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ANALYSES OF FOREST COVER CHANGE DUE TO REFUGEE SETTLEMENT IN KULE, TERKIDI, AND JEWI REFUGEE SITES, GAMBELLA REGIONAL STATE, ETHIOPIA

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ABSTRACT

Following a long civil war in Sudan, nearly half a million South Sudanese refugees have fled their country, crossing the border to neighboring Ethiopia. This study examined the effects of refugee camp establishments on forest cover changes from 2005-2023, taking the Kule, Terkidi, and Jewi refugee camps located in the Gambella regional state of Ethiopia. Landsat 5 TM (Thematic Mapper) and Landsat 8 OLI satellite images from 2005, 2014/2015, and 2023 were used to assess changes in forest cover. The study revealed significant spatial and temporal changes in forest cover across the three refugee camps, with a deforestation rate ranging from 2.35% at Jewi to 3.98% at the Kule camp and 3.76% at Terkidi refugee camp. The forest cover changes identified in this study call for enhancing sustainable forest-based ecosystem planning and implementation approaches. Stakeholders involved in refugee management should initiate and implement critical actions to encourage more sustainable practices.

Keywords: Deforestation; Refugee Camps; Random Forest; Google Earth Engine; Sustainable Development[1]

INTRODUCTION

Armed conflicts and various forms of violence around the world are among the major factors that led to 89.3 million people being displaced worldwide at the end of 2021, which led to human-induced changes in landscapes (Daiyoub et al., 2023; UNHCR, 2025). Civil wars cause massive casualties and human rights violations, disrupt development, damage the environment, weaken institutions, seriously disturb public order, restrict governance and civil liberties, and forcibly displace predominantly noncombatant populations (Baez, 2011; Maystadt et al., 2020). The number of people who have been forcibly displaced has increased steadily over the past decade due to war, violence, persecution, and human rights abuses (Sakamoto et al., 2024). Refugee camps are built in nearby countries to host those who have fled conflict areas. Refugee settlements are rarely sustainable. The establishment of refugee settlements has had profound effects on forest cover. While the humanitarian needs of refugees cannot be ignored, their impact on ecologically important forests is also as significant for both the host community and the refugee community. This is particularly significant in light of the wide-ranging benefits of forests for rural livelihoods.

Hosting refugees over extended periods can have a profound impact on the economic and social conditions of the local environment (Daiyoub et al., 2024). Camps are often situated in semiarid zones or near protected forests, with an absence of regulations restricting extractive practices (Maystadt et al., 2020; Owen et al., 2023). Anthropogenic pressures emanating from such conflict-induced refugee settlements in ecologically rich areas can have significant environmental impacts, particularly on forest cover (Hassan et al., 2023). The establishment of refugee camps resulted in the indiscriminate clearing of vegetation cover for the establishment of refugee camps to construct shelters, farm, and firewood (Akokpari, 1998; Bildirici et al., 2023). Refugees' reliance on firewood for cooking and heating significantly accelerates deforestation around their camps, as they extensively harvest from local forests to meet their urgent fuel needs (Gianvenuti et al., 2022, 2018; Salemi, 2021).

The UN Sustainable Development Goals (SDGs) include several goals directly related to environmental sustainability. In particular, SDG 13 (climate action) and SDG 15 (life on land) emphasize the need to address natural resource management, biodiversity, and climate change, aiming to protect the planet and ensure prosperity for all by 2030. A decline in natural capital through forest loss is a crisis of environmental sustainability and a threat to local and regional social stability in the context of host–refugee relations. This undermines the Sustainable Development Goals, as it triggers long-term ecological imbalance and affects ecological integrity.

Gambella region in Ethiopia hosts multiple refugee camps that primarily accommodate South Sudanese refugees, resulting in deforestation and biodiversity loss (UNHCR, 2025). Despite their humanitarian necessity, the long-term environmental consequences of refugee settlements remain understudied in Ethiopia in general and in the Gambella region specifically, necessitating a systematic assessment of forest cover changes due to refugee settlements. Deforestation, driven by the expansion of refugee sites, has caused conflict with the host community, but the extent and causes of this conflict remain unclear. (World Bank, 2020). This lack of data limits the ability of policymakers, humanitarian organizations, and conservation agencies to develop sustainable solutions that balance refugee needs with environmental protection and/or ecological conservation.

Remote sensing has become a crucial tool in mapping and monitoring forest resources, driven by advancements in data analysis techniques and the integration of advanced sensor technologies and machine learning algorithms (Daiyoub et al., 2023). Remote sensing can be used as a cost-efficient option for assessing degradation through proxies such as canopy cover percentage, with a decreasing trend indicating forest degradation (Akhtar et al., 2022). In remote areas where on-the-ground methods can be challenging, satellite imagery through remote sensing serves as a valuable tool for assessing the effects of conflict on the landscape, providing a distinct historical record and enabling the analysis of changes in land cover over time and space (Aldiansyah and Saputra, 2023; Lodhi et al., 1998). Land cover classification with satellite imaging time series has been shown to be effective for mapping forest dynamics surrounding refugee camps (Akhtar et al., 2022; Daiyoub et al., 2023; Lodhi et al., 1998).

This study aimed to assess forest cover changes in Kule, Terkidi, and Jewi refugee settlements in the Gambella region by quantifying deforestation trends via remote sensing techniques. Understanding these changes is crucial for balancing refugee needs with environmental conservation, informing policymakers, humanitarian organizations, and local stakeholders on strategies to mitigate forest degradation while ensuring sustainable livelihoods for both refugees and host communities. The findings of the current study can contribute to broader discussions on the environmental impact of forced migration and support evidence-based decision-making for sustainable refugee management in Ethiopia.

MATERIALS AND METHODS

Study Area

This study was conducted in Jewi, Kule, and Terkidi refugee camps in the Gambella regional state of Ethiopia, where South Sudanese refugees reside in significant numbers (UNHCR, 2025). The three refugee camps were selected purposely on the basis of their relatively high refugee population, early establishment year compared with the other camps, comparatively higher host community presence in the camp areas, and accessibility for the study in terms of physical and security access (Table 1).

Table 1: Refugee and host community population sizes of Kule, Terkidi, and Jewi camps

Population size	Kule	Terkidi	Jewi
Refugee population size	51,524	70,394	66,421
Host Community size	59,212	59,212	17,753
Total	110,736	129,606	84,174

The Jewi refugee camp, established on March 15, 2015, provides a safe and dignified home for refugees relocated from Leitchour, which was established in 2014, and Nip Nip, due to floods that left them homeless (UNHCR, 2024). Kule Refugee Camp was established in May 2014 in response to the influx of refugees from South Sudan and became fully stable by 2016. Tierkidi is the second oldest refugee camp in the Gambella region, after Pugnido-1, and hosts refugees following the outbreak of conflict in December 2013 in South Sudan. Kule and Tierkidi refugee camps are located in the Itang district, whereas the Jewi refugee camp is located near the Gambella Town administration (UNHCR, 2024).

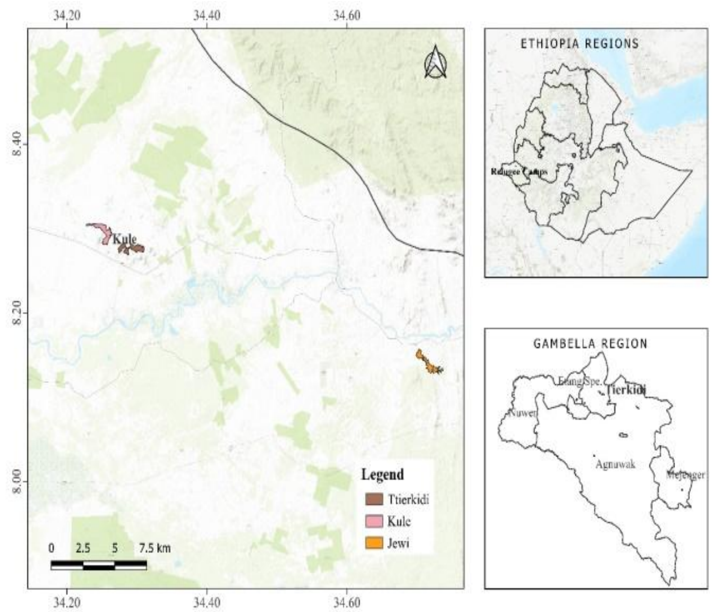


Figure 1: Map of the study area

Data and Sources

The area of interest (AOI) was defined by manually digitizing the boundaries of the refugee camps, creating a five-kilometer buffer zone around them. To assess forest cover changes due to the presence of refugee camps, Landsat 5 and Landsat 8 images were acquired for the years 2005, 2015, and 2023, covering the three camps of Jewi, Kule, and Tierkidi. Landsat 5 had the Thematic Mapper sensor and collected visible bands, a thermal band, a shortwave infrared band, and 15 m (panchromatic) with 8-bit radiometric resolution from 1984-2013. Landsat 8 has carried operational land imager (OLI) and Thermal Infrared Sensor (TIRS) sensors onboard and has collected visible bands, a thermal band and a shortwave infrared band, and 15m (panchromatic) with 8-bit radiometric resolution since 2013.

A total of 239 training data points were collected for three classes: deforestation (76 points), stable forest (60 points), and stable nonforest (103 points). These training data points were collected for image-to-image change detection, employing visual interpretation of Very High Resolution (VHR) imagery from Google Earth. The System for Earth Observation Data Access, Processing, and Analysis for Land Monitoring (SEPAL) platform was used to train the random forest classification algorithm. All data collection, correction, and composition were implemented within the Google Earth Engine (GEE) API integrated with SEPAL. Points for changes were carefully assessed through visual evaluation via a time series of Sentinel-2 images, vegetation indices, and very high-resolution imagery available from Google Earth.

Class definitions

According to Ethiopia's Forest Reference Emission Level (FREL/FRL), as outlined by the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation (UN-REDD) in 2017, a forest is defined as land spanning at least 0.5 hectares, covered by trees (including bamboo) with a minimum width of 20 meters, attaining a height of at least 2 meters and a canopy cover of at least 20%, or trees with the potential to reach these thresholds in situ over time (UN-REDD, 2017). Nonforest refers to any land use or land cover (LULC) that does not meet the criteria for a forest. Deforestation/forest loss is defined as the human-induced, permanent conversion of forestland to another land use or land cover within the spatial resolution of the satellite imagery used.

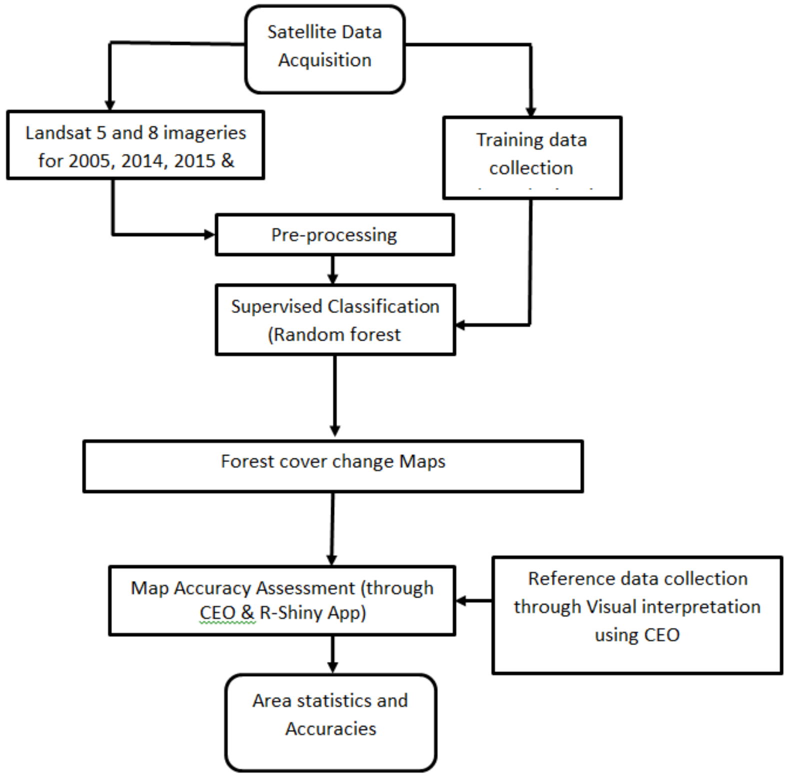
Image classification and change detection

The classification was performed via the Google Earth Engine (GEE) (Gorelick et al., 2017) Statistical Machine Intelligence & Learning Engine (smile) random forest algorithm. Random forest (Breiman, 2001) is an ensemble classification algorithm that combines multiple decision trees via the concepts of bagging and random feature selection (Belgiu and Drăguţ, 2016; Ibrahim, 2023). Near Infrared (NIR), red, green, and blue spectral bands of Landsat 5 TM and Landsat 8 OLI were utilized during classification. Auxiliary data sources, such as the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) data and the European Commission's Joint Research Centre (JRC) Global Surface Water Mapping Layers integrated with SEPAL, were also applied to enhance classification accuracy. For the current study, post-classification change detection is not a suitable option because of the insufficient accuracy of most historical LULC maps, which leads to compounded errors in each single-date classification (Olofsson et al., 2013). Instead, a supervised change detection approach using change training points was selected (Tewkesbury et al., 2015).

Validation of Data Collection and Accuracy Assessment

The classified maps may contain systematic errors related to the classification technique, the nature of the satellite data, and the data capture methods. This study undertook an accuracy assessment to ensure their usability, these errors was quantitatively evaluated using standard accuracy assessment techniques, and the representations of the classified images were comprehended (Gashaw et al. 2017). The errors in the classified images were identified by verifying the classification through visual interpretation and an accuracy assessment using validation points collected from high-resolution imagery on Google Earth via the Collect Earth Online application. A total of 812 validation points, 333 points for the Deforestation Class, 314 points for the Stable Forest Class, and 165 points for the Stable Non-Forest Class, were collected in a proportional allocation. The overall sample size was calculated to be proportional to the area of the classes. The classified maps may contain systematic errors related to the classification technique, the nature of the satellite data, and the data capture methods. To ensure their usability, these errors were quantitatively evaluated using standard accuracy assessment techniques. The overall methodology is illustrated below in Figure 2.

Figure 2: Workflow of forest cover change mapping of the three refugee camps



RESULTS

Classification Process Accuracy

The evaluation of the forest cover change maps for the Jewi (2015–2023), Kule (2014–2023), and Tierkidi (2014–2023) refugee camps reveals a high level of classification accuracy, with overall accuracies recorded at 95%, 94%, and 93%, respectively. In all locations, stable forest areas demonstrated the highest producer accuracy, reaching 98% in Jewi, 95% in Kule, and 96% in Tierkidi, which indicates that the majority of actual forested regions were accurately identified. The producer accuracy for deforestation ranged from 91% to 92%, indicating the effective detection of forest loss. User's accuracy also remained notably high, with stable forest classification reaching 97% in Jewi, 90% in Kule, and 93% in Tierkidi. The stable nonforest category exhibited the highest user accuracy in Kule (98%) and Tierkidi (96%), indicating a low rate of misclassification.

Accuracy assessment

The accuracy assessment of the forest cover change maps for Jewi (2015–2023), Kule (2014–2023), and Tierkidi (2014–2023) refugee camps demonstrated high classification reliability, with overall accuracies of 95%, 94%, and 93%, respectively. Across all the sites, stable forest areas presented the highest producer's accuracy, reaching 98% in Jewi, 95% in Kule, and 96% in Tierkidi, indicating that most actual forested areas were correctly classified. The accuracy of the deforestation producers ranged from 91% to 92%, reflecting accurate detection of forest loss. The user's accuracy was also consistently high, with stable forest classification accuracy reaching 97% in Jewi, 90% in Kule, and 93% in Tierkidi. The stable nonforest class showed the highest user accuracy in Kule (98%) and Tierkidi (96%), confirming minimal misclassification (Tables 2–4).

Table 2: Confusion matrix for the forest cover change map of Jewi refugee camp for the period 2015–2023

2015-2023		Reference data			Total	User's accuracy
		Stable Forest	Stable non-Forest	Deforestation		
Map data	Stable Forest	173	3	3	179	97%
	Stable non-Forest	1	47	2	50	94%
	Deforestation	2	3	49	54	91%
Total		176	53	54	283	
Producer's accuracy		98%	89%	91%	Overall accuracy	95%

PA = Producer's Accuracy (Omission errors); UA = User's Accuracy (Commission errors)

Table 3: Confusion matrix for the forest cover change map of Kule refugee camp from 2014–2023

2014-2023		Reference data			Total	User's accuracy
		Stable Forest	Stable non-Forest	Deforestation		
Map data	Stable Forest	54	4	2	60	90%
	Stable non-Forest	1	142	2	145	98%
	Deforestation	2	4	47	53	89%
Total		57	150	51	258	
Producer's accuracy		95%	95%	92%	Overall accuracy	94%

Table 4: Confusion matrix for the forest cover change map of Tierkidi refugee camp from 2014–2023

2014-2023		Reference data			Total	User's accuracy
		Stable Forest	Stable non-Forest	Deforestation		
Map data	Stable Forest	87	5	2	94	93%
	Stable non-Forest	2	114	3	119	96%
	Deforestation	2	4	52	58	90%
Total reference samples per class		91	123	57	271	
Producer's accuracy		96%	93%	91%	Overall accuracy	93%

Rate of deforestation

The deforestation analysis from 2014/2015 to 2023 across Jewi, Kule, and Tierkidi revealed significant forest loss, with notable variations in both the extent and rate of deforestation. Jewi experienced the highest absolute deforestation (2,908.31 ha) and annual deforestation (323.15 ha/yr), yet it had the lowest percentage loss (2.35%/yr) because of its larger initial forest area (13,765.49 ha) (Figure 3).

In contrast, Kule and Tierkidi, despite lower absolute deforestation rates, presented higher annual deforestation rates of 3.98% and 3.76%, respectively, indicating a more intense relative impact on their smaller forested areas (Figures 4 and 5).

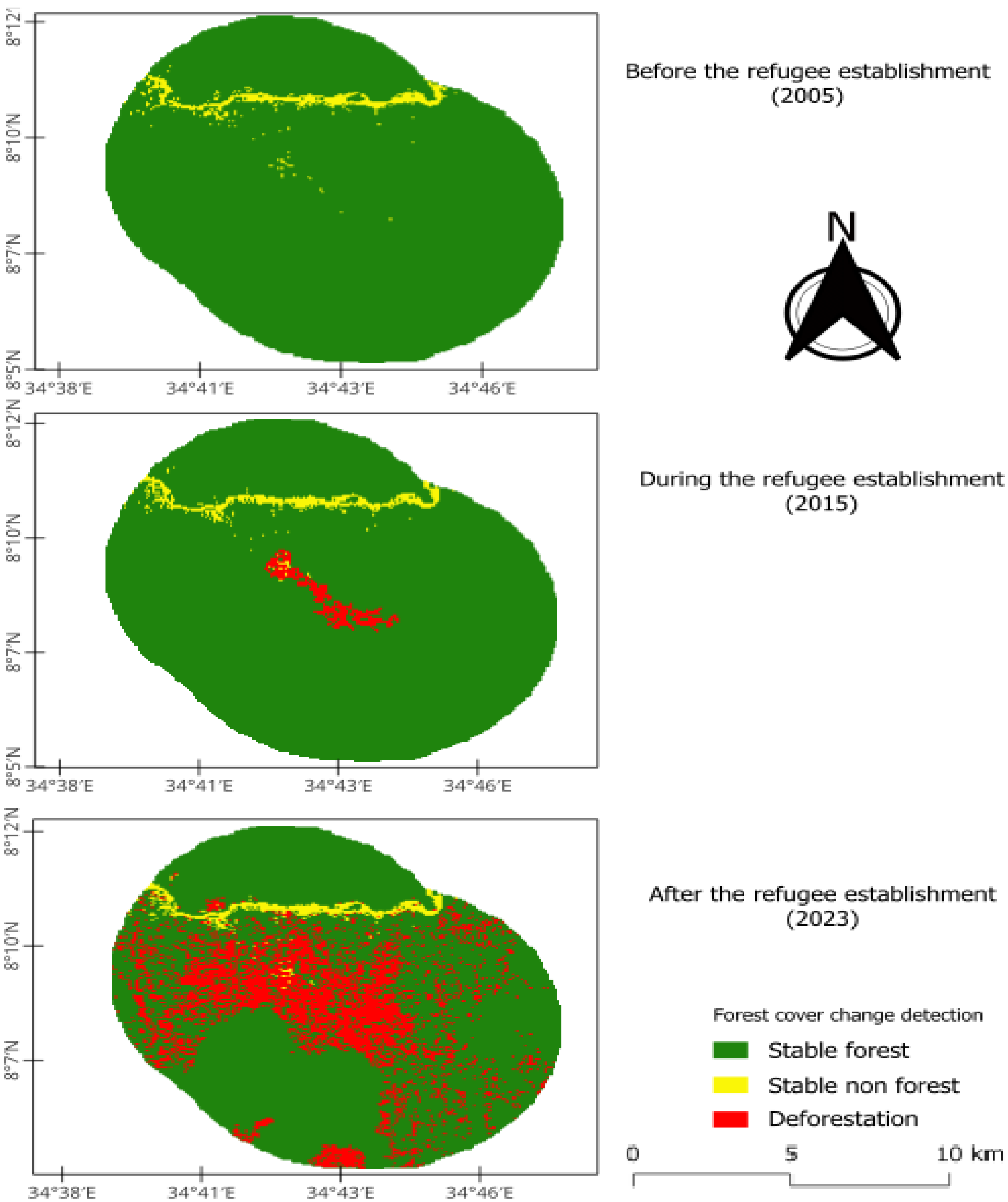


Figure 3: Forest cover change map of Jewi refugee camp (2015-2023)

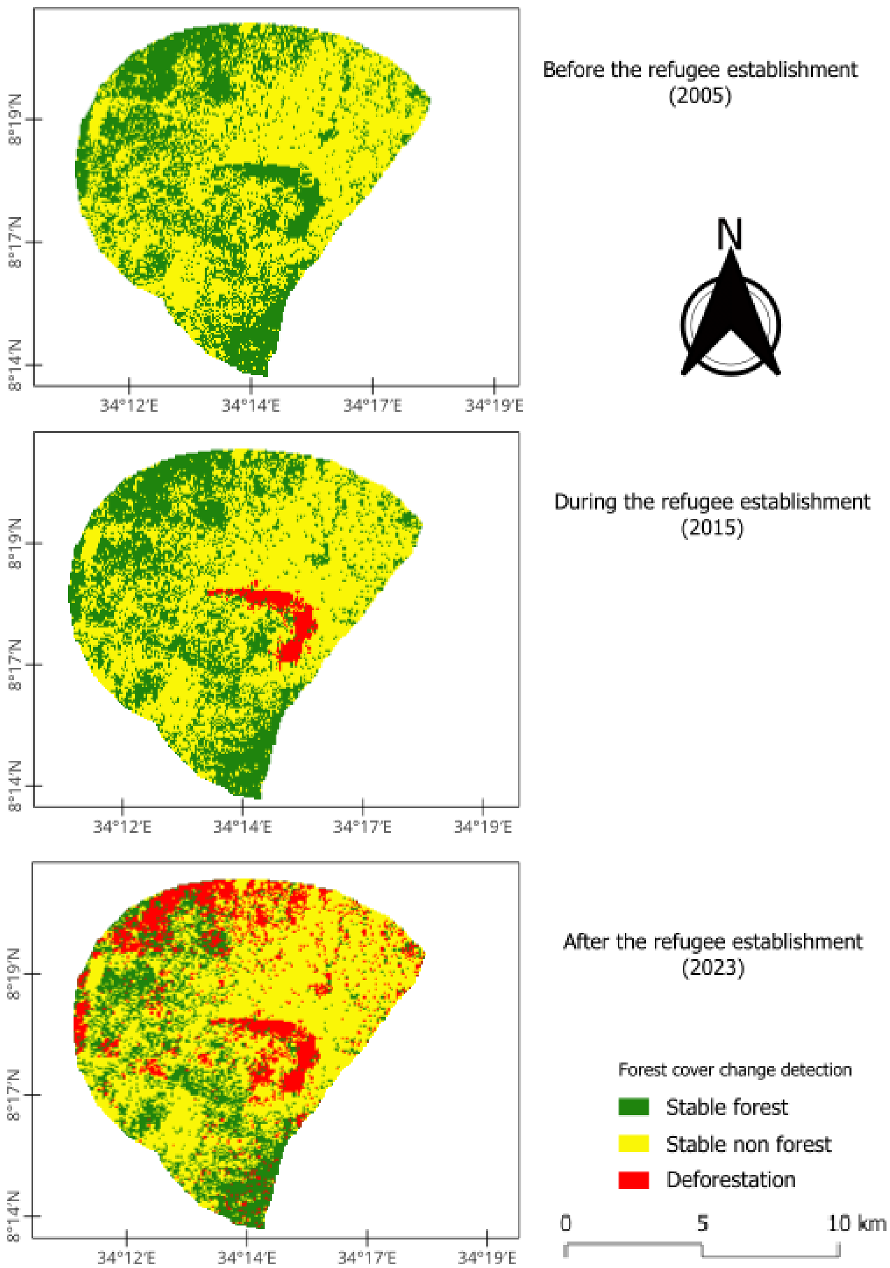


Figure 4: Forest cover change map of Kule refugee camp (2014-2023)

The analysis revealed that all three sites experienced significant deforestation, with the Jewi refugee camp losing the largest forest area (2,908.31 ha) but at the lowest annual deforestation rate (2.35%). Kule and Tierkidi refugee camps presented higher deforestation rates of 3.98% and 3.76% per year, respectively, despite having lower absolute forest loss. Jewi camp faced the most extensive deforestation in terms of area.

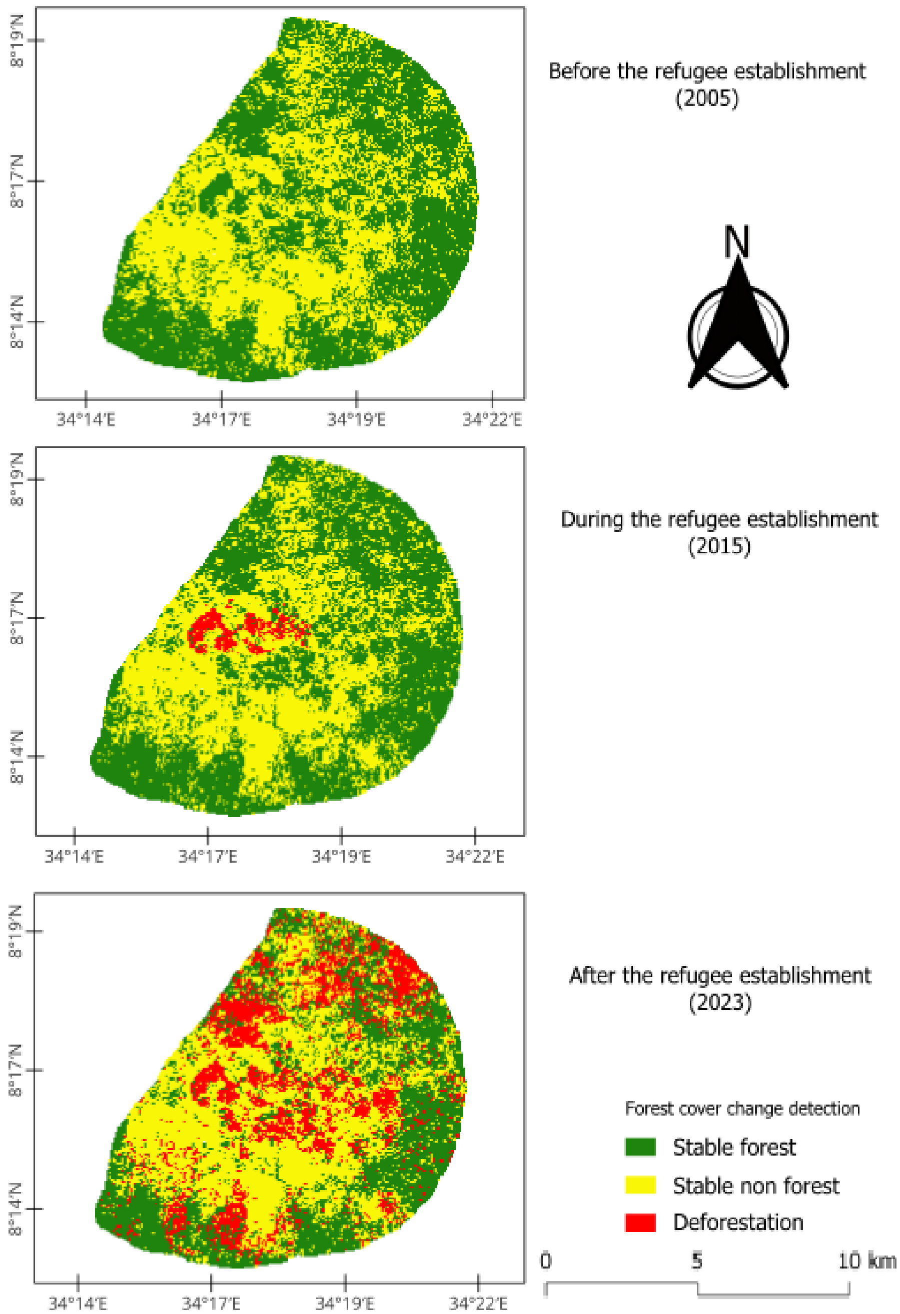


Figure 5: Forest cover change map of Tierkidi refugee camp (2014-2023)

Kule camp experienced the most rapid forest decline relative to its initial forest cover, highlighting varying degrees of forest vulnerability across the sites (Table 5). These findings underscore the urgent need for targeted forest conservation strategies in refugee camps, as a decline in forests could threaten the livelihoods of communities dependent on these forests for resources and ecosystem services.

Table 5: Rate of deforestation

Description of Rate of deforestation	Jewi	Kule	Tierkidi
	2015 - 2023	2014 - 2023	2014 - 2023
Deforestation (ha)	2908.31	1666.47	2016.69
Deforestation (ha/yr)	323.15	166.65	201.67
Forest area at the beginning of the period (ha)	13,765.49	4185.08	5367.55
Rate of deforestation (%/year)	2.35%	3.98%	3.76%

Key informants' perceptions of deforestation

The key informants of the three refugee camps included in this study indicated that the main driver of deforestation was the establishment of refugee camps, which led to population increases in the refugee settlement areas. They also noted that pushing factors such as livelihood requirements by both the host and the refugee community on forest products also contribute to forest cover degradation to some extent.

DISCUSSION

In this study, a random forest classification method was employed with Landsat 5 TM and Landsat 8 OLI multispectral satellite imagery to classify forest cover maps at two different time points. This approach allowed us to observe the growth of refugee settlements and the corresponding loss of forest in the Gambella region of Ethiopia. The land cover maps of two time steps with three broad land categories, i.e., stable forest, stable nonforest, and deforestation, show promising results, which are reflected by the high overall classification accuracy. This research revealed the patterns of changes in forest cover across various spatial contexts over time when refugee settlements began in Jewi, Kule and Tierkidi refugee camps. The results have shown that the immediate surroundings of refugee camps are among the areas exposed to the highest pressure on natural resources. The results of this research are consistent with those of previous studies on the impact of deforestation caused by the establishment of refugee camps in Africa and around the world driven by the immediate resource needs of displaced populations, often with limited environmental planning (Maystadt et al., 2020; Owen et al., 2023; Salemi, 2021).The establishment of refugee settlements involved the clearing of forested areas. The growth in population resulting from these settlements in the study regions has led to an increased demand for a range of ecosystem services. Additionally, the host community noted that they did observe significant changes in forest cover following the establishment of these refugee settlements.

The establishment and expansion of refugee settlements have been linked to significant changes in forest cover across various regions globally. Research suggests that refugee settlements often lead to forest cover loss, mainly due to land clearing and resource use. In Bangladesh, the Rohingya refugee crisis has caused notable forest loss (Ahmed and Sabastini, 2024; Dampha et al., 2022; Rahman, 2018). Similarly, in Uganda, refugees have influenced the conservation and protection of the forest ecosystem in the Bugoma forest reserve through timber cutting, charcoal burning, cultivation, and unauthorized fuel wood collection (Kusuro et al., 2023). Refugee movements result in deforestation as refugees do, and host households are highly dependent on forests and other woodlands for fuel wood for cooking and income generation, which contributes to their livelihood resilience (Ahmed and Sabastini, 2024).

The various environmental consequences of deforestation are widely acknowledged by local host communities. All key informants from these communities in the study areas concur on the detrimental effects of forest loss, citing an increase in soil erosion, a decline in local biodiversity, and a future scarcity of forest products. These issues are attributed not only to ongoing deforestation practices but also to insufficient efforts in afforestation.

Lodhi et al. (1998)reported that the rapid increase in the local population coupled with the influx of refugees from the Afghan Civil War increased pressure on the forest resources of Siran Valley, Pakistan, resulting in a drastic decline of approximately 40% in forested land in just 14 years. Akhtar et al. (2022)indicated that from 2014-2018, the Ukhia forest in Bangladesh experienced a significant forest cover decline of 82%, resulting in a net loss of 6.6 square miles over five years for making shelters, roads, creating water sources, camp offices, schools, and other infrastructures for Rohingya refugees. The sudden influx of thousands of displaced people significantly increases the local population, potentially driving forest loss due to expanded land use for shelter and energy needs, often at the expense of forests without appropriate technologies (Dampha et al., 2022). Similarly, Ahmed and Sabastini (2024)reported that the influx of Rohingya refugees resulted in the loss of more than 3,000 hectares in the Teknaf Wildlife Sanctuary and various forest-dependent livelihoods, such as fuel wood collection, livestock rearing, and agro forestry. These deforestations result from the significant impact of the refugee population on energy consumption, and an increased population means increased energy needs (Bildirici et al., 2023).

CONCLUSION

Ethiopia's forest cover was 18.5% in 2000, and it has severely declined for many years. With a total forest area of 17.22 million hectares, the newest projection increased to 15.7% (FAO, 2020) due to ongoing efforts to restore degraded areas, afforestation/reforestation initiatives, and, in part, changes in the definition of forests. This study aimed to analyze the rate of deforestation around the Jewi, Kule, and Terkidi refugee camps in the Gambella region of Ethiopia. The forest cover in the study areas has experienced considerable alterations since the establishment and subsequent settlement of refugees in Jewi, Kule, and Tierkidi. These changes in forest cover are observed both spatially and temporally. The annual deforestation rate in the areas surrounding these refugee camps ranges from 2% to 4%, which is considered very high. The main drivers of forest cover changes are related to the establishment of refugee camps. Key Informants from the host community in the three refugee camps interviewed in this study reported that the primary cause of deforestation was the establishment of refugee camps, which has resulted in an increase in the population within the settlement areas. They also perceived that factors such as the need for livelihoods among both the host and refugee populations, which are reliant on forest resources, contribute to changes in forest cover to a certain degree.

The forest cover changes identified in this study call for enhancing forest-based ecosystem planning and implementation approaches. This study recommends investigating local conditions and changing drivers to develop effective policies aimed at reducing natural forest loss and protecting ecosystems in Gambella's refugee camps, as the deterioration of forest cover in refugee settlement areas needs to be averted. Stakeholders involved in refugee management should initiate and implement critical actions to encourage more sustainable practices. These include the provision of alternative energy sources, the promotion and support of agro forestry, the development and implementation of sustainable land management strategies, and capacity building at the local level regarding sustainable natural resource management. More specifically, this study suggests the establishment of woodlots, encouragement and advancement of alternate sources of household sources of energy, and settlement construction materials to reduce the deterioration of forest cover in refugee settlement areas toward efforts to sustainably balance refugee management efforts and trends in the degradation of forest cover. If these measures are effectively executed, they would contribute to reversing forest cover depletions and guarantee the sustainable availability of resources for both host and refugee populations over time.

While refugee camps are essential for providing immediate humanitarian relief, it is crucial to assess and address their environmental impacts, particularly deforestation. Implementing sustainable resource management and ecological conservation strategies can help mitigate these effects, benefiting both refugees and host communities. The results confirm the robustness of the classification method and highlight significant forest cover changes in all three refugee-affected landscapes, emphasizing the urgent need for sustainable land-use policies to mitigate environmental degradation. The analysis and results draw attention to the impacts of the increasing refugee population on deforestation.

The management of natural resources, greenhouse gas emissions, water resources, and agricultural outputs may all be impacted by changes in forest cover. The three refugee camp locations exhibit distinct patterns of change. To prevent further loss of natural forests, which provide a multitude of ecosystem services, we advise conducting additional research on local conditions and change factors. The key insights derived from the findings of this study highlight the urgent need for the execution of environmental initiatives both before and after the arrival of refugees to reduce ecological harm.

Furthermore, it is essential for all stakeholders involved in refugee management—such as the refugee community, the host community, UN agencies, government bodies, and NGOs—to actively engage with the environmental challenges that may arise from the establishment of refugee camps. In addition, this study proposes that the trends of unsustainable resource dependency that compromise both SDG 7 and SDG 15 be addressed through the targeting of economic sustainability initiating income generation in non-forest-extractive sectors, thus addressing SDG 8, which focuses on decent work. Additionally, the implementation of joint management structures for social sustainability and large-scale reforestation to contribute to advancing SDG 15 is necessary. It is also very important that refugee management stakeholders focus on actionable, SDG-aligned steps and need to comprehensively implement the Comprehensive Refugee Response Framework (CRRF) which is essential for achieving long-term sustainability in refugee-host locations. Finally, this study proposes that further research on the full societal cost–benefit analysis of shifting to sustainable camp management models be undertaken for comprehensive and sustainable refugee management.

Monitoring changes in forest cover and understanding their underlying causes offers significant opportunities for informed decision-making, sustainable management, and effective policy development. Thus, governments and nongovernmental organizations need to plan long-term environmental policies and reforestation efforts in the context of the potential adverse effects of settlements of the refugee population on the basis of sustainability.

DATA AVAILABILITY STATEMENT

The data are available from the corresponding author upon reasonable request.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

ETHICAL APPROVAL

This article does not contain any studies with human participants or animals performed by any of the authors.

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