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The Effect of Al-Rustimiyah WWTPS' on the Nutrients' Distribution in Diyala River

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ABSTRACT

Nutrients, represented by nitrogen and Phosphorus compounds, are found in wastewaters and rivers at different concentrations. Al-Rustimiyah Wastewater Treatment Plants (WWTPs) in Baghdad, Iraq are over loaded with high concentrations of wastewater that exceeds the plants' capacities, which intern are bypassed directly to the receiving water body represented by Diyala River. The reach of Diyala River just before its confluence with Tigris River south of the capital city Baghdad and opposite to Al-Rustimiyah WWTPs', was taken as the case study. Its pollution status was assessed with regard to nutrient compounds levels. The parameters: ORP, TN, TKN NH_4-N, NH_3-N, NO_3-N, and NO_2-N were monitored and measured at nine sites along the river reach for a period of one year to evaluate seasonal variations. The first site represents a point upstream the discharges of the WWTPs' flowing into Diyala River, while the second to eighth sites were located at each discharge from the WWTPs of Al-Rustimiyah in which each plant has two discharges into the river; the treated effluent and the raw bypass. The last site was located downstream of all discharges above. It was found that water at sites two, seven, and four, respectively, were the most polluted points among all duo to the presence of the bypasses from the WWTPs at these sites. Regarding TN, NH_3-N, and NH_4-N, concentrations, the river was classified as heavily contaminated with raw wastewater at site two and between low to medium strength at further sites, excluding site one. NO_3-N and NO_2-N concentrations classified the river water as effluent water rather than river water with regard to Iraqi standards. As for the ORP concentrations, the river was categorized as anoxic through winter to anaerobic in summer from station two to the end. Furthermore, the strong odor observed on site mainly during summer, might be attributed to the formation of acid and methane production that goes with the obtained low levels of ORP. Reversed relations were found connecting the ORP levels and each of the nitrogen and phosphorous compounds.

Keywords: Al-Rustimiyah WWTPs', Diyala River, ORP, TN, NO_3-N, NH

I. INTRODUCTION

One of the most important problems facing mankind nowadays is water pollution. Water quality deterioration in surface water is the impact of anthropogenic activities due to rapid industrialization [1]. Major sources of surface water contamination are construction, municipalities, agriculture, and industry [2].

Wastes are most often discharged into receiving water bodies with little or no regard to their assimilative capacities [3]. Monitoring the parameters of a receiving water body should be essential in order to obtain its capacity to accommodate wastes. Physico-chemical properties such as pH, dissolved oxygen and others can be used to determine the water ecosystem integrity [4].

Nutrients, represented by nitrogen and Phosphorus compounds, are found in wastewaters and rivers as well at different concentrations.

Nitrogen compounds contain one of the biggest groups of natural and drinking water contaminants [7]. These compounds could be oxidized or reduced by organisms [8]. Nitrogen loads in rivers has different sources, such as deposition from the atmosphere, the direct discharging from industrial, residential or agricultural residuals, and others [9].
Nitrogen's most common compounds are the ammonium (NH_4-N), ammonia (NH_3-N), nitrate (NO_3-N), nitrite (NO_2-N), Total Kjeldahl nitrogen (TKN), and Total nitrogen (TN). Ammonia is toxic to aquatic life. It occurs in nature duo to the degradation of organic nitrogen compounds in water. High ammonia concentrations in surface water create a large oxygen demand owing to the ammonia conversion to nitrate. High ammonium concentrations motivate algal and plants growth. Their subsequent death and decomposition may produce anoxic conditions [10].

NO_3-N is considered as the most oxidized forms of nitrogen found in wastewater. It has a serious and sometimes fatal effect on infants [11]. As for nitrite, one of the oxidation states of nitrogen, it occurs both in the reduction of nitrate and the oxidation of ammonia into nitrate. It occurs in low concentrations in both surface water and wastewater duo to its rapid oxidation to nitrate, however it is extremely toxic to most types of fish and other aquatic species [11].

The TN is approximately the sum of TKN and the NO_xN [10]. The TKN is defined as the sum of the ammonia nitrogen and organic nitrogen, the organic nitrogen contains proteins, urea, peptides, and other organic matters [12].

In spite of what was mentioned above, Nitrogen is regarded as a necessary nutrient in aquatic life. It significantly influences the growth of algae and other plants in freshwater [13]. The overloads of some of its compounds in surface waters is what concerns environmental researchers.

Phosphorus occurs in wastewaters and natural waters almost individually as phosphates. When Orthophosphates are applied to agricultural land as fertilizers, they are carried into the surface waters with the storm runoff. On the other hand, organic phosphates are mainly formed by biological processes. Phosphorus is necessary to the growth of organisms; it is one of the nutrients that limit the primary productivity of a water body.

The point and nonpoint sources of different pollution in small rivers, as like NH_3, NO_3, PO_4 and others, has an important role in the river's behavior as much as the self purification of the rive itself [14]. Several studies have been done to identify different types of nutrient loads in rivers around the world [7, 9, 15-25]. The ORP, Oxidation Reduction Potential, represents the water ability to oxidize contaminants. It is one of the essential indicators of natural and wastewater properties [26]. Higher numbers of ORP represents greater number of oxidizing agents.

The ORP may be related to some of the biological processes that happen in the aquatic environment, such as organic matter degradations, nitrification, and denitrification [27]. It can be used to classify the river condition; aerobic, anoxic, or anaerobic depending on the range of ORP concentration, as depicted in Fig. 1. It also gives an indication of the present state of the river; for example, the oxidation of ammonia to nitrate is performed when the ORP concentration lies between the ranges +100 to +350 mV, while the reduction of nitrate to nitrogen occurs during the ORP ranges +10 to − 50 mV [28]. Table 1 illustrates ORP values for different biochemical reactions.

The aim of this research was to study the effect of the effluents from the wastewater treatment plants of Al-

Rustimiyah on Diyala River with regard to nutrients distribution and other measurements, and to detect the pattern of the nutrient distribution along the reach of interest of Diyala River within Baghdad city.

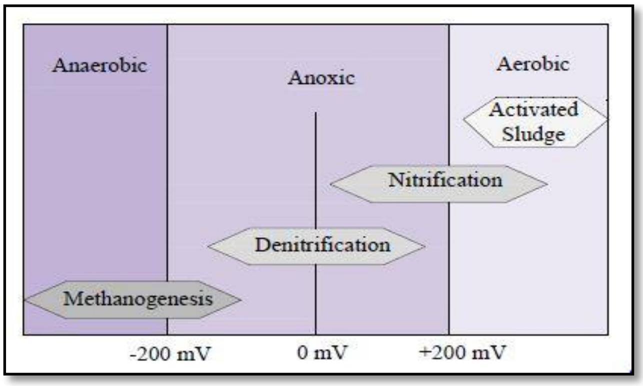

Fig.1: ORP ranges (mV) for typical wastewater processes [29].

Table 1: ORP values for different biochemical reactions [30].

Biochemical Reaction	ORP range, mV
Nitrification	+100 to +350
cBOD degradation	+50 to +250
Biological phosphorus removal	+25 to +250
Denitrification	+50 to -50
Sulfide (H_2S) formation	-50 to -250
Biological phosphorus release	-100 to -250
Acid formation (fermentation)	-100 to -225
Methane production	-175 to -400

II. MATERIALS AND METHODS

The study area

Diyala River is one of the tributaries of Tigris River. In the past, it contributed in about 11% of river Tigris's total water income. Unfortunately, know it is considered an effluent receiving water body.

The segment of Diyala River concerned in this study was opposite Al-Rustimiyah WWTPs, were pollution loads exceeds the standard concentrations by long shots, just before its confluence with Tigris River in about 15 km, and located within the capital city of Baghdad, Iraq.

This segment of Diyala River is exposed to multiple points of treated and raw municipal wastewater discharges. These are represented by the outfalls and bypass of three wastewater treatment plants (WWTP) of Al-Rustimiyah, R3, R2, R01. The WWTPs mentioned above are over loaded with influent that exceeds their operational capacities which in turn, affects the aquatic life of the receiving river represented by the river Diyala.

Figure 2 illustrates the zone of the study area and the locations of the WWTPs in the vicinity as well [31]. Several studies have been done on the river Diyala [32-36], in which none of them reported the nutrients' distribution in the river reach and their relation to other parameters.

Fig.2: The study area and the locations of the WWTP's along the reach[31].

Field Sampling

The river reach taken in this study was about 7 km long. It was divided into nine sites according to the points of pollution entering Diyala River (Fig.2). The first site was located upstream of all three WWTPs while further sites were located after each point of pollution submitted to the river, in an adequate distance to insure the mixing of pollutant with the river water. The final and ninth site was located downstream the last point of pollution were no other point inters the river till it pours into Tigris river. The location of each site was identified by the use of the GPS device. Figure 3 shows the locations of the sampling sites and their profile in kilometers along the river reach, with an indication to the position of the most polluted point among all. Table 2 illustrates the description and coordinate of each point.

Fig. 3: Sampling profile in kilometers along Diyala River in Baghdad.

Table 2: The description and coordinates of the nine sampling sites

Site No.	Description	Coordinates
S1	Upstream point	33º 17' 31.77" N 44 º 32' 16.66" E
S2	Bypass R3	33º 17' 29.18" N 44 º 32' 16.42" E
S3	Outfall R3	33º 17' 19.33" N 44 º 32' 15.95" E
S4	Bypass R2	33º 16' 27.87" N 44 º 32' 16.21" E
S5	Outfall R2	33º 16' 16.32" N 44 º 32' 2.08" E
S6	Outfall R01	33º 16' 25.83" N 44 º 31' 42.68" E
S7	Bypass R01	33º 16' 39.04" N 44 º 31' 43.00" E
S8	Army Channel	33º 16' 47.68" N 44 º 31' 36.55" E
S9	Downstream point	33º 16' 46.71" N 44 º 31' 34.23" E

The field sampling was carried out during a whole year starting from April 2014 till March 2015 in order to cover all seasonal variation that may occur in the region.

A polyethylene bottle was used to collect the samples of nutrients, ORP and other tests. All bottles were rinsed with de-ionized water before usage. During sampling, the bottles were rinsed with the river water at points of collecting samples three times before taking any sample. Afterwards, all samples of nutrient tests were preserved at a temperature of 4˚C and transferred to laboratory.

Field analysis and lab measurements

The measurements were classified into two categories; Field and laboratory measurements. The field measurements were represented by ORP, pH, and Temperature. On the other hand, the laboratory measurements were TN, TKN, NH_4-N, NH_3-N, NO_3-N, NO_2-N, P, and PO_4. Field measurements were conducted on site immediately after each sample taken in order to prevent any error in the results due to their sensitivity to time and location. Devices such as ORP meter, and pH meter were taken each trip to conduct the measurements onsite. The ORP, and temperature measurements were done by the use of the ORP 200 meter which adopts standard methods number 4500-H^+ of ORP measuring used in the APHA [12]. The pH measure was done by the use of the pH meter (pH 200) Lovibond. This device adopts the standard method number 4500-H^+ of pH measuring used in the APHA [12]. The laboratory measurements were carried out at The Environmental Research Center, University of Technology, Baghdad, Iraq. The TN test is done by the WTW photo lab S12 device, which adopts the standard method number 4500-N-C of TN measuring, used in the APHA [12]. NH_4-N, NH_3-N, NO_3-N, NO_2-N, P, and PO_4 tests were done by the C200 Multiparameter Bench photometer device. This device adopts the Nessler method number D1426-92 of NH_3-N and NH_4-N measuring used in the ASTM

Manual of Water and Environmental Technology [37], the Cadmium Reduction method of NO_3^--N measuring and the Ferrous Sulfate method of NO_2^--N measuring used in the ASTM Manual of Water and Environmental Technology [38], the 4500-P E. Ascorbic acid method for PO_4^{-3} and P measuring used in the APHA [12]. The TKN was calculated from relations in literature [10].

III. Results and discussion

ORP

The ORP levels at the river reach were very low during the year and along sites. The lowest ORP concentration occurred at site number two during summer season with a value of -352 mV followed by site number four and seven respectively, as depicted in Fig. 4. The highest ORP value occurred during the spring at site number one with a value of 75mV. All sites, except for number one, recorded negative ORP values during the year.

When comparing the ORP results with Fig. 1, the river reach can be classified from site number two and downstream as anoxic conditions during winter to anaerobic conditions during summer.

It is concluded, when compared to Table 1, that acid formation and methane production might occur at the river reach during the summer. This can be the reason of the strong odor observed on site especially during summer.

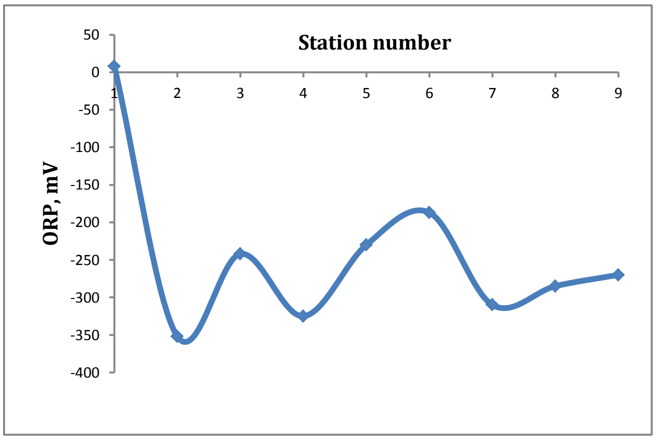

Fig. 4: ORP pattern along the river reach during August, 2014.

Nitrogen Compounds

The nitrogen compounds, measured in this study, varied along the river reach, as depicted in Fig. 5. The highest concentration among all four compounds of ammonium, ammonia, nitrate, and nitrite was the ammonia followed by ammonium, while the nitrite and nitrate concentrations were rather low. The nitrate and nitrite concentrations increased, in small portions, at the sites where the ammonia and ammonium decreased, which complies the natural cycle of nitrogen compounds transformation.

NO_2-N and NO_3-N concentrations had a minimum value of zero, at some site, during winter and a maximum value of 4.2 and 5.8 mg/l respectively, during the summer. Both were within the Iraqi effluent standard, but not within the Iraqi stream standard, taken from the Iraqi rivers protection act number 25 [39]. This indicates that the water at the river reach was rather an effluent than a stream.

The minimum concentrations of NH_3-N and NH_4-N were 2.16 and zero mg/l respectively, while their maximum concentrations were 46.8 and 32.9 mg/l respectively. When compared to the typical compositions of untreated domestic wastewater shown in literature [11], the water should be classified as untreated wastewater of high strength at site two and between low and medium strength at other sites except for site one.

The TN concentrations gave their lowest values at site one, like others, but its highest average levels occurred at sites nine, two, and seven, as illustrated in Fig. 5. This may be attributed to the additional components in the total nitrogen, such as protein, DNA, urea and benzalkonium [10]. The maximum individual TN concentration was 114 mg/l, which was measured at site two during summer season. When comparing the TN concentrations with the typical compositions of untreated domestic wastewater shown in literature [11], the river could be classified as highly strengthen untreated wastewater during summer at site two, seven, and nine and between low and medium strength at other sites except for site one, which almost matches the classification obtained above with respect to ammonia concentrations. The TKN average trend shows an identical pattern with the TN. The small, almost undetected, difference between TN and TKN indicates the absence of NO_x-N compounds in the river reach which matches the measurements. The difference between the TKN curve and the NH_3-N curve indicates the presence of organic nitrogen in the river reach especially at sites nine, seven, and two. The high levels of NH_3-N at sites two and four might indicate the beginning of organic nitrogen transformation, in which ammonia is the first stage of the organic nitrogen degradation.

In general, site one gave the lowest values of all nitrogen compounds compared to the rest, while sites two, four, and seven were high in some of the nitrogen compounds levels. This can be attributed to the presence of the bypasses of AL-Rustimiyah WWTPs at these sites, as depicted in Table 2. Finally, site nine gave high concentrations of TN and TKN only; this might be attributed to the presence of the fresh raw sewage discharged temporarily into the river at this site during the last four months of monitoring which increased their average values. This also means that the organic nitrogen was at its highest levels and its degradation has not started yet at this site.

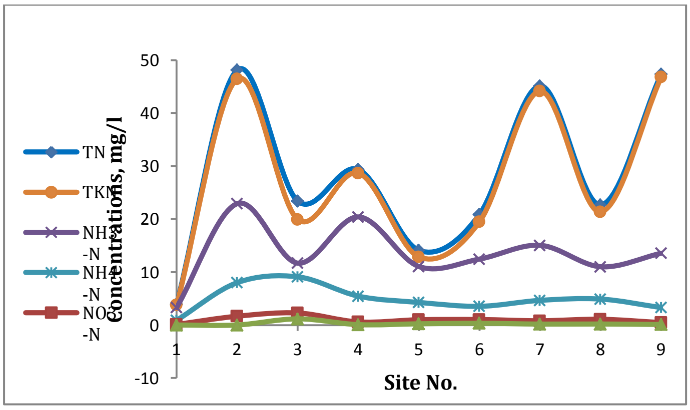

Fig. 5: Average nitrogen compounds concentrations along the river reach.

Phosphate

Phosphate concentrations were found almost constant during the year along the river reach starting from station two and downstream. Its concentrations ranged between 6 and 10 mg/l, while station one gave a smaller value as usual, this can be illustrated in Fig. 6.

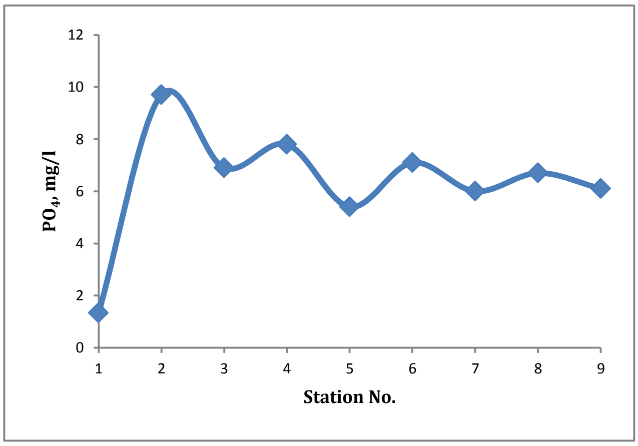

Fig. 6: PO_4 concentrations at the river reach during March, 2015.

ORP – Nitrogen compounds relations

The relation between ORP and the nitrogen compound measured in this study was found to be reversed for most of them. This could be explained simply as follows; the presence of high concentrations of NH_4-N, for instance, consumes the available DO during oxidation. Figure 7 shows the relations between the average values of the TN, and NH_4-N concentrations along the river reach and the corresponding average ORP concentrations.

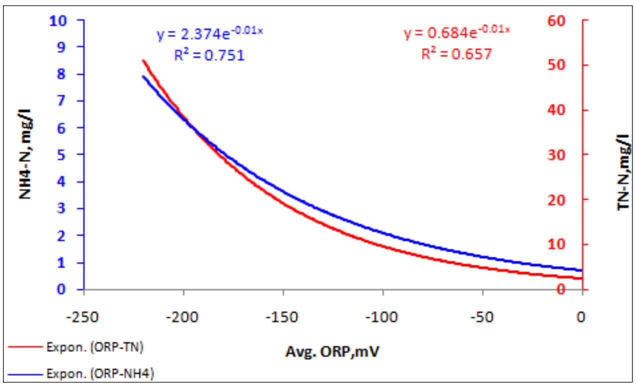

Fig. 7: ORP relations with TN and NH_4-N

ORP – Phosphate relation

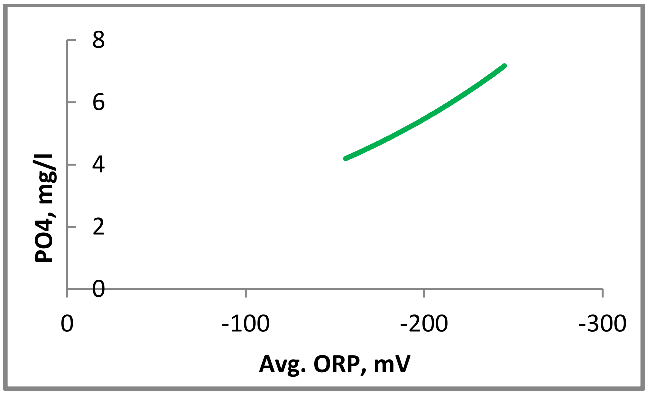

Fig. 8: ORP relations with TN and NH_4-N

The relation between ORP and Phosphate measured was found to be reversed as illustrated in Fig. 8. This can be attributed to the fact that the presence of Phosphate is related to the presence of pollutants that will lead to the depletion of oxygen and by that in decrease of ORP values.

Statistical Analysis of Results

The statistical analyses of the measured parameters are summarized in Table 3.

Table 3: Statistical analysis of the studied parameters

Parameter	Unit	Min	Max	Mean	Standard Deviation	Variance	Range	Standard Error
PO_4-P	mg/l	0.6	12	7	±0.83	0.42	11.4	5.37
TN	mg/l	2.7	114	27.21	±21.16	447.8	111.3	3135.2
TKN	mg/l	2.68	113.96	25.81	±22.00	484.4	111.28	3391.44
NH_4-N	mg/l	0	32.9	5.48	±25.99	675.55	32.9	4872.32
NH_3-N	mg/l	2.16	46.8	17.73	±12.99	168.83	44.64	1205.91
NO_3-N	mg/l	0	5.8	1.08	±1.12	1.253	5.8	9.04
NO_2-N	mg/l	0	4.2	0.25	±0.61	0.37	4.2	2.66
ORP	mV	-352	75	-175.55	86.08	7409.7	427	8.65

IV. Conclusions

The final reach of Diyala River, opposite Al-Rustimiyah WWTP's, was monitored. Parameters such as ORP, TN, TKN, NH_4-N, NH_3-N, NO_3-N, NO_2-N, and PO_4-P were tested. The study area was found heavily contaminated. The pollutants were at maximum levels next to sites 2, 4, and 7 which are located downstream the bypasses of Al-Rustimiyah WWTPs, the concentrations varied at other sites of the river reach with respect to the location taken. The opposite can be said on the ORP levels in which the maximum concentrations occurred at site 1 before any discharge from the WWTPs flow into Diyala River. The minimum levels of ORP occurred at site 2 which had the highest levels of contaminants among all.

As for the nitrogen and phosphorous compounds, the river reach could be categorized as untreated wastewater of high strength at site two and between low and medium strength at other sites excluding site one.

The ORP, nitrogen, and phosphorous compounds relations were found to be reversed, which complies with the fact that ORP decreases with the presence of pollutants.

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