Novel Nano Aerator for Cleaning a Eutrophicated Lake

Performance Evaluation Report

Dr. Aviraj Datta

Scientist-Wastewater Management

Mr. Jagjit Singh Kochar

Chairman and Managing Director

KBK Environ Infrastructures Limited

ICRISAT INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

EMPOWERING INDIA KBK GROUP SINCE 2004

Performance evaluation report of a novel nano aerator for cleaning a eutrophicated lake

Brief introduction to nanobubble aeration: Nanobubble aeration is an emerging area of science and engineering. The main advantage of the nanobubble aeration is the significantly higher surface area per cubic meter of air it can achieve. Moreover, some reports suggest that due to its very small size, nanobubbles take longer time to rise to the water surface, as it experiences minimal upward buoyancy force. Some argue that nanobubbles exhibit Brownian motion inside a water column. The large surface area and longer residence time inside the water column together make this mode of aeration efficient in terms of SOTE (specific oxygen transfer efficiency). However, there is lot of research going on to make this process consistent, cost-effective and easy to operate. With advancement made in instrumentation and material science, generating nanobubble economically and consistently has become possible. It is worth mentioning here that the term 'Nanobubble aeration' is often used to describe aerators which produce predominately 'micro' or 'mini' air-bubbles. Moreover, there are several different methods of generating nanobubbles. Often nanobubbles are produced by making a homogenous liquid undergo a phase change caused by sudden pressure reduction below a critical value, this method is known as cavitation. Based on hydrodynamic cavitation mechanism or by applying shear force, often bulk volume of nanobubbles get generated.

Background of the study: In recent decades, impact of water quality on crop productivity has seen increasing research interest. Particularly for leafy vegetables, strawberry, or tomato cultivation under controlled environment, an increase of productivity of up to 15% has been reported by some researchers when crops were irrigated with water having higher dissolved oxygen concentration. Recent studies carried out in China has reported an increase in rice yield, reduced cultivation period and reduced methane emission when paddy fields were irrigated with water having higher dissolved oxygen concentration (Wang et al., 2021). Moreover, most of the ponds, lakes and other surface irrigation sources near human settlements are experiencing the ever-increasing load of anthropogenic pollution. Hence, it was felt that this study would give us a firsthand efficacy of the nanobubble aeration technology and its potential while cleaning a eutrophicated lake located inside ICRISAT Patancheru campus. The lake known as Red Tank, located in the red soil area of the campus has been receiving domestic wastewater and storm water from a nearby housing colony for several years. This inflow of pollution has gradually made the lake eutrophicated. The total area of the lake for which this performance evaluation was carried out was about 9.4 ha. The depth of the lake varied between 1.2 m to 1.5 m. No dredging operation has been carried out in the lake in the recent years and the quantity of benthic sludge accumulated in the lake was unknown (Fig 1).

Placement of the aerator: The nanobubble aerator supplied by KBK group was placed near the point of pollution inflow in the flow channel about 200 m upstream of the point of outfall in the lake. The location is marked as Aeration Point in Fig 1. This location was chosen by the KBK team, the Farm and Engineering Services (FES) team of ICRISAT kindly facilitated the installation with suitable platform and electric supply. Near the point of pollution inflow, the pollutant concentration being highest, it was felt that providing aeration at this location will be ideal.

Description of the equipment: The novel nanobubble aerator equipment provided by KBK had a flowrate of 12 m^3 per hour. The machine was operated with a 5 HP pump. The innovatively designed equipment has an in-built oxygenator. The equipment received from KBK claims to produce air-bubbles of less than 200 nm. However, the size of the bubbles could not be verified during the study. Details of the instrument, flowrate of oxygen from the oxygenator and overall specific oxygen transfer efficiency of the equipment was beyond the scope of this evaluation.

Fig 1: The lake, aeration point and sampling points at ICRISAT Patancheru campus

Mode of operation: The equipment was installed and operated by two technicians from KBK for the entire duration of the demonstration. The equipment started operating on 8th June 2022. Typically, it was running between 9.30 am to 4.30 pm. Dissolved oxygen (DO) concentration was noted at different locations at different time intervals of the day (Table 1). The machine was operated till 5.00 pm on 23rd June. The idea was to observe the residual impact on dissolved oxygen concentration during the next 4 days.

Scope of the evaluation: The scope of this study was to evaluate the impact of this novel equipment on water quality and not the evaluation of the instrumentation for its merits.. The main objective of this evaluation was to observe the effect of the nanobubble aeration equipment on the dissolved oxygen (DO) concentration profile of the lake. The DO measurements were carried out by a hand-held DO probe after due calibration (Make: Eutech; Model No. PCD650). As there was no system in place to measure the inflow of wastewater/storm water, exact quantitative assessment of the impact of the aeration on other water parameters such as chemical oxygen demand or ammoniacal-nitrogen concentration or any other parameters was beyond the scope of this evaluation. However, we could do qualitative assessment via grab sampling and analysis of water from different locations. The rainfall and weather data during the study period noted at the weather station located in ICRISAT campus is provided in Annexure-1.

Findings of our study:

Observations in the wastewater channel: The shallow flow channel carrying the wastewater flow from the inflow point to the lake had two hydraulically connected segments (Fig 1). The segment near the wastewater inflow point was having an area of 0.54 ha whereas the segment near the lake was having an area of 0.36 ha. During the first day of operation i.e. on 8th June, ammonia smell was noticed near the aeration point. However, the smell subsided over the next two days. Probably the aeration in the water column triggered volatilization of ammoniacal-nitrogen present in the water. Due to power fluctuations the nanobubble aerator stopped working for some time on 10th June. The equipment is provided with in-built safety mechanism against voltage fluctuations which switches it off automatically in case of such voltage fluctuations. An increase in DO level was observed near the aeration point and DO raise was observed from 1.68 mg/L to about 10 mg/L during the period of aeration. The sludge accumulated at the bottom of this channel was seen rising to the water surface as small clumps during 11th June to 15th June period (Fig 2). The increased sunlight penetration triggered growth of algae in this shallow channel. From 14th June onwards, high DO level was observed in the wastewater channel immediately after starting the aerator, hence from 16th June onwards (on each day at 09.00 hrs), the first DO value noted was before the start of the aerator. This was done to check whether there was any residual impact of nanobubbles on the DO levels (Annexure-II, Table 1). No such residual impact was observed in the wastewater channel. Hence, it was concluded that the channel being shallow gets affected by the inflow of wastewater frequently and bulk of the nano-bubbles might have traveled along the flow direction to the lake itself which is deeper and has a much higher water volume. As mentioned above, the wastewater channel is divided in two segments and at the juncture of the two segments i.e. at sampling point 3 (Fig 1), DO values never reached 7 mg/L. This is interesting as higher DO values were observed both upstream and downstream of this point consistently. Being a location near the channel bent, higher benthic sludge volume may be the

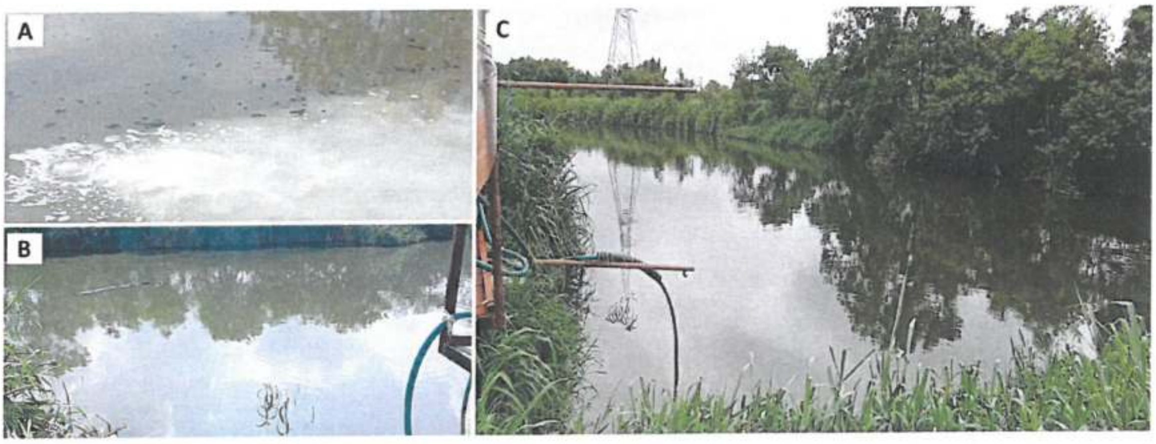

Fig 2: Effect of nanobubble aeration near the aeration point: A) clumps of benthic sludge was seen at the water surface B) water colour turned grey on 18th June; C) clear water surface observed 22nd June onwards.

The probable reason for this observation. The COD value (Annexure-II, Table 2) did show slight gradual dip at this location though high ammoniacal-nitrogen (Annexure-II, Table 3) concentration highlights that the site remained anoxic in nature.

Observations in the lake water quality:

The nanobubble aerator despite having a low flow rate of only 12 m^3/hr, could improve the dissolved oxygen concentration of the lake over the period of this study. Sampling Point 4 represented the quality of water in the lake (Fig 1). Normal DO level observed during the sunlight hours for this lake was 6 – 7 mg/L which is typical of a eutrophicated lake with algal infestation. The impact of the aeration on the DO level of the lake was noticed and on 11th June DO level reached 10.4 mg/L. This rise of DO level above 10 in just 3-4 days of operation was encouraging. As we continued the aeration for a few more days, DO levels started increasing faster for the lake as the aerator began to function. By 15th June, DO level reached 12.51 mg/L (Annexure-II, Table 1). The sunlight penetration (Fig 3) in the lake water column increased which was reflected by the low turbidity (Annexure-II, Table 5) level of approximately 10 NTU (Nephlometric Turbidity Unit).

Fig 3: Red Lake on 15th June 2022 at ICRISAT Patancheru campus

The rapid increase of dissolved oxygen concentration at sampling point 4 was indicative of the impact of the aeration. Considering the small capacity of 12 m^3/hr its impact on a 9.4 ha sizelake was truly remarkable. Such positive dissolved oxygen concentration if maintained consistently over a period of few weeks can significantly clear the sludge accumulated at the bottom of a lake or pond. It is not possible though to accurately predict the timeframe in absence of information about the volume of the accumulated sludge or inflow. However, I it is worth mentioning that the volume of accumulated sludge and the exact inflow of wastewater remains unknown for most polluted lakes in India. Hence, this evaluation was more qualitative in nature rather than precise quantification. After the first significant rainfall event since the start of the study period, there was a dip in the DO level in the lake before the start of the aerator (Annexure 1). This may be due to inflow of high pollutant load to the lake. It's worth mentioning here that dissolved oxygen concentration gets influenced by photosynthesis activity of the algae present in the water column and passive natural aeration at the water surface as well. Hence, the evaluation does not claim that the higher DO level observed was solely due to the nanobubble aerator alone and the positive impact of the nanobubble aeration on the dissolved oxygen concentration of the lake was evident. Overall, nanobubble aerator was found to be an efficient aeration system which, despite its relatively small aeration capacity, could influence the dissolved oxygen concentration of a large water body.

Assessment based on other water quality parameters:

Chemical oxygen demand: A significant improvement of the lake water quality could be attributed to nanobubble aeration as a gradual decrease in the chemical oxygen demand (COD) concentrations was observed for the lake. As already mentioned in the previous section, dissolved oxygen concentration being a function of multiple factors such as photosynthesis, natural aeration at the water surface etc., measurement of chemical oxygen demand (COD) was carried out at different sampling locations, often during several times of the day to assess whether there was any tangible improvement of lake water quality in terms of COD ((Annexure-II, Table 2). The sampling and analysis of COD was carried out by closed reflux method as per the standard methods prescribed by American Public Health Association (APHA). Overall, the COD of the lake showed tangible but gradual decrease during this rather short evaluation period. The significantly higher than usual inflow of wastewater at the onset of monsoon affected the study, particularly after 20th June. Nevertheless, the positive impact on the lake water quality in terms of COD was noted. Once the aerator stopped operating on 23rd June, COD value in the lake showed steady pattern for the next two days. The COD values observed for sampling point 3 was not showing any pattern., Probably the shallow nature of the channel and benthic sludge present at this channel bent both influenced COD values.

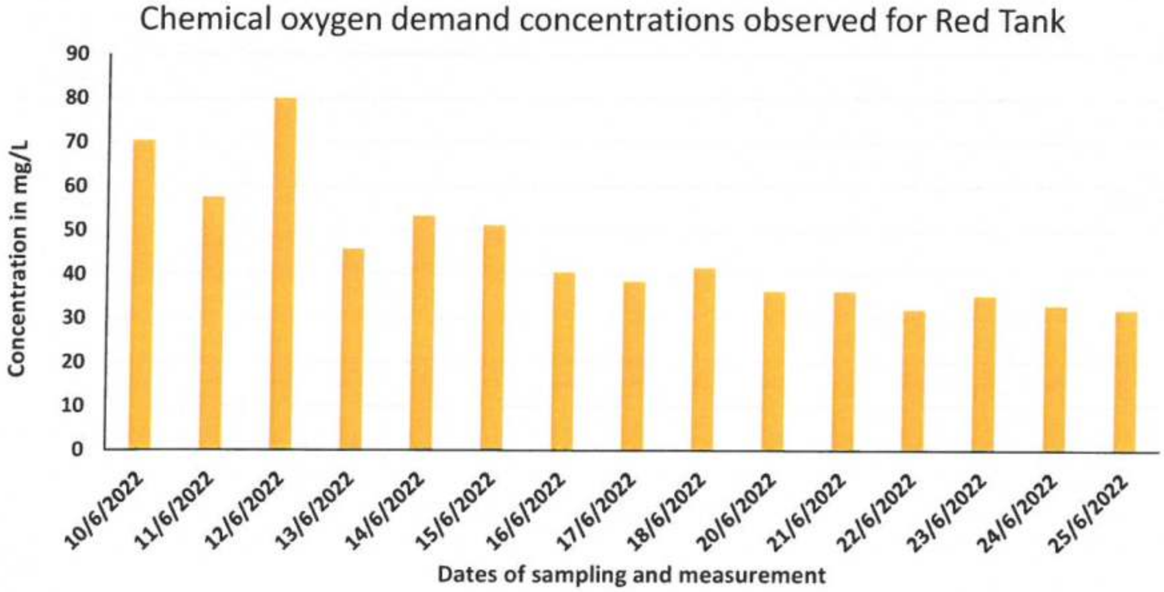

Fig 3: Gradual decrease of chemical oxygen demand concentration observed in Red Tank

Turbidity: As an effect of nanobubble aeration, the bottom sludge of the water body may get oxidized and may alter the turbidity level in the water column above. Hence, turbidity level was monitored for the study period at multiple locations (Annexure-II, Table 5). The turbidity of the lake water showed significant decrease from a high value of 14.5 NTU to 5.72 NTU over a period of about 12 days of aeration. Oxidation of the suspended fine organic particles present in the water column due to higher dissolved oxygen concentration might be the reason for the drop in turbidity. There was a visible increase in the sunlight penetration into the lake water (Fig 4). Rainfall event of 21st June (Annexure 1) resulted in large storm water inflow into the lake and a as a result post 21st June an increase in turbidity was observed in the lake.

31st May 2022 **20th June 2022**

Fig 4: Gradual decrease of chemical oxygen demand concentration observed in Red Tank Lake

Inorganic nitrogen and phosphate: The impact of high dissolved oxygen concentration in the lake was reflected by the ammoniacal-nitrogen and nitrate-nitrogen concentrations observed in the lake (Annexure-II, Table 3 and Table 4). These measurements provide a validation of the overall oxic state of the lake during the study period. The phosphate concentration was not affected much by the aeration process (Annexure-II, Table 6). This is not surprising as aeration is an oxidative process. However, phosphate concentration was monitored to understand the state of eutrophication in the lake. The data suggests that the phosphate concentration in the lake was relatively low.

Limitations observed: The operation of the equipment required the presence of skilled technicians which may be difficult in remote locations and increase operational cost. The equipment gets affected by voltage fluctuations common in many parts of India.

On behalf of the **International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)**	On behalf of **KBK Environ Infrastructures Limited**
Aviraj Datta	
Dr. Aviraj Datta Scientist-Wastewater Management *Dated:* 18-07-2022	**Jagjit Singh Kochar** Managing Director *Dated:* 18-07-2022

References:

1. Wang, Ying & Wang, Shuo & Sun, Jingjing & Dai, Hengren & Zhang, Beijun & Xiang, Weidong & Hu, Zixin & Hu, Jianhua & Li, Pan & Yang, Jinshui & Zhang, Wen. (2021). Nanobubbles promote nutrient utilization and plant growth in rice by upregulating nutrient uptake genes and stimulating growth hormone production. *Science of The Total Environment*, (800), 149627 (DOI: 10.1016/j.scitotenv.2021.149627).

2. Wang, Shuo & Liu, Yunsi & Lyu, Tao & Pan, Gang & Li, Pan. (2020). Aquatic Macrophytes in Morphological and Physiological Responses to the Nanobubble Technology Application for Water Restoration. *ACS EST Water* (DOI: 10.1021/acsestwater.0c00145).

Annexure -1: ICRISAT Weather data for the months of June 2022

Date	Rain (mm)	Evap	Max Temp (°C)	Min Temp (°C)	Rel Humidity at 7.17 hrs	Rel Humidity at 14.17 hrs
6/1/2022	12.4	9.9	38.4	21.4	82	35
6/2/2022	0	7.8	36.4	25.4	64	45
6/3/2022	0	8.6	38.6	25.2	56	27
6/4/2022	0	8.7	39.2	27.4	58	24
6/5/2022	0	8.8	39.2	22.6	72	20
6/6/2022	0	9.6	40	25.2	64	22
6/7/2022	0	8.1	37.6	26.4	62	30
6/8/2022	0	9.2	40.2	25.6	68	19
6/9/2022	0	7.8	36.6	23.8	68	37
6/10/2022	0	9.2	37.6	25.2	68	33
6/11/2022	0	8.8	37	23.2	76	37
6/12/2022	0	7.2	36.4	24.2	74	37
6/13/2022	0	8.3	36.4	23.4	71	37
6/14/2022	4.6	7.4	37.8	22.4	92	32
6/15/2022	0	6	36.2	23.2	84	45
6/16/2022	0	6.4	34.8	23.4	75	49
6/17/2022	2.2	4.2	35	23.4	88	45
6/18/2022	0	5.4	35.2	23.6	83	47
6/19/2022	0	6.2	35.6	23.6	77	45
6/20/2022	4.2	4	35	23.2	84	92
6/21/2022	82.4	4.6	35.2	20.6	95	47
6/22/2022	1.2	6.9	33.6	22.2	88	51
6/23/2022	0	6	32.6	22.8	90	52
6/24/2022	0	5.2	35.6	23	85	46
6/25/2022	8.4	6.2	32.6	22.4	80	49
6/26/2022	2	3.9	32.6	21.8	87	57
6/27/2022	6.2	4.1	31.2	21.4	90	58
6/28/2022	14.2	4	30	21.6	90	64
6/29/2022	13.4	5.2	31.6	21.6	90	57
6/30/2022	0	4.6	32.2	22.4	88	56

Annexure -2: Complete set of Water Quality Data generated during this study

Table 1: Dissolved oxygen (DO) concentration readings

Day	Date	Time	Unit	Sampling Point 1	Aeration Point	Sampling Point 2	Sampling Point 3	Sampling Point 4
4	11/6/2022	14:00	mg/L	1.73			4	8.56
		17:00	mg/L	1.13			5.28	10.37
5	12/6/2022	10:00	mg/L	1.2			3.83	10.39
		17:00	mg/L	2.25			2.8	9.51
6	13/6/2022	9:00	mg/L	1.72			3.83	6.78
		13:30	mg/L	1.57			4.51	8.54
		17:00	mg/L	1.93			3.75	9.15
7	14/6/2022	9:00	mg/L	2.12	7.34	6.22	3.69	8.62
		13:30	mg/L	1.22	6.73	5.87	2.83	8.37
		17:00	mg/L	2.37	3.54	5.45	3.11	8.23
8	15/6/2022	9:00	mg/L	1.29	7.57	7.25	4.28	7.58
		13:30	mg/L	1.38	10.74	7.54	5.81	9.38
		17:00	mg/L	2.19	8.57	6.99	5.26	12.51
9	16/6/2022	9:00	mg/L	2.76	1.45	1.33	4.2	7.83
		13:30	mg/L	2.09	10.64	9.2	6.92	11.72
		17:00	mg/L	2.29	7.17	6.42	4.88	4.6
10	17/6/2022	9:00	mg/L	1.94	1.59	1.89	2.28	6.56
		13:30	mg/L	2.15	6.89	11.53	5.53	12.01
		17:00	mg/L	2.11	6.38	4.66	4.5	15.94
11	18/6/2022	10:00	mg/L	1.64	2.76	3.55	3.3	6.64
13	20/6/2022	9:00	mg/L	1.55	1.45	2.65	3.37	3.96
		13:30	mg/L	2.58	2.97	12.37	6.85	6.75
		17:00	mg/L	1.82	3.51	8.25	6.74	7.01
14	21/6/2022	9:00	mg/L	4.2	4.6	3.4	5.5	8.4
		13:30	mg/L	4.07	3.61	6.45	4.39	10.12
		17:00	mg/L	2.75	3.1	5.3	5.06	5.38
15	22/6/2022	9:00	mg/L	1.38	1.2	2.7	1.8	7
		13:30	mg/L	2.68	8.15	6.45	5.93	9.25
		17:00	mg/L	2.04	2.08	4.72	4.84	13.95
16	23/6/2022	9:00	mg/L	1.64	1.38	1.09	1.18	3.78
		13:30	mg/L	2.43	5.55	10.85	6.83	8.52
		17:00	mg/L	1.68	2.16	9.51	6.52	9.42
17	24/6/2022	9:00	mg/L	2.97	1.32	1.83	1.32	3.29
		13:30	mg/L	2.35	3.23	7.5	2.04	6.57
		17:00	mg/L	1.79	0.87	9.85	2.55	8
18	25/6/2022	13:30	mg/L	2.29	12.68	12.33	2.48	6.91
19	27/6/2022	9:00	mg/L	1.94	1.08	2.35	1.47	5.6
		13:30	mg/L	2.81	5.29	5.42	1.64	7.52
		17:00	mg/L	1.84	3.05	3.66	2.26	8.39

Table 2: COD values observed at different sampling locations during the study period

Date	Unit	Sampling Point 1	Sampling Point 3	Sampling Point 4
10/6/2022	mg/L	160.00	92.80	70.40
11/6/2022	mg/L	144.00	108.80	57.60
12/6/2022	mg/L	150.40	99.20	80.00
13/6/2022	mg/L	129.07	97.07	45.87
14/6/2022	mg/L	116.27	100.27	53.33
15/6/2022	mg/L	132.27	86.40	51.20
16/6/2022	mg/L	113.07	90.67	40.53
17/6/2022	mg/L	101.33	75.73	38.40
18/6/2022	mg/L	108.80	83.20	41.60
20/6/2022	mg/L	96.00	75.73	36.27
21/6/2022	mg/L	105.60	72.53	36.27
22/6/2022	mg/L	123.73	75.73	32.00
23/6/2022	mg/L	131.20	77.87	35.20
24/6/2022	mg/L	129.07	75.73	33.07
25/6/2022	mg/L	128.00	89.60	32.00

Table 3: Ammoniacal-nitrogen (NH_4^+-N) concentrations observed at different sampling locations

Date	Unit	Sampling Point 1	Sampling Point 3	Sampling Point 4
10/6/2022	mg/L	6.720	5.698	0.865
11/6/2022	mg/L	5.687	4.480	0.594
12/6/2022	mg/L	5.060	4.091	0.615
13/6/2022	mg/L	5.686	5.174	0.663
14/6/2022	mg/L	6.422	5.369	0.596
15/6/2022	mg/L	5.915	5.446	0.672
16/6/2022	mg/L	6.143	5.718	0.681
17/6/2022	mg/L	6.283	5.543	0.638
18/6/2022	mg/L	6.608	5.513	0.635
20/6/2022	mg/L	6.107	5.581	0.727
21/6/2022	mg/L	5.783	5.203	0.686
22/6/2022	mg/L	5.433	4.655	0.818
23/6/2022	mg/L	4.662	4.243	0.826
24/6/2022	mg/L	3.812	3.573	0.667
25/6/2022	mg/L	4.576	3.507	0.563

Table 4: Nitrate-nitrogen (NO_3^-) concentrations observed at different sampling locations

Date	Unit	Sampling Point 1	Sampling Point 3	Sampling Point 4
10/6/2022	mg/L	4.113	3.030	3.823
11/6/2022	mg/L	4.290	3.383	3.717
12/6/2022	mg/L	3.984	3.529	3.426
13/6/2022	mg/L	3.375	2.725	3.204
14/6/2022	mg/L	3.012	2.840	3.093
15/6/2022	mg/L	3.101	2.814	3.341
16/6/2022	mg/L	2.827	2.903	3.478
17/6/2022	mg/L	2.920	2.872	3.286
18/6/2022	mg/L	3.085	2.928	3.188
20/6/2022	mg/L	2.522	2.443	3.215
21/6/2022	mg/L	2.685	2.197	3.069
22/6/2022	mg/L	3.294	2.422	3.241
23/6/2022	mg/L	3.626	2.493	3.235
24/6/2022	mg/L	3.571	2.903	3.303
25/6/2022	mg/L	3.797	3.606	3.197

Table 5: Turbidity values observed (Make: Oakton, Model No. T-100 Handheld)

Date	Unit	Sampling Point 1	Sampling Point 3	Sampling Point 4
10/6/2022	NTU	27.6	13.5	14.5
11/6/2022	NTU	28.4	16.1	8.3
12/6/2022	NTU	23.2	19.2	12.6
13/6/2022	NTU	19.04	16.80	11.13
14/6/2022	NTU	17.79	14.98	7.79
15/6/2022	NTU	20.15	16.85	11.91
16/6/2022	NTU	19.26	15.04	10.61
17/6/2022	NTU	20.49	16.04	11.18
18/6/2022	NTU	19.55	13.86	7.67
20/6/2022	NTU	14.04	8.04	5.72
21/6/2022	NTU	19.98	11.31	7.96
22/6/2022	NTU	22.39	12.62	8.50
23/6/2022	NTU	21.34	12.63	9.26
24/6/2022	NTU	20.86	13.72	10.30
25/6/2022	NTU	25.77	15.34	12.89

Table 6: Phosphate (PO_4^{3-}) values observed

Date	Unit	Sampling Point 1	Sampling Point 3	Sampling Point 4
10/6/2022	mg/L	0.214	0.138	0.047
11/6/2022	mg/L	0.229	0.124	0.078
12/6/2022	mg/L	0.147	0.114	0.056
13/6/2022	mg/L	0.160	0.119	0.049
14/6/2022	mg/L	0.149	0.130	0.071
15/6/2022	mg/L	0.171	0.139	0.054
16/6/2022	mg/L	0.163	0.154	0.059
17/6/2022	mg/L	0.157	0.106	0.051
18/6/2022	mg/L	0.163	0.167	0.048
20/6/2022	mg/L	0.147	0.083	0.042
21/6/2022	mg/L	0.133	0.088	0.034
22/6/2022	mg/L	0.170	0.099	0.032
23/6/2022	mg/L	0.159	0.094	0.041
24/6/2022	mg/L	0.127	0.096	0.028
25/6/2022	mg/L	0.156	0.14	0.02