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Ecosystem Service Valuation in Kalu Oya and Mudun Ela Basins, Sri Lanka

Chaturangi Wickramaratne, Avinandan Taron, Mark Mulligan, Sophia Burke,
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Citation:

Wickramaratne, C.; Taron, A.; Mulligan, M.; Burke, S.; McCartney, M. 2026. *Ecosystem service valuation in Kalu Oya and Mudun Ela basins, Sri Lanka*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 69p.

doi: <https://doi.org/10.5337/2025.245>

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Cover photo: Abandoned paddy fields in Kalu Oya basin, Sri Lanka (*photo*: Chaturangi Wickramaratne/IWMI)

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Acknowledgments

The authors would like to thank the Sri Lanka Land Development Corporation (SLLDC) and Japan International Cooperation Agency - Ogata Research Institute (JICA-ORI) for providing information and related data. Dr. Priyanie Amerasinghe (Emeritus Scientist, International Water Management Institute [IWMI], Colombo, Sri Lanka), Radheeka Jirasinha (Researcher - Freshwater and Wetland Management, IWMI, Colombo, Sri Lanka), Sujeewa Dissanayaka (Research Analyst - Remote Sensing and GIS, IWMI, Colombo, Sri Lanka), Anjana Herath (Intern, IWMI, Colombo, Sri Lanka), and Upani Gunatileke (Intern, IWMI, Colombo, Sri Lanka) are gratefully acknowledged for their contributions and insights. We are also grateful for the assistance provided by the IWMI publications team with the editing and designing of this report.

Project

This study was conducted under the *Wetland Ecosystem Modelling and Valuation in Kalu Oya Basin, Sri Lanka* project.

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Funding received from the Reversing Environmental Degradation in Africa and Asia (REDAA) program (www.redaa.org) is gratefully acknowledged. The REDAA program is funded by UK International Development from the Foreign, Commonwealth and Development Office (FCDO) and managed by the International Institute for Environment and Development (IIED).



This work was also supported by the CGIAR Initiative on NEXUS Gains and finalized with support from the CGIAR Policy Innovations Program. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund (www.cgiar.org/funders).





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Executive Summary

The Kalu Oya and Mudun Ela basins located in southwestern Gampaha District in Sri Lanka, are peri-urban sub-catchments of the Kelani River Basin on the northern periphery of Colombo. The two basins cover 78 km² and encompass 5 Divisional Secretariat Divisions (DSDs): Wattala, Mahara, Kelaniya, Biyagama, and Ja-Ela, with a total population of 548,232. The wetlands, covering 10.50 km², provide crucial ecosystem services such as flood mitigation, urban agriculture, recreation, biodiversity, temperature regulation, and educational opportunities. They also contribute to water purification, water supply, recharge, and carbon storage.

Despite their value, the wetlands of Kalu Oya and Mudun Ela basins face significant and increasing pressures, primarily driven by urban sprawl and associated land use changes to accommodate Colombo's growing population. Although perceptions are changing, there is a widespread lack of understanding of the importance and ecosystem services provided by wetlands; many still view them primarily as wastelands, suitable for conversion. In recent decades, this has led to loss and degradation of wetland areas, with major threats coming from encroachment, indiscriminate solid waste disposal, pollution from industrial waste, domestic sewage, agricultural runoff, and invasive species. Despite efforts by government agencies like the Sri Lanka Land Development Corporation, Urban Development Authority, and Central Environmental Authority to manage and conserve these areas, the pressures continue to grow.

A wetland management strategy was developed in 2018 to guide conservation efforts. It emphasizes evaluating ecosystem services for better land-use planning in the basin and for integrating wetland management into broader planning processes. Against this background, this report presents a comprehensive economic valuation of ecosystem services in the two basins, employing two different approaches (a combination of market-price based and benefit transfer, and a biophysical ecosystem services approach using Co\$tingNature) to understand the total economic value (TEV) of the wetlands and the return on conservation investments. Market-price based approaches derive absolute economic values from real transactions, providing tangible financial metrics but limited to services with established markets and subject to existing market distortions. Benefit transfer approaches adapt economic values from existing studies to new contexts, improving cost effectiveness and adaptability under data-scarce environments, but potentially introducing transfer errors when contexts differ. Co\$tingNature employs spatially-explicit biophysical models that quantify relative ecosystem service provision through standardized indices, offering comprehensive coverage across multiple services and with the flexibility to use global and local economic data. The use of multiple approaches demonstrates how different valuation methodologies produce different results depending on their conceptual foundation and data utilized.

1. Localized economic valuation using market price-based and benefit transfer methods: This combined method was used to evaluate only wetland-specific ecosystem services, and therefore, considers only the wetland extent within the basins. The benefit transfer approach assists in valuing a diverse range of ecosystem services that would otherwise remain unquantified due to significant data limitations in the local context. This approach valued 13 wetland-specific ecosystem services, utilizing local data, and provides an estimated TEV of USD 25.1 million-27.6 million for 2025. The benefit transfer approach allows additional ecosystem services to be valued, in which key services with the highest economic value were carbon storage (i.e., stock), flood attenuation, and biodiversity (i.e., habitat and nursery functions). It should be noted that the value for carbon stock is static (i.e., it can only be realized once) and is not likely to be attained unless REDD+ (Reducing Emissions from Deforestation and forest Degradation, plus the sustainable management of forests, and the conservation and enhancement of forest carbon stocks or voluntary carbon markets finance the protection of all carbon in the wetland. Removing this carbon stock results in an annualized estimate of USD 12.98 million-14.45 million (USD 12,362-13,762/ha/year).

2. Total economic valuation using Co\$tingNature and local or global values: This model combines spatially-explicit biophysical and socio-economic data at 30 m resolution to determine the TEV of 11 ecosystem services across the entirety of the two basins. Using the same local values as for the market price-based approach, adjusting for inflation and discounting for net present values (NPV), the baseline scenario estimated a 25-year TEV at USD 1.67 billion (or USD 66.8 million/year). Wetlands contribute a small percentage to the TEV because they are a small part of the basin (~2.7% of TEV, so USD 1.8 million/year on average over 25 years; USD 2.33 million for 2025) but they have a high mean TEV per unit area (USD 6,807/ha/year on average over 25 years). Accounting for both direct and opportunity costs, analyses show that the return on investment on conservation spending is always positive across the basins and ranges from 23-341%, depending on which Sri Lanka Land Development Corporation (SLLDC) costs are included as nature investments. Consequently, it makes sense to prioritize conservation spending in these high unit value and actionable (not built up) areas.

The annualized wetland-specific estimate without the carbon stock (i.e., USD 12.98 million-14.45 million) using the market price-based and benefit transfer approaches is approximately five times lower than the basin-wide estimate (USD 66.8 million) of Co\$tingNature. In contrast, the annualized value for wetlands alone is approximately seven times greater than the estimate of Co\$tingNature (USD 1.8 million). This reflects the effect of 3% per year discounting over the 25-year time horizon used by Co\$tingNature and the inclusion of more non-use values as well as global valuations and/or higher-end willingness to pay (WTP) figures from a range of economies used in the benefit transfer approach.

This report highlights the critical role of the wetlands, particularly in flood mitigation and carbon storage but also for other ecosystem services as well as the value of other ecosystems. It calls for prioritizing conservation investments and balancing local needs with long-term sustainability.

Report Structure

This report is divided into two complementary sections. The first section presents a valuation approach that focused on 13 ecosystem services provided directly by the wetland ecosystems. This approach integrated locally acquired land use and land cover (LULC) maps with the best available data collected at the lowest administrative level. The valuation employed two complementary analytical frameworks: A market price-based approach that quantified the economic value of wetland outputs based on existing market transactions, and a benefit transfer approach that captured additional ecosystem services (e.g., biodiversity) without established market values.

The second section presents economic valuation estimates for 11 ecosystem services across the two basins, using economic valuation of the ecosystem services mapped by Co\$tingNature (Mulligan 2024). The valuation was repeated for globally derived values and the same local values as for the market price approach for each service. The analysis examined the distribution of value across different services and over time with the aim of understanding valuation uncertainties and the impacts of timeframes, gross domestic product (GDP), and valuation on the cost-benefit ratio of conservation investments. The services mapped and valued encompass both the wetlands and other ecosystems in the basin.

Using both locally derived estimates and Co\$tingNature provides a comprehensive and robust approach to valuing wetland ecosystem services. Co\$tingNature offers a consistent, spatially explicit framework based on globally available, high-resolution datasets, enabling replication across geographies and application to user-defined values. Co\$tingNature may not be able to reflect the local ecological conditions, land use practices, and socio-economic realities of the Kalu Oya Basin, but locally derived valuations are fundamentally limited by the local data available and the cost of data acquisition, meaning they are often driven by values defined elsewhere. The dual approach allows the assessment of uncertainty in valuation and can support decision-making at multiple scales and across geographies and timescales.

Introduction

The Kalu Oya and Mudun Ela basins are in southwestern Gampaha District, Western Province, Sri Lanka, and are sub-basins of the Kelani River Basin, the fourth longest river in the country (145 km). They lie within five Divisional Secretariat Divisions (DSDs): Wattala, Mahara, Kelaniya, Biyagama, and Ja-Ela, which are densely populated (>6,000 persons/km²) with a total population of around 548,232 and 144,271 housing units (Sakalasooriya 2021). The basins cover 78 km² (5.6% of Gampaha District which spans 1,387 km²) and are characterized by fragmented, sensitive wetland systems that provide essential ecosystem services. Wetlands within the basins consist of diverse typologies ranging from open water bodies, woodlands and herb dominated areas to abandoned and active paddy fields. The basins are 38.4% built-up and have 54.2% tree cover (largely in home gardens). Intensive croplands cover 1.47% and agroforestry (home gardens) cover 35% of the basins. Both basins are vulnerable to flooding due to recent land use changes, coupled with their low-lying and coastal location.

Gampaha District is one of Sri Lanka's most economically active areas. Its proximity to Colombo, the Bandaranaike International Airport, and the Colombo-Katunayake Expressway give it a strategic advantage. It houses industries relating to electronics, textiles and apparel, machinery, and plastics. Due to its proximity to Colombo, Gampaha also benefits from trade, logistics, and other service-oriented activities. While urbanization has impacted agricultural activities, areas within the district still engage in farming (paddy, horticulture, and coconut), contributing to the local economy. The GDP (PPP, Purchasing Power Parity) for the basins calculated by Wang and Sun (2022) is estimated to be USD 12.36 billion, which equals USD 3.21 billion (nominal) using the World Bank PPP coefficient for Sri Lanka.

Ecosystem Services and Stakeholder Priorities

Initial stakeholder consultations identified a number of high priority ecosystem services provided by the wetlands. Flood mitigation, urban agriculture, recreation (particularly the use of wetland-based walking paths), biodiversity, temperature regulation, and educational opportunities were recognized as priorities. These wetlands also deliver additional benefits, similar to those documented in the Colombo Wetland Complex, including water purification, water supply and recharge, and carbon storage that remain important for both ecological and socio-economic well-being. Stakeholders also identified ecosystem dis-services including the wetland habitat provision for mosquitoes, important in the transmission of vector-borne diseases. Due to the high impermeability of urban surfaces and inadequate stormwater drainage infrastructure, flood risk is particularly acute. This risk is heightened by the lack of natural drainage from the basin into the Kelani River, emphasizing the vital flood retention role of the wetlands.

Pressures and Management Responses

The wetlands within the Kalu Oya and Mudun Ela basins face significant and increasing pressures, primarily driven by urban sprawl and associated land use changes to accommodate Colombo's growing population. Although perceptions are changing, there is a widespread lack of understanding of the importance of the ecosystem services provided by wetlands which are still widely perceived as wastelands, suitable for conversion. Over recent decades, this has led to loss and degradation of wetland areas. Key pressures include urbanization and land reclamation, as expansion of built-up areas and infrastructure development encroach upon and convert wetland habitats. Pollution presents another serious threat, with discharge of industrial waste, domestic sewage, and agricultural runoff degrading water quality within the wetlands, harming biodiversity and reducing their ability to provide clean water and other services. Additionally, these wetlands have historically and are currently being used as unregulated dumping sites for solid waste, further exacerbating pollution. The spread of invasive exotic species compounds these issues, disrupting the ecological balance of these sensitive habitats and threatening native biodiversity.

Government agencies, including the Sri Lanka Land Development Corporation (SLLDC), Urban Development Authority (UDA), and Central Environmental Authority (CEA) have implemented multiple initiatives to manage and conserve the Kalu Oya and Mudun Ela basin wetlands. These coordinated efforts focus on improving drainage infrastructure, mitigating flood risks, and preserving critical wetland ecosystems throughout the watershed, yet there is growing demand for land in the basin. A wetland management strategy for both the basins, with an actionable implementation plan and a monitoring framework, was developed in 2018. The plan outlines the need for detailed evaluation of ecosystem services for effective land use planning in the basins. Ecosystem service valuation provides crucial insights to guide both land use planning and wetland management decisions. Integrating wetland management into land use planning enhances conservation by designating protected zones, regulating development, and promoting green infrastructure to maintain ecological functions like flood control and water purification. By quantifying the economic value of wetland ecosystem services, policymakers can better understand both the true costs and, importantly, the benefits of wetland conservation.

Project Overview and Objectives

The Wetland Ecosystem Modelling and Valuation Project was an 18-month initiative led by the International Water Management Institute (IWMI), SLLDC, King's College London, and [AmbioTEK Community Interest Company, UK](#). It was funded under the Foreign, Commonwealth and Development Office (FCDO) International Institute for Environment and Development (IIED) [Reversing Environmental Degradation in Africa and Asia \(REDAA\)](#) program. The project estimated the monetary value of wetland ecosystem services and applied the [Co\\$tingNature](#) ecosystem services model to assess their value under baseline, climate change, and land-use scenarios. The research was designed to inform land use planning, enhance stakeholder capacity, and support long-term wetland conservation strategies.

1. Localized Economic Valuation using Market Price-Based and Benefit Transfer Methods

The objective of this initial analytical component was to quantify the ecosystem service benefits derived exclusively from the wetlands within the Kalu Oya and Mudun Ela basins, using locally sourced data and established economic valuation frameworks. Two valuation methodologies were employed:

- A market price-based approach applying observed prices and local supply-demand data to estimate the economic value of directly utilized ecosystem goods and services; and
- A benefit transfer method using meta-analytic data from peer-reviewed global valuation studies to approximate values for non-market services not captured in local datasets.

Valuation inputs were grounded in spatially disaggregated socio-economic and land use data, collected at the *Grama Niladhari* (GN) division level, the lowest administrative unit. The methodological approach prioritized data efficiency and replicability, making it suitable for application in data-constrained settings.

1.1 Methods

1.1.1 Market price-based method

The economic value of wetlands can be grouped under direct and indirect uses (Somda and Awaïss 2013; Markandya 2019).

Total economic value=Direct use value+Indirect use values+Option values+Non-use values

Direct use values are the benefits derived from some physical use of the resource that may be derived from on-site extraction of resources (e.g., food production or material resources) or non-consumptive activities (e.g., nature-based tourism, aesthetic/cultural values). Indirect use values are derived from off-site services or other processes that are impacted by the resource (e.g., flood attenuation, water quality regulation, carbon sequestration). Option values are the values that people place on maintaining the option to use a resource in the future (e.g., the option to extract genetic resources). Non-use values are derived from the knowledge that an ecosystem or biodiversity is maintained without regard to any current or future personal use, which may be related to altruism (maintaining an ecosystem for use by others), bequest (for future generations), and existence (preservation unrelated to any use) motivations. This study is more concerned with the derivation of the use values (direct and indirect). Derivation of non-use values requires stated preference approaches whereby non-market valuation of the resources (natural capital) is used. In these approaches, people reveal their valuations for non-use wetland services through explicit citing of monetary payments for conservation and restoration of wetland services (i.e., willingness to pay – WTP).

1.1.2 Benefit transfer-based method

The benefit transfer approach was also used to triangulate the estimates provided by the market-based approach. The approach has two methods: (i) direct value transfer and (ii) function value transfer. In the direct value transfer method, the economic valuation of ecosystem services from a particular site are directly used as the corresponding values for the policy site where valuation estimates are being assessed. Ideally, the study site and policy site should be similar in characteristics, or adjustments should be made (for example, temporal adjustment of the values using proper deflators or exchange rates) to the transferred value to reflect differences in site characteristics (Brouwer et al. 2022). The function value transfer method involves transferring values to a policy site based on its known characteristics using a value transfer function, which may be estimated through a meta-regression. In the present study, a combination of both these methods was employed, particularly for ecosystem values which are not accounted for in the meta-regression. The two meta-regressions used for estimating the economic values of ecosystem services are from Brander et al. (2006) and Chaikumbung et al. (2016). While the first equation provided by Brander et al. (2006) serves as a base estimation, the final estimations are fine-tuned using the second equation, which has a broader scope of ecosystem services and also considers wetland studies from the global south.

The following equation (Brander et al. 2006) is used to estimate ecosystem services using local contextualized values like area of the wetland, GDP per capita of Sri Lanka, and the latitude:

$$\ln(y) = -6.98 + 1.16 \ln(\text{GDP per capita}) + 0.47 \ln(\text{population density}) - 0.11 \ln(\text{wetland size}) \\ + 0.03 \text{ latitude (absolute value)} - 0.0007 \text{ latitude}^2 + 2.01 (\text{Asian wetlands}=1) \\ - 0.04 (\text{market prices}) - 1.46 (\text{fresh marsh}) + 0.14 (\text{flood control}) \\ - 0.95 (\text{water supply}) + 0.63 (\text{water quality}) - 0.03 (\text{habitat \& nursery}) + 0.06 (\text{fishing}) \\ - 1.24 (\text{fuelwood}) + 0.06 (\text{amenity}) + 0.06 (\text{biodiversity})$$

The following equation (Chaikumbung et al. 2016) for freshwater wetlands of the global south is used to estimate the economic values of ecosystem services with local parameters like population density, GDP per capita, and area of the wetland:

$$\ln(y) = 6.816 - 0.036 \ln(\text{population density}) + 0.475 (\ln \text{GDP per capita}) - 0.404 (\ln \text{area}) \\ - 0.1 (\text{riverine wetland}) - 1.123 (\text{constructed wetland}) + 0.024 (\text{lacustrine wetland}) \\ - 1.540 (\text{palustrine wetland}) - 0.02 (\text{other wetlands}) - 0.19 (\text{disturbance regulation}) \\ + 1.697 (\text{water regulation}) - 0.993 (\text{water supply}) + 1.427 (\text{nutrient cycling}) \\ + 0.483 (\text{erosion control}) - 0.468 (\text{gas regulation}) + 0.73 (\text{water treatment}) \\ + 1.663 (\text{biodiversity habitat}) - 0.268 (\text{food production}) + 0.225 (\text{raw materials}) \\ - 0.241 (\text{cultural}) + 0.052 \text{ latitude (absolute value)} - 0.214 (\text{Asian wetlands}=1) \\ + 0.567 (\text{replacement cost}) + 0.426 (\text{Net Factor Income}) - 1.520 (\text{opportunity cost}) \\ + 0.885 (\text{damage cost}) + 1.954 (\text{urban wetland})$$

To estimate the value of the different ecosystem services, wetland characteristics and ecosystem services are substituted using binary values of 0 and 1 based on the choice of the ecosystem service. For example, to derive the value of water regulation, the actual values of population density, GDP per capita, and area of the wetland are used in the equation above. Along with these values and coefficients, water regulation, lacustrine wetland, Asian wetland, urban wetland, and opportunity cost are given a value of 1, and all others are set to 0. The values thus computed are then used to compute the value of ecosystem services using natural logarithm. It is to be noted that neither of these equations account for the economic value of carbon sequestered. To estimate carbon sequestration, benefit transfer by direct value transfer method was used, as described in Emerton and Kekulandala (2003). To derive the economic value of carbon sequestration, the value provided by the above study was considered (USD 89.2/ha). This value was converted to 2023 prices using a deflator of 7.1 and then multiplied by the wetland area, assuming that the wetlands provide far reaching benefits to the basinwide population.

Table 1 provides an overview of the ecosystem services specific to the wetlands, valued under the market-based and benefit transfer methods. While many of the important ecosystem services (identified as relevant and highly important under the literature review) have been valued, explicit valuation of ecosystem services such as educational services, cooling, and fisheries were not included in the study due to the lack of necessary data. Nevertheless, educational and fisheries services are incorporated within the cultural and food production service categories, respectively, in the benefit transfer functions developed by Chaikumbung et al. (2016). Other values such as option values and non-use values that are based on preferences and require choice experiments to estimate willingness to pay, have not been considered in the study.

TABLE 1. Ecosystem services in the Kalu Oya and Mudun Ela wetlands included in the second component of the study.

Ecosystem service	Valuation technique	Data used/required	Method used	Type of use value considered
1 Flood attenuation	Replacement costs, damage costs, benefit transfer	Data on project costs and benefits for increasing drainage, market prices for damage assessments	Market price based, benefit transfer	Direct use value
2 Food production	Productivity method which includes yield, market prices of agricultural outputs, and cost of inputs	Yield, market prices, cost of cultivation	Market price based, benefit transfer	Direct use value
3 Water supply and recharge	Indirect approach of valuing for water recharge, market prices of water extraction – aversive expenditure, benefit transfer	Cost of water extraction	Market price based, benefit transfer	Indirect use value (opportunity costs)
4 Grazing land	Estimation of grass production in abandoned land, market prices, benefit transfer	Number of households dependent on grazing, market prices of fodder	Market price based	Direct use value
5 Carbon sequestration	Carbon stock and carbon sequestration rate – models and life-cycle assessments, benefit transfer	Carbon market prices, carbon stock and carbon sequestration estimates	Market price based, benefit transfer	Indirect use value, option value
6 Carbon stock	Biomass carbon storage (above ground and below ground), market prices of carbon, benefit transfer	Carbon market prices, estimation of above ground and below ground biomass, estimation of soil carbon stock	Market price based	Indirect use value
7 Water quality	Replacement costs, avoided costs method, hedonic pricing method, benefit transfer	Water quality data, market prices for treatment	Benefit transfer	Indirect use value
8 Raw materials (cash crops, wood)	Market prices of agricultural outputs, cost of inputs, benefit transfer	Yield, market prices, cost of cultivation	Market price based, benefit transfer	Direct use value
9 Amenities/cultural	Recreation value, travel costs, benefit transfer	Number of visitors, associated costs	Benefit transfer	Direct use value
10 Biodiversity (habitat and nursery)	Travel cost method, contingent valuation/choice experiment, hedonic pricing, benefit transfer	Actual payments made/ expenses, willingness to pay included	Benefit transfer	Indirect use value
11 Water regulation	Water productivity (for water allocated to irrigation, hydropower), benefit transfer	Volume of water allocated, valuation of the productivity based on market prices	Benefit transfer	Indirect use value
12 Erosion control	Replacement costs, hedonic pricing, productivity method, benefit transfer	Cost of artificial sediment traps or engineered soil retention measures, changes in land values near wetlands, and agricultural yields	Benefit transfer	Indirect use value
13 Nutrient cycling	Avoided costs method, benefit transfer	Costs of water quality degradation (loss of fish, disease and illness cost), treatment costs	Benefit transfer	Indirect use value

1.2. Results

1.2.1 Market price-based method

1.2.1.1 Flood attenuation

Flooding in the Kalu Oya and Mudun Ela basins has costs associated with infrastructure destruction, agricultural losses, and livelihood disruption. In any given year, the magnitude of costs is a function of flooding intensity and duration. However, there is little information and estimating these costs is a difficult task.

In recent years, two major floods occurred in the basin in 2010 and 2016, with an inundated area of 9.7 km² and 5.4 km², respectively (estimated using the inundation maps (Figure 1 and Figure 2) (JICA, pers. comm, 2024). Based on analyses elsewhere in Sri Lanka (ADPC 2017), the return period (T) of these two floods was estimated at 45 and 10 years, respectively.

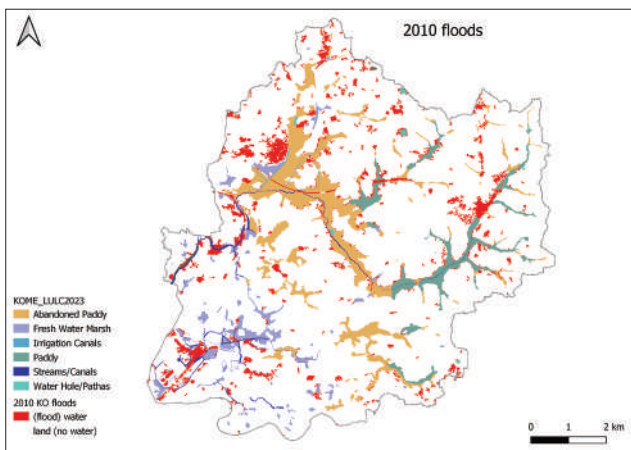


FIGURE 1. Flood map of 2010.

Source: JICA.

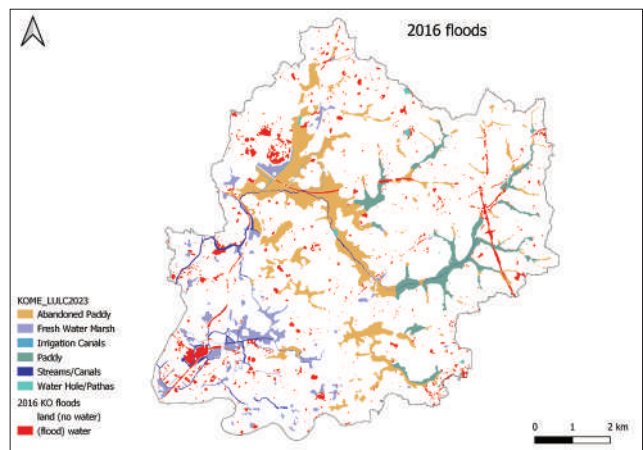


FIGURE 2. Flood map of 2016.

Source: JICA.

The cost of flooding for different return periods was estimated based on IMF reported losses as a percentage of GDP for Sri Lanka (IMF 2018)¹. A simple regression analysis was conducted to determine the relationship between the flood return period and associated costs for floods of different return periods (Figure 3). This relationship was assumed to be the same for the Kalu Oya Basin.

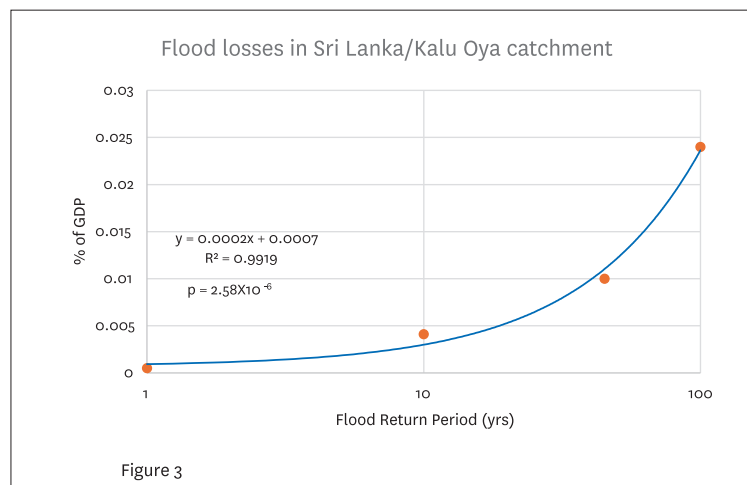


Figure 3

FIGURE 3. Relationship between flood return period and flood-induced losses in Sri Lanka and the Kalu Oya Basin.

Source: Authors' creation.

¹ <https://www.elibrary.imf.org/downloadpdf/journals/002/2018/176/article-A003-en.xml>

Based on this relationship and an estimated GDP of USD 3.21 billion for the basin, the cost of floods of different magnitudes in the Kalu Oya and Mudun Ela basins are presented in Table 2.

TABLE 2. Estimated costs associated with floods of different magnitudes in the Kalu Oya and Mudun Ela basins.

GDP for the basin = USD 3.21 billion			
Flood return period (years)	Inundated area (km²)	Annual loss (% of GDP)	Cost in USD (×10⁶ basin level)
1	0.7	0.05	1.61
10	5.4	0.41	13.16
45	9.7	1.00	32.1
100	23.3	2.40	77.04

In any given flood event, the extent to which wetlands in the basin mitigate flood damage depends on a range of factors, including the antecedent conditions and the intensity, and temporal and spatial distribution of rainfall. To provide an estimate of the mitigation effect of the wetlands, the flood volume with and without the wetlands was estimated, effectively assuming that the wetlands could always provide the same amount of water storage, and hence flood mitigation.

In a study on water retention in the Colombo wetland complex, Dona et al. (2024) estimated that 2.68 km² of wetlands had a water absorption capacity of 166,347 m³. The volume of flooding was estimated assuming that the wetlands were not present as well as the following:

- Both the Kalu Oya wetlands and the Colombo wetlands complex have the same proportional absorption capacity (i.e., a storage of 651,732 m³ over 10.5 km² of wetland); and
- All floods have a mean flood depth of 0.5 m (i.e., the area of flooding changes depending on the return period of the flood, but the average depth does not).

The flood volume in the 'without wetlands' scenario was determined by adding the additional volume (651,732 m³) to the 'with wetland' flood volume, determined assuming an average flood depth of 0.5 m.

Table 3 and Figure 4 present the results of these analyses and indicate that based on the assumptions made:

- In the Kalu Oya Basin, wetlands reduce the loss and damage costs of floods by between USD 3.18 million and USD 4.31 million/year, with an average of USD 3.75 million; and
- The saving decreases proportionally as the magnitude of the flood increases.

TABLE 3. Estimated average costs of flooding in the Kalu Oya Basin, with and without wetlands.

Flood return period (years)	Inundated area (km²)	Flood volume (m³)		Cost of flooding (USD ×10⁶)			Difference (%)
		With wetlands	Without wetlands	With wetlands	Without wetlands	Difference	
1	0.66	329,268	981,001	1.61	4.78	3.18	66.30
10	5.40	2,700,000	3,351,732	13.16	16.34	3.18	19.40
45	9.70	4,850,000	5,501,732	32.1	36.41	4.31	11.85
100	23.28	11,640,000	12,291,732	77.0	81.35	4.31	5.30

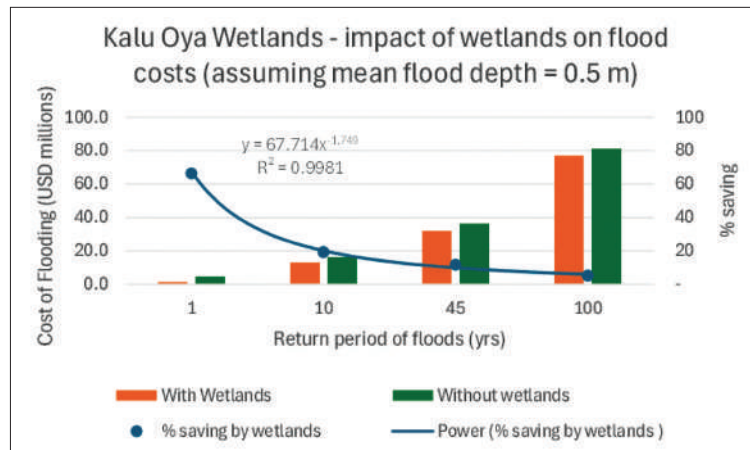


FIGURE 4. Impact of wetlands on flood loss and damage costs of floods at different return periods. Source: Authors' creation.

1.2.1.2 Food production

The contribution of wetland ecosystem services is estimated using the net income approach, which attributes the net agricultural income to wetland support by deducting input costs from total revenue. The TEV of water for agriculture is calculated as follows:

where,

$$TEV_w = p_i q_i - \sum_{inputs=l}^k I_k r_k$$

$p_i q_i$ = total crop revenue (price × quantity) for the i^{th} crop

$I_k r_k$ = total cost of inputs (seeds, land rent, fertilizers, and chemicals) used for the crop.

The areas under different crops or farming practices were derived from the LULC map for 2023 obtained from the Land Use Policy and Planning Department (LUPPD) under this project (Figure 5). Using this data, the total basin area was estimated at 7,500 ha and wetland area including active and abandoned paddy was estimated at 1,050 ha, with abandoned paddy dominating the wetland area (800 ha). Home gardens stand out with the largest land cover in the basin, followed by residential areas (particularly in the Mudun Ela sub-Basin) (Figure 5). Another level of additional classification that includes commercial crops such as paddy can be selected within the LULC cover (grouped under croplands category) to get specific area estimates. Since this analysis focuses solely on the direct food production services provided by the wetlands (excluding the broader basin area), the only relevant crop production within the Kalu Oya wetland identified through LULC data is paddy. The total active paddy area is estimated to be 189.17 ha.

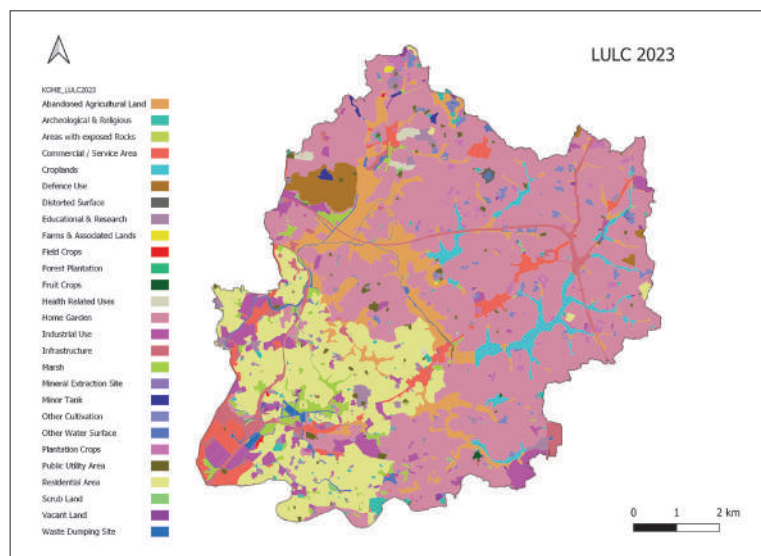


FIGURE 5. Land use land cover map for the Kalu Oya and Mudun Ela basins. Source: LUPPD (2023).

The market value of rice in Sri Lanka fluctuates between two primary annual paddy growing seasons, *Yala* (April to August) and *Maha* (September to March) (Table 4). However, seasonal production statistics specific to the Kalu Oya and Mudun Ela paddy areas are unavailable. Therefore, this analysis uses the combined annual paddy production cost of USD 431/ha for valuation purposes. Based on the 189.17 ha of paddy fields identified within the Kalu Oya wetland complex in the LULC assessment, the estimated economic value is USD 0.082 million, assuming that all identified paddy areas are under active commercial cultivation.

TABLE 4. Economic value of annual rice production within the Kalu Oya Basin.

Seasons	Value (USD/ha)	Area under production within the wetland (ha) ^a	Total Value (10 ⁶) (USD)	Data references
Paddy (<i>Yala</i>)	266	189.17		75th volume of the series Cost of cultivation of agricultural crops Net returns per acre to farmers in Gampaha, including the cost of the farmers' own inputs, are LKR 15,895 ²
Paddy (<i>Maha</i>)	165			74th volume of the series Cost of cultivation of agricultural crops Net returns per acre to farmers in Gampaha, including the cost of the farmers' own inputs, are LKR 9,459 ³
	431		0.082	

Note:

^a Based on the land use land classification provided by the Land Use Policy and Planning Department (LUPPD) 2023.

1.2.1.3 Water supply: groundwater recharge

In the basins, wetlands are believed to play a crucial role in recharging freshwater supply and maintaining groundwater levels near the surface, supporting household water access. It has been estimated that approximately 42% of households rely on dug wells for their water needs (Sakalasooriya 2021). Assuming that all recharge is from the wetlands, this equals to about 60,594 households that are dependent on wetland-supported groundwater recharge. The loss of the natural recharge function would necessitate deeper well drilling or the construction of additional shallow wells, particularly during the dry season. If each well serves an average of three households, and USD 50/ m⁴ is required to deepen wells by at least 5 m⁵ to access lower groundwater reserves, the annual cost avoided on this additional infrastructure is estimated at USD 5 million. Using this result, the value of recharge/ha is valued at USD 672, and considering a total wetland area of 1050 ha, the economic value for wetland extent within the basin is estimated at USD 0.7 million.

1.2.1.4 Fodder production

Wetlands serve as an essential source of fodder and support livestock grazing. Gedara (2019) estimated the market price of significant fodder varieties as follows:

- Hybrid Napier at USD 45.44/t;
- Fodder sorghum at USD 75.73-90.60/t; and
- Fodder maize at USD 106-136/t.

² This value is converted to USD/ha for 2023 based on an inflation factor of 2 and an exchange rate of 1 USD = 295 LKR.

³ This value is converted to USD/ha for 2023 based on an inflation factor of 2.09 and an exchange rate of 1 USD = 295 LKR.

⁴ This value is obtained from philanthropies (<https://taalofalkhair.com/en/product/surface-well-sri-lanka/>; https://zadalkhaer.com/en/shop/drill-surface-and-artesian-wells/a-surface-well-in-sri-lanka/?srsltid=AfmBOorWtVWZD4zO3F6CZaGB_eS8S6DyHA5-wPchWqRqkaQk-JEByG-62) that help in constructing dug wells for communities and expert opinions.

⁵ This had been assumed based on expert consultation about the requirement for aversive expenditures.

For this study, the price of hybrid Napier grass was considered the grazing value since households usually get it primarily from abandoned paddy fields. Converting the price for 2023, the estimated price of grass is USD 87.7/t.

To estimate livestock fodder requirements, livestock numbers recorded in select DSDs (according to local resource profiles called *Sampath Pethikada*) were used (Table 5).

TABLE 5. Livestock population recorded in three Divisional Secretariat Divisions.

Divisional Secretariat Divisions	Cows	Buffaloes	Goats
Biyagama	467	226	3,000
Ja Ela	670	86	600
Kelaniya	250	80	536
Total	1387	392	4,226

The annual requirement of grass per animal is 20 t for cows and buffaloes (Gedara 2019), while it is 1-1.5 t for goats. Considering this demand, the total requirement is 41,934 t. It has been estimated that approximately 30-50 t (40 t on average) of dry grass/ha (NBRO n.d.)⁶ is produced in abandoned paddy fields. According to Sakalasooriya (2021), families harvest grass from abandoned paddy fields of the wetland for their cattle, and Kalu Oya and Mudun Ela wetlands contain 631 ha of abandoned paddy land (as per the LULC), where the estimated production is 25,240 t. Since an exact figure for the fodder harvested is unavailable, we considered a range between 30% and 50% to help estimate the livestock fodder produced and used by households. Using this range, the estimated economic value of fodder production is USD 0.5 million-0.84 million annually.

1.2.1.5 Carbon sequestration

This estimation includes only the undisturbed wetland area without active paddy cultivation, encompassing 861 ha. The estimated carbon sequestration potential of freshwater wetlands in Sri Lanka is approximately 6.82 t of CO₂/ha/year. This estimate is derived from global studies indicating that the median value of carbon sequestered by a freshwater tropical wetland is approximately 1.86 t of carbon per hectare per year (t C/ha/year) (Villa and Bernal 2018). This is converted to tons of carbon dioxide equivalent using a factor of 3.67. With a value of USD 6.89/t CO₂e⁷, the estimated economic value of the carbon sequestered is USD 0.04 million.

1.2.1.6 Carbon stock

A previous study estimated soil organic carbon (SOC) and t carbon content of above ground biomass (AGB) and below ground biomass (BGB) in two freshwater wetlands in Colombo (Dayathilake et al. 2020; Dayathilake et al. 2021) (Table 6). It is assumed that the same value for the area of undisturbed natural Kalu Oya and Mudun Ela wetlands as above (861 ha) gives a total carbon content of between 493,708 t and 534,971 t. To economically value this stock, it is then converted to carbon dioxide equivalent by using the factor of 3.67. With a value of USD 6.89/t CO₂e⁸, the estimated value of the carbon stock is USD 12.1 million-13.1 million.

TABLE 6. Carbon stock (t/ha) in freshwater wetlands in Colombo.

Wetlands	Soil organic carbon ^a	Above ground biomass	Below ground biomass	Total
Kolonnawa	504	40.14	6.29	550.4
Thalawathagoda	550	40.14	6.29	596.4

Note:

^a Mean value from the range provided in Dayathilake et al. 2021.

⁶ http://www.nbro.gov.lk/images/special_projects/Nature_based/Plant-manual--FINAL---Attachment-iii.pdf

⁷ The World Bank provides the price of carbon credits in the following markets (Asian) – (i) Indonesia - USD 0.61/t CO₂e and (ii) China – USD 12.57/t CO₂e. For this study, we considered an average value of USD 6.89/t CO₂e (World Bank 2025).

⁸ The World Bank provides the price of carbon credits in the following markets (Asian) – (i) Indonesia – USD 0.61/t CO₂e and (ii) China – USD 12.57/t CO₂e. For this study, we considered an average value of USD 6.89/t CO₂e (World Bank 2025).

1.2.1.7 Total economic value of the ecosystem services assessed for Kalu Oya wetlands

Results of the wetland-specific ecosystem service valuation indicate that carbon stock is the most economically valuable service, accounting for between 68% and 73% of the total economic value of the ecosystem services assessed (Table 7). As noted previously, while this is an extremely valuable service, it may be hard to realize a monetary return; furthermore, it is a one-off value that is not annualized. Flood attenuation is the second most economically valuable service accounting for between 19% and 22% of the total economic value of the ecosystem services assessed (Table 7). Livestock fodder production and water supply (groundwater recharge) both account for between 3% and 4.4% of the total economic value of the ecosystem services assessed (Table 7). The remaining services valued (i.e., paddy production and carbon sequestration) both account for less than 1% of the total.

The differences between sections 1 and 2 reflect differences in value attributed, methods used, and that the former focuses on the wetlands whereas the latter covers all the land within the basin.

TABLE 7. Economic value of the ecosystem services derived from the market price-based approach.

Ecosystem service ⁹	Use value (USD/ha)	Biophysical value	Economic value (USD × 10 ⁶ /annum)	Total economic value assessed (%)
Paddy production	431	189.17 ha	0.08	0.43-0.49
Water supply: Groundwater recharge	672	1,050 ha	0.7	3.67-4.22
Provision of water resources (USD/ha)				
Livestock fodder production (USD/t)	3,508	631 ha	0.50-0.84	3.01-4.40
Carbon sequestration (USD/t/year CO ₂ e)	6.89	6.82 t CO ₂ e	0.04	0.21-0.24
Carbon stock (USD/t CO ₂ e)	6.89	1.8-1.9 million t CO ₂ e	12.1-13.1 ¹⁰	68.7-72.9
Flood attenuation	1,857	1,050 ha	3.18-4.31	19.2-22.6
Economic value of the ecosystem services assessed			16.60-19.07	100.0

1.2.2 Benefit transfer-based method

Table 8 presents benefit transfer value functions for the different ecosystem services considered in the meta-regression. The function presented in Chaikumbung et al. (2016) incorporates a higher number of ecosystem services than those in Brander et al. (2006), which include globally representative values for wetlands. When considering the values for ecosystem services in the benefit transfer approach, the higher of the two estimates has been used to derive the total value of ecosystem services, except for amenity/cultural. In the case of amenity/cultural, the lower value of USD 42/ha has been considered since three different ecosystem services yield the same value, i.e. USD 811/ha for fishing, amenity/cultural, and biodiversity using Brander et al. (2006) (since the coefficients are identical in the value function). To avoid duplication, the value derived from Chaikumbung et al. (2016) has been used for the valuation of cultural ecosystem services within the Kalu Oya and Mudun Ela wetlands.

⁹ There are relatively few trees in the wetlands; so fuelwood production was not included as a wetland service.

¹⁰ This is a one-off value that is not annualized.

TABLE 8. Economic values derived from the two different benefit transfer approaches.

Ecosystem service		Values derived using the function estimated by Brander et al. (2006)	Values derived using the function estimated by Chaikumbung et al. (2016)
1	Flood control	USD 875/ha	USD 499/ha
2	Water supply	USD 295/ha	USD 162/ha
3	Water quality/ water treatment	USD 1,434/ha	USD 1,252/ha
4	Habitat and nursery	USD 741/ha	- ^a
5	Fishing	USD 811/ha	-
6	Fuelwood	USD 221/t	-
7	Amenity/cultural	USD 811/ha	USD 42/ha
8	Biodiversity	USD 811/ha	-
9	Biodiversity and habitat		USD 3,183/ha
10	Nutrient cycling	-	USD 226/ha
11	Water regulation (for irrigation, hydropower)	-	USD 2,081/ha
12	Erosion control	-	USD 978/ha
13	Raw materials (fuelwood, lumber, reed)	-	USD 68/t
14	Food production (fish, crops, nuts, fruit and honey)	-	USD 291/ha

^a Not available.

The benefit transfer approach identified biodiversity services with the highest economic value (32.43% of the total estimated economic value), followed by water regulation (21.20%) and water quality (13.68%) services (Table 9). Within this approach, water-related ecosystem services were considered to provide distinct but interconnected benefits. Water regulation services refer to the management of the flow of water systems, offering natural irrigation for agriculture, and providing waterways for transportation. Water supply services focus on water storage, ensuring availability for household consumption and various industrial activities. Water quality/treatment services involve the ecosystem's ability to recover mobile substances and remove or break down excess or toxic nutrients and compounds, control pollution, and detoxify contaminants.

TABLE 9. Economic values of the ecosystem services derived from the benefit transfer approach.

Ecosystem service	Use value (USD/ha)	Area considered (ha)	Economic value (USD ×10 ⁶ /year)	Total economic value assessed (%)
Flood control	875	1,050	0.92	8.91
Water supply	295	1,050	0.31	3.01
Water quality	1,343	1,050	1.41	13.68
Raw materials	221	1,050	0.23	2.25
Amenities/cultural	42	1,050	0.04	0.43
Biodiversity (habitat and nursery)	3,183	1,050	3.34	32.43
Food production	291	189.17	0.06	0.53
Water regulation	2,081	1,050	2.19	21.20
Erosion control	978	1,050	1.03	9.96
Nutrient cycling	226	1,050	0.24	2.30
Carbon sequestration	634	861	0.55	5.30
Economic value derived from the benefit transfer approach			10.31	100

1.3 Discussion

The two valuation approaches produced varying estimates across wetland ecosystem services, reflecting each one's inherent strengths and limitations. Notably, the benefit transfer approach yielded significantly higher values for biodiversity and habitat provisioning, driven by globally derived estimates. However, due to the absence of robust local ecological or economic data on biodiversity, these services could not be reliably quantified using market-based valuation techniques.

In addition, the benefit transfer method enabled estimation of non-market ecosystem services such as cultural values, erosion control, and nutrient cycling, which are also excluded from direct market transactions. These insights expand the understanding of the total value of wetlands beyond what is captured through market pricing alone. Conversely, carbon stock, the highest valued ecosystem service in the study, was captured exclusively by the market-based approach and is not reflected in the benefit transfer estimates. This omission accounts for much of the discrepancy in total economic value between the two methods.

When values from both approaches are integrated, applying benefit transfer values to services not captured in the market-based analysis, the total estimated economic value of wetland ecosystem services in the Kalu Oya and Mudun Ela basins ranges from USD 25 million to 28 million (Table 10). Among the services assessed, carbon stock, flood mitigation, and biodiversity emerged as the most economically significant.

This combined value equals approximately 0.76-0.86% of the nominal basin GDP (USD 3.21 billion). Excluding carbon stock, which represents a static rather than annual flow value, yields an annualized value of USD 12.98-14.45 million, or approximately USD 12,362-13,762/ha/year. By comparison, the Ecosystem Services Valuation Database (ESVD), based on over 9,400 standardized estimates, indicates that inland and urban wetlands globally have mean values ranging from USD 33,447 to USD 64,167/ha/year, with cultural services alone averaging USD 57,262/ha/year. However, these estimates are characterized by high variability (ranging from <USD 1 to over USD 1 million/ha/year) (Brander et al. 2024). Thus, the present estimates, constrained by data availability, are conservative.

TABLE 10. Economic values of the ecosystem services derived from the market value and the benefit transfer approaches.

Ecosystem service	Economic value (USD ×10 ⁶ /year)	Total economic value assessed (%)
Market Value		
Paddy production	0.08	0.30-0.33
Water supply: Groundwater recharge	0.70	2.54-2.79
Livestock fodder production	0.50-0.84	1.99-3.05
Carbon sequestration	0.04	0.15-0.16
Carbon stock	12.1-13.1	47.55-48.24
Flood mitigation	3.18-4.31	12.68-15.64
Benefit transfer		
Water quality	1.41	5.12-5.62
Raw materials	0.23	0.83-0.92
Amenities/cultural	0.04	0.15-0.16
Biodiversity (habitat and nursery)	3.34	12.12-13.32
Water regulation	2.19	7.95-8.73
Erosion control	1.03	3.74-4.11
Nutrient cycling	0.24	0.87-0.96
Total	25.08-27.55	

2. Total Economic Valuation Using Co\$tingNature and Local or Global Values

In this section we present economic valuation techniques applied to Co\$tingNature biophysical ecosystem service outputs to understand the total economic value and return on current conservation investments and a range of scenarios, to highlight optimal conservation investments to retain and restore important ecosystem services in the region.

Co\$tingNature (C\$N) and Co\$tingNature/local (C\$N/local) produce a range of valuation types:

- Biophysical characterization, in which each service is mapped biophysically, meaning bundling or comparison is not possible but there is a provision for more intervention-relevant metrics (e.g., km³ of water);
- Nature's contribution to the UN Sustainable Development Goals (SDGs), in which contributions are assigned against specific SDG goals and targets, which allows a more environment and development-focused analysis of ecosystem services;
- Relative valuation for multiple ecosystem services, in which each ecosystem service is normalized (0-1) from its highest values in the study region to its lowest, allowing all ecosystem services to be bundled and compared on an equal footing, on the basis of their priority (low to high); and
- Economic valuation, in which economic value is assigned to ecosystem services as use or non-use value and combined with their biophysical magnitude to produce a total economic value.

A range of methods are used to assign economic value to ecosystem services. These include:

Market pricing: Direct use values of ecosystem services that have a market price, such as timber, fish, and medicinal plants, are valued based on their current market price.

Cost-based valuation: Estimating costs associated with not having the service provided, including valuing services by estimating the cost of replacing them with manmade systems, e.g., the cost of building a water filtration plant to replace the filtering services of a wetland (replacement cost); estimating the expense of restoring an ecosystem to provide services as opposed to the costs incurred if the ecosystem were lost (restoration cost); and the cost associated with relocating activities or infrastructure due to the loss of ecosystem services (relocation cost).

Revealed preference methods: Inferring the value of goods, services, or resources based on observed behaviors rather than direct responses or stated preferences. These include examining how features of ecosystems such as proximity to water bodies or parks affect real estate prices (hedonic pricing) and valuing services based on the amount people are willing to pay for travel and other expenditures to get to them (travel cost method).

Stated preference methods: Asking people to directly state their willingness to pay for specific environmental changes. These include asking people how much they would be willing to pay to preserve an ecosystem service or what they would accept for its loss (contingent valuation) and offering choices between sets of ecosystem services to determine the preferences and trade-offs individuals make (choice modelling).

Benefit transfer: Using existing valuation estimates from similar ecosystem services or sites in other locations to estimate economic values for the site being assessed, adjusted for differences in size, quality, and socio-economic contexts.

Production function approach: Valuing ecosystem services that contribute directly to the production of economic goods, such as water quality improving crop yield, by quantifying how changes in the service affect production quantities and market prices.

We use a number of these techniques to derive economic value per unit service provision and scale these with the magnitude of each service as determined by Co\$tingNature/local.

Economic valuation is much more inexact than biophysical valuation

The economic valuation of ecosystem services is an imprecise science due to the complex and often intangible nature of ecosystem services. Assigning monetary value to things like biodiversity, clean air, or water purification is challenging because they lack traditional market prices (Costanza et al. 1997). Valuation methods often rely on estimates, surveys, and assumptions, which can introduce significant variability and subjectivity (Fisher and Turner 2008). Furthermore, ecosystems are dynamic and interconnected, making it difficult to isolate the contribution of a single service or to predict how changes in one area will affect others (Daily et al. 2000). The presence of non-use values, such as the intrinsic worth of nature, further complicates matters, as these are difficult to quantify with economic tools (Krutilla 1967). Therefore, while economic valuation can provide valuable insights, it should be recognized as an approximation rather than a precise value. Uncertainty in biophysical value, relative value and even nature's contributions to the SDGs can be better managed than uncertainty in economic value since even for use values, assigning a value to an ecosystem service is very difficult.

Here we provide the economic valuation of a range of ecosystem services mapped biophysically in the Kalu Oya and Mudun Ela basins using CostingNature (C\$N). The distribution of value between services and over time are highlighted. Total economic valuation in relation to opportunity and investment costs for a range of investment scenarios are analyzed and the sensitivity of total economic value and return on investment to uncertainty in input values and changes in GDP, economic growth, time horizons, and discount rates are highlighted.

2.1 Methods

2.1.1 Biophysical services

In the C\$N/local economic valuation model, economic valuation of ecosystem services is carried out to assess the TEV that these services contribute over a specified time horizon, relative to GDP over the same period. The costs and opportunity costs associated with maintenance of nature (or investment in nature restoration) can also be specified and the return on this investment calculated, based on maintenance of TEV of ecosystem services. The valuation takes into account all C\$N/local mapped ecosystem services in biophysical units. These include species richness, wildlife services, realized fuelwood, realized grazing, carbon sequestration, carbon stock, pollution dilution benefits, water resource benefits, flood risk mitigated, soil erosion mitigation, and drought risk mitigated for irrigated crops. They are mapped across the basins using a physically based model of ecosystem service supply and demand (CostingNature/local, see CostingNature documentation http://www1.policysupport.org/costingnature/res/CostingNature_v3.x_Model_Documentation.pdf).

2.1.2 Economic valuation

The user specifies a time horizon, GDP growth rate, discount rate, nature investment costs, and opportunity costs as well as both use and non-use values and maximum attainable values (MAV). MAV can be used to specify an annual limit on the economic value attainable, to represent a cap on value, such as income available for a REDD+ project. The key concepts included are:

- 1. Valuation of ecosystem services:** This involves quantifying the benefits provided by ecosystems in monetary terms, which include both direct use values (e.g., timber, water purification) and non-use values (e.g., biodiversity conservation). Unless explicitly stated as PPP, all USD values are in nominal USD.
- 2. Return on investment (ROI):** This is calculated to determine the efficiency of investments in nature conservation, reflecting the financial returns on TEV per dollar spent.
- 3. Inflation and discount rate:** The future values of ecosystem services are adjusted for inflation and discounted to NPV to reflect both the changing value of money over time and the preference for immediate benefits over future ones.
- 4. Investment and opportunity costs:** Investments refer to the initial and ongoing costs associated with the conservation and maintenance of nature. Opportunity costs represent the economic benefits foregone as a result of not utilizing the land for alternative, potentially more lucrative purposes. Opportunity costs can be set by the user or calculated according to the average GDP of non-natural land in the study area.

The model operates on the following equations applied across all ecosystem service use and non-use values:

- **Calculation of discounted values:**

$$V_t = \frac{V_0 \times (1+i)^t}{(1+r)^t}$$

Where, V_t is the value at year t , V_0 is the initial value, i is the inflation rate, and r is the discount rate.

- **Total Economic Value (TEV):**

$$TEV = \sum_{t=0}^T V_t$$

Where, T is the time horizon over which the valuation is conducted.

- **Annual ROI:**

$$ROI_t = \frac{(TEV_t - C_t)}{C_t} \times 100$$

Where, C_t represents the total cost at year t , including both investment and opportunity costs.

The model does the following:

1. Retrieves user-provided inputs such as baseline year, time horizon, discount rate, GDP growth rate, investment rate, and opportunity cost rate and multiplies biophysical values from C\$/local by their corresponding use and non-use value.
2. Applies discounting formula to ecosystem services over the time horizon and caps values if constrained by maximum attainable service limits.
3. Sums discounted ecosystem service values to obtain TEV over the study period and calculates TEV as a percentage of GDP for both the first year and the full study period. Some services are tied to GDP so that the growth in their value reflects changing GDP. These services are wildlife services, pollution dilution, carbon sequestration, water resource benefits, flood risk mitigation, soil erosion mitigation, and drought risk mitigation. GDP (PPP) is calculated from Wang and Sun (2022), validated against web searches for the region.
4. Estimates investment costs per unit area based on value-specified natural land area and GDP growth.
5. Investment costs are front-loaded and adjusted for GDP growth. Since investment occurs mostly upfront, only a portion of total costs are subject to discounting. Opportunity costs are scaled to real GDP growth and only discounted once.
6. Applies discounting to investment and opportunity costs and computes total discounted costs over the study period.
7. Computes ROI per year based on TEV and total costs and calculates overall ROI, showing how much higher TEV is compared to costs.
8. GDP (PPP) for the basin is calculated from Wang and Sun (2022), validated against web searches for the region. The 2023 GDP (nominal) for Sri Lanka according to the [World Bank](#) (2024) is USD 84.36 billion, from a 2018 peak of USD 94 billion (World Bank 2023). The average per capita GDP for Sri Lanka as per the [World Bank](#) is USD 14,461 for 2023 (PPP, 2021). With a 2023 population of 22.04 million, it equals to a GDP (PPP) of USD 318.87 billion. PPP adjusts for differences in cost of living and inflation across countries, offering a more accurate measure of purchasing power, and is important for cross-country comparisons. The Western Province of Sri Lanka represents 43.4% of Sri Lanka's GDP (Central Bank of Sri Lanka 2023). The Kalu-Oya and Mudun Ela basins are at the edge of the urbanized Colombo District. Its value of USD 12.36 billion (PPP) equals USD 3.21 billion (nominal) using the World Bank PPP coefficient for Sri Lanka. This is in line with the Western Province's figures and reflects its urbanized setting on the periphery of the urban fabric of Sri Lanka's capital city. Further verification is provided by estimates of per capita GDP (12.36 billion (PPP) estimate by [Lanka Econ.](#)(Damsinghe 2024), which vary from USD 21,000-27,000 (Old Colombo District); USD 23,000-30,000 (Colombo District) to

USD 57,000-67,000 (Colombo District, Harvard Metroverse (Neffke et al. 2021). Given the basins' population of ~501,988, these ranges would produce the basinwide GDP (PPP) below:

- Old Colombo District (USD 21,000-27,000): Low: USD 10.54 billion; High: USD 13.55 billion; and
- Colombo District (USD 23,000-30,000): Low: USD 11.55 billion; high: USD 15.06 billion; and
- Harvard Metroverse (USD 57,000-67,000): Low: USD 28.61 billion; high: USD 33.63 billion. Throughout Co\$tingNature and this report, ecosystem services values, investment and opportunity costs as well as model outputs are in nominal USD since our purpose is not cross-country comparison. In this report, where values are stated in PPP, this is denoted by the annotation (PPP).

The valuation interface in the model is shown in Figures 6 and 7.

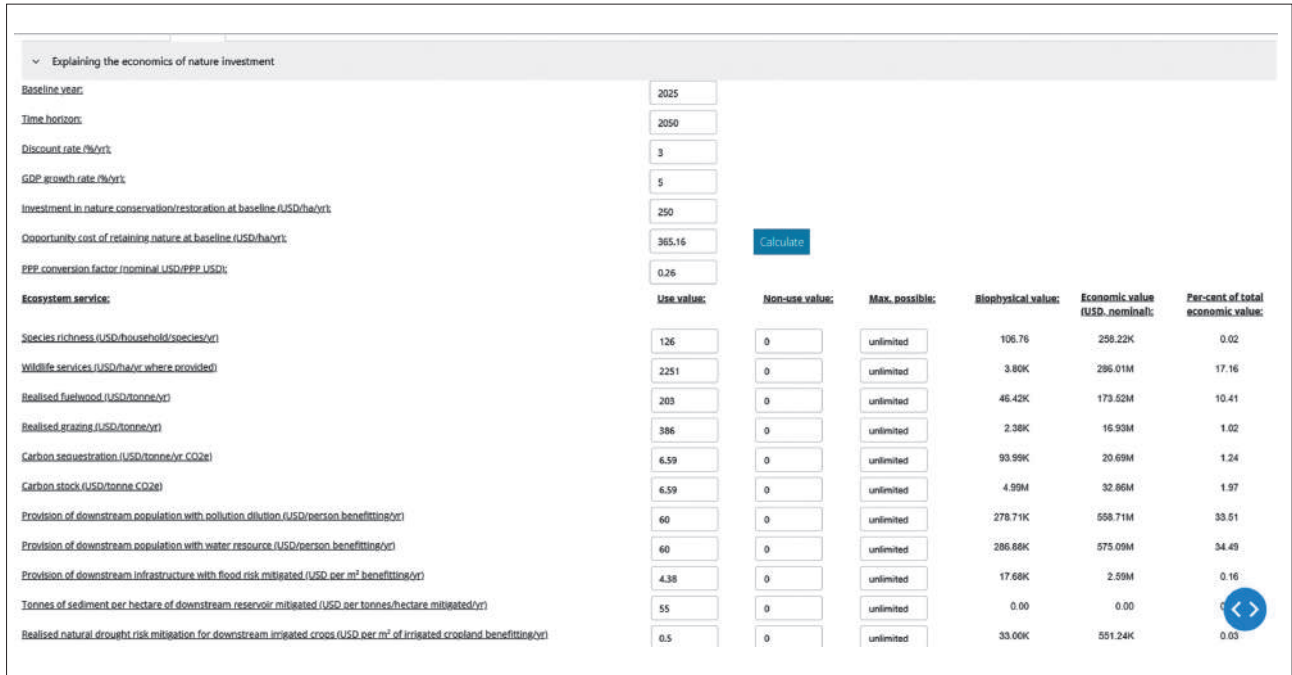


FIGURE 6. Input and output screen in the Co\$tingNature/local valuation tab.

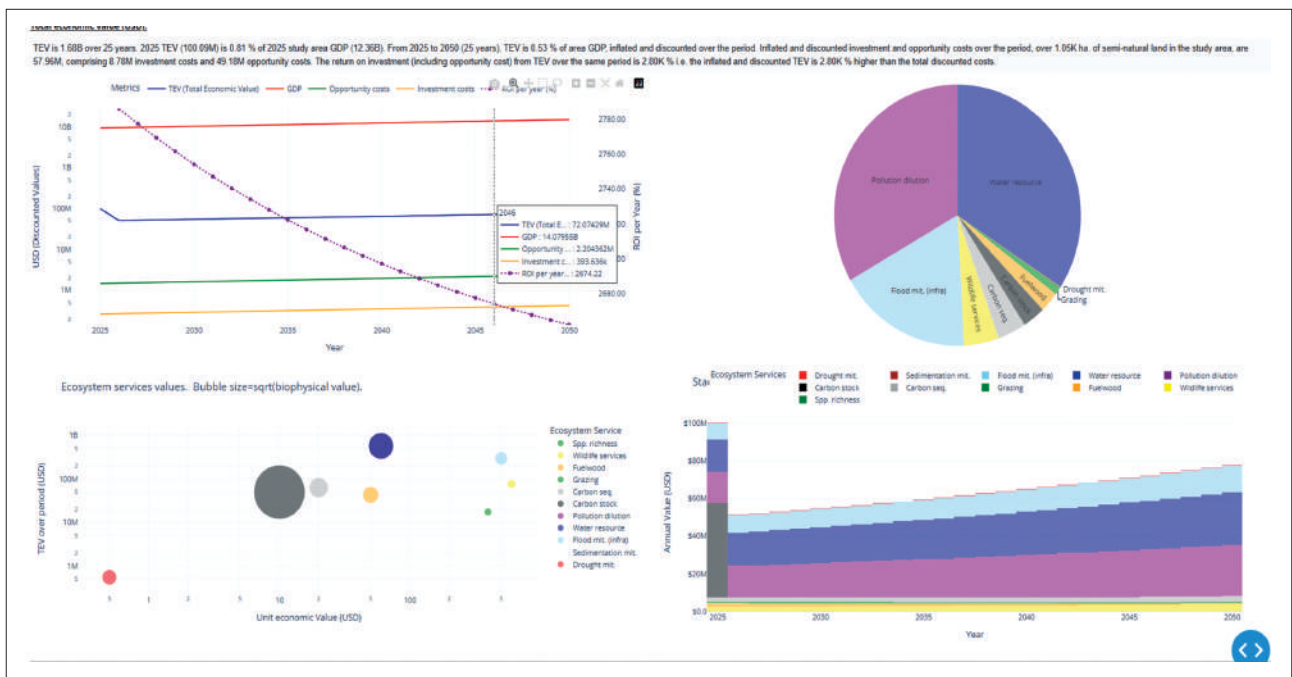


FIGURE 7. The analytics screen in the Co\$tingNature/local valuation tab.

The C\$N/local economic valuation functions enable a variety of analyses that help quantify and monetize the benefits of ecosystem services, supporting more informed and effective environmental management and conservation strategies, including:

- Economic valuation of multiple ecosystem services according to user-defined use and non-use values;
- Time series analysis taking into account factors like inflation and discount rates;
- Return on Investment to determine the financial efficiency of nature investments, comparing the returns to the costs involved, including opportunity costs;
- Impact of inflation and discounting, allowing for a present value assessment of long-term benefits;
- Scenario analysis under different valuation, economic (growth, recession), and nature investment scenarios; and
- Sensitivity analysis of key parameters such as discount rates, growth rates, and investment levels.

2.1.3 Analyses conducted

A series of numerical experiments were conducted examining the impact of economic valuation assumptions or socio-economic or nature investment scenarios on TEV and ROI. The differences in value when using globally assigned values versus locally assigned values were first investigated, followed by an analysis of the uncertainty in TEV and ROI resulting from the use of different economic values for each service in the range available from studies around the world. We then investigated a range of valuation scenarios:

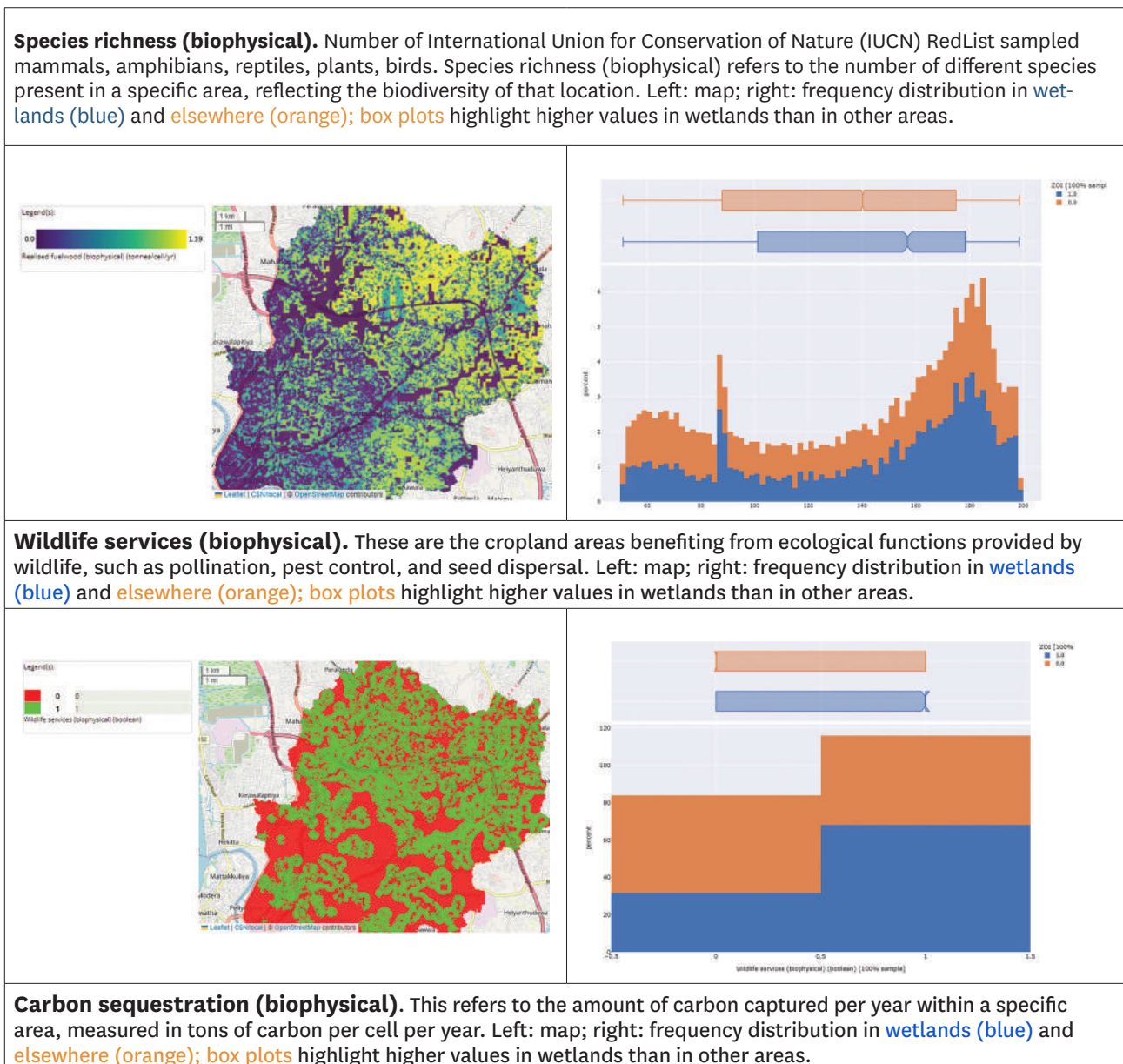
- Examining the difference between TEV and ROI based on global versus local valuation of key services;
- Examining the impacts of business-as-usual land use and climate change in the basin on TEV and ROI;
- Increasing the value of specific services through financial mechanisms such as Payment for Ecosystem Services (PES) schemes whereby beneficiaries of a service contribute to the costs of sustainable management of land that generates those services;
- Sensitivity of TEV and ROI to discount rate used;
- The influence of GDP growth or recession on TEV and ROI;
- Trade-offs between conservation investment and opportunity costs; and
- Temporal dynamics of TEV over different time horizons.

2.2 Results

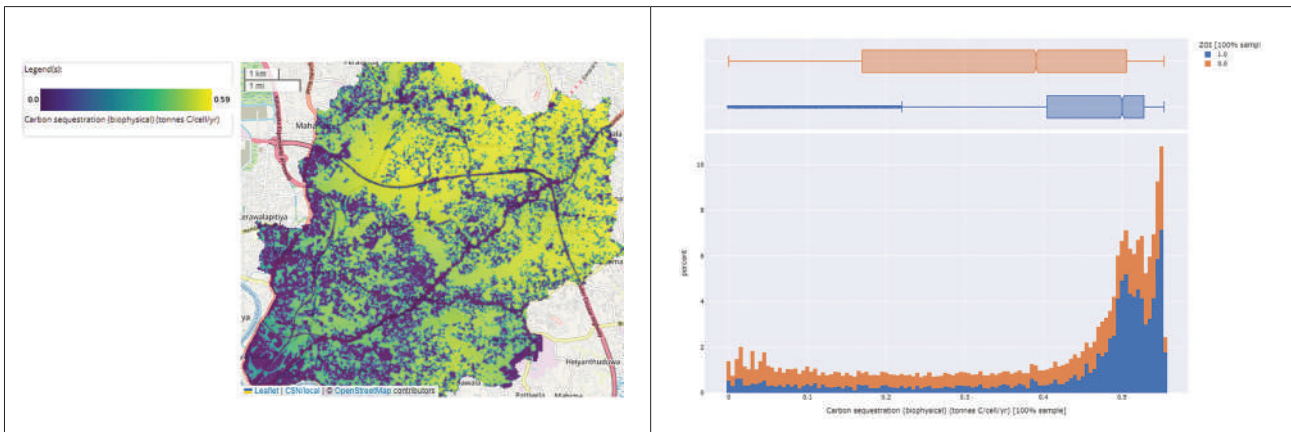
2.2.1 Biophysical outputs of C\$N/local

The biophysical outputs of C\$N are presented in Table 11 in both map form and as a frequency distribution with box plots for pixels inside and outside the wetlands within Kalu Oya and Mudun Ela basins.

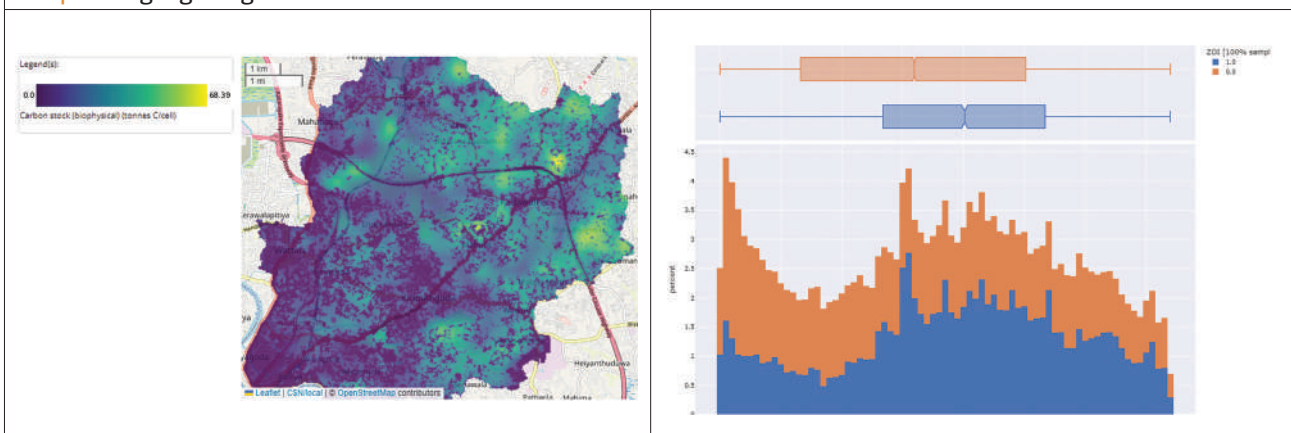
TABLE 11. Biophysical outputs of Co\$tingNature/local for the Kalu Oya and Mudun Ela basins as maps and frequency distributions with box plots comparing services from wetlands with those from other land covers.



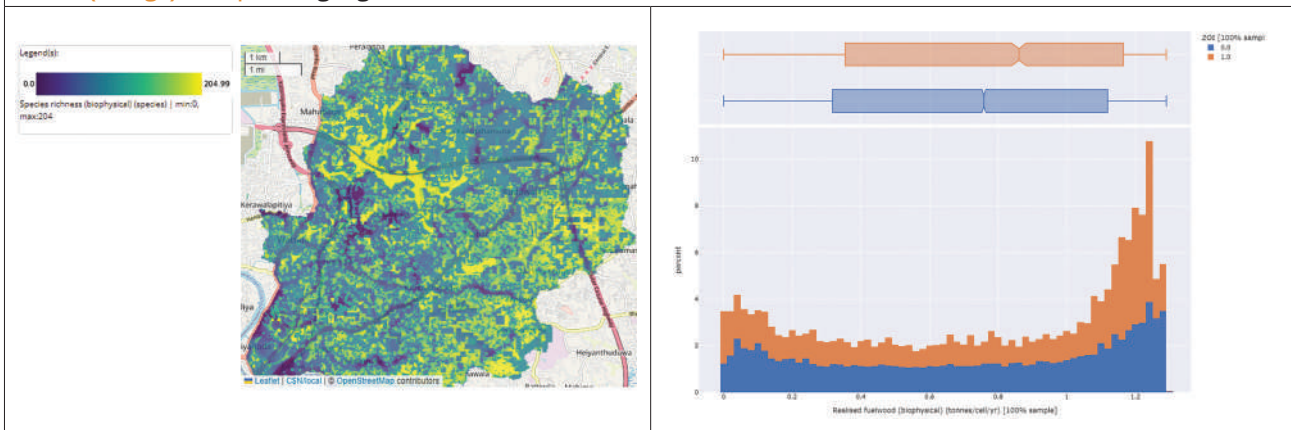
continued



Carbon stock (biophysical): This refers to the total amount of carbon stored above ground in vegetation and in at-risk soil within a specific area. Left: map; right: frequency distribution in wetlands (blue) and elsewhere (orange); box plots highlight higher values in wetlands than in other areas.

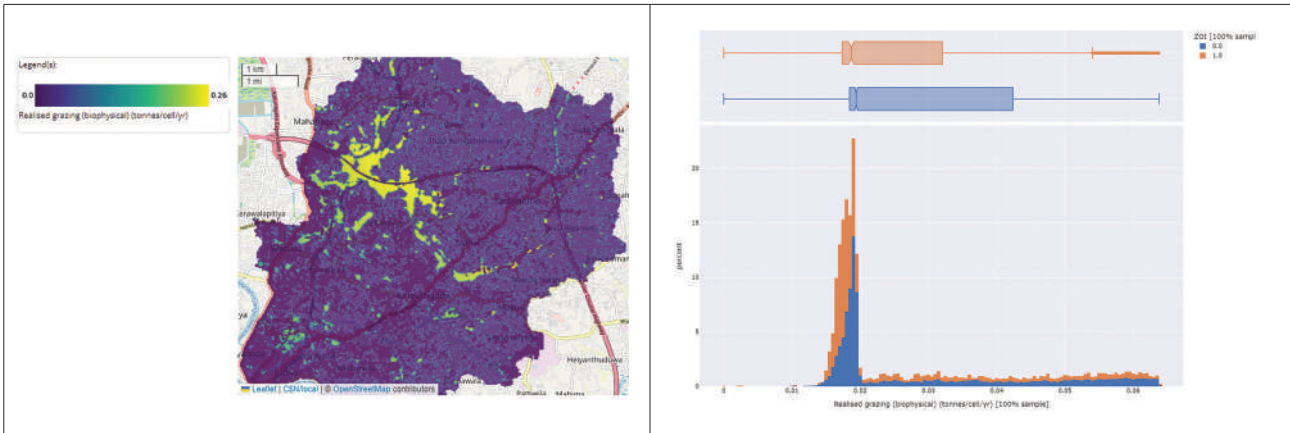


Realized fuelwood (biophysical): This refers to the amount of wood (t/year) that is harvested and used as fuel, derived from natural or managed ecosystems. Left: map; right: frequency distribution in wetlands (blue) and elsewhere (orange); box plots highlight lower values in wetlands than in other areas.

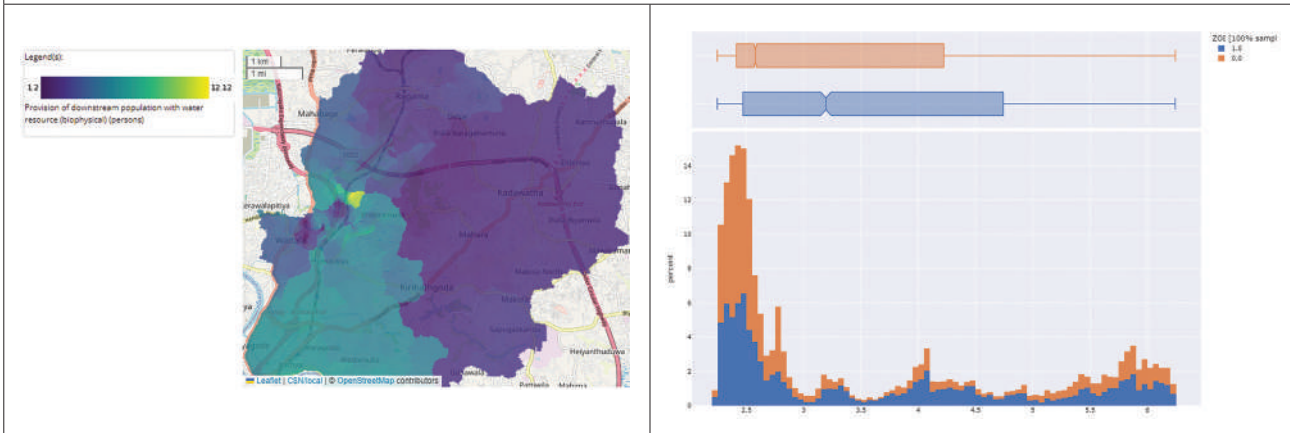


Realized grazing (biophysical): This refers to the actual grazing and fodder provision measured in tons per cell per year. Left: map; right: frequency distribution in wetlands (blue) and elsewhere (orange); box plots highlight high values in some wetlands but similar overall means.

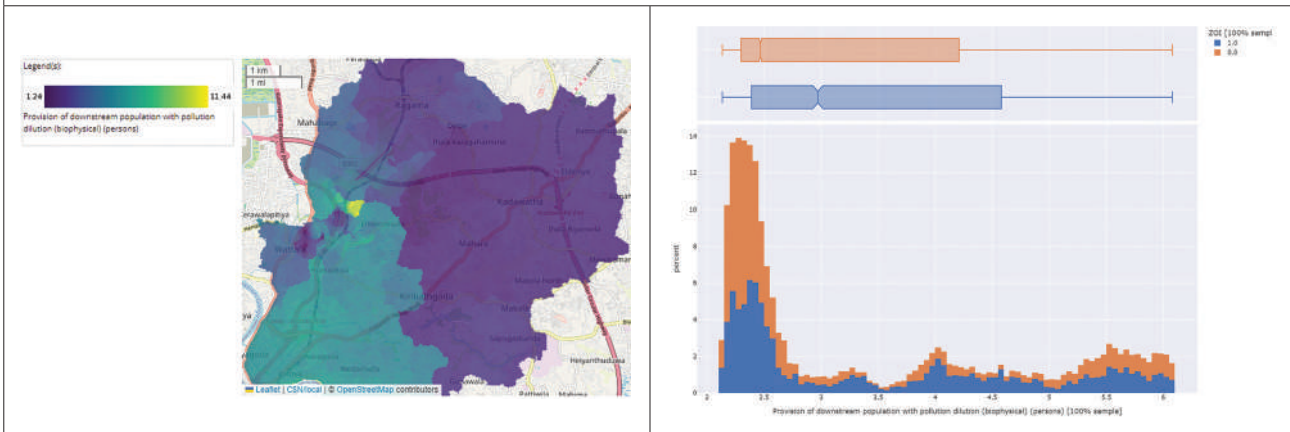
continued



Provision of downstream population with water resource (biophysical): This refers to the number of people who depend on the water resources provided by upstream ecosystems. Left: map; right: frequency distribution in wetlands (blue) and elsewhere (orange); box plots highlight higher values in wetlands than in other areas.

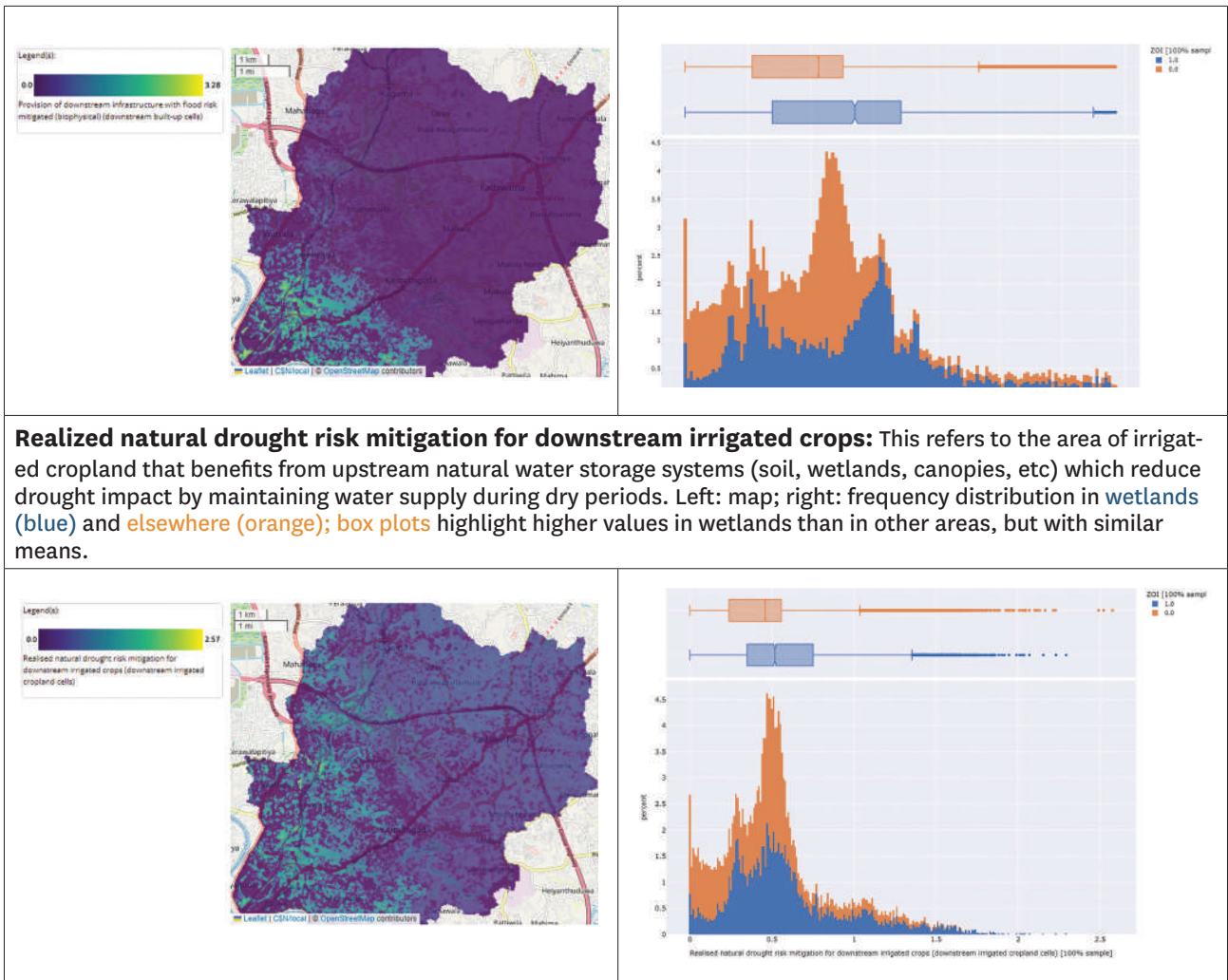


Provision of downstream population with pollution dilution (biophysical): This refers to the number of people benefiting from the natural processes that dilute and reduce pollution as water flows downstream. Left: map; right: frequency distribution in wetlands (blue) and elsewhere (orange); box plots highlight higher values in wetlands than in other areas.



Provision of downstream infrastructure with flood risk mitigated (biophysical): This refers to the percentage of built-up areas that benefit from reduced flood risk due to upstream ecosystems. Left: map; right: frequency distribution in wetlands (blue) and elsewhere (orange); box plots highlight higher values in wetlands than in other areas.

continued



Realized natural drought risk mitigation for downstream irrigated crops: This refers to the area of irrigated cropland that benefits from upstream natural water storage systems (soil, wetlands, canopies, etc) which reduce drought impact by maintaining water supply during dry periods. Left: map; right: frequency distribution in **wetlands (blue)** and **elsewhere (orange)**; **box plots** highlight higher values in wetlands than in other areas, but with similar means.

In moving from biophysical characterization to economic valuation, we first investigate the differences in value when using globally-assigned values versus locally-assigned values.

2.2.2 Conservation investments in the Kalu Oya and Mudun Ela basins

Based on the document Disclosure of information on development projects for general public as a right of the people - 2024 from the Sri Lanka Land Development Corporation (SLLDC), current land management investments in the Kalu Oya and Mudun Ela basins amount to between USD 11 million and 40 million/year. Distributed over 1,050 ha of wetland area in the basin, this amounts to between USD 10,377 and USD 38,219/ha/year, depending on which projects are included. This includes the USD 9.4 million/year, 6-year Kalu Oya Storm Water Drainage & Environment Improvement Project. These are considered current costs of land management/conservation against which benefits can be compared. We have used the upper value in the range to factor in the full costs of environmental management in the basin, beyond those reported in the list of projects.

Interventions include maintenance and rehabilitation of canals, lakes, and walkways; drainage improvements and flood remediation; upkeep of drainage structures, especially during rainy periods; and environmental and urban landscaping projects. There are also efforts toward wetland conservation, water quality enhancement, and installation of flood management systems. Projects focus on specific geographic areas, reflecting local needs and priorities.

In addition to these direct costs, we estimate the opportunity costs of retaining and maintaining nature in the basin as the mean GDP (nominal) of all non-natural land in the basin, multiplied over the remaining semi-natural land, reflecting the contribution that this land could make to total GDP, should it be developed like the rest of the developed basin.

2.2.3 Conservation investment scenario, global values

According to Sakalasooriya et al. (2021), the Kalu Oya and Mudun Ela basins have been divided into 18 sub-basins by SLLDC and cover 5 DSDs (Wattala, Mahara, Kelaniya, Biyagama, and Ja-Ela) with high population density. There are 135 Grama Niladhari Divisions in the 5 DSDs. The DSDs have a total population 501,988 and 134,404 housing units (Sakalasooriya 2021).

In this scenario, baseline ecosystem service values are produced alongside ROI on the current conservation investment. Valuations are based on global average values for each service derived from multiple sources and studies (Table 12 shows the default values in C\$/local). The key inputs used in the valuation are as follows:

- Baseline year: 2025;
- Time horizon: 2050;
- Discount rate: 3%/year;
- GDP growth rate: 5%/year;
- Investment in nature conservation/restoration at baseline: USD 38,219/ha/year; and
- Opportunity cost of retaining nature at baseline: USD 365.16/ha/year.

The inputs and outputs are given in Annex A.1.

TABLE 12. Globally applicable values from C\$/local based on literature survey (more details in Annex A.1).

Category	Biophysical value	Biophysical units	Value used (USD)	Economic units	Context and basis
Species richness	107	Species	126	USD/household/species/year	Willingness to pay (WTP): USD 5-126/household/year for conserving a single species, USD 18-194/household/year for a multi-species program.
Wildlife services	3.80 K	Hectares benefitting	600 (pollination + pest control)	USD/ha/year, where provided	Pollination: USD 314/ha/year in areas adjacent to nature reserves, USD 27/ha/year further away from crop-nature boundary. Pest control: USD 360 (apple orchards), USD 182 (pear orchards), USD 4-33 (soybean, aphid).
Realized fuelwood	46.42 K	T/year	50	USD/t/year	USA: USD 39; Canada: USD 93; UK: USD 80-145; Italy: USD 160-245; Dominican Republic: USD 20 (rural) to USD 50 (urban); and Democratic Republic of the Congo (DRC): USD 20-50.
Realized grazing	2.38 K	T/year	396	USD/t/year	Cultivated forage crops (global average): USD 396, USA pasture land value: USD 4,520, EU permanent grassland prices: USD 10,364 (average); from USD 2,150 (Bulgaria) to USD 63,000 (Austria).

continued

Category	Biophysical value	Biophysical units	Value used (USD)	Economic units	Context and basis
Carbon sequestration	93.99 K	T/year CO ₂ e	20	USD/t/yr CO ₂ e	Capture on emission: USD 15-25. Direct air capture: USD 600-1000, voluntary carbon markets: USD 8-30, Clean Development Mechanism (CDM): USD 25 (2008), USD 0.5 (2012); REDD+ USD 6-12.
Carbon stock	4.99 M	T/CO ₂ e	10	USD/t CO ₂ e	Voluntary carbon markets: USD 3-20, REDD+ projects (forests): USD 5-15 (avoided deforestation), high-quality conservation projects (e.g., peatland protection): USD 30-50.
Pollution dilution	278.71 K	Person benefitting	60	USD/person benefitting/year	WTP: Kenya: USD 4.50/ household, China: USD 45/household, USA: USD 78, USA and Canada: USD 21-257/household. Replacement: Catskills USA: USD 50-72/person/year over 10 years. USA Clean Water Act: USD 100/person/year.
Water resource	286.88 K	Person benefitting/year	60	USD/person benefitting/year	WTP: Kenya: USD 4.50/household, China: USD 45/household, USA: USD 78, USA and Canada: USD 21-257/household. Replacement: Catskills USA: USD 50-72/person/year over 10 years. USA Clean Water Act: USD 100/person/year.
Flood mitigation to infrastructure	17.68 K	m ² benefitting	150	USD/m ² benefitting/year	Residential: USD 32-108/m ² (minor damage), USD 100-300/m ² (moderate damage), USD 300-2,700/m ² (severe damage). Industrial: USD 108-756/m ² , road: USD 40-1,300/m ² , agriculture: USD 0.09-0.54/m ² . Damage costs: USA: USD 604-1,666/m ² /year. WTP (flood insurance): National Flood Insurance Program (USA): USD 4.58/m ² /year, Portland, USA: USD 2.23-2.76/m ² /year, UK/EU: USD 2.25/m ² /year.
Sedimentation mitigated	0	T/ha of reservoir mitigated	55	USD/t/ha mitigated/year	Dredging costs: USD 3-148/t.

continued

Category	Biophysical value	Biophysical units	Value used (USD)	Economic units	Context and basis
Drought mitigation irrigated crops	33.00 K	m ² of irrigated cropland benefitting	0.5	USD/m ² of irrigated cropland benefitting/year	Maize: USD 0.30/m ² /year, beans: USD 0.15/m ² /year. Irrigated cropland rent (USA): USD 0.0586-0.12/m ² /year.

Based on globally derived values, TEV is USD 1.47 billion over 25 years (Figure 8). The 2025 TEV (USD 93.91 million) is 2.92% of the 2025 study area GDP (USD 3.21 billion nominal). From 2025 to 2050 (25 years), TEV is 1.80% of area GDP, inflated and discounted over the period. Inflated and discounted investment and opportunity costs over the period, over 1,050 ha of semi-natural land in the study area, are USD 1.36 billion, comprising USD 1.34 billion in investment costs and USD 12.83 million in opportunity costs. The ROI (including opportunity cost) from TEV over the same period is 8.6 %, i.e. the inflated and discounted TEV is 8.62% higher than the total discounted costs. ROI declines over time because future ecosystem service benefits are discounted, reducing their present value. Simultaneously, GDP grows faster (5%) than the realizable growth in ecosystem service value, which is either front-loaded (like carbon stock) or, for some services, is not tied to GDP growth.

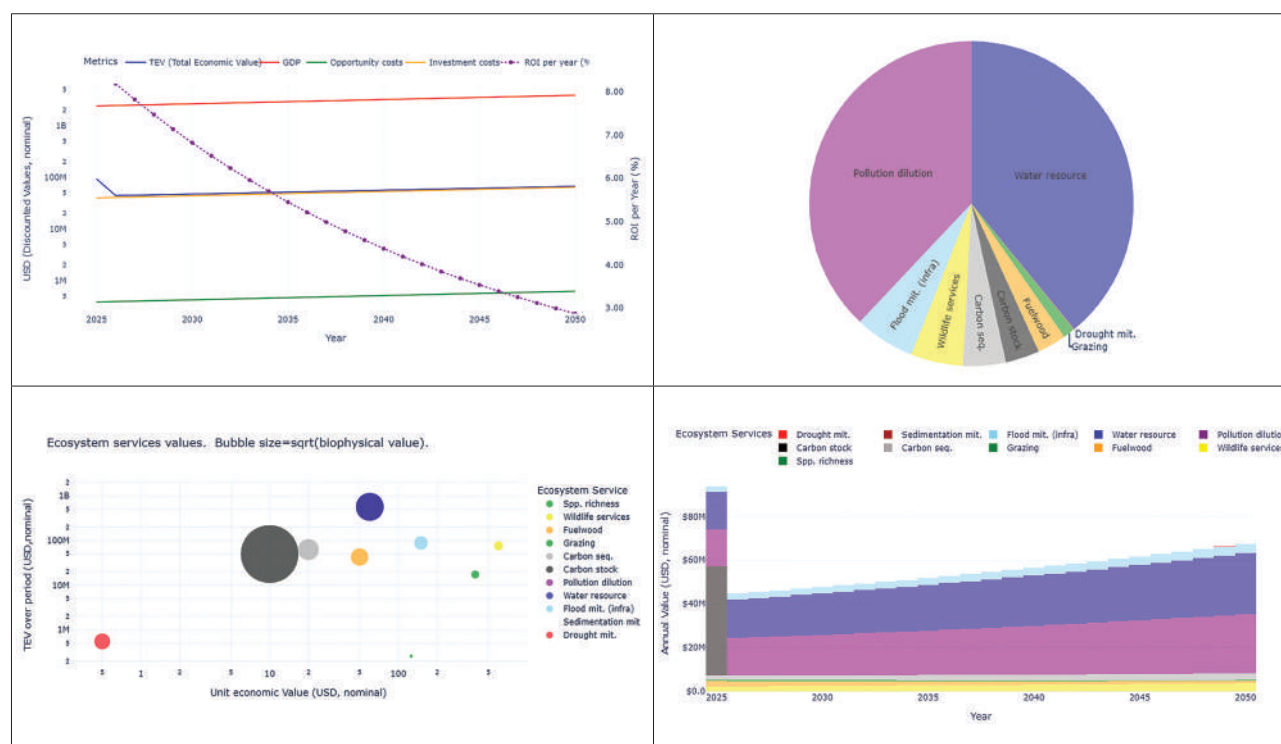


FIGURE 8. (Top left): Investment costs, TEV, GDP and ROI; (top right): Distribution of values across ecosystem services; (bottom left): Comparison of unit economic value, TEV and total biophysical value across the study area for each service; and (bottom right): Time series of service value given trends in GDP and discount rate.

Source: Authors' creation.

Based on globally derived values, water resource provision is the most economically significant ecosystem service, contributing 39.06% to the TEV, followed closely by pollution dilution at 37.95%. Flood risk mitigation accounts for 6.02%, with wildlife services contributing 5.18%. Carbon sequestration stands at 4.27% and carbon stock adds 3.39%. Realized fuelwood holds a share of 2.90%, and realized grazing contributes 1.18%. Natural drought risk mitigation contributes minimally at 0.04% and sediment mitigation records no economic value. Unit economic value combines with biophysical value to determine total economic value for each service. Some services (e.g., carbon) have high TEV on the basis of low unit value but high biophysical value. Others (e.g., wildlife services) have a low biophysical value but high unit value, resulting in a high TEV. With the specified GDP growth and discount rate, annual TEV grows over time; note that carbon stock is added to TEV only in the first year.

2.2.4 Conservation investment scenario, local values

In this scenario, baseline ecosystem service values are produced alongside ROI on the same conservation investment. This time, valuations for some services are based on local values calculated by IWMI (Table 13) where available, and global values are used where not available. The key inputs are as follows:

- Baseline year: 2025
- Time horizon: 2050
- Discount rate: 3%/year
- GDP growth rate: 5%/year
- Investment in nature conservation/restoration at baseline: USD 38,219/ha/year
- Opportunity cost of retaining nature at baseline: USD 365.16/ha/year

The inputs and outputs are given in Annex A.2.

TABLE 13. A summary of local values. For all other services, local values were used.

Ecosystem service	Use value (USD)	Notes
Wildlife services (USD/ha/year)	Paddy (<i>Yala</i>): 262; paddy (<i>Maha</i>): 163-425; rubber: 1.356; banana: 3,192; home garden: 3,263; perennial trees: 2,100; coconut: 299 Representative: USD 2,252/ha/year	It uses the value added (net income) approach annualized to NPV.
Realized fuelwood (USD/t/year)	Market: 108-261; benefit transfer: 221 Representative: USD 203/t/year. 78% of rural and 26% of urban households still use firewood for cooking. The Department of Census and Statistics (2018) estimated that approximately 72% of households still use firewood for cooking for various reasons.	Market: Based on three waves of nationwide Household Income and Expenditure Survey (HIES) data collected in 1990–1991, 2002, and 2016. Indicated value of firewood is USD 98/t. A higher value is however indicated in the retail market (USD 236.65/t) (Pallegedara and Kumara 2023). Benefit transfer: Values derived using the function estimated by Brander et al. (2006).
Realized grazing (USD/t/year)	Market value for fodder: USD 117-150 WTP: USD 100-117 Representative: USD 386/t/year Animal grazing is common in wetlands and 2.9% of the Kalu/Oya Mudun Ela basins feed animals like goats, cows, bulls, chicken, pigs, and ducks (Sakalasooriya 2021).	Market value from Gedara (2019): Hybrid Napier: Market price of USD 45.44/t, fodder sorghum: Market price of USD 75.73-90.60/t, fodder maize: market price of USD 106-136/t. WTP by dairy farmers: Silage: USD 151.46-227.2/t, green fodder: USD 90.6-106/t (Gedara 2019).
Carbon sequestration (USD/t/year CO _{2e})	Emissions Trading Scheme (ETS): Indonesia: 0.61, China: 12.57 Representative: USD 6.59/t/year CO _{2e}	Carbon pricing dashboard (World Bank 2025)

continued

Ecosystem service	Use value (USD)	Notes
Carbon stock (USD/t CO ₂ e)	ETS: Indonesia: 0.61, China: 12.57 Representative: USD 6.59/t CO ₂ e	Carbon pricing dashboard (World Bank 2025)
Flood mitigation (infra) (USD/m ² benefitting/year)	Max damage cost: USD 43,878/ha Replacement cost: USD 1,715/ha Benefit transfer 1: USD 1,711/ha Benefit transfer 2: USD 499-876 Representative: USD 6,198/ha Representative: USD 0.6198/m ² benefitting/year Maximum (damage costs): USD 4.38 /m ² benefitting/year	Replacement costs calculated as capital, operational, and maintenance costs for stormwater drainage plan with a discount rate of 12% and a time period of 59 years. Benefit transfer 1: Flood attenuation benefits provided by Muthurajawela wetland with similar characteristics (Emerton and Kekulandala 2003). Benefit transfer 2: Values derived using the function estimated by Chaikumbung et al. (2016) and Brander et al. (2006).
Drought mitigation irrigated crops (USD/m ² of irrigated cropland benefitting/year)	No local value available, global values used.	The Irrigation Department, Sri Lanka (n.d.) lists 15 irrigation projects in Gampaha with an irrigable area of 2,930 ha (Irrigation Department, Sri Lanka, n.d.). Many other areas will practice seasonal or occasional irrigation of parklands, gardens, and homesteads.

Based on locally derived values, TEV is USD 1.67 billion over 25 years (Figure 9). The TEV (USD 86.43 million) is 2.69% of the 2025 study area GDP (USD 3.21 billion nominal). From 2025 to 2050 (25 years), TEV is 2.04% of area GDP, inflated and discounted over the period. Inflated and discounted investment and opportunity costs over the period, over 1,050 ha of semi-natural land in the study area, are USD 1.36 billion, comprising USD 1.34 billion in investment costs and USD 12.83 million in opportunity costs. The ROI (including opportunity cost) from TEV over the same period is 23.01%, i.e., the inflated and discounted TEV is 23.01% higher than the total discounted costs.

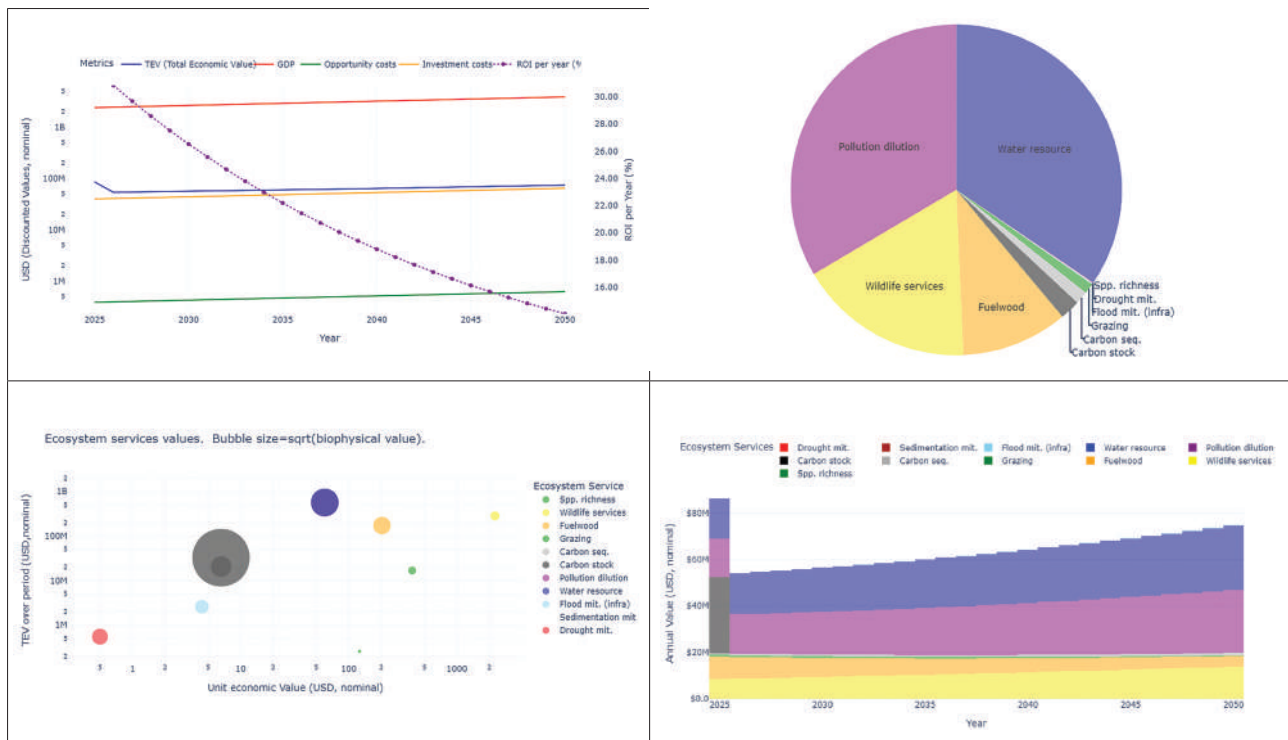


FIGURE 9. (Top left): Investment costs, TEV, GDP and ROI; (top right): Distribution of values across ecosystem services; (bottom left): Comparison of unit economic value, TEV, and total biophysical value across the study area for each service; and (bottom right): Time series of service value given trends in GDP and discount rate.

Source: Authors' creation.

For locally derived values, water resource provision takes up the greatest proportion of TEV, with 34.50% of the total economic value, followed by pollution dilution at 33.52%. Wildlife services are substantial, accounting for 17.16%, while flood risk mitigation is considerably lower at 0.16%. Realized fuelwood contributes 10.41%, and carbon stock is valued at 1.97%. Carbon sequestration stands at 1.24%, with realized grazing slightly less at 1.02%. The smallest contribution is from natural drought risk mitigation at 0.03%, with sediment mitigation showing no economic impact. With the specified GDP growth and discount rate, annual TEV grows over time; note that carbon stock is added to TEV only in the first year.

2.2.5 Distribution by land cover

The distribution of TEV between land covers was examined to understand priority areas for value creation and thus conservation investment. Both total TEV per land cover (a function of land cover) and mean TEV per land cover (an indicator of the TEV per unit area) were examined. Table 14 shows how total and mean TEV vary with land cover. The contribution of different land covers to TEV varies significantly based on total area and mean per unit contribution. Tree cover dominates TEV in both local (66.08%) and global (64.91%) values due to its extensive area, but its mean contribution is lower (51.65% in local, 50.47% in global). Built-up areas contribute 31.12% (local) and 32.21% (global), and their mean values are higher (~34%), indicating high TEV per unit area as a result of proximity of beneficiaries. This highlights the critical importance of urban and peri-urban nature to TEV. Wetlands represent a small percentage of total TEV (~2.7%) but high mean TEV (~11%), indicating their significance across a range of services. Minor variations exist between local and global valuations, with local values slightly prioritizing tree cover, given the importance of fuelwood, and global values slightly favoring built-up areas, given the greater values attributed to flood mitigation.

TABLE 14. Comparison of total and mean TEV by land cover under local and global valuations.

Local values, chart	Total Economic Value, total by land use	Total Economic Value, average by land use
Local values, statistics	Percentage of TEV, total and average land by use: Wetland: 2.64% (avg: 10.72%); tree cover: 66.08% (avg: 51.65%); shrubland: 0% (avg: 0.01%); grassland: 0.14% (avg: 2.60%); cropland: 0.02% (avg: 0.87%); built-up: 31.12% (avg: 33.95%); bare/sparse vegetation: 0% (avg: 0.11%); permanent water bodies: 0% (avg: 0.06%); and herbaceous wetland: 0% (avg: 0.02%).	
Global values, chart	Total Economic Value, total by land use	Total Economic Value, average by land use
Global values, statistics		
	Percentage of TEV, total and average land by use: Wetland: 2.72% (avg: 10.99%); tree cover: 64.91% (avg: 50.47%); shrubland: 0.00% (avg: 0.01%); grassland: 0.14% (avg: 2.59%); cropland: 0.02% (avg: 0.80%); built-up: 32.21% (avg: 34.95%); bare/sparse vegetation: 0% (avg: 0.12%); permanent water bodies: 0% (avg: 0.06%); and herbaceous wetland: 0% (avg: 0.02%).	

Source: Authors' creation.

2.2.6 Comparison of globally tuned vs locally tuned valuation

The scenarios based on local versus global values result in different economic outcomes. A valuation based on global numbers gives a TEV of USD 1.49 billion with an ROI of 5.80%, reflecting a slightly higher contribution of TEV to GDP at 0.77% in 2025, decreasing to 0.48% over 25 years. Locally-derived TEV totals USD 1.67 billion, achieving a significantly higher ROI of 19.82%, with TEV contributing 0.70% to GDP in 2025 and increasing to 0.53% over the same period. Locally-derived values are higher for some widely used services and this results in higher TEV. Whether using globally-derived or locally-derived values, the current expenditure on environmental management by SLLDC earns an ROI between ~6% and ~20%. An ROI of 6% means that the returns (or benefits) from an investment are 6% higher than the total costs of that investment over a specified period. In other words, for every USD 1 invested, the investor receives USD 1.06 in total.

The much lower flood mitigation value based on local data reflects the dominantly agricultural nature of areas flooded in recent floods, leading to lower values. In the 2010 floods, the flood mitigation values were as follows: Residential – 1%, commercial – 1%, industrial – 2%, infrastructure – 3%, institutional (schools, colleges, churches) – 3%, public utility – 1%, and agricultural – 89%. Similarly, inundation in the 2016 floods was as follows – residential – 1%, commercial – 2%, industrial – 5%, infrastructure – 8%, institutional (schools, colleges, churches) – 2%, public utility – 2%, and agricultural – 78%.

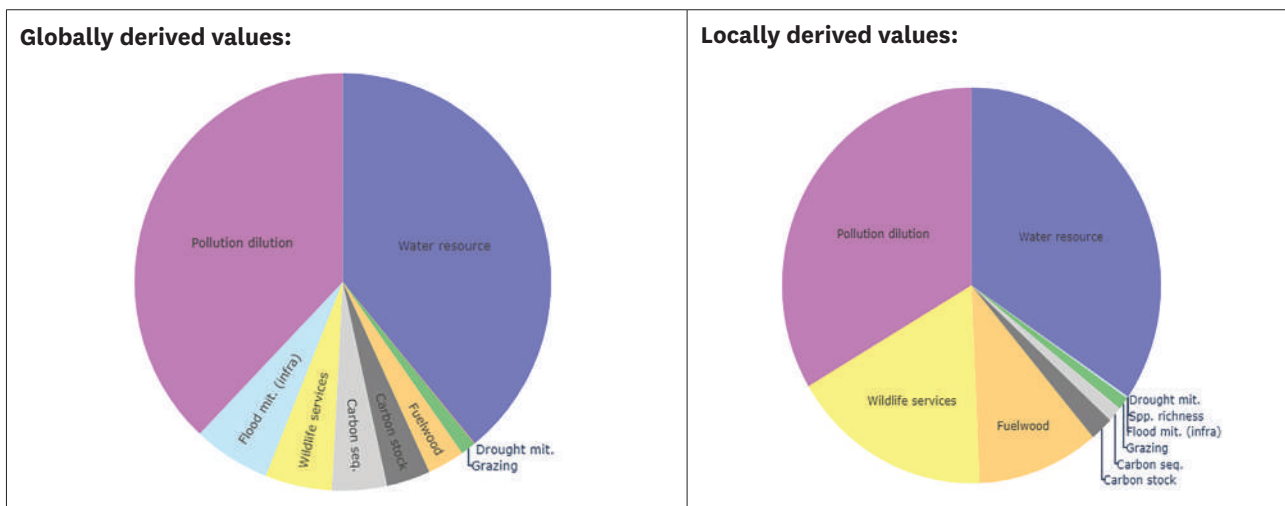


FIGURE 10. A comparison of the distribution of value across services derived from globally-sourced and locally-sourced values.
Source: Authors' creation.

Valuation based on global numbers show the most substantial contributions from water resource provision and pollution dilution, accounting for 39.06% and 37.95%, respectively (Table 15). Conversely, using local values showed water resource provision's contribution slightly reduced to 34.49% but still leading, followed by pollution dilution at 33.51%. Notably, the contribution of wildlife services in the local valuation rose significantly to 17.16%, contrasting with the global valuation at 5.18%. Realized fuelwood also shows a marked increase locally (10.41%) compared to globally (2.90%). In contrast, carbon sequestration and carbon stock values drop locally by 3.03% and 1.42%, respectively (Figure 10). Additionally, flood risk mitigation shows a significant decline from 6.02% globally to 0.16% locally. This variance underscores the importance of localized valuation of ecosystem services reflecting regional dependencies which prioritize provisioning services.

Locally specific valuations shift economic emphasis toward provisioning services such as wildlife services (+11.98%) and realized fuelwood (+7.51%), reflecting regional dependencies and economic realities. These increases suggest that local conservation investments would be more focused on biodiversity-related and resource-based services compared to global estimates, which place greater weight on regulatory services. Conversely, carbon sequestration (-3.03%) and carbon stock (-1.42%) have lower valuations locally, implying that climate-related ecosystem services may receive less investment priority at the local level due to their less immediate economic returns. Similarly, flood risk mitigation declines sharply (-5.86%), suggesting that infrastructure protection benefits may be undervalued locally compared to broader global assessments.

For policymakers, this highlights the importance of balancing local priorities with long-term sustainability. While local valuations ensure relevance to regional economic and social needs, they may undervalue critical regulatory services with broad, long-term benefits. Conservation funding strategies should therefore integrate local valuations while

ensuring that global priorities such as carbon sequestration and flood mitigation are not neglected. Ultimately, locally-adapted conservation investments should align with immediate regional benefits while securing funding for globally significant ecosystem functions to ensure comprehensive and sustainable ecosystem management.

TABLE 15. A comparison of per service values based on global versus local valuation preferences.

Ecosystem service	Globally-derived economic value (USD)	Global (%)	Locally-derived economic value (USD)	Local (%)	Difference in economic value (USD)	Difference (%)
Species richness	258.22 K	0.02	258.22 K	0.02	0	0
Wildlife services	76.24 M	5.18	286.01 M	17.16	209.77 M	11.98
Realized fuelwood	42.74 M	2.90	173.52 M	10.41	130.78 M	7.51
Realized grazing	17.37 M	1.18	16.93 M	1.02	-0.44 M	-0.16
Carbon sequestration	62.81 M	4.27	20.69 M	1.24	-42.12 M	-3.03
Carbon stock	49.87 M	3.39	32.86 M	1.97	-17.01 M	-1.42
Pollution dilution	558.71 M	37.95	558.71 M	33.51	0	-4.44
Water resource provision	575.09 M	39.06	575.09 M	34.49	0	-4.57
Flood risk mitigation	88.62 M	6.02	2.59 M	0.16	-86.03 M	-5.86
Sediment mitigation	0	0	0	0	0	0
Drought risk mitigation	551.24 K	0.04	551.24 K	0.03	0	-0.01

Note: Further valuation studies are presented in Annex A.3.

2.2.7 Valuation uncertainty

Here the impact of adjusting the estimated values of ecosystem services within their potential upper and lower bounds is examined (Table 16). This analysis helps in understanding how valuation ambiguity impacts the TEV and the ROI for conservation efforts, alongside the distribution of value across different services. By incorporating a range of probable valuations, we can assess the sensitivity of economic outcomes to changes in perceived ecosystem service values. We change valuations one at a time keeping all other values as those defined by the local valuation process.

- Baseline year: 2025
- Time horizon: 2050
- Discount rate: 3%/year
- GDP growth rate: 5%/year
- Investment in nature conservation/restoration at baseline: USD 38,219/ha/year
- Opportunity cost of retaining nature at baseline: USD 365.16/ha/year

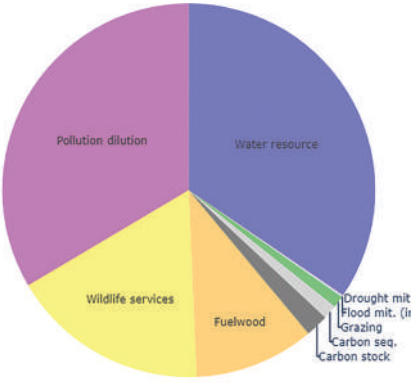
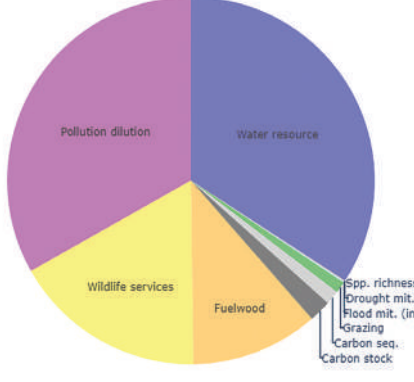
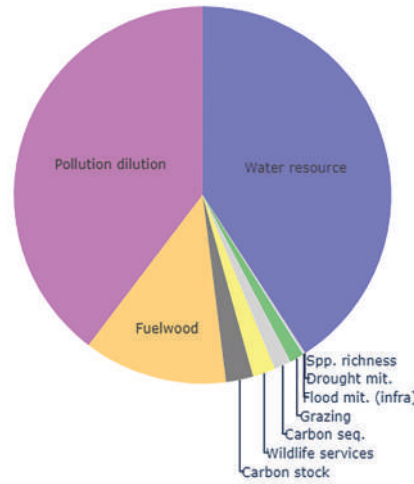
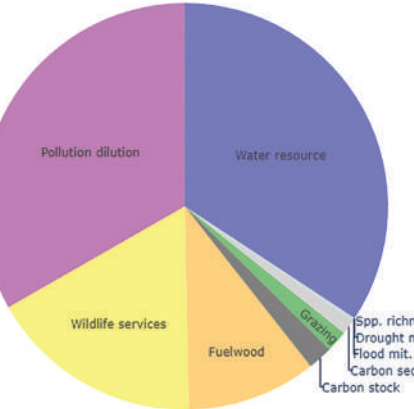
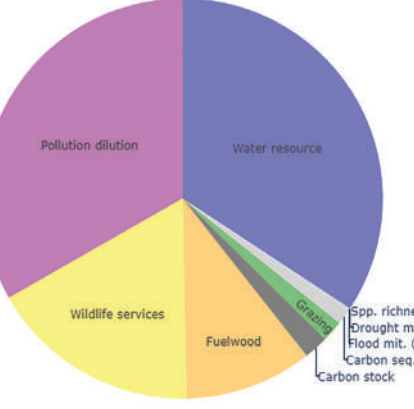
TABLE 16. Lower and upper values used to examine uncertainties in economic valuation.

Ecosystem service	Units	Default local value used (USD)	Lower value based on global studies (USD)	Upper value based on global studies (USD)	Source
Species richness	USD/household/species/year	126	5	126	Global
Wildlife services	USD/ha/year, where provided	2251	214	501	Global
Realized fuelwood	USD/t/year	203	184.5 (market)	221 (benefit transfer)	Local
Realized grazing	USD/t/year	386	108.5 (WTP)	663.5 (market)	Local
Carbon sequestration	USD/t/year CO ₂ e	6.59	0.61	12.57	Local
Carbon stock	USD/t CO ₂ e	6.59	0.61	12.57	Local
Pollution dilution	USD/person benefitting/year	60	4.5	257	Global
Water resource	USD/person benefitting/year	60	4.5	257	Global
Flood mitigation infrastructure	USD/m ² benefitting/year	4.38	32	2,700	Global
Sedimentation mitigated	USD/t/ha mitigated/year	55	3	148	Global
Drought mitigation Irrigated crops	USD/m ² of irrigated cropland benefitting/year	0.5	0.0586	0.30	Global

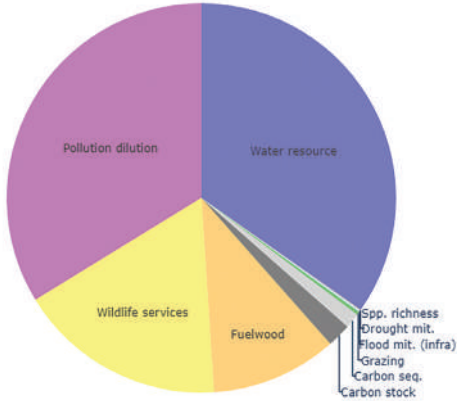
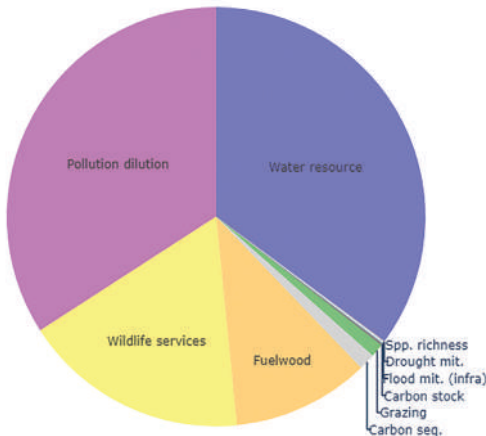
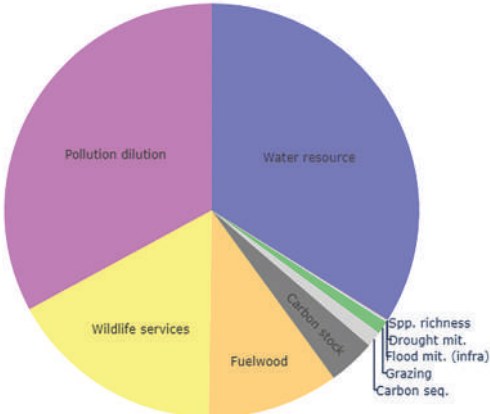
In each case, a value for only one service was changed between lower and upper values and the implications for TEV, ROI, and distribution of TEV between services was determined. The biophysical service values remained the same in each case.

The sensitivity analysis highlights that TEV and ROI are highly dependent on the assigned values of specific ecosystem services, with significant investment implications (Table 17). Water resource provision and pollution dilution exhibit the greatest influence, where higher valuations dramatically increase TEV and ROI. For example, increasing water resource value from USD 4.5-257 raises TEV from USD 1.14 billion to 3.56 billion and ROI from -18.43% to 155.47%, shifting conservation investments from economically unviable to highly profitable. Similarly, flood mitigation shows a sharp ROI increase per unit area, from 20.97% at USD 32/m² to 134.23% at USD 2,700/m², emphasizing its importance in protecting infrastructure. In contrast, species richness has negligible economic impact, with ROI remaining between 19.78% and 19.80%. Carbon sequestration and carbon stock contribute moderately, raising ROI by 3-4%, while realized fuelwood and grazing provide small but consistent gains (~2%). Sedimentation mitigation and drought mitigation for irrigated crops show little to no impact, suggesting these services are under-represented economically.

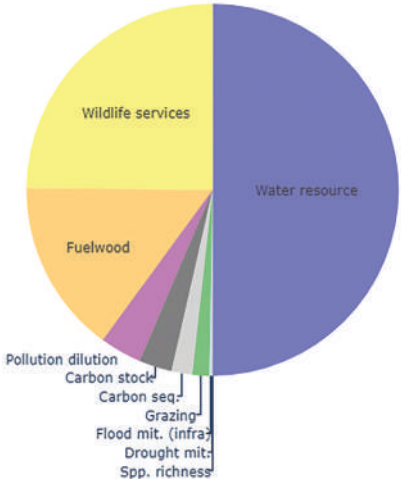
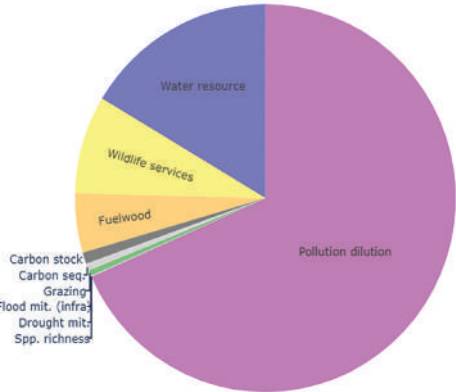
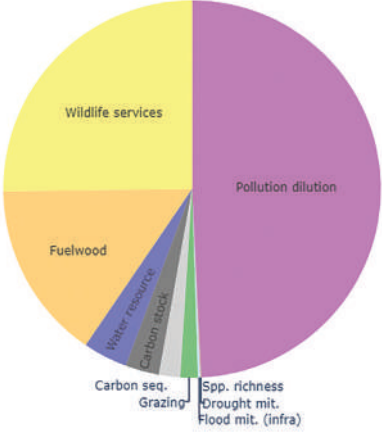
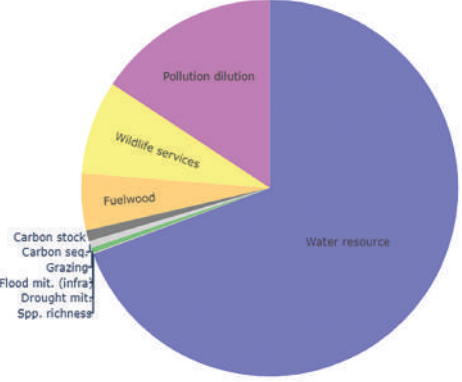
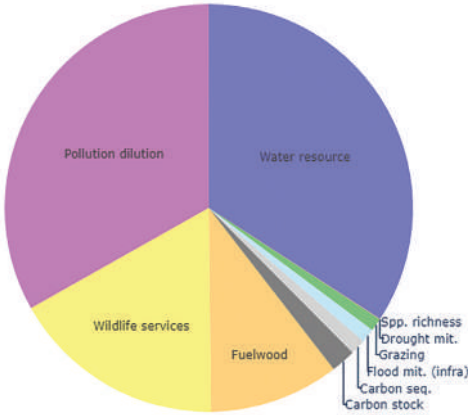
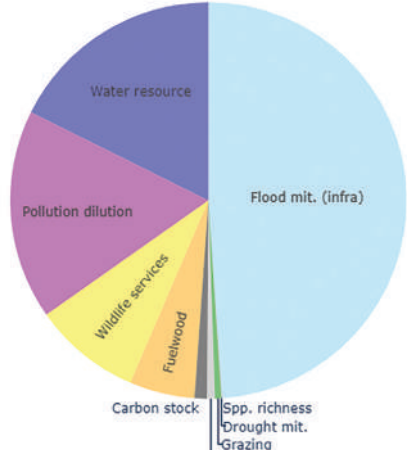
TABLE 17. Sensitivity of TEV and ROI to the ecosystem service unit values used.

Ecosystem service	Lower value outcomes	Upper value outcomes
<p>Species richness</p>	<p>Value: USD 5 TEV: USD 1.67 billion over 25 years ROI: 19.78%</p> 	<p>Value: USD 126 TEV: USD 1.67 billion over 25 years ROI: 19.80%</p> 
<p>Wildlife services</p>	<p>Value: USD 214 TEV: USD 1.41 billion over 25 years ROI: 1.20%</p> 	<p>Value: USD 501 TEV: USD 1.44 billion over 25 years ROI: 3.82%</p> 
<p>Realized fuelwood</p>	<p>Value: USD 184.5 TEV: USD 1.65 billion over 25 years ROI: 18.66%</p> 	<p>Value: USD 221 TEV: USD 1.68 billion over 25 years ROI: 20.90%</p> 

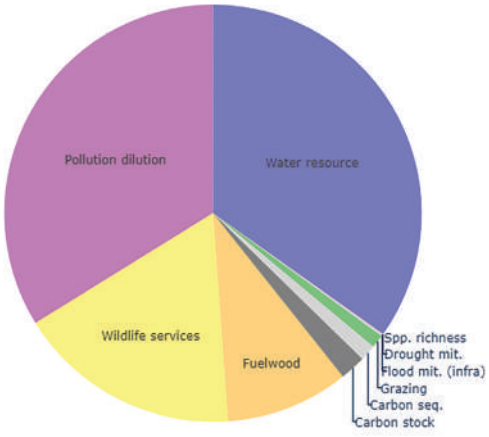
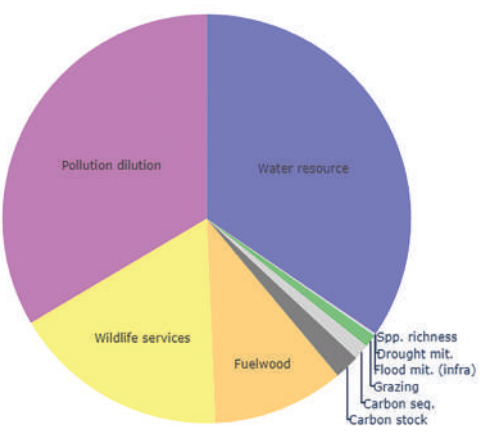
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Ecosystem service	Lower value outcomes	Upper value outcomes
<p>Realized grazing</p>	<p>Value: USD 108.5 TEV: USD 1.66 billion over 25 years ROI: 18.92%</p> 	<p>Value: USD 663.5 TEV: USD 1.68 billion over 25 years ROI: 20.67%</p> 
<p>Carbon sequestration</p>	<p>Value: USD 0.61 TEV: USD 1.65 billion over 25 years ROI: 18.45%</p> 	<p>Value: USD 12.57 TEV: USD 1.69 billion over 25 years ROI: 21.15%</p> 
<p>Carbon stock</p>	<p>Value: USD 0.61 TEV: USD 1.64 billion over 25 years ROI: 17.65%</p> 	<p>Value: USD 12.57 TEV: USD 1.70 billion over 25 years ROI: 21.94%</p> 

continued

Ecosystem service	Lower value outcomes	Upper value outcomes
Pollution dilution	<p>Value: USD 4.5 TEV: USD 1.15 billion over 25 years ROI: -17.34%</p> 	<p>Value: USD 257 TEV: USD 3.50 billion over 25 years ROI: 151.61%</p> 
Water resource	<p>Value: USD 4.5 TEV: USD 11.14 billion over 25 years ROI: -18.43%</p> 	<p>Value: USD 257 TEV: USD 3.56 billion over 25 years ROI: 155.47%</p> 
Flood mitigation infrastructure	<p>Value: USD 32D TEV: USD 11.68 billion over 25 years ROI: 20.97%</p> 	<p>Value: USD 2700 TEV: USD 3.26 billion over 25 years ROI: 134.23%</p> 

continued

Ecosystem service	Lower value outcomes	Upper value outcomes
Sedimentation mitigated	Since there are no significant reservoirs, changing this value makes no difference to the outcome.	
Drought mitigation irrigated crops	Value: USD 0.0586 TEV: USD 1.67 billion over 25 years ROI: 19.76% 	Value: USD 0.30 TEV: USD 1.67 billion over 25 years ROI: 19.78% 

Source: Authors' creation.

2.2.8 Land use change and climate change impacts on flood mitigation

Here the effects of land use and climate change on the valuation of ecosystem services are examined. Deliverable 3 under this project produced climate change and land use scenarios for the Kalu Oya and Mudun Ela basins using shared economic pathways. These are global development scenarios that explore future societal, economic, and environmental trends for climate change research. Both types of scenarios are expected to affect the supply of and demand for a range of services but the particular focus here is to understand the impact of both on the value of the Kalu Oya and Mudun Ela wetlands for flood mitigation services. Both climate and land use changes are happening and will continue to happen concurrently in the basins. The scenarios conducted in this project show that by 2050 business as usual urbanization leads to a loss of 33.08% in providing the downstream population with flood mitigation (biophysical), equaling 78,365 people. The remaining service is 66.92% of its original value of 236,894 people (assuming demand remains constant). Scarcity increases its value by 49% (116,078 people). At the same time, climate change is expected to increase the magnitude of events, and urbanization increases the value of assets on the floodplain. The damage costs of the 2016 flood were estimated at USD 20,680/ha and of the 2020 flood at USD 43,879/ha. Both floods were considered one in 50-year events (Wagenaar et al. 2019). Analysis of CMIP6 climate change data in deliverable 3 of this project shows an increase in the frequency of high intensity rainfall in the range +1.85 days/year (~0.5%). Finally, changes in urbanization projected for 2025-2050 in deliverable 3 of this project are 30% in 2050 compared to 2025. Combining these impacts, we would need to multiply the baseline unit valuation by 1.49 to account for the greater unit value of the remaining service provision, multiply by 1.05 to account for climate change, and by 1.3 to account for increased exposure. In total, the unit value should thus increase by 2.84 (1.49+0.05+1.3). We multiply the global value (USD 150/ha) for the service since this is more reflective of a highly urbanized floodplain than the local value; all other services remain at their local values.

- Baseline year: 2025
- Time horizon: 2050
- Discount rate: 3%/year
- GDP growth rate: 5%/year
- Investment in nature conservation/restoration at baseline: USD 38,219/ha/year
- Opportunity cost of retaining nature at baseline: USD 1.40 K//ha/year
- Multiply global value (USD 150/ha) of flood mitigation service by 2.84 (USD 426/ha)

Table 18 compares this climate and land use change scenario with the baseline local valuation to assess the relevance of this change for TEV and ROI. The inclusion of climate and land use change significantly increases TEV and ROI compared to the baseline. TEV rises from 1.67 billion to -1.92 billion, and ROI improves from 19.80% to 37.70%, reflecting higher valuation of flood mitigation services (USD 426/ha vs USD 4.38/ha) as exposure to flood risk increases with further urbanization and flood hazard potential increases with climate change. Wetland contribution to total TEV increases slightly from 2.64% to 2.71%, with average TEV per unit area for wetlands rising from 10.72% to 11.09%, indicating the continued importance of other land covers and ecosystem services under land use and climate change. Tree cover also shows a higher contribution under climate change, since it is a source of flood mitigation.

TABLE 18. Comparison of outcomes under baseline and business as usual climate and land use change scenarios.

Scenario	Outcomes
Local valuation (USD 4.38/ha)	<p>The return on investment (including opportunity cost) from TEV over the same period is 19.80%, i.e. the inflated and discounted TEV is 19.80% higher than the total discounted costs.</p> <p>Percentage of TEV, total, and average by land use: Wetland: 2.64% (avg 10.72%); tree cover: 66.08% (avg 51.65%); shrubland: 0% (avg 0.01%); grassland: 0.14% (avg 2.60%); cropland: 0.02% (avg 0.87%); built-up: 31.12% (avg 33.95%); bare/sparse vegetation: 0% (avg 0.11%); permanent water bodies: 0% (avg 0.06%); and herbaceous wetland: 0% (avg 0.02%).</p>
Local valuation with climate and land use changes (USD 426/ha)	<p>The return on investment (including opportunity cost) from TEV over the same period is 37.70%, i.e. the inflated and discounted TEV is 37.70% higher than the total discounted costs.</p> <p>Percentage of TEV, total, and average by land use: Wetland: 2.71% (avg 11.09%); tree cover: 68.64% (avg 54.06%); shrubland: 0% (avg 0.01%); grassland: 0.14% (avg 2.51%); cropland: 0.02% (avg 0.82%); built-up: 28.49% (avg 31.31%); bare/sparse vegetation: 0% (avg 0.11%); permanent water bodies: 0% (avg 0.06%); and herbaceous wetland: 0% (avg 0.02%).</p>

2.2.9 Land use change and climate change impacts across all services

It is impossible to consider all impacts of climate and land use change on all services. These impacts include the greater unit value of a diminished service, the greater demand for some services resulting from urbanization, and the greater requirement for some services under climate change. We attempt as many as possible in Table 19; all others remain at their local values.

TABLE 19. Inputs used to represent impacts of business as usual climate and land use changes on ecosystem service valuation.

Ecosystem service	Baseline use value (USD)	Use value under climate and land use changes (USD)	Climate and land use changes unit value
Species richness (USD/household/species/year)	126	Decreased availability multiplier: 1.48	~186
Realized fuelwood (USD/t/year)	203	Decreased availability multiplier: 1.59	~323
Realized grazing (USD/t/year)	386	Decreased availability multiplier: 2.11	~814
Carbon sequestration (USD/t/year CO ₂ e)	6.59	Decreased availability multiplier: 1.85	~12
Carbon stock (USD/t CO ₂ e)	6.59	Decreased availability multiplier: 1.93	~13

continued

Ecosystem service	Baseline use value (USD)	Use value under climate and land use changes (USD)	Climate and land use changes unit value
Providing downstream population with pollution dilution (USD/person/year)	60	Decreased availability multiplier: 1.31 Increased demand multiplier: 1.3 Climate change multiplier: Uncertain	156.6
Providing downstream population with water resource (USD/person/year)	60	Decreased availability multiplier: 1.31 Increased demand multiplier: 1.3 Climate change multiplier: Uncertain	156.6
Providing downstream infrastructure with flood risk mitigated (USD/m ² /year)	150	Decreased availability multiplier: 1.40 Increased demand multiplier: 1.3 Climate change multiplier: 0.05	426

Table 20 shows the results of the scenario which includes climate and land use change impacts relative to the (baseline) local valuation. It shows a substantial increase in TEV to USD 3.91 billion, more than doubling the baseline USD 1.67 billion. The ROI also jumps significantly to 181.11%, reflecting higher perceived benefits relative to costs. Wetlands' contribution to total TEV remains stable at around 2.65%, with a slight increase in average contribution (10.75%). Tree cover's share drops slightly from 66.08% to 65.07%, while that of built-up areas rises to 32.13%, reflecting the greater value associated with services that are produced in peri-urban areas. The higher TEV and ROI in the scenario highlights the increased economic value of ecosystem services under changing conditions, emphasizing the importance of integrating climate and land use factors into conservation planning.

TABLE 20. Outcomes of multiple service analysis of the impact of business as usual climate and land use changes.

Scenario	Outcomes
Local valuation (USD 4.38/ha)	<p>TEV is USD 1.67 billion over 25 years. From 2025 to 2050 (25 years), TEV is 0.53% of the area GDP, inflated and discounted over the period. Inflated and discounted investment and opportunity costs over the period are over USD 1.05 K/ha of semi-natural land in the study area, and total USD 1.39 billion, comprising USD 1.34 billion in investment costs and USD 49.18 million in opportunity costs. The ROI (including opportunity cost) from TEV over the same period is 19.80%, i.e. the inflated and discounted TEV is 19.80% higher than the total discounted costs.</p> <p>Percentage of TEV, total, and average by land use: Wetland: 2.64% (avg 10.72%); tree cover: 66.08% (avg 51.65%); shrubland: 0% (avg 0.01%); grassland: 0.14% (avg 2.60%); cropland: 0.02% (avg 0.87%); built-up: 31.12% (avg 33.95%); bare/sparse vegetation: 0% (avg 0.11%); permanent water bodies: 0% (avg 0.06%); and herbaceous wetland: 0% (avg 0.02%).</p>

continued

Scenario	Outcomes
Local valuation with climate and land use change impacts across many services	<p>TEV is USD 3.91 billion over 25 years. From 2025 to 2050 (25 years), TEV is 1.25% of area GDP, inflated and discounted over the period. Inflated and discounted investment and opportunity costs over the period are over USD 1.05 K/ha of semi-natural land in the study area, and are a total of USD 1.39 billion, comprising USD 1.34 billion in investment costs and USD 49.18 million in opportunity costs. The return on investment (including opportunity cost) from TEV over the same period is 181.11%, i.e. the inflated and discounted TEV is 181.11% higher than the total discounted costs.</p> <p>Percentage of TEV, total, and average by land use: Wetland: 2.65% (avg 10.75%); tree cover: 65.07% (avg 50.81%); shrubland: 0% (avg 0.01%); grassland: 0.14% (avg 2.47%); cropland: 0.02% (avg 0.77%); built-up: 32.13% (avg 35.01%); bare/sparse vegetation: 0% (avg 0.11%); permanent water bodies: 0% (avg 0.06%); and herbaceous wetland: 0% (avg 0.02%).</p>

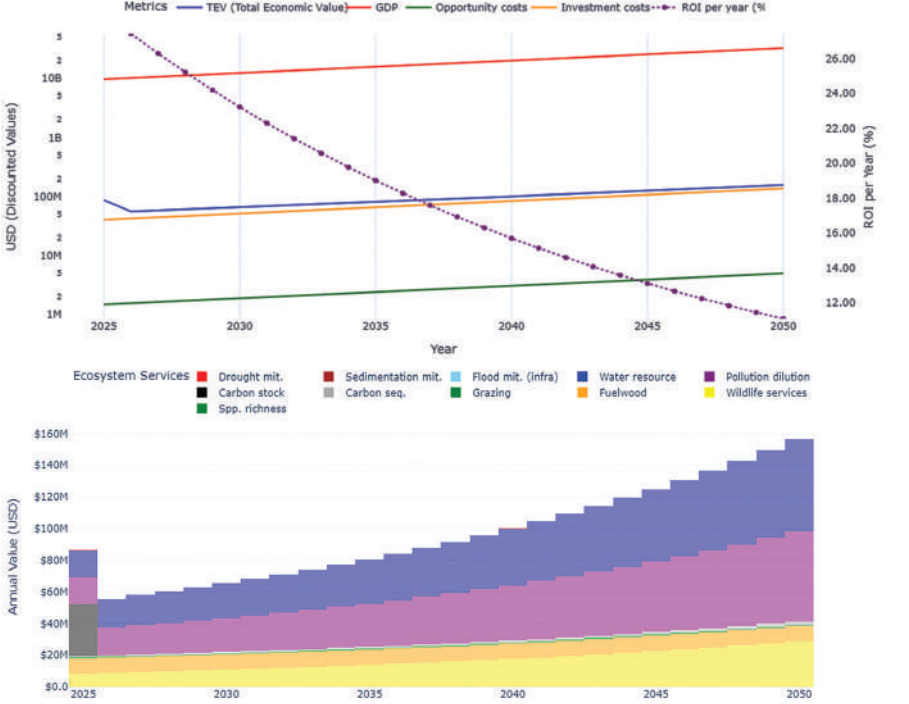
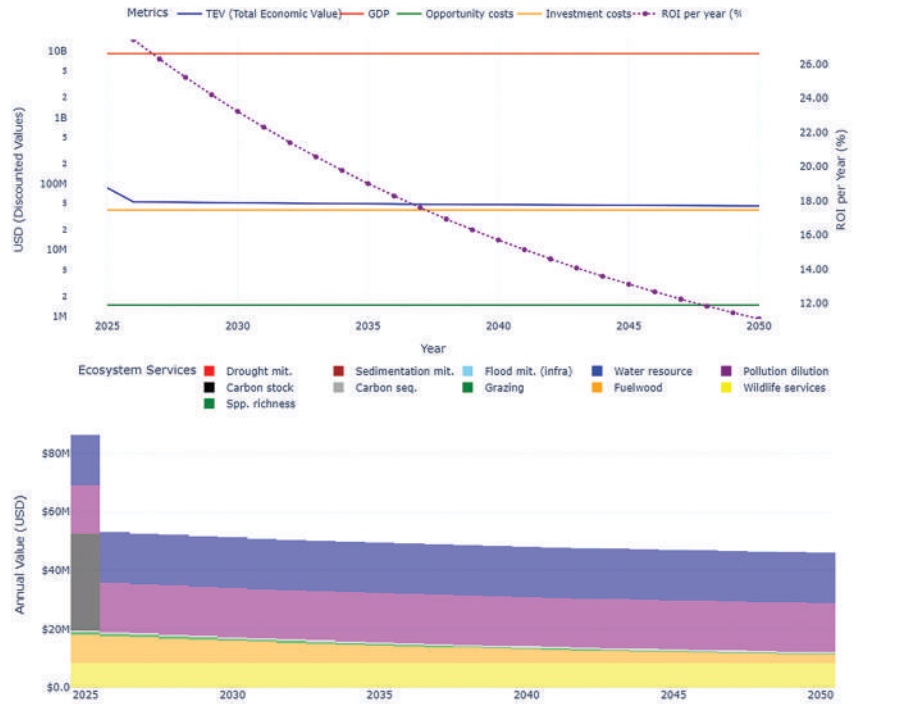
2.2.10 Discount rate sensitivity analysis

Here the effect of discount rates on long-term ecosystem service values is examined by running the model with discount rates ranging from 0% to 10%. The impacts of climate and land use changes have not been incorporated here as the focus is only on understanding discount rate impacts. Higher discount rates will significantly reduce the present value of future benefits, especially for services with long-term returns (e.g., carbon sequestration, species richness). Discounting reflects the preference for immediate benefits over future ones. As the discount rate increases, future ecosystem services contribute less to total valuation, favoring short-term economic gains over long-term sustainability.

- Baseline year: 2025
- Time horizon: 2050
- Discount rate: 0-20%/year
- GDP growth rate: 5%/year
- Investment in nature conservation/restoration at baseline: USD 38,219/ha/year
- Opportunity cost of retaining nature at baseline: USD 1.40 K/ha/year

Results in Table 21 reflect expected economic valuation trends, where increasing the discount rate reduces TEV, alters its relationship with GDP, and increases ROI. At 0%, TEV is USD 2.51 billion, declining non-linearly to USD 1.31 billion (5%), USD 804.24 million (10%), and USD 560.41 million (15%), as higher discount rates diminish future values. TEV as a percentage of GDP rises from 0.51% to 0.64%, as TEV shrinks faster than the GDP. ROI increases from 17.92% (0%) to 29.12% (15%), since future ecosystem benefits are discounted more aggressively than investment costs. TEV declines non-linearly over time at high discount rates, demonstrating short-term bias. Low discount rates emphasize conservation by preserving future benefits, while higher rates prioritize short-term economic returns. This reinforces the trade-off between immediate costs and future gains, aligning with economic theory and influencing policy decisions on ecosystem investment. The results highlight a critical trade-off in conservation investment. Low discount rates (0-5%) preserve the long-term economic value of ecosystem services, making conservation investments more economically justified by emphasizing future benefits. However, as the discount rate increases (10-15%), TEV declines rapidly, reducing the perceived long-term value of conservation projects and making short-term economic alternatives appear more attractive. A higher ROI at higher discount rates (29.12% at 15%) suggests that short-term conservation projects appear more financially viable, but this is misleading since future ecosystem benefits are disproportionately devalued. This bias toward immediate returns may lead to underinvestment in long-term conservation efforts, particularly for services with delayed payoffs, like carbon sequestration, biodiversity protection, and watershed restoration. Policy decisions must balance economic efficiency with sustainability, using lower discount rates for conservation investments to avoid undervaluing ecosystem benefits essential for future resilience and economic stability.

TABLE 21. Outcomes of sensitivity analysis to discount rate.

Discount rate (%)	Impact	Values over time
0	TEV: USD 2.51 billion TEV as % of GDP: 0.51% ROI: 17.92 %	<p>GDP, TEV, investment and opportunity costs increase over time. ROI declines over time. TEV for each service increases non-linearly over time.</p>  <p>The top chart displays five metrics over time (2025-2050). GDP (red line) increases from approximately 100B to 150B USD. TEV (blue line) increases from about 100M to 200M USD. Opportunity costs (green line) increase from 1M to 5M USD. Investment costs (orange line) increase from 10M to 20M USD. ROI per year (purple line) decreases from 26.00% to 12.00%.</p> <p>The bottom chart shows the annual value of ecosystem services. Total value increases from about \$80M in 2025 to \$160M in 2050. Services include Drought mit., Sedimentation mit., Flood mit. (Infra), Water resource, Pollution dilution, Carbon stock, Carbon seq., Grazing, Fuelwood, and Wildlife services.</p>
5	TEV: USD 1.31 billion TEV as % of GDP: 0.55% ROI: 21.20%	<p>GDP, TEV, investment and opportunity costs are static over time. ROI declines over time. TEV for each service decreases linearly over time.</p>  <p>The top chart displays five metrics over time (2025-2050). GDP (red line) is static at approximately 100B USD. TEV (blue line) is static at about 100M USD. Opportunity costs (green line) are static at 1M USD. Investment costs (orange line) are static at 10M USD. ROI per year (purple line) decreases from 26.00% to 12.00%.</p> <p>The bottom chart shows the annual value of ecosystem services. Total value decreases linearly from about \$80M in 2025 to \$40M in 2050. Services include Drought mit., Sedimentation mit., Flood mit. (Infra), Water resource, Pollution dilution, Carbon stock, Carbon seq., Grazing, Fuelwood, and Wildlife services.</p>

continued

<p>10</p> <p>TEV: USD 804.24 million</p> <p>TEV as % of GDP: 0.59%</p> <p>ROI: 25.08%</p>	<p>GDP, TEV, investment and opportunity costs decline over time. ROI declines over time. TEV for each service decreases non-linearly over time.</p>	
<p>15</p> <p>TEV: USD 560.41 million</p> <p>TEV as % of GDP: 0.64%</p> <p>ROI: 29.12%</p>	<p>GDP, TEV, investment and opportunity costs are static over time. ROI declines over time. TEV for each service decreases steeply, non-linearly over time.</p>	

Source: Authors' creation.

2.2.11 Influence of GDP growth

Here the relationship between GDP growth and ecosystem service valuation is examined by testing GDP rates from negative (recession) to high growth. Ecosystem services linked to GDP (e.g., water provisioning, pollution dilution) will have higher valuations in scenarios with positive GDP growth, while economic downturns will reduce their contribution. Many services scale with economic activity. For instance, pollution dilution is more valuable as industrial output (and pollution levels) rise. Conversely, during recessions, reduced demand lowers their marginal value.

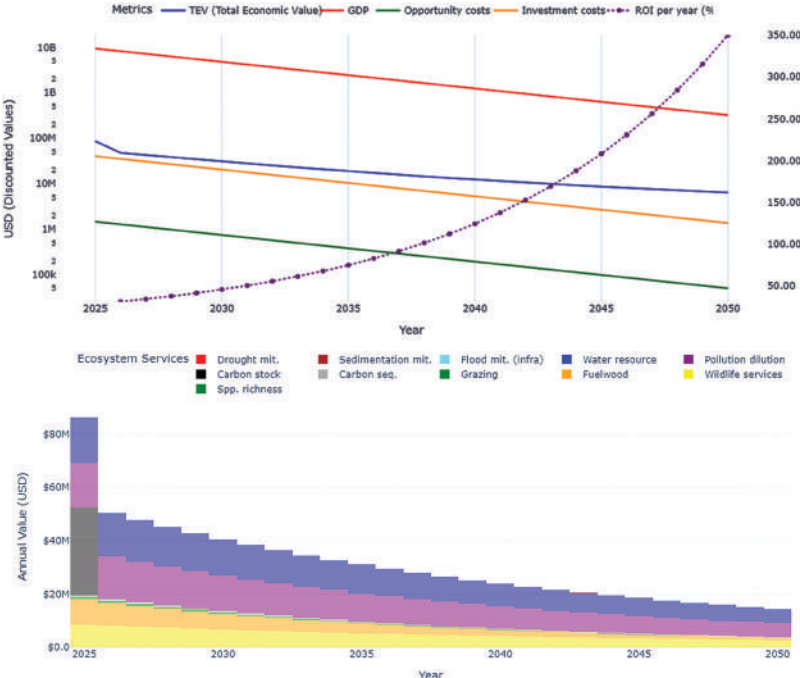
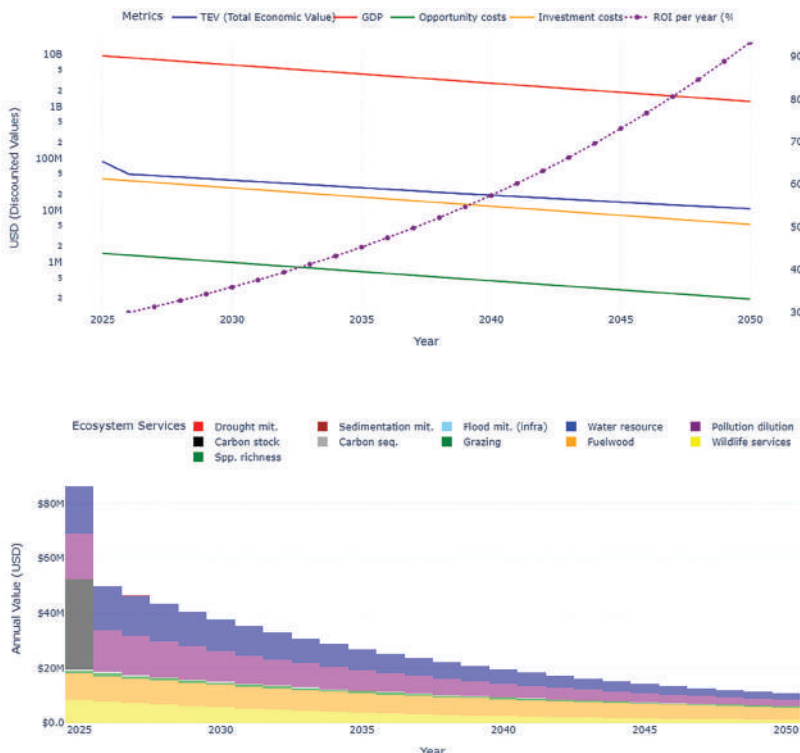
- Baseline year: 2025
- Time horizon: 2050
- Discount rate: 3%/year
- GDP growth rate: -10% to +10%/year
- Investment in nature conservation/restoration at baseline: USD 38,219/ha/year
- Opportunity cost of retaining nature at baseline: USD 1.40 K/ha/year

Table 22 shows the results of this analysis. The GDP growth rate significantly influences TEV, TEV as a percentage of GDP, and ROI, reflecting expected economic valuation dynamics. Higher GDP growth rates increase both TEV and investment costs, but ROI declines due to rising costs outpacing discounted ecosystem benefits. At negative GDP growth rates (-10% and -5%), TEV is low (USD 555.67 million and USD 711.92 million, respectively) due to shrinking economic activity. However, ROI is highest (73.57% at -10%) because investment and opportunity costs decline faster than TEV. TEV declines steeply and non-linearly over time, mirroring economic contraction.

At 0% growth, TEV reaches USD 1.02 billion, and ROI stabilizes at 32.88%, as there are no GDP-driven changes in valuation. TEV declines linearly over time, maintaining a constant discounting effect. At positive GDP growth rates (5% and 10%), TEV increases sharply (USD 1.67 billion -3.10 billion), reflecting expanding economic activity. However, ROI declines from 19.80% (5%) to 11.79% (10%), as rising investment and opportunity costs outpace the growth in ecosystem benefits. TEV increases non-linearly at higher GDP growth, indicating the compounding effect of economic expansion.

Negative GDP growth favors short-term conservation investment, as lower investment costs drive high ROI, but ecosystem services lose long-term economic value. Stable or low GDP growth (0-5%) balances moderate TEV with sustainable ROI, making conservation investment more predictable. High GDP growth (10%) prioritizes economic expansion, but reduces ROI, making ecosystem investments appear less attractive relative to other economic activities. Policymakers must balance conservation investment strategies to ensure that long-term ecosystem benefits remain economically viable under varying economic conditions.

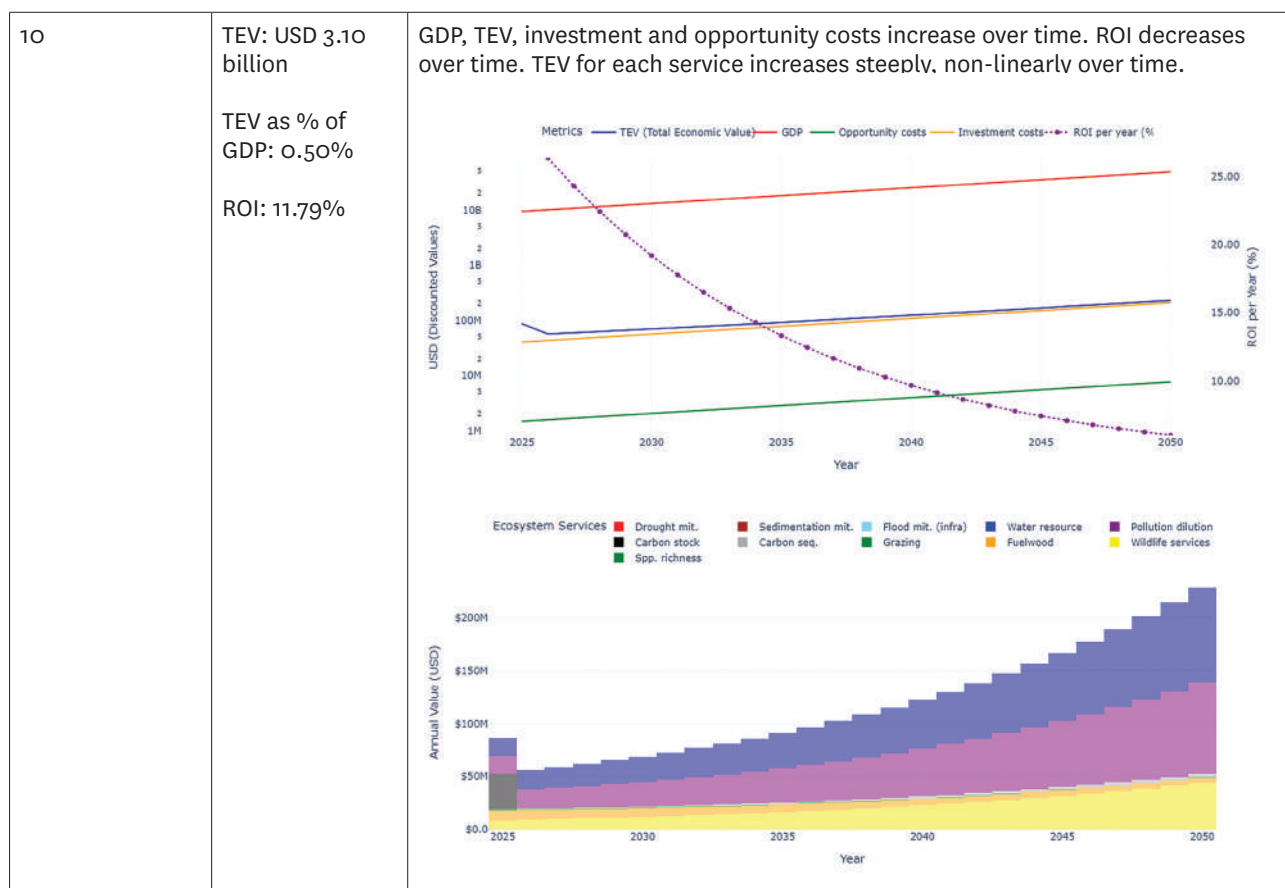
TABLE 22. Outcomes of sensitivity analysis to GDP growth rate.

GDP growth rate (%)	Impact	Values over time
-10	<p>TEV: USD 555.67 million</p> <p>TEV as % of GDP: 0.77%</p> <p>ROI: 73.57%</p>	<p>GDP, TEV, investment and opportunity costs decrease over time. ROI increases over time. TEV for each service decreases steeply, non-linearly over time</p>  <p>Metrics</p> <ul style="list-style-type: none"> TEV (Total Economic Value) GDP Opportunity costs Investment costs ROI per year (%) <p>Ecosystem Services</p> <ul style="list-style-type: none"> Drought mit. Sedimentation mit. Flood mit. (infra) Water resource Pollution dilution Carbon stock Carbon seq. Grazing Fuelwood Wildlife services Spp. richness
-5	<p>TEV: USD 711.92 million</p> <p>TEV as % of GDP: 0.67%</p> <p>ROI: 51.22%</p>	<p>GDP, TEV, investment and opportunity costs decrease over time. ROI increases over time. TEV for each service decreases steeply, non-linearly over time.</p>  <p>Metrics</p> <ul style="list-style-type: none"> TEV (Total Economic Value) GDP Opportunity costs Investment costs ROI per year (%) <p>Ecosystem Services</p> <ul style="list-style-type: none"> Drought mit. Sedimentation mit. Flood mit. (infra) Water resource Pollution dilution Carbon stock Carbon seq. Grazing Fuelwood Wildlife services Spp. richness

continued

<p>O</p> <p>TEV: USD 1.02 billion</p> <p>TEV as % of GDP: 0.59%</p> <p>ROI: 32.88%</p>	<p>GDP, TEV, investment and opportunity costs decrease over time. ROI is static over time. TEV for each service decreases steeply and linearly over time.</p>	<p>Metrics — TEV (Total Economic Value) — GDP — Opportunity costs — Investment costs — ROI per year (%)</p> <p>USD (Discounted Values)</p> <p>Year</p> <p>ROI per Year (%)</p> <p>Ecosystem Services: Drought mit., Carbon stock, Spp. richness, Sedimentation mit., Carbon seq., Grazing, Flood mit. (infra), Water resource, Fuelwood, Pollution dilution, Wildlife services</p> <p>Annual Value (USD)</p> <p>Year</p>
<p>5</p> <p>TEV: USD 1.67 billion</p> <p>TEV as % of GDP: 0.53%</p> <p>ROI: 19.80%</p>	<p>GDP, TEV, investment and opportunity costs increase over time. ROI increases over time. TEV for each service increases linearly over time.</p>	<p>Metrics — TEV (Total Economic Value) — GDP — Opportunity costs — Investment costs — ROI per year (%)</p> <p>USD (Discounted Values)</p> <p>Year</p> <p>ROI per Year (%)</p> <p>Ecosystem Services: Drought mit., Carbon stock, Spp. richness, Sedimentation mit., Carbon seq., Grazing, Flood mit. (infra), Water resource, Fuelwood, Pollution dilution, Wildlife services</p> <p>Annual Value (USD)</p> <p>Year</p>

continued



Source: Authors' creation.

2.2.12 Temporal dynamics of TEV and ROI

Here we examine how TEV changes over time by extending or reducing the time horizon (10 years vs. 50 years). Longer time horizons typically yield higher TEV, but with diminishing returns if discount rates are high. Some services (e.g., carbon sequestration, species recovery) provide slow-building benefits. Short horizons may undervalue these services, while longer periods capture their full contribution, provided discounting doesn't suppress future values.

- Baseline year: 2025
- Time horizon: 2035-2100
- Discount rate: 3%/year
- GDP growth rate: 5%/year
- Investment in nature conservation/restoration at baseline: USD 38,219/ha/year
- Opportunity cost of retaining nature at baseline: USD 1.40 K/ha/year

Table 23 shows the results of this scenario. As the time horizon extends, TEV increases substantially, but investment and opportunity costs rise at an even faster rate, causing ROI to decline over time. In a short-term horizon (10 years, 2025-2035), TEV is USD 655.82 million, with relatively low investment costs (USD 487.52 million) and opportunity costs (USD 17.86 million). ROI is highest at 29.77%, as costs remain manageable and ecosystem benefits accrue quickly. TEV grows slightly and linearly, while ROI declines gradually. At 50 years (2025-2075), TEV increases to USD 4.02 billion, but investment (USD 3.45 billion) and opportunity costs (USD 126.34 million) rise substantially, leading to a lower ROI (12.40%). TEV increases non-linearly as long-term ecosystem benefits compound, but ROI declines non-linearly, reflecting the rising financial burden. For an extended 75-year horizon (2025-2100), TEV reaches USD 7.72 billion, but investment (USD 6.86 billion) and opportunity costs (USD 251.12 million) increase drastically, reducing ROI to 8.67%. TEV follows an accelerating growth pattern, while ROI declines even more steeply, indicating that long-term investment costs outweigh discounted future benefits.

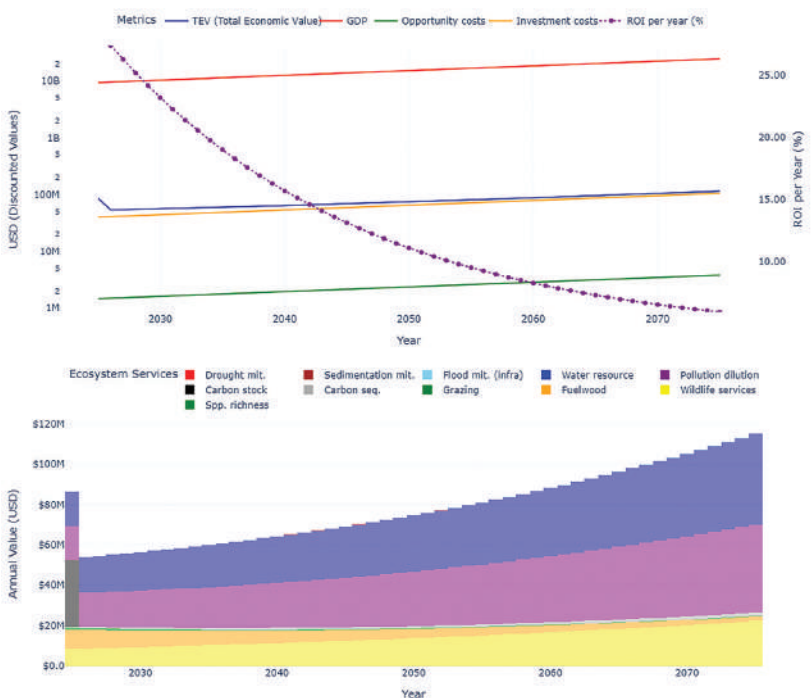
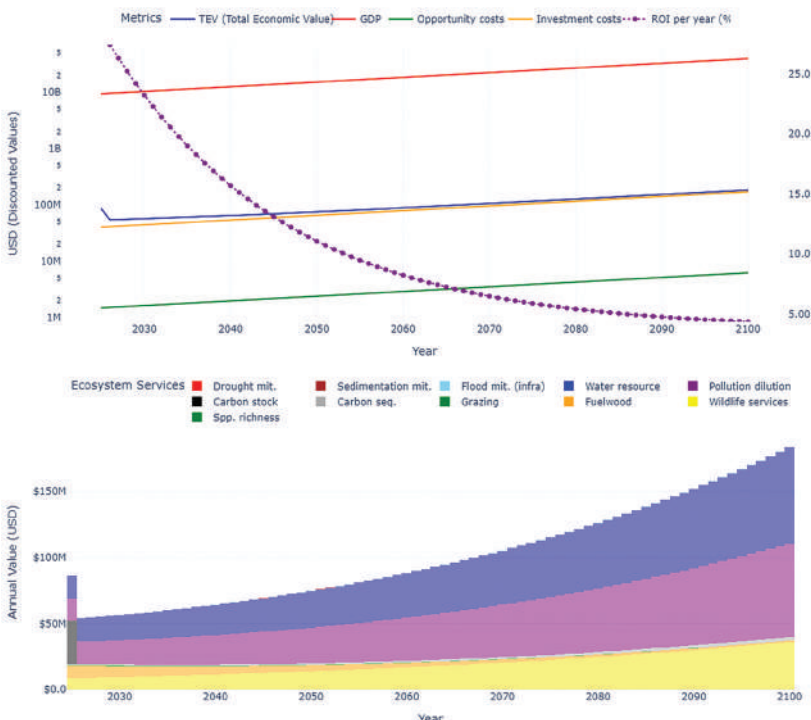
The choice of time horizon in conservation investment affects TEV, ROI, and financial feasibility. Under the model parameters—3% discount rate, 5% GDP growth, and baseline conservation investment of USD 38,219/ha/year—longer timeframes generate higher TEV but lower ROI due to increasing costs. The short term (10 years) has the highest ROI as investment and opportunity costs remain low. TEV is USD 655.82 million, and benefits accumulate linearly, ideal for projects needing quick returns with minimal financial risk. In the medium term (50 years), TEV rises but investment and opportunity costs increase significantly. ROI drops and TEV compounds over time, making this a balanced investment strategy. The long term (75 years) has the highest TEV but lowest ROI, as investment and opportunity costs continue to rise. Long-term benefits justify sustained funding, but conservation financing must be planned carefully.

Short-term projects are most financially attractive but may miss long-term ecological gains. Medium-term investments balance economic returns and sustainability. Long-term commitments maximize TEV but require robust funding strategies to offset lower ROI. Policymakers should align investment periods with ecosystem service benefits, ensuring that financial mechanisms support long-term conservation without compromising short-term feasibility.

TABLE 23. Outcomes of sensitivity analysis to time horizon.

Time horizon	Impact	Values over time
2025-2035 (10 years)	TEV: 655.82 M TEV % GDP: 0.57% Inv costs: 487.52 M Opp costs: 17.86 M ROI: 29.77%	<p>GDP, TEV, Investment and opportunity costs are fairly static over time. ROI decreases linearly over time. TEV for each service increases slightly, linearly over time.</p>

continued

Time horizon	Impact	Values over time
2025-2075 (50 years)	TEV: 4.02 B TEV % GDP: 0.50% Inv costs: 3.45 B Opp costs: 126.34 M ROI: 12.40%	GDP, TEV, Investment and opportunity increase over time. ROI decreases non-linearly over time. TEV for each service increases non-linearly over time. 
2025-2100 (75 years)	TEV: 7.72 B TEV % GDP: 0.48% Inv costs: 6.86 B Opp costs: 251.12 M ROI: 8.67%	GDP, TEV, Investment and opportunity increase time. ROI decreases non-linearly over time. TEV for each service increases non-linearly over time. 

Source: Authors' creation.

2.3 Discussion

The Kalu Oya and Mudun Ela basins are characterized by high urbanization, population growth, and considerable pressure on wetlands and other ecosystems. They require targeted investments to safeguard critical ecosystem services. The economic valuation carried out by CostingNature reveals that water resource provision and pollution dilution contribute substantially to TEV, with water resources accounting for up to 39.06% and pollution dilution 37.95% in global valuation scenarios. In local valuations, these services remain dominant, highlighting their importance for urban populations reliant on these functions. Wetlands, despite covering a small area, provide disproportionately high average TEV per unit area for flood mitigation and water purification services. The average contribution of wetlands to TEV is 10.72% locally, indicating that investments in wetland conservation could yield significant economic returns in terms of reduced flood risk and improved water quality. Forested home gardens also show considerable value through carbon sequestration and biodiversity benefits, underscoring the need to integrate these landscapes into urban planning and green infrastructure strategies.

These valuation experiments have the following implications for conservation investment in the basins, going by each section of the results:

- The high TEV of wetlands and forested areas suggests prioritizing investments in their conservation to maximize ecosystem service returns.
- The significant contributions from tree cover and built-up areas indicate a need for integrated urban and peri-urban conservation strategies.
- The high sensitivity of TEV to the valuation of specific services like water resources and pollution dilution highlights the importance of accurate local valuations for informed investments.
- High discount rates are used to reflect a preference for immediate benefits over future ones, accounting for investment risks, opportunity costs, and uncertainty about long-term outcomes. They prioritize short-term gains and can help in scenarios where immediate returns are essential or when future benefits are highly uncertain. The sharp decline in TEV with higher discount rates suggests prioritizing conservation projects with short-term benefits unless sustainable long-term funding can be secured. Sustainable funding is essential to support long-term investments.
- Higher GDP growth reduces relative TEV, implying that conservation investments must account for benefits under economic expansion to remain attractive.
- Increased TEV under climate and land use change scenarios supports investments in adaptation-focused conservation to safeguard future ecosystem services.

However, the analysis also highlights uncertainties in economic valuation. Variability in local vs global valuation data suggests a potential risk of underestimating or overestimating ecosystem service benefits. For instance, flood mitigation values showed significant differences depending on whether local or global multipliers were applied. Discount rate sensitivity further complicates investment decisions, with higher rates favoring short-term gains at the expense of long-term ecosystem sustainability. Policy recommendations should therefore include adopting a precautionary approach, prioritizing investments in services with high and reliable TEV contributions, such as water resources, pollution control, and flood mitigation. Additionally, enhancing data accuracy through further local valuation studies and adopting adaptive management strategies can help mitigate remaining valuation uncertainties, ensuring that conservation investments remain both effective and economically justified in the long term.

Monetary valuation approaches, while useful for translating ecosystem services into economic terms, often oversimplify complex ecological processes and introduce significant uncertainties. In contrast, biophysical valuation provides more consistent and constrained uncertainty estimates. Monetary methods risk undervaluing services with diffused or long-term benefits, such as carbon sequestration or biodiversity, potentially skewing conservation priorities toward services with immediate economic returns. Moreover, monetary valuation often only has the data to focus narrowly on single value metrics, such as damage costs or WTP, overlooking the comprehensive suite of values each service provides. This limitation risks underestimating ecosystem contributions and may misinform conservation priorities by neglecting indirect and non-use values essential for long-term sustainability. A reliance on monetary valuation can thus lead to suboptimal policy decisions, neglecting broader ecological resilience and sustainability, and should be treated with caution. The whole human economy and all economic value rests on nature in some way, and this should be the basis for careful stewardship and protection of biodiversity and ecosystem services.

3. Conclusion

This report presents a comprehensive attempt to value the ecosystem services provided by wetlands in the Kalu Oya and Mudun Ela basins using a combination of complementary methodologies. The first set of approaches—the market price-based and benefit transfer methods—derived economic values using locally contextualized data sources, including prices, land use, and ecological conditions combined with global best estimates. These approaches allow for the inclusion of local knowledge and basin-specific ecological and socio-economic dynamics. Their limitations stem from data scarcity at the local scale and the need for simplified assumptions in biophysical estimation compared to the GIS-driven detail of Co\$tingNature.

The second approach applied the Co\$tingNature model, which integrates globally available, high-resolution geospatial datasets to simulate biophysical processes and combines these with locally-derived per service economic values to estimate TEV across the basins. This approach offers a high level of replicability and comparability across basins and geographic regions and provides insights into the spatial distribution of services, cost-benefit ratios, and changes in value under different scenarios. However, it is limited by uncertainties in biophysical inputs and outputs and a lack of local data for validation.

Together, the two approaches offer a triangulated perspective on ecosystem service values, highlighting the uncertainties involved in economic valuation and the strengths and trade-offs of each method. Importantly, they underscore the value of using multiple valuation approaches to better understand and navigate the uncertainties inherent in ecosystem service assessment.

Despite efforts to integrate the best available local data, some services—such as thermal regulation, which significantly influences human health—could not be valued due to data gaps. Similarly, non-use values (e.g., existence and option values) were excluded due to the absence of robust valuation studies in the region. Wherever secondary data were used, care was taken to ensure ecological and socio-economic relevance to the study context, and sources of uncertainty have been transparently documented throughout the analysis.

4. The Way Forward

Findings from the different approaches consistently demonstrate the substantial ecological and economic contributions of wetland ecosystems in the Kalu Oya and Mudun Ela basins. These ecosystems provide critical services—such as food production, flood mitigation, water purification, and carbon storage—that directly support public health, livelihoods, and socio-economic resilience. Yet, despite their importance, these wetlands remain under-recognized in policy and vulnerable to degradation due to unregulated land use and insufficient conservation measures. Other ecosystems within the basins also provide valuable services and must be considered in broader basin-scale planning.

Recognizing the monetary value of wetland ecosystem services is essential to:

- Inform national and regional land use and development planning;
- Strengthen legal and regulatory frameworks; and
- Promote nature-based solutions and community-based conservation strategies.

Future research should prioritize:

- Improving the precision of valuation techniques through better integration of local biophysical and socio-economic data;
- Incorporating climate change projections to understand long-term risks and vulnerabilities; and
- Assessing trade-offs between development, ecosystem integrity, and human well-being over time.

Numerous studies (e.g., Mitsch and Gosselink 2015; Dale and Connelly 2012; Zedler and Kercher 2005) have shown that wetland conservation enhances public health by improving water quality, reducing disease vectors, and offering mental health benefits through nature access. Simultaneously, wetlands support economic development through sustainable fisheries, enhanced agricultural productivity, flood protection, and tourism (Barbier et al. 2011; Costanza et al. 2014; Zhang et al. 2017).

Crucially, the process of stakeholder engagement significantly enhanced the accuracy, relevance, and legitimacy of the valuation results. Local knowledge contributed to identifying ecosystem functions, validating assumptions, and aligning the analysis with community needs and priorities. Bridging the gap between science and policy will depend on sustaining this integrative approach—one that combines robust technical analysis with inclusive, participatory decision-making.

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Annex A.

Table A.1. Global input and output values.

Ecosystem service	Use value	Non-use value	Maximum possible	Biophysical value	Economic value (USD, nominal)	Percentage of total economic value
Species richness (USD/household/species/year)	126	0	Unlimited	106.76	258.22 K	0.02
Wildlife services (USD/ha/year, where provided)	600	0	Unlimited	3.80 K	76.24 M	5.18
Realized fuelwood (USD/t/year)	50	0	Unlimited	46.42 K	42.74 M	2.90
Realized grazing (USD/t/year)	396	0	Unlimited	2.38 K	17.37 M	1.18
Carbon sequestration (USD/t/year CO ₂ e)	20	0	Unlimited	93.99 K	62.81 M	4.27
Carbon stock (USD/t CO ₂ e)	10	0	Unlimited	4.99 M	49.87 M	3.39
Pollution dilution (USD/person benefitting/year)	60	0	Unlimited	278.71 K	558.71 M	37.95
Water resource provision (USD/person benefitting/year)	60	0	Unlimited	286.88 K	575.09 M	39.06
Flood risk mitigation (USD/m ² benefitting/year)	150	0	Unlimited	17.68 K	88.62 M	6.02
Sediment mitigation (USD/ha mitigated/year)	55	0	Unlimited	0	0	0
Drought risk mitigation (USD/m ² of irrigated cropland benefitting/year)	0.5	0	Unlimited	33.00 K	551.24 K	0.04

Table A.2. Local input and output values.

Ecosystem service	Use value	Non-use value	Maximum possible	Biophysical value	Economic value (USD, nominal)	Percentage of total economic value
Species richness (USD/household/species/year)	126	0	Unlimited	106.76	258.22 K	0.02
Wildlife services (USD/ha/year, where provided)	2251	0	Unlimited	3.80 K	286.01 M	17.16
Realized fuelwood (USD/t/year)	203	0	Unlimited	46.42 K	173.52 M	10.41
Realized grazing (USD/t/year)	386	0	Unlimited	2.38 K	16.93 M	1.02
Carbon sequestration (USD/t/year CO ₂ e)	6.59	0	Unlimited	93.99 K	20.69 M	1.24
Carbon stock (USD/t CO ₂ e)	6.59	0	Unlimited	4.99 M	32.86 M	1.97
Provision of downstream population with pollution dilution (USD/person/year)	60	0	Unlimited	278.71 K	558.71 M	33.51
Provision of downstream population with water resource (USD/person/year)	60	0	Unlimited	286.88 K	575.09 M	34.49
Flood risk mitigation for downstream infrastructure (USD/m ² /year)	4.38	0	Unlimited	17.68 K	2.59 M	0.16
Sediment mitigation for downstream reservoirs (USD/t/ha/year)	55	0	Unlimited	0	0	0
Drought risk mitigation for irrigated crops (USD/m ² /year)	0.5	0	Unlimited	33.00 K	551.24 K	0.03

Table A.3. Further valuation studies.

Ecosystem service	Valuation (USD)	Method	Context and basis
Species richness (per household/species/year)	USD 6-95	Contingent valuation	Range of WTP by US households to protect individual rare/endangered species. For example, protecting the northern spotted owl was valued at up to USD 95/household/year (Loomis and White 1996).
Species richness (USD/household/species/year)	USD 5-126/ (willingness-to-pay range)	Contingent valuation (stated preference of households for biodiversity conservation)	Meta-analysis of 60 studies on species conservation WTP; e.g., Nunes and van den Bergh (2001) report U.S. household WTP from USD 5 up to USD 126 for a single species. Martin-López et al. (2008) similarly found mean WTP values up to USD 206/ species/year.
Wildlife services (habitat, biodiversity/ha/year)	USD 270/ha/ year (average)	Benefit transfer (meta-analysis of Contingent valuation studies)	Non-use (existence) value of wildlife habitat in tropical forests. A meta-study of Amazon forest valuations found a mean of about USD 270/ha/ yr for “habitat for species” services, derived from multiple contingent valuation estimates (Brouwer et al. 2022).
Wildlife services (USD/ha/year)	USD 50 (upper-end estimate for wildlife tourism benefits)	Market price (land lease rate for wildlife tourism use)	In the Maasai Mara reserve (Kenya), landowners can earn up to USD 50/ha/yr by leasing land for wildlife-based tourism. The average lease payment is around USD 10/ha/yr in that region. This reflects the market value of habitat for wildlife viewing enterprises (e.g., safari camps) (Norton-Griffiths 2007).
Realized fuelwood (t/year)	USD 40-100 (market price)	Market price method	Illustrative market values for fuelwood. In developing countries, fuelwood prices range from as low as USD 3-4/m ³ at the source to USD 40-50/ m ³ delivered to cities. This is roughly in the order of USD 50-100/t of wood, depending on wood density (FAO 1983).
Realized fuelwood (USD/t/year)	USD 60 (market value)	Market price (direct market value of harvested fuelwood)	A UNDP valuation report for Yemen used a fuelwood price of about USD 60/t as the basis for estimating forest provisioning value. This represents the local market price for firewood, providing a proxy for its annual value/t (UNDP 2014).

continued

Ecosystem service	Valuation (USD)	Method	Context and basis
Realized grazing (forage consumed/t/year)	≈USD 66/t of dry matter	Market price (grazing fee)	Imputed from private grazing lease rates. On U.S. private rangelands, grazing fees average about USD 23.40/Animal Unit Month (AUM), equivalent to roughly USD 65-70/t of forage (1 AUM ≈ 0.35 t of forage). This reflects the market value of open grazing for livestock (as reported in Vincent 2019).
Realized grazing (USD/t/year of forage)	USD 170/t of fodder (approximately USD 0.17/kg of dry matter)	Replacement cost (avoided cost of purchasing equivalent feed)	Grazing in Yemen was valued via the cost of supplementary livestock feed. Based on feed prices of USD 0.17/kg, the forage was valued at about USD 170/t of dry fodder. This represents the benefit of natural grazing resources to local herders each year (UNDP 2014).
Carbon sequestration (t CO ₂ /year)	USD 51	Benefit transfer (damage cost)	Social cost of carbon used in policy evaluation. The US Interagency Working Group on Social Cost of Greenhouse Gases (2021) estimates that avoiding 1 t CO ₂ e emissions yields about USD 51 in global damage avoided. This proxy value is often applied to carbon sequestration benefits.
Carbon stock (stored carbon/t CO ₂ e)	USD 5-15	Market price (carbon credit)	Approximate voluntary carbon market price for forest carbon. Recent REDD+ forest carbon credits have traded in the range of about USD 5-15/t CO ₂ e, reflecting payments for maintaining carbon stocks (e.g., avoided deforestation).
Carbon stock (USD/t CO ₂ e)	USD 32-33/t of CO ₂ in stored carbon (market price of carbon credits)	Market price (emissions trading value for a ton of CO ₂)	In carbon markets, prices have fluctuated. For example, EU ETS carbon allowances averaged about USD 32.46/t CO ₂ in 2020. This indicates the market value of one ton of CO ₂ stored (or avoided) at that time. Voluntary carbon offset prices can vary (often USD 5-15/t historically), but regulated markets in 2023 exceeded USD 80/t CO ₂ (Postic and Fetet 2021; Marcu et al 2021).
Pollution dilution (water purification/person/year)	USD 2	Replacement cost (avoided treatment cost)	Example of watershed protection for drinking water. Protecting source watersheds can provide filtration benefits at about USD 2/person annually (estimated cost to achieve similar water quality). For instance, investment in upstream habitat in Quito, Ecuador yields water quality improvements at roughly USD 2/consumer/year.

continued

Ecosystem service	Valuation (USD)	Method	Context and basis
Pollution dilution (USD/person benefiting/year)	USD 40-50 (avoided water treatment cost)	Replacement cost (cost of man-made filtration infrastructure avoided by ecosystem's dilution/purification service)	A classic example is New York City's watershed. Protecting natural water filtration in the Catskills avoided building a USD 6 billion-10 billion filtration plant, plus USD 250 million in annual operating costs. Spread over ~9 million residents, this yields an equivalent benefit in the order of USD 40-50/person/year in water purification value (by avoiding those costs) (Kenny 2006).
Water resource (water supply/person/year)	~USD 2.5-20/person/year	Benefit transfer	WTP for reliable water provision. In a UK basin (Broadland Rivers), provisioning services for domestic water were valued around £1.96-15.54 / person/year (~USD 3-21), based on benefit transfer of multiple studies. This represents the annual value of clean water supply per beneficiary.
Water resource (USD/person benefiting/year)	USD 250/household/year (for reliable water supply, which is roughly USD 60-80/person/year)	Contingent valuation (households' WTP for ecosystem-supplied water)	A contingent valuation study of river ecosystem services in Colorado estimated about USD 252/household/year WTP for improved streamflow and water supply reliability. This implies the order of tens of dollars/person/year for secure water resources. In practice, protected watersheds often reduce municipal water costs (e.g., Boston's watershed protection saves consumers ~USD 90/household/year in treatment costs) (Loomis et al. 2000).
Flood mitigation (to infrastructure) (storm protection/m ² /year)	0.32	Replacement/avoidance cost	Value of flood damage prevented by ecosystems. For example, mangrove forests in the Philippines provide an estimated USD 3,200/ha/year of flood protection benefits – roughly USD 0.32/m ² in avoided damage to buildings and infrastructure annually (Narayan et al. 2017).
Flood mitigation to infrastructure (USD/m ² benefiting/year)	USD 0.8 (in high-risk developed areas; lower in others at ~USD 0.19/m ²)	Avoided damage cost (value of reduced flood damage to built infrastructure)	Research in the US quantified that one hectare of wetland can reduce annual flood damage by about USD 1,900 on average, and up to USD 8,000/ha/year in densely developed areas. The latter equates to roughly USD 0.8/m ² of property protected/year. These values come from observed flood insurance payouts: wetland loss was found to increase claims, so intact ecosystems provide equivalent savings (Taylor and Druckenmiller 2022).

continued

Ecosystem service	Valuation (USD)	Method	Context and basis
Sedimentation mitigated (erosion control/t reduced)	USD 8-26/t sediment	Replacement cost (dredging)	Avoided dredging and reservoir maintenance costs. In Puerto Rico, the cost to dredge sediment is about USD 8.64/t, with some projects that go up to USD 26/t. Each ton of soil retained by upstream ecosystems saves on dredging expenses (De Jesus Crespo et al. 2023).
Sedimentation mitigated (USD/t mitigated/year)	USD 8-20/t of sediment prevented from entering waterways/year	Replacement/ avoided cost (cost to remove or treat sediment if not mitigated by the ecosystem)	Engineering cost analyses suggest that trapping or removing sediment costs are around USD 8/t. For example, installing farm sediment basins in Washington constituted about USD 8.10/t of sediment captured per year. Likewise, studies of reservoir dredging and water treatment often use USD 10-20/t as the damage or removal cost for sediment pollution. Healthy forests and wetlands that reduce erosion provide savings in this range by avoiding dredging, filtration, and infrastructure damage costs (Washington State Department of Ecology 2022; Hansen and Ribaudo 2008).
Drought mitigation (for irrigation) (water regulation/m ² of cropland/year)	~USD 0.02	Production function (benefit to agriculture)	Value of dry-season flow regulation for irrigated farming. For instance, in semi-arid regions, the value of irrigation water for drought protection has been estimated at USD 37-42/1000 m ³ . This translates to USD 0.02/m ² of irrigated cropland/year (assuming ~500 mm of additional water) as the increased crop yield/profit due to reliable baseflows (Pattanayak and Kramer 2001).
Drought mitigation for irrigated crops (USD/m ² of cropland/year)	USD 0.03-0.06 (additional crop value due to irrigation water/m ²)	Market price/ productivity (value of water supply for crops, allocated per area)	The economic value of water for irrigation is often a few cents per cubic meter. For instance, for grain crops in India the value is about USD 0.07/ per cubic meter. If an irrigated field receives ~0.5 m ³ of supplemental water/m ² in a dry year, this translates to roughly USD 0.035/m ² in increased crop output. In practice, irrigation during drought can vastly reduce crop losses – in Australia's Millennium Drought, upgraded irrigation infrastructure yielded large benefits by maintaining yields (hundreds of USD/ha, i.e. several cents/ m ²) compared to rainfed fields (as reported in Ziolkowska 2015; Crossman et al. 2010).



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