

GIS-Based Spatial Distribution of Surface Water Quality in Relation to Barge Traffic Intensity in Onne and Port Harcourt Ports, Rivers State, Nigeria

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ABSTRACT

Barge transport is an important component of cargo movement in the Eastern Nigerian ports, but spatially explicit evidence on surface-water quality along barge corridors remains limited. This study assessed the spatial distribution of eleven surface-water quality parameters in relation to distance from the jetty at Onne Port and Port Harcourt Port, Rivers State, Nigeria. Surface-water samples were collected from 12 stations at each port during the wet season in July 2026. The parameters analysed were turbidity, total suspended solids (TSS), biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), ammonia (NH₃), lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), faecal coliform, and total coliform. A composite Pollution Index was calculated using min-max normalisation, and Geographic Information System (GIS) interpolation was used to examine spatial patterns. The interpolated surfaces showed substantial spatial heterogeneity, with localised higher-pollution zones in central sections of the sampled corridors. However, corridor-wide correlation and regression analyses showed that distance from the jetty was not a statistically significant predictor of the composite Pollution Index at either Onne Port ($R^2 = 0.0003$, $p = .954$) or Port Harcourt Port ($R^2 = 0.022$, $p = .642$). The findings therefore indicate that the mapped hotspots should be interpreted as localised spatial patterns rather than evidence of a consistent distance-based or causal effect of barge operations. Hydrodynamic mixing, sediment transport, and non-maritime discharges remain plausible contributing factors. GIS mapping complements station-based analysis by identifying spatially concentrated areas that may warrant targeted environmental monitoring.

Keywords: surface water quality; barge corridors; spatial distribution; Geographic Information System (GIS); Pollution Index; Onne Port; Port Harcourt Port

INTRODUCTION

Water bodies have been useful for human habitation, transport, trade, and sustenance in many ways throughout history. In Nigeria, this is especially significant in the Niger Delta, where water bodies such as rivers, creeks, estuaries, and coastal areas are utilised for commercial, industrial, fishing, and transport purposes (Okwechime, 2025; Ayodele, 2025). The Eastern Nigeria ports of Port Harcourt, Onne, Calabar, and Warri make up an important portion of the national maritime network. The increase in maritime activities and petroleum-based activities has made the use of barges to transport petroleum products, bulk cargoes, containers, and other cargoes by shallow waterways increasingly common (Nze & Nze, 2023).

Environmental pressures resulting from the use of barges can be attributed to discharges from bilges or ballast water, fuel and oil spills, cargo handling, and disturbed sediments. Ship movement can cause resuspension of sediments through waves and the propeller wash of the ship, thereby causing an increase in suspended solids and sediment contaminants (Chakraborty et al., 2023). The intensity and distribution of such environmental pressures can be influenced by tidal movement, freshwater inflows, sedimentation, dredging, ship movement, and hydrodynamics. Therefore, barge movements are viewed in this study as potential sources of environmental pressure rather than causality arising from observations. Water quality analysis thus plays an essential role in assessing the impact of vessels' operations on the environment. Traditional approaches to water quality analysis using selective sampling sites produce good results in terms of providing information

about the state of water, but may fail to show the geographical spread of pollution. Areas of pollution around jetties, navigation routes, cargo handling sites, and highly busy places for vessels' operations may be hidden when only point data or average figures are used.

The use of Geographic Information Systems (GIS) technology provides a means of integrating water-quality observations with their geographic locations. Spatial interpolation can be used to estimate patterns between sampled locations and to visualise areas of relatively higher or lower water-quality values (Balogun & Islam, 2025; Yudhistira et al., 2022). In this study, GIS is used to describe the spatial pattern of the sampled parameters rather than to establish causation.

This study is further situated within the Driver-Pressure-State-Impact-Response (DPSIR) framework, which organises environmental problems into a causal chain that is useful for linking human activity to observed environmental outcomes and to policy response. In the present context, increasing maritime trade and petroleum-based activity in the Eastern Nigerian ports constitute the underlying Driver; the resulting barge traffic, with its associated bilge and ballast discharge, propeller-wash sediment resuspension, and cargo-handling activity, constitutes the Pressure; the measured surface water quality parameters (turbidity, TSS, BOD₅, COD, ammonia, heavy metals, and coliforms) represent the State of the receiving water body; the resulting pollution hot spots and their implications for aquatic ecology, fisheries, and public health represent the Impact; and the GIS-based monitoring and regulatory actions recommended in this study constitute the Response. The DPSIR framework is used here as an organising lens for interpreting the spatial results reported in the Discussion, rather than as a separately modelled or statistically tested component of the analysis.

It becomes especially pertinent for Onne Port and Port Harcourt Port, which are situated in the Bonny River system in Rivers State and where commercial vessels, barges, dredging, oil-related operations, and other navigation activities occur. Earlier studies related to Nigerian ports have often focused on particular sites or selected water-quality parameters (Aaron, 2020; Onwuegbuchunam, 2021). GIS-based assessments have also been applied to river water quality and sediment contamination in Nigeria (Balogun & Islam, 2025; Oriabure & Ogbeibu, 2022; Ezekwe et al., 2025). However, spatially explicit assessment of multiple surface-water quality parameters along barge corridors in the Eastern Nigerian ports remains limited.

In light of the above, this study evaluates the spatial distribution of surface-water quality parameters in relation to distance from the barge jetties at Onne Port and Port Harcourt Port. Distance from the jetty is used as a proxy measure of potential exposure to barge-related activity, not as a direct measurement of barge traffic intensity. GIS interpolation is applied to visualise spatial patterns and identify areas of relatively higher pollution pressure. The findings are intended to provide spatial evidence that can support environmental monitoring and further investigation by relevant regulatory and port-management authorities.

The Study Area

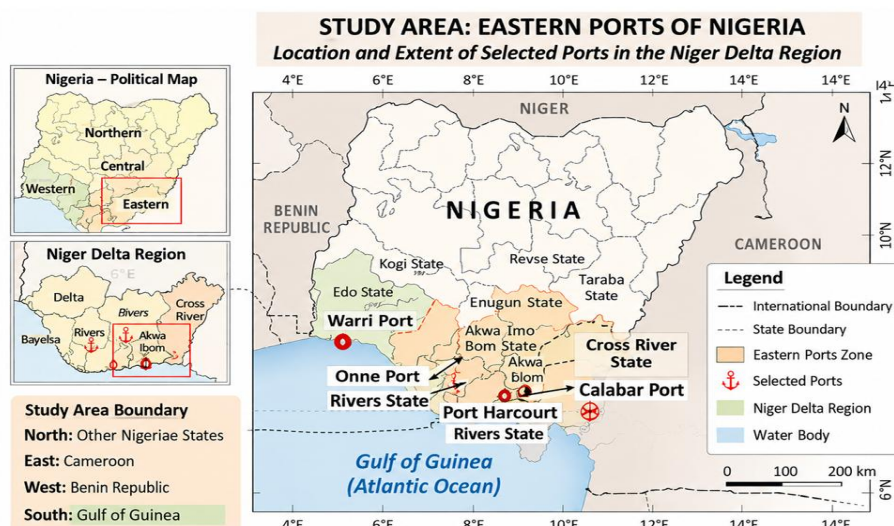


Figure 1: Niger Delta Showing States with Eastern Ports

Source: Researchers' Analysis, 2026

This study is based on Onne Port and Port Harcourt Port, which are located in Rivers State of the Niger Delta region in the south of Nigeria on the Bonny River System draining into the Gulf of Guinea. Onne Port and Port Harcourt Port sit along the Bonny River estuary, between roughly 4.61°N and 4.77°N latitude and 6.96°E and 7.18°E longitude. Together, they handle maritime traffic and barge transport entering Nigeria's Eastern region. The study area has a Tropical Monsoon (Am) climate. Moist air from the South Atlantic keeps relative humidity above 75 per cent in many periods, while temperatures generally range from 25–32°C. Annual rainfall can exceed 4,000 mm along parts of the Niger Delta coast, making the region one of Nigeria's wettest (NIMET, 2020). The precipitation regime shows a double maximum, with peaks in June-July and September and a brief interlude in August.

Hydrologically, the ports exist in the Niger Delta, an expansive delta system that is defined by numerous interconnected rivers, tidal creeks, estuaries, and distributaries due to sedimentation and fluvial activities over a long period (Abam & Fubara, 2022). The Bonny River, which exists in the two ports, is tidally controlled; hence, the activities of tidal mixing and sedimentation can result in changes in water level, flow, salinity, and sediment redistribution. During the wet season, there could be more freshwater discharge that results in changes in turbidity and dilution of the water body. The changes in freshwater discharges seasonally can impact the extent of upstream intrusion of saline waters. Both port-neighbouring communities have reasonably high levels of population density, coupled with a way of life that revolves around traditional fisheries, trade, and port-related economic activities (Uduji & Okolo-Obasi, 2020). Siltation of the channel entrances has led to an increasing dependence on barges to transport cargo in the two ports, resulting in vessel activity in well-defined navigational channels that form the operational framework for the current assessment of surface water quality.

METHODOLOGY

Surface-water samples were collected from Onne Port and Port Harcourt Port, Rivers State, Nigeria, to obtain primary data. A cross-sectional observational design was adopted to assess spatial variation in surface-water quality in relation to distance from the barge jetty. Spatial analysis was conducted using Geographic Information System (GIS) techniques. Surface-water samples were collected from twelve stations at each port in July 2026 during the wet season. The twelve stations at each port (SW1–SW10 and SWC1–SWC2 at Onne Port; S1–S12 at Port Harcourt Port) were distributed along the active barge corridor at varying distances from the port jetty. Their geographic coordinates are presented in Tables 1 and 2 and mapped in Figures 14 and 27. The stations were selected to provide spatial coverage along the active barge corridor and at varying distances from the jetty. Surface-water samples were collected from the surface-water column at each designated station using the study sampling protocol. Geographic coordinates were recorded at each sampling location using a GPS receiver. The samples were labelled, preserved, and transported to the laboratory for physicochemical, heavy-metal, and microbiological analyses. Sampling was conducted during the July 2026 field campaign under the prevailing field and tidal conditions. The distance of each sampling station from the nearest barge jetty was determined and used as a spatial proxy for potential exposure to barge-related activities. This approach was adopted because reliable station-level records of barge movements or vessel counts for the study period were not available from NIMASA or other accessible sources. Consequently, distance from the jetty was used as an indirect measure of potential proximity to barge activity rather than as a direct measure of barge-traffic intensity. The resulting relationships between distance and water-quality conditions were therefore interpreted as spatial associations and not as direct evidence of the effects of vessel traffic.

Table 1: Sampling Station Coordinates – Onne Port

Station	Latitude (°N)	Longitude (°E)	Distance from Jetty (km)
SW2	4.6655	7.1401	0.459
SW3	4.6674	7.1361	0.826
SW1	4.6609	7.1474	0.879
SW6	4.6666	7.1541	1.173
SW10	4.6583	7.1343	1.472
SW4	4.6686	7.1298	1.532

SW7	4.6749	7.1562	1.603
SW5	4.6707	7.1247	2.12
SW8	4.6747	7.1169	3.058
SW9	4.6735	7.1127	3.481
SWC1	4.6106	7.1765	7.339
SWC2	4.7123	7.0944	7.36

Source: Field survey, 2026.

Table 2: Sampling Station Coordinates – Port Harcourt Port

Station	Latitude (°N)	Longitude (°E)	Distance from Jetty (km)
S1	4.7733	7.00296	0.35
S2	4.77127	6.99786	0.61
S3	4.76916	6.99186	0.94
S4	4.76409	6.98443	1.05
S5	4.75778	6.97675	1.38
S6	4.75483	6.96448	1.61
S7	4.7626	6.96447	1.95
S8	4.77377	6.96196	2.34
S9	4.74565	7.00146	2.98
S10	4.7285	7.01506	3.62
S11	4.71375	7.02406	6.85
S12	4.694	7.00076	7.1

Source: Field survey, 2026.

The eleven surface-water parameters analysed were turbidity, total suspended solids (TSS), biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), ammonia (NH₃), lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), faecal coliform, and total coliform. Distance from the jetty was treated as the explanatory proxy variable, while the water-quality parameters and composite Pollution Index were treated as response measures.

The Pollution Index was calculated using min–max normalisation. For each parameter, station values were rescaled to 0–1 using the minimum and maximum observed across the twelve stations within each port, with 1 representing the highest observed value. The composite index was calculated as the arithmetic mean of the eleven normalised parameters, giving equal weight to each. Recalculation from the underlying normalised values reproduced the reported index values for all 24 stations. The index was classified descriptively as low (0.00–0.33), moderate (0.34–0.66), or high (0.67–1.00). These categories are study-specific and are not regulatory limits. Because normalisation was performed separately for each port, index values represent relative pollution pressure within each port and should not be interpreted as directly comparable absolute pollution levels.

Spatial analysis was performed in ArcGIS 10.8.2 using geographic coordinates referenced to WGS 84. IDW interpolation was applied to the eleven water-quality parameters and composite Pollution Index. The analysis incorporated an IDW power parameter, search radius/neighbourhood specification, raster cell size, and defined interpolation extent/mask, with the resulting surfaces displayed as thematic maps. The specific numerical settings for these processing parameters could not be reliably recovered from the available project records and are therefore not retrospectively inferred. Cross-validation was not performed, and consequently RMSE or other interpolation-accuracy statistics were not calculated. The resulting surfaces are therefore interpreted as spatial representations of the observed sampling data rather than independently validated predictive surfaces.

RESULTS

Spatial Distribution of Barge Traffic Intensity and Surface Water Quality Parameters at Onne Port

The interpolation maps (Figures 2–13) show substantial spatial heterogeneity in surface-water quality at Onne Port/Bonny River. The maps cover turbidity, TSS, BOD₅, COD, NH₃, Pb, Cd, Cr, Cu, faecal coliform, total coliform, and the composite Pollution Index. These maps provide a visual description of spatial variation and help identify locations with relatively higher or lower observed values along the sampled corridor.

Table 3: Surface Water Quality Characteristics around Onne Port (Station, Distance from Jetty, and All Measured Parameters)

Station	Dist. (km)	Turb. (NTU)	TSS (mg/L)	BOD ₅ (mg/L)	COD (mg/L)	NH ₃ (mg/L)	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	FC	TC	Poll. Index
SW2	0.46	7.4	6.3	10.1	33.7	0.2	0.009	0.012	0.014	0.083	4	43	0.205
SW3	0.83	6.7	6.4	9.7	30.6	0.1	0.014	0.016	0.013	0.078	7	150	0.15
SW1	0.88	7.2	6	9.2	31.8	0.2	0.011	0.015	0.018	0.045	210	1100	0.316
SW6	1.17	12.2	10.9	10.5	36.5	0.4	0.058	0.068	0.082	0.17	3	16	0.601
SW10	1.47	9.2	7.7	8.5	30.6	0.3	0.026	0.11	0.045	0.116	9	29	0.301
SW4	1.53	6.1	5.2	9.2	32.4	0.3	0.012	0.036	0.072	0.042	6	11	0.224
SW7	1.6	16.7	13.8	8.9	38.3	0.4	0.065	0.06	0.091	0.264	9	21	0.669
SW5	2.12	6.5	4.9	8.5	29.8	0.2	0.017	0.087	0.055	0.063	4	9	0.177
SW8	3.06	7.3	6.1	8.7	30.6	0.3	0.012	0.037	0.018	0.082	3	37	0.16
SW9	3.48	8.4	6.9	9	27.6	0.3	0.016	0.084	0.019	0.064	6	24	0.198
SWC1	7.34	7.8	6.6	8.7	32.1	0.2	0.035	0.144	0.052	0.142	28	290	0.362
SWC2	7.36	10.4	9.1	9.8	28.5	0.5	0.001	0.042	0.017	0.058	64	460	0.334

Source: Field sampling and laboratory analysis of surface water samples, 2026.

The interpolation of turbidity, TSS, and BOD₅ (Figures 2–4) shows spatial variation, with distinct zones of relatively higher concentrations in parts of the sampling corridor and lower values elsewhere. These patterns indicate that suspended matter and biodegradable organic loading were not spatially uniform within the sampled port area. The distribution maps for COD and NH₃ (Figures 5–6) also show spatially varied concentration patterns, including localised areas of relatively elevated values. These patterns may reflect differences in organic and nutrient inputs, mixing, and dispersion among sampling locations; the available data do not identify a specific source.

The distribution maps of Pb, Cd, Cr, and Cu (Figures 7–10) show distinct spatial patterns, with relatively higher concentrations occurring in different parts of the sampling corridor. The lack of a common spatial pattern suggests that the metals may be influenced by multiple localised inputs and transport processes rather than by a single distance-based gradient. It is obvious from the faecal and total coliform maps (Figures 11–12) that there exists considerable spatial variability, which implies that microbial contamination existed variably in the water samples.

The composite Pollution Index Map (Figure 13) demonstrates a localised area of high pollution index values in the middle part of the sampled corridor. This pattern indicates spatial concentration of the combined index within particular sections of the port waterway rather than a uniform distribution. However, because the index is relative to the observed station ranges and the interpolation was not independently validated, the mapped hotspot should be interpreted as an estimated spatial pattern rather than a confirmed source-specific pollution hotspot. Figure 14 shows the spatial location of the sampling stations.

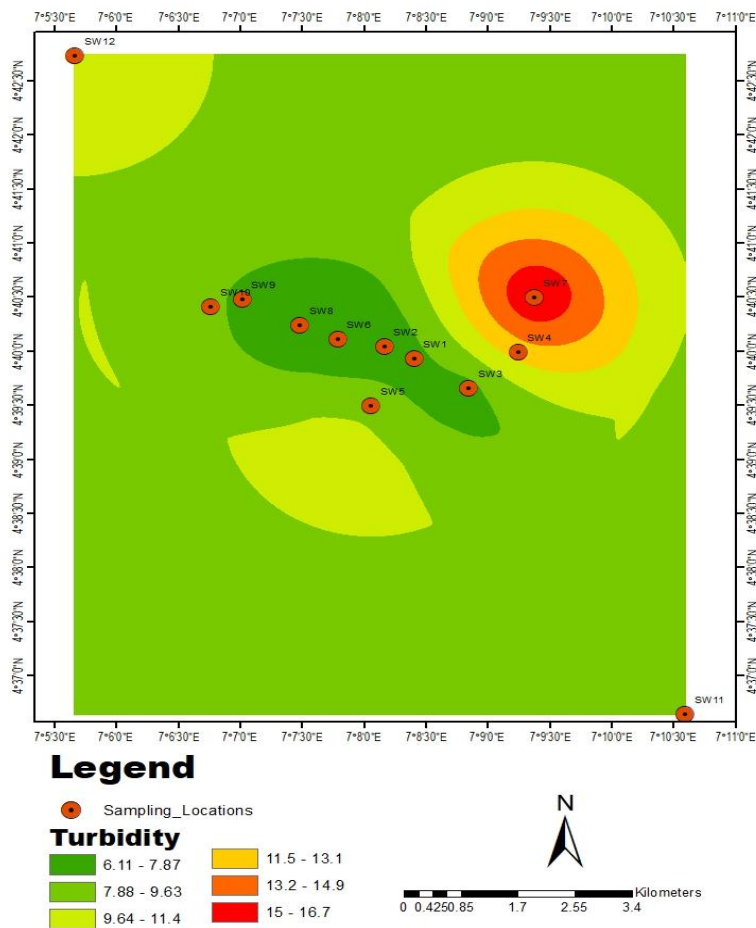


Figure 2 Spatial Distribution of Turbidity (NTU) in Onne Port/Bonny River, Rivers State, Nigeria

Source: Researchers' Analysis, 2026

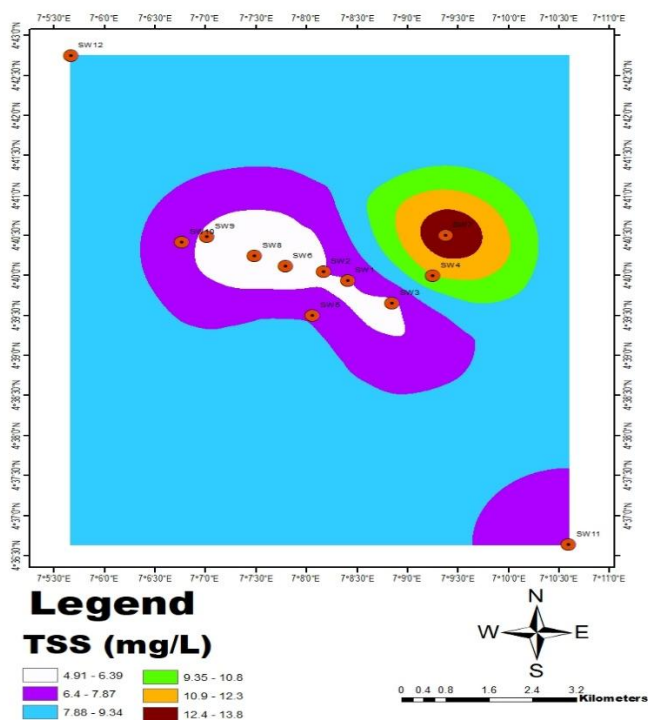


Figure 3 Spatial Distribution of Total Suspended Solids (TSS) in Onne Port/Bonny River, Rivers State, Nigeria

Source: Researchers' Analysis, 2026

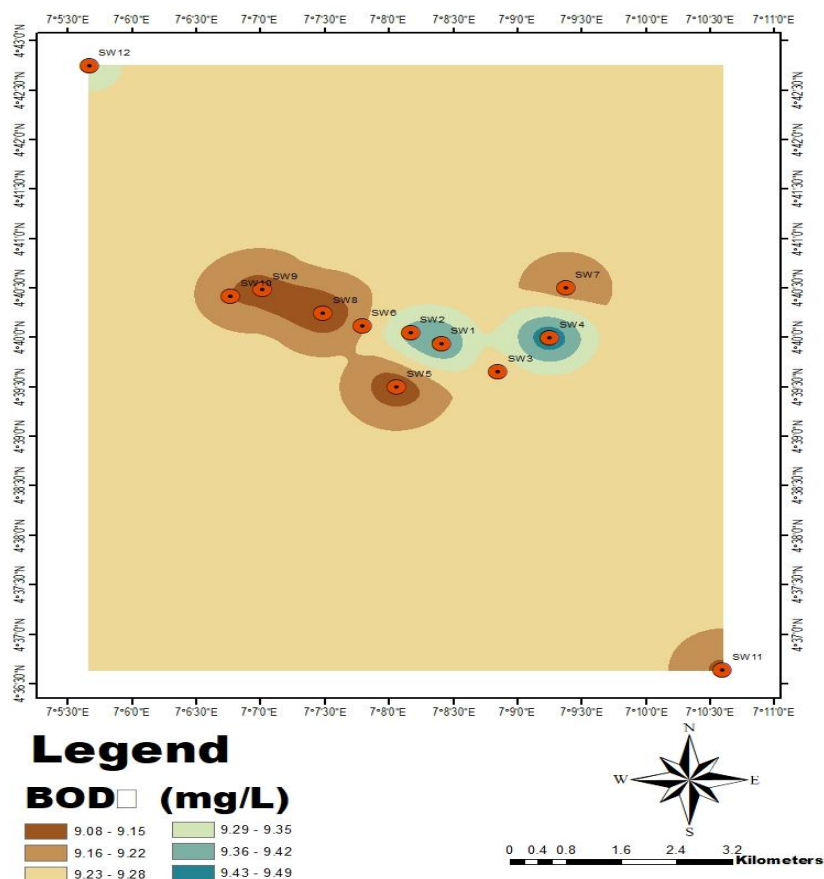


Figure 4 Spatial Distribution of BODs in Onne Port/Bonny River, Rivers State, Nigeria

Source: Researchers' Analysis, 2026

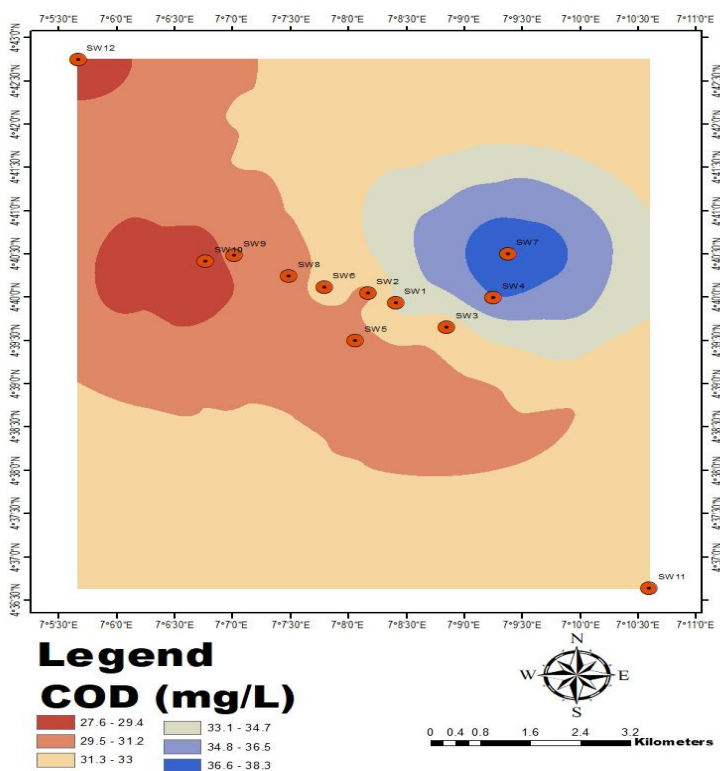


Figure 5 Spatial Distribution of COD in Onne Port/Bonny River, Rivers State, Nigeria

Source: Researchers' Analysis, 2026

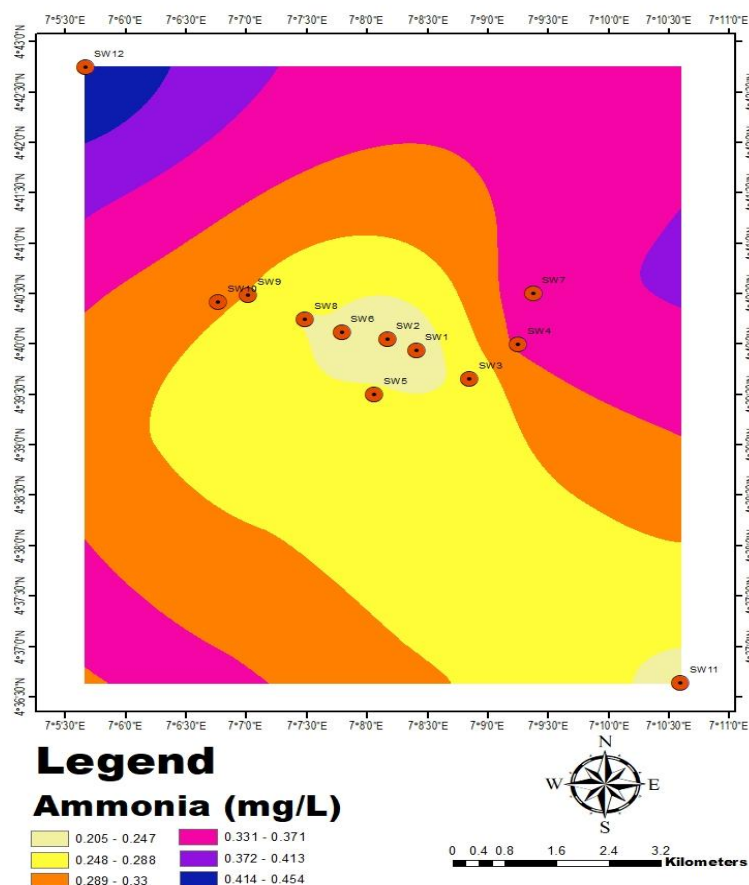


Figure 6 Spatial Distribution of Ammonia (NH_3) in Onne Port/Bonny River, Rivers State, Nigeria

Source: Researchers' Analysis, 2026

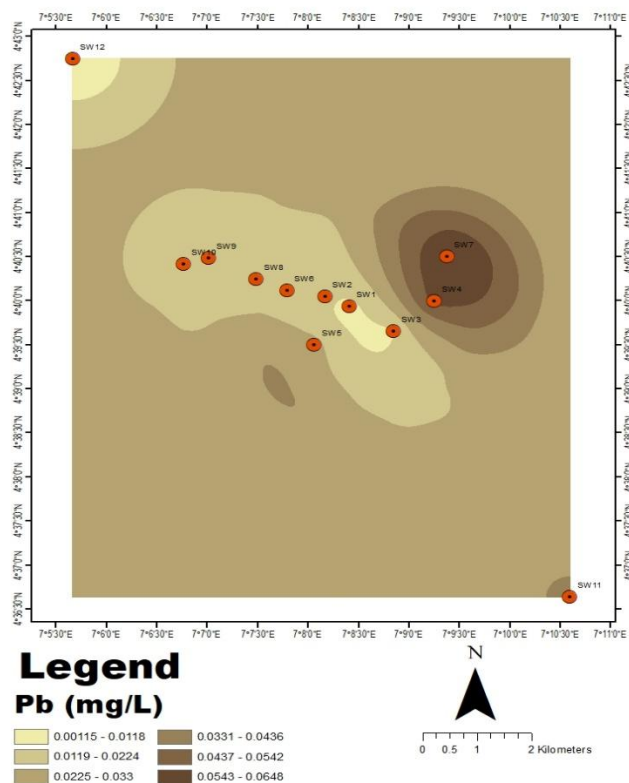


Figure 7 Spatial Distribution of Lead (Pb) in Onne Port/Bonny River, Rivers State, Nigeria

Source: Researchers' Analysis, 2026

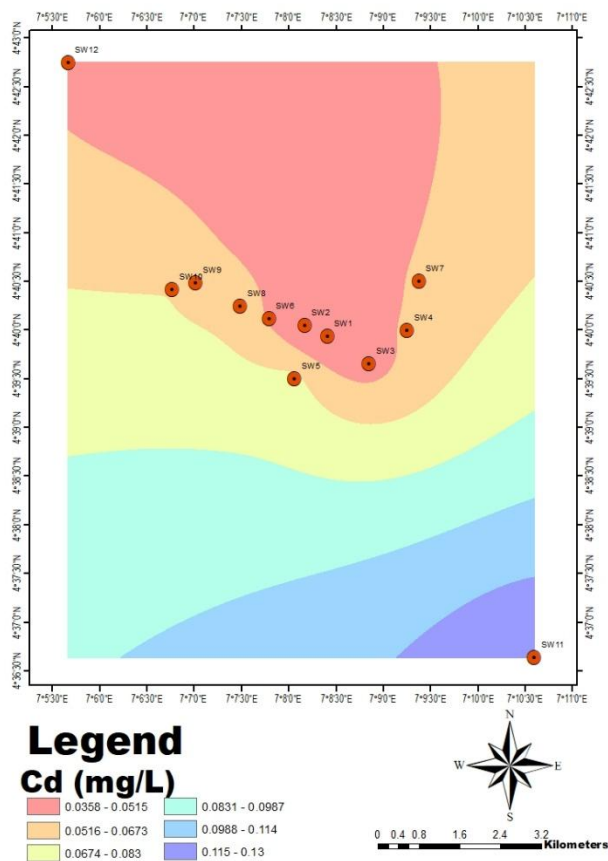


Figure 8 Spatial Distribution of Cadmium (Cd) in Onne Port/Bonny River, Rivers State, Nigeria

Source: Researchers' Analysis, 2026

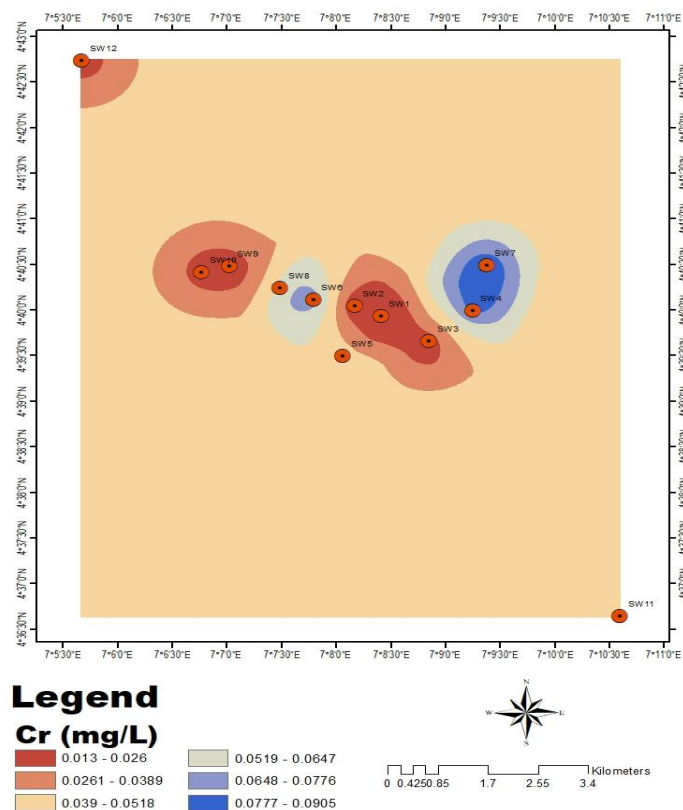


Figure 9 Spatial Distribution of Chromium (Cr) in Onne Port/Bonny River, Rivers State, Nigeria

Source: Researchers' Analysis, 2026

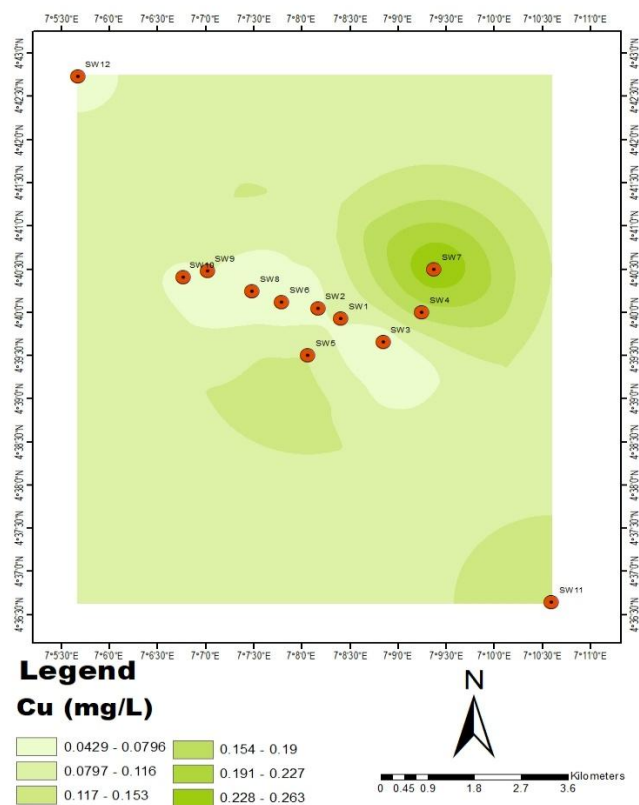


Figure 10 Spatial Distribution of Copper (Cu) in Onne Port/Bonny River, Rivers State, Nigeria

Source: Researchers' Analysis, 2026

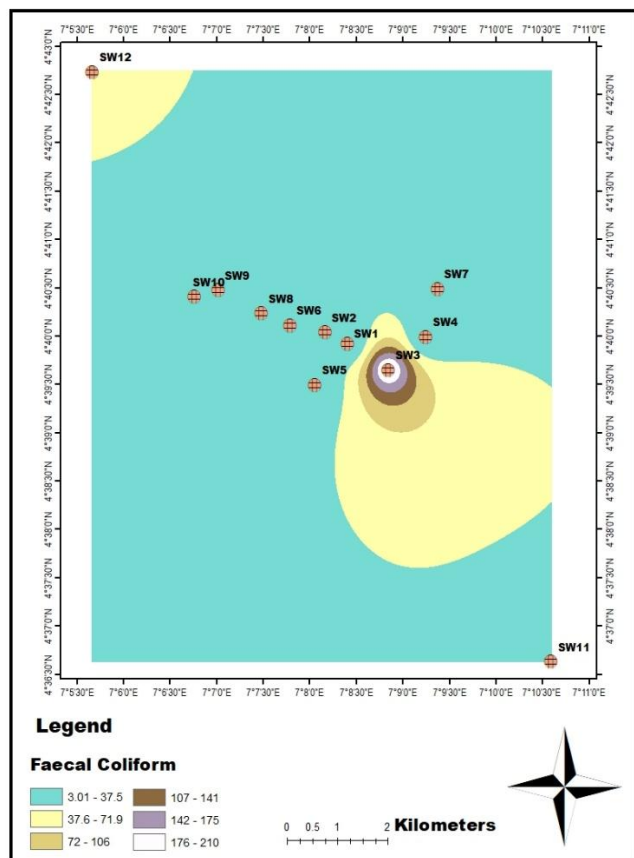


Figure 11 Spatial Distribution of Faecal Coliform in Onne Port/Bonny River, Rivers State, Nigeria

Source: Researchers' Analysis, 2026

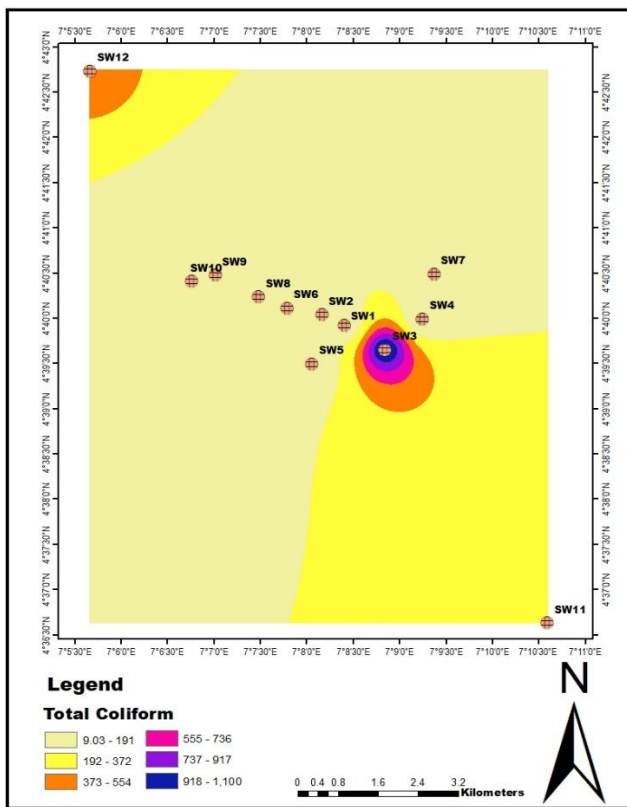


Figure 12 Spatial Distribution of Total Coliform in Onne Port/Bonny River, Rivers State, Nigeria

Source: Researchers' Analysis, 2026

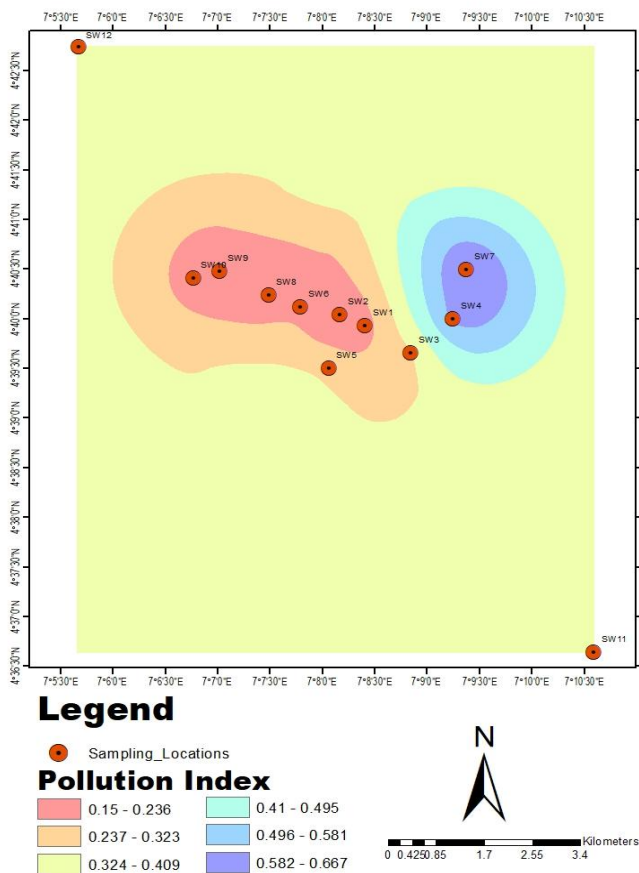


Figure 13 Spatial Distribution of Composite Pollution Index in Relation to Barge Traffic Intensity in Onne Port/Bonny River, Rivers State, Nigeria

Source: Researchers' Analysis, 2026

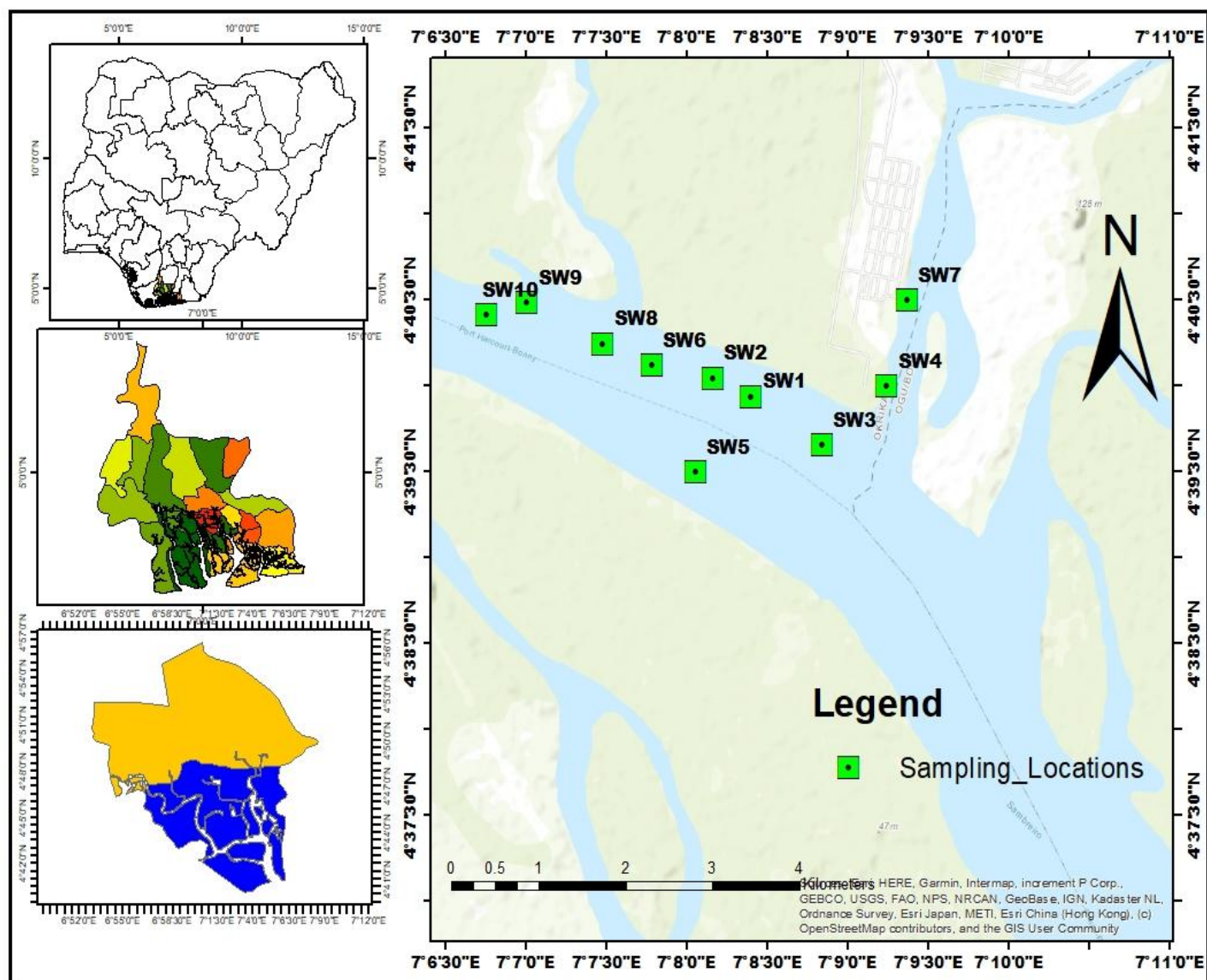


Figure 14 Location Map of Surface Water (SW) Sampling Points along the Onne Port/Bonny River, Rivers State, Nigeria

Source: Researchers' Analysis, 2026

Spatial Distribution of Barge Traffic Intensity and Surface Water Quality Parameters at Port Harcourt Port

The spatial variation of surface-water quality within the Port Harcourt Port River, shown in the interpolation maps (Figures 15–26), indicates substantial spatial heterogeneity. The figures display turbidity, TSS, BOD₅, COD, NH₃, Pb, Cd, Cr, Cu, faecal coliform, total coliform, and the composite Pollution Index. Distance from the jetty is used as a spatial reference and proxy for potential exposure to barge activity, rather than as a direct measurement of traffic intensity.

Table 4: Surface Water Quality Characteristics around Port Harcourt Port (Station, Distance from Jetty, and All Measured Parameters)

Station	Dist. (km)	Turb. (NTU)	TSS (mg/L)	BOD ₅ (mg/L)	COD (mg/L)	NH ₃ (mg/L)	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	FC	TC	Poll. Index
S1	0.35	9.8	8.1	12.4	39.5	0.3	0.014	0.02	0.019	0.098	12	90	0.242
S2	0.61	8.5	7.4	11.1	35.2	0.2	0.018	0.019	0.016	0.089	9	210	0.167
S3	0.94	15.4	12.9	13	44.1	0.5	0.031	0.028	0.026	0.061	320	1600	0.589

S4	1.05	8.1	6.9	10.5	34	0.2	0.01	0.016	0.021	0.052	5	22	0.111
S5	1.38	11.2	9.6	12.8	41.6	0.4	0.022	0.048	0.051	0.071	15	55	0.349
S6	1.61	19.6	16.3	13.9	47.8	0.6	0.079	0.088	0.104	0.305	18	60	0.781
S7	1.95	7.9	6.2	9.8	32.5	0.2	0.009	0.014	0.012	0.048	6	18	0.07
S8	2.34	6.8	5.4	9.1	30.1	0.1	0.006	0.011	0.009	0.041	4	12	0
S9	2.98	8	6.8	10.2	33.4	0.3	0.011	0.017	0.014	0.055	8	40	0.117
S10	3.62	9.1	7.6	10.8	35.9	0.3	0.015	0.021	0.019	0.062	7	33	0.169
S11	6.85	8.9	7.2	9.9	34.8	0.3	0.041	0.16	0.06	0.165	45	380	0.364
S12	7.1	12.1	10.4	11.6	38.7	0.4	0.052	0.145	0.058	0.15	78	610	0.504

Source: Field sampling and laboratory analysis of surface water samples, 2026.

Comparison with Regulatory Standards

The water quality data from the two ports were analysed against the criteria provided by the National Environmental (Surface and Groundwater Quality Control) Regulations, 2011 (S.I. No. 22 of 2011), while the WHO (2017) drinking-water guideline values were used only for context since the sampled water is not considered as drinking-water sources. BOD₅ and COD levels breached the applicable criteria from NESREA in many of the stations in the two ports. BOD₅ reached 16.3 mg/L at Port Harcourt Port, which is higher than the criteria stated in the manuscript. High faecal and total coliform levels were observed in selected stations, which could be due to localised presence of sewage, wastewater or organic waste, but the study did not identify the source of such contamination. Levels of Pb, Cd, Cr, and Cu were mostly within the range of the applicable criteria except for Cd that was close to or above the WHO drinking-water guideline of 0.003 mg/L in several stations. In general, the major breaches observed in the analysis are in terms of organic and microbial parameters.

Table 5: Comparison of Measured Water Quality Ranges with NESREA (2011) and WHO (2017) Standards

Parameter	NESREA Ambient Criterion — Fisheries/Recreation*	NESREA Effluent-Discharge Criterion*	WHO (2017) Drinking-Water Guideline	Onne Port Range	PH Port Range
Turbidity (NTU)	—	10 NTU above background†	5	6.1–16.7	6.8–19.6
BOD ₅ (mg/L)	3	6	—	4.9–13.8	5.4–16.3
COD (mg/L)	30	30	—	27.6–38.3	30.1–47.8
Pb (mg/L)	0.01	0.1	0.01	0.001–0.065	0.006–0.079
Cd (mg/L)	0.005	0.01	0.003	0.012–0.144	0.011–0.160
Cr (mg/L)	0.001 (Cr ⁶⁺) / 0.5 (Cr ³⁺)	0.5	0.05	0.013–0.091	0.009–0.104
Cu (mg/L)	0.001	0.01	2	0.042–0.264	0.041–0.305
Ammonia, NH ₃ (mg/L)	—	—	1.5	0.1–0.5	0.1–0.6
Faecal/Total Coliform (cfu/100mL)	20 / 50‡	5000 / 100‡	Not detectable	3–1100	4–1600

Source: NESREA (2011), National Environmental (Surface and Groundwater Quality Control) Regulations, S.I. No. 22 of 2011, Schedules I–III; WHO (2017). The NESREA and WHO values are presented according to their respective contexts. The turbidity criterion in the relevant NESREA schedule is expressed relative to

natural background rather than as a single absolute value. Coliform criteria should be reported using the units and definitions specified by the respective source. WHO (2017) values are drinking-water guideline values and are included here for contextual comparison only; they are not receiving-water discharge limits

Turbidity, TSS, and BOD₅ interpolation maps (Figures 15–17) reveal substantial spatial variability across Port Harcourt Port, with distinct concentration zones. The uneven distribution of suspended solids and biodegradable organic matter may reflect localised port activities, sediment resuspension, and hydrodynamic mixing; these mechanisms were not directly measured in the present study.

COD and NH₃ (Figures 18–19) show spatially varied concentration patterns, including localised elevated zones, indicating differences among sampling locations in organic-matter and nutrient-related indicators. Similarly, Pb, Cd, Cr, and Cu (Figures 20–23) exhibit distinct spatial concentration patterns. These variations may be associated with localised anthropogenic inputs, sediment interactions, transport, deposition, and mixing processes, but the available observations do not establish a specific source.

Faecal and total coliforms (Figures 24–25) display marked spatial differences, indicating that microbial contamination is unevenly distributed. The Pollution Index map (Figure 26) integrates the eleven assessed water-quality parameters and identifies areas with relatively higher overall pollution pressure within the observed range.

Overall, the interpolation results indicate clear spatial heterogeneity in surface-water quality at Port Harcourt Port. The observed patterns may reflect the combined effects of localised human activities and hydrodynamic processes. Figure 27 provides the spatial reference for the sampling locations within the Port Harcourt Port/Bonny River and their relationship to the jetty. Figures 15–27 therefore provide the GIS-based spatial description used for subsequent analysis of the relationship between distance from the jetty and water-quality parameters.

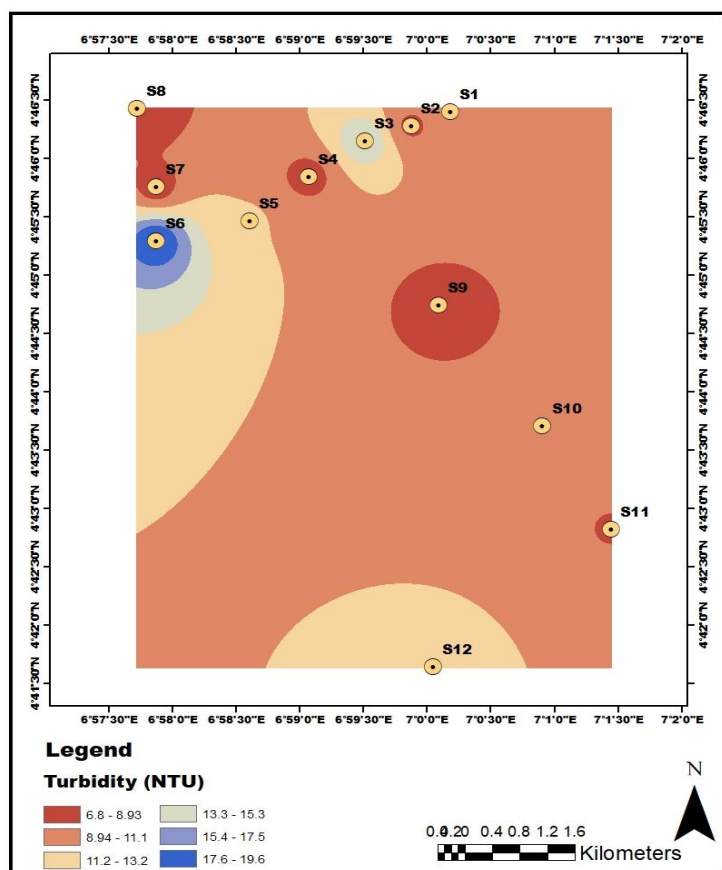


Figure 15. Spatial Distribution of Turbidity (NTU) in Port Harcourt Port River, Rivers State

Source: Researchers' Analysis, 2026

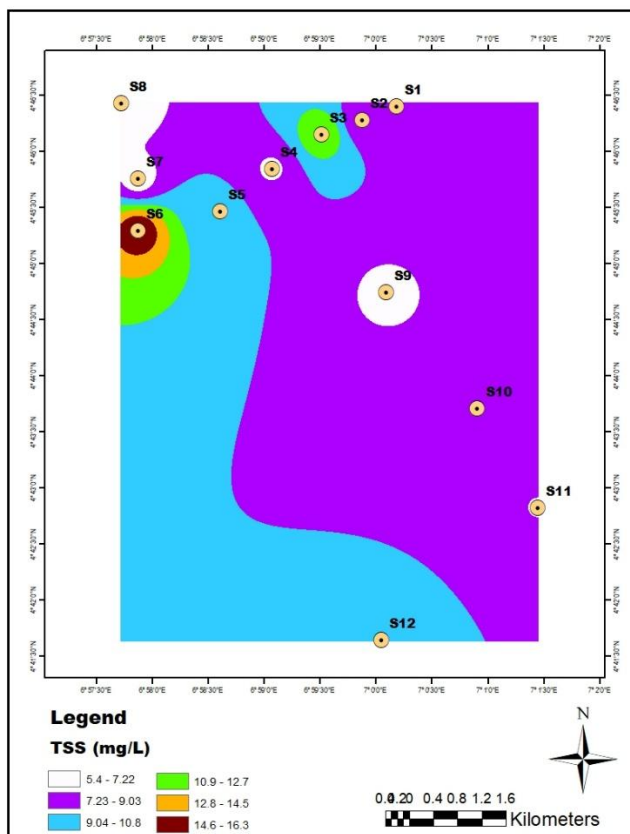


Figure 16. Spatial Distribution of TSS (mg/L) in Port Harcourt Port River, Rivers State

Source: Researchers' Analysis, 2026

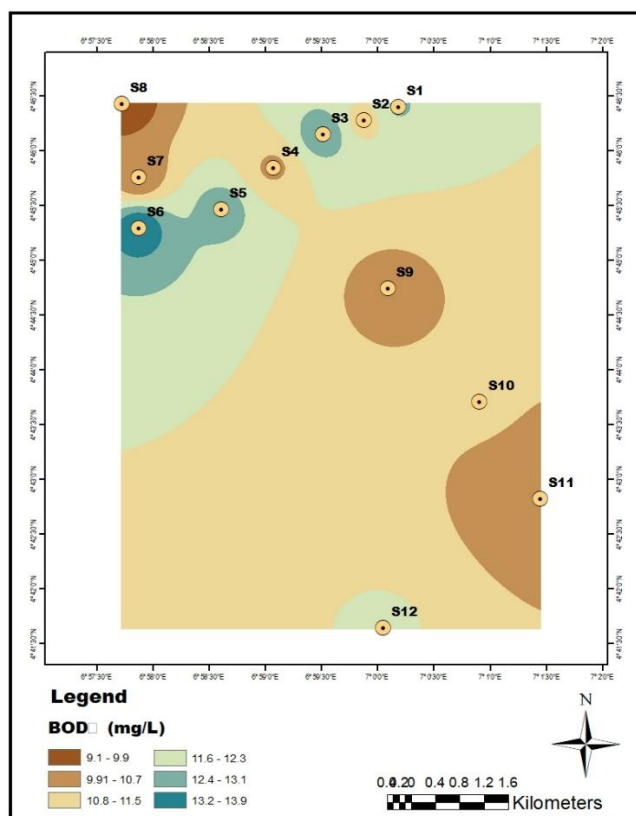


Figure 17. Spatial Distribution of BOD₅ (mg/L) in Port Harcourt Port River, Rivers State

Source: Researchers' Analysis, 2026

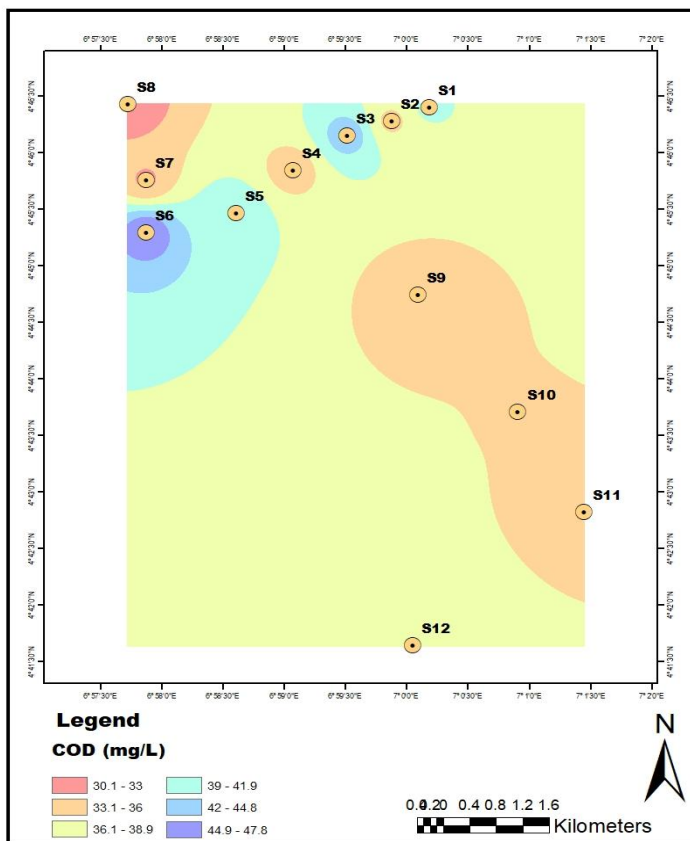


Figure 18. Spatial Distribution of COD (mg/L) in Port Harcourt Port River, Rivers State

Source: Researchers' Analysis, 2026

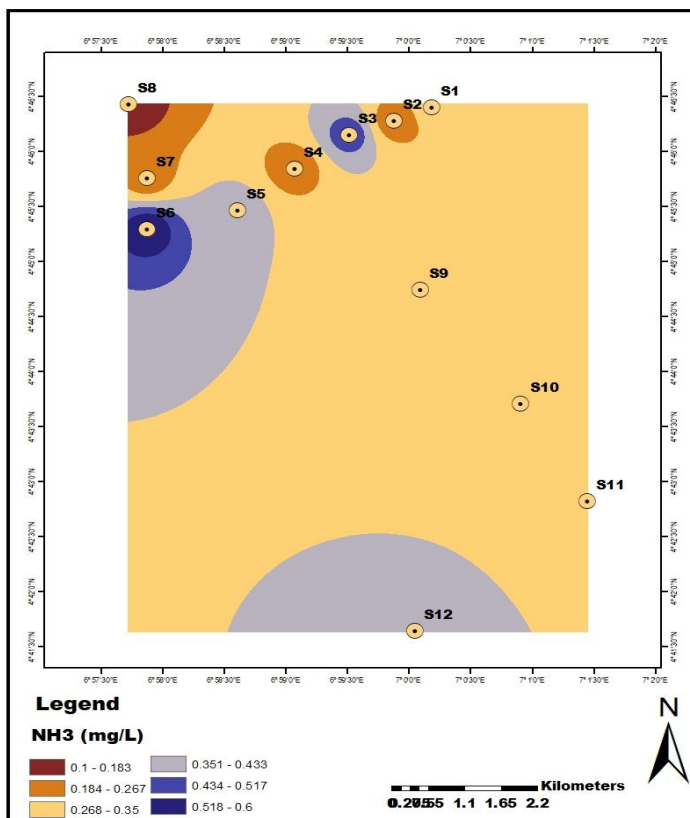


Figure 19. Spatial Distribution of Ammonia (NH₃) in Port Harcourt Port River, Rivers State

Source: Researchers' Analysis, 2026

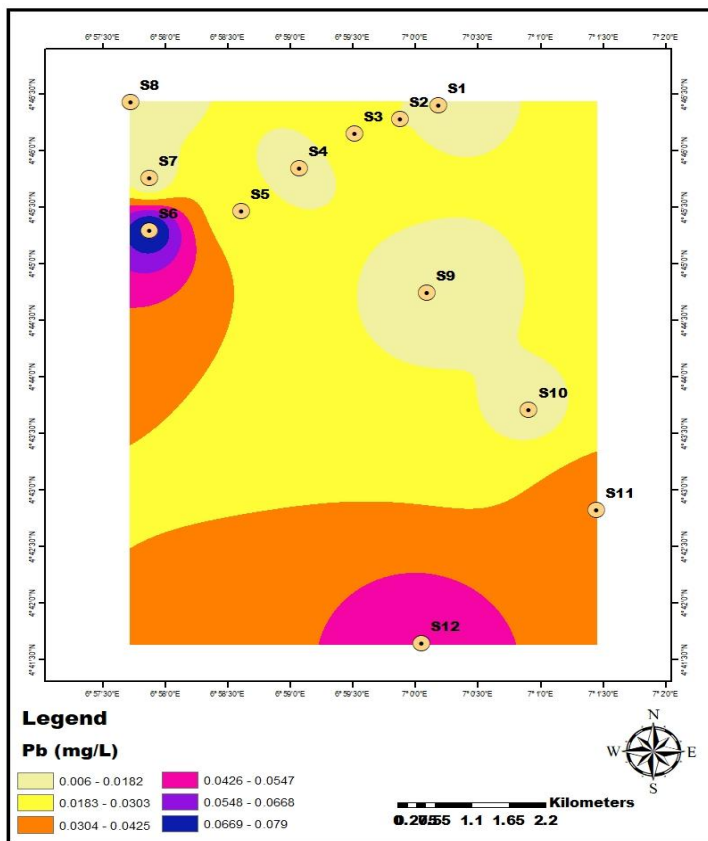


Figure 20. Spatial Distribution of Lead (Pb) in Port Harcourt Port River, Rivers State

Source: Researchers' Analysis, 2026

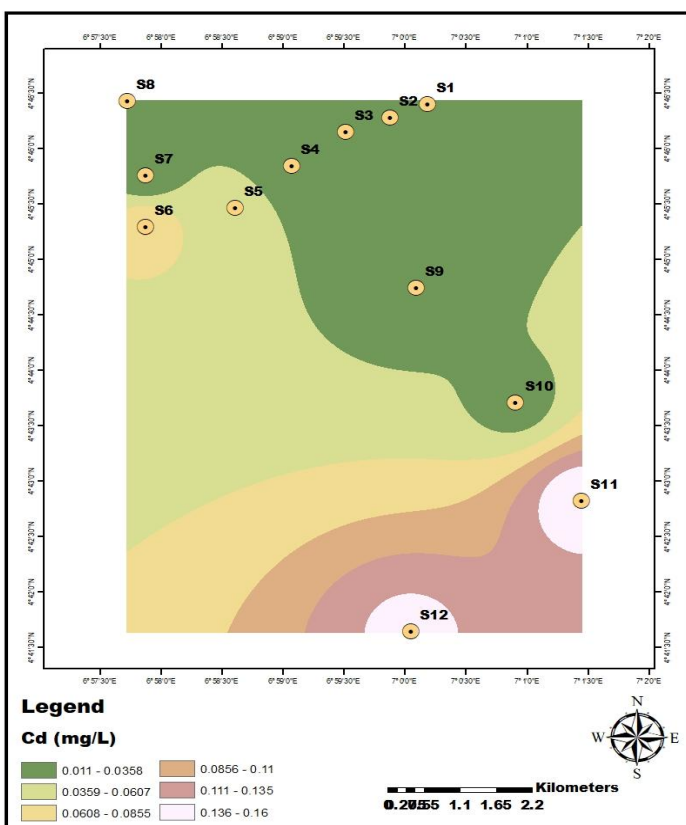


Figure 21. Spatial Distribution of Cadmium (Cd) in Port Harcourt Port River, Rivers State

Source: Researchers' Analysis, 2026

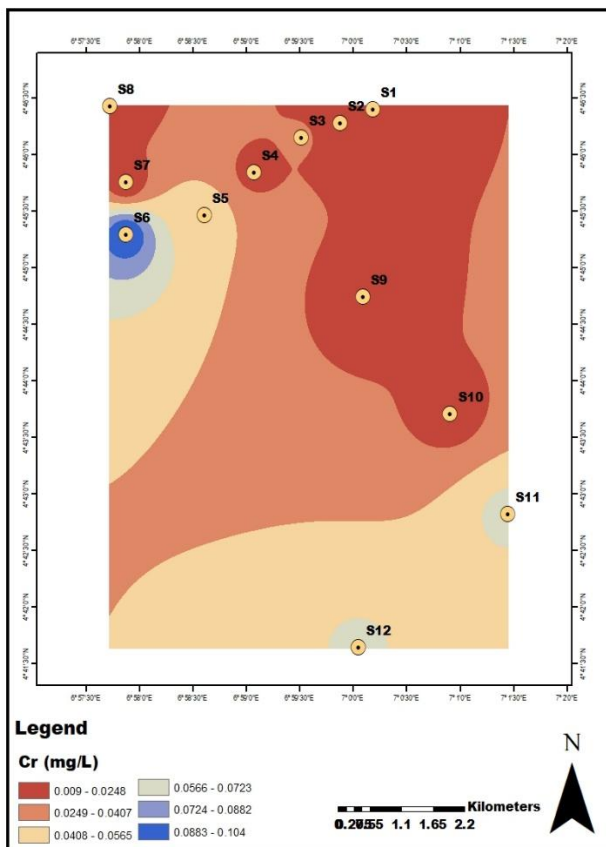


Figure 22. Spatial Distribution of Chromium (Cr) in Port Harcourt Port River, Rivers State

Source: Researchers' Analysis, 2026

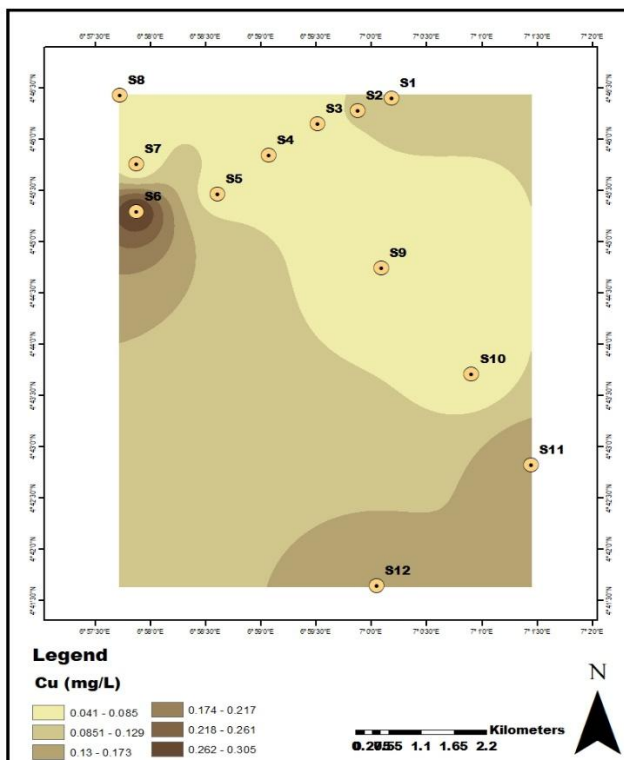


Figure 23. Spatial Distribution of Copper (Cu) in Port Harcourt Port River, Rivers State

Source: Researchers' Analysis, 2026

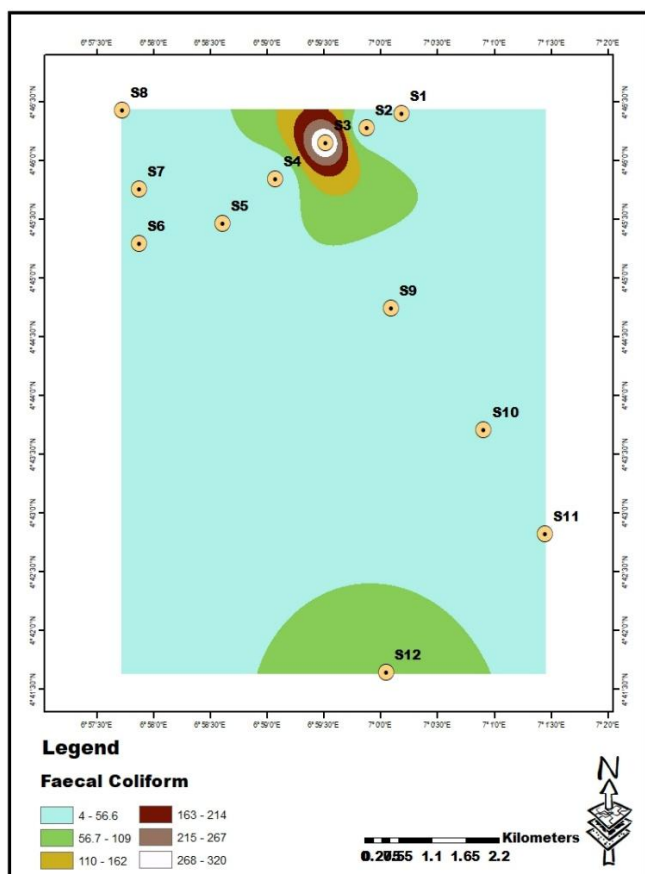


Figure 24. Spatial Distribution of Faecal Coliform in Port Harcourt Port River, Rivers State

Source: Researchers' Analysis, 2026

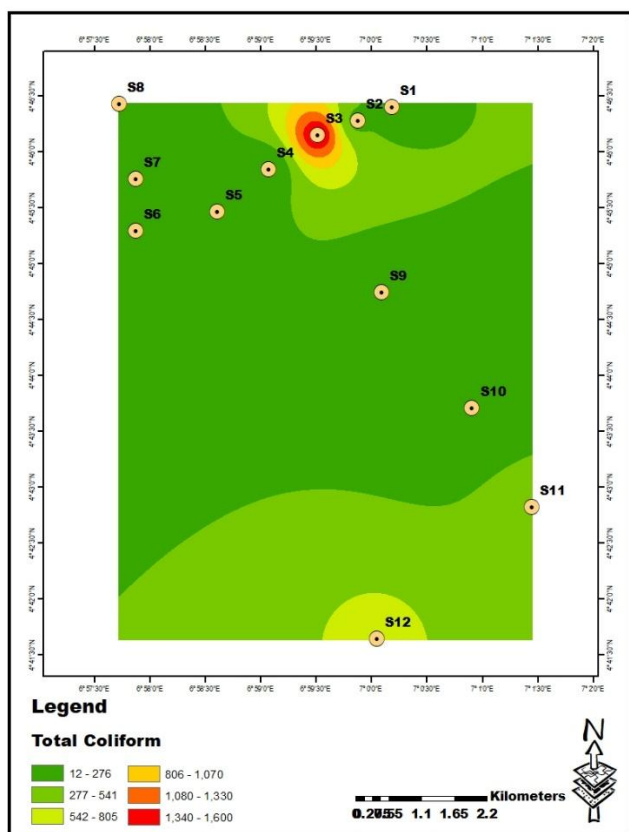


Figure 25. Spatial Distribution of Total Coliform in Port Harcourt Port River, Rivers State

Source: Researchers' Analysis, 2026

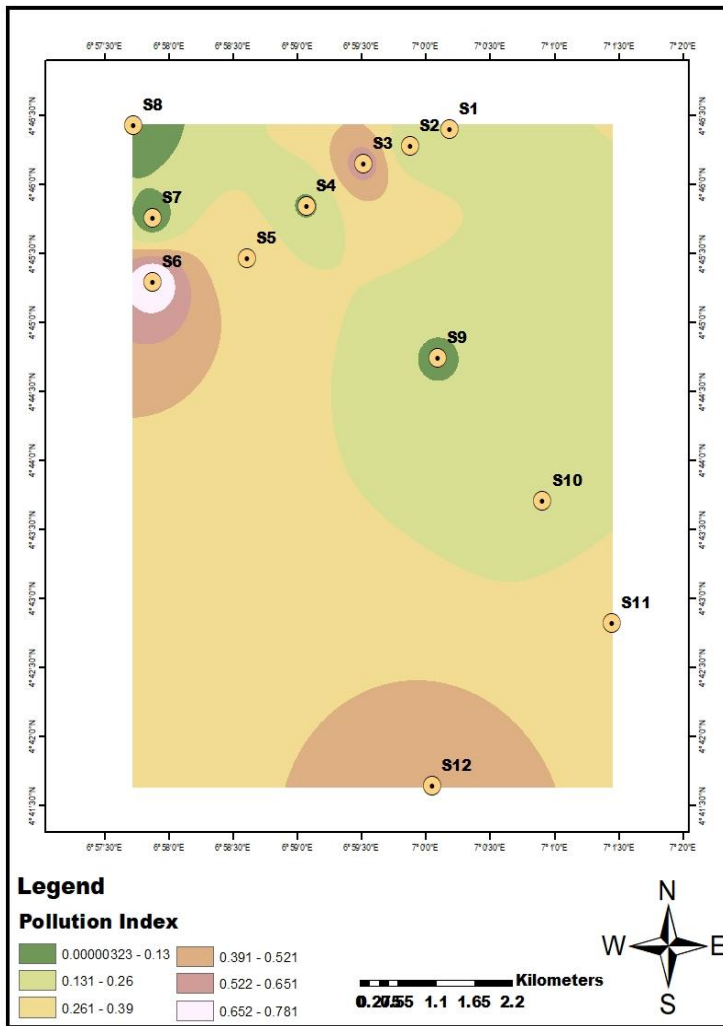


Figure 26. Spatial Distribution of Composite Pollution Index in Port Harcourt Port River, Rivers State

Source: Researchers' Analysis, 2026

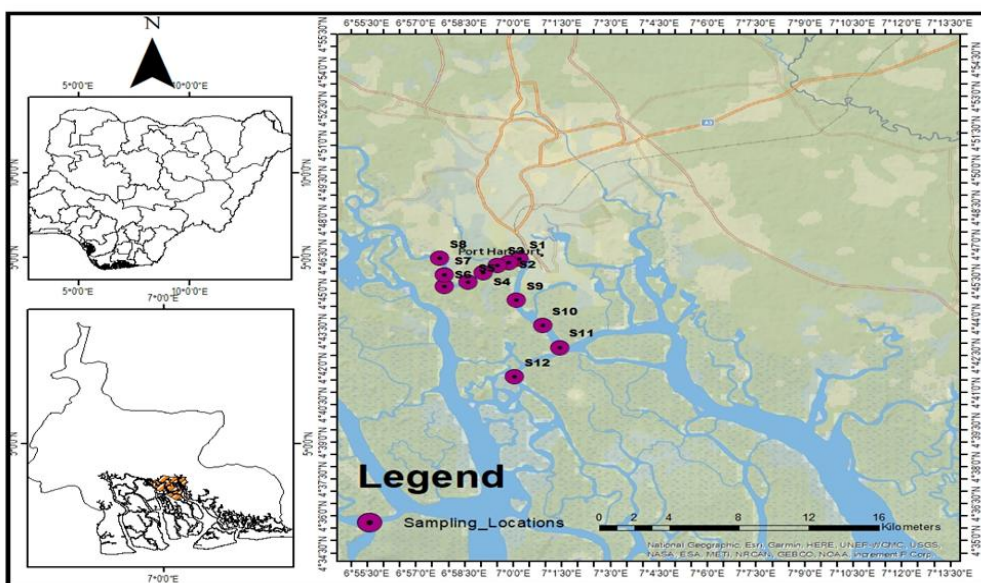


Figure 27. Location Map of Surface-Water (SW) Sampling Points along the Port Harcourt Port/Bonny River, Rivers State, Nigeria

Source: Researchers' Analysis, 2026

DISCUSSION OF FINDINGS

The results for Onne Port and Port Harcourt Port indicate that surface-water quality is spatially heterogeneous rather than characterised by a uniform distance-graded pollution gradient. At both ports, the composite Pollution Index showed localised areas of relatively higher pollution pressure, while individual parameters displayed different spatial patterns. The spatial concentration of some higher values in sections of the barge corridors is consistent with the possibility that local operational activities contribute to environmental pressure; however, the spatial coincidence alone does not establish that barge operations caused the observed patterns. Hydrodynamic mixing, sediment transport, wastewater inputs, cargo handling, and other local activities may also contribute. Within the DPSIR framework, barge operations can therefore be interpreted as one potential Pressure among several interacting pressures, while the measured water-quality conditions represent the observed State.

The station-level statistical results provide an important qualification to the interpolated maps. At Onne Port, regression of the Pollution Index on distance from the jetty was not significant ($R^2 = 0.0003$, $p = .954$, $n = 12$). Among the individual parameters, cadmium showed a significant positive Spearman correlation ($\rho = .594$, $p = .042$), whereas its Pearson correlation was not significant ($r = .488$, $p = .108$). At Port Harcourt Port, the regression analysis between distance from the jetty and the water-quality measures was not statistically significant ($R^2 = .022$, $p = .642$, $n = 12$). Pearson correlation analysis showed significant positive relationships between distance from the jetty and lead (Pb) concentration ($r = .716$, $p = .013$) and cadmium (Cd) concentration ($r = .810$, $p = .001$). However, the corresponding Spearman rank-order correlations were not statistically significant. These results indicate that the significant Pearson associations for Pb and Cd were not consistently supported by the non-parametric correlation analysis.

The apparent contrast between the maps and the corridor-wide statistics is therefore not necessarily contradictory: interpolation describes estimated local spatial patterns, whereas correlation and regression summarise relationships across the sampled stations. The maps can identify localised areas of relatively high values even when distance from the jetty does not explain the overall station-to-station variation. Full results are presented in Tables 6–9.

Table 6: Correlation between Distance from Jetty and Surface Water Quality Parameters – Onne Port ($n = 12$)

Parameter	Pearson r	p-value	Spearman ρ	p-value	Remark
Pollution Index	0.019	0.954	0.161	0.618	Not significant
Turbidity	0.027	0.935	0.238	0.457	Not significant
TSS	0.024	0.941	0.175	0.587	Not significant
BOD5	-0.185	0.566	-0.408	0.188	Not significant
COD	-0.395	0.204	-0.479	0.115	Not significant
Ammonia	0.351	0.263	0.436	0.157	Not significant
Pb	-0.14	0.665	0.088	0.787	Not significant
Cd	0.488	0.108	0.594	0.042	Significant (Spearman only)
Cr	-0.13	0.688	0.21	0.512	Not significant
Cu	-0.043	0.895	-0.077	0.812	Not significant
Faecal Coliform	0.017	0.958	0.183	0.569	Not significant
Total Coliform	0.147	0.648	0	1	Not significant

Significance level = 0.05.

Table 7: Linear Regression of Pollution Index on Distance from Jetty – Onne Port

Variable	Value
Slope	0.0013
Intercept	0.3046
Correlation (R)	0.0186
Coefficient of Determination (R ²)	0.0003
Standard Error	0.0224
p-value	0.954
Sample size (n)	12

Table 8: Correlation between Distance from Jetty and Surface Water Quality Parameters – Port Harcourt Port (n = 12)

Parameter	Pearson r	p-value	Spearman ρ	p-value	Remark
Pollution Index	0.15	0.642	0.028	0.931	Not significant
Turbidity	-0.087	0.788	-0.126	0.697	Not significant
TSS	-0.088	0.784	-0.189	0.557	Not significant
BOD5	-0.325	0.303	-0.434	0.159	Not significant
COD	-0.192	0.55	-0.315	0.319	Not significant
Ammonia	0.051	0.876	0.057	0.859	Not significant
Pb	0.716	0.013	0.161	0.618	Significant (Pearson only)
Cd	0.81	0.001	0.294	0.354	Significant (Pearson only)
Cr	0.322	0.307	0.144	0.656	Not significant
Cu	0.26	0.414	0.077	0.812	Not significant
Faecal Coliform	-0.024	0.941	0.042	0.897	Not significant
Total Coliform	0.093	0.774	-0.084	0.795	Not significant

Significance level = 0.05.

Table 9: Linear Regression of Pollution Index on Distance from Jetty – Port Harcourt Port

Variable	Value
Slope	0.016
Intercept	0.249
Correlation (R)	0.15
Coefficient of Determination (R ²)	0.022
Standard Error	0.245
p-value	0.642
Sample size (n)	12

Source: Field sampling and laboratory analysis of surface water samples, 2026 (statistical computation by the authors).

These findings can be considered alongside previous studies of port, river, and coastal water quality. Yudhistira et al. (2022) reported that port development can be associated with changes in coastal water quality, while Balogun and Islam (2025) demonstrated spatial variation in Niger River water quality associated with anthropogenic pressures. In the present study, the observed spatial heterogeneity is likewise consistent with the possibility that water quality reflects multiple localised pressures and hydrodynamic conditions. The evidence, however, does not support attributing the mapped patterns to barge activity alone.

The non-uniform spatial distributions of heavy metals at the two ports are also notable. Rather than following a consistent decline with increasing distance from the jetty, individual metals displayed different spatial patterns. This is consistent with the broader observation from Nigerian sediment studies that metal contamination can vary substantially among stations and may reflect localised discharges, sediment interactions, and transport processes (Oriabure & Ogbeibu, 2022; Ezekwe et al., 2025). The localised clustering of faecal and total coliforms similarly suggests that microbial contamination may be influenced by spatially discrete sources rather than by a simple traffic-distance gradient. These interpretations remain inferential because the study did not directly measure source contributions.

From a systems perspective, the findings indicate that environmental conditions in port waterways may result from several spatially distributed pressures rather than a single linear distance effect. Consequently, environmental monitoring at Onne Port and Port Harcourt Port should combine fixed-station sampling with spatial analysis so that localised patterns are not obscured by corridor-wide averages. GIS should be used as a complementary monitoring and visualisation tool, with adequate sampling density and interpolation-validation procedures reported to support confidence in mapped surfaces.

LIMITATIONS OF THE STUDY

Several limitations should be considered when interpreting these findings. First, sampling was conducted during a single wet-season campaign in July 2026. Given the semi-diurnal tidal regime and seasonal variation in freshwater discharge, the spatial patterns reported may not hold in the dry season. Repeat sampling across seasons is therefore needed before the findings can be generalised.

Second, the sample size of twelve stations per port is small relative to the length and complexity of the study corridors. The resulting interpolated surfaces should therefore be treated as indicative estimates rather than definitive representations of conditions throughout the waterways, particularly in areas farther from sampled points.

Third, distance from the jetty was used as a proxy for barge traffic intensity rather than a direct measure of barge movements. While this provides a reasonable first approximation, it does not capture variation in barge frequency, size, speed, or dwell time. The proxy could not be independently validated because corresponding NIMASA vessel-traffic records were unavailable for the study period.

Finally, the IDW interpolation was not cross-validated against withheld sample points; hence, the accuracy of the interpolated surfaces in unsampled areas remains unverified. In addition, the composite Pollution Index is a relative, port-specific index derived from the observed minimum and maximum values, rather than an absolute regulatory pollution scale. These limitations mean that the relationship between barge-related exposure and observed spatial patterns should be interpreted cautiously and not as evidence of confirmed causation.

CONCLUSION

The study evaluated the spatial distribution of surface-water quality in relation to distance from the barge jetties at Onne Port and Port Harcourt Port, Rivers State, Nigeria, using GIS interpolation of eleven water-quality parameters and a composite Pollution Index across twelve sampling stations at each port. The results revealed substantial spatial heterogeneity, with localised areas of relatively higher cumulative pollution pressure in sections of both sampled corridors. Individual water-quality parameters displayed different spatial patterns and did not conform to a consistent distance-based gradient. Corridor-wide correlation and regression analyses showed that distance from the jetty was not a statistically significant predictor of the composite Pollution Index at either port. The GIS-identified areas of relatively higher pollution pressure therefore represent localised spatial patterns that cannot be interpreted as evidence that barge operations caused the observed pollution. Hydrodynamic mixing, sediment transport, wastewater or other non-maritime inputs, and local operational activities remain plausible contributing factors. GIS-based mapping complements station-based statistical analysis by revealing spatial variation that may not be apparent from individual measurements alone. Establishing the specific contribution of barge operations requires direct traffic measurements, source-oriented observations, improved interpolation validation, and multi-season sampling.

RECOMMENDATIONS

1. Environmental regulatory agencies and port management bodies need to look into GIS-based monitoring of water quality along Onne Port and Port Harcourt Port Corridors in view of the high water quality levels detected in the current study.
2. These patterns should be taken into account while developing pollution prevention techniques such as waste management, spill response measures, and operational practices for vessels. Before any control measure is suggested, it is advisable to conduct an analysis of traffic conditions and operational issues in terms of vessel speeds, manoeuvring, wave making, etc.
3. Monitoring programmes should combine fixed-station water-quality measurements with spatial analysis and, where feasible, validated interpolation methods. This combined approach can help identify localised gradients while retaining the quantitative evidence provided by station-based measurements.
4. Future studies should include multiple seasons and, where resources permit, additional Eastern Nigerian ports such as Calabar and Warri. Such studies would help determine whether the spatial patterns observed at Onne and Port Harcourt are persistent across seasons and representative of other riverine barge corridors.
5. Further research should directly measure barge traffic frequency, vessel characteristics, operating practices, tidal conditions, sediment dynamics, and potential non-maritime discharge sources. These measurements would allow the relative contributions of barge activity and other environmental pressures to be evaluated more rigorously.

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