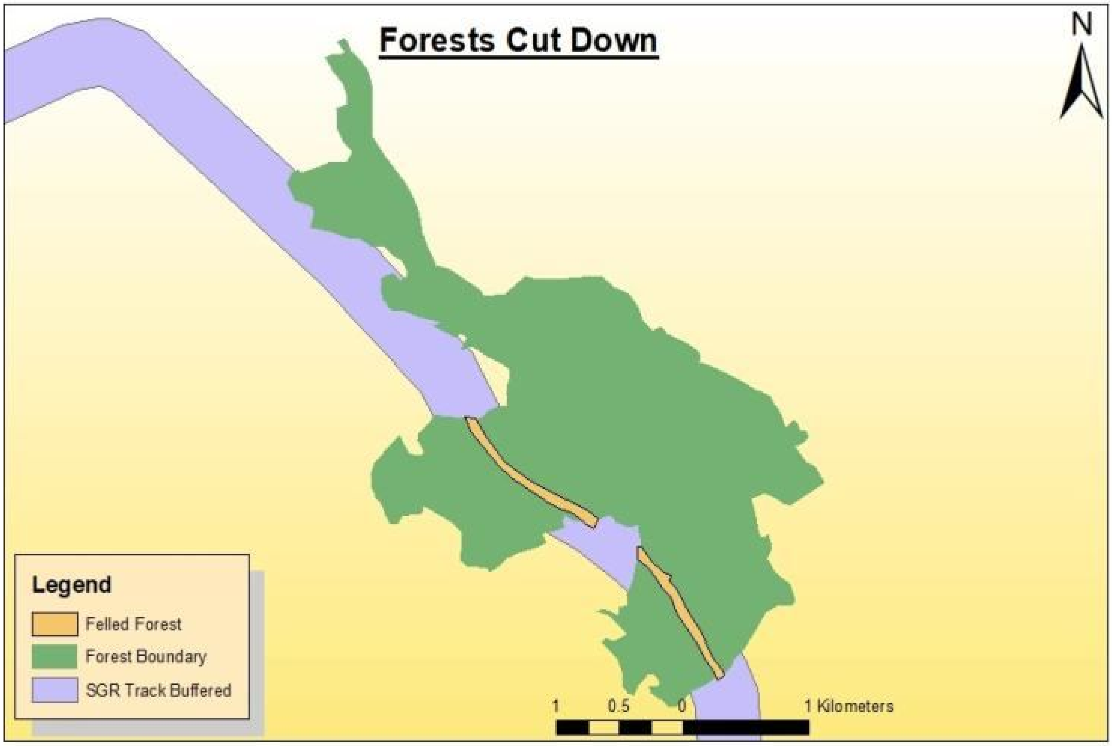

Fig. 7. A map of the Oloolua Forest cut down areas to clear a path for the SGR track

An analysis of the dug areas revealed that 15 sites had been excavated covering a total area of 1.786 sq. km were dug up. Summary statistics can be seen from the Table 3.

Table 3: Values for the descriptive statistics of the dugout areas

Statistics	Values in sq.km
Count	15
Minimum	0.036556
Maximum	0.86938
Sum	1.786332
Mean	0.119089
Standard Deviation	0.202502

3.5 Demolished houses mapping

The mapping out of houses that were directly cleared for the SGR development was made possible through high resolution image analysis. Essentially, all of the demolished houses were in Kajiado County, mostly in areas where the railway track passed through and where the population density and residential houses were the highest (Fig. 8). Demolished houses were discovered in close proximity to the SGR track, often less than 50 to 100 meters away. The Ngong and Ongata Rongai railway station areas, where house demolition also extended further away from the SGR track, were exceptions to this general rule. It also appears that more smaller houses along the track were demolished than larger houses (Fig. 8).

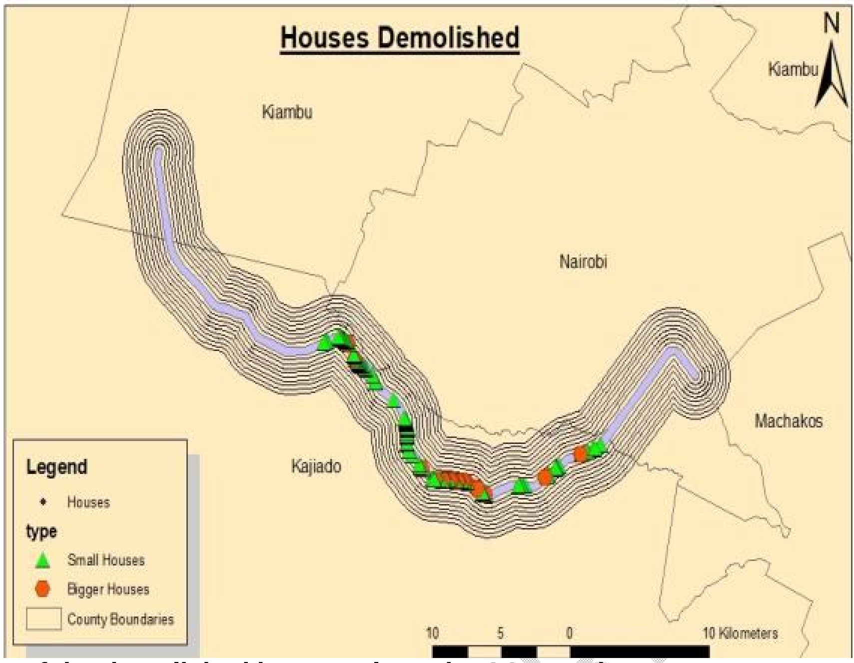

Fig. 8. Map of the demolished houses along the SGR track

3.6 Socio-Economic Analysis Results

This section entails the socio-economic analysis findings that are related to SGR construction.

3.6.1. Residents' Concerns about SGR traversing their residential area

Table 4 presents the results of a survey conducted to assess the concerns of residents living along the SGR route. According to the Table 4, 35% of the respondents were somewhat concerned, 33% were not concerned, 16% were extremely concerned, and the remaining 16% were very concerned about the SGR traversing through their areas of residence.

Table 4. Residents concern on SGR traversing in area of residence

		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Extremely concerned	16	16.0	16.0	16.0
	Very concerned	16	16.0	16.0	32.0
	Somewhat concerned	35	35.0	35.0	67.0
	Not concerned	33	33.0	33.0	100.0
	Total	**100**	**100.0**	**100.0**	

3.6.2. Respondents' current status after displacement by SGR

Table 5 presents the current status of the respondents after the displacement caused by the SGR project. The respondents were asked whether their current residence was a result of displacement to pave way for the construction of SGR. The results indicate that only 34% of the respondents had been displaced by the SGR project, whereas 66% had not been displaced by the SGR.

Table 5. Current status after displacement by SGR

Displaced SGR?		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	34	34.0	34.0	34.0
	No	66	66.0	66.0	100.0
	Total	**100**	**100.0**	**100.0**	

3.6.3. Levels of noise pollution with the advent of SGR

About the levels of noise pollution with the advent of the SGR, 61% point out that there were high levels of noise pollution, 5% said that there were moderate levels of noise pollution, while 34% of the respondents indicated that there were low levels of noise pollution since the construction of SGR, as shown in Table 6.

Table 6. Levels of noise pollution

Your opinion on levels of noise pollution		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	34	34.0	34.0	34.0
	Moderate	5	5.0	5.0	39.0
	High	61	61.0	61.0	100.0
	Total	**100**	**100.0**	**100.0**	

3.6.4. Dust pollution as a result of the SGR construction

During the survey, respondents were queried about their perception regarding dust pollution caused by the SGR within their vicinity. The majority of the respondents (76%) concurred that the SGR had caused dust pollution. Conversely, 14% of the respondents disagreed with the notion, while 10% were undecided. The proportion of respondents who expressed concerns about the SGR's contribution to dust pollution suggests that this is a pressing issue that needs to be addressed. These findings are presented in Table 7.

Table 7. Dust pollution as a result of the SGR

Any dust pollution as result of the SGR		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	76	76.0	76.0	76.0
	No	14	14.0	14.0	90.0
	Not sure	10	10.0	10.0	100.0
	Total	**100**	**100.0**	**100.0**	

3.6.4. Flooding cases during rainy seasons

Inquiring about the effect of SGR on the local environment, the researcher asked respondents whether they had experienced unusual flooding during the rainy seasons. A majority of the respondents (60%) reported experiencing unusual flooding, while 37% had not experienced any flooding. The remaining 3% were unsure. These findings are summarized in Table 8.

Table 8. Flooding cases during rainy seasons

Has any unusual flooding been noticed during rainy seasons?		**Frequency**	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Yes	60	60.0	60.0	60.0
	No	37	37.0	37.0	97.0
	Not sure	3	3.0	3.0	100.0
	Total	**100**	**100.0**	**100.0**	

3.6.5. Effect of SGR construction through the Nairobi National Park

In the survey, the respondents were asked about their perceptions regarding the impact of the SGR construction through the Nairobi National Park on their lives. The results indicated that 40% of the respondents felt that they had been affected by the SGR construction, while 45% of the respondents indicated that they had not been affected. A further 15% of the respondents were uncertain whether they had been impacted by the SGR construction. These findings are presented in Table 9.

Table 9. Effect of SGR construction through the Nairobi National Park

Has SGR construction through Nairobi National Park affected you?		**Frequency**	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Yes	40	40.0	40.0	40.0
	No	45	45.0	45.0	85.0
	Not sure	15	15.0	15.0	100.0
	Total	**100**	**100.0**	**100.0**	

3.6.6. Human–Wildlife Conflict

Table 10 presents the results of an inquiry made to the respondents on whether the community living in the neighborhood of the SGR had witnessed any cases of human–wildlife conflict in the recent past. The results show that a majority of the respondents, 80%, indicated that they had witnessed incidences of human-wildlife conflict, while 18% indicated that they had not witnessed any such conflict. Only 2% of the respondents were not sure about the occurrence of human-wildlife conflict in their area.

Table 10. Human–wildlife conflict

Any cases of human–wildlife conflict		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	80	80.0	80.0	80.0
	No	18	18.0	18.0	98.0
	Not sure	2	2.0	2.0	100.0
	Total	**100**	**100.0**	**100.0**	

3.6.7. Difficulties in accessing grazing land

The respondents were asked if they experienced any difficulties accessing grazing land due to the construction of the SGR. Of all the respondents, 35% answered positively, indicating that they had experienced difficulties accessing grazing land. On the other hand, 46% of the respondents indicated that they had not experienced any difficulties accessing grazing land, while 19% were uncertain about whether there were any difficulties in accessing grazing land resulting from the construction of the SGR. These findings are presented in Table 11.

Table 11. Difficulties in accessing grazing land

Any difficulties in assessing grazing land?		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	35	35.0	35.0	35.0
	No	46	46.0	46.0	81.0
	Not sure	19	19.0	19.0	100.0
	Total	**100**	**100.0**	**100.0**	

3.6.8. Possible positive Impact of SGR on the surrounding community

Inquiring about the respondents' opinions on the possibility of any positive impact of the SGR on the surrounding, the study found that 57% of the respondents anticipated a positive impact. On the other hand, 28% believed that there would be no positive impact, while 15% were unsure of any possibility of positive impact. The positive impact mentioned included job creation, town connectivity, economic growth, increased population along the SGR corridor, and increased business opportunities, as indicated in Table 12.

Table 12. Possible positive impact of SGR on the surrounding community

Will SGR have any positive impact on the surrounding community?		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	57	57.0	57.0	57.0
	No	28	28.0	28.0	85.0
	Not sure	15	15.0	15.0	100.0
	Total	**100**	**100.0**	**100.0**	

3.6.9. Measures to mitigate environmental challenges as a result of SGR

It is notable that the majority of the respondents recommended environmental conservation measures to address the challenges brought about by the SGR. Specifically, planting more trees was suggested as a possible solution, along with measures to control dust and noise pollution. Respondents also called for measures to secure and rehabilitate the park, including relocating stone crushing sites and creating more water drainage channels. These suggestions indicate a focus on mitigating the environmental impact of the SGR, particularly in the context of the Nairobi National Park, while also addressing the needs and concerns of local communities.

4. DISCUSSION

4.1 Changes in land cover

4.1.1. Built-up areas

The built-up areas class initially took up only 16% of the study area but over the four years had grown to cover close to 22% of the area. That's a change of 6% over four years or 1.5% per year. Similar findings were reported by [15] who reported the conversion of other land classes to built-up areas as a result of the increased expansion of urban areas. In addition to the construction of the SGR line, another possible reason for the increase in could be due to the increase in urban population as a result of rapid urbanization in Kenya [16]. This has led to increased pressure on agricultural lands, shrub land, grassland and other resources which are already limited [17]. There are several reasons for the increase in urbanization, however, none has had such an impact by the devolution of resources over the past 20 years, initially initiated by the Constituency Development Fund in 2003 [18], and later the implantation of the devolved system of governance in 2013 [6] The ripple effects of this have been the increase in the construction of buildings, roads, and railways; leading to the creation of more employment opportunities [18]. The resulting impact has been a rapid increase in the urban population, for example, the urban population in Kenya in 2009 was 12.84 million [18], this has risen, and by 2019 the population was 14.83 million KNBS, 2019. Other causes of the increase in urbanization are infrastructure development [19] subdivision of agricultural lands [18] and inefficient land use policies [13]. The above findings call for efforts to sustainably manage the transitions to built-up areas, especially considering its negative impact on water resource quantity and quality [20].

4.1.2. Forests

The map shown in figure 7 demonstrates the portioning effect that the SGR track has had on the Oloolua Forest. The map shows that a once contiguous forest has been broken down into 3 smaller parts, making it vulnerable to transitioning. The impact of the development on the forest comes not only from the 2.56% of the forest destroyed to pave way for the track but also from the interruption of the ecosystem by the manmade feature. Deforestation can be attributed to a lack of public awareness of the role of forests in both environmental conservation and the economy [18]. Additionally, there is a lack of adequate policy implementation on the conservation and protection of forests [21]. The need to expand agricultural activities has further increased pressure on this forest with the growing demand for food as a result of an increase in the human population [22]. Changes in forest cover could potentially close off parts of the range enjoyed by wildlife living in that forest. The clearance also has implications for ecosystem services provision and mitigation against climate change as they influence the amount of carbon dioxide in the air [23]. Other impacts of deforestation include degradation of water towers impacting water availability, and loss of biodiversity and habitat [24].

4.1.3. Cropland

The results of the study indicate that there was a significant decline of almost 13% in the cropland class throughout the entire period under review. This reduction in cropland has the potential to negatively impact food security if not managed sustainably. The decreasing trend in cropland size could also have implications on future productivity and food security of the area. The decrease in cropland is largely attributed to the conversion of agricultural land to built-up areas, as documented in previous studies [25,26].

4.1.4. NDVI

The analysis revealed that the 2018 - 2019 epoch exhibited the most significant changes in NDVI values compared to other epochs, indicating a reduction in vegetation density in several areas. This reduction in vegetation density could potentially lead to adverse impacts on soil erosion and flooding as vegetation plays a crucial role in moderating surface runoff. Therefore, the loss of vegetation cover is a matter of concern, and appropriate measures must be taken to mitigate its negative effects.

4.2 Environmental impacts

4.2.1. Habitat fragmentation and ecosystem degradation

The most obvious impact of the SGR has been habitat fragmentation, habitat alteration, and barrier effects. The SGR made way across key ecosystems such as parks, forests, and grasslands limiting the movement of both animals and reduction in available resources. The park's partitioning of both the rangelands in the Nairobi National Park as well as the major forest has an impact on the habitat of wild areas. [27] made a similar observation when they looked at the impact of road and rail infrastructure on wildlife. Wildlife residing close to infrastructure is mainly affected by vibration, noise, chemical pollution, and human presence [28]. Planned mitigation measures of having underpasses and bridges to allow free movement of animals have been compromised by people settling around them. This was emphasized by most respondents with one of them saying “The underpasses have done nothing to aid the movement of animals; in fact, they created favorable areas for illegal settlement with the animals avoiding the areas entirely”. The destruction of a swathe of the forest as well as its partitioning might have an impact on the services it provides. In particular, there may be impacts on carbon sequestration, groundwater recharge, and the aesthetic appeal of the forest as noted by [29].

The loss of vegetation in the study area can lead to land degradation and impact the value of ecosystem services. This is especially concentrated in the central part where croplands are located. The causes of reduced vegetation density need to be investigated further. The study also found excavated areas for railway construction that pose a risk to people and the environment during rainy seasons as they can hold water and encourage soil erosion.

4.2.2. Pollution and flooding

With regards to pollution, a majority of the respondents reported being impacted by the dust from the SGR project either during its development or afterward. Similar sentiments are expressed with regard to noise pollution where 61% of the respondents reported the impact of the SGR on their health. The respondents stated that noise pollution is mainly experienced when the trains are passing, and due to blasting during the construction stage.

Dust pollution also came up as a challenge and there was increased evidence of pulmonary diseases i.e. coughs and chest pains. It can therefore be seen that the SGR has had a tangible impact on the population with regard to pollution. This is something that needs mitigating to prevent future deterioration of the health of residents in the area.

Regarding water, 60% of the respondents reported having experienced flooding which they believe to be tied to the SGR development. The flooding may be indicative of the loss in vegetation cover. This will be exacerbated by the expected increase in precipitation extremes due to landscape stressors on natural vegetation leading to negative feedback as reported by [30]. Similar reports of flooding along the SGR have been recorded. For example, [31] reported flooding along underpasses when it rained while some rivers had been blocked due to the construction

4.3 Socio-economic Impacts

4.3.1. Human displacement

According to the study, one-third of the respondents reported feeling displaced due to the SGR development, with a significant impact on multi-resident dwellings. However, the majority of residents do not have concerns about the SGR passing through their area and feel safe about its presence. While there are challenges associated with the development, 57% of respondents reported net positive impacts, such as job creation, economic growth, and increased business opportunities.

4.3.2. Pasture availability

The conversion of grasslands to built-up areas has implications for the availability of fodder for livestock and wildlife. Approximately one-third of respondents reported difficulty accessing grazing lands due to SGR development, which may impact livestock and wildlife. Additionally, wildlife may be forced into areas settled by people due to denied access to feeding grounds. Further investigation is needed to better understand the impact of the SGR on domestic and wild animals.

4.3.3. Human–wildlife conflict

The study found that many people reported experiencing conflict with wildlife, which may suggest that human activities are encroaching on wildlife habitats. The results showed that human and wildlife ranges often overlap in the study area, and as more land is developed, it is likely that conflicts between humans and wildlife will increase. Respondents noted that settlements have been built in buffer areas since the construction of the SGR, leading to more interactions between humans and wildlife.

4.4 Mitigation Measures

The study shows that the SGR track has caused significant land cover change, leading to negative socio-economic and social-ecological impacts such as loss of biodiversity and habitat, water pollution, reduced river flows and groundwater recharge, and land degradation. To address these impacts, measures must be taken to mitigate their effects.

To prevent land degradation, regular monitoring and soil protection measures should be implemented based on findings from studies such as this one. Additionally, impacts on domestic and wild animals due to their ranges being disrupted should be mitigated through the use of underpasses and other measures. More attention should be given to herders' complaints about not being able to access certain fields to reduce instances of human-wildlife conflict in the future.

Impacts on forested areas can be mitigated by ensuring sustainable land management within these areas [32]. Techniques such as fencing could be taken into consideration but with allowances made for animal migration. Non-contiguous forested areas should be prioritized in implementing interventions to conserve the forests. Impacts on cropland and food security can be mitigated by controlling the rate of transitions from cropland to built-up areas. Implementation of zoning regulations where agricultural land is maintained free of housing might provide one way to do this. In addition, improved agricultural practices and intensified production can also be used to mitigate future food security concerns. In the future, policymakers should come up with robust policies considering that land management policies influence land cover change [33].

Impacts on displacement caused by the SGR can be mitigated by resettling affected residents whose houses were demolished. For future infrastructure projects, participatory planning should be considered to enhance inclusivity and sustainability [34]. Managing pollution is more complex, and while dust pollution during development was mitigated using trucks with water sprinklers, other technologies might have to be employed in areas where residents are seriously impacted by dust during operation of the SGR track. Noise pollution is even more challenging to mitigate, and the only option may be to resettle the worst affected residents further from the SGR track.

4. CONCLUSIONS

This study has demonstrated the utility of geographic information systems (GIS) and remote sensing (RS) techniques for assessing environmental impact. The integration of socioeconomic analysis with GIS and RS enabled a comprehensive characterization of the study area, enabling a better understanding of the changes occurring and their associated impacts on the environment and society. The study area has undergone a significant transformation, with an increasing dominance of the built environment class at the expense of grasslands, croplands, and forestlands. The analysis of the impacts of these changes on the environment and society revealed the need for mitigation measures to address future challenges. These findings emphasize the importance of utilizing GIS and RS tools in environmental assessment and decision-making processes to facilitate effective planning and sustainable management of natural resources.

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