Microbial Water Quality in Urban Watersheds: Spatiotemporal Assessment, Urban Planning Implications, and Urban Management Strategies for Sustainable Water Management in Qingdao, China

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Abstract: This study investigated microbial pollution in Qingdao's urban surface waters. Results revealed clear seasonal peaks in summer and higher bacterial levels in non-flowing water bodies. Urban planning should prioritize enhancing water connectivity to prevent pollutant accumulation. Elevated coliforms in residential rivers indicated impacts from domestic sewage, underscoring the necessity for improved sewage infrastructure in urban management. The reservoir in agricultural areas showed pollution spikes after rainfall, highlighting the need for integrated planning that coordinates land use with water quality protection. These findings emphasize that effective urban water management must incorporate targeted pollution control and regular microbial monitoring.

Keywords: Surface Water; Bacterial Level; Water Quality Protection; Microbial Monitoring

1. Introduction

Qingdao, situated on the southern Shandong Peninsula adjacent to the Yellow Sea, is a major central city and port hub on China's eastern coast. Its jurisdiction encompasses numerous water systems, many of which are characterized by short sources, rapid flows, and seasonal variations, making water resources susceptible to fluctuations influenced by precipitation and possessing relatively weak self-purification capacities [1]. Urban surface water bodies are not only vital components of the city's ecosystem, serving functions such as flood control, drainage, and landscape aesthetics, but their quality also directly impacts the residential environment, regional ecological health, and even the coastal marine environment[2,3]. With accelerating urbanization and intensified economic activities, industrial wastewater, domestic sewage, agricultural non-point source pollution, and urban runoff exert significant pressure on urban rivers, lakes, and reservoirs[4,5]. Particularly during the summer season with high temperatures and humidity, the risk of water eutrophication increases, facilitating microbial proliferation, which can lead to water quality deterioration, potentially trigger "bloom" phenomena, and impair water body functions and aesthetic value[6]. Consequently, continuous monitoring and evaluation of the microbial pollution status in urban water bodies are crucial for understanding pollution dynamics, assessing environmental risks, and guiding water environment management strategies. Furthermore, such research provides a direct scientific basis for urban planning decisions and urban management practices supporting the development of more livable and sustainable cities.

In recent years, researchers in China have extensively studied urban river water quality, encompassing various aspects such as physicochemical parameters, heavy metals, nutrients, and biological indicators[7]. Specific studies concerning the Qingdao region have focused on nearshore marine water quality, the status and countermeasures for drinking water source protection[8], and comprehensive water quality assessments of specific rivers or areas. However, long-term, systematic monitoring and comparative analysis focusing specifically on microbial indicators (particularly Total Bacterial Count and Total Coliforms) across diverse water types (rivers, channels, lakes/reservoirs) representing different functional zones (industrial, residential, agricultural) and hydrological conditions (flowing, non-flowing) within the Qingdao urban area remain limited.

Total Bacterial Count (TBC) and Total Coliforms are internationally recognized key sanitary indicators reflecting the degree of contamination by organic matter and fecal material in water bodies[9,10]. TBC can indicate the organic content and conditions suitable for microbial growth, whereas the presence of total coliforms (especially fecal coliforms or Escherichia coli) typically signifies potential contamination from human or animal feces, posing risks associated with potential pathogens[11]. Monitoring these indicators allows for a direct assessment of the water's sanitary condition and associated potential health risks[12].

This study selected six representative water bodies within the main urban district of Qingdao, encompassing industrial, residential, agricultural, and landscape areas, and including both flowing and non-flowing systems (Table 1). Continuous monitoring was conducted over an 18-month period from September 2023 to March 2025. By determining the TBC and total coliform counts in each water body, we analyzed their temporal and spatial variation patterns across different months, water body types, and different sections of the same river. The objectives were to: (1) reveal the overall status and seasonal dynamics of microbial pollution in major urban water bodies of Qingdao; (2) compare the microbial contamination characteristics under different functional zoning and hydrological conditions; (3) explore the primary factors influencing changes in microbial indicators; and (4) evaluate the effectiveness and challenges associated with existing water treatment or management measures in some locations. The findings aim to provide foundational data and scientific reference for developing more targeted water environment protection strategies, optimizing water resource management, and safeguarding urban ecological security and public health in Qingdao.

Table 1. Attributes of Each Sampling Water Body

No.	Sampling Water Body	Water Body Code	Attribute Area	Flow Condition
1	Xiangmaohe Jinhui Road Channel	XM-JH	Industrial Area	Non-flowing
2	Mohe River - Linxi Section	MS-LX	Residential Area	Flowing
3	Mohe River Huanxiu Section	MS	Residential Area	Flowing
4	Licun River	LC	Residential Area, Landscape Area	Flowing
5	Xiaoxi Lake	XX	Residential Area	Non-flowing
6	Wushan Reservoir	WS	Agricultural Area	Non-flowing

2. Methods

2.1 Main Reagents and Instruments

Culture media: Nutrient Agar, Lactose Peptone Broth, Endo Agar.

Experimental instruments: Biological microscope, Constant Temperature Electric Incubator, Clean Bench, Vertical Steam Pressure Sterilizer, etc.

2.2 Sample Collection

From September 2023 to March 2025, water samples were collected twice monthly from the six selected water bodies, with an interval of approximately 2 weeks between the two samplings. Three sampling points were established for each water body. At each point, water samples were collected from approximately 30 cm below the surface using a sterile sampler and then stored in 500 mL sterile water sample collection bags (Qingdao Haibo Biotechnology Co., Ltd., CYD005).

2.3 Detection Methods

2.3.1 Total Bacterial Count (TBC) Determination

The pour plate method was used, referencing the "Standard Examination Methods for Drinking Water - Microbiological Parameters". (1) Sample Dilution: Based on the estimated pollution level of the water sample, serial 10-fold dilutions were prepared using sterile water. Three consecutive appropriate dilutions were selected. (2) Inoculation and Incubation: 1 mL of the sample or each dilution was inoculated into sterile Petri dishes (two parallel plates per dilution). Approximately 15-20 mL of Nutrient Agar, cooled to about 45°C, was poured into each dish and mixed by swirling. After the agar solidified, the plates were inverted and incubated at 36 ± 1°C in a constant temperature incubator for 48 ± 2 h. (3) Counting: Plates with colony counts between 30 and 300 CFU were selected for counting. Results were reported as CFU/mL, calculated using the formula: Total Bacterial Count (CFU/mL) = (Average colony count per plate × Dilution factor) / Inoculation volume (1 mL). Blank controls were performed concurrently.

2.3.2 Total coliform group determination

The membrane filtration method was used, referencing the "Standard Examination Methods for Drinking Water - Microbiological Parameters". Briefly: (1) Filtration: Depending on the sample's pollution level, an appropriate volume of water was filtered through a sterile membrane filter with a pore size of 0.45 μm. (2) Incubation: Using sterile forceps, the membrane was placed onto the surface of Endo Agar, ensuring no air bubbles were trapped underneath. The plates were inverted and incubated at 36 ± 1°C for 24 ± 2 h. (3) Confirmation: Single colonies exhibiting typical characteristics were picked from the Endo Agar plate for Gram staining and microscopic observation. Concurrently, colonies were inoculated into Lactose Peptone Broth and incubated at 36 ± 1°C for 24 ± 2 h. Colonies confirmed as Gram-negative, non-spore-forming rods that fermented lactose to produce acid (yellowing of medium) and gas were identified as positive for coliforms. (4) Result Calculation: Based on the proportion of confirmed positive colonies among the typical colonies counted on the filter, the total coliform count per 100 mL of water sample was calculated. Formula: Total Coliforms (CFU/100 mL) = (Number of confirmed positive colonies / Total suspect colonies on filter) × (Total suspect colonies on filter × 100) / Volume of water sample filtered (mL).

2.4 Data Processing and Analysis

Microsoft Excel 2019 was used for data organization and chart creation. SPSS 26.0 was used for statistical analysis. Descriptive statistics (mean ± standard deviation) were calculated for TBC and total coliform data. For specific comparisons, non-parametric tests were used to compare differences between groups. The significance level was set at $p < 0.05$.

3. Results

3.1 Temporal and Spatial Variation of TBC in Different Water Bodies

The average TBC values for each water body detected are shown in Table 2.

Table 2. Comparison of Total Bacterial Counts in Different Water Bodies

Sampling Time	Season	Total Number of Bacteria in Different Waters（CFU/mL）							
		XM-JH	MS-LX	MS	LC	XX	WS	Max	Min
2023.09.09	Autumn	16633±2230	5883±2023	4350±1830	3933±1320	7583±2368	/	16633	3933
2023.09.21		31917±15215	11683±2205	1082±95	1357±1692	7000±477	2078±1014	31917	1082
2023.10.10		5533±2021	5033±752	8767±2371	6667±3184	792±55	7967±1305	8767	792
2023.10.23		6400±889	3267±144	5083±794	34653±42596	3683±465	5517±801	34653	3267
2023.11.07		83000±7810	9917±1156	3300±436	15458±22614	4017±1102	8367±4136	83000	3300
2023.11.21		4150±427	3783±513	49250±36338	1735±2020	2040±1972	4467±1118	49250	1735
2023.12.06	Winter	8600±568	5700±1268	3183±104	4307±3557	2933±202	508±115	8600	508
2023.12.18		/	5067±202	/	403±361	/	53317±37778	53317	403
2024.01.10		/	1960±145	/	482±426	/	8430±9697	8430	482
2024.01.24		/	/	/	120±125	/	5333±3617	5333	120
2025.02.05		/	/	/	/	/	/	/	/
2024.02.20		/	/	/	135±20	420±152	3533±465	3533	135
2024.03.05	Spring	35500±16628	3467±379	/	590±313	188±84	6133±4211	35500	188
2024.03.19		13300±3827	3067±431	/	277±15	350±20	5348±5083	13300	277
2024.04.08		10333±4250	4217±454	4100±867	2983±553	605±76	4617±846	10333	605
2024.04.24		9933±2036	3517±419	/	7733±1742	400±61	1197±1260	9933	400
2024.05.07		73500±31181	20350±24379	/	74667±118086	4683±275	1853±1822	74667	1853
2024.05.22		38500±5292	40050±58859	7017±2281	14667±9292	4500±770	13083±13784	40050	4500
2024.06.12	Summer	7533±275	77333±13823	155500±44657	60833±28919	33833±2021	/	155500	7533
2024.06.26		4517±775	/	667±95	99000±100041	6233±3263	9550±1132	99000	667
2024.07.10		239000±137903	169333±19553	60500±12816	122333±11730	199500±8529	19633±2677	239000	19633
2024.07.23		160167±24043	/	50833±13013	121833±34425	66333±17280	/	160167	50833
2024.08.07		5933±1497	9500±654	139667±7217	84000±42805	3833±575	4033±3167	139667	3833
2024.08.21		124333±12790	56000±3000	5317±293	53167±19277	7133±2864	/	124333	5317

2024.09.04	Autumn	7500±1276	74667±27122	3517±301	18750±3132	5000±1623	5983±1279	74667	3517
2024.09.25		4917±1795	11983±3155	6833±1475	57360±49280	18300±13391	29950±17018	57360	4917
2024.10.16		18033±1429	17883±1525	6717±1514	82550±75166	14783±17558	5167±558	82550	5167
2024.10.30		8967±2938	797±678	943±331	80±49	5350±557	1230±361	8967	80
2024.11.13		3717±29	/	7117±4505	11900±9820	1408±433	12433±13356	12433	1408
2024.11.27		8217±850	/	12117±4835	378±64	383±119	4500±1441	12117	378
2024.12.11	Winter	3883±231	/	/	448±130	593±135	585±103	3883	448
2024.12.25		1273±416	/	/	0±0	/	4950±917	4950	0
2025.01.08		/	/	/	398±48	/	1733±2050	1733	396
2025.01.21		/	/	/	/	/	8900±2982	8900	8900
2025.02.07		/	/	/	3983±404	/	/	3983	3983
2025.02.19		4583±293	/	/	48±20	363±42	1502±485	4583	48

Note: XM-JH represents Xiangmaohe Jinhui Road Channel, LC represents Licun River, MS represents Mohe River-Huanxiu Section, MS-LX represents Mohe River-Linxi Section, XX represents Xiaoxi Lake, WS represents Wushan Reservoir; "/" indicates that no sample was obtained due to weather or other objective reasons.

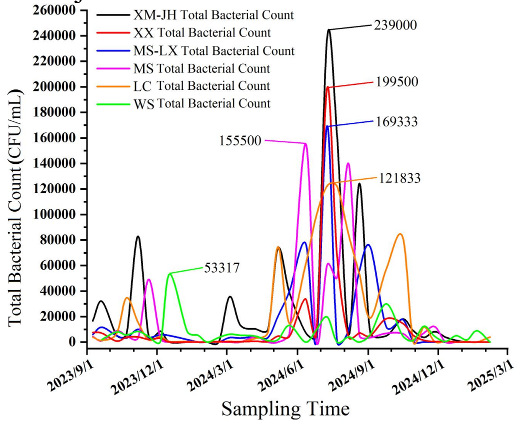

Figure 1. Comparison of Total Bacterial Counts in Different Water Bodies

(XM-JH represents Xiangmaohe Jinhui Road Channel, LC represents Licun River, MS represents Mohe River-Huanxiu Section, MS-LX represents Mohe River-Linxi Section, XX represents Xiaoxi Lake, WS represents Wushan Reservoir)

As shown in the table 2 and figure 1 above, TBC peaks occurred in July or August for five of the six selected water bodies. Among the non-flowing water bodies, two (XM-JH, XX) recorded the highest TBC values; XM-JH reached a maximum of 239,000 CFU/mL, and XX reached 199,500 CFU/mL. The peak TBC in WS reservoir was the lowest at 53,317 CFU/mL. The highest TBC peak in Wushan Reservoir occurred in December. The reason might be that the agricultural planting season was completed, and surrounding farmlands received additional fertilization during winter. A heavy rain event preceded sampling, potentially washing excessive organic and inorganic fertilizers from the farmland into the water body via runoff. Fertilizers in agricultural runoff can increase microbial numbers, and livestock/poultry farming wastewater could also introduce large quantities of microorganisms.

3.2 Temporal and Spatial Variation of Total Coliforms in Different Water Bodies

The average total coliform counts detected in water samples from each water body are shown in Table 3.

Table 3. Comparison of Total Coliform Counts in Water Samples from Different Water Bodies

Sampling Time	Season	Total Number of Coliform Group in Different Waters (CFU/100 mL)							
		XM-JH	MS-LX	MS	LC	XX	WS	Max	Min
2023.09.09	Autumn	1075±118	671±85	37±6	396±104	11993±8515	/	11993	37
2023.09.21		3693±3068	13545±2913	45±16	1143±1273	666±137	332±112	13545	45
2023.10.10		73±55	1966±1254	2561±337	818±584	21±4	195±131	2561	21
2023.10.23		4761±507	49±9	136±178	1495±2294	484±70	1309±2018	4761	49
2023.11.07		10833±171	5091±1373	2758±95	2806±4570	1080±290	533±801	10833	533
2023.11.21		14±25	1235±1706	352±430	0±0	61±72	145±12	1235	0
2023.12.06	Winter	341±145	920±306	837±501	216±188	281±220	64±24	920	64
2023.12.18		/	2027±296	/	133±209	/	56±62	2027	56
2024.01.10		/	198±84	/	0±1	/	0±0	198	0
2024.01.24		/	/	/	0±0	/	0±0	0	0
2024.02.05		/	/	/	/	/	/	/	/
2024.02.20		/	/	/	0±0	127±178	2±4	127	0
2024.03.05	Spring	2735±1667	129±114	/	1±2	0±0	1±1	2735	0
2024.03.19		455±404	0±0	/	2±3	1±2	1±1	455	0

2024.04.08		0±0	1053±943	1220±1164	1±1	284±251	114±126	1220	0
2024.04.24		12140±9648	2053±21	/	3295±1558	280±255	0±0	12140	0
2024.05.07		4670±2156	947±621	/	5852±6797	1371±1033	1822±1522	5852	947
2024.05.22		1807±1471	1640±1444	883±898	1570±1349	4022±696	0±0	4022	0
2024.06.12	Summer	913±834	21454±9167	0±0	5337±4013	36±36	/	21454	0
2024.06.26		223±16	/	328±34	342±245	467±186	255±44	467	223
2024.07.10		2621±636	8644±2021	4462±1068	6027±1876	8830±4018	11±19	8644	11
2024.07.23		15367±2773	/	8557±3425	22496±2369	5875±4904	/	22496	5875
2024.08.07		5402±434	366±118	9807±426	12167±4370	4064±580	2057±914	12167	366
2024.08.21		14364±3959	8212±4641	3019±779	20769±1620	605±483	/	20769	605
2024.09.04	Autumn	561±971	2288±1358	496±512	1848±2365	2292±1631	1330±1789	2292	496
2024.09.25		279±225	2652±1683	0±0	12±21	0±0	3523±2012	3523	0
2024.10.16		1705±782	977±489	129±223	3545±4848	5723±4312	860±399	5723	129
2024.10.30		0±0	1833±1959	179±65	0±0	3076±717	112±5	3076	0
2024.11.13		1527±2073	/	417±722	371±643	49±85	383±663	1527	49
2024.11.27		549±114	/	633±106	0±0	313±370	0±0	633	0
2024.12.11	Winter	162±118	/	/	0±0	31±54	53±46	162	0
2024.12.25		8±13	/	/	0±0	/	3±6	8	0
2025.01.08		/	/	/	0±0	/	1±1	1	0
2025.01.21		/	/	/	/	/	0±0	0	0
2025.02.07		/	/	/	381±66	/	/	381	381
2025.02.19		41±39	/	/	0±0	3±6	0±0	41	0

Note: XM-JH represents Xiangmaohe Jinhui Road Channel, LC represents Licun River, MS represents Mohe River-Huanxiu Section, MS-LX represents Mohe River-Linxi Section, XX represents Xiaoxi Lake, WS represents Wushan Reservoir; "/" indicates that no sample was obtained due to weather or other objective reasons

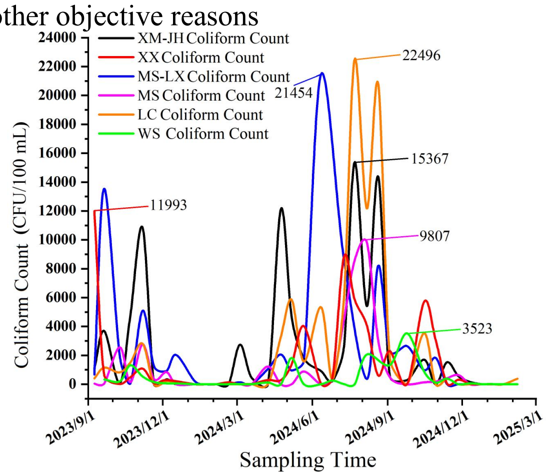

Figure 2. Total Coliform Counts in Water Samples from Different Water Bodies
(XM-JH represents Xiangmaohe Jinhui Road Channel, LC represents Licun River, MS represents Mohe River-Huanxiu Section, MS-LX represents Mohe River-Linxi Section, XX represents Xiaoxi Lake, WS represents Wushan Reservoir)

Total coliform counts also exhibited seasonal variations, with peak values primarily occurring in summer and autumn (July-September), and lower counts in winter and spring (Table 3, Figure 2). This might be related to temperature, rainfall, and variations in human activity intensity [13,14]. Among the water bodies flowing through residential areas, Mohe River-Linxi Section (MS-LX) and Licun River (LC) had relatively high coliform counts, with peak values of 21,454 CFU/100 mL and 22,496 CFU/100 mL, respectively. Wushan Reservoir (WS) had the lowest peak coliform count at 3,523 CFU/100 mL. Both TBC and total coliform counts were lowest in the reservoir samples, indicating better water quality compared to other sites.

In terms of urban planning, the high coliform levels in residential-area rivers (MS-LX, LC) call for optimized sewage infrastructure layout: new residential communities along these rivers should be required (in planning approval) to set up "sewage pre-treatment units".

Total coliform counts can directly or indirectly reflect the degree of fecal contamination in a water body. As seen in Table 3 and Figure 2, coliforms were detected in all six water bodies. Mohe River-Linxi Section (MS-LX) and Licun River (LC) showed relatively higher total coliform levels, while Wushan Reservoir (WS) had the lowest. Both MS-LX and LC flow through residential areas, suggesting that domestic sewage discharge is a likely cause of the higher coliform counts. Daily human activities directly impact the water quality in these areas. The high detection rate of total coliforms, as fecal indicator bacteria, in multiple water bodies (especially those traversing residential zones) suggests potential sanitary risks and necessitates attention to the effectiveness of domestic sewage collection and treatment systems, as well as potential issues like pipe network leakage or overflow[15].

3.3 Relationship between TBC and Total Coliform Counts within the Same Water Body

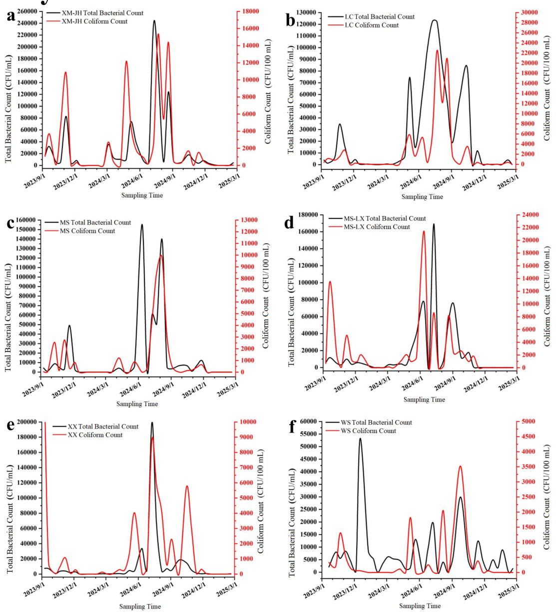

Figure 3. Changes in Total Bacterial Count and Total Coliforms in Six Water Bodies within Qingdao Urban Area

(a. XM-JH represents Jinhui Road Channel, b. LC represents Licun River, c. MS represents Mohe River-Huanxiu Section, d. MS-LX represents Mohe River-Linxi Section, e. XX represents Xiaoxi Lake, f. WS represents Wushan Reservoir)

Comparing the temporal changes in TBC and total coliform counts for each water body (Figure 3) reveals a degree of synchronicity in their seasonal fluctuations; typically, both are higher in summer/autumn and lower in winter/spring. However, not all TBC peaks were accompanied by proportionally equivalent increases in total coliform counts. For instance, significant increases in TBC during certain periods might be driven primarily by non-fecal bacteria adapted to the environmental organic matter, not necessarily indicating increased fecal pollution. Conversely, peaks in total coliforms (such as the summer peaks in MS-LX and LC) point more directly to fecal contamination events. This indicates that the two indicators reflect overlapping yet distinct aspects of pollution, and their combined analysis provides a more comprehensive assessment of water quality status [10].

3.4 Microbial Comparison of Non-flowing Water Bodies in Different Attribute Areas

Xiangmaohe Jinhui Road Channel (XM-JH), Xiaoxi Lake (XX), and Wushan Reservoir (WS) are all non-flowing water bodies located in industrial, residential, and agricultural areas, respectively. The detection results for TBC and total coliforms in these three water bodies are shown in Figure 4.

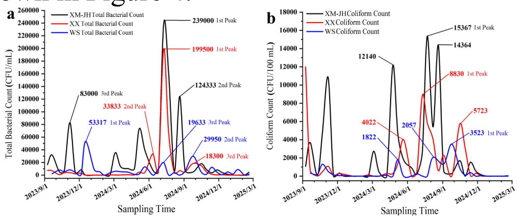

Figure 4. Comparison of Total Bacterial Count and Total Coliform Counts in Non-flowing Water Bodies from Industrial (XM-JH), Residential (XX), and Agricultural (WS) Areas

(a. Total Bacterial Count, b. Total Coliform Count)

Regarding TBC, the industrial area channel (XM-JH) had the highest peak value, followed by the residential area lake (XX), while the agricultural area reservoir (WS) had the lowest TBC. Mann-Whitney U tests showed that TBC in XM-JH was significantly higher than in XX ($p<0.05$) and WS ($p<0.05$); there was no significant difference between XX and WS ($p>0.05$). This suggests that the non-flowing water body in the industrial area may experience the most severe organic pollution, supporting the highest bacterial biomass.

Regarding total coliform counts, the industrial area channel (XM-JH) had the highest peak coliform count, followed by the residential area lake (XX), with the agricultural reservoir (WS) being the lowest. U-tests showed no significant difference between XM-JH and XX ($p>0.05$); XM-JH was significantly higher than WS ($p<0.05$), and XX was also significantly higher than WS ($p<0.05$). This indicates that non-flowing water bodies in both industrial and residential areas are subject to considerable fecal contamination, while the agricultural reservoir is relatively better in this regard.

Overall, for non-flowing water bodies, industrial activities appear to have the greatest impact on increasing total bacterial counts, while human activities (in residential areas and potentially around industrial sites) contribute significantly to fecal pollution indicators (total coliforms). The agricultural reservoir exhibits better overall water quality but requires vigilance against pulse pollution events related to agricultural practices.

3.5 Microbial Comparison of Upstream and Downstream Sections of the Same River

A comparison was made between the monitoring results from the upstream Mohe River section MS (Huanxiu Section) and the downstream section MS-LX (Linxi Section) (Figure 5).

The trends in TBC variation over the monitoring period were generally consistent between the upstream and downstream sections (Mann-Whitney U test, $p>0.05$). Regarding the timing of summer peaks, the downstream section (MS-LX, starting to rise in June, peaking in July) showed a slight lag compared to the upstream section (MS, already high in June, peaking in August, but also showing a peak in November). This supports the view that upstream water quality directly impacts downstream conditions, with pollutants migrating downstream. Although the overall trend consistency test was not significant ($p>0.05$), specific peak values and fluctuation patterns differed. Downstream (MS-LX) peak coliform counts (e.g., June, July 2024) were notably higher than upstream (MS) levels during the same periods. Particularly in the autumn of 2024, U-tests showed that total coliform counts in MS-LX were significantly higher than in MS ($p<0.05$), while TBC showed no significant difference. This indicates that coliform contamination in the downstream river section is more heavily influenced by local sources along its banks (e.g., sewage outlets, combined sewer overflows, surface runoff) rather than being solely determined by upstream inputs [16].

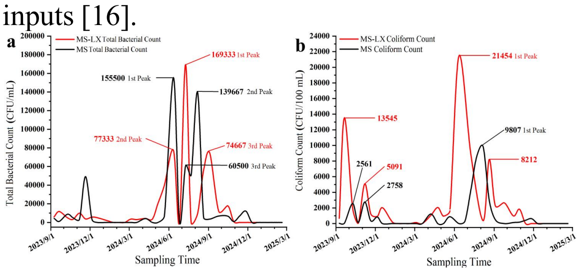

Figure 5. Comparison of Total Bacterial Count and Total Coliform Counts between Upstream (MS) and Downstream (MS-LX) Sections of the Same River (a. Total Bacterial Count, b. Total Coliform Count)

3.6 Microbial Comparison of a Treated Water Body and an Untreated Water Body

The residential area river LC (Licun River), which has undergone some form of treatment, was compared with the industrial area channel XM-JH, for which systematic treatment was not explicitly mentioned (Figure 6). At most time points, especially outside the summer season, TBC in LC was lower than in XM-JH. Peak TBC values in XM-JH were also generally higher than in LC. This preliminarily suggests that river restoration efforts may have some effect in controlling the total bacterial load in the water body. Total coliform counts in XM-JH remained at relatively high levels throughout the year, with less pronounced peak variations. In contrast, coliform counts in LC showed significant seasonality: very low levels in winter/spring, followed by extremely high peaks in summer/autumn (especially July, August), sometimes exceeding those in XM-JH. This indicates that despite potential treatment measures, substantial inputs of domestic sewage or runoff containing fecal contamination (e.g., combined sewer overflows during rain, surface wash-off) from the residential area can still cause sharp increases in coliform levels in LC, particularly during the rainy season or periods of high human activity. This highlights the complexity of controlling both point source (continuous discharge) and non-point source (event-driven, diffuse) pollution, and underscores the importance of rainy season pollution control[17].

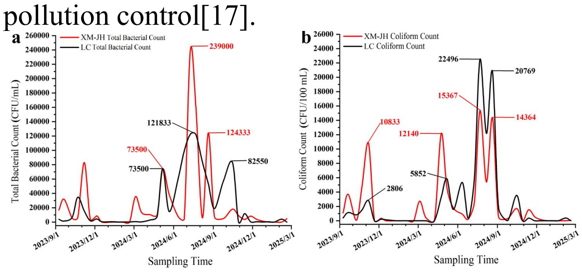

Figure 6. Comparison of Water Quality Status between a Treated Water Body (LC) and an Untreated Water Body (XM-JH) (a. Total Bacterial Count, b. Total Coliform Count)

4. Discussion

This study, through 18 months of microbial indicator monitoring across six different types of water bodies in urban Qingdao, reveals the temporal and spatial variation characteristics of their sanitary status and potential influencing factors.TBC and total coliforms generally peaked during the high-temperature seasons of summer and autumn, consistent with numerous domestic and international studies[13]. Higher water temperatures favor bacterial growth and reproduction. Additionally, increased summer rainfall, while potentially diluting pollutants, can also flush accumulated pollutants (including organic matter and fecal bacteria) from urban surfaces, agricultural lands, and potentially overflowing sewage systems into water bodies via surface runoff, leading to sharp increases in microbial counts, often associated with the “first flush” effect[17,18].

Non-flowing water bodies (XM-JH, XX) exhibited generally higher TBC, likely due to slower water exchange, facilitating pollutant accumulation, and relatively weaker self-purification capacity. Water bodies in residential areas (MS-LX, LC, XX) commonly showed higher coliform contamination, clearly indicating domestic sources as the primary driver, including sewage discharge, pipe leakage, cross-connections between storm and sanitary sewers, and runoff carrying surface pollutants like pet waste [16]. The agricultural reservoir (WS) was relatively cleaner, but the abnormal TBC increase during a specific period (rainfall after fertilization) highlights agricultural non-point source pollution (e.g., organic fertilizer, nutrient runoff stimulating indigenous bacteria) as a potential risk that should not be overlooked.

The Mohe River case demonstrates that upstream pollution contributes to downstream TBC levels, reflecting the common principle of pollutant transport along a watercourse. However, the greater influence of local discharges on downstream coliform counts underscores the critical importance of controlling shoreline emissions for indicators with strong local source characteristics, such as fecal contamination. This suggests that comprehensive watershed management requires both source water protection and strengthened pollution control in downstream segments. The comparison between Licun River (treated) and Xiangmaohe Channel (untreated) suggests that restoration measures might help lower baseline TBC levels but struggle to completely prevent drastic increases in coliforms during rain events or pollution incidents. This indicates that for urban rivers significantly impacted by non-point source pollution, end-of-pipe treatment or in-stream engineering measures alone may be insufficient. Strengthening source control, particularly by improving separate storm and sanitary sewer systems, controlling combined sewer overflow (CSO) pollution, and enhancing urban stormwater management, is crucial [17]. Septic tank management is another area requiring special attention, as leakage from septic systems is a significant potential source of fecal contamination in residential areas.

Although this study covered various water body types and a relatively long time series, it has limitations. For instance, using only three sampling points per water body might not fully represent the average condition of the entire water body; synchronous measurement of physicochemical parameters was not performed, limiting quantitative analysis of the drivers of microbial changes. Future research could consider increasing sampling density, incorporating analysis of physicochemical parameters, using more specific indicator organisms (like E. coli), or employing molecular methods for Microbial Source Tracking (MST) [19] to gain a deeper understanding of pollution sources and mechanisms.

5. Conclusions

This study comprehensively analyzed the temporal and spatial distribution characteristics of total bacterial count and coliform group in six representative urban water bodies in Qingdao. The results confirmed pronounced seasonal variations, with microbial levels peaking during high-temperature and rainfall periods. Flow conditions and surrounding land use significantly influenced microbial abundance and contamination levels. Non-flowing waters in industrial and residential areas showed higher bacterial loads, while flowing rivers in residential zones exhibited elevated coliform concentrations, indicating substantial influence from domestic sewage and localized pollution sources. The findings highlight the complex interplay between hydrodynamics, anthropogenic activities, and pollution pathways. By integrating microbial monitoring across diverse functional zones and hydrological conditions, this research provides critical insight into urban water sanitation dynamics and offers practical value for optimizing water quality management strategies in rapidly urbanizing coastal cities.

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