Long-term Water Quality Trends (1994–2024) in the Tamsui River: Application of the Mann-Kendall Test and Sen's slope Estimator

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Abstract

Long-term water quality monitoring and trend analysis are crucial for effective river basin management. This study employed the Mann-Kendall test and Sen's slope estimator to analyze long-term trends in water quality in the Tamsui River Basin, northern Taiwan, from 1994 to 2024. The River Pollution Index (RPI) and four key water quality parameters—dissolved oxygen (DO), five-day biochemical oxygen demand (BOD_5), suspended solids (SS), and ammonia nitrogen (NH_3-N)—were used to assess water quality conditions. The results indicate a significant improvement in overall water quality within the Tamsui River basin. The proportion of monitoring stations classified as "unpolluted/slightly polluted" and "mildly polluted" has increased significantly, while the proportion of stations categorized as "moderately polluted" and "severely polluted" has declined. In terms of specific parameters, DO concentrations have increased, whereas BOD_5, SS, and NH_3-N concentrations have decreased. However, despite these improvements, monitoring stations located in highly urbanized and densely populated areas remain at moderate pollution levels, as indicated by the River Pollution Index. Therefore, implementing more effective water quality management strategies in urban regions is recommended to sustain and further enhance water quality conditions in the Tamsui River basin.

Keywords: Trend analysis, Mann-Kendall test, Sen's slope estimator, River Pollution Index, the Tamsui River

Introduction

The Tamsui River basin is located approximately between 24°40' to 25°15' N and 121°10' to 122°00' E, covering the northern region of Taiwan. Its primary tributaries include the Xindian River, Tamsui River, and Keelung River, flowing through urban areas such as Taipei City, New Taipei City, and Taoyuan City (Chen et al., 2019). Due to the basin's passage through densely developed urban zones, the river water quality has been long affected by industrial wastewater, domestic sewage, and agricultural pollution (e.g., Huang, 2021; Jang, 2016), leading to the accumulation of pollutants and subsequent impacts on water quality and ecosystems.

To improve the water quality of the Tamsui River basin, the government in Taiwan implemented the River Restoration Plan, which involves constructing wastewater treatment plants (e.g., Taipei City Neihu Wastewater Treatment Plants) and executing sewage interception projects to reduce pollutant discharge into the river (He-Tuo Planning and Design Consulting Co., Ltd., 2012). Despite years of remediation efforts, whether the water quality of the Tamsui River has significantly improved remains to be further examined. Consequently, water quality monitoring has become a critical basis for evaluating the effectiveness of river restoration measures. The core objective of river water quality monitoring is to understand the current pollution status and long-term trends, providing a scientific foundation for water quality management and pollution prevention strategies. This ensures the continuous improvement of the Tamsui River's water quality and promotes the sustainable development of the aquatic environment.

Literature Review

River Pollution Index: a quantitative assessment of water quality status

Water Quality Index serves as a comprehensive indicator that integrates multiple water parameters along with their respective weights to provide a quantitative assessment of water quality status (Chidiac et al., 2023; Miah et al., 2025). In Taiwan, the Ministry of Environment (MOE) widely employs the River Pollution Index (RPI) to evaluate the degree of river pollution. The calculation of RPI is based on the concentrations of four key water quality parameters: dissolved oxygen (DO), biochemical oxygen demand over five days (BOD_5), suspended solids (SS), and ammonia nitrogen (NH_3-N) (Ministry of Environment, Taiwan, 2025).

SS refers to suspended solids in water. Higher SS values indicate a greater concentration of undissolved solid particles in the water, which reduces the light penetration rate of the water body. This, in turn, affects the photosynthesis of aquatic plants and the transparency of the water. BOD_5 is used to measure the concentration of organic pollutants in the water. An increase in BOD_5 values signifies that micro-organisms require more oxygen to break down organic matter. This may lead to a decrease in dissolved oxygen levels in the water, further impacting the living environment of aquatic organisms. NH_3-N primarily originates from the fermentation and decomposition of nitrogen-containing organic matter. When its concentration rises, it often indicates organic pollution in the water, which can cause toxicity in aquatic organisms, eutrophication of the water body, and deterioration of water quality. DO reflects the amount of oxygen present in the water. Adequate dissolved oxygen helps reduce odors produced by the decomposition of NH_3-N and other organic matter (World Health Organization, 2003). Therefore, higher DO concentrations, accompanied by lower BOD_5, SS, and NH_3-N values, generally indicate purer water quality, suitable for the survival of aquatic organisms and human recreational activities. Since RPI is calculated based on indicators such as DO, BOD_5, SS, and NH_3-N, trend analysis can reveal long-term patterns of RPI changes, further assessing improvements or deteriorations in river pollution levels (Jang, 2016).

The formula for RPI is expressed as: RPI = $1/4 \sum S_i$, where Si represents the pollution score for each parameter, *i* refers to the water quality parameter, and RPI ranges between 1 and 10. For instance, at the monitoring station near the Tamsui River estuary in December 2003, the observed data were as follows: DO at 3 mg/L, BOD_5 at 2.2 mg/L, SS at 13.6 mg/L, and NH_3-N at 1.54 mg/L. As shown in Table 1, the corresponding pollution scores for these parameters were 6, 1, 1, and 6, respectively. Averaging these scores yields an RPI value of 3.5, which falls within the range of 3.1–6.0, indicating moderately polluted (Ministry of Environment, Taiwan, 2025).

Table 1. The criteria of River Pollution Index (Adapted from Ministry of Environment, Taiwan, 2025)

Water Quality / Parameter	Unpolluted /Slightly Polluted	Mildly Polluted	Moderately Polluted	Severely Polluted
DO (mg/L)	$DO \geq 6.5$	$6.5 > DO \geq 4.6$	$4.5 \geq DO \geq 2.0$	$DO < 2.0$
BOD_5 (mg/L)	$BOD_5 \leq 3.0$	$3.0 < BOD_5 \leq 4.9$	$5.0 \leq BOD_5 \leq 15.0$	$BOD_5 > 15$
SS (mg/L)	$SS \leq 20$	$20 < SS \leq 49.9$	$50 \leq SS \leq 100$	$SS > 100$
NH_3-N (mg/L)	$NH_3\text{-}N \leq 0.50$	$0.50 < NH_3\text{-}N \leq 0.99$	$1.0 \leq NH_3\text{-}N \leq 3.0$	$NH_3\text{-}N > 3.0$
Score(s)	1	3	6	10
Pollution Index Score (S)	$S \leq 2.0$	$2.0 < S \leq 3.0$	$3.1 \leq S \leq 6.0$	$S > 6.0$

Note: DO = Dissolved Oxygen; BOD_5 = Biochemical Oxygen Demand;
SS = Suspended Solids; NH_3-N = Ammoniacal Nitrogen

Trend Analysis of Water Quality

Trend analysis is a method used to explore changes in data over a specific time range (Antonopoulos et al., 2001). Water quality trend analysis enables the examination of long-term data to observe changes in specific water quality parameters within a defined timeframe, determining whether the values of water quality parameters show an upward or downward trend during the monitoring period. This can help predict future water quality conditions (Hashim et al., 2021; Tabari et al., 2011) and provide references for water resource management and decision-making (Modi et al., 2024).

To effectively evaluate long-term trends in water quality changes, researchers widely employ statistical methods to identify the significance and direction of changes. Among these methods, the Mann-Kendall test and Sen's slope estimator have become primary tools for trend analysis due to their applicability to non-normally distributed data. The Mann-Kendall test detects the significance of data trends, while Sen's slope estimator quantifies the magnitude of changes. Together, they provide a more precise evaluation of water quality changes (Hashim et al., 2021; Modi et al., 2024; Tabari et al., 2011).

Mann-Kendall test and Sen's slope estimator for time-series data

The Mann-Kendall test, a non-parametric method, was employed to detect monotonic trends (either increasing or decreasing) in the time-series data. To further quantify the rate of change in trends, Sen's Slope method was applied. This method estimates the median slope of change in time-series data and is less sensitive to the influence of outliers.

Many studies have applied the Mann-Kendall test and Sen's slope estimator to analyze long-term water quality changes in various regions (Hashim et al., 2021; Modi et al., 2024; Tabari et al., 2011). Modi et al. (2024) analyzed changes in water quality across seven monitoring stations along the Godavari River in India over the period from 1981 to 2005. Their study examined parameters including total alkalinity (Alk), calcium (Ca^{2+}), chloride (Cl^-), total hardness (Hard), magnesium (Mg^{2+}), sodium (Na^+), and sulfate (SO_4^{2-}) ions. Using the Mann-Kendall test and Sen's slope estimator, the results showed that Alk, Ca^{2+}, and Hard exhibited upward trends, Cl^-, Na^+, and SO_4^{2-} showed downward trends, while Mg^{2+} displayed mixed changes. Tabari et al. (2011) investigated 16 water quality parameters at four monitoring stations within the Maroon River basin over the period from 1989 to 2008. Employing the Mann-Kendall test, Sen's slope estimator, and linear regression for trend analysis, their findings revealed that the concentrations of water quality parameters increased during spring and winter, while decreasing during summer and autumn, primarily due to river dilution effects. Parameters such as calcium, magnesium, sodium adsorption ratio, pH, and turbidity showed significant changes. Additionally, most water quality parameters were negatively correlated with river flow, demonstrating the significant impact of flow variations on water quality. Hashim et al. (2021) analyzed water quality changes in the upstream region of the Bernam River basin in Malaysia from 1998 to 2018, focusing on six water quality indicators: DO, BOD_5, COD, NH_3-N, TSS (total suspended solids), and pH. Using the Mann-Kendall test and Sen's slope estimator, the results showed that most monitoring stations exhibited a downward trend in water quality index (WQI), while DO, BOD_5, NH_3-N, and pH increased, and COD and TSS decreased, reflecting changes in water quality. Due to significant land-use changes upstream, this study serves as a reference for water pollution prevention and water resource management.

The purpose of this study

Although studies have employed the Mann-Kendall test and Sen's slope estimator to analyze water quality changes in different regions, most focus on specific water quality parameters, such as total alkalinity, hardness, or dissolved oxygen, with less attention given to comprehensive water quality evaluation indicators like the RPI. Particularly in Taiwan, existing studies lack a complete analysis of long-term water quality trends in the Tamsui River basin and a systematic evaluation of water quality changes over the past 30 years.

This study aims to fill the research gap by using trend analysis to evaluate long-term water quality changes in the Tamsui River basin from 1994 to 2024, focusing on the River Pollution Index (RPI) and related water quality parameters. By applying the Mann-Kendall test and Sen's slope estimator, this study will analyze the changes in the number of monitoring stations with varying pollution levels over different years, assess the trends in RPI and water quality parameters, test their statistical significance, and quantify the rate of change. The goal is to deeply explore the trends and corresponding influencing factors of water quality changes in the Tamsui River, providing a more comprehensive reference for sustainable water resource management.

Methods

This study utilized 31 years of monitoring data (1994–2024) for the Tamsui River basin, sourced from Taiwan's National Environmental Water Quality Monitoring Information Network. The dataset included the RPI and its constituent parameters: DO, BOD_5, SS, and NH_3–N. The analysis proceeded in two main stages: data processing, followed by trend analysis with statistical testing.

Data processing

The data collected from 1994 to 2024 for the Tamsui River basin were organized and processed using Microsoft Excel. Monitoring stations were categorized into different pollution levels based on the criteria of RPI, DO, BOD_5, SS, and NH_3-N values (See Table 1).

Trend analysis and statistical testing

Mann-Kendall test The Mann-Kendall test was conducted using the R programming language to evaluate the statistical significance of trends in RPI and water quality parameters over the period from 1994 to 2024.

Sen's slope estimation Sen's slope estimation method was applied in R to quantify the rate of change during the same period, providing a detailed assessment of the extent of water quality variation in the Tamsui River basin.

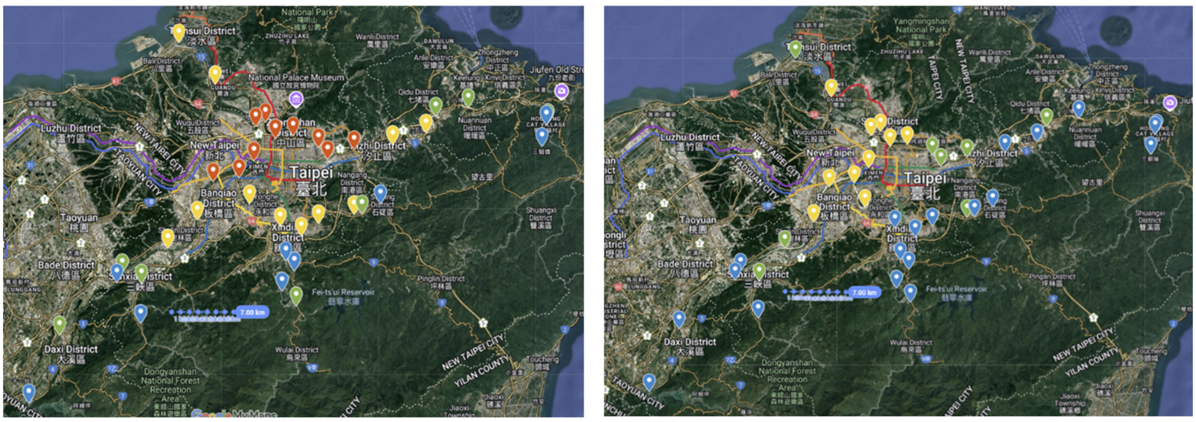
Code refinement The R script was developed through an iterative process guided by our literature review and research questions. We began by generating baseline code for the Mann-Kendall test and Sen's slope with ChatGPT. This script then underwent a cycle of refinement, where it was tested in R and subsequently improved with assistance from ChatGPT to optimize its performance for analyzing the RPI and its constituent parameters.

Results

Analysis of RPI variations across different years in the Tamsui River basin

Visualizing the differences between monitoring stations in 1994 and 2024 As shown in Figure 1, the different levels of RPI are represented by blue, green, yellow, and red, indicating not (or slightly) polluted, mildly polluted, moderately polluted, and severely polluted, respectively. The figure also illustrates the spatial distribution of RPI across monitoring stations for the years 1994 and 2024.

From the figure, notable improvements in water quality can be observed. In 1994, 27% of the monitoring stations (10 out of 37) were marked in red, indicating severely polluted. By 2024, this proportion decreased to 0% (0 out of 37 stations), with most of these stations transitioning to yellow, indicating moderately polluted (22%, 8 out of 37 stations), or green, indicating mildly polluted (5%, 2 out of 37 stations). Additionally, the proportion of stations marked in blue, indicating not (or slightly) polluted, increased significantly from 24% (9 out of 37 stations) in 1994 to 54% (20 out of 37 stations) in 2024. These results highlight some improvements in the water quality of the Tamsui River basin over the past 30 years, as evidenced by the decreasing proportion of stations classified as severely polluted and the increasing proportion of stations classified as not (or slightly) polluted.



Note: Blue represents RPI values of 1–2, indicating not (slightly) polluted; green represents RPI values of 2–3, indicating mildly polluted; yellow represents RPI values of 3–6, indicating moderately polluted; red represents RPI values above 6, indicating severely polluted

Figure 1. RPI of monitoring stations in 1994 (left) and in 2024 (right)

Statistical differences between monitoring stations in 1994 and 2024 The results of the Mann-Kendall trend test and Sen's slope estimates for different levels of RPI are presented in Figure 2 and Table 2. The Mann-Kendall test statistics reveal significant trends across all pollution levels.

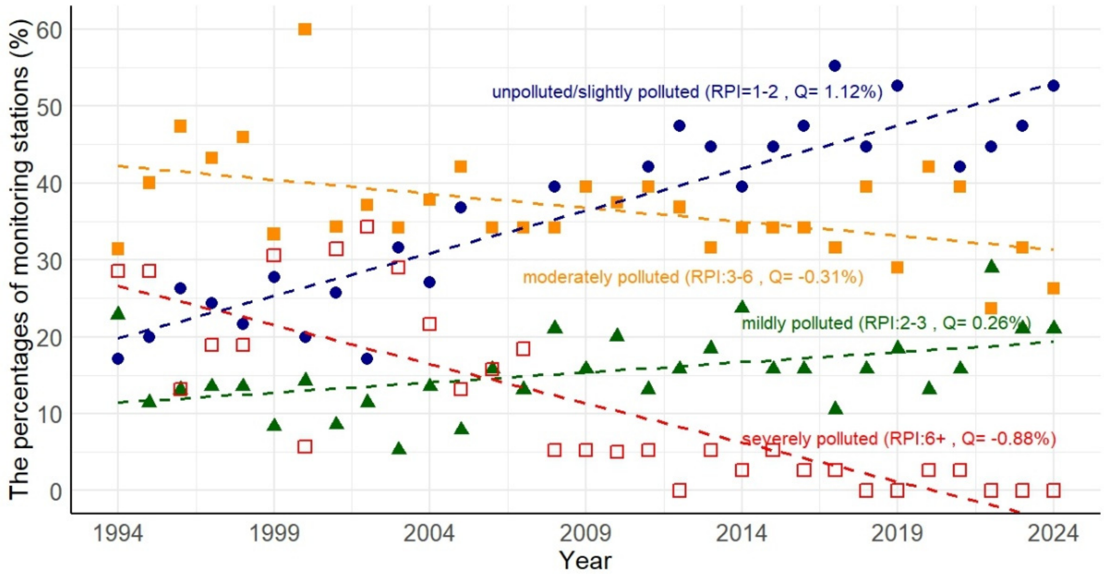


Figure 2. Trends in the percentage of monitoring stations at different pollution levels in the Tamsui River (1994–2024), analyzed using the Mann-Kendall test and Sen's slope estimator.

For unpolluted/slightly polluted, the test revealed a strong increasing trend (τ = 0.75, S = 342, Z = 5.82, p < .001) with a Sen's slope of 1.12% per year (95% CI [0.89, 1.32] %). Similarly, for mildly polluted, a significant positive trend was observed (τ = 0.36, S = 160, Z = 2.73, p = .006) with a Sen's slope of 0.26% per year (95% CI [0.08, 0.46] %).

In contrast, a significant decreasing trend was detected for moderately polluted (τ = -0.33, S = -148, Z = -2.52, p = .012). The Sen's slope estimate was -0.31% per year (95% CI [-0.58, -0.01] %), indicating a decline in moderately polluted levels over time. For severely polluted, the strongest negative trend was observed (τ = -0.71, S = -317, Z = -5.42, p < .001) with a Sen's slope of -0.88% per year (95% CI [-1.23, -0.53] %), suggesting a significant reduction in severely polluted levels.

Overall, the findings indicate a positive improvement in water quality, characterized by decreasing trends in moderately polluted and severely polluted levels, alongside increasing trends in unpolluted/slightly polluted and mildly polluted levels.

Table 2. Statistical results for different levels of RPI obtained through the Mann-Kendall test and Sen's slope estimator

Pollution Level	τ	S	Z	*p*	Slope (%)	95% CI Lower (%)	95% CI Upper (%)	Trend
Unpolluted /Slightly Polluted	0.751	342	5.82	0.000	+1.119	0.887	1.318	significant increase
Mildly Polluted	0.358	160	2.73	0.006	+0.260	0.075	0.456	significant increase
Moderately Polluted	-0.329	-148	-2.52	0.012	-0.314	-0.583	-0.005	significant decrease
Severely Polluted	-0.711	-317	-5.42	0.000	-0.877	-1.228	-0.527	significant decrease

The changes in RPI parameters over different years in the Tamsui River basin

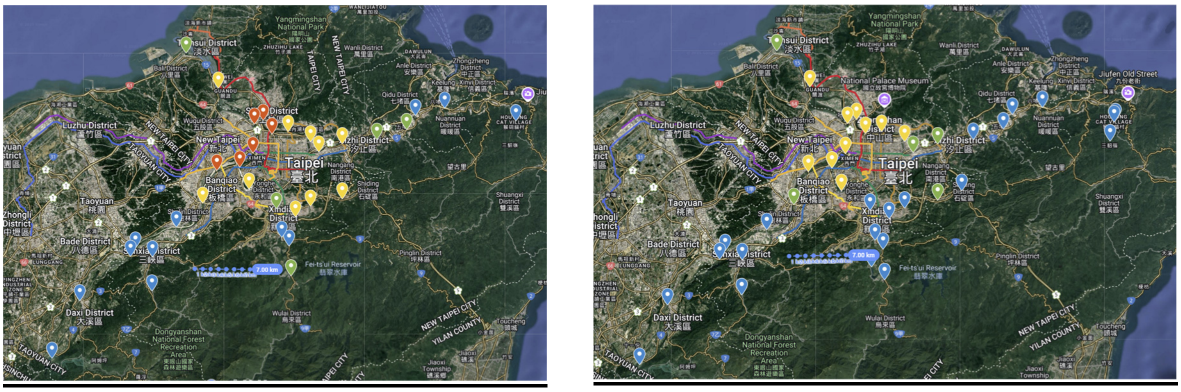
Visualizing the differences between monitoring stations in 1994 and 2024 As illustrated in Figures 3, in 1994, DO levels were generally low, particularly in urbanized areas, with approximately 30% of monitoring stations (11 out of 37) showing severely polluted oxygen conditions (DO < 2 mg/L). By 2024, the proportion of stations with severely polluted DO levels decreased dramatically to 0% (0 out of 37 stations), and most monitoring stations achieved good DO levels (DO ≥ 6.5 mg/L), accounting for 60% of total stations (22 out of 37).

The changes in BOD_5 are illustrated in Figures 4. In 1994, about 5% of monitoring stations (2 out of 37) recorded BOD_5 values exceeding 15 mg/L, and about 59% of monitoring stations (22 out of 37) achieved BOD_5 values within 5 to 15 mg/L, indicating organic pollution at the time. After 30 years of pollution control, the 2024 data shows that the proportion of high BOD_5 stations (> 5 mg/L) decreased to 3% (1 out of 37 stations), while the proportion of stations with acceptable BOD_5 levels (< 5 mg/L) increased from 35% (13 out of 37 stations) in 1994 to 97% (36 out of 37 stations) in 2024.

The distribution of SS is presented in Figure 5. In 1994, approximately 32% of the monitoring stations (12 out of 37) recorded SS levels exceeding 50 mg/L, with the majority of these stations concentrated in downstream river areas. By 2024, the proportion of stations with SS levels exceeding 50 mg/L had decreased to 0% (0 out of 37 stations). Furthermore, most monitoring stations in 2024 reported SS levels below 20 mg/L, accounting for 70% of the total stations (26 out of 37).

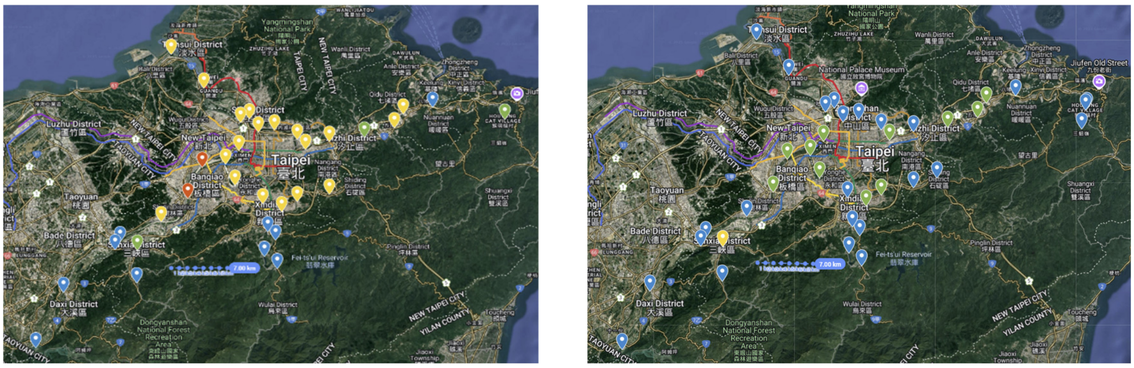
The changes in NH_3-N are shown in Figures 6. In 1994, nearly 46% of monitoring stations (17/37 stations) recorded NH_3-N exceeding 3 mg/L, reflecting insufficient domestic wastewater treatment at the time. After 30 years of sewerage system development, the 2024 data shows that the proportion of high ammonia nitrogen stations (>3 mg/L) decreased to 0% (0 out of 37 stations), while the proportion of stations with good NH_3-N levels (< 1 mg/L) increased from 32% (12 out of 37 stations) in 1994 to 73% (27 out of 37 stations) in 2024.

These results demonstrate some improvements in water quality across the Tamsui River basin over the past 3 decades, particularly in terms of increased dissolved oxygen levels and reduced organic pollutants.



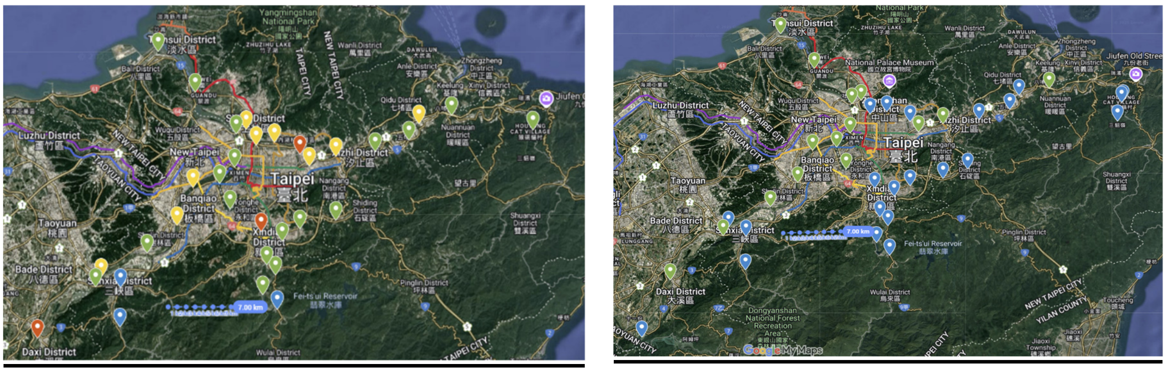
Note: Blue represents DO values above 6.5 ppm, indicating not (slightly) polluted; green represents DO values of 4.6–6.5 ppm, indicating mildly polluted; yellow represents DO values of 2–4.5 ppm, indicating moderately polluted; red represents DO values below 2 ppm, indicating severely polluted

Figure 3: DO of monitoring stations in 1994 (left) and in 2024 (right)



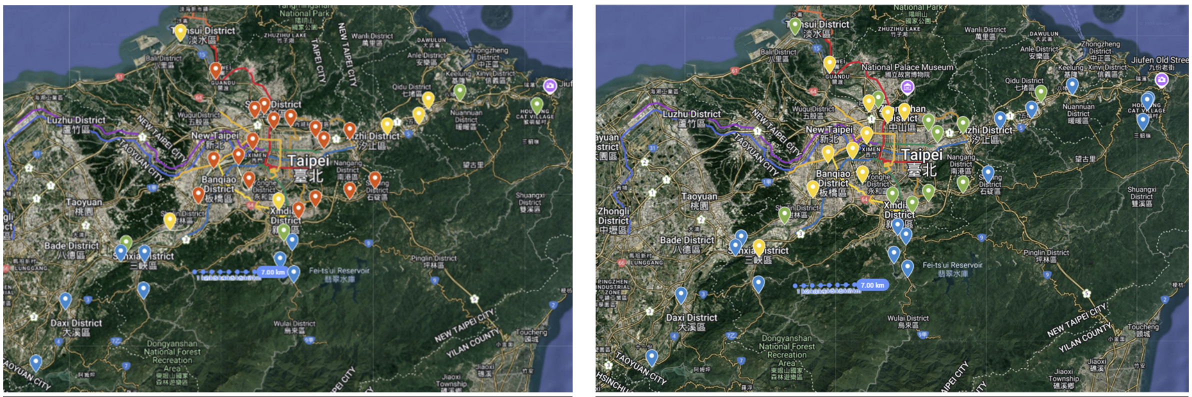
Note: Blue represents BOD_5 values below 3 ppm, indicating not (slightly) polluted; green represents BOD_5 values of 3–4.9 ppm, indicating mildly polluted; yellow represents BOD_5 values of 5–15 ppm, indicating moderately polluted; red represents BOD_5 values above 15 ppm, indicating severely polluted

Figure 4: BOD_5 of monitoring stations in 1994 (left) and in 2024 (right)



Note: Blue represents SS values below 20 ppm, indicating not (slightly) polluted; green represents SS values of 20–49.9 ppm, indicating mildly polluted; yellow represents SS values of 50–100 ppm, indicating moderately polluted; red represents SS values above 100 ppm, indicating severely polluted

Figure 5: SS of monitoring stations in 1994 (left) and in 2024 (right)



Note: Blue represents NH_3-N values below 0.5 ppm, indicating not (slightly) polluted; green represents NH_3-N values of 0.5–0.99 ppm, indicating mildly polluted; yellow represents NH_3-N values of 1.0–3.0 ppm, indicating moderately polluted; red represents NH_3-N values above 3.0 ppm, indicating severely polluted

Figure 6. NH_3-N of monitoring stations in 1994 (left) and in 2024 (right)

Statistical differences in corresponding parameters from 1994 to 2024 The trend in DO levels over the period from 1994 to 2024 was analyzed using the Mann-Kendall test and Sen's slope estimator. As illustrated in Figure 7 and Table 3, the Kendall's tau (τ) for the DO levels was 0.485, indicating a moderate positive trend over the 31-year period. The S statistic was 225, with a corresponding Z value of 3.81. The *p*-value for the Mann-Kendall test was highly significant ($p < 0.001$), confirming that the observed trend is statistically significant.

Sen's slope for the dissolved oxygen levels was calculated to be 0.071, indicating an average increase in oxygen levels of 0.071 mL per year. The 95% confidence interval for the Sen's slope ranged from 0.043 to 0.096, further supporting the robustness of the positive trend observed. These results suggest a significant upward trend in the DO levels over the study period. The analysis confirms that DO levels in the study area have significantly increased over the past three decades.

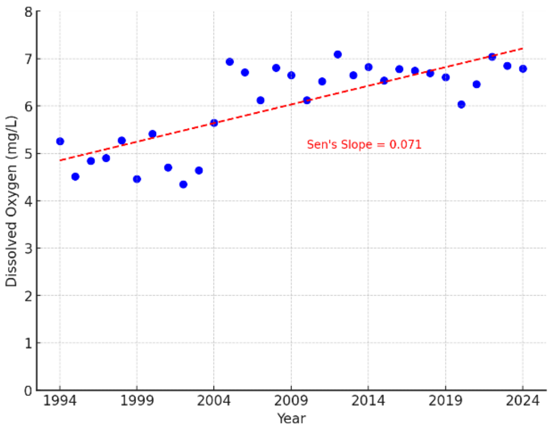


Figure 7. The trend of annual mean DO from 1994 to 2024.

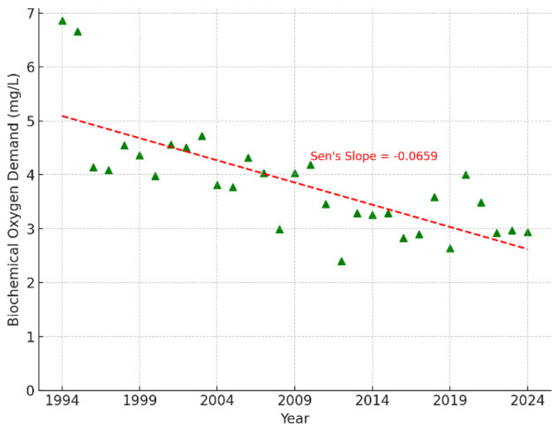


Figure 8. The trend of annual average BOD_5 from 1994 to 2024.

As shown in Figure 8 and Table 3, according to the results of the Mann-Kendall test, BOD_5 exhibited a significant negative trend (τ = -0.584, $p < 0.001$), indicating a notable decline in BOD_5 over time. The results of the Sen's slope method showed a slope of -0.066 for BOD_5, with a 95% confidence interval of [-0.096, -0.044], suggesting an average annual decrease in BOD_5 of -0.066. This change was statistically significant ($p < 0.001$), further confirming the declining trend in BOD_5 values during the study period.

The trend analysis of BOD_5 indicates a significant decline, which is statistically significant. This negative correlation with pollution levels likely reflects an improvement in water quality.

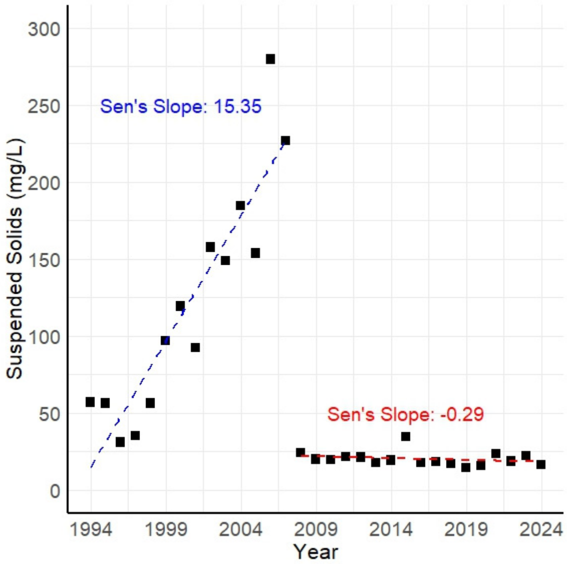


Figure 9. The trend of annual mean SS from 1994 to 2024.

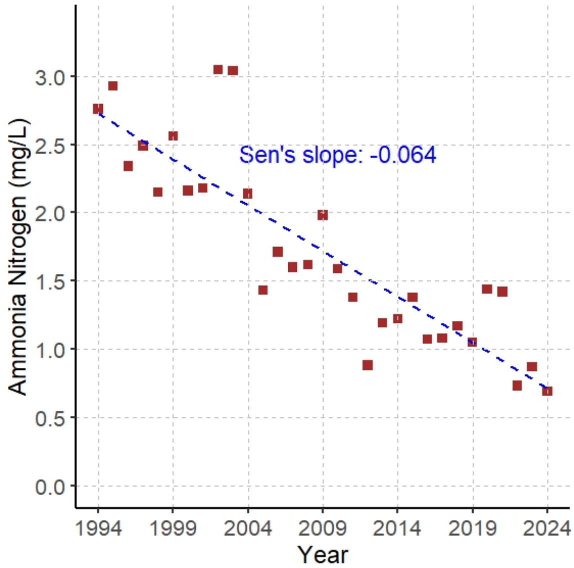


Figure 10. The trend of annual mean NH_3-Nfrom 1994 to 2024

The trend analysis of SS is divided into two periods: 1994-2007 and 2008-2024. As shown in Figure 9 and Table 3, the first segment (1994-2007) shows an increasing trend with a Sen's slope estimate of 15.35 mg/L per year. In contrast, the second segment (2008-2024) presents a decreasing trend with a Sen's slope estimate of -0.29 mg/L per year. These trends are depicted with separate dashed regression lines, each colored differently to distinguish the two periods. The statistical significance of the trends was evaluated using Kendall's Tau, with the earlier period displaying a statistically significant upward trend, while the later period indicates a weaker downward trend.

This analysis provides insight into the temporal variations in SS concentration, potentially reflecting changes in environmental conditions, land use, or pollution control measures over the decades.

As shown in Figure 10 and Table 3, The analysis revealed a significant negative trend in NH_3-N concentrations, with a Kendall's tau (τ) of -0.715, indicating a moderate inverse relationship between the years and NH_3-N levels ($Z = -5.63$, $p < 0.001$). The Sen's slope estimate for the trend was -0.064, suggesting a consistent decrease in NH_3-N concentrations over time. The 95% confidence interval for the Sen's slope ranged from -0.076 to -0.053, confirming the robustness of the observed downward trend. Given the *p*-value of 1.84e-08, the trend was statistically significant.

These results suggest a notable reduction in NH_3-N concentrations over the study period, and this trend was statistically significant, supporting the hypothesis of a decreasing environmental impact related to NH_3-N.

Table 3. Kendall's tau and Sen's slope for DO, BOD_5, SS, and NH_3-N

Water quality parameters	τ	*S*	*Z*	*p*	Slope	95% CI Lower	95% CI upper	trends
DO	0.485	225	3.81	0.000	0.071	0.043	0.096	significant increase
BOD_5	-0.584	-271	-4.59	0.000	-0.066	-0.096	-0.044	significant decrease
SS (1994-2007)	0.736	67	3.61	0.000	15.351	11.977	21.130	significant increase
SS (2008-2024)	-0.324	-44	-1.77	0.077	-0.290	-0.636	0.088	non-significant
NH_3-N	-0.715	-332	-5.63	0.000	-0.064	-0.076	-0.053	significant decrease

Discussion

Consistency with global practices in trend analysis

This study employed the Mann-Kendall test and Sen's slope estimator, two methods widely used for long-term water quality analysis, to investigate pollution trends in the Tamsui River. The results revealed significant trends in the RPI and in the concentrations of DO, BOD_5, SS, and NH_3-N. This methodological approach is consistent with recent research in the field. For example, Modi et al. (2024) used the same statistical tools to analyze various water quality parameters in the Godavari River, as did Hashim et al. (2021) for the Bernam River basin in Malaysia and Tabari et al. (2011) for the Maroon River in Iran. The preference for these non-parametric methods across different geographical regions and river systems highlights their robustness and suitability for environmental time-series data, which is often non-normally distributed and may contain outliers. This shared analytical framework provides a common basis for discussing and contextualizing water quality trends from diverse international river basins.

Holistic improvement in trends in contrast to specific parameter variations

A key finding of this study is the significant and consistent improvement across the comprehensive RPI and its constituent parameters in the Tamsui River over the past 31 years. The results show a significant increase in the proportion of unpolluted/slightly polluted and mildly polluted monitoring stations, coupled with a significant decrease in moderately polluted and severely polluted stations. This contrasts with findings from other studies where water quality trends were more varied. For instance, Modi et al. (2024) observed mixed trends in the Godavari River, with some parameters like alkalinity and hardness increasing while others like chloride and sodium decreased. Similarly, Hashim et al. (2021) found that while the overall water quality index in the Bernam River basin showed a downward trend at most stations, some individual parameters like DO, BOD_5, and pH actually increased.

Conclusion

An analysis of approximately three decades of monitoring data reveals a significant improvement in the overall water quality of the Tamsui River. This is evidenced by a substantial decrease in stations classified as moderately or severely polluted by the RPI, alongside a significant increase in those rated unpolluted/slightly or mildly polluted. In terms of specific parameters, DO concentrations have increased, whereas BOD_5, SS, and NH_3-N concentrations have decreased. However, despite these improvements, monitoring stations in highly urbanized and densely populated areas remain at moderate pollution levels, as indicated by the RPI. To sustain and further enhance water quality conditions in the Tamsui River basin, implementing more effective water quality management strategies in urban regions is recommended, such as establishing or expanding sewage treatment plants, adding small decentralized sewage treatment facilities in highly polluted areas of New Taipei City and Taipei City, formulating stricter discharge standards, and strengthening the regulation of pollution sources.

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