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ENVIRONMENTAL STUDIES

CORRELATION BETWEEN LOCATION OF ILLEGAL ACTIVITIES AND INFRASTRUCTURE (ROADS, RANGER POSTS AND FENCE) IN THE ABERDARE RANGES

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ABSTRACT

Purpose of the Study: To determine the correlation between the location of illegal activities and infrastructure (roads, ranger posts, and fences) in the Aberdare Ranges.

Statement of the Problem: Forest loss in mountain ecosystems, driven by factors such as agriculture, forest fires, and commercialization of forest products, is rapidly increasing. The impact of infrastructure, specifically roads, ranger posts, and fences, on illegal activities in the Aberdare Ranges remains inadequately understood, despite the area's ecological importance.

Methodology: The study utilized routine ecological monitoring data collected by the Kenya Wildlife Service (KWS) and Aberdare Joint Surveillance Unit (AJSU). KWS collected data during elephant surveys in 2017 and 2021, while AJSU continuously collected data on illegal activities from 2017 to 2021. A total of 955 records were collated from 2015 to 2021 to form a dataset for analysis. Data was analyzed using ArcMap 10.8 and R software to assess the relationship between infrastructure (roads, fences, guard posts) and illegal activities.

Findings: The study found a significant correlation between the proximity of illegal activities and various types of infrastructure (road, fence, KFS station, and KWS park gates). Most illegal activities occurred closer to roads and fences compared to KWS and KFS stations. This proximity suggests that infrastructure may facilitate illegal activities in protected areas.

Recommendations: The study recommends that infrastructure development in protected areas should consider diverse factors, including environmental, social, and economic implications in both the short and long term.

Keywords: *Location of illegal activities, infrastructure roads, ranger posts, fence, Aberdare ranges*

INTRODUCTION

One of Kenya's most important protected regions, the Aberdare Ranges, sometimes referred to as Nyandarua, is a major water tower spanning 2162 square kilometers. According to the Aberdare Ecosystem Management Plan (2010), it includes the Aberdare Forest Reserve, Lake Ol' Bollosat, Kikuyu escarpment, Kipipiri Forest Reserves, and Aberdare National Park. 160 kilometers make up the range (Scoon, 2016). It is distinguished on the western side by a prominent escarpment. The range was constructed by a series of ridges that joined in an almost straight line. The Gregory Rift Valley's eastern flank is home to the Aberdare Mountain. They make up the central highlands together with Mount Kenya (Chuah-Petiot, 1997). Illegal resource use is typically linked to biodiversity loss in protected areas (Critchlow et al., 2015). Both plant and animal species are included.

Illegal logging is a significant international issue with wide-ranging implications for law, politics, society, and the economy. Although there is no universally accepted definition, it is typically understood as the harvesting, movement, processing, purchase, or sale of wood in violation of national or local laws (Hembery et al., 2007). Deforestation, largely driven by the conversion of forest lands for agriculture and urban development, has been a major concern in temperate and subtropical regions (Chakravarty et al., 2011). From 2010 to 2015, countries like Brazil, Indonesia, Myanmar, Nigeria, and Tanzania experienced the greatest annual forest loss, while China, Australia, Chile, the USA, and the Philippines reported the highest forest gains (FAO, 2015). In countries like Cameroon, Brazil, and Indonesia, illicit logging has significantly decreased due to government interventions (Lawson & MacFual, 2010). In Kenya, between 2000 and 2018, the country lost 9.8% of its tree cover, amounting to 103 metric tons of carbon dioxide emissions. The decline in tree cover, particularly in counties like Nakuru, Kilifi, Lamu, Kwale, and Kericho, has worsened, with Narok showing the largest loss of 74.5kha. Overall, Kenya’s tree cover decreased by 6% between 2000 and 2020 (Global Forest Watch, 2020; Global Forest Watch, 2023).

Statement of the Problem

Forest Management in Kenya faces the challenges of monitoring and tracking illegal logging and other crimes. There is a great need for information that can provide a baseline for setting up a system for regular monitoring (KFS, 2007). Due to the increase in human population; grasslands, forest reserves, national parks, wetlands, and other fragile areas are becoming a target for human settlement in Kenya (Ministry of Environment and Forestry, 2018).

Aberdare ecosystem is the major source of water to Kenya's capital city of Nairobi, supplying water to over 4 million people. Ndakaini dam and Sasumua dams are the major water sources and are supplied by the Aberdare ranges (Nairobi City Water and Sewerage Company, 2020). The Aberdare ecosystem, both the Forest Reserve and the National Park are facing threats from human impacts such as over-grazing, over-abstraction of water, poaching of wildlife, degradation of riparian systems, habitat loss, forest excisions, encroachment, illegal charcoal production, and visitor impacts (KWS & KFS, 2010). Aberdare is also home to the critically endangered Mountain Bongo (*Tragelaphus eurycerus isaaci*) whose population has been declining over the years with only 96 individuals remaining in Mt Kenya, Aberdare, Eburu, and Mau forests (KFS, 2019). In addition, lake Ol Bolossat is a wetland that depends on Aberdare for water. The lake is a biodiversity hotshot and Important Bird Area (IBA). The lake faces numerous threats as well such as encroachment and impacts of climate change (EAWLS, 2023).

The ecosystem is currently faced with the challenge of inadequate information on the threats facing it. There has been a challenge in streamlining data collection protocols, automation, and consistency between key players involved in the Aberdare ecosystem management (KWS & KFS, 2010). Considering the great importance of Aberdare Ecosystem, both for production and conservation purposes, there is a great need for data to help in the conservation of the ecosystem. This study assessed the correlation between location of illegal activities and infrastructure (roads, ranger posts and fence) in the Aberdare ranges.

Research objective

To determine the correlation between location of illegal activities and infrastructure (roads, ranger posts and fence) in the Aberdare ranges.

LITERATURE REVIEW

Road network in protected areas

The Programme for Infrastructure Development in Africa anticipates a significant increase in road infrastructure projects across sub-Saharan Africa. These large-scale projects are strategically designed to boost trade and foster economic development There is a growing concern about the potential negative impacts of road infrastructure development in sub-

Saharan Africa (SSA), particularly in relation to conservation and ecological integrity (Perumal *et al*, 2021).

The conservation community however expresses concern about the environmental consequences of the expanding road network. There is apprehension that these developments may lead to extensive and prolonged exploitation of natural resources, potentially resulting in biodiversity loss. The development of new roads might have detrimental effects on natural ecosystems. Large-scale and long-term overexploitation of resources is seen as a potential consequence, raising concerns about the ecological integrity of the affected areas. The term "deleterious" is used to describe most of the impacts associated with road development. This term indicates that the effects are harmful or damaging to the natural environment.

The presence of roads in protected areas globally is a complex and varied issue. Protected areas, such as national parks, wildlife reserves, and other conservation zones, are established to safeguard natural ecosystems, biodiversity, and cultural heritage. However, roads can have both positive and negative impacts on these areas, depending on various factors such as their design, location, and management.

The ecological effects of roads are described as varying over time and having a multidimensional nature. This complexity makes it challenging to assess and quantify the impacts accurately. The effects of roads are heterogeneous, meaning they vary across different contexts and conditions. Factors such as road quality and size, construction and management practices, law enforcement, the presence of roads in protected areas, and the underlying mechanisms of effects all contribute to this heterogeneity. Assessing and quantifying the ecological effects of roads is described as challenging due to their multifaceted nature. The impacts can be influenced by various factors, and the understanding of these factors is not always comprehensive.

Various factors influencing the effects of roads include road quality and size, construction and management practices, law enforcement, the presence of roads in protected areas, and the specific mechanisms by which certain effects occur (Rytwinski & Fahrig, 2015).

The handbook of road ecology emphasizes the diverse and complex nature of the ecological effects of roads, calling attention to the need for a comprehensive, landscape-level perspective and the consideration of various influencing factors in assessing and managing road impacts on wildlife and ecosystems (Rytwinski & Fahrig, 2015).

Well-planned roads can provide access for scientists, researchers, and conservationists to study and manage protected areas effectively. Roads can also facilitate responsible tourism, allowing visitors to appreciate and learn about the natural beauty and biodiversity within protected areas (Perumal *et al*, 2021).

On the other hand, roads can separate habitats interfering with species and negatively affecting natural migration patterns of wildlife. Habitat fragmentation can cause loss of genetic diversity and negatively impact ecosystems. The ecological threats posed by road development are likely diverse and encompass issues such as habitat fragmentation, altered migration patterns, increased accessibility for illegal activities, soil erosion, pollution, and potential introduction of invasive species. Accessible roads may make it easier for poachers and illegal loggers to enter protected areas, posing a threat to wildlife and undermining conservation efforts (Perumal *et al*, 2021).

To mitigate negative impacts of road access, it is important to carefully plan on road networks within protected areas. Ecological sensitivity and connectivity should be the basis to help minimize negative impacts. Employing technologies such as wildlife corridors, overpasses, and underpasses can mitigate the effects of habitat fragmentation caused by roads. In addition, protected area managers can restrict vehicle access in certain areas and promote low-impact recreational activities to protect sensitive ecosystems. Involving local communities in the management of protected areas and educating them about the importance of conservation can lead to better protection and responsible use of natural resources. Conducting regular monitoring of road impacts and strict enforcement of regulations can help address issues such as illegal logging, poaching, and other detrimental activities (Perumal *et al*, 2021).

Effects of road network on species

The vulnerability of species to roads and traffic, depends on ecological traits and behavioural responses. This includes reproductive rate and mobility. Higher reproductive rates enable populations to recover more effectively from road mortality. More mobile species are likely to encounter roads more frequently than sedentary species (Rytwinski & Fahrig, 2015).

Animals' behaviour towards roads can be classified into four main types. Firstly, animals may exhibit avoidance behaviour by minimizing their use of road surfaces, and/or avoid areas with high traffic disturbance. Some animals may avoid vehicles whereas some may be attracted to roads (Rytwinski & Fahrig, 2015).

Avoidance behaviours such as avoiding the road surface or traffic disturbance can reduce the risk of road mortality but may lead to habitat fragmentation or loss. Some species may be drawn to more movement on roads for resources like carrion, nesting sites, or basking. This attraction can make them more susceptible to being hit by the

they may face challenges accessing important habitats on the other side. Species with the ability to move out of the path of an oncoming vehicle are less susceptible to road mortality and may navigate roads when traffic is low. Some species may be attracted to roads for resources, making them vulnerable to road mortality (Rytwinski & Fahrig, 2015).

Rytwinski & Fahrig based their study on a formal review of 75 studies published from 1979 to early 2011. To determine whether a species was negatively or positively affected or had a neutral effect due to roads, the studies involved analysing population size changes in relation to road and traffic impacts. This means the impact of roads on different species is a complex interplay between ecological traits and behavioural responses in influencing how species interact with roads and traffic. Larger, more mobile mammal species with lower reproductive rates were more susceptible to road mortality. This vulnerability may be due to increased encounters with roads and a slower reproductive capacity, making it challenging for populations to recover (Rytwinski & Fahrig, 2015).

Species that avoid roads due to traffic-related disturbance may be more exposed to habitat fragmentation, loss, and degradation. While this avoidance behaviour may reduce the risk of road mortality, it can lead to negative consequences for the overall habitat and population dynamics (Rytwinski & Fahrig, 2015).

There are instances where the populations of rodent and hoofed mammal species have been observed to increase near roads in response to roads, while carnivore populations tended to decrease. Among rodents, only a few species showed negative effects from roads, while a larger number were either positively affected or unaffected. This indicates that many rodents may adapt to or benefit from the presence of roads. Many rodent species showed positive or neutral effects in response to roads, suggesting that these species may be more resilient or adaptable to the changes associated with road development (Rytwinski & Fahrig, 2015).

The differential responses of mammal populations to roads, with larger, less reproductive species being more susceptible to road mortality. Additionally, it emphasizes that the impact on mammal populations varies among different orders, with rodents often exhibiting positive or neutral responses to road presence (Rytwinski & Fahrig, 2015). Understanding these dynamics is crucial for developing effective strategies to mitigate the negative impacts of roads on wildlife populations.

Fencing in protected areas

The creation and fencing of protected areas are identified as popular methods for isolating biodiversity from human activities, aiming to achieve conservation protection. Fences can provide numerous benefits to both people and wildlife if properly planned. Fences have been helpful in mitigation of human wildlife conflict. For instance, they act as barriers to prevent crop damage, predation of livestock and improving human safety. This suggests that well-implemented fencing can contribute to human safety and livelihoods. This implies that fencing can contribute to the protection of these species, potentially helping to maintain ecological balance and biodiversity. In addition, fences can reduce encroachment into protected areas and mitigate wildlife poaching (Adam *et al*, 2019).

Though fencing protected areas has many benefits, it might negatively affect connectivity of landscapes and wildlife dispersal areas: Fences can disrupt natural wildlife migrations and dispersals. The restriction of wildlife mobility by fences can also affect resource utilization and grazing pressure by wildlife. This alteration may have ecological consequences for vegetation and other elements of the ecosystem. Additionally, fences may modify predator-prey interactions by influencing predation patterns. This alteration can have cascading effects on the dynamics of both predator and prey populations. Fences interference with wildlife movements is expected to intensify with climate change. For example, with more cases of prolonged drought, wild animals require to move for longer distances via different routes for resources like food and water, and fences may pose additional challenges.

Fences can also isolate wildlife populations, which can lead to increased vulnerability. Isolated populations are at risk of inbreeding, which can have negative consequences for genetic diversity and long-term population health (Adam *et al*, 2019).

Massey *et al*. (2014) did a study to assess the behaviour of wildlife populations and diversity before and after fence construction in Aberdare Conservation Area. They assessed the effectiveness fencing as a conservation measure. At Treetops lodge, a hotel that is closer to the park boundary experienced a significant reduction of wildlife numbers. Species richness was also affected, with decline recorded post fence construction (Massey *et al*, 2014). However, at Ark Lodge, situated farther away from the park boundary the wildlife population numbers remained almost constant during the data collection period before and after fence construction. The wildlife numbers were higher near the park boundary immediately after fence construction in 1989. From late 1990s, this trend was reversed, and wildlife numbers started to decline near the park boundaries.

While the data do not dismiss the potential value of fences, they suggest that their success is contingent on effective management practices. Fencing has complex dynamics involved in conservation efforts, especially in the context of protected areas and perimeter electric fences. It highlights the importance of ongoing management and enforcement to ensure the sustained effectiveness of such conservation measures (Massey, King, & Foufopoulos, 2014) .

A case study on social impact of fencing communal land in Eastern Namibia showed that fencing can infringe on land rights, suggesting that the installation of fences may encroach upon or restrict the traditional land-use practices of local communities. This can lead to tensions and conflicts over land ownership and access (Twyman *et al*, 2002). The presence of fences can limit the ability of people to access natural resources. This restriction may affect local communities that depend on these resources for their livelihoods, such as grazing land, water sources, or areas for gathering plants. Fences can interfere with travel routes traditionally used by local communities. This disruption can impact the movement of people and livestock within and across landscapes, potentially affecting migration patterns or access to essential areas. The installation of fences may generate conflicts with nearby communities. This could result from perceived injustices related to land rights, resource access, or disruptions to established travel routes, leading to tensions between conservation goals and the needs of local populations. The social impacts of fences emphasize the importance of considering social equity in conservation practices. Balancing the goals of protected areas with the rights and needs of local communities is crucial for fostering positive relationships and sustainable conservation strategies. The social perspective shows the potential conflicts and challenges that can arise when fences are introduced in protected areas. It emphasizes the need for a holistic approach to conservation that considers the social dynamics, land rights, and livelihoods of nearby communities to ensure a more inclusive and sustainable conservation strategy (Twyman *et al*, 2002).

RESEARCH METHODOLOGY

The study used data collected by the Kenya Wildlife Service (KWS) and Aberdare Joint Surveillance Unit (AJSU) routine ecological monitoring. KWS collected data during elephant surveys in 2017 and 2021 while AJSU collected data during routine monitoring that was continuously done on a priority basis from 2017 to 2021. All data on illegal activities collected from 2015 to 2021 from both sources was collated to make one data set of 955 records. The data was analysed using ArcMap 10.8 and R software to determine the relationship between roads, fences, guard outposts, and illegal activities.

RESULTS AND DISCUSSION

Proximity of illegal activities location to infrastructure

Near distance to roads

The shortest distance of illegal activity to the nearest road was 0.9 meters, while the farthest distance of illegal activity to the nearest road was 5.8 kilometres (Table 1). Most of the incidents, (98%), happened within a radius of 5 kilometres and below, while only 1.23% happened within a nearest distance of between 5.1 to 10 Kilometres (Table 1, Figure 1 &2). The short range was due to the high road network especially in the forest reserve where most of the illegal activities were observed. Support your findings from research or literature of others.

Near distance to electric fence

Most illegal activities observed (93.8%) had the nearest distance to the electric fence between 0-5 kilometres. Only 6.2% whose nearest distance to the fence was between 5.1 - 10 kilometres (Table 1, Figure 1 & 2) This could be attributed to the fact that the fence forms a major barrier and it’s located closer to the settlements. Fence damage was likely to happen to move resources out of the protected area.

Near distance to KWS Gates

The mean near distance of illegal activities to closest KWS gates was 20.1 kilometres while the farthest and closest near distance was 51.1 and 0.4 kilometres respectively. The nearest distance for most of the illegal activities (30.8%) was between 10.1 to 20 kilometres, while 14.4% nearest distances were between 0 to 5 kilometres. 14.7 % observations were between 5.1-10 kilometres and 16.3% nearest distance were between 20.1 to 30 kilometres. However, this was the only class with the greatest variation in nearest distances with 8.3%, 12.4% and 3.1% observed between 30.1-40km, 40.1-50 km and above 50 km respectively (Table 1). The variability of near distances was larger in the upper quartile and had significant positive skew (Figure 1 & 2).

Near distance to KFS Stations

The mean near distance of illegal activities to the closest KFS station was 7.8 kilometres while the farthest and closest distance was 30.7 and 0.2 kilometres respectively. Most of the illegal activities (43%) were observed within 5 kilometres and below, while 28.6% were between 5.1 to 10 kilometres. 22.8% of illegal activities were between 10.1-20 kilometres and 5.5% between 20.1 to 30.7 kilometres. The variability of near distances from illegal activities location to nearest KFS station also showed a significant positive skew with longest distances in the upper quartile (Figure 1 & 2). Table 1 shows the summary of the number of illegal activities in different distance classes per infrastructure. Table 2 is a show the maximum, average and minimum distances from each infrastructure.

Table 1: Classes of near distances between location of illegal activities and different infrastructures

Distance	Infrastructure				
(Kilometres)	Fence	KFS Station	Road	KWS Gate	Total %
0-5	93.83	43.16	98.77	14.35	62.53
5.1-10	6.17	28.59	1.23	14.69	12.67
10.1-20	0.00	22.76	0.00	30.83	13.40
20.1-30	0.00	5.49	0.00	16.26	5.44
30.1-40	0.00	0.00	0.00	8.30	2.07
40.1-50	0.00	0.00	0.00	12.44	3.11
Above 50	0.00	0.00	0.00	3.14	0.78
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Table 2 below further demonstrates a summary of near distances in kilometres between location of illegal activities and different infrastructures

Table 2: A Summary Of Near Distances In Kilometres Between Location Of Illegal Activities And Different Infrastructures

	Maximum(km)	Average(km)	Median(km)	Minimum(km)
Electric fence	9.2000	1.8880	1.3770	0.0002
KFS Station	30.7030	7.7850	5.4710	0.1740
Park gate	51.0800	20.1440	16.3060	0.3940
Road	5.8020	1.4620	0.8230	0.0009

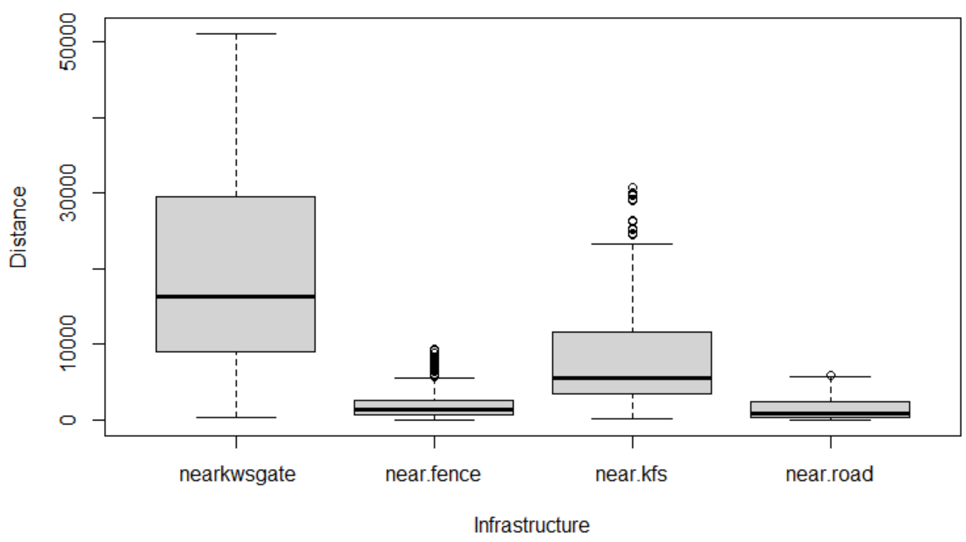

Figure 1: A box plot showing variation of near distances(km) to respective infrastructure.

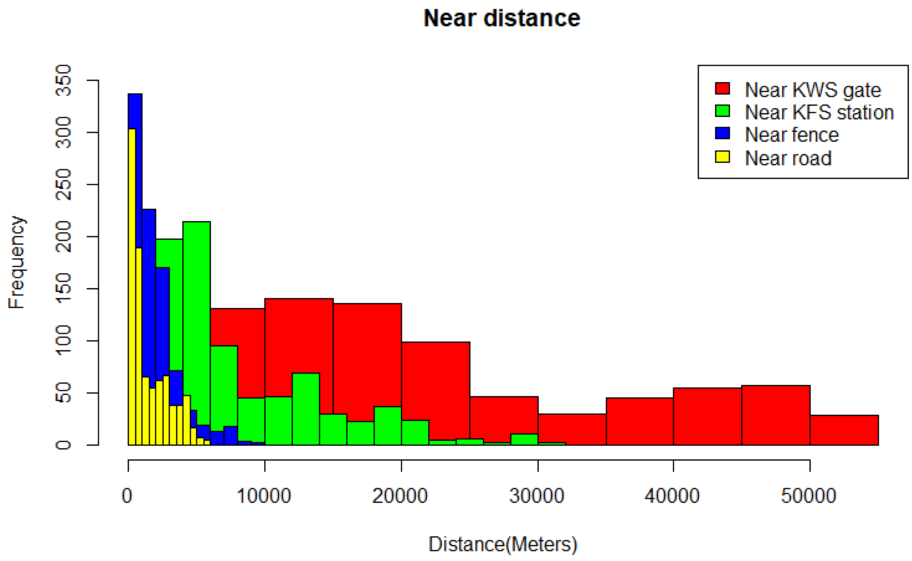

Figure 2: A Histogram Showing Variation In Distribution Of Near Distance Of Illegal Activities To Different Infrastructure.

The analysis of variance- One Way ANOVA

The comparison between the means of near distance of location of illegal activities to different types of infrastructure (roads, fence, KWS and KFS outposts) showed a significant variation. The F value was very high >0.05. This shows that variation caused by independent variables (infrastructure types) is real and not by chance. The extremely small p value <0.05 shows that there was a significant difference of proximity of illegal activities location in relation to different types of infrastructure (road, fence, KFS station and KWS Park gate). Therefore, reject null hypothesis. H0: There is no difference in intensity of illegal activities in relation to proximity of different types of infrastructures (roads, ranger posts and fence) in Aberdare Ranges, Kenya. The post hoc test from all different infrastructure types using TukeyHSD however showed that near road and near fence distances means were not significantly different (Table 3).

Table 3: One way ANOVA results

	Df	Sum sq	Mean sq	F value	Pr(>F)
Infrastructure	3	2.03E+11	6.76E+10	1073	<2e-16
Residuals	3564	2.25E+11	6.31E+07		
Signif. codes:	0.001	0.01	0.05	0.1	1

Table 4: Post hoc test: from all possible comparisons TukeyHSD

Infrastructure	p adj
Near fence- Near KWS gate	0.000
Near KFS station - Near KWS gate	0.000
Near road- Near KWS gate	0.000
Near KFS station- Near fence	0.000
Near road - Near fence	0.668
Near road - Near KFS station	0.000

Forests and infrastructure have a complex relationship, where development is necessary for economic growth, but it can also pose risks to the environment. Infrastructure development, such as roads, railways, powerlines, and irrigation canals, can negatively impact ecosystems by causing habitat loss, fragmentation, and species decline through wildlife collisions and the spread of invasive species. Increased accessibility may also encourage illegal activities like snaring and logging, further depleting wildlife populations (Sharma et al., 2018). In the Amazon, for example, 95% of deforestation occurs within 5km of road infrastructure, highlighting the direct impact of development on forests (Tyrrell and Allan, 2020).

Many protected areas in Africa were established without a complete understanding of ecosystem dynamics and wildlife resource requirements. As a result, these areas may struggle to function as self-sustaining systems. One exception is the Okavango complex in Botswana, which is maintained through a network of interconnected national parks and reserves, preserving both wet and dry season resource zones (Ferguson & Hanks, 2010). This approach contrasts with the challenges faced by other regions, like the Aberdare

Ranges in Kenya, where infrastructure projects, including the "Mau-Mau Road project" and "Ihithe-Aberdare Forest-Kahuruko-Ndunyu Njeru Road," have threatened the ecosystem (Koech, 2022).

In June 2023, the East Africa Wildlife Society raised concerns about the proposed upgrade of the Ihithe-Aberdare Forest-Ndunyu Njeru road. The main issues included insufficient environmental consideration in the Environmental Impact Assessment (EIA), such as the lack of security implications after road completion and the potential loss of revenue for Kenya Wildlife Service (KWS) and Kenya Forest Service (KFS) due to increased access. Previous studies, including those by the University of Nairobi, Oxford, and Amsterdam, concluded that the upgrade would provide negligible socioeconomic benefits, criticizing the EIA for failing to consider alternative routes and adequately involve environmental experts (EAWLS, 2023).

CONCLUSION

The study concludes that there is a significant correlation between the proximity of illegal activities and various types of infrastructure, such as roads, fences, KFS stations, and KWS park gates. Most illegal activities, including illegal logging, snaring, charcoal making, firewood collection, honey harvesting, waste disposal, and motorbike access, were found to be concentrated near roads and fences. The study emphasizes that intensive surveys and patrols are crucial for detecting and preventing these activities. It recommends strengthening security in areas close to roads and fences to protect the Aberdare ecosystem. Furthermore, the study highlights the importance of strategic planning, environmental impact assessments, and mitigation measures to address the ecological concerns arising from increased infrastructure development. Sustainable management practices, ongoing research, and balancing human development with biodiversity preservation are essential for minimizing negative impacts while supporting conservation and sustainable development.

RECOMMENDATIONS

The study recommends that sustainable and effective management policies be based on a solid scientific foundation, ensuring that decisions regarding resource management, conservation, and development are informed by comprehensive scientific evidence (Ferguson & Hanks, 2010). It emphasizes that infrastructure development in protected areas should consider environmental, social, and economic factors in both the short and long term to enhance sustainability. Policies should be formulated with an understanding of the inherent complexities in ecological systems, acknowledging that scientific knowledge may not always provide definitive answers. Therefore, decision-making must balance economic interests, such as timber production, with the necessity to conserve and sustainably manage forest ecosystems. This approach ensures that economic benefits can be realized without compromising the long-term health and resilience of the environment.

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