Storm-event Dynamics of Nitrogen and Dissolved Oxygen in Urban River: The Upper Tame, Birmingham

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Abstract. Nitrogen (N) and dissolved oxygen (DO) are essential indicators of urban water pollution, with excess nitrogen causing eutrophication and low dissolved oxygen damaging the living environment of aquatic organisms and affecting biodiversity. Urban areas cover a high proportion of impervious areas. When heavy rainfall occurs, it rapidly generates surface runoff in urban areas and carries nitrogen into river systems. This study aims to assess the water quality of the river tame through the Birmingham metropolitan area over the last 15 years, investigate whether excess nitrogen input during storm events causes significant changes in dissolved oxygen, and find a linear relationship between nitrogen and dissolved oxygen. By comparing the water quality at the Sandwell Park sample point, which does not flow through urban Birmingham, with the water quality at the Minworth sample point, which is the final outlet of Birmingham, it was found that the nitrogen content of the river Tame increased from 4.17 mg/L to 13.09 mg/L, indicating a decline in water quality after the river Tame flowed through urban Birmingham. The correlation coefficient between nitrogen and dissolved oxygen increases from 0.65 to 0.8 between the rainfall event and the storm event, which is highly correlated, suggesting that combined sewer overflow (CSO) events coincided with peak nitrogen and strengthened the correlation between nitrogen and dissolved oxygen in the river Tame. A regular and continuous monitoring program should be established for the Tame catchment through urban Birmingham to prevent overflows as a priority and to enhance the treatment capacity of the sewage treatment plant.

Keywords: Nitrogen; dissolved oxygen; storm events; combined sewer overflow.

1. Introduction

The combination of urban, industrial and agricultural activities has contributed globally to severe surface-water pollution. This damages agricultural activities, drinking water sources, economic activities, and recreation, and severely impacts human health [1, 2]. Generally, the most critical indicators for monitoring surface water quality are water temperature, pH, DO, dissolved and suspended solids, phosphorus and N compounds, biochemical oxygen demand and chemical oxygen demand [3].

Urban rivers provide invaluable ecosystem services [3-5]. The most fundamental problem with the degradation of urban rivers in the last decade is urbanization's impact [6]. Since the 1950s, more than 50% of the world's population has lived in urban areas [7]. As urbanization progresses steadily around the world, the conflict between the demand for urban resources and the quality of the environment is becoming increasingly evident. Increased urbanization leads to the deterioration of aquatic ecosystems. Among the water quality problems in cities, sewage and industrial wastewater are the primary sources of pollution in urban rivers. Studies have shown that DO and N concentrations are key parameters for severe water pollution in urban rivers [8].

Rapid urban expansion, lagging environmental management and investment have exacerbated riverine N pollution, which is widely reported worldwide in urban rivers [9]. Many studies have shown a strong relationship between urbanization, N, and DO. Li et al. [10-12] found urbanization was positively correlated with river ammonia levels. While DeVilbiss et al. [13] found a negative correlation between urbanization and DO in their study. The input of ammonia nitrogen from surface water leads to algal blooms in river ecosystems [14]. Wang et al. [16] found that the decomposition of algae significantly reduced DO water body. DO in water is depleted by algal blooms and

decomposition caused by urban activities. DO is a barometer of the ecological balance of a river, and it is an essential indicator of the survival of river fish. Low DO concentrations and high N concentrations are the leading causes of fish stress [17].

In addition, there is a close relationship between changes in climate and weather and water quality dynamics, with many extreme weather conditions resulting in a rapid decline in water quality conditions [18-20]. The dependence of ammonia nitrogen on dispersion pathways to surface water from extreme weather, such as storms, results in persistent and not easily managed pollution [21]. After the storm, low DO events in the water body led to a dramatic drop in fish abundance [22]. It has been shown that the dynamics of N and DO in the water changed considerably during the storm. Therefore, the objectives of this study are that learn about river water quality dynamics and assess the impact of storm events on N concentrations, final describes the linear relationship between N and DO during storms.

2. Method

2.1. Sample points

This study focuses on four sampling points in the Tame catchment of Staffordshire Warwickshire and West Midlands, UK. There are Sandwell Park Golf Club B/H, West Brom, R Tame Timet UK Ltd 100 M Ds Brookvale Rd, River Tame - At Water Orton and Minworth Stw, Fe (Disch 1 & 2). Sandwell Park Golf Club B/H, West Brom is a sampling site for groundwater – borehole before the River Tame flows through the city of Birmingham. R Tame Timet UK Ltd 100 M Ds Brookvale Rd is a surface water sampling site where the River Tame flows through the Birmingham area, Timet UK is a metal working plant upstream of the River Tame. Water Orton is a sampling point for studying the impact of CSOs on urban river water quality during storms. Minworth Stw, Fe (Disch 1 & 2) is the final outfall from the Birmingham city region.

2.2. Data sources

Environment Agency (EA) river flow and automatic water quality monitoring and rain gauge stations were the sources for the flow, ammonia and rainfall data used. As the EA water quality data for Sandwell Park Golf Club B/H date back to as early as 2007, this study chose to study the time series from 2007 to 2022.

3. Results and discussion

3.1. Sandwell Park Golf Club B/H, West Brom

Analysis of the data from the Sandwell Park Golf Club B/H, West Brom sampling site, which does not flow through the Birmingham urban area, shows that the variation in N over the last 15 years has not been significant, with a peak of 4.99 mg/L on 16 October 2007 and a low of 3.63 mg/L on 18 April 2017 (Fig. 1a). The average value from 2007 to 2022 is 4.17 mg/L, with an overall decreasing trend. However, there was some fluctuation in DO between 2007 and 2022, ranging from 5.94 mg/L on 9 August 2018 to 11.6 mg/L on 4 April 2022, with a mean value of 8.68 mg/L, with an overall increasing trend (Fig. 1b). This indicates that the groundwater quality at Sandwell Park is well-protected and stable.

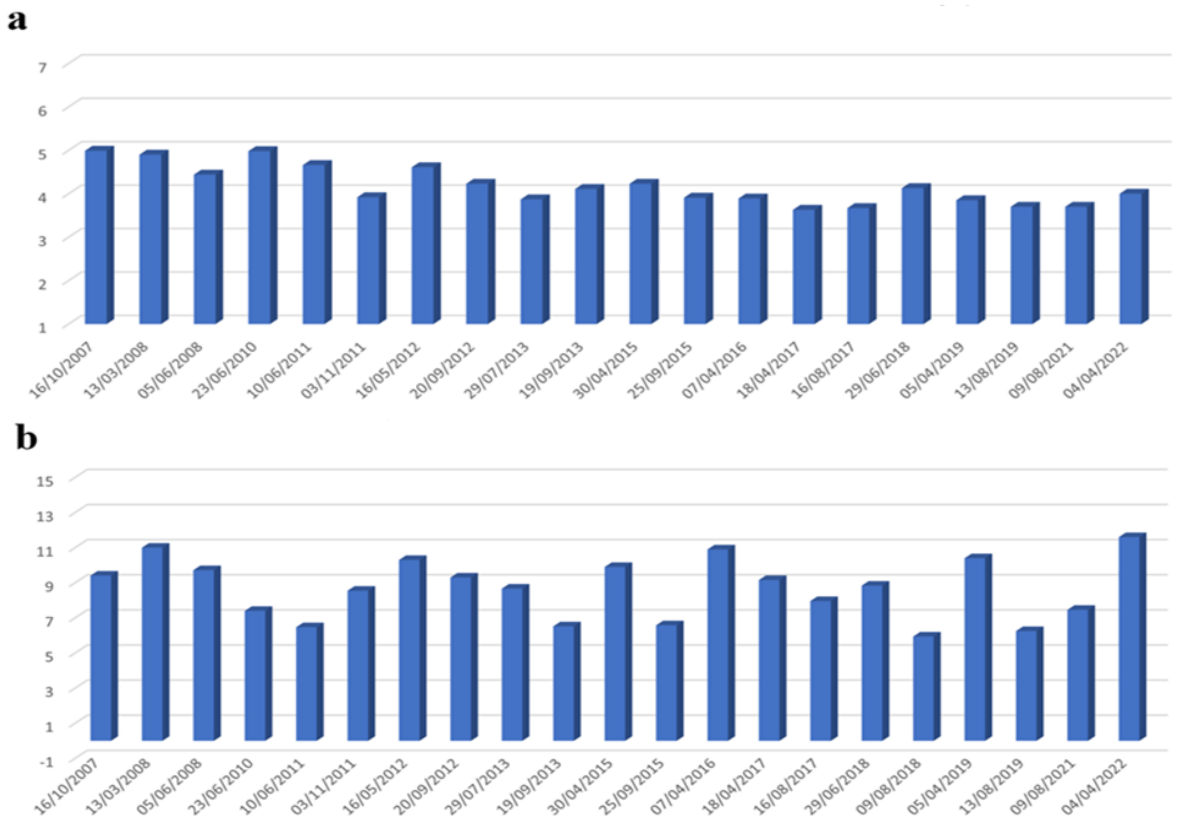

Fig. 1 (a) River Tame change in Nitrogen, Total Oxidised as N (mg/L) from 2007 to 2022 at Sandwell Park Golf Club B/H, West Brom sample point. (b) River Tame change in Oxygen, Dissolved as O_2 (mg/L) from 2007 to 2022 at Sandwell Park Golf Club B/H, West Brom sample point.

Based on the limited data available from the environmental agency, this study obtained trends in N and DO from 2007 to 2022 at the Sandwell Park sampling point (Fig. 2). The relationship between the two is not obvious from the graph; correlation is analysed in this study (Table 1). The correlation coefficient between nitrogen, Total Oxidised as N and Oxygen, Dissolved as O_2, was 0.15 mg/L. In general, correlation coefficients between at greater than 0. 8 were determined to be correlated [23], so after correlation analysis it was clear that nitrogen, total oxidation as N and oxygen, dissolved as O_2 showed a weak correlation, indicating that there was no pattern to the trend between the two. Although no relationship was found between DO and N at this point, the water quality at the Sandwell Park sampling point is relatively well protected.

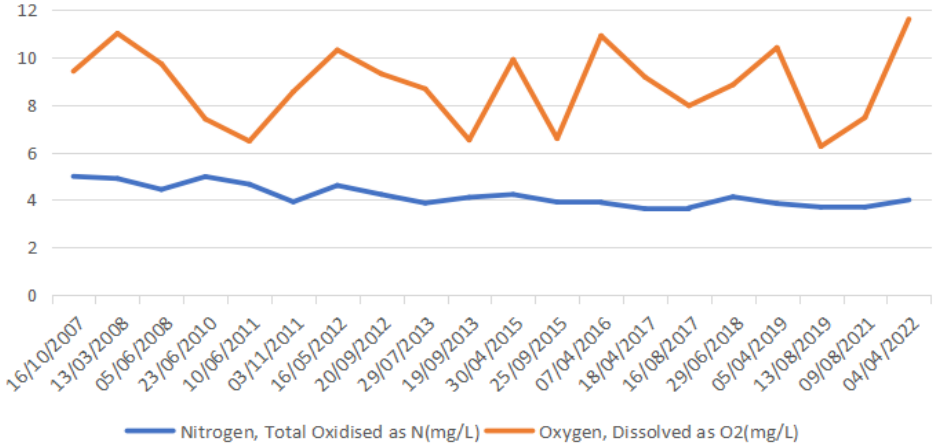

Fig. 2 Trends in Nitrogen, Total Oxidised as N (mg/L) and Oxygen, Dissolved as O_2 (mg/L) at Sandwell Park Golf Club sampling point between 2007 and 2022.

Table 1. Correlation between Nitrogen, Total Oxidised as N and Oxygen, Dissolved as O_2 at Sandwell Park Golf Club sample point.

Correlation coefficient	Nitrogen, Total Oxidised as N (mg/L)	Oxygen, Dissolved as O_2 (mg/L)
Nitrogen, Total Oxidised as N (mg/L)	1	
Oxygen, Dissolved as O_2 (mg/L)	0.152419133	1

3.2. R Tame Timet Uk Ltd 100 M Ds Brookvale Rd

R Tame Timet Uk Ltd 100 M Ds Brookvale Rd flows through Birmingham urban area, and a titanium metal processing plant is upstream of this sample site. N was calculated to fluctuate significantly from a maximum of 12.5 mg/L on 16 November 2007 to 3.7 mg/L on 6 August 2021 (Fig. 3a). The mean value of 8.01 mg/L of N in the river at this sample site compares to the mean value of 4.17 mg/L at the Sandwell Park Golf Club B/H, West Bromage sample site, which does not flow through urban Birmingham, and is subject to urbanisation and industrial pollution at River Tame. Similarly, the highest DO value at this site was 14.3 mg/L on 14 May 2008, and the lowest value was 5.49 mg/L on 2 August 2019, with an average of 8.98 mg/L from 2007 to 2022 (Fig. 3b). The range of fluctuations is generally consistent with the DO at the Sandwell Park Golf Club B/H, West Bromage sampling site. However, the overall trend shows a gradual decrease in DO levels compared to the upstream sample points.

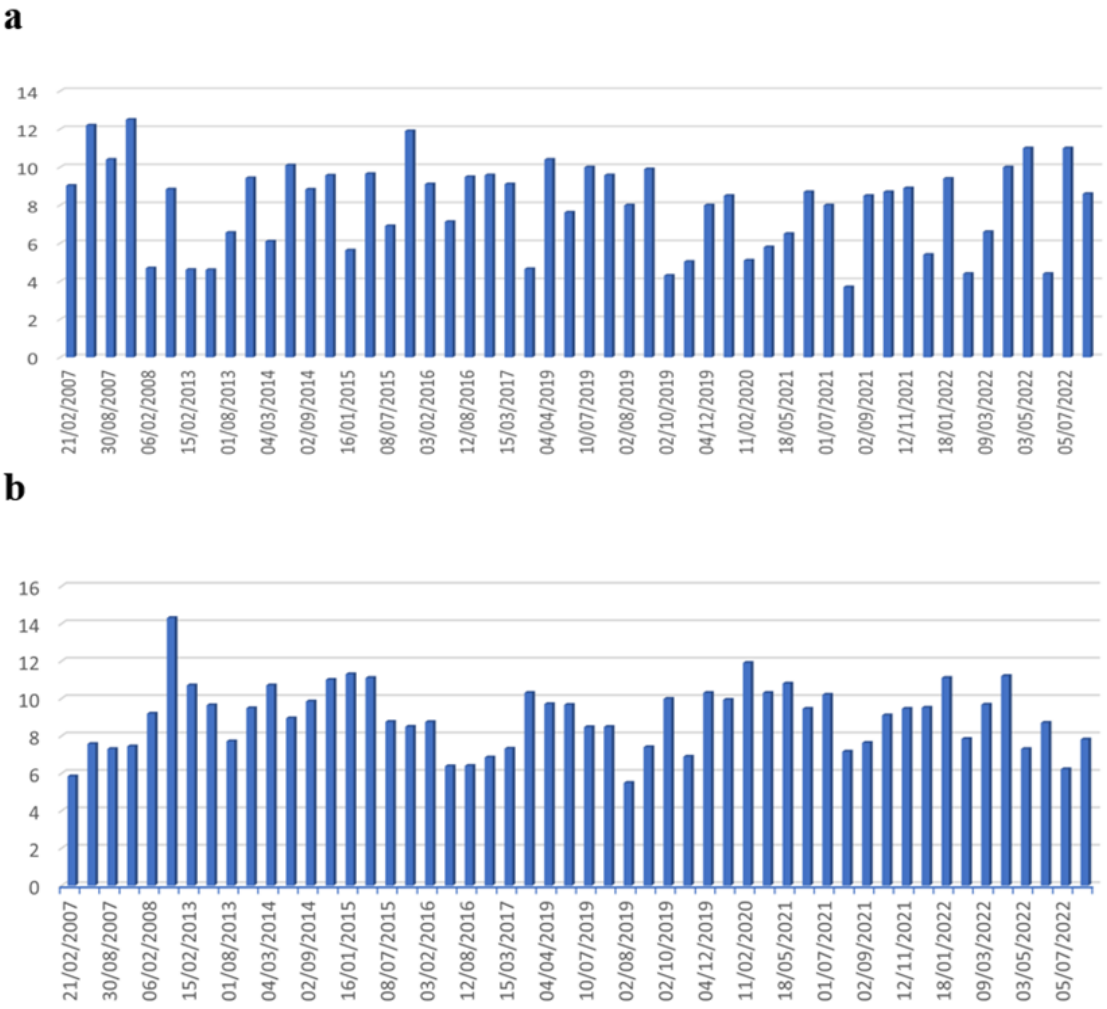

Fig. 3 (a) River Tame change in Nitrogen, Total Oxidised as N (mg/L) from 2007 to 2022 at R Tame Timet Uk Ltd 100 M Ds Brookvale Rd sample point. (b) River Tame change in Oxygen, Dissolved as O_2 (mg/L) from 2007 to 2022 at R Tame Timet Uk Ltd 100 M Ds Brookvale Rd sample point.

The trends for Nitrogen, Total Oxidised as N and Oxygen, and Dissolved as O_2 at the R Tame Timet UK sample point are shown in Fig.4. The correlation coefficient of -0.22 was obtained from the correlation analysis (Table 2). It can only be roughly concluded that there is a negative correlation between Nitrogen, Total Oxidised as N and Oxygen, Dissolved as O_2 at the R Tame Timet UK sample point.

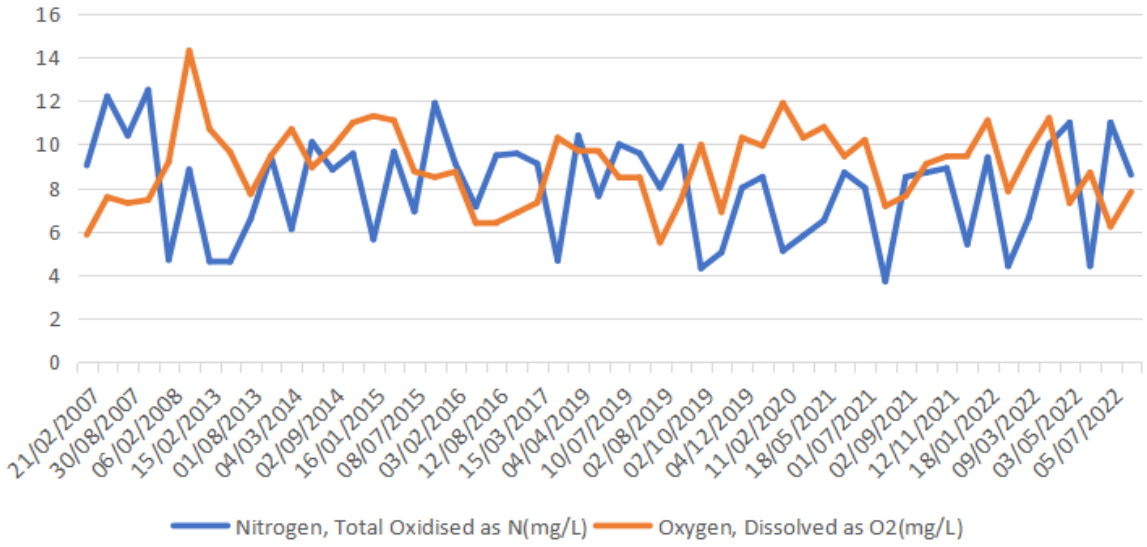

Fig. 4 Trends in Nitrogen, Total Oxidised as N (mg/L) and Oxygen, Dissolved as O_2 (mg/L) at R Tame Timet UK Ltd 100 M Ds Br sampling point between 2007 and 2022.

Table 2. Correlation between Nitrogen, Total Oxidised as N and Oxygen, Dissolved as O_2 at R Tame Timet UK Ltd 100 M Ds Br sampling point.

Correlation coefficient	Nitrogen, Total Oxidised as N (mg/L)	Oxygen, Dissolved as O_2 (mg/L)
Nitrogen, Total Oxidised as N (mg/L)	1	
Oxygen, Dissolved as O_2 (mg/L)	-0.224680008	1

3.3. River Tame - At Water Orton

The Water Orton sampling point is located downstream of the R Tame Timet Uk Ltd 100 M Ds Brookvale Rd sampling point. It is close to the Minworth Stw, Fe (Disch 1 & 2) sampling point. Due to the lack of DO data at the downstream Minworth Stw, Fe (Disch 1 & 2) sampling site, data for BOD5 at the Water Orton sample point were also collected for comparison purposes (Fig. 5a). The N data obtained from the Water Orton sampling point are shown in Fig. 5b. It can be seen that the N levels in the water at the Water Orton point fluctuated between a maximum of 10 mg/L on 23 October 2007 and 2.3 mg/L on 1 October 2009, with a mean value of 7.06 mg/L. Comparing the N data from the Sandwell Park site, it can be seen an increase in the maximum, minimum and mean values. This indicates that external N sources are constantly feeding the River Tame as it flows through the urban area of Birmingham, leading to an increase in overall N concentrations in the water body. After flowing through the Water Orton area, the water quality of the river is slightly better than at the observation site near the metalworking plant, which is related to the self-purification function of the river itself [24]. Similarly, the DO at the Water Orton sampling site fluctuated between a maximum value of 12.6 mg/L on 3 April 2013 and a minimum value of 6.77 mg/L on 12 June 2007, with an average value of 9.48 mg/L (Fig. 5c). DO lies between Sandwell Park and Timet UK. However, the water bodies have some self-purification ability, downstream Water Orton performs better than Timet Uk and the water quality has improved to some extent. The fluctuations in BOD5 between 2007 and 2021 were primarily stable at 1-5 mg/L with a mean value of 2.84 mg/L. On 3 November 2009, the BOD5 spiked to 21.1 mg/L, it was rainy season in the River Tame between 30 October and 6

November 2009, and the river flow spiked on 3 November; this suggests that it is highly likely that CSOs occurred on 3 November 2009, resulting in a jump in BOD5 values in the water body.

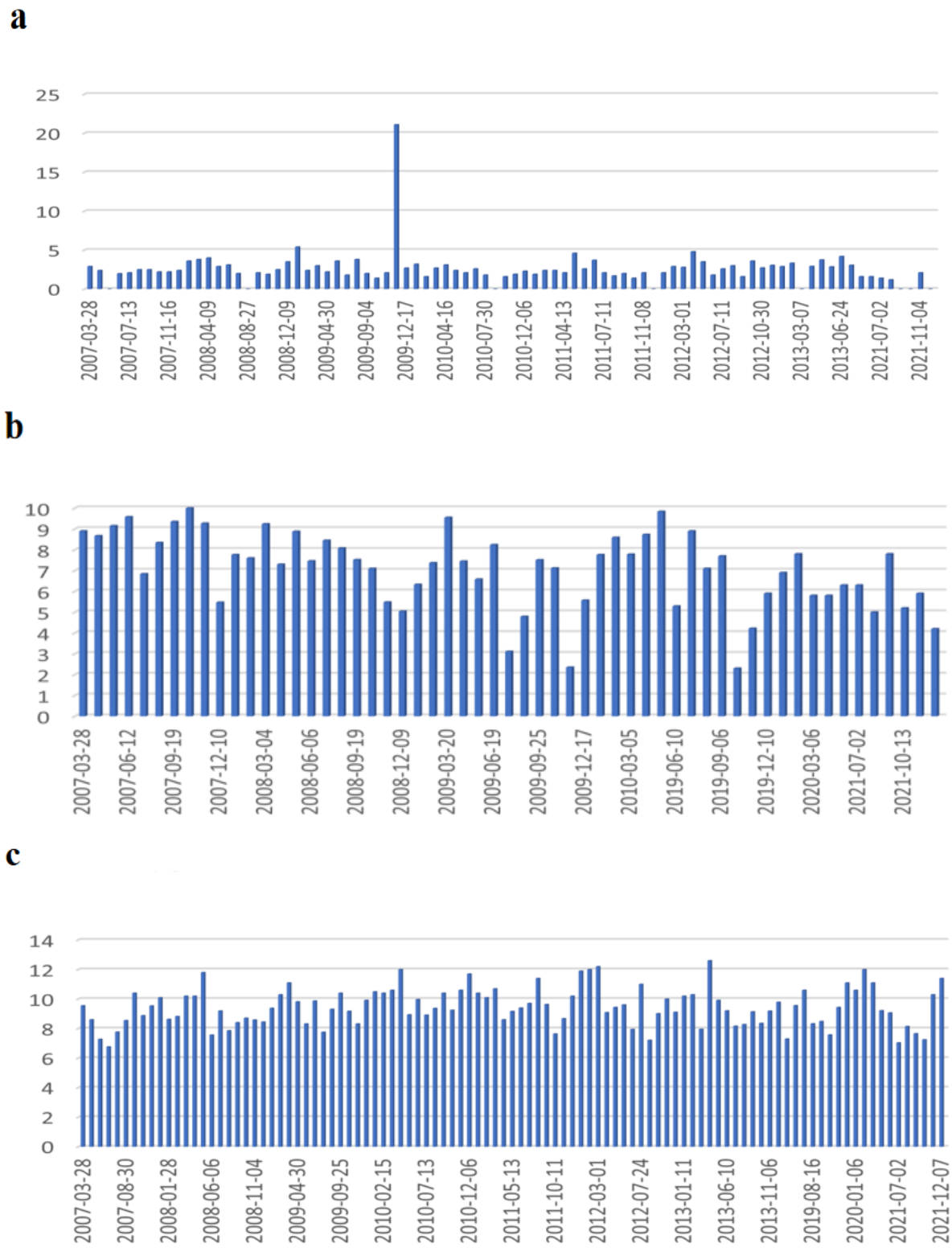

Fig. 5 (a) River Tame change in BOD5 (mg/L) from 2007 to 2022 at R Tame Timet Uk Ltd 100 M Ds Brookvale Rd sample point. (b) River Tame change in Nitrogen, Total Oxidised as N (mg/L) from 2007 to 2021 at R Tame Timet Uk Ltd 100 M Ds Brookvale Rd sample point. (c) River Tame change in Nitrogen, Total Oxidised as N (mg/L) from 2007 to 2022 at R Tame Timet Uk Ltd 100 M Ds Brookvale Rd sample point.

There is no correlation between N and DO at the Water Orton sampling sites over the long period from 2007 to 2021 (Fig. 6), with a coefficient of 0.12 (Table 3). The lack of correlation is mainly since the samples published by the EA from 2007 to 2021 include water quality data with rainfall and dry weather, which does not provide a clear picture of the linear variation in N and DO during storm events.

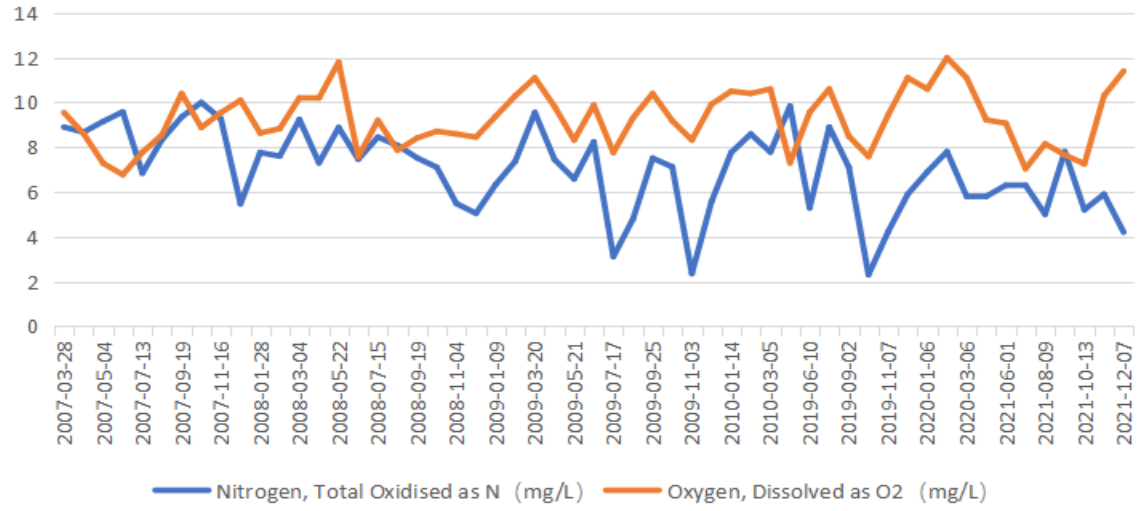

Fig. 6 Trends in Nitrogen, Total Oxidised as N (mg/L) and Oxygen, Dissolved as O_2 (mg/L) at Water Orton sampling point between 2007 and 2021.

Table 3. Correlation between Nitrogen, Total Oxidised as N and Oxygen, Dissolved as O_2 at the Water Orton sampling point.

Correlation coefficient	Nitrogen, Total Oxidised as N (mg/L)	Oxygen, Dissolved as O_2 (mg/L)
Nitrogen, Total Oxidised as N (mg/L)	1	
Oxygen, Dissolved as O_2 (mg/L)	0.12235558	1

3.4. Storm Event at Water Orton

In this study, rainfall and flow monitoring stations are located at the Water Orton sampling site, and the inclusion of storm event references at the Water Orton sampling site reduces the time lag in data collection at the three upstream sites. This study selected 58 storm events from the Water Orton monitoring station (Table 5) and selected water quality data from the Water Orton for the period 2007 to 2021 during storm events, plotted the trends in N and DO during rainfall events and storm events (Fig. 7 and Fig. 8), and analyzed the correlation between N and DO during rainfall and storm events (Table 5 and Table 6). Based on the trend plots, both N and DO have a strong correlation in the dates with rainfall. The correlation coefficients of 0.65 for wet days and 0.8 for storm events indicate that the relationship between N and DO strengthens with increasing rainfall and flow. When storm events occur, only a small proportion of the N carried by the stormwater flows into the soil, farmland, etc., urban areas cover a large amount of impermeable area, and most of the N flows along the impermeable area into the river Tame. In addition, surface runoff from stormwater flows into the sewerage system in urban areas and CSOs can occur when underground pipes receive more sewage than the pipes and treatment plants handle. The combination of these two factors results in a surge in N concentrations in the River Tame, which leads to nutrient overloads in the water body and proliferation of river organisms in the excess nutrient environment that consumes DO in the water. The final correlation coefficient between N and DO at Water Orton is 0.8, which is highly correlated.

Table 4. 58 storm events from 2007 to 2021 at the Water Orton monitoring station.

Date	Flow(m^3s^{-1})	Daily flow variation (m^3s^{-1})	Rainfall (mm)
04/03/2007	26.2	12.4	15.4
13/05/2007	36.1	25.3	29.9
15/06/2007	79.9	54.1	13.9
22/06/2007	21.6	13.96	11.4
25/06/2007	42.8	26.8	15.9
20/07/2007	84.9	41.9	54.3
26/07/2007	29.4	18.6	15.1
11/01/2008	45.3	29	28.4
15/01/2008	44.6	29.6	10.9
05/02/2008	21.7	14.77	7.9
28/05/2008	26.9	20.82	7.4
28/07/2008	34.8	21.7	31.8
06/09/2008	65.4	48.6	19.9
09/09/2008	33.1	25.74	7.3
09/11/2008	47.3	24.6	26.9
13/12/2008	34.5	26.5	6.5
15/05/2009	19.6	12.26	8.6
07/06/2009	21.6	15.93	5.4
26/06/2009	37.7	23.7	29.8
29/07/2009	28.9	22.22	17.1
22/01/2010	20	13.22	11.1
09/06/2010	16.6	12.84	10.1
01/10/2010	29.1	22.97	19.9
03/10/2010	28.5	23.05	6.5
08/11/2010	17.8	13.06	5.8
25/04/2012	23.1	15.92	13.5
29/04/2012	37.3	28.17	11.9
03/06/2012	28.4	22.09	16.5
15/06/2012	21.1	13.93	9.4
28/06/2012	41.6	34.11	25.8
06/07/2012	40.4	30.3	20.4
24/09/2012	58.9	45.4	15
21/11/2012	43.5	13.5	8.7
22/11/2012	30	19.1	14.7
14/12/2012	26.9	17.75	18.3
20/12/2012	32.6	21.3	10.1
22/12/2012	41.7	28.1	11.5
24/12/2012	23.2	12.8	7.9
29/12/2012	25.2	15.35	9.8
27/07/2013	28.3	16.8	34.2
22/10/2013	20.8	12.32	12
23/12/2013	26.7	13.6	19
01/01/2014	23.6	14.17	16.5
12/02/2014	27.8	18.22	11.4
25/04/2014	22.4	15.23	23.8
24/05/2014	24.6	17.17	15.4
04/06/2014	18.9	12.89	12.3
19/07/2014	31.8	26.39	9.8
25/08/2014	27.5	12.8	26.7
13/10/2014	36.5	21.2	30.3
08/11/2014	23	16.55	11.4
31/08/2015	27.6	13.4	13.9
06/10/2015	15.8	12.09	11.4
03/01/2016	21.7	13.35	10.1
06/02/2016	32.8	19.3	21.2
08/06/2016	23.1	18.71	13.8
16/06/2016	55.6	42	29.3
21/11/2016	48.3	34.2	28.3

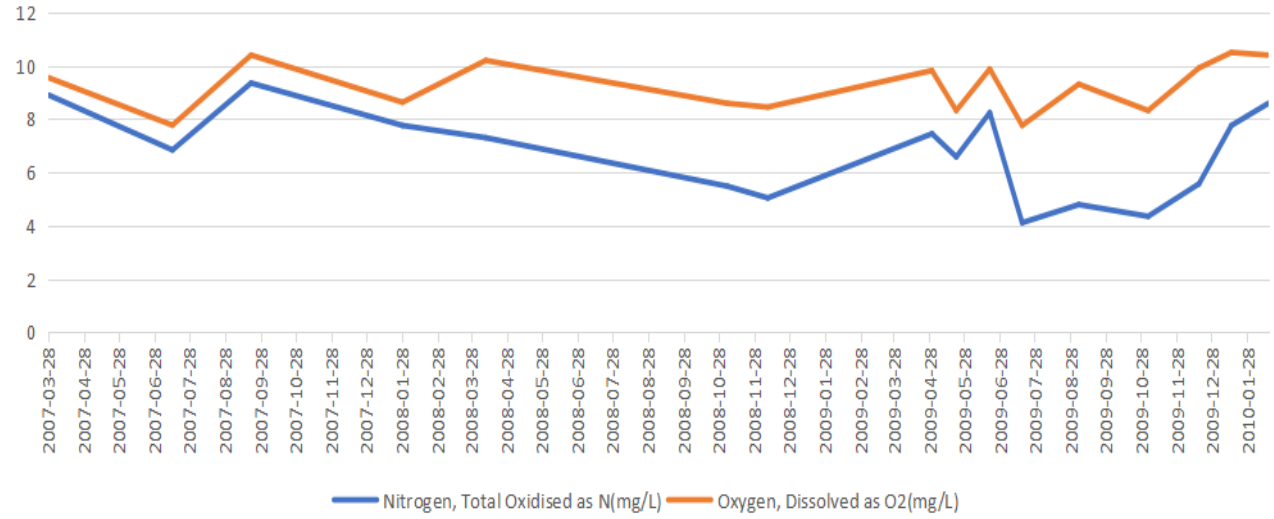

Fig. 7 Trends in Nitrogen, Total Oxidised as N (mg/L) and Oxygen, Dissolved as O_2 (mg/L) at the Water Orton sampling point in rainy day.

Table 5. Correlation between Nitrogen, Total Oxidised as N and Oxygen, Dissolved as O_2 at the Water Orton sampling point in rainy day.

Correlation coefficient	Nitrogen, Total Oxidised as N (mg/L)	Oxygen, Dissolved as O_2 (mg/L)
Nitrogen, Total Oxidised as N (mg/L)	1	
Oxygen, Dissolved as O_2 (mg/L)	0.64688021	1

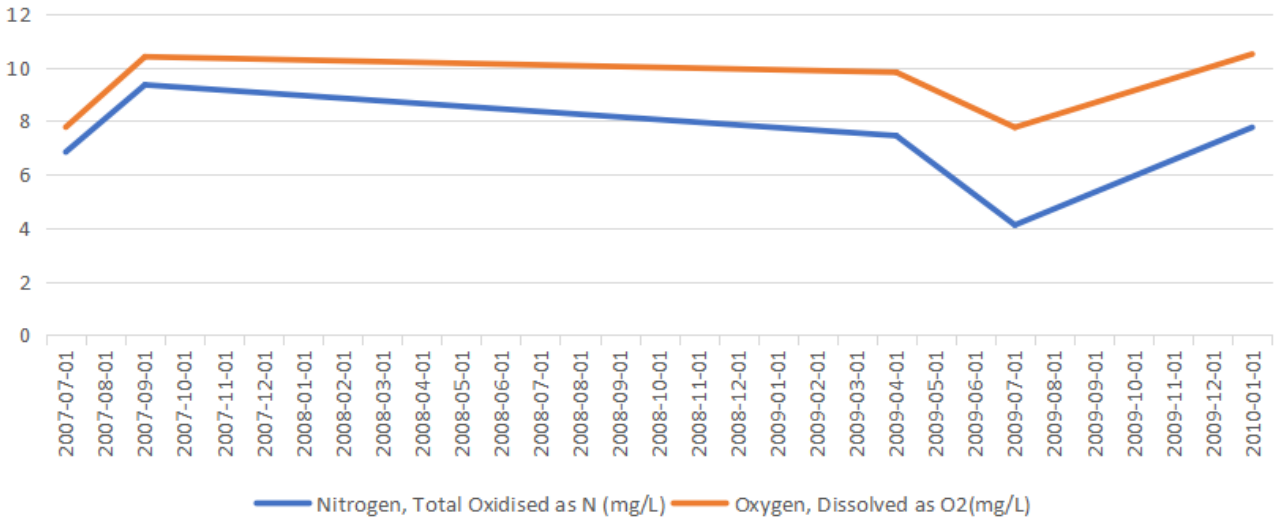

Fig. 8 Trends in Nitrogen, Total Oxidised as N (mg/L) and Oxygen, Dissolved as O_2 (mg/L) at the Water Orton sampling point during storm events.

Table 6. Correlation between Nitrogen, Total Oxidised as N and Oxygen, Dissolved as O_2 at the Water Orton sampling point during storm events.

Correlation coefficient	Nitrogen, Total Oxidised as N (mg/L)	Oxygen, Dissolved as O_2 (mg/L)
Nitrogen, Total Oxidised as N (mg/L)	1	
Oxygen, Dissolved as O_2 (mg/L)	0.800513819	1

3.5. Minworth Stw, Fe (Disch 1 & 2)

As the data on N from 9 July 2008 to 13 July 2022 are missing from the EA, this dissertation only plotted the change in N from 2007 to 2008 (Fig. 9a). The peak value of 18.9 (mg/L) occurred on 28 March 2007 and the trough value of 6 (mg/L) occurred on 27 May 2008, with a mean value of 13.09 (mg/L). As a result, this study found that the N value at the Minworth sample point was the highest of the four sampling points and the water quality was the worst. The BOD5 at this point fluctuated from 2007 to 2022 between a peak of 50 (mg/L) on 22 October 2013 and several troughs of less than 1 (mg/L) with the mean value of 3.42 (mg/L) (Fig. 9b), it is higher than the mean BOD5 value of 2.84 (mg/L) for the upstream water Orton.

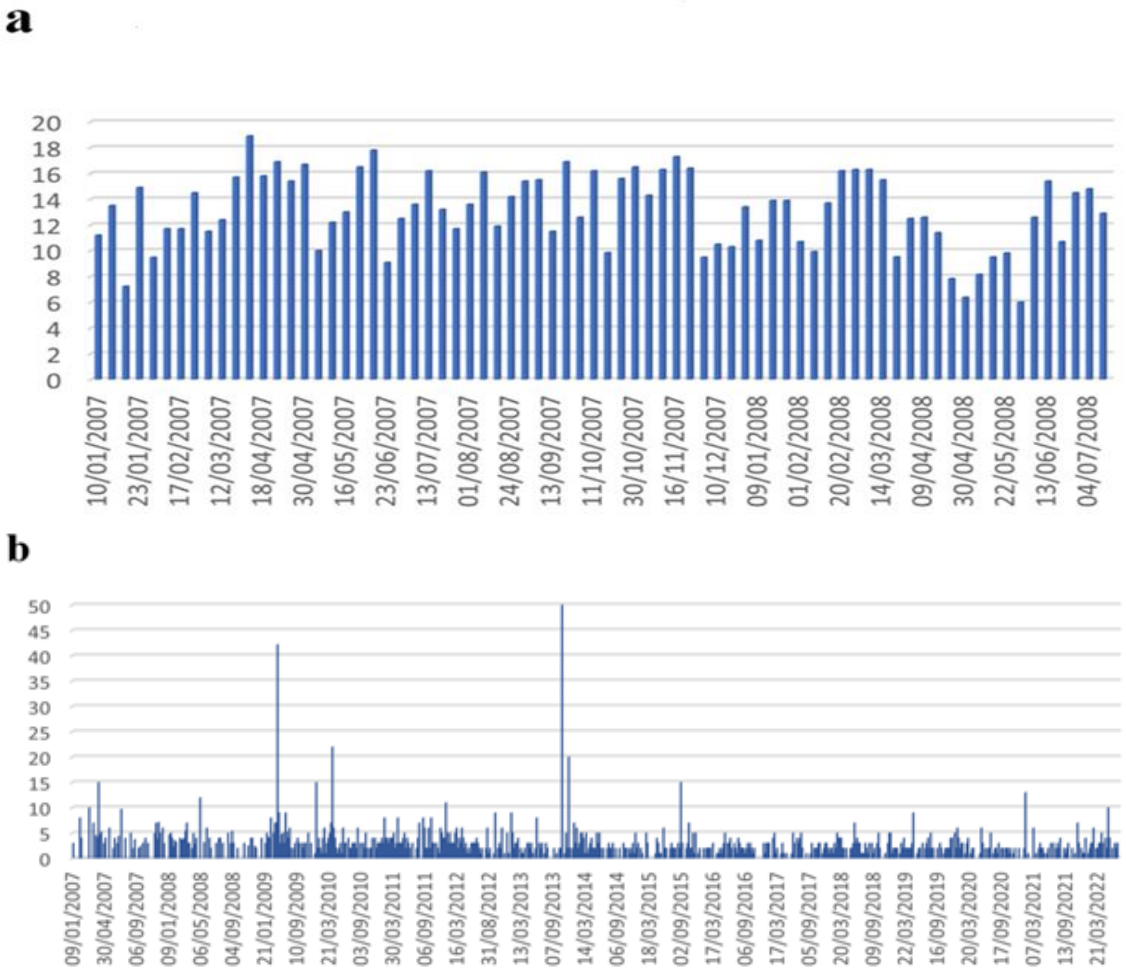

Fig. 9 (a) River Tame change in Nitrogen, Total Oxidised as N (mg/L) from 2007 to 2008 at Minworth Stw, Fe (Disch 1 & 2). (b) River Tame change in BOD5 (mg/L) from 2007 to 2022 at Minworth Stw, Fe (Disch 1 & 2).

EA had no available DO data at the Minworth Stw, Fe (Disch 1 & 2) sample point, only for BOD5 between 2007 and 2008, so here BOD5 is used instead of DO to investigate the relationship between N and BOD5. The amount of DO consume by aerobic microorganisms to decompose the organic matter present in the water sample is called biochemical oxygen demand or biological oxygen demand

(BOD), BOD and DO are inversely proportional to each other and BOD5 is the five-day BOD. Figure 5.3 shows the intermittent and simultaneous variation of N and BOD5, with a correlation coefficient of 0.32, which is higher than at the upstream Sandwell Park and R Tame Timet Uk sample point. The use of BOD5 as an indicator of water quality avoids the lag in the consumption of DO in the water body as it takes some time to be decomposed by microorganisms. However, due to the limited number of samples, the results for N and DO at the Minworth Stw, Fe (Disch 1 & 2) sample sites are not convincing.

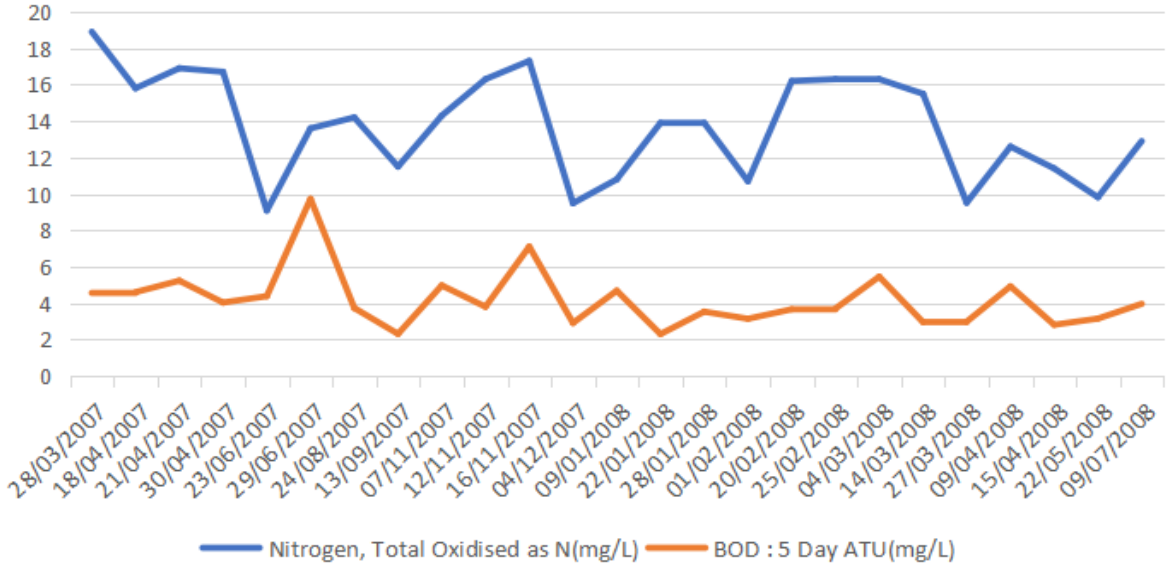

Fig. 10 Trends in Nitrogen, Total Oxidised as N (mg/L) and BOD: 5 Day ATU (mg/L) at Minworth Stw, Fe (Disch 1 & 2) sampling point between 2007 and 2008

4. Conclusion

The water quality of the River Tame before urbanization was good, with an annual average total N value of 4.17 mg/L and a yearly average DO value of 8.68 mg/L. Although the total N value is higher than the strict standard of 2.8 mg/L, the DO concentration is much higher than the minimum DO standard of 4 mg/L for fish survival. This indicates that no eutrophic contamination of the water column has occurred at the Sandwell Park site. Water quality stable over the 15 years, with no significant year-round fluctuations. As the River Tame flows through Birmingham, water quality deteriorates to varying degrees at all three sites compared to the source site, Sandwell, because of urbanization. The results show that N and DO were positively correlated during rainfall events in the river, with a correlation coefficient of 0.65. The correlation was even stronger during storm events with a correlation coefficient of 0.8. Future studies should strengthen water quality observations for rainfall and storm events to ensure that the data are adequate and that the results are more convincing. The placement of rainfall stations at each water quality monitoring site will allow for more accurate determination of CSOs events and a more detailed understanding of water quality variability.

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