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Lands use dynamics and the role of war in the forest cover change in Marawi City, Philippines

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Abstract

The 2017 Marawi City Siege caused widespread destruction and displacement, along with significant environmental impacts, particularly on the forest ecosystems. This study assessed land cover changes in Marawi City, Philippines, associated with the 2017 armed conflict using Landsat satellite imagery from 2010, 2017, and 2024. Remote sensing analysis utilizing QGIS and Maximum Likelihood Classification generated six distinct land cover classes: forests, grassland, cropland, bare land, water bodies, and built-up areas. Results revealed significant post-conflict landscape transformations, with forest areas decreasing by 185.47 ha (-5.35%) between 2017 and 2024, while grassland declined by -778.43 ha (-21.72%). Simultaneously, agricultural lands and built-up areas increased substantially, with built-up areas expanding by 440.09 (+62.55%) by 2024. Accuracy assessment of the 2024 classification demonstrated 89.93% overall accuracy with a kappa coefficient of 0.86. Interviews with local environmental offices confirmed that the forced relocation of commercial and residential infrastructure due to the destruction of the city's economic center and increased illegal logging activities for livelihood purposes like charcoal production significantly contributed to these changes. The accelerated post-conflict forest loss pattern in Marawi mirrors experiences documented in other post-conflict regions globally, where environmental concerns are often sidelined in favor of infrastructure development and economic recovery. These findings highlight the environmental vulnerabilities in conflict-affected areas and the necessity for sustained conservation efforts to promote ecological resilience and support post-conflict recovery.

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Introduction

Land-use decisions can often undergo sudden alteration in response to shocks, with armed conflicts being the most violent and globally prevalent (Baumann and Kuemmerle, 2016). While armed conflicts can lead to significant destruction of infrastructure and displacement of populations, their environmental impact is also a mounting global concern and can be long-lasting (Daiyoub *et al.*, 2023). Studies have confirmed that armed conflicts and wars have a causative link to environmental degradation (Ebert, 2020). In conflict zones, environmental damage can be direct or indirect (Daiyoub *et al.*, 2023), with deforestation as one primary representation of the environmental suffering caused by armed conflicts (Baumann and Kuemmerle, 2016; Lindholm and Kropp, 2019).

Armed conflicts have also been shown to maintain complex relationships with ecosystem and land use change and have been responsible for some cases of increased deforestation rates (Baumann and Kuemmerle, 2016; Ebert, 2020). These conflicts lead to land cover change, a decline in biodiversity, and changes to the overall ecosystem services. In the context of Marawi City, Philippines, the siege in 2017 depicts an important narrative of the city's history. It caused widespread damage and displacement of its local population, significantly affecting the urban landscape and the surrounding forest ecosystems, potentially altering forest ecosystem dynamics in ways yet to be fully understood. Hence, this study aims to assess the changes in Marawi City's land cover associated with the siege.

Materials and methods

The study used land satellite images for land classification downloaded from United States Geological (USGS) Earth Explorer (https://earthexplorer.usgs.gov/) (Rwanga and Ndambuki, 2017). The satellite images taken from the website across 2010, 2017, and 2024 served as input to QGIS v. 3.34 software to generate land cover maps. The study also utilized interviews with concerned offices to further support the analysis.

Description of study area

Marawi City, perched at an estimated elevation of 716.1 m (~2,350 ft.) above sea level, is nestled in the region of the Bangsamoro Autonomous Region in Muslim Mindanao (BARMM), Southern Philippines (Fig. 1). The city has a land area of 87.55 sq km. Its population, as determined by the 2020 Census, was 207,010, which represents 17.32% of the total population of Lanao del Sur province or 4.70% of the overall population of the Bangsamoro Autonomous Region in Muslim Mindanao (PSA, 2020).

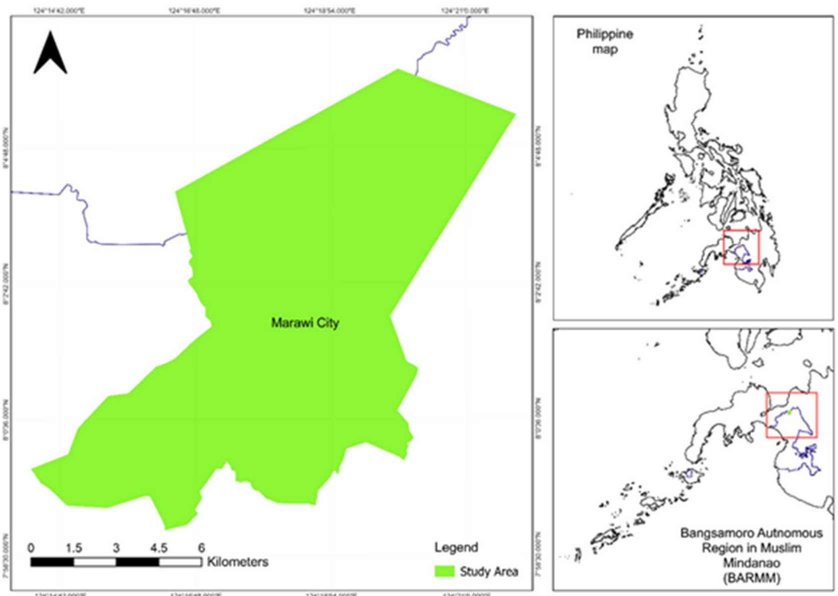

Fig. 1. Location map of the study area-Marawi City, Lanao del Sur, Philippines generated using QGIS 3.34

Results

Land cover classification

Land cover maps for the years before the siege (2010), during the siege (2017), and after the siege (2024) were generated using satellite data. This includes Landsat 5 Thematic Mapper (TM) for 2010 and Landsat 8 Operational Land Imager/ Thermal Infrared Sensor (OLI/TIRS) for 2017 and 2024 via the USGS Earth Explorer website (Jia *et al.*, 2014). Utilizing these data sets were essential to provide a foundation for robust analysis of the land cover changes for the years before, during, and after the siege.

Table 1. Land cover classification categories and their descriptive characteristic

Land cover class	Description
Forest	Primarily covered by trees and woody vegetation
Grassland	Areas dominated by shrubs and grasses
Cropland	Includes areas utilized for cultivating crops
Bare land	Exposed soils that are devoid of vegetation
Water bodies	Streams, rivers, and lakes
Built-up	Areas characterized by artificial structures, such as buildings and roads

Table 2. Confusion matrix and accuracy assessment of land cover classification – 2024

Matrix	Forest	Built-up	Cropland	Water bodies	Grassland	Bare land	Total	User's accuracy (%)	Producer's accuracy (%)
Forest	574	0	3	0	0	0	577	99.48	93.55
Built-up	0	81	0	0	0	0	81	100.00	100.00
Cropland	0	0	17	0	5	0	22	77.27	78.63
Water bodies	1	0	1	4	0	0	6	66.67	100.00
Grassland	6	0	4	0	66	0	76	86.84	87.41
Bare land	0	0	3	0	0	4	7	57.14	100.00
Total	581	81	28	4	71	4	769		
Over all accuracy (%)			89.93						
Kappa			0.86						

After extracting and projecting the research region, a supervised classification procedure based on the Maximum Likelihood Classification (MLC) algorithm using the Semi-Automatic Plugin (SCP) in QGIS was utilized to generate six distinct classes: forests, grassland, cropland, bare land, water bodies, and built-up (Table 1). During the image classification process, training samples using SCP were generated for each class by delineating polygons that contain pixels representing a particular class.

Accuracy assessment

Ground truthing and Google Earth are the most commonly adopted accuracy assessment techniques as they relate the classified image data with accurate on-field data sources for the affirmation process (Tilahun, 2015). After the satellite images were classified, 50 random points were assigned. These random points were validated using on-site verifications and Google Earth to adapt validation approaches.

The accuracy assessment evaluates the reliability of land use classification results. The minimum acceptable interpretation accuracy for land use and land cover classification should not fall below 80% (Anderson *et al.*, 1976; Islami *et al.*, 2022). The 2024 classification (Table 2) demonstrated 89.93% overall accuracy with a kappa coefficient of 0.86, achieving an "Excellent" rating showing high agreement (Dorhi *et al.*, 2022), validating the reliability of the land cover classification.

Only the 2024 land cover map was evaluated in terms of accuracy. The validation of the most recent classification was valid for the earlier dates when working with historical data series when data for the earlier dates is not available (Cabral *et al.*, 2010; Vasconcelos *et al.*, 2015; Cabral and Costa, 2017; Temudo *et al.*, 2020).

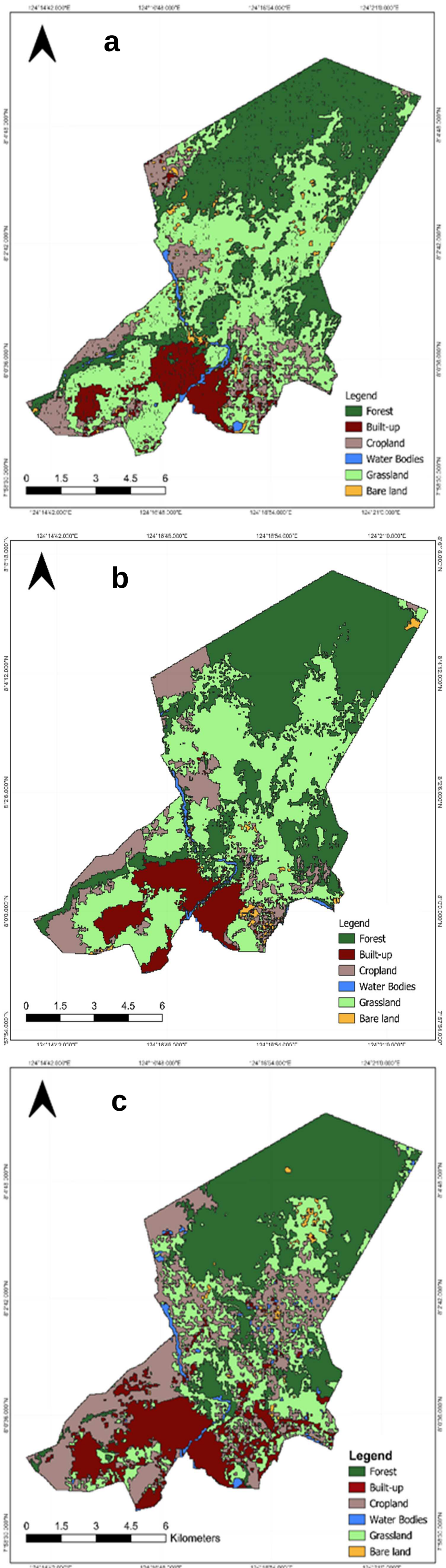

Fig. 2. Land use land cover map of Marawi City – (a) 2010, (b) 2017, (c) 2024

Land cover dynamics

The data shows the land cover changes from each land cover class from the years before (2010) the siege, the year (2017) of the siege, and the post-conflict year (2024). The 2010, 2017, ad 2024 land cover maps (Fig. 2. a, b and c) revealed that forest had the largest land cover area (Table 2), while water bodies had the smallest land cover area among all land cover classes. The result shows most of the land cover classes are steadily increasing from 2010 to 2017 (Table 3), except for grassland and bare land. The city's central livelihood and major government and commercial infrastructures fueling the city's economy are located in the southern part of the city, which can also explain why built-up areas and cropland areas are mostly concentrated and increasing in the southern part of the city, although an evident increase of cropland areas are starting to advance in the central part of the city during 2017.

In 2024, however (Table 4), the forest have experienced a decrease, losing a total of 197.92 ha (-5.86%), while grassland areas also declined by 1,278.93 ha (-44.06%). This pattern of post-conflict forest loss mirrors the experience of the Zagros forest after the Iran-Iraq war, where deforestation intensified in the post-war periods, with losses of 2,066 ha during 1993-1998 (Heidarlou *et al.*, 2020). Conversely, both cropland and built-up areas had increased by 1,179.24 ha (+110.83%) and 298.87 ha (+32.39%) respectively, which can be attributed from the population shift after the Marawi Siege.

Table 3. Area changes in land cover areas in hectares from 2010 to 2024

Land cover	2010	2017	2024
Forest	3,069.26	3,378.16	3,180.24
Grassland	3,450.77	2,902.71	1,623.78
Cropland	921.62	1,064.04	2,243.28
Water bodies	65.4	60.86	68.33
Built-up	765.16	922.85	1,221.72
Bare land	132.75	76.34	67.61

Table 4. Total Area changes in land cover areas (ha) and (%) from 2010 to 2024

Land cover class	Change 2010-2017 (ha)	Change 2010-2017 (%)	Change 2017-2024 (ha)	Change 2017-2024 (%)
Forest	308.90	10.06%	-197.92	-5.86%
Grassland	-548.06	-15.88%	-1,278.93	-44.06%
Cropland	142.42	15.45%	1,179.24	110.83%
Water bodies	-4.54	-6.94%	7.47	12.27%
Built-up	157.69	20.61%	298.87	32.39%
Bare land	-56.41	-42.50%	-8.73	-11.44%

Discussion

The changing trend in land covers shows a decreasing trend in grassland and forest areas during the post-war period from 2017 to 2024 while agricultural lands and built-up areas increase significantly during the post conflict. The rapid urban expansion and shifting cultivation can mainly be attributed with the population shift in the study area (Kisangga *et al.*, 2024), recognizing the contribution of forced migration (Gbanie *et al.*, 2018). Forkuor andand Cofie (2011) and Mansary *et al.* (2016) further support this result of the study.

In most cases, post-conflict recovery prioritizes infrastructure development while environmental concerns are sidelined (Chan *et al.*, 2019). The study's result agrees with this argument as the interview with the city's Environment and Natural Resource Office (CENRO) states that one of the drivers of this transformation in the city is the forced relocation of commercial and residential infrastructures to the different parts of the city due to the destruction of the city's economic heart, resulting in a 298.87 ha (+32.39%) increase in built-up areas. This pattern is comparable to the increase of built-up areas observed in Sardasht from 18 km² to 34 km² during the post-conflict period (Heidarlou *et al.*, 2020) and during the post-war in the western area of Sierra Leone from 1976 to 2011, as their analysis shows a 54% decline in forest cover and 241% in the urban expansion (2342.0 ha) due to the increase of population in the area (Gbanie *et al.*, 2018). Further, the data from the Community Environment, Natural Resources, and Energy Office, District 1 (CENREO-01) shows that there is an increase in illegal logging activities during the post-conflict period, mainly for livelihoods like charcoal making and conversion for agricultural purposes.

A crucial generalization emerging from this and similar studies is that post-conflict recovery creates a critical "environmental vulnerability window" where accelerated resource exploitation coincides with weakened institutional capacity. Post-conflict recovery strategies therefore should include forest protection, conservation, and restoration while strengthening local institutional capacity.

Conclusion

The study documented significant land cover transformations in Marawi City following the 2017 siege, with substantial forest and grassland decline and an increase in built-up and agricultural areas. The 5.86% and 44.06% decrease in forest cover and grassland along with the 32.39% increase in built-up areas between 2017 and 2024 demonstrate the rapid land conversion occurring during the post-conflict period, driven by forced relocation of commercial and residential infrastructure due to displaced populations which caused increase illegal logging activities mainly for livelihood, and agricultural expansion. These findings align with global patterns observed in other post-conflict regions.

Recommendation(s)

Based on the findings, the study recommends that local government units establish dedicated environmental monitoring teams to assess forest resources regularly. Integrating community-based forest management approaches would empower local stakeholders in conservation efforts while providing alternative livelihood options to reduce pressure on forest resources, as recommended by the Community Environment, Natural Resources, and Energy Office, District 1 (CENREO-01). The city also needs localized expertise in sustainable forest management rather than depending solely on regional offices. Finally, a balance between post-conflict infrastructure development and environmental conservation should be established through strategic land use planning incorporating ecosystem services valuation in rehabilitation programs. Incorporate forest conservation and green space development into the city's long-term urban development plan. This would help mitigate the observed pattern of uncontrolled urban expansion and improve urban climate resilience.

Future land cover studies should prioritize acquiring cloud-free satellite imagery to overcome the classification challenges encountered with cloud cover in Landsat data. Additionally, while Landsat imagery provides accessible data, supplementing with higher-resolution satellite imagery such as Sentinel-2 (10m) or PlanetScope (3m) would enable more accurate detection of small-scale forest changes and fragmentation patterns, ultimately improving land classification accuracy.

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