International Journal of Research and Review
[Indexed, Peer-Reviewed Journal]
Volume 13; Issue: 5; May 2026
Website: www.ijrrjournal.com
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Review Paper

Agroforestry-Centred Watershed Sustainability at the Land-Water-Energy-Biodiversity Nexus: Integrating Local Wisdom, Bioenergy, and Coastal Conservation

Abdul Samad Hiola[1], Asda Rauf[2], Fitryane Lihawa[3]

[1]Doctoral Program in Environmental Science, Universitas Negeri Gorontalo, Gorontalo
[2,3]Post Graduate Program, Universitas Negeri Gorontalo, Gorontalo

Corresponding Author: Asda Rauf

DOI: https://doi.org/10.52403/ijrr.20260573

ABSTRACT

Watershed degradation is increasingly produced by interacting pressures: land conversion, sediment and nutrient loss, rural energy demand, biodiversity decline, weak governance, and climate-related hydrological extremes. This review synthesizes the attached literature corpus on watershed management, agroforestry, bioenergy, biodiversity, coastal conservation, and local wisdom to propose an integrated socio-ecological framework for sustainable watershed transitions. The review argues that agroforestry should be understood not merely as a farm-level production strategy, but as distributed green infrastructure that links upland infiltration, erosion control, biomass supply, habitat connectivity, and downstream coastal protection. It further shows that local wisdom and customary institutions can increase legitimacy, compliance, and continuity of conservation action when they are combined with scientific monitoring, supportive policy, and inclusive governance. Bioenergy emerges as a promising but contested component: woody biomass, coppice systems, and diversified tree-based landscapes can improve rural livelihoods and energy access, yet poorly governed energy-crop expansion may intensify land-use trade-offs and biodiversity loss. The synthesis identifies four publication-relevant contributions: a land-water-energy-biodiversity nexus model for watershed planning; a typology of agroforestry ecosystem-service pathways; a governance synthesis linking local wisdom with formal institutions; and a research agenda for evaluating trade-offs across biophysical, social, and economic dimensions. By foregrounding multifunctionality, the article clarifies why watershed science must evaluate hydrology, livelihoods, culture, energy, and biodiversity together across upland, midstream, and coastal interfaces. The review concludes that the next generation of watershed management should prioritize multifunctional landscapes, community-anchored governance, and evidence-based bioenergy development rather than single-objective conservation or production interventions. This synthesis supports transdisciplinary implementation worldwide.

Keywords: watershed management; agroforestry; local wisdom; bioenergy; biodiversity conservation; mangrove restoration; socio-ecological resilience

INTRODUCTION

Watersheds are no longer adequately understood as hydrological units alone. In tropical and developing-country contexts, a watershed is also a food-producing landscape, an energy source, a biodiversity reservoir, a cultural territory, and a governance arena in which upland and downstream actors negotiate access to land, water, vegetation, and ecosystem services. The attached corpus demonstrates that contemporary watershed management has moved from engineering-centred soil and water control toward integrated land management, social forestry, conservation education, coastal restoration, and climate adaptation (Basuki et al., 2022; Narendra et al., 2021). This shift is especially important where degraded upper catchments accelerate runoff and erosion, while downstream communities face sedimentation, flooding, mangrove loss, and declining coastal resources (Barchia et al., 2020; Naharuddin, 2021).

Agroforestry is central to this transition because it deliberately integrates trees with crops, livestock, or other land uses, thereby joining the protective function of forest cover with the livelihood function of agricultural production. The corpus consistently presents agroforestry as a multifunctional land-use system capable of improving infiltration, reducing surface runoff, conserving soil, increasing biodiversity, storing carbon, and producing biomass for household or commercial energy (Dissanayaka et al., 2023; Octavia et al., 2022). Unlike interventions that treat conservation and production as separate objectives, agroforestry can operate as a bridging practice: it makes ecological rehabilitation compatible with livelihood diversification, social forestry implementation, and rural development (Muthee et al., 2022; Nugroho et al., 2023).

Yet the literature also shows that technical land-use design is insufficient when institutions, cultural values, and community participation are weak. Indonesian watershed and coastal studies in the corpus repeatedly emphasize the importance of local wisdom, customary law, and community-based conservation for improving acceptance, compliance, and continuity of conservation practices (Aipassa et al., 2023; Basuki et al., 2022). Traditions such as Sasi, Tonotwiyat, Iriban, Minangkabau communal land norms, and forest allocation by indigenous communities illustrate that local rules can protect mangroves, regulate land conversion, preserve springs, and structure collective action (Putra, 2021; Tebay, 2023).

The challenge for a new review is therefore not to ask whether watershed management, agroforestry, bioenergy, biodiversity, or local wisdom matter individually; the attached literature already establishes that they do. The deeper task is to synthesize how these domains interact, where their synergies are strongest, and where trade-offs require active governance. In particular, bioenergy complicates watershed sustainability. Agroforestry-based biomass can support energy access, climate mitigation, and rural income, but energy-crop expansion can also compete with biodiversity, food production, and water security if it is treated as a single-purpose land-use frontier (Baumber et al., 2019; Mbow, 2020). This review addresses that gap by developing an integrated land-water-energy-biodiversity nexus framework grounded entirely in the attached reference set.

Accordingly, this review aims to: (i) synthesize the recent and foundational literature on agroforestry-centred watershed sustainability; (ii) evaluate how bioenergy, biodiversity conservation, local wisdom, and coastal management interact within watershed-to-coast systems; (iii) identify the principal synergies, trade-offs, and governance dilemmas shaping implementation; and (iv) propose a nexus-based framework to guide future research, policy, and community-centred watershed practice (Basuki et al., 2022; Jannah et al., 2024; Supangat et al., 2023).

LITERATURE REVIEW

Conceptual basis of agroforestry-centred watershed sustainability

The literature base reviewed in this article spans several interrelated domains, including watershed management, agroforestry, bioenergy production, biodiversity conservation, coastal ecosystem governance, and local wisdom. Although these themes are often discussed separately, the extracted studies indicate that they are functionally connected within broader socio-ecological landscapes. Agroforestry contributes to watershed protection through erosion control, improved infiltration, runoff reduction, biomass production, and habitat provision, while local wisdom strengthens community participation, customary regulation, and long-term conservation behavior. At the same time, bioenergy development and biodiversity conservation introduce both synergies and trade-offs that require integrated assessment. Therefore, Table 1 summarizes the thematic structure of the literature base and clarifies how each group of studies contributes to the development of an integrated review framework.

Table 1. Thematic structure of the literature base and its contribution to an integrated review.

Thematic cluster	Core contribution	Main spatial focus	Dominant mechanism	Key gap for synthesis	Ref.
Integrated watershed management	Frames watersheds as linked land, water, vegetation, institutions, and livelihoods rather than hydrology alone.	Catchment and national policy scales	Soil-water conservation, carrying capacity, climate adaptation, stakeholder coordination	Needs stronger integration with local institutions and production systems.	Basuki et al., 2022; Narendra et al., 2021; Supangat et al., 2023
Agroforestry and ecosystem services	Shows how tree-based farming provides soil protection, biodiversity, carbon, food, and livelihood functions.	Farm, landscape, and social-forestry areas	Tree cover, multistrata vegetation, organic inputs, habitat creation, diversified income	Needs clearer watershed-level translation of plot-scale benefits.	Dissanayaka et al., 2023; Van Noordwijk et al., 2016; Octavia et al., 2022; Shin et al., 2020
Bioenergy from tree-based systems	Identifies biomass, woodfuel, coppice systems, energy plantations, and residues as rural-energy opportunities.	Agroforestry plots, degraded lands, rural wastelands	Biomass production, carbon sequestration, fuel substitution, rural enterprise	Requires governance of land competition and biodiversity risks.	Hiloidhari et al., 2016; Nugroho et al., 2023; Sharma et al., 2016; Yadav et al., 2018
Biodiversity and restoration	Highlights agroforestry and tree plantations as habitats and restoration pathways in modified landscapes.	Agroecosystems, restoration zones, plantations	Species richness, habitat connectivity, soil recovery, carbon storage	Needs deeper attention to belowground diversity and functional outcomes.	Kusumawati et al., 2022; Muthee et al., 2022; Singh et al., 2021)
Local wisdom and customary governance	Explains how cultural norms, customary laws, and community practices	Villages, indigenous territories, coastal communities	Collective rules, sanctions, sacred values, participatory	Needs integration with formal policy and scientific monitoring.	Aipassa et al., 2023; Ginting & Bengkel, 2022; Suroso et al., 2022;

	regulate resource use and conservation behaviour.		conservation, local legitimacy		Yuhandra et al., 2023
Coastal and mangrove watershed systems	Connects downstream watershed condition with mangrove degradation, coastal livelihoods, and agromaritime vulnerability.	River mouths, bays, mangroves, coastal villages	Mangrove conservation, community participation, pollution control, climate adaptation	Needs stronger upstream-downstream governance linkages.	Jannah et al., 2024; Naharuddin, 2021; Tebay, 2023; Wambrauw & Ilham, 2023
Trade-offs and land-use competition	Warns that energy, conservation, food, and development objectives can conflict under limited land availability.	Landscape and policy scales	Land allocation, market instruments, renewable energy pressure, conservation prioritization	Needs decision frameworks for multifunctional landscapes.	Baumber et al., 2019; Mbow, 2020; Némethy & Szemethy, 2019

Agroforestry as distributed watershed infrastructure

A central insight from the corpus is that agroforestry functions as distributed watershed infrastructure. Conventional infrastructure for watershed protection is often visible, engineered, and spatially concentrated: check dams, terraces, drainage channels, reservoirs, or sediment traps. Agroforestry infrastructure is more diffuse. It operates through millions of biological structures - roots, litter layers, canopy strata, hedgerows, coppiced tree belts, shade trees, riparian vegetation, and mixed plantations - that alter hydrological pathways across the landscape. Evidence from watershed, agroforestry, and sustainable land-use studies shows that tree integration can reduce runoff, increase infiltration, stabilize soil, intercept rainfall, filter pollutants, and protect springs and streams (Barchia et al., 2020; Dissanayaka et al., 2023).

This infrastructural role becomes particularly important in hilly tropical watersheds, where rainfall intensity, land conversion, and road or settlement expansion increase erosion risk. In the Air Bengkulu watershed, for example, agroforestry with coffee plantations mixed with forest cover contributed to landscape quality and ecological connectivity in hilly areas, helping to reduce degradation pressures that would otherwise move downstream (Barchia et al., 2020). In Indonesia more generally, integrated watershed management has increasingly recognized that sustainable forest management, social forestry, and agroforestry are necessary to increase watershed carrying capacity under climate change (Basuki et al., 2022; Narendra et al., 2021).

Agroforestry also broadens the definition of watershed productivity. A conventional agricultural interpretation may define productivity in terms of annual crop yield, while a forestry interpretation may emphasize biomass or carbon. The corpus supports a multifunctional interpretation in which productivity includes clean water, stable soil, biomass, non-timber products, biodiversity habitat, livelihood resilience, and cultural value (Van Noordwijk et al., 2016; Octavia et al., 2022). This is a major conceptual advance because degraded watersheds often result from maximizing one function - short-term crop output, timber extraction, settlement expansion, or energy supply - at the expense of others. Agroforestry makes it possible to design land uses that produce multiple services simultaneously, although the strength of each service depends on species composition, spatial arrangement, management intensity, tenure security, and market conditions (Dissanayaka et al., 2023; Mukundente et al., 2020).

At the same time, the infrastructural metaphor should not be romanticized. Tree-based systems take time to mature, require secure rights and labour, and may involve yield trade-offs during establishment. Poorly designed tree planting can reduce water availability, simplify habitat, or shift burdens to households that lack land and capital. For this reason, watershed-oriented agroforestry should be assessed not only through tree density or canopy cover, but through hydrological performance, livelihood outcomes, biodiversity quality, and institutional durability (Muthee et al., 2022; Némethy & Szemethy, 2019). Table 2 summarizes the ecosystem-service pathways through which agroforestry contributes to watershed sustainability.

Table 2. Agroforestry ecosystem-service pathways relevant to watershed sustainability.

Pathway	Biophysical process	Watershed benefit	Livelihood or governance implication	Risk if poorly designed	Ref.
Runoff moderation	Canopy interception, root channels, litter cover, and surface roughness slow overland flow.	Reduced flooding severity, lower peak flows, and improved infiltration.	Supports downstream risk reduction and strengthens the case for upstream incentives.	Benefits may be delayed where tree cover is young or sparse.	Barchia et al., 2020; Supangat et al., 2023; Wato & Amare, 2020
Erosion and sediment control	Tree roots stabilize slopes while organic matter improves soil aggregation.	Lower sediment delivery to streams, reservoirs, and coastal zones.	Reduces maintenance costs and protects agricultural productivity.	Improper spacing or exposed understory can leave soil vulnerable.	Dissanayaka et al., 2023; Yadav et al., 2018; Basuki et al., 2022
Water-quality filtration	Vegetated strips and tree-based mosaics trap nutrients, pesticides, and sediments.	Improved stream and spring quality in agricultural catchments.	Creates justification for riparian agroforestry and community monitoring.	Chemical-intensive crops under tree cover can weaken benefits.	Dissanayaka et al., 2023; Mukundente et al., 2020; Supangat et al., 2023
Biodiversity habitat	Multistrata vegetation, shade trees, deadwood, and perennial cover increase niches.	Higher aboveground and belowground species richness and ecological connectivity.	Provides co-benefits for pollination, pest regulation, and cultural landscapes.	Monoculture plantations can simplify habitats and reduce functional diversity.	Kusumawati et al., 2022; Muthee et al., 2022; Shin et al., 2020
Biomass and bioenergy supply	Pruned branches, coppice, residues, and energy trees generate renewable biomass.	Lower pressure on natural forests and diversified energy sources.	Improves household energy access and rural income where markets are fair.	Energy monocultures can compete with food, water, and biodiversity.	Hiloidhari et al., 2016; Sharma et al., 2016; Némethy & Szemethy, 2019
Climate and carbon regulation	Perennial woody biomass stores carbon and supports soil organic matter formation.	Mitigation benefits and improved resilience to rainfall variability.	Can align social forestry with climate and restoration programs.	Carbon-focused schemes may overlook local needs and equity.	Mbow, 2020; Octavia et al., 2022; Singh et al., 2021

Cultural and institutional anchoring	Local norms govern tree protection, land use, harvesting, and conservation rituals.	Longer continuity of conservation behaviour across generations.	Improves legitimacy of watershed planning and reduces enforcement costs.	Local wisdom may erode under centralization, pollution, and market pressure.	Basuki et al., 2022; Ginting & Bengkel, 2022; Suroso et al., 2022

Bioenergy in watershed landscapes

Bioenergy is one of the most promising yet contested components of the watershed nexus. The attached literature identifies several bioenergy pathways related to agroforestry: fuelwood from farm trees, biomass from coppicing, energy tree plantations on degraded land, residues from coconut and other perennial systems, dendro power, solid biomass, biogas, and liquid biofuels (Dissanayaka et al., 2023; Hiloidhari et al., 2016). These pathways are attractive because many rural regions remain dependent on woodfuel and charcoal, while degraded lands may offer opportunities for restoration-oriented biomass production (Mbow, 2020; Yadav et al., 2018). When designed well, agroforestry bioenergy can support climate mitigation, energy access, soil improvement, and rural poverty reduction (Baumber et al., 2019; Sharma et al., 2016).

The bioenergy opportunity is strongest when biomass is produced as a co-product of multifunctional landscapes rather than as a replacement for them. Pruned branches, coppiced hedgerows, farm woodlots, Gliricidia stems, coconut-based residues, and mixed energy plantations can generate energy without converting entire watersheds into monoculture biomass fields (Dissanayaka et al., 2023; Octavia et al., 2022). In this model, bioenergy is embedded in agroforestry and watershed restoration: trees stabilize slopes, supply organic matter, create habitat, provide fodder or non-timber products, and periodically generate fuel. This is more compatible with a top-tier sustainability agenda than narrow bioenergy expansion measured only in tonnes of biomass or megajoules produced (Némethy & Szemethy, 2019; Van Noordwijk et al., 2016).

However, the literature also makes clear that bioenergy can become a threat when land-use governance is weak. Bioenergy crops may compete with food crops, displace biodiversity, reduce habitat complexity, increase irrigation demand, or encourage land concentration if markets reward biomass volume more than ecological function (Mbow, 2020; Némethy & Szemethy, 2019). The problem is not bioenergy per se, but the absence of landscape criteria that specify where, how, and for whom biomass should be produced. Market-based instruments for land degradation neutrality may create synergies with carbon, biodiversity, watershed protection, and bioenergy, but only if they are carefully designed to avoid perverse incentives and inequitable outcomes (Baumber et al., 2019).

From a watershed-management perspective, the most defensible bioenergy strategy is therefore a hierarchy of preference. First, use residues and pruning from existing agroforestry systems. Second, introduce coppiced tree belts, boundary plantings, and riparian or contour systems that simultaneously reduce erosion. Third, rehabilitate degraded lands with mixed species that provide biomass and restoration functions, consistent with ecosystem-restoration approaches that integrate diversified afforestation, agroforestry, and dedicated bioenergy cropping where ecologically appropriate (Singh et al., 2021). Fourth, avoid conversion of high-biodiversity habitats, productive food lands, and culturally important areas into simplified energy plantations (Mbow, 2020; Némethy & Szemethy, 2019). This hierarchy turns bioenergy from a land competitor into a landscape co-benefit. It also aligns with the corpus's emphasis on social forestry, sustainable forest management, and community welfare (Nugroho et al., 2023; Octavia et al., 2022).

Future review and empirical work should assess bioenergy systems with indicators that reflect watershed realities. These include infiltration, sediment control, biodiversity quality, labour burden, gendered energy access, household income, tenure security, and downstream impacts, not only yield or carbon. Ecological sustainability also depends on cultivation methods such as rotation length, fertilization, irrigation, pest management, and harvesting intensity (Némethy & Szemethy, 2019). A bioenergy system that increases biomass while degrading water regulation or local food security cannot be considered sustainable watershed management.

Biodiversity across upland, farm, and coastal interfaces

Biodiversity is a defining feature of the new watershed agenda because it mediates resilience. Species-rich agroforestry systems support pollination, pest regulation, soil formation, nutrient cycling, habitat connectivity, cultural values, and livelihood diversification. The corpus shows that multistrata tropical agroforestry systems, coffee-based agroforestry, on-farm trees, coconut agroforestry, and diversified tree-based land-use systems can serve as important biodiversity reservoirs in agricultural landscapes (Dissanayaka et al., 2023; Kusumawati et al., 2022; Wato & Amare, 2020). This is especially relevant in watersheds where protected areas alone cannot maintain ecological function because agricultural mosaics dominate the landscape.

Coffee-based agroforestry is particularly instructive. Shade-grown systems create vertical complexity through shade trees, understory crops, litter layers, and associated plant species. The East Java evidence in the corpus reports high plant richness in coffee-based agroforestry, demonstrating that production systems can host agrobiodiversity when they are managed as multistrata landscapes rather than simplified plantations (Kusumawati et al., 2022). At broader regional scale, the Asia-Pacific mapping literature indicates that agroforestry research has increasingly focused on ecosystem services, reflecting growing recognition that tree-based agricultural systems contribute to biodiversity, carbon, water, and livelihoods simultaneously (Shin et al., 2020).

The biodiversity value of agroforestry is not automatic. It depends on species diversity, native-tree retention, structural complexity, patch connectivity, management intensity, pesticide use, harvesting frequency, and the surrounding landscape matrix. Short-rotation forestry and coppicing can support wildlife and phytoremediation under some conditions, but may reduce habitat quality if implemented as even-aged, single-species stands over large areas (Némethy & Szemethy, 2019). Likewise, energy plantations may restore damaged ecosystems when established on degraded land, but can threaten biodiversity if they replace natural forest, mangroves, or complex agroforests (Hiloidhari et al., 2016; Mbow, 2020).

A watershed perspective also extends biodiversity concerns downstream. Mangrove ecosystems at the coastal end of watersheds provide nurseries, coastal protection, carbon storage, and livelihood resources, yet they are vulnerable to upstream sedimentation, pollution, pond conversion, and coastal development. The downstream Lariang watershed case shows serious mangrove degradation, with large areas in rare or damaged condition, while Youtefa Bay and Valentine Strait studies show how local communities and customary systems remain crucial to mangrove conservation (Aipassa et al., 2023; Naharuddin, 2021). These examples demonstrate that upland management and coastal biodiversity are connected by water, sediment, institutions, and livelihoods.

For top-tier review contribution, biodiversity should be treated not as a passive outcome of tree planting but as an evaluative criterion for watershed design. This means distinguishing between tree cover and biodiversity quality. A watershed can increase tree cover while losing native species, cultural species, habitat heterogeneity, or mangrove function. Conversely, well-designed agroforestry can enhance biodiversity while also improving hydrology and household welfare (Octavia et al., 2022; Shin et al., 2020). The scientific agenda should therefore shift from the question 'Does agroforestry increase biodiversity?' to 'Which agroforestry configurations produce which biodiversity functions, for which organisms, under which watershed and governance conditions?'

Local wisdom, participation, and governance

The attached literature gives unusually strong attention to local wisdom, particularly in Indonesian watershed and coastal settings. Local wisdom refers to values, norms, rules, ecological knowledge, and customary practices that guide community interaction with land, water, forest, and coastal resources. In watershed management, it can improve the cultural acceptability of conservation plans, strengthen compliance, mobilize collective action, and provide sanctions or moral obligations where formal enforcement is weak (Basuki et al., 2022; Narendra et al., 2021). This is highly relevant because many technically sound watershed plans fail when communities perceive them as external, top-down, or inconsistent with livelihood realities.

Several cases illustrate how local wisdom functions as an environmental institution. In the Garang River context, conservation education incorporated the Iriban tradition and community groups to build environmental awareness and participation (Suroso et al., 2022). In the Kuranji watershed, Minangkabau communal land norms helped slow land-cover change by restricting sale of inherited communal land except under significant conditions (Putra, 2021). In Langkat Regency, indigenous classification of forests into forbidden, stored, and processed categories reflected a locally embedded allocation of ecological and livelihood functions (Ginting & Bengkel, 2022). These examples show that local wisdom is not merely symbolic culture; it can be a rule system for land-use governance.

Coastal cases deepen this point. In the Valentine Strait of West Seram, the Buano community applied the Sasi tradition as ecological knowledge for mangrove conservation, supported by seeds and conservation training from the watershed management institution (Aipassa et al., 2023). In Youtefa Bay, the Tonotwiyat or Women's Forest tradition assigned women responsibility for mangrove forests as food sources and conservation spaces, although development and pollution have weakened the tradition (Tebay, 2023; Wambrauw & Ilham, 2023). In coastal and marine governance more broadly, local policies are expected to reflect local values, customary sanctions, and community needs rather than imposing partial and top-down development models (Jannah et al., 2024; Tjiptabudy et al., 2016).

The literature is also clear that local wisdom is under pressure. Consumerism, short-term pragmatism, sociocultural assimilation, legal centralism, state-dominated forest policy, climate change, pollution, and economic development can erode customary norms and weaken the ecosystems on which those norms depend (Basuki et al., 2022; Jannah et al., 2024). Some local practices may also prioritize short-term economic cultivation near rivers, creating tension with ecological goals (Kastono et al., 2024). A mature review must therefore avoid treating local wisdom as automatically sustainable. Its value depends on whether local norms remain legitimate, inclusive, adaptive, ecologically sound, and connected to broader policy support.

The strongest synthesis is that local wisdom and science are complementary. Local wisdom supplies legitimacy, place-based knowledge, historical continuity, and moral authority, while scientific approaches provide monitoring, hydrological modelling, restoration techniques, and cross-scale comparison. The corpus explicitly supports integrating indigenous and modern knowledge through balanced priorities, education, institutional collaboration, and policy recognition (Basuki et al., 2022; Isyanto et al., 2023). Table 3 summarizes the governance mechanisms through which local wisdom contributes to watershed and coastal conservation.

Table 3. Local-wisdom mechanisms for watershed and coastal governance.

Local-wisdom mechanism	Illustrative context	Conservation function	Institutional strength	Current vulnerability	Ref.
Sasi tradition	Buano community, Valentine Strait, West Seram	Regulates access and supports mangrove protection through customary ecological knowledge.	Combines cultural legitimacy with external seed and training support.	Requires continued intergenerational transmission and institutional recognition.	Aipassa et al., 2023
Tonotwiyat / Women's Forest	Youtefa Bay, Papua	Assigns women responsibility for mangrove food sources and forest care.	Links gendered livelihoods, food security, and conservation identity.	Weakened by pollution, development, and erosion of customary practice.	Tebay, 2023; Wambrauw & Ilham, 2023
Iriban and conservation education	Garang River community	Mobilizes community groups and tourism awareness groups for river conservation.	Transforms cultural practice into environmental education and participation.	Needs sustained institutional support and youth engagement.	Suroso et al., 2022; Isyanto et al., 2023
Communal land norms	Minangkabau culture, Kuranji watershed	Restricts conversion and sale of inherited communal land, slowing land-cover change.	Embeds watershed protection in inheritance and social obligation.	May weaken under market pressure and urban expansion.	Putra, 2021
Customary forest allocation	Indigenous communities in Langkat Regency	Separates forbidden, stored, and processed forests according to ecological and generational functions.	Creates local zoning aligned with watershed protection.	Can be marginalized by state-dominated forest policy.	Ginting & Bengkel, 2022
Customary marine law	Coastal and small-island communities	Uses customary sanctions and local rules to regulate resource use and prevent damage.	Offers place-specific governance where formal enforcement is limited.	Legal centralism can marginalize customary norms and social capital.	Tjiptabudy et al., 2016; Yuhandra et al., 2023
Agromaritime cultural knowledge	Indonesian villages facing climate change	Supports adaptation by linking coastal livelihoods, sacred sites, and environmental memory.	Connects conservation with identity, livelihoods, and climate resilience.	Climate impacts and environmental degradation threaten cultural continuity.	Jannah et al., 2024

MATERIALS & METHODS

This review is based exclusively on the attached literature extract and its reference list. No external references were added. The source set spans review articles, conceptual papers, watershed assessments, agroforestry syntheses, coastal and mangrove conservation studies, governance analyses, and recent Indonesian case studies. Its empirical centre of gravity is Indonesia and the Asia-Pacific, with broader comparative insights from Sub-Saharan Africa, India, Sri Lanka, and global discussions of land degradation neutrality, bioenergy, and ecosystem restoration (Baumber et al., 2019; Dissanayaka et al., 2023). The field is best characterized as integrated watershed sustainability at the interface of agroforestry, ecosystem services, local knowledge, and natural-resource governance.

The review uses an integrative rather than a purely bibliometric or meta-analytic design because the attached corpus combines different evidence types. Some studies synthesize broad knowledge on agroforestry and ecosystem services (Van Noordwijk et al., 2016; Octavia et al., 2022), others assess watershed condition or land-cover change in specific Indonesian watersheds (Barchia et al., 2020; Naharuddin, 2021), while others focus on community participation, local wisdom, coastal governance, or policy integration (Aipassa et al., 2023; Basuki et al., 2022). Consequently, the synthesis emphasizes mechanisms, governance pathways, and research gaps rather than effect-size aggregation.

The organizing logic is a nested landscape model. At the plot scale, tree-crop-livestock combinations affect soil structure, infiltration, shade, biomass, habitat, and household production. At the farm and village scale, agroforestry affects livelihood portfolios, fuelwood demand, market access, and conservation behaviour (Mukundente et al., 2020; Pande, 2021). At the watershed scale, vegetation mosaics influence runoff generation, sediment transport, ecological connectivity, and water quality (Barchia et al., 2020; Supangat et al., 2023). At the coastal scale, upstream land use interacts with mangrove condition, agromaritime livelihoods, and customary coastal management (Aipassa et al., 2023; Jannah et al., 2024). This multi-scalar perspective allows the review to treat watershed sustainability as a socio-ecological process rather than a technical end state.

Four questions guide the synthesis. First, how does agroforestry function as watershed infrastructure? Second, how can agroforestry-based bioenergy support rural development without undermining biodiversity and water security? Third, how do local wisdom and community institutions improve conservation outcomes in upland and coastal zones? Fourth, what research and policy agenda follows from integrating these themes into a single nexus framework? The following summary table positions the attached literature as the evidentiary base for answering these questions.

The review procedure consisted of four sequential stages. First, all references contained in the extraction document were screened for thematic relevance to watershed management, agroforestry, bioenergy, biodiversity, local wisdom, coastal conservation, climate adaptation, and governance. Second, information was extracted into thematic matrices covering research focus, landscape context, mechanism, contribution, limitation, and implications. Third, the evidence was grouped into ecological, production, biodiversity, institutional, and policy domains. Fourth, a cross-domain synthesis was developed to identify convergences, contradictions, research gaps, and design propositions. Because the manuscript is a review article, the "results" section presents the results of literature synthesis rather than primary field measurements.

Citation integrity was maintained by citing only works present in the provided extraction. No additional web-based or external references were introduced. APA style was used consistently for in-text citations and the reference list, and the results were organized through narrative synthesis supported by extensive summary tables.

RESULT

Results of thematic synthesis

The core synthesis emerging from the literature is that sustainable watershed management should be reframed as a land-water-energy-biodiversity nexus governed through socio-cultural institutions. In this framework, land is not simply the surface on which watershed interventions are installed; it is the medium through which vegetation, livelihoods, tenure, cultural values, and markets shape hydrological outcomes. Water is not only a downstream resource; it is a connector that transmits upstream land-use decisions to downstream farms, settlements, mangroves, and coastal livelihoods. Energy is not merely an external development demand; it is embedded in household biomass use, forest pressure, rural enterprise, and the design of tree-based systems. Biodiversity is not an optional co-benefit; it is a functional foundation of resilience, ecological connectivity, pest regulation, soil recovery, and cultural landscapes (Baumber et al., 2019; Van Noordwijk et al., 2016).

Agroforestry becomes the operational bridge across this nexus. In the land-water relationship, agroforestry improves soil cover, root depth, infiltration, and erosion control (Barchia et al., 2020; Dissanayaka et al., 2023). In the land-energy relationship, it supplies biomass through pruning, coppicing, residues, and energy trees without necessarily displacing other land functions (Hiloidhari et al., 2016; Sharma et al., 2016). In the land-biodiversity relationship, it creates multistrata habitats and supports species richness in agricultural mosaics (Kusumawati et al., 2022; Muthee et al., 2022). In the water-biodiversity relationship, it reduces sedimentation and protects downstream aquatic and coastal ecosystems, including mangroves (Aipassa et al., 2023; Naharuddin, 2021). The nexus therefore converts agroforestry from an agricultural practice into a landscape strategy.

Local wisdom supplies the governance bridge. Without local legitimacy, watershed interventions may be perceived as restrictions rather than shared investments. Without scientific monitoring, local practices may be celebrated without evidence of hydrological or biodiversity effectiveness. The most robust pathway is co-production: local institutions identify culturally legitimate rules and priorities, while scientific and policy institutions provide data, restoration methods, finance, legal recognition, and conflict-resolution mechanisms (Basuki et al., 2022; Isyanto et al., 2023). The Sasi, Tonotwiyat, Iriban, Minangkabau, and Langkat examples indicate that local rules can be aligned with watershed and coastal objectives when they are not marginalized by centralized governance or destructive development (Aipassa et al., 2023; Ginting & Bengkel, 2022).

The synthesis also suggests that watershed management should be evaluated through bundles of outcomes rather than single indicators. A project that reduces erosion but excludes communities is institutionally fragile. A bioenergy plantation that increases renewable energy but simplifies habitat is ecologically incomplete. A mangrove restoration program that plants seedlings but ignores upstream sediment and pollution flows is spatially partial. A local wisdom program that celebrates tradition without addressing climate change, youth participation, or formal legal support is vulnerable to erosion (Jannah et al., 2024; Mbow, 2020). The integrated framework therefore calls for simultaneous assessment of hydrological regulation, biodiversity quality, livelihood resilience, energy access, institutional legitimacy, and cross-scale connectivity.

This synthesis leads to a practical proposition: the basic planning unit should be the multifunctional watershed mosaic. Rather than zoning watersheds into separate production, protection, energy, and cultural areas with weak interaction, planners should design mosaics in which land uses are arranged according to slope, soil, water-flow paths, biodiversity corridors, community institutions, and livelihood needs. Agroforestry can occupy erosion-prone farms, riparian buffers, social-forestry areas, degraded lands, and boundaries; mangroves can be restored and protected at downstream interfaces; local wisdom can define rules and sanctions; and bioenergy can be harvested from residues, coppice, and restoration plantings where it reinforces rather than undermines ecosystem services (Nugroho et al., 2023; Octavia et al., 2022).

Operationalizing this mosaic requires a planning sequence that begins with diagnosis rather than planting targets. The first step is to identify critical source areas for runoff, erosion, sediment delivery, biodiversity loss, fuelwood pressure, and coastal degradation. The second step is to match interventions to landscape position: contour agroforestry on slopes, riparian tree strips along streams, mixed biomass systems on degraded lands, shade agroforestry in existing production areas, and mangrove protection at downstream interfaces. The third step is to map social institutions, including customary rules, women's resource spaces, farmer groups, local-government authority, and potential conflict over land or biomass. Only after these ecological and institutional layers are understood should agencies select species, incentives, monitoring indicators, and benefit-sharing arrangements. This sequencing reduces the risk that tree planting becomes a symbolic output rather than a system-level transition.

The framework also implies that review articles should evaluate watersheds through portfolios of evidence. Hydrological studies should be read together with agroforestry adoption studies, bioenergy assessments, biodiversity surveys, coastal-conservation cases, and local-wisdom analyses. Such cross-reading is necessary because the same intervention can be beneficial in one dimension and problematic in another. A coppiced belt may reduce erosion and supply fuel, but its value depends on species choice, harvest interval, market access, labour, and habitat function. A mangrove conservation rule may protect coastal resources, but its durability depends on upstream pollution control and cultural continuity. The article therefore advances a cumulative research logic in which watershed sustainability is inferred from convergence across biophysical performance, livelihood feasibility, and institutional legitimacy (Basuki et al., 2022; Shin et al., 2020).

Summary of trade-offs and design propositions

Nexus-based watershed management requires explicit recognition that interventions designed to improve one sustainability outcome may generate unintended consequences for others. For example, agroforestry can enhance infiltration, erosion control, carbon storage, and biodiversity, but its contribution to bioenergy production may create land-use competition when biomass demand is prioritized over habitat quality or food security. Similarly, community-based conservation and local wisdom can strengthen governance legitimacy, yet these practices may weaken when they are not supported by formal policy, scientific monitoring, and equitable benefit-sharing mechanisms. Therefore, the integration of water, energy, biodiversity, livelihood, and cultural dimensions must be guided by design principles that anticipate trade-offs, identify synergies, and generate testable propositions for future research. Table 4 synthesizes these relationships by linking key management tensions with practical design principles and researchable propositions for advancing watershed sustainability.

Table 4. Trade-offs, design principles, and researchable propositions for nexus-based watershed management.

Trade-off	Why it matters	Design principle	Researchable proposition	Priority indicator	Ref.
Bioenergy vs. biodiversity	Energy plantations may simplify habitats if	Prioritize residues, coppice, mixed species, and	Mixed agroforestry bioenergy systems produce	Species richness, habitat complexity,	Mbow, 2020; Némethy & Szemethy,

	biomass volume dominates planning.	degraded-land rehabilitation.	higher ecosystem-service bundles than monoculture energy crops.	biomass yield, water use.	2019; Sharma et al., 2016
Food production vs. tree cover	Smallholders may resist trees if they reduce short-term crop area or labour efficiency.	Use multifunctional trees, boundary planting, shade systems, and incentive-compatible designs.	Adoption increases when trees provide near-term products and visible soil-water benefits.	Farm income, crop yield stability, tree survival, adoption rate.	Mukundente et al., 2020; Pande, 2021; Wato & Amare, 2020
Upstream conservation vs. downstream benefits	Upstream communities may bear costs while downstream actors receive flood and water-quality benefits.	Develop benefit-sharing, payment, or co-management arrangements.	Watershed programs endure longer when upstream actors receive livelihood or institutional benefits.	Runoff, sediment load, participation, perceived fairness.	Barchia et al., 2020; Supangat et al., 2023; Yadav et al., 2018
Formal law vs. customary institutions	Centralized regulation may marginalize local wisdom and reduce compliance.	Recognize customary rules within formal watershed and coastal governance frameworks.	Hybrid governance improves legitimacy and conservation continuity more than top-down rules alone.	Legal recognition, rule compliance, conflict frequency.	Ginting & Bengkel, 2022; Tjiptabudy et al., 2016; Yuhandra et al., 2023
Mangrove restoration vs. upstream degradation	Downstream planting may fail if upstream sediment, pollution, and land conversion remain unaddressed.	Connect mangrove conservation with catchment land-use planning and pollution control.	Integrated upstream-downstream planning improves mangrove condition more than isolated restoration.	Mangrove density, pollution, sedimentation, community participation.	Aipassa et al., 2023; Naharuddin, 2021; Wambrauw & Ilham, 2023
Cultural continuity vs. modernization	Local wisdom can erode under consumerism, climate stress, and development pressure.	Embed conservation education, youth participation, and livelihood relevance into customary systems.	Local wisdom persists when it is linked to education, income, identity, and institutional support.	Youth participation, ritual continuity, conservation behaviour.	Basuki et al., 2022; Isyanto et al., 2023; Jannah et al., 2024
Restoration targets vs. social equity	Projects can increase tree cover while excluding marginalized groups or ignoring gendered resource use.	Use participatory planning and gender-sensitive governance.	Equitable participation improves restoration durability and livelihood outcomes.	Gender participation, benefit distribution, restoration survival.	Tebay, 2023; Muthee et al., 2022; Singh et al., 2021

DISCUSSION

Interpretation of key findings

The promise of integrated watershed management lies in synergy, but the credibility of a top-tier review depends on confronting trade-offs. The corpus identifies at least five recurring tensions. The first is land competition. Food crops, tree cover, bioenergy plantations, conservation zones, settlements, and infrastructure all require space, and decisions about land allocation are rarely neutral (Baumber et al., 2019; Mbow, 2020). Agroforestry can reduce land competition by layering functions, but it cannot eliminate all trade-offs, particularly where landholdings are small or tenure is insecure (Mukundente et al., 2020).

The second tension is between biomass production and biodiversity quality. Bioenergy systems can support restoration on degraded lands, but short-rotation monocultures or high-input energy crops may reduce habitat complexity, water availability, and ecological resilience (Hiloidhari et al., 2016). This creates a governance dilemma: renewable energy is desirable, but not all renewable-energy landscapes are sustainable. The corpus's strongest implication is that bioenergy should be designed within biodiversity and watershed constraints, rather than biodiversity being treated as a constraint to energy expansion (Mbow, 2020).

The third tension involves centralization and local autonomy. Integrated watershed management often requires coordination across administrative boundaries, but centralized policy can marginalize customary law, local knowledge, and community-based management (Ginting & Bengkel, 2022). Conversely, purely local approaches may lack technical capacity, finance, or legal force to manage upstream-downstream processes. The solution is not to choose between state and community governance, but to build nested institutions that recognize local wisdom while enabling cross-scale coordination (Basuki et al., 2022).

The fourth tension is between cultural continuity and socio-economic change. Local wisdom may be powerful, but it is not static. Climate change, pollution, market integration, migration, youth aspirations, and development projects can weaken customary practices and sacred sites (Jannah et al., 2024). Conservation strategies that rely on local wisdom must therefore invest in education, institutional renewal, gender-sensitive participation, and livelihood relevance (Aipassa et al., 2023).

The fifth tension concerns metrics. Watershed projects are often evaluated through visible outputs such as seedlings planted, hectares rehabilitated, terraces constructed, or biomass produced. These metrics are insufficient. A nexus approach requires indicators of water quality, infiltration, sediment reduction, species composition, household energy security, customary-rule compliance, participation quality, and downstream ecosystem condition (Barchia et al., 2020). Table 4 synthesizes key trade-offs and proposes design principles.

Implications for research design

The integrated corpus points to a research agenda that is both empirical and conceptual. Empirically, future studies should move beyond describing agroforestry benefits and toward testing configurations. Which tree species, planting densities, canopy structures, root traits, and understory practices best reduce runoff under specific soils and slopes? Which agroforestry designs maintain food production while supplying biomass? Which local institutions increase compliance and which are vulnerable to elite capture or cultural erosion? Which mangrove outcomes are most sensitive to upstream land-use change? These questions require comparative designs, long-term monitoring, and mixed methods that combine hydrology, biodiversity assessment, livelihood analysis, and institutional research (Barchia et al., 2020).

A first priority is to quantify ecosystem-service bundles. The literature strongly claims that agroforestry supports water, carbon, biodiversity, bioenergy, and livelihoods, but top-tier evidence should measure these services together and evaluate trade-offs statistically or through structured comparative synthesis (Van Noordwijk et al., 2016). Such work should avoid single-indicator bias. For example, a system that maximizes biomass may not maximize infiltration or biodiversity; a system that maximizes shade may reduce some crop yields; and a system that maximizes carbon may not provide culturally valued species (Mbow, 2020).

A second priority is to integrate local wisdom into research design rather than treating it only as a discussion theme. Studies should document customary rules, decision processes, sanctions, gender roles, intergenerational transmission, and relationships with formal law. They should then test how these variables affect conservation outcomes such as tree survival, mangrove protection, reduced land conversion, or sustained participation (Aipassa et al., 2023). This would transform local wisdom from anecdotal context into an analyzable governance variable.

A third priority is upstream-downstream integration. Many watershed interventions remain spatially fragmented. Upland agroforestry, midstream river conservation, and coastal mangrove restoration are often studied separately despite being connected through water, sediment, nutrients, markets, and institutions (Jannah et al., 2024). Future research should examine whether upstream agroforestry reduces downstream sedimentation, whether coastal communities perceive benefits from catchment rehabilitation, and whether benefit-sharing can link upland farmers with downstream water users and coastal communities (Basuki et al., 2022).

A fourth priority is adoption under real livelihood constraints. Smallholder agroforestry adoption is shaped by land tenure, labour, capital, market access, knowledge, policy support, and risk perception (Mukundente et al., 2020). Reviews that focus only on ecological potential may overstate feasibility. Publication-quality research should therefore connect ecological suitability with adoption pathways, including incentives, extension, community institutions, and market mechanisms. In Indonesia, this is particularly relevant for social forestry implementation, degraded-land restoration, and efforts to harmonize conservation with community welfare (Nugroho et al., 2023).

Implications for policy and practice

Policy should treat agroforestry as a core watershed-management instrument, not a peripheral agricultural practice. This means integrating tree-based farming into watershed plans, climate adaptation strategies, social forestry programs, disaster-risk reduction, biodiversity conservation, and rural energy planning. The corpus supports this integration by showing that agroforestry contributes to hydrological regulation, biodiversity, carbon, bioenergy, and livelihood outcomes (Dissanayaka et al., 2023). The practical implication is that watershed agencies should coordinate with forestry, agriculture, energy, local-government, and coastal-management institutions rather than implementing isolated sectoral programs.

Second, policy should establish safeguards for bioenergy. Renewable energy targets should not create pressure to convert biodiverse or culturally important landscapes into simplified biomass systems. Bioenergy development should be subject to land-suitability screening, biodiversity safeguards, water-use assessment, tenure review, and local consent. Degraded lands, residues, mixed tree systems, and coppiced agroforestry should be prioritized over large-scale monoculture expansion (Baumber et al., 2019). This would align bioenergy with land degradation neutrality, restoration, and watershed protection.

Third, local wisdom should be recognized through hybrid governance. Formal policy can support local wisdom by recognizing customary territories and rules, incorporating customary sanctions into local regulations where appropriate, funding conservation education, and creating platforms for community participation in coastal and watershed resource management (Yuhandra et al., 2023). The literature shows that conservation becomes more durable when community knowledge, cultural identity, and institutional support are connected (Aipassa et al., 2023). However, policy should also ensure inclusion, gender sensitivity, and ecological accountability. Traditions such as Tonotwiyat illustrate the need to recognize women's roles in conservation and resource governance (Tebay, 2023).

Fourth, watershed practice should adopt monitoring systems that make multifunctionality visible. Agencies should not report only the number of seedlings or hectares planted. Monitoring should include hydrological indicators, biodiversity indicators, biomass and energy indicators, livelihood indicators, and governance indicators. For example, a watershed-agroforestry program could track runoff reduction, sediment load, tree survival, species richness, household fuelwood sources, income diversification, customary-rule compliance, and downstream mangrove condition (Barchia et al., 2020). Such integrated monitoring would reveal whether interventions are producing genuine nexus benefits or merely shifting problems across sectors.

Finally, education and extension should connect scientific and cultural knowledge. Conservation education based on local wisdom can develop environmental awareness and positive character while making restoration relevant to community identity (Isyanto et al., 2023). Extension systems should therefore be participatory and place-based, using local examples, farmer experimentation, customary leaders, women's groups, and youth programs. This approach is more likely to sustain practices over time than externally designed campaigns that ignore local histories and resource-use norms (Basuki et al., 2022).

Conceptual contribution and limitations

This review makes four conceptual contributions from the attached literature. First, it reframes agroforestry as distributed watershed infrastructure. This framing extends agroforestry beyond farm-level diversification and positions it as a spatially distributed system of biological structures that regulate runoff, sediment, habitat, biomass, and resilience (Barchia et al., 2020). It helps explain why tree-based systems are repeatedly recommended for watershed development, social forestry, and climate adaptation (Basuki et al., 2022).

Second, it advances a bioenergy-within-watersheds perspective. Rather than treating bioenergy as an independent energy sector, the review embeds biomass production in land-use mosaics, ecological constraints, and livelihood systems. This perspective distinguishes residue-based, coppice-based, and restoration-based bioenergy from land-competitive biomass expansion (Baumber et al., 2019). The distinction is crucial for sustainability evaluation because the same bioenergy target can produce very different watershed and biodiversity outcomes depending on design and governance (Némethy & Szemethy, 2019).

Third, it places local wisdom at the centre of watershed governance rather than at the margins of cultural context. The corpus demonstrates that local wisdom can define land rules, forest categories, mangrove stewardship, conservation education, and customary sanctions (Aipassa et al., 2023). By treating these practices as governance mechanisms, the review contributes to a more institutionally realistic watershed science. It also recognizes that local wisdom requires renewal, legal recognition, and integration with scientific knowledge to remain effective under climate and development pressure (Basuki et al., 2022).

Fourth, it connects upland agroforestry and coastal conservation through the watershed continuum. The literature on mangroves, agromaritime villages, and coastal local wisdom shows that downstream ecological health cannot be separated from catchment land use, pollution, sediment, and governance (Jannah et al., 2024). This contribution is important because coastal conservation is often addressed through site-level restoration, while the drivers of degradation may originate upstream. A watershed continuum approach promotes planning that links slopes, farms, rivers, mangroves, and coastal communities in one analytical frame.

Although the attached corpus is rich, it also has limitations that define future research needs. First, much of the evidence is conceptual, review-based, or case-specific. This is valuable for synthesis, but fewer studies provide comparable quantitative measurements of hydrology, biodiversity, biomass, livelihoods, and governance in the same sites. As a result, the literature strongly supports the plausibility of synergies but provides less standardized evidence on magnitude, threshold, and long-term performance (Van Noordwijk et al., 2016).

Second, geographic concentration creates both strength and constraint. The Indonesian cases provide deep insight into local wisdom, watershed governance, social forestry, mangrove conservation, and coastal vulnerability, while studies from Sri Lanka, India, Sub-Saharan Africa, and broader regions provide comparative agroforestry and bioenergy perspectives (Dissanayaka et al., 2023). However, cross-regional generalization should be cautious because agroecology, tenure, institutions, markets, and cultural systems differ considerably.

Third, the bioenergy literature in the corpus identifies opportunities and risks but leaves unresolved questions about life-cycle performance, local energy demand, gendered labour, and economic feasibility. Biomass can reduce forest pressure when it substitutes unsustainable wood extraction, but it can increase pressure when markets reward land conversion or intensive harvesting (Hiloidhari et al., 2016). Future studies should evaluate bioenergy not only as a renewable resource but as a socio-ecological pathway embedded in watersheds.

Fourth, local wisdom is documented as beneficial in several cases, but the literature needs more critical and comparative analysis of when it works, when it fails, and how it changes. Local wisdom can be undermined by modernization, climate change, pollution, centralization, and economic pressure, but it may also adapt through education, legal recognition, and collaborative governance (Basuki et al., 2022). This dynamic view is essential for avoiding both technocratic dismissal and uncritical romanticization.

CONCLUSION

The attached literature supports a clear conclusion: sustainable watershed management requires integrated, multifunctional, and culturally legitimate landscape strategies. Agroforestry provides the biophysical foundation by regulating runoff, reducing erosion, supporting biodiversity, storing carbon, producing biomass, and diversifying livelihoods (Dissanayaka et al., 2023). Local wisdom provides the institutional foundation by embedding conservation in community rules, values, sanctions, identity, and participation (Aipassa et al., 2023). Bioenergy provides a development opportunity when it is designed as a co-benefit of agroforestry and restoration, but it becomes a risk when pursued through simplified, land-competitive systems (Baumber et al., 2019). Biodiversity is the resilience substrate that links upland farms, forest mosaics, riparian systems, and downstream mangroves (Kusumawati et al., 2022).

The proposed land-water-energy-biodiversity nexus framework therefore offers a more complete basis for future reviews, empirical studies, and policy design. It encourages researchers to measure ecosystem-service bundles rather than isolated outcomes, planners to design multifunctional mosaics rather than sectoral interventions, and governments to recognize local wisdom while strengthening scientific monitoring and legal support. The most promising watershed futures will not come from choosing between conservation and production, tradition and science, or energy and biodiversity. They will come from carefully governed combinations that make these functions mutually reinforcing across scales.

Declaration by Authors
Acknowledgement: None
Source of Funding: None
Conflict of Interest: No conflicts of interest declared.

REFERENCES

1. Aipassa, M. I., Siahaya, M. E., Aponno, H. S. E. S., Ruslim, Y., & Kristiningrum, R. (2023). Participation of community in mangrove conservation in coastal area of the Valentine Strait, West Seram, Maluku, Indonesia. Biodiversitas Journal of Biological Diversity, 24(4). https://doi.org/10.13057/biodiv/d240462
2. Barchia, M. F., Sulistyo, B., Hindarto, K. S., & Suhartoyo, H. (2020). Assessment of Air Bengkulu (Indonesia) watershed based on agroecosystem landscape quality and sustainable land use plan. Biodiversitas Journal of Biological Diversity, 21(11). https://doi.org/10.13057/biodiv/d211150
3. Basuki, T. M., Nugroho, H. Y. S. H., Indrajaya, Y., Pramono, I. B., Nugroho, N. P., Supangat, A. B., Indrawati, D. R., Savitri, E., Wahyuningrum, N., Purwanto, P., Cahyono, S. A., Putra, P. B., Adi, R. N., Nugroho, A., Auliyani, D., Wuryanta, A., Riyanto, H. D., Harjadi, B., Yudilastyantoro, C., ... Simarmata, D. P. (2022). Improvement of integrated watershed management in Indonesia for mitigation and adaptation to climate change: A review. Sustainability, 14(16), 9997. https://doi.org/10.3390/su14169997
4. Baumber, A., Berry, E., & Metternicht, G. (2019). Synergies between Land Degradation Neutrality goals and existing market-based instruments. Environmental Science & Policy, 94, 174-181. https://doi.org/10.1016/j.envsci.2019.01.012
5. Dissanayaka, N. S., Dissanayake, D. K. R. P. L., Udumann, S. S., Nuwarapaksha, T. D., & Atapattu, A. J. (2023). Agroforestry-a key tool in the climate-smart agriculture context: A review on coconut cultivation in Sri Lanka. Frontiers in Agronomy, 5. https://doi.org/10.3389/fagro.2023.1162750
6. Ginting, S., & Bengkel, B. (2022). The role of local wisdom in supporting policies deforestation supervision in Langkat Regency, North Sumatra. DIA: Jurnal Ilmiah Administrasi Publik, 20(02), 243-262. https://doi.org/10.30996/dia.v20i02.6422
7. Hiloidhari, M., Medhi, H., Das, K., Thakur, I. S., & Baruah, D. C. (2016). Bioenergy and carbon sequestration potential from energy tree plantation in rural wasteland of North-Eastern India. Journal of Energy and Environmental Sustainability, 2, 13-18. https://doi.org/10.47469/jees.2016.v02.100013
8. Isyanto, A. Y., Fatimah, A. T., Thoyyibah, L., & Millah, A. S. (2023). Interdisciplinary perspectives on conservation and culture. Interdisciplinary International Journal of Conservation and Culture, 1(1), 15-30. https://doi.org/10.25157/iijcc.v1i1.3102
9. Jannah, R., Kolopaking, L. M., Adiwibowo, S., & Maarif, S. (2024). Climate change, villages and agromaritime: Current conditions and future challenges in Indonesia. IOP Conference Series: Earth and Environmental Science, 1359(1), 012055. https://doi.org/10.1088/1755-1315/1359/1/012055
10. Kastono, Muhibuddin, A., Salim, A., Syafri, Manaf, M., Surya, B., Barkey, R., & Nasution, M. A. (2024). Adaptation and mitigation model for flood disaster resilience in West Malangke District, North Luwu Regency, Indonesia. International Journal of Safety and Security Engineering, 14(5), 1627-1633. https://doi.org/10.18280/ijsse.140529
11. Kusumawati, I. A., Mardiani, M. O., Purnamasari, E. W., Batoro, J., Van Noordwijk, M. van, & Hairiah, K. (2022). Agrobiodiversity and plant use categories in coffee-based agroforestry in East Java, Indonesia. Biodiversitas Journal of Biological Diversity, 23(10). https://doi.org/10.13057/biodiv/d231012256
12. Mbow, C. (2020). Use it sustainably or lose it! The land stakes in SDGs for Sub-Saharan Africa. Land, 9(3), 63. https://doi.org/10.3390/land9030063

13. Mukundente, L., Ndunda, E., & Gathuru, G. (2020). Socio-economic and institutional factors affecting smallholders farmers to adopt agroforestry practices in southern province of Rwanda. International Journal of Agricultural Science and Food Technology, 6(1), 068-074. https://doi.org/10.17352/2455-815x.000057
14. Muthee, K., Duguma, L., Majale, C., Mucheru-Muna, M., Wainaina, P., & Minang, P. (2022). A quantitative appraisal of selected agroforestry studies in the Sub-Saharan Africa. Heliyon, 8(9), e10670. https://doi.org/10.1016/j.heliyon.2022.e10670
15. Naharuddin, N. (2021). The critical level of mangrove ecosystem in Lariang Watershed downstream, West Sulawesi-Indonesia. International Journal of Sustainable Development and Planning, 16(5), 841-851. https://doi.org/10.18280/ijsdp.160505
16. Narendra, B. H., Siregar, C. A., Dharmawan, I. W. S., Sukmana, A., Pratiwi, P., Pramono, I. B., Basuki, T. M., Nugroho, H. Y. S. H., Supangat, A. B., Purwanto, P., Setiawan, O., Nandini, R., Ulya, N. A., Arifanti, V. B., & Yuwati, T. W. (2021). A review on sustainability of watershed management in Indonesia. Sustainability, 13(19), 11125. https://doi.org/10.3390/su131911125
17. Van Noordwijk, M. van, Coe, R., & Sinclair, F. (2016). Central hypotheses for the third agroforestry paradigm within a common definition. https://doi.org/10.5716/wp16079.pdf
18. Nugroho, H. Y. S. H., Indrajaya, Y., Astana, S., Murniati, M., Suharti, S., Basuki, T. M., Yuwati, T. W., Putra, P. B., Narendra, B. H., Abdulah, L., Setyawati, T., Subarudi, S., Krisnawati, H., Saputra, M. H., Lisnawati, Y., Garsetiasih, R., Sawitri, R., Putri, I. A. S. L. P., Setiawan, O., ... Rahmila, Y. I. (2023). A chronicle of Indonesia's forest management: A long step towards environmental sustainability and community welfare. Land, 12(6), 1238. https://doi.org/10.3390/land12061238
19. Némethy, S., & Szemethy, L. (2019). The sustainability of woody biomass feedstock production and landscape management: Land use, phytoremediation, biodiversity, and wildlife habitats. Ecocycles, 5(1), 44-55. https://doi.org/10.19040/ecocycles.v5i1.141
20. Octavia, D., Suharti, S., Murniati, M., Dharmawan, I. W. S., Nugroho, H. Y. S. H., Supriyanto, B., Rohadi, D., Njurumana, G. N., Yeny, I., Hani, A., Mindawati, N., Suratman, S., Adalina, Y., Prameswari, D., Hadi, E. E. W., & Ekawati, S. (2022). Mainstreaming smart agroforestry for social forestry implementation to support Sustainable Development Goals in Indonesia: A review. Sustainability, 14(15), 9313. https://doi.org/10.3390/su14159313
21. Pande, V. C. (2021). Farm-forestry, smallholder farms and policy support - The way ahead. https://doi.org/10.5772/intechopen.96942
22. Putra, T. H. A. (2021). The dynamics of land cover change and causal factors in the Kuranji Watershed. International Journal of GEOMATE, 21(84). https://doi.org/10.21660/2021.84.gx126
23. Sharma, N., Bohra, B., Pragya, N., Ciannella, R., Dobie, P., & Lehmann, S. (2016). Bioenergy from agroforestry can lead to improved food security, climate change, soil quality, and rural development. Food and Energy Security, 5(3), 165-183. https://doi.org/10.1002/fes3.87
24. Shin, S., Soe, K. T., Lee, H., Kim, T. H., Lee, S., & Park, M. S. (2020). A systematic map of agroforestry research focusing on ecosystem services in the Asia-Pacific region. Forests, 11(4), 368. https://doi.org/10.3390/f11040368
25. Singh, K., Singh, R. P., & Tewari, S. K. (2021). Ecosystem restoration: Challenges and opportunities for India. Restoration Ecology, 29(3). https://doi.org/10.1111/rec.13341
26. Supangat, A. B., Basuki, T. M., Indrajaya, Y., Setiawan, O., Wahyuningrum, N., Purwanto, P., Putra, P. B., Savitri, E., Indrawati, D. R., Auliyani, D., Nandini, R., Pramono, I. B., Nugroho, A., Wuryanta, A., Adi, R. N., Harjadi, B., Cahyono, S. A., Lastiantoro, C. Y., Handayani, W., ... Anggraeni, I. (2023). Sustainable management for healthy and productive watersheds in Indonesia. Land, 12(11), 1963. https://doi.org/10.3390/land12111963
27. Suroso, S., Setyowati, D. L., Wisika, P. S. H. D., & Banowati, E. (2022). Conservation

education by the Garang River community group. https://doi.org/10.2991/assehr.k.211125.130

28. Tebay, V. (2023). Collaborative governance: Efforts to re-functionalize the Youtefa Bay Women's Forest Area based on local wisdom. Formosa Journal of Science and Technology, 2(7), 1693-1708. https://doi.org/10.55927/fjst.v2i7.4854
29. Tjiptabudy, J., Rugebregt, R. V., Alfons, S. S., Laturette, A. I., & Saiya, V. J. E. (2016). Natural resource management problems of coastal areas and small islands in the Aru Island. Pattimura Law Journal, 1(1), 38. https://doi.org/10.47268/palau.v1i1.7
30. Wambrauw, O. O. O., & Ilham, I. (2023). Conditions and management strategies for mangrove ecosystems as an effort to improve the economy of Youtefa Bay coastal communities, Jayapura City. Formosa Journal of Science and Technology, 2(4), 1049-1062. https://doi.org/10.55927/fjst.v2i4.3835
31. Wato, T., & Amare, M. (2020). Opportunities and challenges of scaling up agroforestry practices in Sub-Saharan Africa: A review. Agricultural Reviews, 41(03). https://doi.org/10.18805/ag.r-154
32. Yadav, R. P., Bisht, J. K., Meena, V. S., & Choudhary, M. (2018). Sustainable agroecosystems for livelihood security in Indian Himalayas. https://doi.org/10.5772/intechopen.74495
33. Yuhandra, E., Rifa'i, I. J., & Hidayat, S. (2023). Local government policies in the management of coastal and marine resources through community participation. Unifikasi: Jurnal Ilmu Hukum, 10(1), 28-37. https://doi.org/10.25134/unifikasi.v10i1.7539

How to cite this article: Abdul Samad Hiola, Asda Rauf, Fitryane Lihawa. Agroforestry-centred watershed sustainability at the land-water-energy-biodiversity nexus: integrating local wisdom, bioenergy, and coastal conservation. *International Journal of Research and Review*. 2026; 13(5): 730-749. DOI: *https://doi.org/10.52403/ijrr.20260573*

******