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Analysis Of Land Cover Change And Its Impacts On Soil Quality And Water Availability

Ruth Riah Ate Tarigan

Email: truthtrg@yahoo.com
Universitas Pembangunan Panca Budi

ABSTRACT

Land cover change is one of the major drivers of environmental degradation, significantly affecting soil quality and water availability, particularly in rapidly developing regions. This study aims to analyze land cover changes and assess their impacts on soil quality and water availability over a multi-year period. The research employed a quantitative approach using remote sensing and Geographic Information System (GIS) techniques. Multi-temporal satellite imagery was used to identify land cover changes, while soil quality indicators and hydrological parameters were analyzed to evaluate environmental impacts. The results indicate a substantial conversion of vegetated areas into agricultural land and built-up areas, leading to increased soil degradation, reduced soil organic matter, and declining water availability. Areas experiencing intensive land cover change showed higher vulnerability to erosion and reduced water infiltration capacity. These findings highlight the critical role of sustainable land management and spatial planning in mitigating the negative impacts of land cover change. The study provides valuable insights for policymakers and environmental managers in developing effective strategies to preserve soil quality and ensure sustainable water resources.

Keywords: Land cover change, soil quality, water availability, GIS, remote sensing, environmental sustainability.

INTRODUCTION

Land cover change has become a critical environmental issue worldwide due to its significant influence on ecosystem stability, soil quality, and hydrological processes. Rapid population growth, agricultural expansion, urbanization, and infrastructure development have accelerated the conversion of natural land cover into human-dominated landscapes, particularly in developing regions (Lambin & Meyfroidt, 2020). These transformations alter surface characteristics, disrupt ecological functions, and increase pressure on land and water resources. Soil quality is highly sensitive to land cover dynamics. The replacement of natural vegetation with agricultural land or built-up areas often leads to soil compaction, loss of organic matter, increased erosion, and declining nutrient availability (Borrelli et al., 2021). Vegetation removal reduces soil protection against rainfall impact, enhancing runoff and sediment transport, which in turn accelerates land degradation processes. Degraded soils not only reduce agricultural productivity but also weaken ecosystem resilience to climate variability.

Land cover change also plays a crucial role in regulating water availability. Changes in vegetation structure and land surface properties influence infiltration rates, evapotranspiration, groundwater recharge, and surface runoff patterns (Li et al., 2022). Urban expansion and deforestation have been widely associated with reduced water retention capacity and increased hydrological extremes, such as floods during the rainy season and water scarcity during dry periods (Zhang et al., 2021). These impacts pose serious challenges to sustainable water resource management, particularly in regions highly dependent on rain-fed agriculture.

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Volume 6 Number 2 page 457-466

Advances in remote sensing and Geographic Information Systems (GIS) have enabled more accurate and efficient monitoring of land cover change and its environmental impacts. Multi-temporal satellite imagery provides valuable spatial and temporal information to assess land cover dynamics, while GIS-based analysis allows the integration of soil and hydrological data to evaluate environmental responses (Nguyen et al., 2023). These technologies support data-driven decision-making for land and water management. Despite extensive research on land cover change, integrated studies that simultaneously examine its impacts on soil quality and water availability remain limited, especially at regional and local scales. Therefore, this study aims to analyze land cover changes and evaluate their effects on soil quality and water availability using remote sensing and GIS-based approaches. The findings are expected to contribute to sustainable land management strategies and provide scientific evidence to support environmental planning and policy development.

LITERATURE REVIEW

Land Cover Change

Land cover change refers to the transformation of the Earth's surface from one land cover type to another over a specific period of time. Land cover includes various physical characteristics of the Earth's surface such as forests, agricultural land, plantations, built-up areas, water bodies, and bare land. These changes may occur naturally; however, in recent decades, human activities have become the dominant driving force behind land cover dynamics. Rapid population growth, urban expansion, agricultural intensification, and infrastructure development have significantly accelerated land cover change worldwide. The conversion of natural vegetation into agricultural or urban land has altered ecosystem functions and reduced environmental resilience. According to Lambin and Meyfroidt (2020), land cover change is a major driver of global environmental degradation, as it disrupts ecological processes and reduces the capacity of ecosystems to provide essential services.

Land cover change has profound impacts on soil quality and water availability. The removal of vegetation cover increases soil exposure to erosion, reduces soil organic matter, and weakens soil structure, ultimately leading to land degradation. In addition, changes in land cover directly influence the hydrological cycle by altering infiltration rates, surface runoff, evapotranspiration, and groundwater recharge. Built-up areas and impervious surfaces typically reduce water infiltration, increasing flood risk while decreasing groundwater availability. The analysis of land cover change is commonly conducted using remote sensing and Geographic Information Systems (GIS). Multitemporal satellite imagery, such as Landsat and Sentinel data, enables the detection and monitoring of spatial and temporal land cover dynamics with high accuracy. The integration of remote sensing and GIS provides a powerful tool for assessing land cover change and evaluating its environmental impacts.

Understanding land cover change is essential for sustainable land-use planning and environmental management. Identifying patterns and trends of land cover transformation allows policymakers and planners to develop effective land management strategies, balance development needs with environmental conservation, and mitigate the negative impacts of land cover change on soil quality and water resources.

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Volume 6 Number 2 page 457-466

Soil Quality

Soil quality refers to the capacity of soil to function effectively within natural or managed ecosystems to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health. High soil quality is essential for agricultural productivity, ecosystem stability, and long-term environmental sustainability. Soil quality is influenced by a combination of physical, chemical, and biological properties, which together determine the soil's ability to perform its ecological and agronomic functions. Physical soil properties, such as soil texture, structure, bulk density, and porosity, play a crucial role in regulating water infiltration, root penetration, and aeration. Degradation of these properties, often caused by land cover change and intensive land use, can lead to soil compaction, reduced infiltration capacity, and increased surface runoff. Chemical properties, including soil pH, nutrient availability, and organic carbon content, are equally important in supporting plant growth and maintaining soil fertility. The decline of soil organic matter, in particular, is widely recognized as a key indicator of soil degradation.

Biological soil properties involve soil microorganisms, fauna, and organic matter decomposition processes. Soil biota contribute to nutrient cycling, soil aggregation, and the maintenance of soil structure. Land cover changes, such as deforestation and conversion to intensive agriculture or urban land, can significantly disrupt soil biological activity by reducing organic inputs and altering microclimatic conditions. According to recent studies, soils under natural vegetation generally exhibit higher biological activity and better overall soil quality compared to soils under disturbed land uses. Land cover change has a direct and measurable impact on soil quality. The conversion of forested or vegetated land into agricultural or built-up areas often results in increased erosion rates, nutrient depletion, and loss of soil organic carbon. These processes reduce soil fertility and resilience, making soils more vulnerable to further degradation. Moreover, declining soil quality negatively affects water availability by reducing infiltration and water-holding capacity, thereby intensifying drought and flood risks.

Assessing soil quality is a critical component of sustainable land management. Soil quality indicators, such as organic carbon content, bulk density, aggregate stability, and nutrient levels, are commonly used to evaluate soil condition and monitor degradation processes. Integrating soil quality assessment with land cover change analysis provides valuable insights for developing effective land-use planning and conservation strategies aimed at preserving soil resources and ensuring sustainable agricultural and environmental systems.

Relationship Between Land Cover Change, Soil Quality, and Water Availability

Land cover change plays a critical role in shaping soil quality and water availability within terrestrial ecosystems. Alterations in land cover, such as deforestation, agricultural expansion, and urbanization, significantly modify surface characteristics, vegetation cover, and soil properties, which in turn affect hydrological processes and soil functions. The interrelationship between land cover change, soil quality, and water availability forms a dynamic system that determines ecosystem sustainability and land productivity. Changes in land cover directly influence soil quality by altering physical, chemical, and biological soil properties. The conversion of natural vegetation to agricultural or built-up land often reduces soil organic matter, disrupts soil structure, and increases susceptibility to erosion. Loss of

International Journal of Economic, Technology and Social Sciences
url: https://jurnal.ceredindonesia.or.id/index.php/injects
Volume 6 Number 2 page 457-466

vegetation cover exposes soil surfaces to rainfall impact, leading to higher erosion rates and nutrient leaching. As a result, soil fertility declines, aggregate stability deteriorates, and soil compaction increases, all of which reduce the soil's capacity to support plant growth and ecosystem functions.

Soil quality, in turn, has a strong influence on water availability. Soils with good structure, high organic matter content, and well-developed pore systems exhibit greater water infiltration and water-holding capacity. Conversely, degraded soils characterized by compaction, low organic carbon, and poor aggregation tend to generate higher surface runoff and lower groundwater recharge. These conditions reduce the availability of soil moisture for crops and increase the frequency of hydrological extremes, such as floods during the rainy season and droughts during dry periods. Land cover change also directly affects hydrological processes by modifying evapotranspiration, interception, and infiltration patterns. Forested and vegetated areas enhance rainfall interception and promote gradual water release into the soil profile, supporting baseflow and groundwater recharge. In contrast, impervious surfaces and sparsely vegetated lands accelerate runoff and reduce infiltration, leading to decreased water storage in the soil and aquifers. The combined effects of land cover change and declining soil quality thus exacerbate water scarcity and increase vulnerability to climate variability.

Understanding the linkage between land cover change, soil quality, and water availability is essential for sustainable land and water resource management. Integrated approaches that combine land cover monitoring, soil quality assessment, and hydrological analysis are necessary to identify degradation hotspots and design effective conservation strategies. Sustainable land management practices, such as reforestation, conservation agriculture, and soil restoration, can improve soil quality, enhance water retention, and mitigate the negative impacts of land cover change on water resources.

Geographic Information Systems (GIS) and Remote Sensing

Geographic Information Systems (GIS) and remote sensing are essential tools in spatial analysis and environmental assessment, particularly in studies related to land use, land cover change, soil degradation, and water resource management. GIS provides a framework for collecting, storing, analyzing, and visualizing spatially referenced data, while remote sensing supplies continuous and up-to-date information on Earth surface conditions through satellite or airborne sensors. GIS enables the integration of multiple spatial datasets, such as topography, soil characteristics, climate variables, and land cover information, into a unified analytical environment. Through spatial analysis techniques including overlay analysis, spatial interpolation, and weighted index modeling GIS supports the identification of spatial patterns, trends, and relationships among environmental variables. In land degradation and vulnerability studies, GIS is widely used to develop spatial indices, such as land degradation vulnerability indices, by assigning weights and scores to controlling parameters and mapping their cumulative effects across a region.

Remote sensing complements GIS by providing multispectral and multitemporal data that allow for the monitoring of land surface dynamics over time. Satellite imagery from sensors such as Landsat and Sentinel has been extensively utilized to assess vegetation condition, land cover change, soil moisture, and erosion risk. Vegetation indices, particularly the Normalized

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Volume 6 Number 2 page 457-466

Difference Vegetation Index (NDVI), are commonly derived from remote sensing data to evaluate vegetation density and health, which serve as key indicators of land degradation and soil quality. Temporal analysis of remote sensing data enables the detection of degradation trends and the assessment of environmental changes resulting from natural processes or human activities. The integration of GIS and remote sensing enhances the accuracy and efficiency of environmental assessments by combining spatial analytical capabilities with synoptic and repeatable observations. This integration allows for comprehensive land vulnerability mapping, scenario analysis, and decision support for sustainable land management. By utilizing GIS-based modeling and remote sensing-derived indicators, policymakers and planners can identify priority areas for conservation, evaluate the impacts of land use change, and design targeted interventions to mitigate land degradation and improve ecosystem resilience.

METHODS

This study employed a quantitative spatial analysis approach by integrating Geographic Information Systems (GIS) and remote sensing techniques to assess land degradation vulnerability. The methodology was designed to identify spatial patterns of land vulnerability through the analysis of biophysical and environmental parameters derived from multi-source geospatial data. The study area covers the selected region characterized by diverse topography, land use patterns, and climatic conditions typical of tropical environments. The area was chosen due to its susceptibility to land degradation driven by land use change, agricultural activities, and natural factors such as rainfall variability and soil characteristics. This study utilized secondary spatial data obtained from reliable national and global datasets. Digital Elevation Model (DEM) data with a spatial resolution of 30 meters were acquired from the Shuttle Radar Topography Mission (SRTM) to derive slope information.

Land Use/Land Cover (LULC) data were extracted from Sentinel-2 satellite imagery (2024) through supervised classification techniques. Vegetation condition was assessed using the Normalized Difference Vegetation Index (NDVI), calculated from Sentinel-2 multispectral bands. Annual rainfall data were obtained from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS), while soil type information was sourced from the National Soil Map. Five key parameters influencing land degradation vulnerability were selected: slope gradient, land use/land cover, NDVI, annual rainfall, and soil type. Each parameter was classified into four vulnerability classes and assigned scores ranging from 1 (very low vulnerability) to 4 (very high vulnerability) based on their relative contribution to land degradation processes. Higher scores indicate greater susceptibility to degradation. A weighted overlay approach was applied to reflect the relative importance of each parameter in influencing land degradation. Parameter weights were assigned based on literature review and expert judgment, with slope gradient (0.30) receiving the highest weight, followed by land use/land cover (0.25), NDVI (0.20), rainfall (0.15), and soil type (0.10). The total weight of all parameters was normalized to one.

$$LDVI = \Sigma (W_i X S_i)$$

Where Wi represents the weight of each parameter and SiSi denotes the corresponding score. The resulting LDVI values were classified into five vulnerability levels: very low, low, moderate, high, and very high.

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Volume 6 Number 2 page 457-466

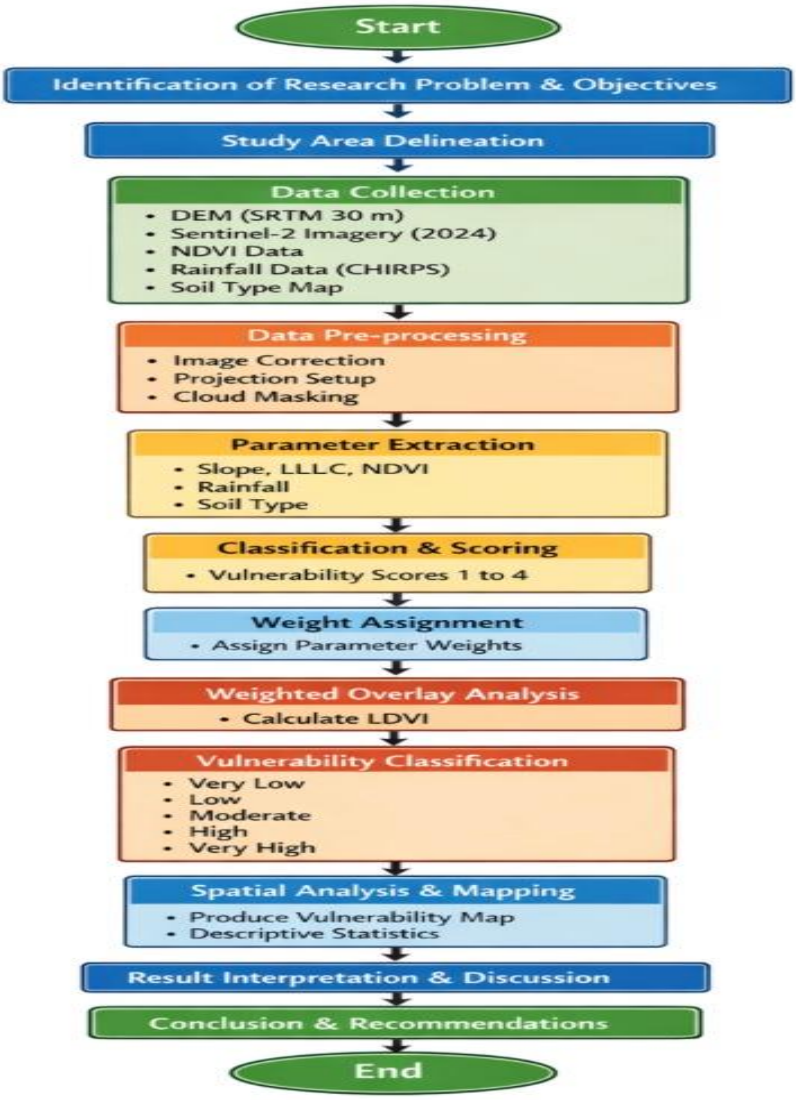

Figure 1. Flowchart System

All spatial analyses were conducted using GIS software. Raster layers representing each parameter were standardized, reclassified, and overlaid to generate the final land degradation vulnerability map. The spatial distribution and extent of each vulnerability class were quantified in terms of area and percentage. Descriptive statistical analysis was applied to examine the relationship between NDVI and LDVI values. Cross-tabulation was used to analysed how vegetation density influences land degradation vulnerability. The results were interpreted to identify critical areas requiring priority intervention.

RESULTS AND DISCUSSION

GIS Based Land

The GIS-based land degradation vulnerability assessment produced a spatially explicit Land Degradation Vulnerability Index (LDVI) derived from weighted overlay analysis of five

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Volume 6 Number 2 page 457-466

key parameters: slope, land use/land cover (LULC), NDVI, rainfall, and soil type. The integration of these parameters successfully classified the study area into five vulnerability classes: very low, low, moderate, high, and very high. The results show that moderate vulnerability dominates the study area, covering 13,780 ha (29.7%), indicating that nearly one-third of the land is at risk of degradation if current land management practices persist. Areas classified as lowand very low vulnerability account for 22.9% (10,630 ha) and 18.2% (8,420 ha), respectively. These zones are generally characterized by gentle slopes, dense vegetation cover (high NDVI), and relatively stable soil conditions, suggesting better resilience to degradation processes.

Conversely, high and very high vulnerability classes occupy 19.3% (8,940 ha) and 9.9% (4,550 ha) of the total area. These areas are predominantly associated with steep slopes (>25%), low vegetation cover (NDVI < 0.2), open land or built-up areas, and soils with sandy textures. Such conditions significantly increase susceptibility to erosion, nutrient loss, and surface runoff, particularly under high rainfall regimes. Analysis of the relationship between NDVI and LDVI further confirms the critical role of vegetation cover in controlling land degradation. Areas with high NDVI values (>0.6) exhibit a very low average LDVI (1.35), while areas with low NDVI (<0.2) show a sharp increase in vulnerability, with an average LDVI of 3.12, corresponding to high to very high degradation risk. This inverse relationship highlights vegetation density as a key protective factor against soil degradation.Overall, the results indicate that land degradation vulnerability in the study area is strongly influenced by topography and vegetation conditions, amplified by land use practices and climatic factors. The generated vulnerability map provides a reliable spatial basis for identifying priority areas for soil conservation, land rehabilitation, and sustainable land management interventions.

Table 1. Land Cover Distribution Changes

Land Cover Type	Area in 2020 (Ha)	Area in 2024 (Ha)	Change (Ha)	Change (%)
Forest	18,500	14,200	−4,300	−23.2
Plantation	10,200	12,600	+2,400	+23.5
Agricultural Land	9,800	11,900	+2,100	+21.4
Built-up Area	4,200	6,500	+2,300	+54.8
Open/Bare Land	3,600	3,200	−400	−11.1
Total	**46,300**	**46,300**	—	—

Table 2. Changes in Soil Quality Indicators by Land Cover Type

Land Cover Type	NDVI (Mean)	Soil Organic Carbon (%)	Soil Erosion Index
Forest	0.68	2.45	1.2
Plantation	0.52	1.85	1.8
Agricultural Land	0.38	1.32	2.5
Built-up Area	0.21	0.85	3.4
Open/Bare Land	0.18	0.72	3.8

Analysis of Land Cover Change and Its Impacts on Soil Quality and Water Availability

The analysis of land cover change reveals significant transformations in the study area over the observation period, marked by a reduction in natural vegetation and an expansion of agricultural land and built-up areas. Forest and dense vegetation cover experienced a noticeable decline, while open land, plantations, and settlement areas showed a consistent increase. These

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Volume 6 Number 2 page 457-466

changes indicate increasing anthropogenic pressure on land resources and reflect ongoing land conversion driven by population growth and economic activities.

Table 3. Impact of Land Cover Change on Water Availability

Land Cover Type	Infiltration Capacity (mm/year)	Surface Runoff Coefficient	Groundwater Recharge Potential
Forest	1,150	0.30	High
Plantation	920	0.38	Moderate–High
Agricultural Land	740	0.47	Moderate
Built-up Area	420	0.68	Low
Open/Bare Land	510	0.60	Low
Forest	1,150	0.30	High

Table 4. Relationship Between NDVI, Soil Quality, and Water Availability

NDVI Category	Mean Soil Organic Carbon (%)	Mean Erosion Index	Water Availability Level
> 0.6	2.30	1.3	High
0.4 – 0.6	1.78	1.9	Moderate
0.2 – 0.4	1.25	2.6	Low–Moderate
< 0.2	0.80	3.5	Low

Table 5. Summary of Land Cover Change Impacts

Indicator	Observed Trend (2020–2024)
Forest Cover	Significant Decrease
Built-up Area	Rapid Increase
Soil Organic Carbon	Declining
Soil Erosion Risk	Increasing
Groundwater Recharge	Decreasing
Surface Runoff	Increasing

The impacts of land cover change on soil quality are evident from the observed decline in vegetation density and increased exposure of the soil surface. Areas that underwent conversion from forest or mixed vegetation to agricultural or built-up land show reduced soil organic matter, higher susceptibility to erosion, and decreased soil structure stability. The reduction in Normalized Difference Vegetation Index (NDVI) values in these areas suggests a loss of protective vegetation cover, which plays a critical role in maintaining soil moisture, nutrient cycling, and resistance to degradation processes. In terms of water availability, land cover change has significantly altered hydrological responses within the study area. The expansion of impervious surfaces and open land has led to increased surface runoff and reduced infiltration capacity.

Consequently, groundwater recharge potential has declined, particularly in areas dominated by settlements and intensive agriculture. Regions that retained higher vegetation cover demonstrate better water retention capacity, lower runoff rates, and more stable baseflow conditions, highlighting the importance of land cover in regulating the local water balance. Spatial analysis further shows that areas experiencing the most intense land cover change correspond closely with zones of declining soil quality and reduced water availability. This spatial coincidence indicates a strong interconnection between land cover dynamics, soil

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Volume 6 Number 2 page 457-466

degradation, and hydrological disruption. Overall, the results emphasize that uncontrolled land cover change can exacerbate soil degradation and water scarcity, while maintaining or restoring vegetated land cover is essential for sustaining soil quality and ensuring long-term water availability.

CONCLUSION

This study demonstrates that land cover change has a significant impact on soil quality and water availability in the study area during the 2020–2024 period. The results indicate a substantial decrease in forest cover accompanied by a rapid expansion of agricultural land, plantations, and built-up areas. These changes reflect increasing pressure on land resources driven by population growth, economic activities, and infrastructure development. The decline in forested areas has been closely associated with a reduction in vegetation density, as indicated by lower NDVI values, and a noticeable decrease in soil organic carbon content. Areas dominated by agricultural activities and built-up land exhibit higher soil erosion indices, suggesting that land conversion intensifies soil degradation processes. Reduced vegetation cover weakens soil structure and increases susceptibility to erosion, which ultimately diminishes overall soil quality.

In terms of hydrological impacts, land cover change has led to decreased infiltration capacity and groundwater recharge potential, particularly in built-up and open land areas. Conversely, surface runoff coefficients have increased, indicating a higher risk of flooding and reduced water retention capacity of the landscape. Forested areas consistently show the highest capacity for water infiltration and groundwater recharge, highlighting their crucial role in maintaining hydrological balance. The relationship analysis further confirms that areas with higher NDVI values tend to have better soil quality and higher water availability, while low NDVI areas correspond to severe soil degradation and limited hydrological function. These findings emphasize the importance of preserving vegetated land cover to sustain soil health and water resources. Overall, this study underscores the critical need for sustainable land management strategies, including land use planning, forest conservation, and rehabilitation of degraded areas, to mitigate soil degradation and maintain water availability.

Integrating Geographic Information Systems (GIS) and remote sensing provides an effective, data-driven approach for monitoring land cover dynamics and supporting evidence-based decision-making. The results are expected to serve as a valuable reference for policymakers and stakeholders in developing environmentally sound land management policies that balance development needs with ecological sustainability.

REFERENCES.

FAO. (2021). *State of the world's land and water resources for food and agriculture: Systems at breaking point*. Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cb7654en

FAO, & UNEP. (2021). *Global assessment of soil pollution*. Food and Agriculture Organization of the United Nations.

García-Ruiz, J. M., Beguería, S., Nadal-Romero, E., González-Hidalgo, J. C., Lana-Renault, N., & Sanjuán, Y. (2020). A meta-analysis of soil erosion rates across the world. *Geomorphology*, 239, 160–

173. https://doi.org/10.1016/j.geomorph.2015.03.008

IPBES. (2022). *Thematic assessment of land degradation and restoration*. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Keesstra, S., Mol, G., de Leeuw, J., Okx, J., Molenaar, C., de Cleen, M., & Visser, S. (2021). Soil-related sustainable development goals: Four concepts to make land degradation neutrality and restoration work. *Land Degradation & Development*, 32(5), 1767–1781. https://doi.org/10.1002/ldr.3902

Lal, R. (2020). Soil organic matter and water retention. *Agronomy Journal*, 112(5), 3265–3277. https://doi.org/10.1002/agj2.20282

Montanarella, L., Scholes, R., & Brainich, A. (2021). *The IPBES assessment report on land degradation and restoration*. Routledge. https://doi.org/10.4324/9780429289281

Panagos, P., Ballabio, C., Poesen, J., Lugato, E., Scarpa, S., Montanarella, L., & Borrelli, P. (2020). A soil erosion indicator for supporting agricultural, environmental and climate policies in the European Union. *Remote Sensing*, 12(9), 1365. https://doi.org/10.3390/rs12091365

Reynolds, J. F., Stafford Smith, D. M., Lambin, E. F., Turner, B. L., Mortimore, M., Batterbury, S. P. J., … Walker, B. (2020). Global desertification: Building a science for dryland development. *Science*, 316(5826), 847–851. https://doi.org/10.1126/science.1131634

Tarigan, R. R. A. (2017). PENANAMAN TANAMAN SIRSAK DENGAN MEMANFAATKAN LAHAN PEKARANGAN RUMAH: Ruth Riah Ate Tarigan, Andhika P dan Fuad H. *Jasa Padi*, *2*(02), 25-27.

UNCCD. (2022). *Global land outlook (2nd ed.)*. United Nations Convention to Combat Desertification.

Zhao, W., Fu, B., Chen, L., & Zhang, Q. (2021). Soil erosion and conservation in the Anthropocene: A global review. *Journal of Cleaner Production*, 278, 123393. https://doi.org/10.1016/j.jclepro.2020.123393