Flood Regulation Ecosystem Services Performance Based On Slope And Land Cover To Support Soil And Water Conservation In Ternate City

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Abstract

Flood Regulation Ecosytem Services Performance Based On Land Cover To Support Soil And Water Conservation In Ternate City. Ternate City is a multi-island municipality characterized by diverse topographic and ecological conditions, exposing it to significant risks of surface runoff, inundation, and flash floods, consequences of its steep volcanic terrain and rapid land cover change. Flood regulation ecosystem services play a critical role in soil and water conservation and sustainable spatial planning. This study assessed the performance of flood regulation ecosystem services based on slope gradient (landform) and land cover across Ternate City using secondary spatial data from the 2022 Environmental Carrying and Assimilation Capacity Document (D3TLH), computed via the Simple Additive Weighting (SAW) method with a 1" × 1" grid system (approximately 30 m spatial resolution). Results indicate that flood regulation service performance is dominated by the medium class (41.99%), followed by the high-to-very high class (32.78%), and the low-to-very low class (25.23%). Batang Dua and Ternate Barat sub-districts exhibit the highest ecosystem service performance, with high-to-very high coverage accounting for 8.66% and 6.58% of total area, respectively. Dry Land Forest is the primary contributor to the very high class (27.82%), while plantation land cover dominates the medium class (40.90%). The Mid Volcanic Slope (11.37%) and Tectonic Hills (7.97%) landform units are the largest contributors to the very high class. These findings highlight the urgency of prioritizing soil and water conservation efforts in forested volcanic slopes and tectonic hill areas to sustain long-term flood mitigation capacity.

Keywords: Ecosystem Services, Flood Regulation, Land Cover, Slope, Soil and Water Conservation, Ternate City

INTRODUCTION

Ternate City comprises five islands exhibiting diverse topographic characteristics, ranging from the volcanic slopes of Mount Gamalama on Ternate Island and tectonic hills on Batang Dua to coastal lowlands on Hiri and Moti. This spatial diversity is reflected in the high variability of slope gradients and land cover types across the municipality. The combination of intense rainfall and rapid land cover change renders Ternate City particularly susceptible to surface runoff and soil erosion (Dinas Lingkungan Hidup Kota Ternate, 2022).Soil and water conservation on sloping terrain is intrinsically linked to the capacity of ecosystems to regulate hydrological processes. An ecosystem services-based approach has proven effective for identifying the natural capacity of ecosystems to mitigate flooding (Braat & de Groot, 2012). Flood regulation ecosystem services, mediated through land cover characteristics and landform attributes, can reduce surface runoff, enhance infiltration, and stabilize slopes (Costanza et al., 2017).

Forest to plantation or forest to settlement conversion directly diminishes flood regulation capacity. Studies consistently demonstrate that forested areas possess substantially greater surface runoff control capabilities than intensively managed land uses, owing to canopy interception and the considerably higher infiltration capacity of forest soils (Badaruddin et al., 2021). Slope gradient constitutes a key determinant of surface runoff rates: steeper slopes accelerate runoff unless supported by adequate vegetative cover (Shi et al., 2022). The interaction between slope gradient and land cover ultimately determines the magnitude of an ecosystem's capacity to buffer surface flow; vegetation biomass and forest extent are the predominant ecosystem characteristics driving flood prevention at the catchment scale (Várí et al., 2022).

This study builds upon Tidore et al. (2025), which examined water provision ecosystem services in Ternate City, extending the analysis to the flood regulation dimension. Site-specific assessments of flood regulation ecosystem service performance based on slope and land cover in tropical multi-island territories with complex landform diversity, such as

Ternate City, remain scarce, with most analogous studies conducted in continental rather than multi-topographic island settings. This study aims to analyze the performance of flood regulation ecosystem services based on slope gradient and land cover parameters across all sub-districts of Ternate City, providing an evidence base for formulating spatially contextualized soil and water conservation strategies appropriate for island-based municipalities.

METHODS

Study Area

This study was conducted in 2025 through the collection and analysis of secondary data from the 2022 D3TLH (Environmental Carrying and Assimilation Capacity Document) of Ternate City. The study area covers the entire administrative territory of Ternate City, North Maluku Province, encompassing eight sub-districts with a total area of 16,181.51 ha. Ternate City consists of five major islands are Ternate, Hiri, Moti, Mayau/Batang Dua, and Tifuresituated.

Materials and Instruments

ArcGIS software was used for cartographic layout and spatial visualization of ecosystem service performance maps derived from the D3TLH document, while Microsoft Excel was employed for data processing and tabulation. The datasets utilized comprised: (1) the 2022 D3TLH of Ternate City, containing ecosystem service performance data by sub-district, land cover, and landform; (2) flood regulation environmental service performance maps from the Ternate City Regional Development Planning Agency (BAPELITBANGDA), 2022; (3) 2022 land cover data for Ternate City from the Ministry of Environment and Forestry; and (4) the 2020–2040 Spatial Plan (RTRW) of Ternate City as a spatial planning reference.

Analytical Method

Flood regulation ecosystem service performance data were derived from the 2022 D3TLH of Ternate City, calculated using the Simple Additive Weighting (SAW) method with a 1" × 1" grid system (approximately 30 m spatial resolution), in accordance with guidelines for determining environmental carrying and assimilation capacity (Muta'ali, 2015; KLHK, 2018). The SAW method is a widely applied multi-attribute decision-making approach enabling weighted aggregation of multiple criteria into a composite index (Taherdoost, 2023). The index formula applied in the D3TLH is as follows:

$$ESEI = (wlf \times slf) + (wveg \times sveg) + (wlc \times slc) \quad (1)$$

where ESEI = Ecosystem Service Environmental Index; wlf = landform weight; slf = landform score; wveg = vegetation weight; sveg = vegetation score; wlc = land cover weight; slc = land cover score. The weights and scores assigned to each parameter in the D3TLH follow the guidelines issued by the Sulawesi-Maluku Ecoregion Development Control Center, KLHK (2018). The resulting index values are classified into five performance classes: Very Low (1.00–1.80), Low (1.81–2.60), Medium (2.61–3.40), High (3.41–4.20), and Very High (4.21–5.00). This formula and classification scheme are presented to enable readers to understand the assessment basis employed in the D3TLH. The analytical framework of this study encompasses the spatial distribution and interpretation of ecosystem service performance by sub-district, land cover, and landform, with tabulation and spatial visualization conducted using Microsoft Excel and ArcGIS.

RESULTS AND DISCUSSION

Spatial Distribution of Flood Regulation Ecosystem Service Performance by Sub-district

The spatial distribution of flood regulation ecosystem service performance across Ternate City sub-districts in 2022 is presented in Table 1 and Figure 1.

Table 1. Distribution of Flood Regulation Ecosystem Service Performance Area in Ternate City by Sub-district (Dinas Lingkungan Hidup Kota Ternate, 2022)

No.	Sub-district	Ecosystem Service Performance Class										Total	
		Very Low		Low		Medium		High		Very High			
		Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
1	Batang Dua	40.45	0.25	1,311.92	8.11	135.28	0.84	98.51	0.61	1,302.93	8.05	2,889.09	17.85
2	Hiri	0.00	0.00	69.14	0.43	486.13	3.00	22.09	0.14	91.07	0.56	668.43	4.13
3	Moti	202.15	1.25	153.33	0.95	1,550.66	9.58	74.70	0.46	493.69	3.05	2,474.53	15.29

4	Pulau Ternate	71.20	0.44	94.69	0.59	862.19	5.33	4.83	0.03	698.97	4.32	1,731.88	10.70
5	Ternate Barat	171.11	1.06	221.41	1.37	1,924.80	11.90	148.56	0.92	916.16	5.66	3,382.05	20.90
6	Ternate Selatan	245.17	1.52	454.57	2.81	779.65	4.82	56.41	0.35	513.34	3.17	2,049.14	12.66
7	Ternate Tengah	183.06	1.13	235.19	1.45	653.16	4.04	13.10	0.08	321.28	1.99	1,405.79	8.69
8	Ternate Utara	169.82	1.05	460.13	2.84	402.47	2.49	232.84	1.44	315.34	1.95	1,580.59	9.77
TOTAL		**1,082.97**	**6.69**	**3,000.38**	**18.54**	**6,794.35**	**41.99**	**651.03**	**4.02**	**4,652.78**	**28.75**	**16,181.51**	**100.00**

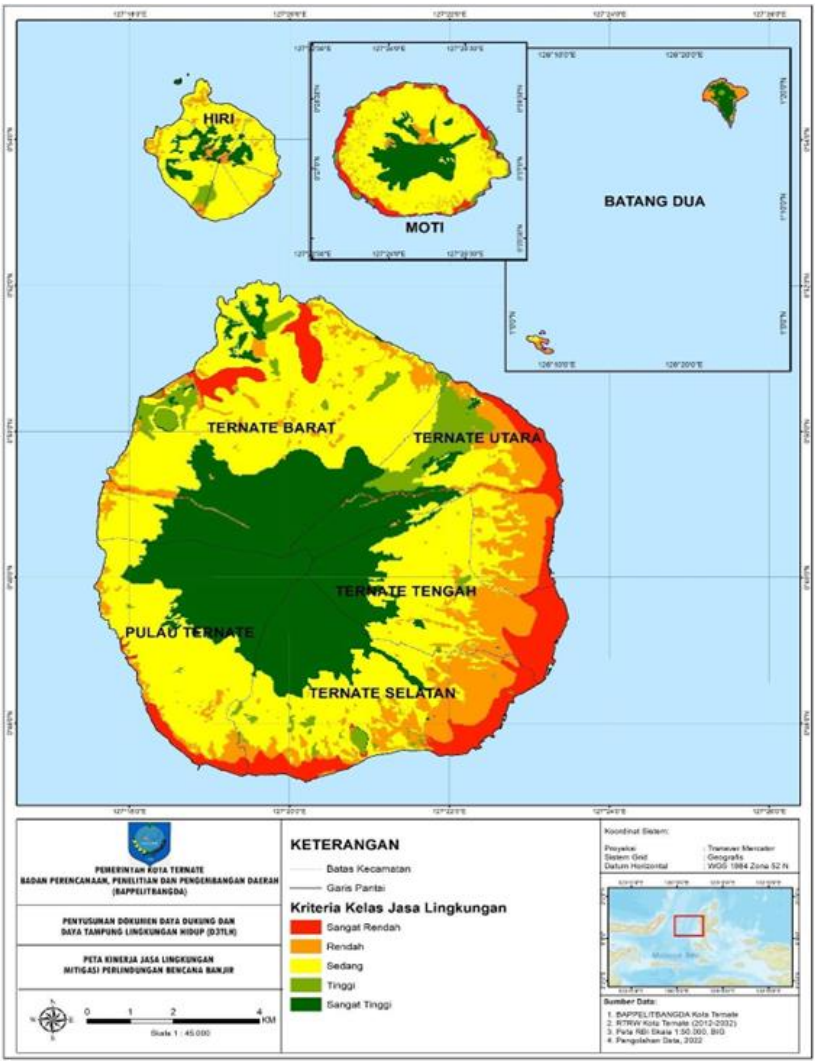

Figure 1. Flood Regulation Environmental Service Performance Map of Ternate City (Source: Dinas Lingkungan Hidup Kota Ternate, 2022)

Overall, flood regulation ecosystem service performance in Ternate City in 2022 is dominated by the medium performance class (41.99%), followed by the high-to-very high class (32.78%), and the low-to-very low class (25.23%). Compared to water provision services, which reached only 1.42% in the high class (Tidore et al., 2025), the city's flood regulation capacity is relatively stronger. This condition is attributable to the relatively intact forest cover remaining on the volcanic slopes of Mount Gamalama and the tectonic hills of Batang Dua, which directly sustains the municipality's capacity to control surface runoff. Nevertheless, the dominance of the medium class signals that land conversion pressure, particularly on lower slopes, is already substantial.

The spatial distribution shown in Figure 1 reveals a pronounced contrast between the mid-to-upper slope areas depicted in dark green (very high class) and the coastal zones dominated by red (very low class). Batang Dua sub-district records the largest high-to-very high class coverage, at 1,401.44 ha (8.66%), as its relatively isolated island setting has preserved relatively intact forest cover. Ternate Barat sub-district follows with 1,064.72 ha (6.58%), supported by protected forest areas on the slopes of Mount Gamalama. In contrast, Ternate Tengah and Ternate Selatan, the two most densely urbanized sub-districts, exhibit the largest low-to-very low class extents, at 418.25 ha and 699.74 ha, respectively. In these areas, the prevalence of impervious surfaces such as asphalt and building footprints leaves virtually no capacity for rainwater to infiltrate the soil, resulting in most precipitation being converted directly into surface runoff, a condition diametrically opposed to that of forested areas with substantially higher infiltration capacity (Badaruddin et al., 2021).

Spatial Distribution of Flood Regulation Ecosystem Service Performance by Land Cover

Table 2 presents the distribution of flood regulation ecosystem service performance by land cover type.

Table 2. Distribution of Flood Regulation Ecosystem Service Performance Area in Ternate City by Land Cover **(**Dinas Lingkungan Hidup Kota Ternate, 2022)

No.	Land Cover	Flood Regulation Ecosystem Service Performance Class										Total	
		Very Low		Low		Medium		High		Very High			
		Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
1	Lake	0.28	0.00	0.42	0.00	0.93	0.01	42.40	0.26	3.81	0.02	47.83	0.30
2	Mangrove Forest	4.26	0.03	1.41	0.01	1.08	0.01	79.50	0.49	5.17	0.03	91.42	0.56
3	Dry Land Forest	1.27	0.01	25.72	0.16	35.62	0.22	87.58	0.54	4,501.40	27.82	4,651.59	28.75
4	Mixed Garden	1.17	0.01	17.73	0.11	28.67	0.18	240.87	1.49	1.53	0.01	289.98	1.79
5	Open Land	69.50	0.43	262.66	1.62	48.82	0.30	1.02	0.01	2.65	0.02	384.65	2.38
6	Other Open Land	7.66	0.05	24.51	0.15	1.13	0.01	0.27	0.00	0.06	0.00	33.63	0.21
7	Shallow Marine Waters	1.72	0.01	-	0.00	-	0.00	0.05	0.00	-	0.00	1.77	0.01
8	Plantation	340.10	2.10	1,442.18	8.91	6,618.07	40.90	18.64	0.12	60.79	0.38	8,479.78	52.40
9	Settlement	642.22	3.97	1,209.38	7.47	51.19	0.32	3.87	0.02	0.55	0.00	1,907.22	11.79
10	Shrubland	0.09	0.00	1.41	0.01	7.17	0.04	176.24	1.09	73.19	0.45	258.11	1.60
11	River	14.71	0.09	14.97	0.09	1.66	0.01	0.59	0.00	3.62	0.02	35.55	0.22
TOTAL		**1,082.97**	**6.69**	**3,000.38**	**18.54**	**6,794.35**	**41.99**	**651.03**	**4.02**	**4,652.78**	**28.75**	**16,181.51**	**100.00**

Among the land cover types present in the study area, dry land forest contributes most dominantly to the very high performance class, covering 4,501.40 ha or 27.82% of the total area. This figure represents 96.77% of the total dry land forest extent (4,651.59 ha), indicating that nearly the entirety of dry land forest in Ternate City retains its hydrological regulation function. The presence of canopy interception slows the kinetic energy of rainfall, deep root systems accelerate infiltration, and litter accumulation retards surface flow (Badaruddin et al., 2021). The concentration of the largest high-to-very high class areas in Batang Dua and Ternate Barat, the sub-districts with the most extensive dry land forest cover as shown in Table 1further, corroborates this pattern. Mangrove forest exhibits the highest proportion of the high class relative to other land cover types: of the total 91.42 ha, approximately 79.50 ha or 86.97% fall within the high performance class. This reflects the capacity of mangroves to attenuate wave energy and buffer inundation in coastal zones (Costanza et al., 2017; Van Hespen et al., 2023). However, the extremely limited extent of mangrove coverage renders its protective reach along Ternate City's coastline considerably inadequate.

Plantation, the dominant land cover in Ternate City (52.40%, or 8,479.78 ha), falls predominantly within the medium performance class (6,618.07 ha, or 40.90%). Nutmeg, clove, and coconut plantations provide canopy cover but intensive management practices reduce litter layer thickness and soil porosity. Suprayogo et al. (2020) demonstrate that maintaining tree canopy cover above 55% is critical to sustaining infiltration capacity on volcanic slopes, and that forest conversion to more open land uses substantially reduces hydrological function. Evidence from tropical Indonesian watersheds consistently shows that forest conversion to plantation or settlement substantially increases peak discharge and reduces infiltration capacity (Lubis et al., 2024; Sugianto et al., 2022). By contrast, settlements occupying 1,907.22 ha are almost entirely (97.07%) classified within the low-to-very low class, confirming that urban expansion represents the most significant factor suppressing flood regulation performance in Ternate City.

Spatial Distribution of Flood Regulation Ecosystem Service Performance by Slope and Landform

Table 3 presents the distribution of flood regulation performance across the 16 landform types identified in Ternate City.

Table 3. Distribution of Flood Regulation Ecosystem Service Performance Area in Ternate City by Landform **(**Dinas Lingkungan Hidup Kota Ternate, 2022)

No.	Landform	Flood Regulation Ecosystem Service Performance Class										Total	
		Very Low		Low		Medium		High		Very High			
		Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
1	Lava Flow	3.51	0.02	69.36	0.43	243.34	1.50	205.16	1.27	674.12	4.17	1,195.50	7.39
2	Anthropic	14.05	0.09	-	0.00	0.08	0.00	0.45	0.00	-	0.00	14.59	0.09
3	Lakes & Rivers	12.00	0.07	15.61	0.10	2.65	0.02	42.34	0.26	2.20	0.01	74.80	0.46
4	Alluvial Plain	756.81	4.68	14.18	0.09	9.09	0.06	1.34	0.01	0.01	0.00	781.43	4.83
5	Karst Plain	8.99	0.06	320.66	1.98	1.11	0.01	2.99	0.02	-	0.00	333.75	2.06
6	Tidal Plain	20.02	0.12	0.84	0.01	0.69	0.00	79.97	0.49	0.58	0.00	102.10	0.63
7	Tectonic Plain	25.14	0.16	341.50	2.11	3.70	0.02	79.97	0.49	1.83	0.01	452.14	2.79
8	Volcanic Crater	-	0.00	-	0.00	-	0.00	-	0.00	55.75	0.34	55.75	0.34
9	Upper Volcanic Slope	0.01	0.00	57.54	0.36	1.89	0.01	-	0.00	610.39	3.77	669.84	4.14
10	Lower Volcanic Slope	21.10	0.13	1,500.31	9.27	4,788.76	29.59	218.89	1.35	165.65	1.02	6,694.71	41.37
11	Mid Volcanic Slope	0.00	0.00	28.40	0.18	1,611.77	9.96	9.82	0.06	1,839.72	11.37	3,489.70	21.57
12	Karst Hills	0.40	0.00	5.84	0.04	115.98	0.72	0.18	0.00	11.44	0.07	133.84	0.83
13	Tectonic Hills	0.14	0.00	642.79	3.97	14.38	0.09	4.70	0.03	1,289.63	7.97	1,951.64	12.06
14	Sandy Coast	175.62	1.09	0.68	0.00	0.91	0.01	4.56	0.03	0.05	0.00	181.81	1.12
15	Volcanic Island	-	0.00	-	0.00	-	0.00	-	0.00	1.43	0.01	1.43	0.01
16	Back Swamp	45.16	0.28	2.65	0.02	-	0.00	0.67	0.00	-	0.00	48.49	0.30
	TOTAL	**1,082.97**	**6.69**	**3,000.38**	**18.54**	**6,794.35**	**41.99**	**651.03**	**4.02**	**4,652.78**	**28.75**	**16,181.51**	**100.00**

The Mid Volcanic Slope and Tectonic Hills landforms are the two largest contributors to the very high performance class, accounting for 1,839.72 ha (11.37%) and 1,289.63 ha (7.97%), respectively. Their high performance is largely attributable to the relatively dense vegetative cover still maintained in these areas. The moderate slope gradient of the Mid Volcanic Slope promotes lateral subsurface flow into the soil profile rather than overland flow, as long as forest cover remains intact (Suprayogo et al., 2020). The Volcanic Crater and Volcanic Island landforms are entirely classified within the very high class, as both units are virtually inaccessible to human activity.

The Lower Volcanic Slope is the most extensive landform unit (41.37% of total area), yet is dominated by the medium performance class (29.59%). This condition reflects tangible pressure on the ground: its accessibility makes it the most intensively converted zone from forest to plantation and settlement. In contrast, the Tectonic Hills landform exhibits a bimodal distribution, with both very high and low classes being simultaneously significant, indicative of heterogeneous land cover conditions wherein portions of the landscape remain forested while others have already undergone land use conversion (Dinas Lingkungan Hidup Kota Ternate, 2022).

Coastal lowland units, including Alluvial Plain, Sandy Coast, Back Swamp, and Tidal Plain, collectively cover 1,113.83 ha (6.88% of total area), yet their combined low-to-very low class coverage amounts to 1,015.96 ha (91.21% of their total extent), a proportion approximately 3.6 times higher than the city-wide low-to-very low average (25.23%). This disproportionate concentration of poor performance relative to spatial extent underscores their role as high-priority vulnerability hotspots. The Alluvial Plain is the most critical unit: its very low class coverage alone (756.81 ha, 96.85% of its total area) exceeds the city-wide very low class average (6.69%) by a factor of 14.5, indicating a near-complete absence of natural flood regulation capacity. The Sandy Coast and Back Swamp, while smaller in area (181.81 ha and 48.49 ha, respectively), exhibit similarly extreme low-to-very low concentration at 96.97% and 98.60%, respectively, confirming that severely suppressed flood regulation capacity is a structural characteristic shared across all coastal lowland landform types rather than an anomaly confined to a single unit. The convergence of flat topography, impervious surface dominance (as evidenced by the 97.07% low-to-very low classification of settlements in Table 2), and high building density in these zones effectively eliminates infiltration pathways, forcing nearly all precipitation inputs into surface runoff. This is further corroborated by the spatial correspondence between the two most densely urbanized sub-districts, Ternate Tengah and Ternate Selatan, which together account for 1,117.99 ha of low-to-very low coverage (Table 1), and which are predominantly underlain by coastal lowland landforms. Given that settlements alone contribute 1,851.60 ha to the low-to-very low class city-wide (Table 2), the spatial overlap between settlement expansion and coastal lowland landforms is the primary quantifiable driver of the observed performance deficit in these units. In such settings, ecosystem-based conservation interventions alone are insufficient; engineered infiltration infrastructure, including infiltration wells and retention ponds is necessary to partially substitute for the natural infiltration function that has been lost across approximately 1,015.96 ha of affected coastal lowland area.

Taken together, the three tables reveal a consistent spatial pattern: flood regulation performance in Ternate City is governed by a gradient extending from forested mid-to-upper zones of each island toward built-up coastal areas. Forested upper watersheds function as hydrological buffers, while densely developed lowland areas constitute the most vulnerable endpoints. This pattern aligns with the carrying capacity framework based on ecosystem services, which emphasizes the importance of maintaining upper watershed functions to protect downstream areas (Braat & de Groot, 2012; Febriarta et al., 2022). Based on these findings, forests on mid-to-upper volcanic slopes require protection, coastal mangroves need restoration, alluvial lowlands must be equipped with infiltration infrastructure to compensate for lost infiltration capacity, and soil conservation techniques such as bench terracing and absorption trenches should be applied on Lower Volcanic Slopes, the zone most intensively subject to land use conversion (Parenja et al., 2025).

CONCLUSION

Based on the 2022 D3TLH data for Ternate City, flood regulation ecosystem service performance is dominated by the medium class (41.99%), followed by the high-to-very high class (32.78%) and the low-to-very low class (25.23%). This represents a comparatively stronger performance than water provision services; however, the dominance of the medium class indicates ongoing pressure from land cover conversion.

Dry land forest (27.82%) constitutes the primary driver of the very high performance class, while plantations dominate the medium class (40.90%) and settlements are almost entirely classified within the low-to-very low class. From a landform perspective, the Mid Volcanic Slope and Tectonic Hills are the largest contributors to the very high class, whereas all coastal lowland units fall within the lowest performance categories.

Soil and water conservation efforts in Ternate City should be prioritized on: (1) protection of forests on mid-to-upper volcanic slopes and tectonic hills; (2) restoration of mangrove ecosystems, whose current extent is critically limited; (3) construction of water infiltration infrastructure in densely settled alluvial lowlands; and (4) application of soil conservation techniques on the Lower Volcanic Slope, which is undergoing the most intensive land use conversion.

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REFERENCES

Badaruddin, B., Kadir, S., & Nisa, K. (2021). Buku Ajar Hidrologi Hutan. Banjarmasin: CV. Batang.

Braat, L. C., & de Groot, R. (2012). The ecosystem services agenda:bridging the worlds of natural science and economics, conservation and development, and public and private policy. Ecosystem Services, 1(1), 4–15. https://doi.org/https://doi.org/10.1016/j.ecoser.2012.07.011

Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., & Grasso, M. (2017). Twenty years of ecosystem services: How far have we come and how far do we still need to go? Ecosystem Services, 28, 1–16. https://doi.org/https://doi.org/10.1016/j.ecoser.2017.09.008

Dinas Lingkungan Hidup Kota Ternate. (2022). Dokumen Daya Dukung dan Daya Tampung Lingkungan Hidup (D3TLH) Kota Ternate Tahun 2022. Ternate: DLH Kota Ternate.

Febriarta, E., Fitria, L., Hati, K., Ghazali, A., Setyono, D., & Nagara, R. (2022). Pemetaan Daya Dukung Lingkungan Penyedia Air Bersih Berbasis Jasa Ekosistem di Tarempa Kabupaten Anambas. Jurnal Wilayah Dan Lingkungan, 10, 107–125. https://doi.org/10.14710/jwl.10.2.107-125

Kementerian Lingkungan Hidup dan Kehutanan [KLHK]. (2018). Skoring dan Bobot Kinerja Jasa Lingkungan Ekoregion Sulawesi Maluku [Scoring and Weighting of Environmental Service Performance for the Sulawesi-Maluku Ecoregion]. Jakarta: Pusat Pengendalian Pembangunan Ekoregion Sulawesi Maluku, Direktorat Jenderal Planologi Kehutanan dan Tata Lingkungan.

Muta'ali, L. (2015). Teknik Analisis Regional untuk Perencanaan Wilayah, Tata Ruang dan Lingkungan [Regional Analysis Techniques for Regional Planning, Spatial Planning, and Environment]. Yogyakarta: Badan Penerbit Fakultas Geografi UGM.

Julia Armita Parenja, Miftah Az-zura Salsabila, Dinda Parasnalurita, Zilvina B, & Fatmawati. (2025). TERASERING SEBAGAI SOLUSI EROSI DI LAHAN KRITIS. Jurnal Pendidikan Sosial Dan Humaniora, 4(3), 4775–4787. https://publisherqu.com/index.php/pediaqu/article/view/2342

Suprayogo, D., van Noordwijk, M., Hairiah, K., Meilasari, N., Rabbani, A. L., Ishaq, R. M., & Widianto, W. (2020). Infiltration-Friendly Agroforestry Land Uses on Volcanic Slopes in the Rejoso Watershed, East Java, Indonesia. Land, 9(8), 240. https://doi.org/10.3390/land9080240

Tidore, M. F. H., Adriani, A., & Arif, N. (2025). Analysis Of Environmental Carrying Capacity And Accompanying Capacity For Water Supply Ecosystem Services In Ternate City. Jurnal Penelitian Kehutanan BONITA, 7(2), 1-11.

Shi, P., Li, P., Li, Z., Sun, J., Wang, D., & Min, Z. (2022). Effects of grass vegetation coverage and position on runoff and sediment yields on the slope of Loess Plateau, China. Agricultural Water Management, 259, 107231. https://doi.org/https://doi.org/10.1016/j.agwat.2021.107231

Lubis MI, Linkie M, Lee JSH (2024) Tropical forest cover, oil palm plantations, and precipitation drive flooding events in Aceh, Indonesia, and hit the poorest people hardest. PLoS ONE 19(10): e0311759. https://doi.org/10.1371/journal.pone.0311759

Sugianto, S., Deli, A., Miswar, E., Rusdi, M., & Irham, M. (2022). The Effect of Land Use and Land Cover Changes on Flood Occurrence in Teunom Watershed, Aceh Jaya. Land, 11(8), 1271. https://doi.org/10.3390/land11081271

Taherdoost, H. (2023). Analysis of Simple Additive Weighting Method (SAW) as a MultiAttribute Decision-Making Technique: A Step-by-Step Guide. Journal of Management Science & Engineering Research, 6(1), 21–24. https://doi.org/10.30564/jmser.v6i1.5400 van Hespen, R., Hu, Z., Borsje, B., De Dominicis, M., Friess, D. A., Jevrejeva, S., Kleinhans, M. G., Maza, M., van Bijsterveldt, C. E. J., Van der Stocken, T., van Wesenbeeck, B., Xie, D., & Bouma, T. J. (2023). Mangrove forests as a nature-based solution for coastal flood protection: Biophysical and ecological considerations. Water Science and Engineering, 16(1), 1–13. https://doi.org/https://doi.org/10.1016/j.wse.2022.10.004

Vári, Á., Kozma, Z., Pataki, B., Jolánkai, Z., Kardos, M., Decsi, B., Pinke, Z., Jolánkai, G., Pásztor, L., Condé, S., Sonderegger, G., & Czúcz, B. (2022). Disentangling the ecosystem service 'flood regulation': Mechanisms and relevant ecosystem condition characteristics. Ambio, 51(8), 1855–1870. https://doi.org/10.1007/s13280-022-01708-0