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Application of Python Programming for Soil Carbon Stock Assessment in the East Kolkata Wetlands: A Digital Approach to Soil Health Evaluation

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Abstract
In the face of escalating climate change, the megacity of Kolkata holds a strategic advantage in implementing a nature-based sewage treatment model through the East Kolkata Wetlands (EKW). This unique ecological system utilizes shallow waste stabilization ponds, where solar irradiation and algae-bacteria symbiosis work synergistically to purify sewage in a low-carbon, energy-efficient manner. Simultaneously, the nutrient-rich effluents support sustainable fish farming, transforming waste into protein and reducing pressure on conventional food systems. Remarkably, portions of raw sewage are diverted for pre-treatment vegetable cultivation, while the treated water is reused for downstream agriculture, including paddy and vegetables, thus reinforcing circular economy principles. This study evaluates Soil Organic Carbon (SOC) across 10 sites in the EKW during 2023 to assess carbon stock levels, offering vital insights into the wetlands' role as a natural carbon sink and its potential contribution to climate mitigation strategies. Interestingly, in this study Python program has been used to compute Soil Organic Carbon (SOC) stock across these ten sites using field data and the standard formula for evaluating soil organic carbon stock. It is the first approach that has automated data analysis and has opened the roadmap for soil health assessment and conservation planning.

Keywords: East Kolkata Wetland, Soil Organic Carbon, Sustainable

INTRODUCTION

The city of Kolkata, spanning an area of 206.08 sq. km, generates a substantial volume of sewage due to its dense population of over 4.5 million (Census of India 2011) and a floating population of approximately 6 million people daily (KMC 2022). Much of this sewage is treated through an eco-friendly and cost-effective method using the natural bioremediation system of East Kolkata Wetlands (EKW), where sewage-fed ponds support both wastewater treatment and fish cultivation. Before entering these ponds, a portion of the sewage is diverted to irrigate vegetable fields, promoting resource recovery. Additionally, the treated water from the fish ponds is reused for cultivating paddy and vegetables, supporting urban food systems while conserving water resources.

The reuse of treated wastewater for irrigation is a widely recognized approach to water conservation, particularly in developing regions across Africa and South Asia (Vymazal 2010). Although Kolkata also operates five municipal sewage treatment plants (STPs), located at Baghajatin, Bangur, Garden Reach, Hatisur, and Keorapukur, their combined treatment capacity is limited to 179 MLD, falling short of the city's daily sewage generation. Moreover, the treated output from these STPs only partially meets discharge standards (Khan et al, 2024).

Natural wetland systems, by contrast, offer a sustainable and energy-efficient method for decentralized wastewater treatment. These systems are valued not only for their ecological compatibility and low operational costs (Cui et al. 2020) but also for their capacity to deliver a range of ecosystem services, including biogeochemical cycling, hydrological regulation, biodiversity conservation, and cultural benefits (Chen et al. 2009; Geber & Bjorklund 2002; Moreno et al. 2007). Wetlands have a long history of use in wastewater treatment (Stanbridge 1976), especially in warm climatic regions where shallow oxidation ponds are particularly effective (Butler et al. 2017). Despite the mechanical simplicity of wetlands, they exhibit remarkable biological complexity, enabling high treatment efficiency (Kadlec & Wallace 2009). These ecosystems significantly reduce suspended solids, organic pollutants, nutrients, pathogens, and heavy metals, thereby enhancing wastewater quality. Their role in climate change mitigation is equally important, as wetland systems can curb greenhouse gas emissions and improve overall carbon management (Gude et al. 2013).

Constructed wetlands have also shown notable success in removing micropollutants from municipal wastewater (Breitholtz et al. 2012) and in treating concentrated livestock waste, with removal efficiencies averaging 65% for BOD_5, 53% for TSS, 48% for ammonium-nitrogen, and 42% for both total nitrogen and phosphate (Knight et al. 2000). The primary mechanism behind this high treatment efficacy lies in algae-bacteria symbiosis. Shallow wetlands (30–45 cm in depth) foster dense algal growth, ensuring sustained dissolved oxygen levels through photosynthesis during the day (USEPA 2011). Wind action further aids in pond aeration (Davis & Cornwell 2008), and the aerobic conditions promote the breakdown of organic matter.

These shallow aerobic ponds, operating with a detention time of 2–6 days and a BOD loading rate of 112–225 kg per 1000 m^3 per day, can achieve up to 95% BOD removal efficiency (USEPA 2011). Maturation ponds play a vital role in reducing faecal coliforms, pathogens, nutrients, and BOD levels (Varon & Mara 2004). Recognized as one of the most productive ecosystems globally, wetlands support a diverse array of aquatic and semi-aquatic organisms, contributing significantly to biodiversity (Cherry 2011; Dalu et al. 2017; Bai et al. 2019; Bird et al. 2019).

This study examines the levels of Soil Organic Carbon (SOC) stock across ten strategically selected sites within the East Kolkata Wetlands (EKW) during the year 2023. The primary objective is to evaluate the carbon stock within this unique and ecologically significant wetland system, which holds international importance as a Ramsar site. By analyzing the SOC stock, the study aims to shed light on the role of EKW as a natural carbon sink, highlighting its relevance in the broader framework of climate change mitigation. The East Kolkata Wetlands, known for their intricate network of sewage-fed aquaculture ponds, agricultural fields, and marshes, are not only vital for wastewater treatment and biodiversity support but also play a crucial role in sequestering atmospheric carbon dioxide. The results of this study can offer a scientific foundation to understand how much carbon is stored in the wetland soils, which is a key component of their ecosystem services. By quantifying the carbon stock, the research underscores the capacity of these wetlands to mitigate greenhouse gas emissions naturally, thereby contributing to climate regulation.

The implications of this study are multifaceted. On an environmental policy level, it provides compelling evidence to integrate the EKW into national and regional climate action plans as a nature-based solution for carbon management. The findings can enhance the ecological valuation of the wetlands, strengthening the case for their continued protection and sustainable management. As urbanization pressure increases around the periphery of the wetlands, the data derived from SOC stock analysis can inform planners and policymakers to adopt land-use strategies that maintain the wetland's carbon sequestration capacity.

Moreover, this study can establish a valuable scientific baseline for future monitoring of carbon dynamics within the EKW. Long-term tracking of SOC can help assess the impacts of climate change, land-use changes, and conservation interventions on carbon storage. Additionally, the quantification of carbon stocks opens up the possibility of accessing global carbon markets, where carbon credits could be generated through the preservation and restoration of these wetlands. Such initiatives not only promote environmental sustainability but also create economic incentives for local communities to engage in conservation efforts.

In this study, Python has been used to assess soil carbon stock in the East Kolkata Wetlands, offering a modern, data-driven approach to soil health evaluation. By processing field data like SOC percentage, bulk density, and area, Python efficiently calculated and visualized total organic carbon across ten zones. This method supports climate mitigation, site-specific conservation, and future integration into carbon credit systems. It marks a significant advancement in using technology for sustainable wetland management.

Thus, this investigation into levels of SOC stock across the East Kolkata Wetlands serves as a vital step toward recognizing and harnessing the carbon sequestration potential of this urban wetland system. It reinforces the importance of wetland conservation in the *era* of climate change and paves the way for innovative, science-backed strategies for ecological and economic resilience.

Methodology

Soil samples were collected from the selected sites of East Kolkata Wetlands (EKW), ensuring uniformity in micro-topography during December 2023. This careful sampling strategy helped minimize spatial variability in key external factors such as soil granulometry, along with inputs of material from adjoining sources.

Surface soil samples from 10 cm depth were collected from 10 strategically selected sites within the EKW. Soil Organic Carbon (SOC) content (%) was analysed using the Walkley and Black method (1934), a standard procedure for estimating organic carbon in wetland soils. Bulk density of the mangrove-associated soils in EKW was determined by extracting a known volume of soil using a core sampler, oven-drying it at 105°C, and then measuring the dry weight. Bulk density was then calculated as the ratio of the dry weight to the volume of the soil sample.

For estimating SOC stock, a standard area of 1 m^2 was considered. The SOC stock (in Kg C m^{-1}) of the selected sites was calculated using the following expression:

$$\text{SOC Stock} = \left(\frac{\text{SOC}(\%)}{100}\right) \times \text{BD} \times \text{Depth} \times \text{Area}$$

We used PYTHON to compute the soil organic carbon content, the code of which is highlighted in Fig. 1.

```python
import pandas as pd
import matplotlib.pyplot as plt
data = pd.read_excel('SUMANA EKW SOIL FOR PYTHON.xlsx')
SOC = data['SOC(%)']
BD = data['BD(kg/m3)']
ht = data['ht.(m)']
Area = data['Area(sq. m)']
Total_organic_carbon_stock = SOC*BD*ht*Area/100
print(Total_organic_carbon_stock)
Total_organic_carbon_stock_array = []
for a,b in Total_organic_carbon_stock.items():
    Total_organic_carbon_stock_array.append(b);
Zone = ['zone 1', 'zone 2', 'zone 3', 'zone 4', 'zone 5', 'zone 6', 'zone 7', 'zone 8', 'zone 9', 'zone 10']
plt.figure(figsize=(20,12))
plt.bar(Zone,Total_organic_carbon_stock_array)
plt.xlabel("Zone")
plt.ylabel("Total organic carbon stock")
plt.title('Total organic carbon stock in different zones')
plt.show()
```

Fig. 1. PYTHON Code to estimate the Total Organic Carbon Stock.

The content provided in Fig. 1 is a Python program specifically written to evaluate and visualize Soil Organic Carbon (SOC) stock across ten zones in the East Kolkata Wetlands. The program begins by importing necessary libraries—**pandas** for data handling and **matplotlib.pyplot** for visualization. It reads soil data from an Excel file, extracting values such as SOC percentage, bulk density (BD), soil height, and area. Using the formula **(SOC × BD × height × area) ÷ 100**, the program calculates the total organic carbon stock for each zone. These values are stored in an array and then plotted as a bar chart, with each bar representing the carbon stock of a specific zone. The graph provides an intuitive visual comparison, aiding in the identification of high and low carbon storage areas. This program exemplifies the practical application of coding in environmental science, automating what would otherwise be a tedious manual process, and offering clear, data-driven insights for soil health assessment and conservation planning.

Result

The soil organic carbon (SOC) stock of ten selected sites in the East Kolkata Wetlands reveals considerable variation. Natur Bhery recorded the highest SOC stock at 6.06 kg/m², followed by Dhapa (5.76 kg/m²) and Dharmatala (4.73 kg/m²), reflecting strong carbon retention. In contrast, Jagatipota registered the lowest SOC stock at 4.00 kg/m², indicating reduced organic matter input or greater disturbance. Intermediate values were observed at sites like Hatgachha, Panchuria, and Hadia (Fig. 2). This spatial pattern emphasizes the need for site-specific conservation strategies to maintain and enhance the wetland's carbon sequestration capacity. Prioritizing zones like Natur Bhery could be instrumental in boosting ecosystem resilience and combating climate change.

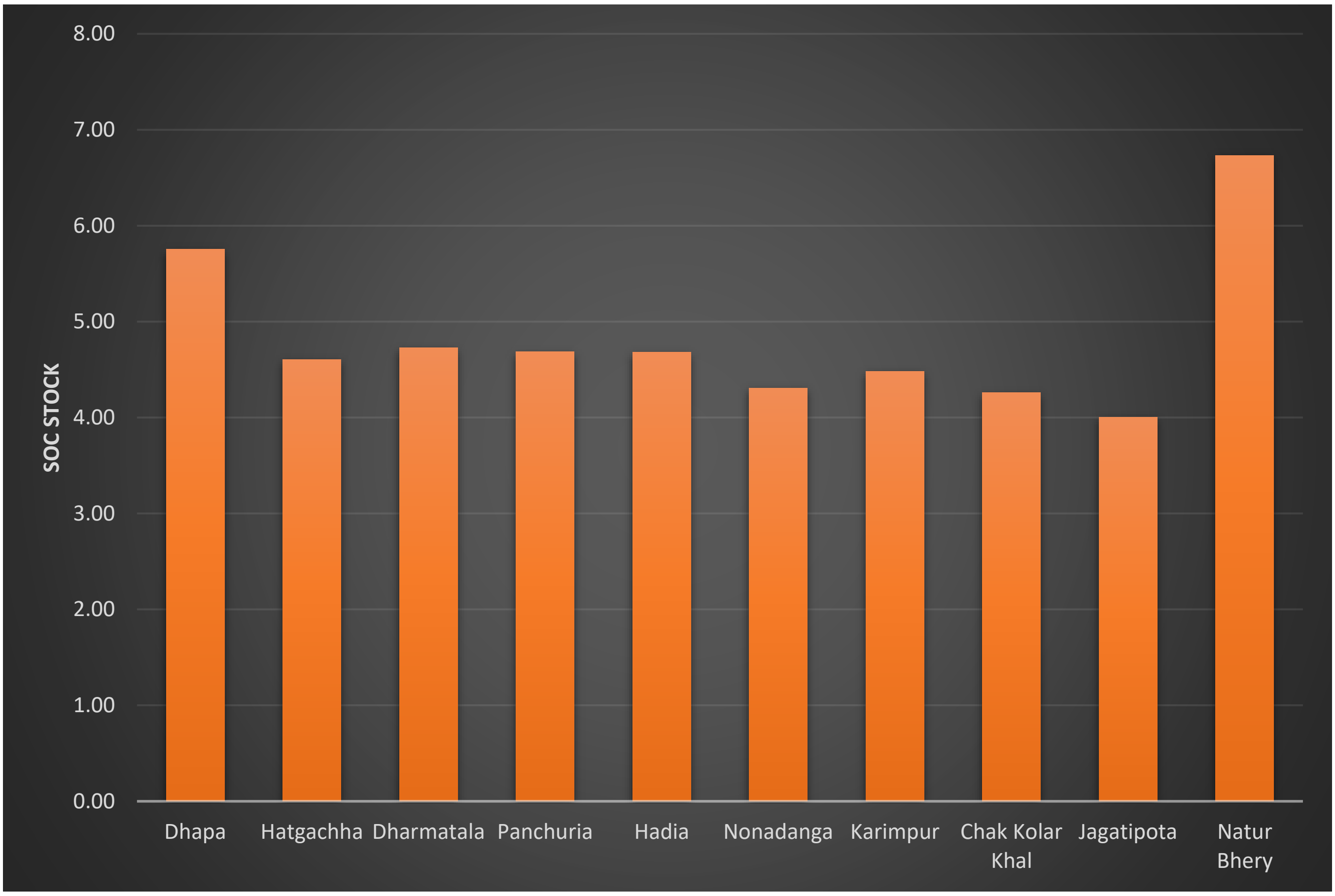

Fig. 2. SOC stock at the selected sites

Discussion

The Soil Organic Carbon (SOC) stock in the East Kolkata Wetlands (EKW) plays a pivotal role in maintaining ecological balance, enhancing soil fertility, and mitigating climate change. As one of the largest natural wastewater-fed wetland systems in the world, EKW acts as a significant carbon sink, sequestering atmospheric carbon and reducing greenhouse gas emissions, particularly carbon dioxide (CO_2) and methane (CH_4). The wetland's unique hydrology, characterized by constant water saturation, limits oxygen availability in the soil, slowing down organic matter decomposition and promoting long-term carbon storage. This makes SOC in EKW a crucial component in the regional climate regulation domain.

Beyond climate benefits, SOC is essential for maintaining soil health and fertility, which directly supports the wetland's agriculture and aquaculture-based livelihoods. The accumulation of organic matter in the soil improves nutrient cycling, enhancing the availability of essential elements like nitrogen and phosphorus, which are vital for plant and aquatic productivity. The presence of SOC also improves soil structure and water-holding capacity, making the wetland ecosystem more resilient to climate-induced

stresses such as droughts and extreme weather events.
Moreover, the wastewater-fed nature of EKW enhances its SOC dynamics. Organic-rich sewage from Kolkata is naturally treated in the wetlands, contributing to nutrient enrichment and organic matter deposition. However, the increasing pressure of urbanization, land-use changes, and pollution threatens the stability of SOC in EKW. Encroachments, land reclamation, and industrial discharge could disrupt carbon sequestration processes, leading to the release of stored carbon into the atmosphere and exacerbating climate change.
Preserving and managing SOC in EKW is, therefore, crucial for ensuring long-term carbon sequestration, sustaining agricultural productivity, and maintaining ecosystem resilience. Implementing conservation measures such as sustainable land management, wetland restoration, and pollution control can help safeguard this critical carbon reservoir. Given its ecological and socio-economic importance, EKW's SOC stock should be integrated into climate adaptation policies and carbon credit mechanisms, reinforcing its role in both regional sustainability and global climate action.
It is to be stated in this context that for the first time, Python programming has been successfully applied to evaluate soil carbon stock and assess soil health in the East Kolkata Wetlands (EKW), a Ramsar-recognized ecological hotspot. The study utilized field data such as Soil Organic Carbon (SOC) percentage, bulk density, soil depth, and area across ten zones, which were fed into a Python script to compute total organic carbon stock using the formula: SOC × BD × height × area ÷ 100. This automated approach allowed for accurate and reproducible estimations of carbon stored per square meter. The resulting values were visualized using bar charts, revealing spatial patterns in SOC stock, with Natur Bhery showing the highest sequestration potential. This digital methodology represents a paradigm shift from traditional manual calculations to efficient, scalable, and data-driven environmental assessments. By pinpointing high and low retention zones, it aids in developing site-specific conservation strategies and reinforces the wetland's role in climate regulation. The tool also lays the groundwork for integrating soil carbon metrics into carbon credit mechanisms, offering both ecological and economic benefits. Moreover, Python's adaptability makes it suitable for replicating this analysis across different ecosystems and soil types. As urbanization pressures mount, such scientific evaluations provide critical evidence to influence policy decisions, promote sustainable land use, and protect natural carbon sinks. Thus, this innovative use of Python enhances the precision and utility of soil health monitoring, making it a vital tool in the domain of climate-smart wetland management.

Conclusion

The observed variation in Soil Organic Carbon (SOC) stock across the ten sites of the East Kolkata Wetlands highlights the differential carbon sequestration potential within this ecologically significant system. Natur Bhery's high SOC stock positions it as a critical carbon sink, while the relatively lower stock at Jagatipota points to the need for enhanced organic matter input and reduced anthropogenic disturbances. The findings underscore the integral role of SOC in climate mitigation, soil fertility, and livelihood support within the EKW. Given its unique wastewater-fed nature and natural capacity for carbon storage, the wetland needs to be preserved through targeted conservation and land management strategies. Effective protection of high-retention zones can strengthen carbon sequestration, promote nutrient cycling, and improve ecosystem resilience against climate extremes. The inclusion of SOC dynamics in environmental planning is essential to counteract urban pressures and safeguard ecological functions. Strengthening policy frameworks and introducing incentives such as carbon credits could further promote sustainable practices. Overall, the SOC stock in EKW is not just a local environmental asset, but a key contributor to regional climate resilience.

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