

Assessment of Surface Water Quality and Environmental Implication in Watari Basin Kano State, Nigeria

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ABSTRACT

This study assessed the spatial and temporal variations of Total Dissolved Solids (TDS), Nitrogen (N), Phosphorus (P), Lead (Pb), and Cadmium (Cd) in surface water across six monitoring stations in the Watari Basin, Nigeria, during August and September 2026. Laboratory results showed low dissolved-solute loading, with mean TDS concentrations of 55.98 ± 17.96 mg/L in August and 65.68 ± 29.70 mg/L in September, remaining below the 500 mg/L Nigerian Standard for Drinking Water Quality (NSDWQ) limit at all stations. Moreover, nutrient concentrations increased temporally, with N rising by 40.3% from 14.38 ± 3.41 to 20.18 ± 8.24 mg/L and P by 17.6% from 3.44 ± 0.99 to 4.04 ± 1.36 mg/L. September maxima at Wankau (30.43 mg/L N) and Gudumin Dutse (6.06 mg/L P) indicate substantial agricultural runoff, fertilizer leaching, and domestic wastewater inputs, with implications for eutrophication and oxygen depletion. Most critically, Pb and Cd exceeded NSDWQ limits at all sites during both months. Mean Pb concentrations were 1.16 ± 0.45 mg/L in August and 0.79 ± 0.33 mg/L in September, while Cd remained 0.22 mg/L, substantially exceeding the respective standards. Paired-samples t-tests showed no significant monthly differences for TDS ($p = .268$), N (.247), P (.426), Pb (.138), or Cd (1.000). The persistent metal contamination indicates chronic ecological and human-health risks, including bioaccumulation, nephrotoxicity, and neurotoxicity. Immediate catchment management, agrochemical regulation, riparian restoration, and sustained sediment and biological monitoring are therefore recommended.

Keywords: watari basin; surface-water quality; heavy-metal contamination; nutrient pollution; environmental risk

INTRODUCTION

Water is an indispensable resource for human survival, ecosystem functioning, agriculture, and socio-economic development, making the protection and continuous assessment of surface-water quality essential for public health and sustainable resource management. Globally, population growth, urbanization, industrialization, and climate variability have increased pressure on freshwater resources, resulting in widespread water-quality deterioration and continued challenges in access to safe water (UNEP, 2026; WHO, 2023, 2026).

In Nigeria, surface waters are important for domestic use, irrigation, livestock, and other livelihoods but are increasingly threatened by agricultural runoff, indiscriminate waste disposal, urban expansion, industrial effluents, and inadequate environmental management, with studies reporting contaminant concentrations that

sometimes exceed WHO and SON permissible limits (Aralu et al., 2022; Iwegbue et al., 2023; Yahaya et al., 2021). These pollutants can pose significant risks to human health, aquatic ecosystems, agricultural productivity, and water-dependent economic activities, highlighting the need for regular monitoring and comparison with established standards (WHO, 2026; Iwegbue et al., 2023).

The Watari Basin in Kano State, an important component of the Hadejia–Jama'are River system within the Chad Basin, supports domestic water supply, irrigation, fishing, and other livelihood activities across surrounding communities. However, increasing agricultural intensification, population growth, urban development, and other anthropogenic pressures may compromise its surface-water quality and suitability for human and environmental uses (Aralu et al., 2022; Iwegbue et al., 2023).

Therefore, current and comprehensive assessment of physicochemical parameters, compliance with national standards, and potential health risks is necessary to support effective management, environmental protection, and sustainable utilization of the Watari Basin water resources (WHO, 2026; UNEP, 2026).

Study Area Description

The Watari Basin, located in northwestern Nigeria within Kano State, forms part of the Hadejia-Jama'are River system that drains into the Chad

Basin and encompasses the Watari River, its tributaries, and the Watari Reservoir, providing water for irrigation, domestic use, and rural livelihoods across several Local Government Areas. Geographically, the basin extends approximately from 11°30'00" N to 12°30'01" N and 7°30'00" E to 8°30'02" E, with elevations of about 350–500 m above sea level and is characterized by a gently undulating Sudan savanna landscape, seasonal rainfall, and intensive agricultural activities that influence surface-water quality, as presented in Figure 1.

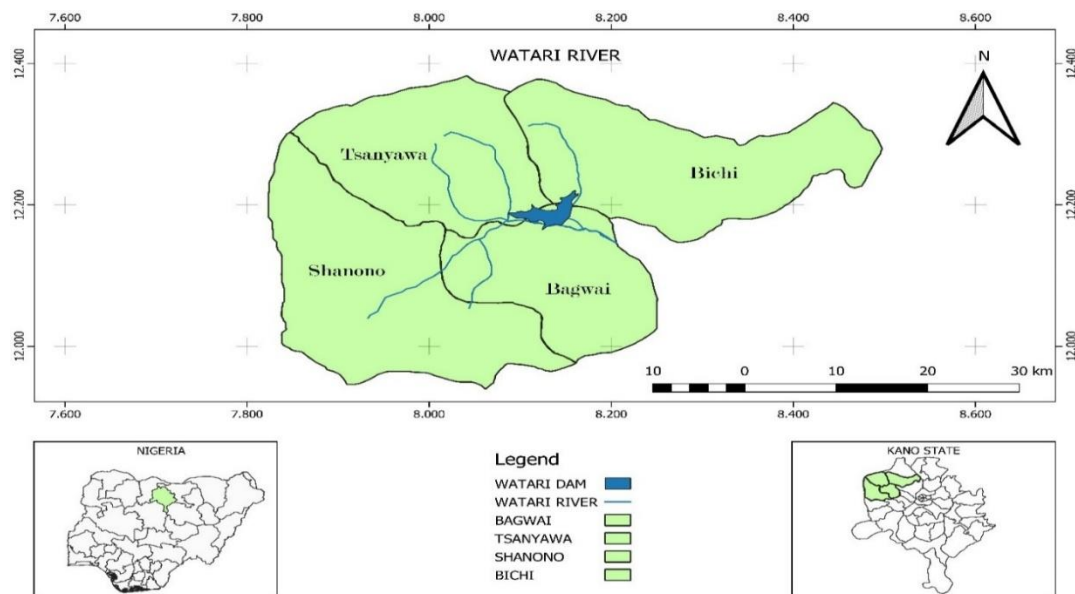


FIGURE 1: Map of the Study Area.

Source: Dangambo, et. al., (2026).

MATERIALS AND METHODS

The study employed a grab-sampling research design involving six strategically selected stations within the Watari River Basin: Watari Dam (A1), Kanyu (A2), Wankau (A3), Rafin Tsamiya (2) (A4), Rafin Tsamiya (1) (A5), and Gudumin Dutse (A6), representing different sections of the river system and associated water bodies. Two sampling rounds were conducted in August and September 2026, yielding a total of 12 surface-water samples (6 stations × 2 sampling rounds), with grab sampling adopted to characterize physicochemical and heavy-metal conditions at specific locations and sampling periods.

The design enabled assessment of spatial and temporal variations, comparison of contaminant concentrations with applicable standards, evaluation of potential human-health risks, and interpretation of the broader environmental implications of observed water-quality conditions.

Sampling Stations and Spatial Coverage

Six sampling stations were selected within the Watari River Basin. The stations were identified based on their hydrological relevance, geographical distribution, accessibility and potential importance for assessing changes in surface-water quality within the basin. The sampling locations and their corresponding geographical coordinates are presented in Table 1.

TABLE 1: Sampling Stations and Geographical Coordinates.

S/N	Points	Station Name	LAT (N)	LON (E)	LGA
1	Watari Dam	A1	12 11'17.69	8 15'23.20	Bagwai
2	Gudumin Dutse (Gogori)	A6	12 9'42.83	8 3'50.02	Bagwai
3	1Rafin Tsamiya (Dumbulum)	A5	12 10'47.08	8 3'8.66	Tsanyawa
4	2Rafin Tsamiya (Dumbulum)	A4	12 11'36.69	8 1'53.57	Tsanyawa
5	Wankau	A3	12 14'9.84	8 5'3.07	Tsanyawa
6	Kanyu	A2	12 14'26.72	8 9'45.55	Bichi

Source: Author's field survey, 2026.

The geographical coordinates of each sampling station were obtained and recorded during field sampling using a Global Positioning System (GPS)

device. The coordinates were subsequently used to identify and map the spatial distribution of the sampling stations within the Watari River Basin.

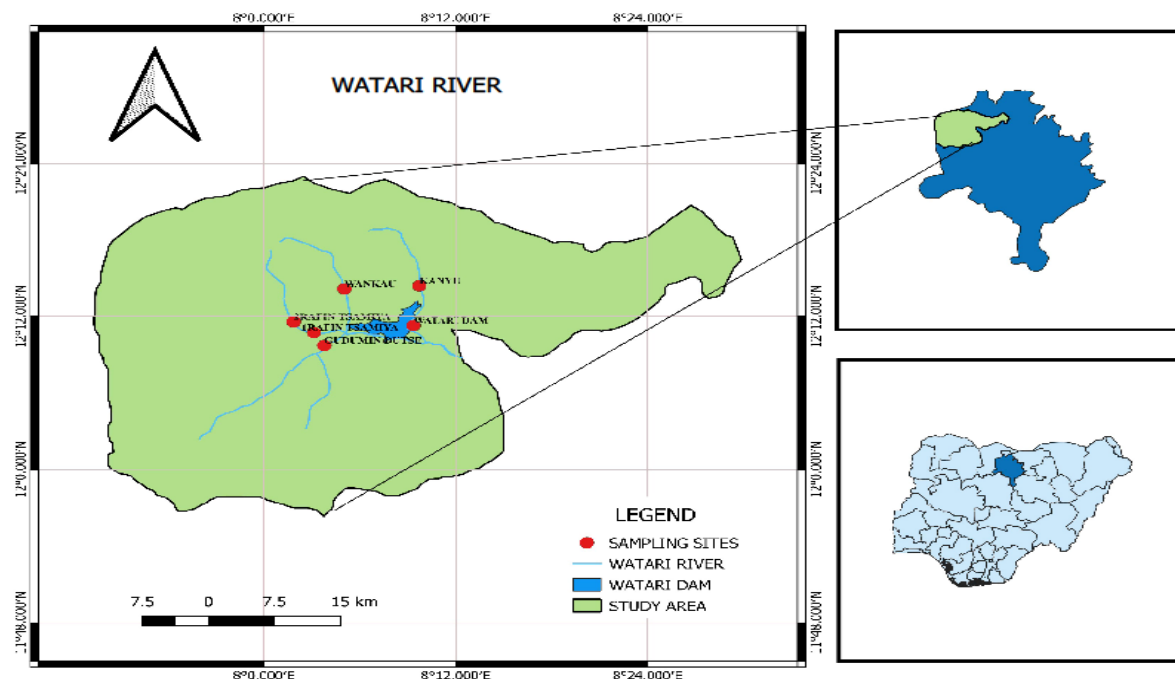


FIGURE 2: Map of the Study Area.

Source: Dangambo, et. al., (2026).

Types and Sources of Data

The primary data comprised laboratory results from surface-water samples collected at six selected sampling stations, focusing on Total Dissolved Solids (TDS), Nitrogen (N), Phosphorus (P), Lead (Pb), and Cadmium (Cd), together with field records including sampling location, date, sampling code, and geographical coordinates.

Secondary data were obtained from relevant scientific publications, textbooks, research reports, government publications, regulatory documents, water-quality standards, and other credible literature on surface-water quality, heavy-metal contamination, environmental pollution, and human-health risk assessment, while national water-quality standards and internationally recognised risk-assessment guidelines were used to interpret laboratory results and assess potential human-health risks associated with Pb and Cd exposure.

Materials, Water-Sample Collection, Preservation and Transportation

The study employed appropriate field and laboratory materials and equipment, including clean sample bottles, distilled/deionised water, disposable gloves, labels and waterproof markers, an ice-packed cooler, concentrated nitric acid (HNO_3), laboratory glassware, reagents, filtration and digestion materials, Atomic Absorption Spectrophotometer (AAS), TDS and nutrient-determination instruments, GPS receiver, and computer software, with all equipment operated according to manufacturers' instructions and standard laboratory procedures.

Surface-water samples were collected using standard grab-sampling procedures from six designated stations during two sampling rounds, giving 12 samples, with bottles properly cleaned, labelled, and handled to minimise contamination; field information including station, date, time, weather conditions, and geographical coordinates was recorded, while samples were immediately sealed, preserved where necessary with HNO_3 for heavy-metal analysis, stored in an ice-packed cooler, transported to the Soil and Water Laboratory, Department of Geography, Bayero University Kano, and analysed within the recommended holding periods using appropriate laboratory procedures.

Laboratory Analysis and Analytical Procedures

Laboratory analyses were conducted using recognised water-analysis principles, standard operating procedures, appropriate reagent preparation, calibration, and analytical controls to determine TDS, N, P, Pb, and Cd in mg/L, with the results evaluated for their spatial and temporal variations and compared with applicable water-quality benchmarks, while TDS indicated dissolved mineral content and N and P provided information on nutrient enrichment and potential ecological effects.

Pb and Cd were determined using Atomic Absorption Spectrophotometry (AAS) following appropriate sample preservation, preparation, digestion, calibration, and measurement against respective calibration curves, with the resulting concentrations compared with applicable guideline values and incorporated into the human-health risk assessment.

Quality Assurance, Quality Control and Water-Quality Standards

Quality assurance and quality control (QA/QC) were maintained through proper cleaning and labelling of sampling bottles, appropriate sample preservation and transportation, instrument calibration, use of reagent blanks, duplicate/replicate analyses, distilled-water reference/control samples, standard operating procedures, and verification of analytical results before statistical analysis, thereby minimising contamination, measurement errors, and analytical variability.

Laboratory concentrations were compared with the Nigerian Standard for Drinking Water Quality (NSDWQ) and other applicable guideline values, with compliance determined as $C \leq L$ and non-compliance as $C > L$, while percentage exceedance was calculated as $[(C - L)/L] \times 100$ and exceedance ratio as C/L , where C is the measured concentration and L is the permissible limit; an exceedance ratio >1 indicated non-compliance, whereas parameters with specified ranges were assessed against both limits, and the stated 6 mg/L phosphate benchmark was treated according to its correct regulatory source rather than being automatically attributed to NSDWQ.

Human Health Risk Assessment

A Human Health Risk Assessment (HHRA) framework was applied to evaluate potential health risks associated with oral ingestion of surface water contaminated with Lead (Pb) and Cadmium (Cd), using recognised exposure parameters and estimating the Average Daily Dose (ADD), Hazard Quotient (HQ), and Hazard Index (HI) for non-carcinogenic effects. The ADD was calculated from contaminant concentration, water-ingestion rate, exposure frequency and duration, body weight, and averaging time, while $HQ = ADD/RfD$ and $HI = \sum HQ$ were used to assess individual and combined non-carcinogenic risks, respectively, with values ≥ 1 interpreted as potential concern rather than proof of adverse health effects. Where a scientifically defensible Cancer Slope Factor (CSF) was available, lifetime carcinogenic risk was estimated as $CR = LADD \times CSF$ and interpreted as an estimated excess

lifetime cancer risk under the specified exposure assumptions, rather than a prediction of actual cancer occurrence in the study population.

Assessment of Environmental Implications

The environmental implications of observed water-quality conditions were assessed through an integrated interpretation of laboratory results, spatial and temporal variations, and compliance with applicable water-quality benchmarks, considering potential effects on aquatic organisms and ecosystem quality, nutrient enrichment, surface-water ecological condition, sediment and soil contamination, agricultural and irrigation activities, domestic water use, and long-term environmental quality within the Watari River Basin, while elevated concentrations and potential pollution sources were interpreted cautiously based on the available field observations and supporting evidence.

Statistical Analysis and Data Presentation

The data were organised and analysed using Microsoft Excel and appropriate statistical software, employing descriptive statistics (mean, standard deviation, minimum, maximum, and coefficient of variation), spatial comparisons across the six sampling stations, temporal comparisons between August and September 2026, and paired-samples t -tests at $\alpha = 0.05$ to determine significant month-to-month differences in TDS, N, P, Pb, and Cd, while one-way ANOVA with Tukey's HSD or the Kruskal-Wallis test was considered, where appropriate, for assessing spatial differences among stations.

Results were presented using tables, charts, and statistical summaries, including mean concentrations, variability measures, percentage temporal changes, spatial and temporal distributions, comparison with applicable water-quality standards and quantified exceedances, while human-health risk results were summarised using contaminant concentrations, estimated daily doses, reference doses, hazard quotients, and hazard indices, followed by interpretation of environmental implications based on concentration magnitude, spatial and temporal patterns, and compliance status.

RESULTS AND DISCUSSIONS

Results of Laboratory Analysis for August 2026

TABLE 2: Concentrations of Selected Physicochemical Parameters and Heavy Metals in Watari Basin Surface Water, August 2026.

S/N	Sampling Location	Code	TDS (mg/L)	N (mg/L)	P (mg/L)	Pb (mg/L)	Cd (mg/L)
1	Watari Dam	A1	59.50	12.71	4.24	0.87	0.30
2	Kanyu	A2	20.60	20.74	4.85	0.43	0.20
3	Wankau	A3	57.50	13.38	3.03	1.30	0.10
4	Rafin Tsamiya (2)	A4	61.30	14.72	2.43	1.30	0.30
5	Rafin Tsamiya (1)	A5	70.00	14.05	3.64	1.75	0.10
6	Gudumin Dutse	A6	67.00	10.70	2.43	1.30	0.30
7	Distilled Water	A7	0.86	1.03	0.61	ND	ND
	NSDWQ	—	500	50	6*	0.10	0.003

Source: Author's laboratory analysis, August 2026.

Table 2 indicates substantial spatial variation in water quality across the Watari Basin, with TDS concentrations (20.60–70.00 mg/L) remaining well below the NSDWQ limit of 500 mg/L, but N (10.70–20.74 mg/L) and P (2.43–4.85 mg/L) showing notable nutrient enrichment potentially associated with agricultural runoff, domestic wastewater, livestock activities, and other catchment inputs, while persistently elevated Pb (0.43–1.75 mg/L) and Cd (0.10–0.30 mg/L) at all six stations, particularly the highest Pb at Rafin Tsamiya (1) (A5) and highest

Cd at A1, A4, and A6, indicate potential contamination and ecological and human-health concerns through bioaccumulation and trophic transfer, consistent with Anyanwu and Nwachukwu (2020) and Onyemesili et al. (2022), thereby underscoring the need for continuous water-quality monitoring, contaminant-source identification and control, riparian protection, and assessment of sediments and aquatic organisms despite the relatively low dissolved-mineral loading indicated by TDS.

Results of Laboratory Analysis for September 2026

TABLE 3: Concentrations of Selected Physicochemical Parameters and Heavy Metals in Watari Basin Surface Water, September 2026.

S/N	Sampling Location	Code	TDS (mg/L)	N (mg/L)	P (mg/L)	Pb (mg/L)	Cd (mg/L)
1	Watari Dam	A1	41.90	20.40	3.03	1.30	0.20
2	Kanyu	A2	23.90	5.69	5.46	0.43	0.20
3	Wankau	A3	70.50	30.43	3.03	0.86	0.10
4	Rafin Tsamiya (2)	A4	68.30	24.08	3.64	0.86	0.30
5	Rafin Tsamiya (1)	A5	81.00	22.41	3.03	0.86	0.20
6	Gudumin Dutse	A6	108.50	18.06	6.06	0.43	0.30
	Distilled Water	A7	0.86	1.03	0.61	ND	ND
	NSDWQ	—	500	50	6*	0.10	0.003

Source: Author's laboratory analysis, September 2026.

The results in Table 3 demonstrate marked spatial variability in the Watari Basin, with TDS remaining well below the NSDWQ limit, but elevated N, P, Pb and Cd, particularly at Wankau (A3), Rafin Tsamiya (A4) and Gudumin Dutse (A6), indicating nutrient enrichment and potentially serious heavy-metal contamination likely associated with agricultural runoff, domestic discharges and other catchment

activities, with consequent risks of eutrophication, ecological disturbance, sediment contamination, bioaccumulation and human exposure, thereby demanding the need for regular water-quality monitoring, pollution-source control, riparian-buffer protection, and assessment of sediments and aquatic biota.

Descriptive Statistical Analysis of August 2026 Results

TABLE 4: Descriptive Statistics of Water-Quality Parameters in August 2026.

Parameter	Mean (mg/L)	SD (mg/L)	Minimum (mg/L)	Maximum (mg/L)	CV (%)
TDS	55.98	17.96	20.60	70.00	32.1
Nitrate (N)	14.38	3.41	10.70	20.74	23.7
Phosphate (P)	3.44	0.99	2.43	4.85	28.7
Lead (Pb)	1.16	0.45	0.43	1.75	39.1
Cadmium (Cd)	0.22	0.10	0.10	0.30	45.4

Source: Author's analysis, September 2026.

The descriptive statistics indicate moderate spatial variability in the Watari Basin in August, with relatively consistent nutrient concentrations but elevated nitrate-N and phosphate-P suggesting nutrient enrichment from agricultural runoff, domestic wastewater and other catchment activities that may promote eutrophication and disrupt aquatic ecosystem functioning, while the greater

spatial variability and elevated concentrations of Pb and Cd indicate localized contaminant inputs and pose significant potential ecological and human-health risks through persistence, sediment accumulation, bioaccumulation and food-chain transfer (Wymore et al., 2021; Bawa-Allah, 2023; Umeh et al., 2023).

Descriptive Statistical Analysis of September 2026 Results

TABLE 5: Descriptive Statistics of Water-Quality Parameters in September 2026.

Parameter	Mean (mg/L)	SD (mg/L)	Minimum (mg/L)	Maximum (mg/L)	CV (%)
TDS	65.68	29.70	23.90	108.50	45.2
Nitrate (N)	20.18	8.24	5.69	30.43	40.9
Phosphate (P)	4.04	1.36	3.03	6.06	33.8
Lead (Pb)	0.79	0.33	0.43	1.30	41.4
Cadmium (Cd)	0.22	0.08	0.10	0.30	34.7

Source: Author's analysis, September 2026.

The results in the month of September demonstrate considerable spatial variability in the Watari Basin, with elevated TDS, nitrate-N and phosphate-P indicating heterogeneous dissolved-solute and nutrient inputs potentially associated with agricultural runoff, domestic wastewater and other anthropogenic activities that may promote eutrophication and oxygen depletion, while the

substantially elevated and spatially variable Pb and Cd concentrations suggest localized anthropogenic and/or geogenic contamination with potential risks of sediment accumulation, bioaccumulation, aquatic toxicity and human exposure through contaminated water and aquatic food resources (Wymore et al., 2021; Turner et al., 2021; Sam et al., 2023).

Comparison of Mean Concentrations Between August and September

TABLE 6: Month-to-Month Comparison of Mean Concentrations.

Parameter	August Mean	September Mean	Absolute Change	Percentage Change (%)	Direction
TDS	55.98	65.68	+9.70	+17.3	Increase
Nitrate (N)	14.38	20.18	+5.80	+40.3	Increase
Phosphate (P)	3.44	4.04	+0.61	+17.6	Increase
Lead (Pb)	1.16	0.79	-0.37	-31.8	Decrease
Cadmium (Cd)	0.22	0.22	~0.00	0.0	No change

Source: Author's analysis, September 2026.

The August–September comparison shows a clear seasonal shift in the Watari Basin, marked by increases in TDS (17.3%), nitrate-N (40.3%) and phosphate-P (17.6%), likely reflecting rainfall-driven runoff, soil leaching, agricultural and domestic inputs that enhance nutrient and dissolved-material mobilization and may increase eutrophication and ecological risks, while the 31.8% decline in Pb may indicate dilution or altered

mobilization pathways; however, the unchanged Cd concentration (0.22 mg/L) suggests persistent Cd loading, underscoring the need for continued monitoring of Pb and Cd because of their potential persistence, sediment association, bioaccumulation and toxicity to aquatic organisms and human consumers (Alozie et al., 2022; Tesi et al., 2023; Jola Osho et al., 2025).

Comparison of Sampling Locations Across the Two Months

TABLE 7: Two-Month Mean Concentrations by Sampling Location.

Sampling Location	TDS	Nitrate	Phosphate	Pb	Cd
Watari Dam	50.70	16.56	3.64	1.09	0.25
Kanyu	22.25	13.22	5.16	0.43	0.20
Wankau	64.00	21.91	3.03	1.08	0.10
Rafin Tsamiya (2)	64.80	19.40	3.04	1.08	0.30
Rafin Tsamiya (1)	75.50	18.23	3.34	1.31	0.15
Gudumin Dutse	87.75	14.38	4.25	0.87	0.30

Source: Author's analysis, September 2026.

The results in Table 7 demonstrate pronounced spatial variability in the Watari Basin, with elevated nitrate and phosphate indicating nutrient enrichment potentially linked to agricultural runoff, domestic wastewater and other catchment activities, while the widespread detection and locally high concentrations of Pb and Cd, particularly

Pb at Rafin Tsamiya (1) (1.31 mg/L) and Cd at Rafin Tsamiya (2) and Gudumin Dutse (0.30 mg/L), suggest potentially significant metal contamination with associated ecological and human-health risks through persistence, sediment accumulation, bioaccumulation and trophic transfer (Anyanwu et al., 2023; Bawa-Allah, 2023).

Compliance and Exceedance Analysis

TABLE 8: Mean Concentration Relative to Stated Benchmark.

Parameter	Benchmark (mg/L)	August Mean	August Mean/Benchmark	September Mean	September Mean/Benchmark
TDS	500	55.98	0.11	65.68	0.13
Nitrate (N)	50	14.38	0.29	20.18	0.40
Phosphate (P)	6*	3.44	0.57	4.04	0.67
Pb	0.10	1.16	11.58	0.79	7.90
Cd	0.003	0.22	72.22	0.22	72.22

Source: Author's analysis, September 2026.

The results show that TDS, nitrate and phosphate remained below their respective NSDWQ benchmarks in both August and September, although the rising nitrate and phosphate ratios indicate increasing nutrient loading and potential nutrient enrichment, while Pb and particularly Cd greatly exceeded their benchmarks, Pb by 7.90–

11.58 times and Cd by 72.22 times, identifying heavy-metal contamination as the principal water-quality concern, with potential ecological and human-health risks from persistence, sediment accumulation, bioaccumulation and trophic transfer (Basheeru et al., 2022; Anyanwu et al., 2023; Iwegbue et al., 2023).

Percentage of Sampling Locations Exceeding the Stated Benchmarks

TABLE 9: Percentage of Sampling Locations Exceeding Benchmarks.

Parameter	August: Number Exceeding	August (%)	September: Number Exceeding	September (%)
TDS	0/6	0.0	0/6	0.0
Nitrate	0/6	0.0	0/6	0.0
Phosphate	0/6	0.0	1/6	16.7
Pb	6/6	100.0	6/6	100.0
Cd	6/6	100.0	6/6	100.0

Source: Author's analysis, September 2026.

The results in Table 9 demonstrate strong water-quality compliance for TDS and nitrate, with no exceedances at any sampling location in either August or September, while phosphate exceeded its benchmark at one location (16.7%) in September; in contrast, Pb and Cd exceeded their respective benchmarks at all six locations (100%) in both

months, identifying persistent heavy-metal contamination, particularly Cd and Pb, as the dominant water-quality concern with potential ecological and human-health risks through toxicity, sediment accumulation, bioaccumulation and trophic transfer (Bawa-Allah, 2023; Umeh et al., 2023; Ediagbonya et al., 2024).

Inferential Paired Statistical Comparison Between August and September

TABLE 10: Paired-Samples Comparison of August and September Concentrations.

Parameter	Mean August	Mean September	Mean Difference (Sep–Aug)	t	df	p-value	Interpretation at $\alpha = 0.05$
TDS	55.98	65.68	9.70	–1.246	5	0.268	Not significant
Nitrate	14.38	20.18	5.80	–1.311	5	0.247	Not significant
Phosphate	3.44	4.04	0.61	–0.866	5	0.426	Not significant
Pb	1.16	0.79	–0.37	1.765	5	0.138	Not significant
Cd	0.22	0.22	0.00	~0.000	5	1.000	Not significant

Source: Author's analysis, September 2026.

The results in Table 10 indicate that although TDS, nitrate and phosphate increased and Pb decreased between August and September while Cd remained unchanged, none of the observed seasonal differences was statistically significant at $\alpha = 0.05$ ($p > 0.05$), indicating no statistically detectable seasonal effect across the six sampling locations; however, the persistent elevated Pb and Cd concentrations remain environmentally significant because statistical non-significance does not indicate absence of contamination, with potential ecological and human-health risks associated with metal toxicity, sediment association and bioaccumulation (Iwegbue et al., 2023; Anyanwu et al., 2023; Jola Osho et al., 2025).

Laboratory Reference/Control Observation

The distilled-water sample showed substantially lower concentrations of TDS (0.86 mg/L), nitrate (1.03 mg/L) and phosphate (0.61 mg/L), with Pb and Cd not detected in either month, providing a useful reference contrast that supports the interpretation that the higher concentrations measured in Watari Basin surface waters are

associated with the sampled waters rather than purified-water background levels; however, definitive laboratory quality assurance would require analytical blanks, calibration standards, duplicates, recovery data and detection limits, which were not provided and therefore cannot be inferred.

Graphical Presentation of Results

The temporal pattern shows a pronounced September increase in TDS (~56 to ~66 mg/L), nitrogen (~14.5 to ~20.2 mg/L) and phosphorus (~3.5 to ~4.1 mg/L), likely reflecting enhanced late-wet-season runoff, agricultural discharge, soil erosion and nutrient mobilization that may promote eutrophication, algal blooms, hypoxia and biodiversity loss, while Pb declined (~1.2 to ~0.8 mg/L) and Cd remained relatively stable (~0.2 mg/L), indicating persistent heavy-metal inputs and potential long-term ecological and public-health risks through toxicity, bioaccumulation and trophic transfer (Ahmad et al., 2021; Kumar et al., 2022; Le Moal et al., 2020; Wurtsbaugh et al., 2019; Ali et al., 2019; Briffa et al., 2020).

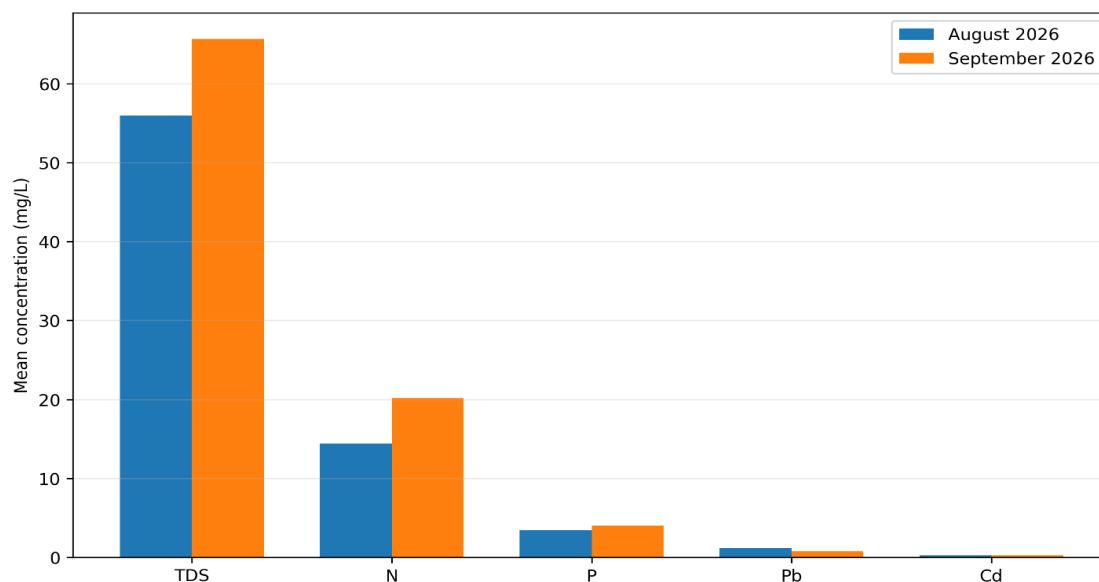


FIGURE 3: Mean Concentrations of Selected Parameters by Sampling Month.

DISCUSSIONS OF MAJOR FINDINGS

Generally, the results demonstrate marked spatial and temporal variability in Watari Basin surface-water quality, with TDS remaining well below the NSDWQ benchmark and nitrate generally within the stated limit, while phosphate showed a marginal exceedance at Gudumin Dutse in September; notably, TDS, nitrate and phosphate increased by 17.3%, 40.3% and 17.6%, respectively, from August to September, whereas Pb decreased by 31.8% and Cd remained unchanged, although none of these month-to-month differences was statistically significant ($p > 0.05$), while Pb and Cd consistently exceeded their respective benchmarks at all six sampling locations in both months, with mean Pb concentrations 7.90–11.58 times and Cd 72.22 times the stated limits, thereby identifying persistent heavy-metal contamination as the dominant water-quality concern, with spatially elevated concentrations at locations such as Rafin Tsamiya (1), Rafin Tsamiya

(2), Watari Dam and Gudumin Dutse suggesting possible localized influences of agricultural runoff, domestic wastewater, sediment interactions and other catchment activities, with potential implications for eutrophication, aquatic toxicity, sediment contamination, bioaccumulation, trophic transfer and human exposure, and consequently highlighting the need for sustained wet- and dry-season monitoring, pollution-source identification and control, riparian protection, sediment and aquatic-biota assessment, laboratory quality assurance, and integrated environmental and health-risk management of the Watari Basin.

CONCLUSION AND RECOMMENDATIONS

Finally, the study concludes that although the Watari Basin surface waters have relatively low dissolved-mineral loading, as reflected by TDS levels within the stated safety threshold, the widespread and persistent exceedance of Pb and Cd across all monitoring locations,

together with increasing nutrient concentrations and associated eutrophication risks, indicates significant ecological and potential public-health concerns, with the absence of statistically significant seasonal differences suggesting that the contamination is persistent rather than merely seasonal; therefore, urgent integrated catchment-management measures, including regulation of agricultural and domestic discharges, control of agrochemical runoff, restoration of riparian buffers, continuous water-quality and biomonitoring, source identification, and ecological and human-health risk assessment, are required to reduce heavy-metal accumulation and trophic transfer, control nutrient enrichment, and protect the long-term environmental integrity of the Watari Basin.

The following recommendations are made based on the findings:

- 1) There is an urgent need to identify and address the sources of lead and cadmium contamination within the basin, and other heavy metals like chromium, arsenic and mercury should be examined to ascertain their limits to prevent further heavy metal contamination.
- 2) The best agricultural management practices should be introduced to reduce water contamination since the basin is agrarian, and small-scale illegal mining should be banned in the study area.

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