Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Long-term trends and spatial contrasts in Soil Organic Carbon (SOC) of Kolkata, India

Simran Banerjee
Techno India University
Ankita Mitra
University of Wisconsin–Stevens Point
Joystu Dutta
joystu.dutta@gmail.com

Sant Gahira Guru Vishwavidyalaya
Sufia Zaman
Techno India University
Abhijit Mitra
Techno India University

Research Article

Keywords: Soil Organic Carbon (SOC), ecosystems, climate change, carbon sequestration, spatio-temporal variation

Posted Date: November 11th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11329837/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Long-term trends and spatial contrasts in Soil Organic Carbon (SOC) of Kolkata, India

Simran Banerjee[1], Ankita Mitra[2] , Joystu Dutta[3*] , Sufia Zaman[1] and Abhijit Mitra[1]

[1]Department of Oceanography, Techno India University, EM-4, EM-4/1, EM Block, Sector V, Bidhannagar, Kolkata, West Bengal 700091, India

[2]Department of Forestry, University of Wisconsin–Stevens Point, USA

[3]Department of Environmental Science, Sant Gahira Guru Vishwavidyalaya, Sarguja, Ambikapur, Chhattisgarh- 497 001, India

***Corresponding Email:** joystu.dutta@gmail.com

ABSTRACT

Soil Organic Carbon (SOC) is used as a proxy to assess the degree of natural as well as anthropogenic stress factors. In an over populated urban zone, the values of SOC is regulated by several factors such as deposition of dust by running vehicles, atmospheric fall out, deposition of plant litter, transference of materials from the surrounding urban environment etc. This research analyzed an yearly SOC dataset for four sites in the megacity of Kolkata, namely Moulali, Rajabazar, Manicktala and Shyambazar, covering more than three decades (1990–2025) of timescale. Over the 36-year period, SOC increased from 0.62 to 1.34% at Moulali, from 0.71 to 1.61% at Rajabazar, from 0.49 to 1.03% at Manicktala and from 0.51 to 1.12% at Shyambazar. Linear trends were positive at all four sites, with fitted slopes between 0.0140 and 0.0207 percentage points per year. A noticeable dip occurred in 2020, followed by only a modest recovery in 2021 and a stronger hike thereafter. Both natural phenomenon and anthropogenic stress factors contribute to this spatio-temporal variations. The study therefore treats the present series as a baseline record and aims to explore the SOC patterns across the four selected sites. The spatio-temporal analysis of SOC is essential to understand the carbon sequestration potential of urban soils. This may further help environmentalists to understand carbon dynamics across urban ecosystems and ways to mitigate the carbon-dioxide through sequestration of terrestrial carbon.

KEYWORDS: Soil Organic Carbon (SOC), ecosystems, climate change, carbon sequestration, spatio-temporal variation.

INTRODUCTION

Soil is the largest terrestrial pool of organic carbon, storing approximately 1,500 to 2,400 gigatons (Gt or Pg) of carbon globally, which is two to three times more than the amount of carbon in the atmosphere (Beillouin *et al*., (2023). Research related to SOC has grown worldwide, influenced by the potential of the soil to become a manageable sink for atmospheric carbon dioxide and thus to mitigate climate change, and the known benefits of increased SOC for the functioning of soils (McBratney et al., 2014;

Stockmann et al., 2013) Estimates of SOC on a global scale vary between 700 to 3000 Pg C (Bouwman, 1990). Urban soils receive organic matter from vegetation, domestic activities, transported materials and atmospheric deposition. SOC level therefore acts as proxy to both ecosystem functioning and the history of human activity (Dutta et al., 2019). Land use, climate and soil parent material are the key drivers of SOC distribution in any landscape (Adhikari et al., 2019). Leaves and roots add organic matter, while soil replacement, construction, drainage, waste handling, dust transmission and deposition through vehicular movements, and airborne deposition can alter SOC profile of the urban soil (Fig. 1). These influences accumulate over time, which makes the long-term records useful when the aim is to understand the pattern of spatio-temporal variation.

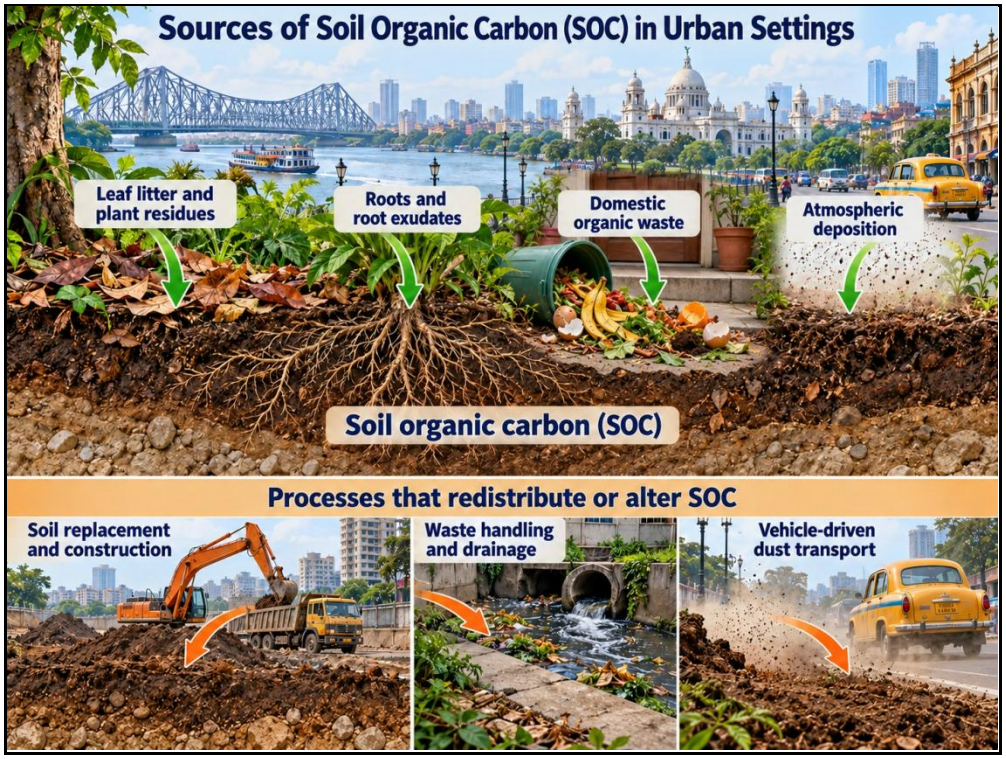


Fig. 1. Sources of SOC in Urban Settings

The megacity of Kolkata offers an ideal experimental urban set up for such study. The city exhibits an assemblage of dense settlement, intense traffic, old residential neighbourhoods, commercial activity and scattered patches of open or vegetated patches. Sites within the same broad climatic setting may therefore experience very different local histories. Kolkata is historically vulnerable to global climate change consequences and sea level rise (Ericson et al., 2006; IPCC, 2022; Mukhopadhyay et al., 2021). Kolkata being bordered by Sundarban mangrove ecosystem; a World Heritage Site, which acts as natural barrier preventing the manifold impact of natural disasters such as floods, tropical cyclones, tidal surges etc (Alongi, 2002; Alongi, 2012) as well as act as nature based solution (NbS) against global climate change and it's consequences (Powlson et al., 2011). Urban green spaces are ideal indicators of biodiversity

conservation and carbon sequestration opportunities in an urban setting grossly influenced by anthropogenic stress factors (Tolangay et al., 2026).

The present study was focused on four localities in Kolkata, for which annual SOC values were analyzed from 1990 to 2025, with sampling conducted in December of each year. Three research questions were formulated: (i) how SOC changed over time at each site across Kolkata, (ii) the magnitude of differences observed among the four sites, and (iii) how the sharp interruption observed around 2020–2021 could be interpreted. The 36-year SOC time series and associated standard deviation (SD) values were utilized as baseline information. Possible environmental explanations are presented as working hypotheses to guide further investigation of the SOC budget and its implications for the megacity of Kolkata. Some earlier scientific investigations throw light on Kolkata from varied viewpoints but scientifically allied research question. (Ahmed et al., 2022; Agarwal et al., 2021; Mitra et al., 2020; Saha et al., 2020)

MATERIALS AND METHODS

STUDY AREA

Four sites were considered in the present study, namely Moulali (22°33′36.0″N; 88°22′00.3″E), Rajabazar (22°34′31.7″N; 88°22′24.5″E), Manicktala (22°35′08.0″N; 88°22′29.5″E) and Shyambazar (22°36′06.5″N; 88°22′21.0″E). Together, they form a compact, broadly north–south sequence across the study area (Fig. 2).

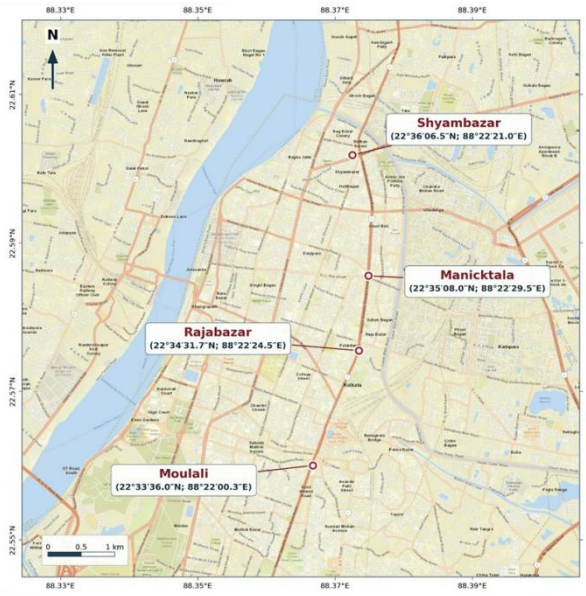


Fig. 2. Location of the four study sites in Kolkata

Sampling and Analysis of Soil Organic Carbon (SOC)

Five 5 m × 5 m sampling plots (five sub-samples) for each of the 4 sites were taken into consideration at our study location during the month of December in every year from 1990 to 2025. The soil samples

were carefully collected to ensure that they were gathered from the same micro-topography. SOC levels were measured in the soil surface layer (1-10 cm depth) of 4 selected sites. The Walkley and Black method was used to analyse the SOC (in %) (Walkley and Black, 1934).

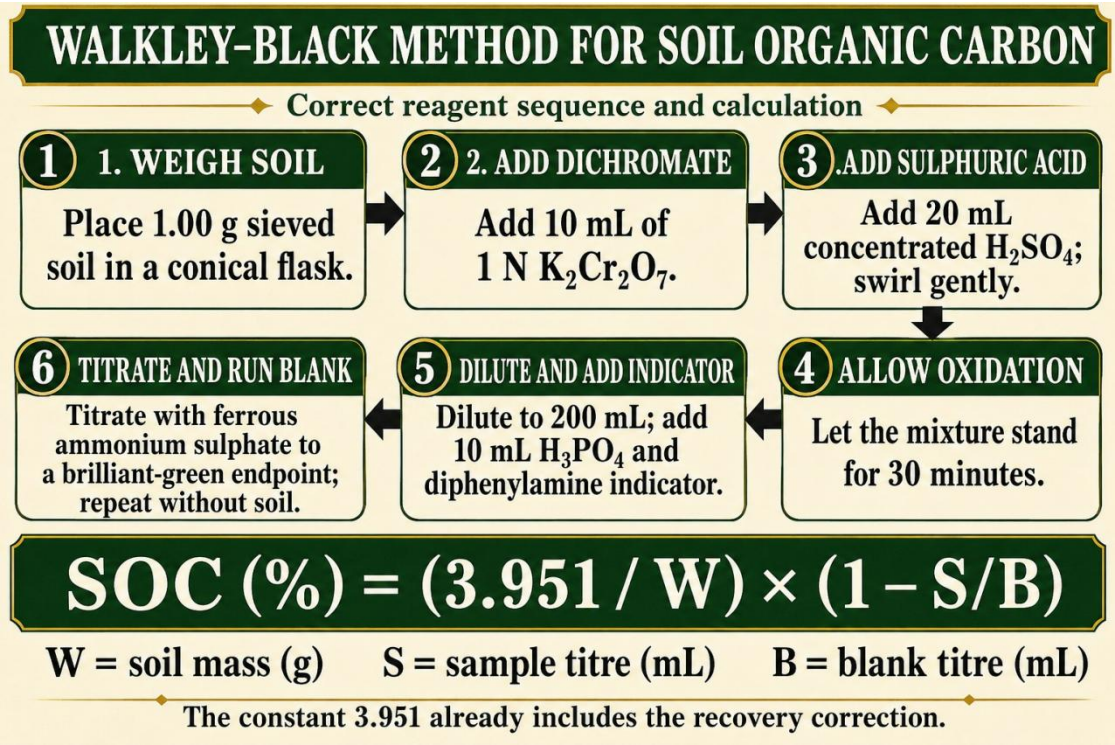


Fig. 3. Chemical method for determination of SOC

Statistical Analysis

Long-term change was summarized separately for each locality using ordinary least-squares regression: SOC = a + b × (year – 1990). In this expression, 'a' represents the fitted value at the beginning of the series and 'b' represents the annual change in SOC concentration. The slope is reported in percentage points per year, while 'R^2' indicates how closely the annual series follows the fitted straight-line trend. Percentage change between 1990 and 2025 was calculated from the two endpoint values. The decline in 2020 was also expressed relative to the 2019 value. In the figures, annual SOC is shown together with the supplied ±SD band and the fitted linear trend. Five analyses were done from five quadrats for every site to assure the quality of the data through enumeration of SD values. With SPSS 9.0 for Windows, all statistical computations were completed.

RESULTS

For most of the years, the sequence of SOC is Rajabazar > Moulali > Shyambazar > Manicktala. The site-specific results, as discussed separately, exhibit a rising trend with a steep dip in 2020.

Moulali

At Moulali, SOC increased from 0.62 ± 0.06% in 1990 to 1.34 ± 0.11% in 2025, which is a hike of 0.72, or 116.1% relative to the initial value. The fitted relationship, SOC = 0.6858 + 0.01697 × (year − 1990), gave an R^2 of 0.849 (Fig. 4). The increment was not perfectly uniform, but the general direction remained upward with time. SOC value reached 1.23 ± 0.09% in 2019 and then dropped sharply to 0.89 ± 0.09% in 2020, a fall of 27.6%. Only a small recovery was evident in 2021 (0.94 ± 0.10%). By 2022, however, the value increased to 1.29 ± 0.08%, slightly above the pre-2020 level.

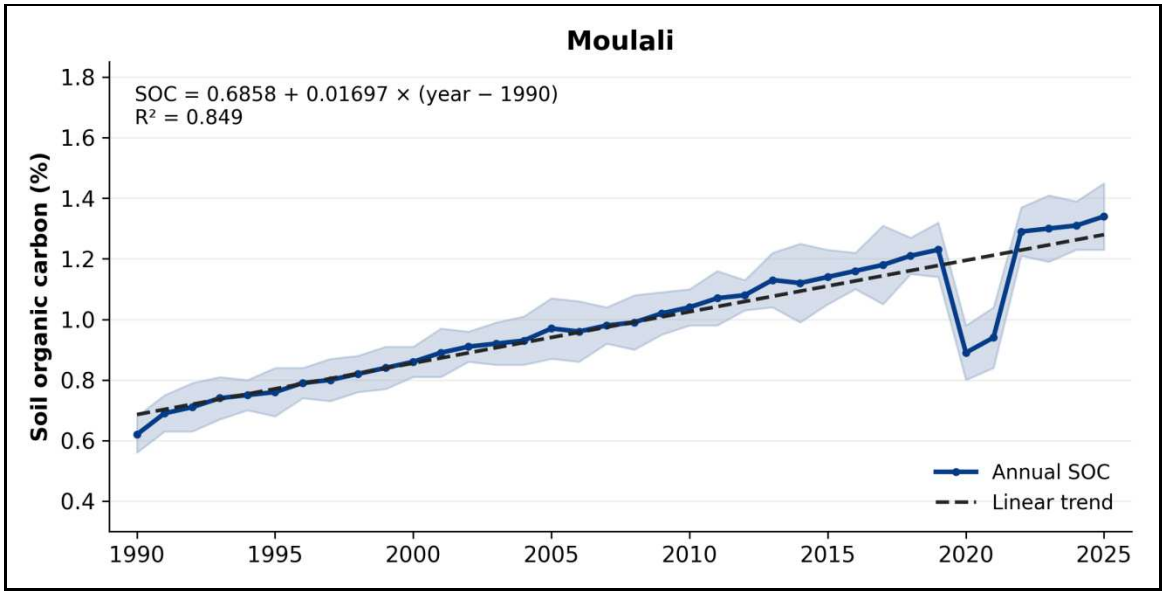


Fig. 4. Annual SOC at Moulali from 1990 to 2025. Shading represents the supplied SD values, and the dashed line shows the fitted linear trend

Rajabazar

This site remained the highest of the four sites throughout the series. SOC increased from 0.71 ± 0.08% in 1990 to 1.61 ± 0.17% in 2025, a rise of 0.90, which is equal to 126.8%. It also had the steepest fitted long-term slope: SOC = 0.7933 + 0.02073 × (year − 1990), with R^2 = 0.786 (Fig. 5). The 2019 value was 1.46 ± 0.15%, followed by a dip to 0.97 ± 0.07% in 2020. This is a decline by 33.6%, the largest proportional drop among the four sites. SOC remained low in 2021 at 1.01 ± 0.05%, before restoring to 1.54 ± 0.10% in 2022.

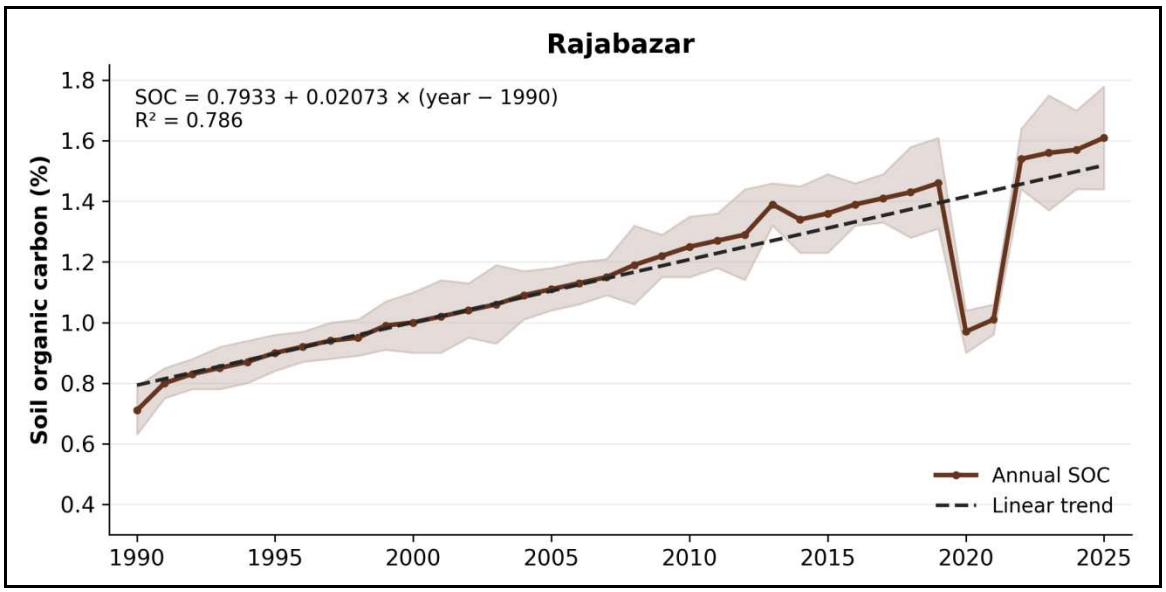


Fig. 5. Annual SOC at Rajabazar from 1990 to 2025. Shading represents the supplied SD values, and the dashed line shows the fitted linear trend.

Manicktala

At Manicktala, the SOC values increased from 0.49 ± 0.05% in 1990 to 1.03 ± 0.14% in 2025, equivalent to a rise of 0.54 equivalent to 110.2% hike. The regression equation was SOC = 0.4997 + 0.01395 × (year − 1990), with R^2 = 0.894 (Fig. 6). Unlike the relatively steady background rise, two short peaks stand out: 0.83 ± 0.09% in 2005 and 0.96 ± 0.05% in 2013. In both years, Manicktala temporarily exceeded the Shyambazar site. The 2020 interruption was again clear, with SOC falling from 0.92 ± 0.09% in 2019 to 0.74 ± 0.07%, a decrease of 19.6%.

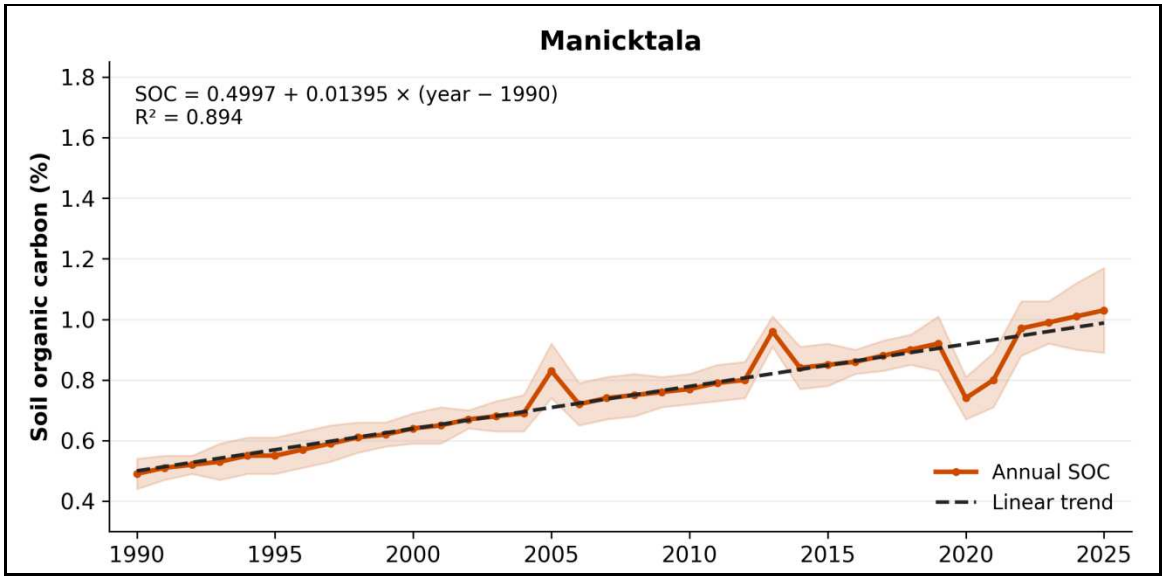


Fig. 6. Annual SOC at Manicktala from 1990 to 2025. Shading represents the supplied SD values, and the dashed line shows the fitted linear trend

Shyambazar

The site Shyambazar showed similar increasing trend (Fig. 7). SOC increased from 0.51 ± 0.05% in 1990 to 1.12 ± 0.12% in 2025, a gain of 0.61 percentage points or 119.6%. The fitted equation was SOC = 0.5391 + 0.01534 × (year − 1990), with $R^2 = 0.902$ (Fig. 7). A decline from 1.03 ± 0.12% in 2019 to 0.78 ± 0.07% in 2020 represented a 24.3% reduction. The SOC value restored to 1.07 ± 0.07% by 2022.

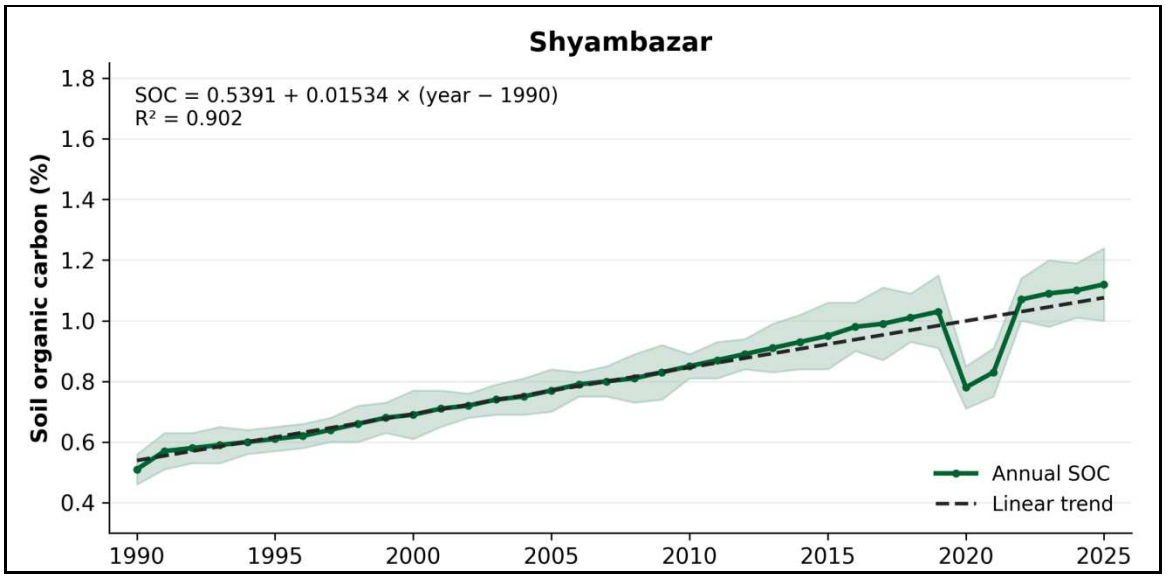


Fig. 7. Annual SOC at Shyambazar from 1990 to 2025. Shading represents the supplied SD values, and the dashed line shows the fitted linear trend

Discussion

The most common feature of the four sites in the megacity of Kolkata is the long-term rise of SOC. In an urban soil, such a pattern is obvious when additions of carbon exceed losses. Plant litter and fine roots are obvious biological sources, but they are not the only sources in an urban setting. Domestic sources, soil replacement, construction, drainage, waste handling, dust transmission and deposition through vehicular movements, and airborne deposition do have roles in altering the SOC profile of the city of Kolkata.

The variation in SOC level among the four sites is not a minor feature of the observed dataset. Rajabazar remained numerically highest, while Manicktala was generally lowest. Local variation in context to presence of vegetated patches, organic waste inputs, soil texture, drainage, deposition and the frequency with which surface soil is disturbed or replaced due to continuous vehicular movements, constructional works etc., could influence SOC.

At present, however, none of these site-level variations can be assigned with confidence in terms of cause-effect relationship. This is mainly because we don't have site-wise parallel measurements of traffic intensity, vegetation cover, waste deposition, soil texture, moisture or land-management history. The brief peaks at Manicktala in 2005 and 2013 illustrate the problem well. They may represent genuine short-lived changes, but they could also arise from local soil addition, maintenance activity or differences from where the sample was taken.

The fall in SOC during 2020 is striking because it appears at all four sites. It is more reliable to connect this feature with the unusual conditions of the COVID-19 period, when traffic, commercial activity and movement of materials in Kolkata were disrupted. Such a link is possible as a hypothesis, particularly if urban deposition contributes to surface-soil carbon.

The fitted slopes provide a convenient summary of direction or SOC trend at these four selected sites. However, a broader assessment would need stratified sampling across residential, commercial, industrial and green-space settings, with attention to both exposed and sealed surfaces, a scientific conclusion inferred earlier in Sundarbans mangrove ecosystem (Ghosh and Mitra, 2025; Mitra and Zaman, 2025; Mitra and Zaman, 2026).

CONCLUSION

Across our observed data sets of 1990–2025, SOC increased at all four Kolkata sites, while clear differences among localities persisted. Rajabazar remained the highest series and had the steepest fitted slope; Manicktala generally remained lowest and had the shallowest slope. All four sites also exhibited a marked decline in 2020, a limited recovery in 2021 and a restoration thereafter. The most probable reason for the long-term rise of soil organic carbon (SOC) across all four sites in Kolkata is that anthropogenic carbon inputs in this megacity consistently exceed natural and management-driven losses, creating a net accumulation regime that is characteristic of many rapidly urbanizing tropical soils. In urban soils, SOC dynamics are governed less by natural litter–decomposition balances and more by human-mediated carbon fluxes. In Kolkata's case, several converging processes likely drive this pattern such as continuous organic inputs from urban activities viz.domestic organic waste, green waste and litter, construction and fill materials, vehicular and industrial dust. Moreover, there is limited SOC loss pathways such as reduced microbial decomposition, low disturbance in some sites such as parks, institutional campuses, and abandoned lands may experience minimal tillage or erosion, allowing SOC to accumulate over decades.

It is important to state from the environmental management point of view that, improved soil fertility in green spaces, and buffering against urban heat lands indicate positive scenario, while the risk of co-accumulation of heavy metals, pathogens and persistent organic pollutants alongside SOC, especially in sites receiving untreated waste or industrial dust displays a negative picture. Future research needs to quantify the proportion of SOC derived from anthropogenic vs. biogenic sources using isotopic tracers or molecular biomarkers (lignin, phenols, black carbon) to distinguish between "natural" and "urban" carbon pools.

AUTHOR CONTRIBUTIONS

S.B. and Abhi. M. conceptualized the study and designed the research. J.D. and Abhi.M. wrote the initial draft of the manuscript while S.B. collected the data. A.M. carried out the statistical analysis. J. D. S.B. and Abhi. M. finalized the manuscript. All authors reviewed the manuscript and gave consent to communicate and publish.

ACKNOWLEDGMENT

The authors would like to thank respective Vice Chancellors of the representing Universities for their constant support and Techno India University for giving laboratory facilities.

FUNDING

This work was supported by ongoing institutional funding. No additional grants to carry out or direct this particular research were obtained.

ETHICS APPROVAL: NOT APPLICABLE

CONSENT TO PARTICIPATE: NOT APPLICABLE

CONSENT TO PUBLISH DECLARATION: NOT APPLICABLE

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest**.**

DATA AVAILABILITY STATEMENT

The datasets generated during the current study are available from the corresponding author on reasonable request.

REFERENCES

Adhikari, K., Owens, P. R., Libohova, Z., Miller, D. M., Wills, S. A., & Nemecek, J. (2019). Assessing soil organic carbon stock of Wisconsin, USA and its fate under future land use and climate change. *Science of the Total Environment*, *667*, 833–845. https://doi.org/10.1016/j.scitotenv.2019.02.420

Agarwal, S., Chakrabarty, S. P., Zaman, S., Pramanick, P., Biswas, P., Mukhopadhyay, N., Dutta, J., & Mitra, A. (2021). Assessment of carbon storage potential of dominant tree species in an educational campus, Kolkata, West Bengal. *Ela Journal of Forestry and Wildlife*, *10*(2), 869–878.

Ahmed, S., Trivedi, S., Pal, N., Pramanick, P., Zaman, S., & Mitra, A. (2022). Study on floral carbon storage potential in the megacity of Kolkata: A roadmap towards net-zero carbon emission. *Journal of Environment and Sociobiology*, *19*(2), 113–123.

Alongi, D. M. (2002). Present state and future of the world's mangrove forests. *Environmental Conservation*, *29*(3), 331–349. https://doi.org/10.1017/S0376892902000231

Alongi, D. M. (2012). Carbon sequestration in mangrove forests. *Carbon Management*, *3*(3), 313–322. https://doi.org/10.4155/cmt.12.20

Beillouin, D., Corbeels, M., Demenois, J., et al. (2023). A global meta-analysis of soil organic carbon in the Anthropocene. *Nature Communications*, *14*, 3700. https://doi.org/10.1038/s41467-023-39338-z

Bouwman, A. (1990). Exchange of greenhouse gases between terrestrial ecosystems and the atmosphere. In A. F. Bouwman (Ed.), *Soil and the greenhouse effect* (pp. 62–127). John Wiley and Sons.

Dutta, J., Banerjee, K., Agarwal, S., & Mitra, A. (2019). Soil organic carbon (SOC): A proxy to assess the degree of anthropogenic and natural stress. *The Journal of Interrupted Studies*, *2*(1), 90–102. https://doi.org/10.1163/25430149-00201002

Ericson, J. P., Vörösmarty, C. J., Dingman, S. L., Ward, L. G., & Meybeck, M. (2006). Effective sea-level rise and deltas: Causes of change and human dimension implications. *Global and Planetary Change*, *50*(1–2), 63–82. https://doi.org/10.1016/j.gloplacha.2005.07.004

Ghosh, R., & Mitra, A. (2025). Decadal variation of soil organic carbon stock in the mangrove-dominated Indian Sundarbans. *Eurasian Soil Science*, *58*, 15.

IPCC. (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama, Eds.). Cambridge University Press. https://doi.org/10.1017/9781009325844

McBratney, A. B., Minasny, B., & Hong, S. Y. (2014). Challenges for soil organic carbon research. In *Progress in soil science* (pp. 3–16). Springer International Publishing.

Mitra, A., & Zaman, S. (2015). *Blue carbon reservoir of the blue planet*. Springer. https://doi.org/10.1007/978-81-322-2107-4

Mitra, A., & Zaman, S. (2016). *Basics of marine and estuarine ecology*. Springer. https://doi.org/10.1007/978-81-322-2707-6

Mitra, A., Ray Chadhuri, T., Mitra, A., Pramanick, P., & Zaman, S. (2020). Impact of COVID-19 related shutdown on atmospheric carbon dioxide level in the city of Kolkata. *Parana Journal of Science and Education*, *6*(3), 84–92.

Mukhopadhyay, M., Mukhopadhyay, S., & Gour, J. (2021). Fluvio-geomorphic environment of Sundarbans: A geographic approach. In *Advances in environmental and earth sciences* (Vol. 1, pp. 1–22). B P International. https://doi.org/10.9734/bpi/mono/978-93-48859-73-0/CH1

Powlson, D. S., Whitmore, A. P., & Goulding, K. W. T. (2011). Soil carbon sequestration to mitigate climate change: A critical re-examination to identify the true and the false. *European Journal of Soil Science*, *62*(1), 42–55. https://doi.org/10.1111/j.1365-2389.2010.01342.x

Saha, A., Sardar, I. N., Pramanick, P., Zaman, S., & Mitra, A. (2020). Decreasing trend of near surface atmospheric CO_2 level in the city of Kolkata during COVID-19 lockdown phase. *NUJS Journal of Regulatory Studies* (Special Issue), 84–88.

Stockmann, U., Adams, M. A., Crawford, J. W., Field, D. J., Henakaarchchi, N., Jenkins, M., Minasny, B., McBratney, A. B., de Remy de Courcelles, V., Singh, K., Wheeler, I., Abbott, L., Angers, D.

A., Baldock, J., Bird, M., Brookes, P. C., Chenu, C., Jastrow, J. D., Lal, R., Lehmann, J., O'Donnell, A. G., Parton, W. J., Whitehead, D., & Zimmermann, M. (2013). The knowns, known unknowns and unknowns of sequestration of soil organic carbon. *Agriculture, Ecosystems & Environment*, *164*, 80–99. https://doi.org/10.1016/j.agee.2012.10.001

Tolangay, D., Hossain, S. S., & Moktan, S. (2026). Carbon storage and sequestration potential of tree stands in urban green spaces of Kolkata, India. *Forestist*, *76*, 0025. https://doi.org/10.5152/forestist.2026.25025

Walkley, A., & Black, I. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, *37*(1), 29–38.