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Influence of Urban Sprawl on Water Quality Parameters in River Rupingazi in Embu Municipality, Kenya

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Abstract

Urban sprawl refers to the uncontrolled or unplanned expansion of urban areas into the surrounding areas. It typically results to inefficient land use and environmental degradation as the urban areas spread outward beyond their planned boundaries. This study aimed to determine the influence of urban sprawl on water quality parameters of water along the Rupingazi River in Embu Municipality, Kenya. A sample of thirty water–soil samples were collected along the river in ten sampling points. Parameters such as temperature and pH were measured in-situ while other parameters were analyzed in the laboratory using standard water testing procedures. These included: Lead, Phosphates, Nitrates, TSL, TDS, Dissolved Oxygen, Turbidity and Electrical Conductivity. Ten key water quality parameters were tested. Mann-Whitney U test results showed that all parameters were statistically significant (< 0.001) between the municipality and catchment areas. Findings revealed that urban sprawl had markedly degraded water quality. Most parameters were higher in the urbanized municipality: lead increased from 0.00378 mg/L to 0.02296 mg/L (above WHO limits), phosphates from 1.8535 mg/L to 5.612 mg/L, nitrates from 0.3663 mg/L to 2.970 mg/L, and TSL from 40.8 mg/L to 250.4 mg/L. Electrical conductivity and turbidity also rose sharply, while DO declined from 10.53 mg/L to 4.94 mg/L, falling below NEMA standards. Pollution Index (PI) values similarly increased, with the Average Pollution Index (API) rising from 3.05 in the catchment to 12.98 in the municipality. The analysis revealed that water quality was significantly degraded in the urban municipality compared to the catchment area due to increased concentrations of pollutants such as lead, phosphates, nitrates, turbidity, and total suspended load, which are associated with urban runoff, waste disposal, and land-use changes caused by urban sprawl. The study recommended for stricter urban land use policies by the county government of Embu to curb the menace.

1. Introduction

Urban sprawl refers to uncontrolled expansion of urban areas beyond the specified area stipulated on the land use plan. Urbanization and the related phenomenon of urban sprawl are accelerating across the globe and are especially rapid in Africa, reshaping landscapes and generating complex environmental pressures on riverine ecosystems (United Nations, 2022; OECD/UN-Habitat, 2025). The conversion of vegetated and permeable land to impervious surfaces, reduces infiltration and groundwater recharge, and amplifies runoff volumes and peak flows to downstream rivers (Ongaga, 2024). These hydrological alterations interact with urban pollutant sources to produce urban stream syndrome, characterized by elevated sediments, higher conductivity and dissolved solids, nutrient enrichment, increased biochemical and chemical oxygen demand (Pang et al., 2023).Sub-Saharan Africa has been experiencing one of the fastest rates of urban expansion worldwide, with profound implications for secondary towns that are growing faster than local infrastructure and environmental management capacity (OECD/UN-Habitat, 2025; UN-Habitat, 2024). Embu county integrated development plan reveals a rapid shift toward urban living and accelerated housing and infrastructure development in non-metropolitan centers, contributing to peri-urban land conversion and pressure on water and sanitation services (Embu County Government, 2023).

Riverine systems within urban and peri-urban landscapes perform multiple ecological and socio-economic functions: they provide water for domestic and productive uses, support biodiversity, offer recreational and cultural benefits, and act as conduits for assimilating and transporting excess nutrient and pollutant loads (Madureira et al., 2024). These services are jeopardized when land-use change and waste discharges exceed natural capacities. Recent regional assessments indicated that a substantial proportion of African rivers show elevated contaminant burdens where drainage networks intersect expanding urban footprints (Nkwasa et al., 2024; Jacobs et al., 2024). Urban activities generate a complex mix of stressors that alter physico-chemical water quality parameters. (EPA, n.d.; WHO, 2017; Omole, 2025). Stormwater flow across impervious surfaces mobilizes oils, metals and fine sediments that increase turbidity and TSS, while sewer leakage and direct discharge of domestic wastewater contribute organic matter and pathogens that reduce dissolved oxygen and pose human health risks (Ngatia, 2023).Studies of urban rivers such as the Ngong and Sosiani revealed spatial patterns of higher conductivity, nutrient enrichment and elevated turbidity in sections influenced by dense settlement, informal dumping and industrial activity (Ngatia, 2023). Previous studies in Embu underscores comparable concerns: hydrological assessments and county planning documents point to accelerating housing development, expanding small-scale industries and road infrastructure in the Embu–Rupingazi corridor, with the findings reporting elevated turbidity, increased nutrient loads and riparian encroachment along the Rupingazi River (Bonareri, 2017; Embu County Government CIDP, 2023).

2. METHODOLOGY

2.1 STUDY AREA

The study was conducted in Embu Municipality in Embu County, Kenya, between Latitude $0^0 32' 24''$& $0^0 32' 46''$ South and Longitude $37°27' 01''$ to $37^0 27' 31''$ (Fig. 1). The Municipality occupies approximately an area of 80km^2. It is approximately 150km North East of Nairobi. Embu County is positioned East of Mt. Kenya, whose summit passes across the southern border's periphery. The county is bounded to the North by Tharaka Nithi County and to the East, by Kirinyaga County

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2.2 Research design

The study adopted a descriptive cross-sectional research design. This design was appropriate because it enabled the researcher to collect and analyze water quality data from different locations along the river at a single point in time and compare the conditions between urbanized and catchment area. The descriptive aspect involved measuring key physicochemical parameters of water, including temperature, pH, lead, phosphates, nitrates, total suspended load (TSL), total dissolved solids (TDS), dissolved oxygen (DO), turbidity, and electrical conductivity. The comparative component allowed the study to determine whether significant differences existed between the municipality and catchment sections of the river.

This design therefore provided a reliable framework for assessing how urban expansion and associated land-use changes influence river water quality.

2.3 Sampling Procedure

The study focused on the section of the Rupingazi River that flows through Embu Municipality and the upstream catchment area. These two zones were selected to allow comparison between urbanized sections affected by urban sprawl and relatively less disturbed upstream areas. A purposive sampling technique was used to identify ten sampling points along the river channel. The points were strategically selected based on: proximity to urban settlements and infrastructure, areas receiving urban runoff and waste discharge, relatively undisturbed upstream locations and accessibility and safety for sampling.

The sampling points were distributed along the river to capture the spatial variation in water quality from the catchment area to the urban municipality. At each of the ten sampling points, three samples were collected, resulting in a total of thirty water–soil samples. This replication was intended to enhance reliability and reduce sampling errors. Water samples were collected using clean, sterilized sampling bottles. The bottles were rinsed with river water before sample collection to avoid contamination. Samples were taken at approximately 20–30 cm below the water surface to ensure that the water represented the main flow rather than surface contaminants. Soil samples were also collected from the riverbed near the sampling points using a clean sampling scoop and stored in labeled containers.

Some parameters that could change rapidly with environmental conditions were measured directly in the field (in-situ) using portable meters. These included: Temperature and pH. The remaining water samples were preserved and transported to the laboratory for further analysis.

The collected data were analyzed to determine variations in water quality parameters between the municipality and catchment areas. The Mann–Whitney U test was applied to determine whether differences in water quality parameters between the two zones were statistically significant.

2.4 Procedure for Measuring Water Quality

Ten sampling points were identified along the Rupingazi River to represent municipality and catchment section. A total of thirty water–soil samples were collected from the ten sampling points along the river. At each point, three samples were taken to increase reliability and minimize sampling error. Temperature and pH parameters were measured directly in the field. Water samples intended for laboratory analysis were carefully sealed, labeled and stored in cool boxes to maintain their integrity during transportation. The samples were then transported to Chuka University laboratory for further analysis within the recommended holding period. Laboratory analysis was conducted using standard water testing procedures to determine the concentration of the remaining physicochemical parameters After obtaining laboratory results, the measured concentrations were compared with recommended water quality standards established by relevant environmental authorities such as the World Health Organization and the National Environment Management Authority.

A Pollution Index (PI) was calculated to determine the extent of contamination at each sampling point. The Average Pollution Index (API) was then computed to summarize pollution levels for both the catchment and municipality sections. To determine whether urban sprawl significantly influenced water quality, the data were subjected to statistical analysis using the Mann–Whitney U test. This non-parametric test was applied to compare water quality parameters between the municipality and the upstream catchment areas.

3. RESULTS AND DISCUSSION

3.1. Spatial Extent of Urban Sprawl Along Rupingazi Riverine Ecosystem

The study sought information on the extent of urban sprawl along the Rupingazi riverine ecosystem. The findings were presented on Fig. 2

The year 2019 was selected as a key reference period in the analysis of urban sprawl along the Rupingazi riverine ecosystem because it represents a stage when the influence of rapid urban expansion in Embu Municipality had become more pronounced. This period falls several years after the introduction of Kenya's devolved governance system in 2013, which significantly accelerated socio-economic development and administrative growth at the municipality. By the year 2019, urban sprawl had intensified dramatically, with more built-up expansion along the Rupingazi riverine ecosystem. This is clearly shown on Fig. 2 by patches of maroon color along Rupingazi. The maroon color implies an increased rate of urban sprawl. The increased urban sprawl as revealed on Fig. 2 necessitated the need to analyze the influence of urban sprawl on water quality of River Rupingazi.

3.2. Influence of Urban Sprawl on Water Quality of River Rupingazi

The study sought information on physical -chemical parameters along river Rupingazi. Table 1and 1 shows the comparison of parameter levels along the municipality with the catchment levels. The municipality levels were further compared with the Kenyan guidelines (KEBS and NEMA), world health organization (WHO) and United Nations Environmental Programs (UNEP) recommendations for riverine ecosystem. The summary findings were presented on Tables 2 and 3

Table 1
Influence of Urban Sprawl on Physical Properties Along Rupingazi Riverine Ecosystem

Parameter	Recommended Limits	Catchment Average Level	Municipality Average Level
Temperature (°C)	-	19.62	25.54
Turbidity (mg/L)	10.6 (KEBS)	10.6	255.9
Total Suspended Load (TSL) (mg/L)	30 (NEMA)	40.8	250.4
Total Dissolved Solids (TDS) (mg/L)	300–900 (NEMA)	48.2	395.6
Electric Conductivity (µS/cm)	200–800 (WHO)	75.7	567.2
Dissolved Oxygen (mg/L)	5.0 mg/L (NEMA	10.53	4.94

Table 1 presents the summary of physical parameters analyzed along the Rupingazi River within both the catchment and municipality sections. The results indicated notable variations in water quality between the two zones. Temperature values ranged from 19.62°C in the catchment area to 25.54°C within the municipality, showing a substantial rise downstream. Turbidity levels were markedly higher in the municipality (255.9 mg/L) compared to the catchment (10.6 mg/L), far exceeding the KEBS recommended limit of 10.6 mg/L. Similarly, Total Suspended Load (TSL) increased from 40.8 mg/L upstream to 250.4 mg/L in the urban section, surpassing the NEMA limit of 30 mg/L. Total Dissolved Solids (TDS) and Electrical Conductivity (EC) followed a similar trend, with municipality averages (395.6 mg/L and 567.2 µS/cm respectively) exceeding those in the catchment (48.2 mg/L and 75.7 µS/cm). Conversely, Dissolved Oxygen (DO) levels decreased from 10.53 mg/L in the catchment to 4.94 mg/L in the municipality, dropping below the NEMA guideline of 5.0 mg/L.

The observed variations in physical parameters revealed the significant influence of urban sprawl on the Rupingazi Riverine ecosystem. The increase in temperature, turbidity, TSL, TDS, and EC within the municipality can be attributed to intensified human activities such as construction, impervious surface expansion, and effluent discharge associated with urban growth. Elevated turbidity and suspended solids indicate high sediment inflow, likely resulting from poor stormwater management and erosion from unplanned developments. The higher electrical conductivity and TDS suggested increased ionic concentration due to wastewater inflow and surface runoff carrying urban pollutants. The reduction in dissolved oxygen downstream reflects organic matter accumulation and reduced aeration from increased sediment load and pollutant presence. These results imply that urban sprawl had altered the river's physical environment.

Further the study sought information on the influence of urban sprawl on chemical properties along Rupingazi riverine ecosystem. The findings were presented on Table 2.

Table 2
Influence of Urban Sprawl on Chemical Parameters Along Rupingazi River

Parameter	Recommended Limits	Catchment Average Level	Municipality Average Level
Lead (Pb^{2+}) (mg/L)	0.01 mg/L (WHO)	0.00378	0.02296
Phosphate (PO_4^{3-}) (mg/L)	≤ 0.1 (UNEP)	1.8535	5.612
Nitrate (NO_3^-) (mg/L)	50 (WHO)	0.3663	2.9700
Ph	6.5–8.5 (WHO)	7.64	8.67

Table 2 shows the variations in chemical parameters of water quality along the Rupingazi River within the catchment and municipality zones. The concentration of Lead (Pb^{2+}) was found to be 0.00378 mg/L in the catchment area and 0.02296 mg/L within the municipality, indicating a rise beyond the WHO permissible limit of 0.01 mg/L. Phosphate (PO_4^{3-}) levels were significantly higher than the UNEP recommended limit of ≤ 0.1 mg/L, with average values of 1.8535 mg/L in the catchment and 5.612 mg/L in the municipality. Nitrate (NO_3^-) concentrations remained below the WHO guideline of 50 mg/L but still increased noticeably from 0.3663 mg/L upstream to 2.9700 mg/L downstream. The pH values were within the WHO acceptable range (6.5–8.5), although a slight increase was observed from 7.64 in the catchment to 8.67 within the municipality.

The increase in chemical concentrations along the municipality stretch of the Rupingazi River reflects the growing influence of urban sprawl. Elevated lead levels indicated contamination likely originating from car battery repair *juaka*li, industrial discharges and runoff from urban surfaces containing metallic wastes. The high phosphate concentrations within the municipality suggest inputs from domestic wastewater, detergents, and agricultural runoff, all common in expanding urban environments. Although nitrate levels remained within permissible limits, their increase downstream points to nutrient enrichment from urban and peri-urban agriculture as well as sewage inflows. The slight rise in pH toward alkalinity may be linked to increased ionic loading from municipality effluents and detergents discharged into the river system. Collectively, these results demonstrated that urban sprawl within Embu Municipality had contributed to chemical pollution of the Rupingazi River.

The study computed the pollution index (PI) by comparing the results between the municipality and the catchment areas along river Rupingazi. Pollution index (PI) was computed by dividing the measured concentration in either catchment area or municipality by the recommended limit. PI of less than I implied that the physical-chemical parameter exceeded the set standards by either the world health organization (WHO) or Kenya bureau of standards (KEBS). PI equal to 1 implied that the parameter was equal to the set guidelines. On the other hand, a PI of less than 1 implied that the parameter was within the guidelines (better than the limit). The study findings were presented on T

Table 3
Comparison of Pollution Index in Municipality and Catchment Areas

Parameter	Catchment Avg	Municipality Avg	PI (Catchment)	PI (Municipality
Lead (Pb^{2+}) (mg/L)	0.00378	0.02296	0.38	2.30
Phosphate (PO_4^{3-}) (mg/L)	1.8535	5.612	18.53	56.12
Nitrate (NO_3^-) (mg/L)	0.3663	2.97	0.007	0.06
Ph	7.64	8.67	1.00	1.02
Temperature (°C)	19.62	25.54	-	-
Total Suspended Load (mg/L)	40.8	250.4	1.36	8.35
Total Dissolved Load (mg/L)	48.2	395.6	0.05	0.44
Electric Conductivity (µS/cm)	75.7	567.2	-	-
Turbidity (mg/L)	10.6	255.9	1.00	24.14
Dissolved Oxygen (mg/L)	10.53	4.94	2.11	1.0
Average pollution Index (API)	-	-	3.05	12.98

The analysis of the physical–chemical parameters of the Rupingazi River Rupingazi revealed a clear contrast in pollution index between the catchment area and Embu municipality section. The average pollution index (API) for the catchment was approximately 3.05, indicating slight pollution, while that of the municipality was markedly higher at 12.98, pointing to heavy pollution, most likely due to the influence of urban sprawl. At the catchment, most parameters fell within acceptable limits, with exceptions such as phosphate (PI = 18.53) and suspended load (PI = 1.36) which elevated the pollution index. In contrast, the municipality section recorded significantly higher deviations from recommended limits. The most critical pollutants were phosphate (PI = 56.12), turbidity (PI = 24.14**)**, and total suspended solids (PI = 8.35), which indicated strong influence of urban sprawl on Rupingazi riverine ecosystem. The study findings mirrored with a previous study by Tau, (2021) in his study on pollution in Apies River who found higher pollution index in downstream than upstream.

4. CONCLUSION AND RECOMMENDATIONS

This study examined the influence of urban sprawl on the physical and chemical properties of water along the Rupingazi Riverine ecosystem in Embu Municipality. The results revealed that rapid and unplanned urban expansion had significantly degraded river water quality, with most parameters such as

lead, phosphate, nitrate, turbidity, total suspended load, and electrical conductivity recording higher concentrations in the municipality than in the upstream catchment. The decline in dissolved oxygen further indicated organic pollution and reduced ecological health. These findings confirmed that urban sprawl had intensified water contamination and disrupted the natural balance of the river ecosystem. The study underscores the urgent need for effective urban planning, enforcement of land-use zoning regulations, pollution control, and the adoption of green infrastructure and riparian restoration measures to safeguard the river system. Future studies should focus on long-term monitoring of spatial-temporal water quality.

Declarations

Author contributions

Conceptualization: J.M, M.K. Writing-original draft: J.M, M.K, D.K B.R. Methodology: J.M, M.K, D.K B. R, Analysis: JM, Visualization: J.M, M.K, D.K B. R, Writing-Review and editing: B.R, M.C.

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Declaration of Competing Interests

The authors declare no conflict of interest

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Data availability statement

The data used in this study are available upon reasonable request to the corresponding author.

Ethics Statement

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki (1964) and its subsequent amendments. Ethical approval was obtained from the Chuka University Ethics Review Committee, and research authorization was granted by the National Commission for Science, Technology and Innovation (NACOSTI). Informed consent was obtained from all participants prior to their inclusion in the study, and confidentiality of the data was strictly maintained.

Informed Consent Statement

Informed consent was obtained from all individual participants included in the study. Participants were informed about the purpose of the research, and their participation was voluntary.

Consent for Publication

Not applicable. The manuscript does not contain any individual person's identifiable data, images, or personal information that would require consent for publication. Therefore, consent for publication was not required.

References

1. American Public Health Association (APHA). American Water Works Association (AWWA), & Water Environment Federation (WEF). (2017). *Standard methods for the examination of water and wastewater* (23rd ed.). Washington, DC: American Public Health Association.
2. Bonareri SP. (2017). *Effects of human activities on water quality of Rupingazi River and its major tributaries that traverse parts of Embu* (Master's thesis, Kenyatta University). https://ir-library.ku.ac.ke/bitstreams/84efe177-be17-4b67-962e-2a863174bd40/download
3. Brown TC, Kroeger T. (2021). *Divergent Perceptions of Streamflow Changes in Urban areas: The Role of Property Location and Flood Experience.* Water Resources Research, 57(4), e2020WR028418. https://doi.org/10.1029/2020WR028418
4. Chen S, Kimirei A&, Shen Q. (2022). *Assessment of Urban River Water Pollution with Urbanisation in East Africa*. Environmental Science and Pollution Research. Volume 29, pg. 40812–40825.
5. Embu County Government. (2023). *Embu County Integrated Development Plan (CIDP) 2023–2027*. https://www.maarifa.cog.go.ke/sites/default/files/2024-06/EMBU%20CIDP%202023-2027.pdf
6. Embu Water and Sanitation Company (EWASCO). Environmental and Social Impact Assessment for Embu Water Supply Project. Embu Water & Sanitation Company; 2018.
7. Environmental Protection Agency (EPA). (n.d.). *Stormwater: The basics*. U.S. EPA. https://www.epa.gov/npdes/npdes-stormwater-program
8. Fenosoa N, Jacques. & (2024). *Urbanization and Floods in Sub-Saharan Africa: Spatiotemporal Study and Analysis of Vulnerability Factors—Case of Antananarivo Agglomeration (Madagascar).* Water Journal.
9. Garcia LM, Thompson R.). Divergent Views on Urban Water Pollution: A Case Study of Stakeholder Perceptions in Latin America. Water Policy. 2020;22(4):567–82. https://doi.org/10.2166/wp.2020.125.
10. Gargiulo V, Satariano A, Di Bartolomei R, Salvati L. (2021). *Urban Sprawl and the Environment*. Geography, Environment, Sustainability. 2021;5(4):46–62. https://doi.org/10.24057/2071-9388-2012-5-4-46-62
11. Grimm W, Foster D&, Groffman P. The Changing Landscape: Ecosystem Responses to Urbanisation and Pollution Across Climatic and Societal Gradients. Front Ecol Environ. 2022;17(5):265–27.
12. Gunawardana S, Chang H, Anderson S. Thermal Regime Shifts in Urbanizing Watersheds: A Meta-Analysis. J Hydrol. 2023;617:128876. https://doi.org/10.1016/j.jhydrol.2022.128876.

13. Jacobs SR, et al. The state of nitrogen in rivers and streams across sub-Saharan Africa. Sci Total Environ. 2024;882., Article 163562. https://doi.org/10.1016/j.scitotenv.2024.163562.
14. Johnson RL, Smith KT. Urban Sprawl and the Loss of Riparian Land Use Diversity: A Multi-Temporal Analysis Using Shannon's Index. Volume 210. Landscape And Urban Planning; 2021. p. 104073.
15. Juma B, Olang O, Hassan M. (2021). *Analysis of Rainfall Extremes in the Ngong River Basin of Kenya: Towards Integrated Urban Flood Risk Management*. 10.1016/j.pce.2020.102929
16. Kamau JW, Mwangi SN. Degradation of Scenic River Values in Rapidly Urbanizing Kenyan Highlands: A landscape Perception Study. Landsc Urban Plann. 2023;231:104663. https://doi.org/10.1016/j.landurbplan.2022.104663.
17. Kipkemboi J, Onywere VO, Mwangi SW. Land-Use Changes and their Ecological Consequences Along Small Urban Rivers in East Africa. Environ Monit Assess. 2022;194(12):876. https://doi.org/10.1007/s10661-022-10560-.
18. Kipkorir EC, Kosgei JR. Community Perceptions of Hydrological Changes in Rapidly Urbanizing Kenyan Watersheds. Environ Manage. 2023;71(2):305–18. https://doi.org/10.1007/s00267-022-01725-5.
19. Lema W. Contamination of urban waterways: A mini-review of water pollution in the rivers of East Africa's major cities. Journal of Hydro Research; 2024.
20. Li F, Zhang J, Liu W. Urban Expansion and Its Impact on Water Quality: A Global Review. Environ Sci Pollut Res. 2021;28(16):19542–59. https://doi.org/10.1007/s11356-021-13045-y.
21. Madureira KH, et al. Rehabilitation of tropical urban streams improves their ecosystem structure and functioning. Sci Total Environ. 2024;905., Article 166146. https://doi.org/10.1016/j.scitotenv.2024.166146.
22. Mekonnen M, et al. Tracing Urban Sediment Sources in East African Catchments Using Geochemical Fingerprints. J Soils Sediments. 2023;23(1):412–25. https://doi.org/10.1007/s11368-022-03309-6.
23. Moges A, Beyene A, Ambelu A. (2023). *Residents' Perceptions of Sediment Pollution in Rapidly Urbanizing Catchments: Evidence from Ethiopia.* https://doi.org/10.1007/s00267-022-01735-3
24. Muthoni FK, Ochieng GM, Ngugi MR. Impacts Of Urban Sprawl on The Hydrology of Peri-Urban Rivers in Eastern Africa: The Case of Athi River Basin. Water Resour Manage. 2022;36(5):1567–82. Https://Doi.Org/10.1007/S11269-022-03099-Z.
25. Mwangi SW, Kiage LM, Obando JA. Accelerated Bank Erosion in Urbanizing East African River systems: Evidence from the upper Tana River basin. Geomorphology. 2023;425:108567. https://doi.org/10.1016/j.geomorph.2023.108567.
26. Ndunge BM, Muendo P. GIS-Based Assessment of Visual Landscape Degradation Along Urban River Corridors in Eastern Africa. Appl Geogr. 2022;145:102732. https://doi.org/10.1016/j.apgeog.2022.102732.
27. Nelson KC, Palmer MA, Pizzuto JE. The Urban Stream Syndrome: Impacts of Sprawl on Thermal Pollution in Rivers. Front Ecol Environ. 2021;19(6):321–9. https://doi.org/10.1002/fee.2341.

28. Ngatia MW. Effects of anthropogenic activities on water quality of Ngong River, Nairobi County, Kenya. Water. 2023;15(4):660. https://doi.org/10.3390/w15040660.
29. Nkwasa A, Chawanda CJ, Nakkazi MT, Tang T, Warner S. One third of African rivers fail to meet the 'good ambient water quality' nutrient targets. Environ Res Lett. 2024;19(8):085002. https://doi.org/10.1088/1748-9326/aaabcd.
30. Nyambane A, Kithiia J. The river we Knew is Gone: Resident Perceptions of Landscape Change in Urbanizing Watersheds. Environ Sci Policy. 2023;142:148–57. https://doi.org/10.1016/j.envsci.2023.02.011.
31. Ochola G. (2018). *Urbanisation and Environmental Stress. A Review of the Impacts of Urban Development on the Environment in Kenya*. IntJ Environ Sci Nat Res.2018: 14(2): 555889. Dol.10.19080/ IJESNR.2018.14.555889
32. Odongo K. Urban Sprawl and its Impact on Morphology of Homabay Town. Kenya Opportunities for Conservation. Environmental Research Letters.13015002; 2023.
33. OECD & UN-Habitat. Africa's Urbanisation dynamics 2025: The economic power of Africa's cities. OECD Publishing. 2025. https://doi.org/10.1787/
34. Ofoezie I, Eludoyin O, Onanuga Y. Climate, Urbanization and Environmental Pollution in West Africa. Journal of Sustainability; 2022.
35. Omole DO. Assessment of industrial and domestic effluents on receiving river systems. Sci Total Environ. 2025;934., Article 175493. https://doi.org/10.1016/j.scitotenv.2024.175493.
36. Ongaga CO. Urbanization and hydrological dynamics: a 22-year analysis of imperviousness and runoff. Front Water. 2024;6., Article 1455763. https://doi.org/10.3389/frwa.2024.1455763.
37. Onyango DA, Olang LO, Kundu PM. Impact of urban sprawl on sediment dynamics in Kenyan rivers. Sci Total Environ. 2023;858(Pt 1). 159732.https://doi.org/10.1016/j.scitotenv.2022.159732.
38. Otieno A, Omondi P. Transport Infrastructure & Urban Sprawl in Mombasa. Implications for Coastal Ecosystems. J Urban Plann Dev. 2024;150(1):040230045.
39. Owuor SO, Butterbach-Bahl K, Guzha AC. *Effects Of Urbanization on Stream Water Quality in Africa*: *A Meta-Analysis*. Sci Total Environ. 2023;857:159432. https://doi.org/10.1016/j.scitotenv.2022.159432.
40. Pang X, Zhou W, Zhang T, Liu Y. Linking downstream river water quality to urbanization signatures: nutrients and pathogens. Sci Total Environ. 2023;857., Article 159618. https://doi.org/10.1016/j.scitotenv.2022.159618.
41. Tau P, Anyasi RO, Mearns K. (2021). *Evaluating the pollution of the Apies River in Pretoria, South Africa*. E3S Web of Conferences, 241, Article 01004.
42. UN-Habitat. (2024). *Annual report 2024: Adequate housing for all*. UN-Habitat. https://unhabitat.org/annual-report-2024

43. Wang L, Lyons J, Kenehl., Bannerman R. Impacts of Urbanization on Stream Water Quality. A Review on Environmental Management; 2022.
44. Wohl E, Beckman ND. Sediment Regime Shifts in Urbanizing Watersheds: A Global Synthesis. Earth Sci Rev. 2022;225:103891. https://doi.org/10.1016/j.earscirev.2021.103891.
45. World Bank. (2024). *World Development Indicators: Urban population (% of total)*. World Bank Open Data. https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS
46. World Health Organization (WHO). Guidelines for drinking-water quality. 4th ed. WHO; 2017. https://www.who.int/publications/i/item/9789241549950.
47. Zhang H. The Impact of Urban Sprawl on Environmental Pollution. Empirical Analysis from Large and Medium -Sized Cities of China. Int J Environ Res Public Health. 2021. 10.3390/ijerph18168650.

Figures

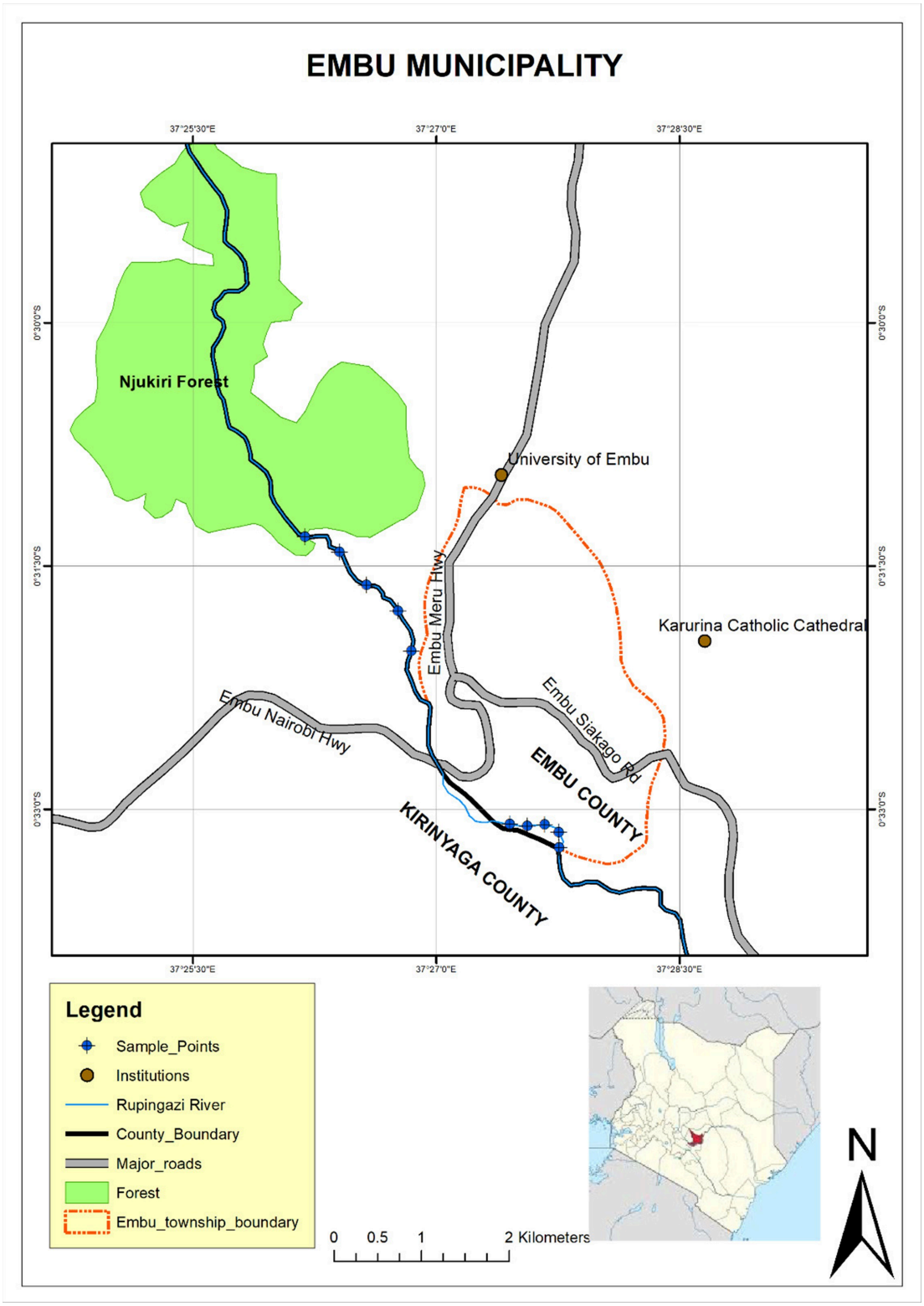


Figure 1

Location of Embu Municipality

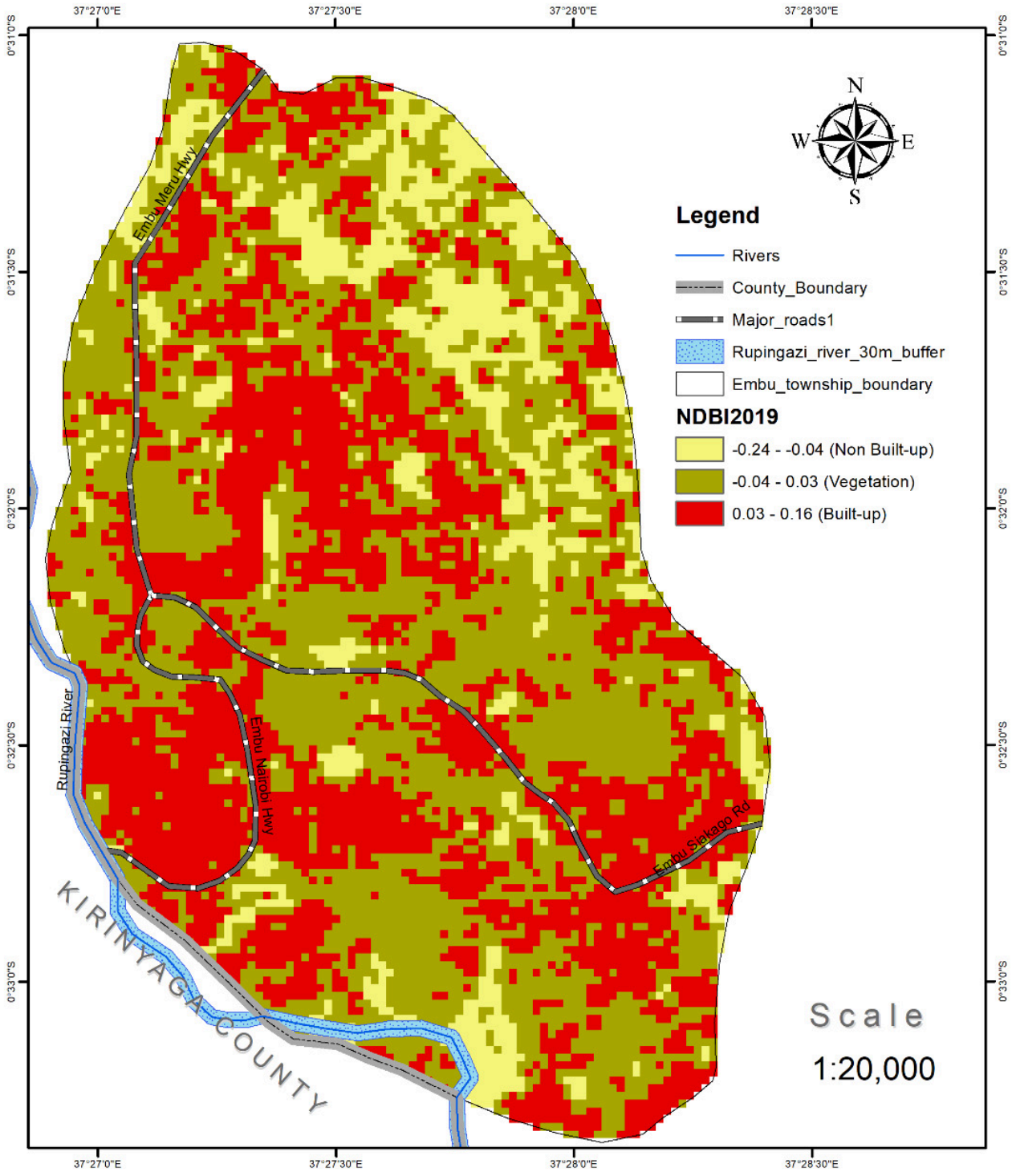


Figure 2

NDBI Choropleth Map in 2019