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# Assessment of ecosystem services for climate regulation: case study of the Madu Ganga wetlands

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**Abstract.** The ecosystem services assessment plays one of the key role in the modern concept of sustainable development, including combat climate change and achievement carbon neutrality, since the value assessment of all benefits and risks from ecosystem services is the most visible for decision makers (business and government). Mangrove forests in developing countries, such as Sri Lanka, are important factor in achieving carbon neutrality. The purpose of present investigation was the economic assessment of climate regulation services on the example of the Madu Ganga wetlands (Sri Lanka). The carbon stock was calculated as the marginal cost of reducing carbon emissions, and the sequestration was assessed through the calculation of the carbon social cost or the marginal cost of damage. As a result, the high cost of carbon storage by the Madu Ganga wetlands was revealed – approximately, it amounted to $153,341,221. The cost of the ES for carbon sequestration was $2,153,424. The total cost of services to regulate the carbon cycle of the Madu Ganga wetlands was $155,494,645, or 0.18% of the nominal GDP of the island of Sri Lanka for 2021. The high value of the mangrove forests of Madu Ganga shows their crucial role in achieving carbon neutrality within the framework of the concept of sustainable development.

**Keywords:** mangroves, wetlands, ecosystem services, carbon neutrality, sustainable development

**Authors' contributions:** *T.S. Kirsanov* – methods' selection, calculations, research, discussion, text preparation for the publication; *A.V. Popkova* and *H. Ranasinghe* – the research concept text preparation for the publication (reviewing and editing).

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# Оценка экосистемных услуг по регулированию климата водно-болотными угодьями Маду-Ганга

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**Аннотация.** Мангровые лесные массивы играют важную роль в достижении углеродной нейтральности. Однако для развивающихся стран, таких как Шри-Ланка, недостаточно представлены данные об экономической ценности способности мангровых экосистем накапливать и поглощать углерод. Целью данного исследования была экономическая оценка услуг по регулированию климата на примере водно-болотных угодий Маду-Ганга (Шри-Ланка). Данные по накоплению углерода были рассчитаны как предельные затраты на сокращение выбросов углерода, а данные по поглощению – через расчет социальной стоимости углерода или предельной стоимости ущерба. В результате исследования установлена общая стоимость услуг по регулированию углеродного цикла водно-болотных угодий Маду-Ганга, которая составила 0,18% от номинального ВВП острова Шри-Ланка на 2021 г. Высокая экономическая ценность мангровых лесных массивов Маду-Ганга отражает их приоритетную роль в достижении углеродной нейтральности в рамках концепции устойчивого развития.

**Ключевые слова:** мангровые заросли, водно-болотные угодья, экосистемные услуги, углеродная нейтральность, устойчивое развитие

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## Introduction

One of the priority tasks of ecosystem services assessment is to attract the attention of decision makers (business and government) to the need to consider the state of natural capital for sustainable economic growth. Complex methods of economic assessment are required for effective integration of ecosystem services into existing markets [2; 20].

Mangrove forests provide a variety of ecosystem services, in particular, food, timber, various raw materials, climate regulation, pollution control, coastal protection, recreational and other services [12; 19]. In addition, mangrove ecosystems are among the most productive ones and represent potentially important carbon sinks in the biosphere, which makes them an important element for achieving carbon neutrality. Due to the high carbon reserves, the assessment of mangrove forests ecosystem services for climate regulation is one of the central directions for achieving carbon neutrality in the framework of the concept of sustainable development [5; 10; 15].

Since many mangrove ecosystem services are a public good, there are no markets for them, and the ability to manage them through conventional market mechanisms is limited. Moreover, due to difficulties in estimating the cost of these services, mangroves are often underestimated when analyzing the benefits and costs of conservation compared to commercial land use, which leads to their degradation and loss [7].

Developing countries contribute to achieving carbon neutrality, in particular, because of the great potential for regulating carbon cycles. For example, Cooray et al. (2021) established that more than 10% of the territory of the Sri Lanka island is occupied by mangrove forests with rich carbon reserves. Hernández-Blanco et al. (2021) also note the significant role of Costa Rica mangrove forests in the global carbon cycle [3; 6].

Despite the importance of assessing ecosystem services for climate regulation for sustainable development and the high potential of ecosystems in developing countries in carbon storage and absorption, Sannigrahi et al. (2020) note that very little attention is paid to developing countries in the modern academic literature on the assessment of ecosystem services. Climate regulation assessment research is mainly focused on the developed countries of Europe, North America and Asia, while the potential of ecosystems, in particular, mangrove forests, developing countries of South America and Southeast Asia is much higher [12; 13].

The objective of this study is an economic assessment of climate management services provided by mangrove forests, the case of the Madu Ganga wetlands (Sri Lanka).

## Research object and methodology

The object of the study. The wetlands of Madu Ganga (Sri Lanka) were selected as the object of the study. Lake Madu Ganga with adjacent mangrove islands is a complex coastal wetland ecosystem, spread over an area of more than 900 hectares and comprising 64 islands. The Madu River basin is a swampy area covered with mangrove forests. 14 out of 24 species of mangrove trees grow in this area. The Madu Ganga wetlands were officially registered in 2003 in accordance with the Ramsar Convention [3; 8].

The Madu Ganga wetlands are located in the humid zone in the southwest, the average annual precipitation is more than 2500 mm, and the southwest monsoon makes a significant contribution to this. The nature of precipitation depends on the monsoon winds of the Indian Ocean and the Bay of Bengal [8].

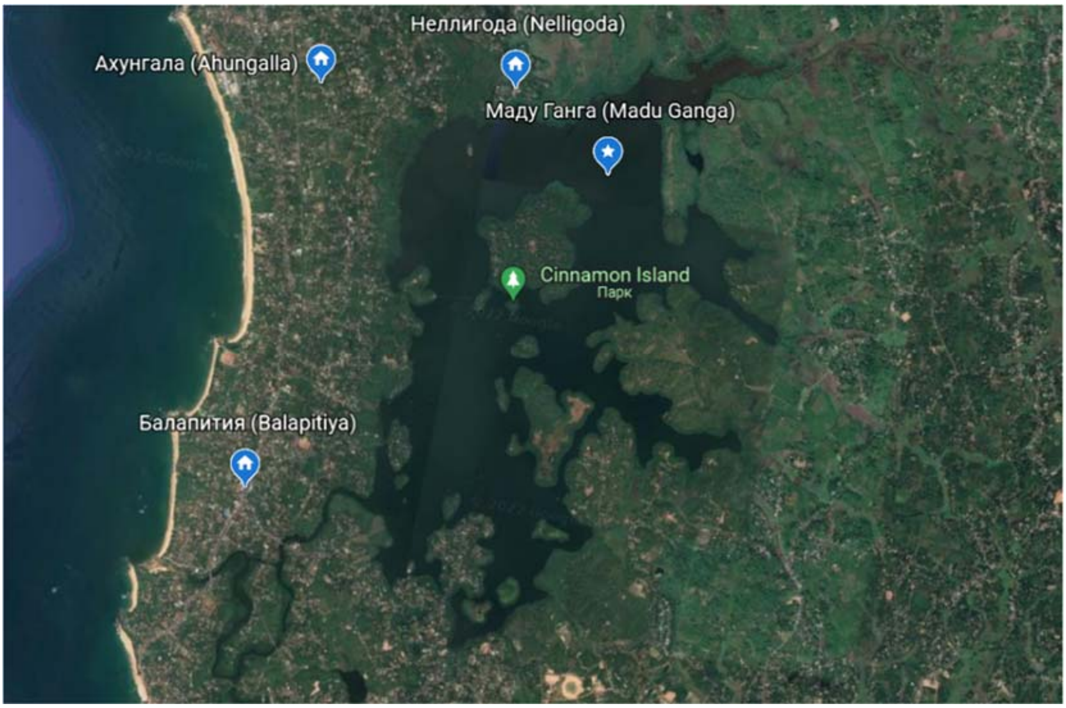


Figure 1. Lake and wetlands of Maduganga in a satellite image

The climate of the island of Sri Lanka is tropical. The average temperature in the area of the Madu Ganga lands is about 27–28°C, dropping to a minimum of 22–24°C and reaching 31–32 °C maximum [3].

Methodology of carbon storage economic assessment. To assess the economic value of organic carbon storage in the mangrove forests of Madu Ganga, a method developed by Fisher et al. (2007) for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) was implemented. It represents the calculation of the marginal cost of reducing carbon emissions as the amount of carbon stock per hectare (MAC) [6; 8]. The average marginal cost figure provided by Fisher et al. (2007), was recalculated according to the inflation coefficient and amounted to $169.78 per ton for 2022 [4; 16].

The following formula was used to estimate the cost of carbon storage services by mangroves:

$$V_{cs} = TC \times MAC \times A_m,$$

where $V_{cs}$ – the cost of carbon storage, *TC* – total carbon stock per hectare, *MAC* – marginal cost of controlling emissions of one ton of carbon, a $A_m$ – the area of mangroves in hectares [8; 15].

Methodology of economic assessment of carbon uptake. To assess carbon uptake, a calculation of the social cost of carbon (*SCC*), or the marginal cost of damage, was carried out, tested by Hernández-Blanco et al. (2021). This parameter is defined as the net present value of additional damage to the environment and society as a result of increased carbon dioxide emissions [8; 11; 20].

Since the *SCC* in theory reflects what society should be willing to pay now in order to avoid future damage caused by increased $CO_2$ emissions [7], for this work the *SCC* was equated to the Pigouvian tax (tax on market activity) [6; 11; 14].

Carbon uptake as an ecosystem service was estimated using the following formula:

$$V_{cseq} = SR \times SCC \times 3{,}67 \times A_m,$$

where $V_{cseq}$ – cost of carbon sequestration services, *SR* – absorption coefficient in tons of $CO_{2eq}$ per hectare per year, 3,67 – conversion factor for obtaining $CO_{2eq}$ from C, $A_m$ – the area of mangroves in hectares, a *SCC* – the social costs of carbon estimated in a meta-analysis that Tool [14] conducted using 311 published estimates [8; 17].

The final cost of *SCC* for 2022 was $108.66/TS [11]. The SR absorption coefficient for mangroves was taken from the data by Murray et al. [9], as well as Maldonado & Zarate-Barrera [18] and is equal to 6 $CO_{2eq}$/ha/year [1; 14].

To obtain data on the carbon stock, satellite imagery data for 06/29/2022 taken from the Landviewer Sentinel-2 EOS.com database was used. The NDWI and NDVI spectra were used to reflect the data.

## Results and discussion

Data on terrestrial carbon stocks were obtained as a result of the study by Cooray et al. [3] and extrapolated to the study area based on the analysis of satellite images of wetlands in the NDVI and NDWI spectra (Figures 2, 3) [9; 18].

It was revealed that carbon reserves per hectare in the Maduganga Lake area differ from carbon reserves per hectare in Lake Randombe and amount to approximately 804.71 mgK/ha at 3 meters depth for Lake Maduganga to 1455.39 mgK/ha at a depth of 3 meters for Lake Randombe [9].

The calculations have shown that significant differences in the studied areas are practically compensated by the difference in the indicators of the carbon stock per hectare – this indicator for the wetlands of Lake Randombe is several times higher than the same indicator for the lands of Lake Madu-Ganga. As a result, the difference in the indicator of accumulated carbon in the studied territories is several times lower than expected and amounts to 502,943.75 mg for Lake Madu Ganga and 400,232.25 mg for Lake Randombe.

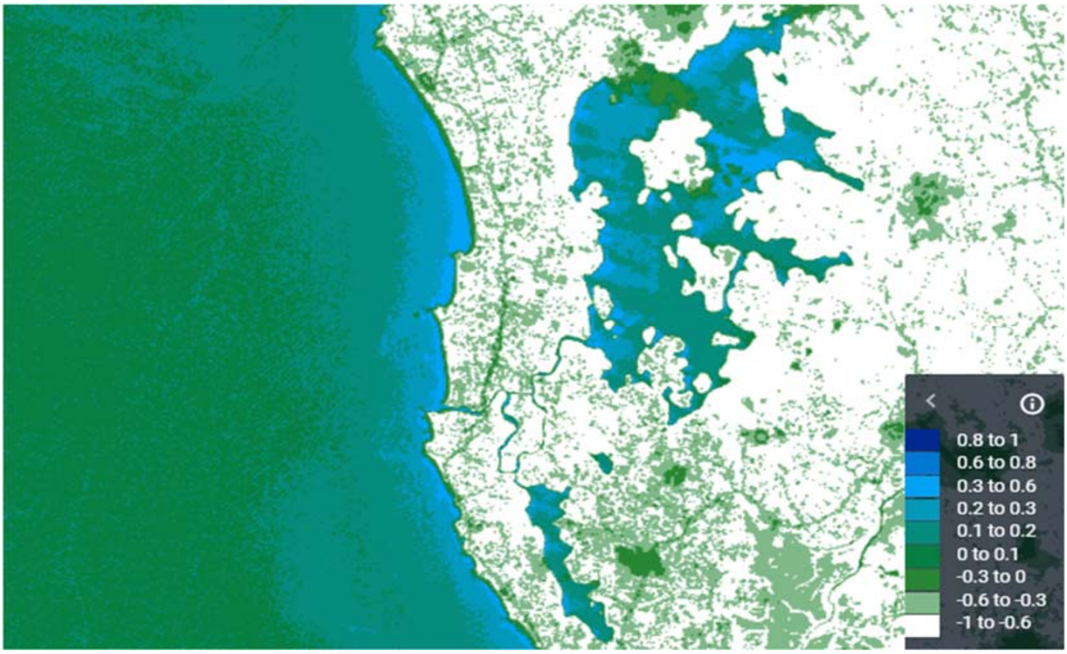


Figure 2. Maduganga wetlands: Maduganga Lake and Randombe Lake in the image in the NDWI spectrum


Figure 3. Maduganga wetlands: Maduganga Lake and Randombe Lake in the NDVI spectrum image

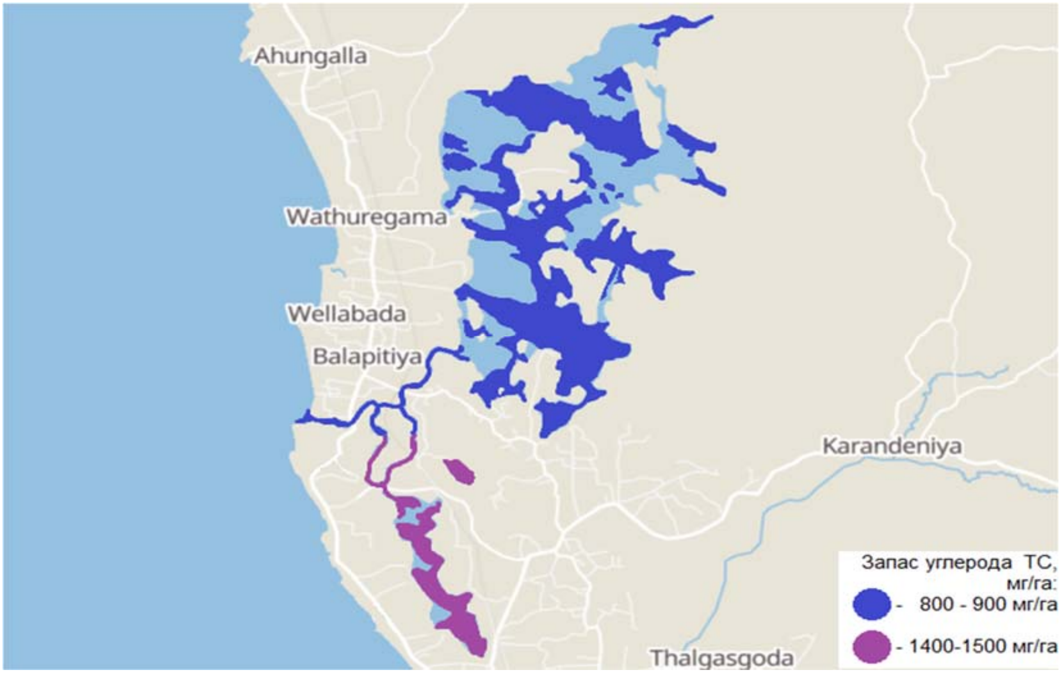


Figure 4. Carbon stocks in the Maduganga wetlands: Maduganga Lake and Randombe

*Table 1.* Calculation of the cost of carbon storage as an ecosystem service

| Research area | Carbon reserves per hectare (TC), mg/ha | Average TC, mg/ha | Area of the research area ($A_m$), ha | The amount of accumulated carbon in the study area, mg | MAC (2022), $/mg | The cost of carbon storage as ES ($V_{cs}$), $ |
|---|---|---|---|---|---|---|
| Madu Ganga Lake | 804.71 | 1130.05 | 625 | 502943.75 | 169.78 | 85389789.88 |
| Randombe Lake | 1455.39 | | 275 | 400232.25 | 169.78 | 67951431.41 |
| Total | | | 900 | 903176 | 169.78 | 153341221.3 |

*Table 2.* Cost of carbon sequestration as an ecosystem service

| $CO_{2eq}$ absorption coefficient (SR), t/ha/year | Social Cost of Carbon (SC) (2022), $/mg | Research area size ($A_m$), ha | Conversion factor for obtaining $CO_{2eq}$ from C | The cost of carbon uptake as ES ($V_{cseq}$), $ |
|---|---|---|---|---|
| 6.00 | 108.66 | 900.00 | 3.67 | 2153423.88 |

The cost of carbon storage as an ecosystem service is $85,389,790 for Lake Madu Ganga and $67,951,431 for Lake Randombe, the total cost of carbon storage ($V_{cs}$) on the wetlands of Madu Ganga was $153,341,221.

The assessment of the ecosystem service for carbon sequestration of the Madu Ganga (Figure 4) wetlands was carried out on the basis of data on the social cost of carbon in the amount of $108.66 and a $CO_{2eq}$ absorption coefficient equal to 6 tons per hectare per year. The cost of carbon sequestration Services ($V_{sceq}$) was approximately $2,153,424.

The economic cost of storing carbon as an ecosystem service was approximately $153 million, and the cost of sequestering, or absorbing carbon as an ES, was about $2 million. The total cost of services for the regulation of the carbon cycle of the Madu Ganga wetlands was $155,494,645, or 0.18% of the nominal GDP of the island of Sri Lanka, which contrasts sharply with the data of Hernández-Blanco et al. [6], where the average cost of all studied ecosystem services of the mangrove forests of the Bay of Nicoya was 0.16% of the nominal GDP of Costa Rica. The difference in indicators is primarily due to the areas of mangrove forests: Nikoya Bay has an area of approximately 1.53 km$^2$, while the wetlands of Madu Ganga are about 900 hectares or 9 km$^2$. At the same time, significant differences in carbon reserves per hectare were also revealed: for the Nikoya Bay, the size of carbon reserves ranged from 547 mgK/ha to 1175 mgK/ha, while for the Madu Ganga wetlands – from 804.71 mgK/ha to 1455.39 mgK/ha [3; 6].

In comparison with the data obtained by Vo et al. [17], where the total cost of carbon uptake is $45,876,280 (which depends primarily on the large area of mangrove forests represented in the study – 73,994 hectares), and the cost of uptake per hectare of wetlands was approximately $600. The cost of carbon uptake per hectare obtained in the current study is much higher – with a smaller land area (only 900 hectares), it amounted to about $2,200 per hectare [17].

## Conclusions

As a result of the study, the cost of ecosystem services of the Madu Ganga wetlands for climate regulation (carbon storage and sequestration) was assessed and the high economic value of these types of services for the island of Sri Lanka was established.

In general, the economic value of ecosystem services, defined through the marginal cost of reducing carbon emissions (*MAC*) and its social costs (*SCC*), demonstrates the great role of mangroves in mitigating and adapting to climate change.

The assessment can be used to influence decision makers (government and business community) to develop a wetland conservation strategy and develop a carbon neutrality policy.

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