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Ecological Health and the Economics of Water Quality: An Assessment of Kolong River, Assam, India

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Abstract River health has become one of the most important environmental issues today because of multiple anthropogenic stressors and other artificial interventions that have led to adverse long-term impacts on the physical habitats, biodiversity, ecological functions and the services provided by a water body. Kolong river, located in Assam, India, has suffered a similar fate with it being listed among the 275 most polluted rivers of India by the Central Pollution Control Board, Government of India, in 2015. This study has been carried out with the primary objective of diagnosing chemical and biological river health of the Kolong river with regard to physico-chemical parameters and abundance of the plankton community, using statistical analysis. Four sites along the river were selected for sampling purposes, namely, Jakhalabandha (Station 1), Samoguri (Station 2), Nagaon town (Station 3) and Roha (Station 4). Thirteen physico-chemical parameters were considered for the study and data were collected month-wise for which results have been shown season-wise (pre-monsoon, monsoon, retreating monsoons and winter). Tests for physico-chemical parameters were done through standard methods. Means and standard deviations along with the Karl Pearson's correlation coefficients were also calculated. Findings indicate significant relationships among the physico-chemical parameters as well as correlation of the abundance of phytoplankton and zooplankton with abiotic factors the river which was further computed by a regression analysis. Phytoplankton dominated over zooplankton in all the Stations in the present study. High abundance of Bacillariophyceae, in case of phytoplankton, and Copepods, in case of zooplankton, were encountered, indicating poor ecological health of the Kolong river. The study also involves a briefing on the economics of water quality and relevant economic strategies for managing ecological quality of Kolong. The study finally asserts on the need for minimising anthropogenic disturbances through both government and people participation, so as to manage pollution while preserving the ecological heath of the Kolong river.

Keywords: *Kolong river, ecological health, physico-chemical, anthropogenic, environment, water economics*

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1. Introduction

Rivers play a vital role in the existence and survival of numerous plant and animal species while nurturing humanity. But due to industrialisation and enormous growth of human civilisation, the ecological health of rivers has come under constant threat, resulting from discharge of sewage and industrial effluents, municipal solid waste, agricultural waste etc., which have adversely impacted the quality of water carried by rivers [1]. Ecological health of a river, as such, relates to ecosystem productivity, its biological diversity and its resilience to the negative impacts of a variety of pressures.

The concept of river health originates from river ecosystem health and is not confined to river ecosystem only. A river has both, natural and social attributes that individually contribute to the overall health of water bodies. Ecosystem health is formed by the interaction between river biota and existing physicochemical parameters of the specific river. River health depends upon the diversity of habitats, plants and animal species, the effectiveness of the linkages and the maintenance of ecological processes. Riparian habitat is a key element of river functioning [2,3,4]. The river and stream habitats [5] can support high biodiversity, especially, in large floodplain rivers [6], protect the main channel from temporal changes [7] and provide refuge and food for wildlife [8]. Moreover, with regard to the economic aspect of water quality, two kinds of benefits arise from clean water, namely, withdrawal benefits and instream benefits [9]. The former pertains to personal hygiene and other benefits associated with household water-use and the latter relates to aesthetic and other commercial benefits from water-use.

Deterioration of river health not only endangers and harms natural ecosystems and the lives of inhabiting species, but also imposes increased costs on households as well as the society. As such, apart from ecological assessments of river health, examining the economics of water quality is central to the idea of environmental policymaking.

The Kolong river, which once used to be a prize possession for the people of Assam and widely perceived to be of high ecological quality with abundant flow volume and high water quality, is presently gasping on its death-bed because of ruthless and untenable acts perpetrated on it in the name of engineering solutions to prevent increasing flood hazards attributed to it in the aftermath of the great Assam earthquake of 1950. These floods were a result of the raised bed level of the Brahmaputra, relative to Kolong, through massive sedimentation because of the earthquake. A consequence of this was inundation of the latter's adjoining areas such as Nagaon town. As a response, the Hatimura dyke was constructed across the river's take-off point in 1964. This drastic intervention resulted in converting the once free flowing river into a string of alternating dry stretches and stagnant pools during the decades that followed, hampering the health of the river and the ecosystem it fostered. Moreover, river flow regulations and land use changes have altered the physico-chemical characteristics of Kolong inflicting harmful consequences on the aquatic biota.

The ecological health of rivers with regard to physico-chemical parameters have been widely studied across the globe. The best instances include the Greater Zab River, Iraq [10], River Haraz, Iran [11], Imo River, Nigeria [12], River Thames, UK [13], and Kenti River, Republic of Karelia [14]. [15] and [16] as part of their research work on the biological assessment and ecological health of rivers of Korea, concluded that that the ecological health of lotic water bodies is extremely influenced by rampant anthropogenic actions. Very recently, [17] studied the ecological health of river Geum in Korea using Chemical Parameter Model and reported the river to be in an abnormal condition, suggesting immediate action for proper management of restoring its health.

As regards India, studied have been conducted for the Yamuna River [18], Ganga River and its tributaries [19], Sutlej River [20] and Jhelum River [21]. More works in similar lines can be found on the ecological assessment of rivers by [22] and [23].

Few scientific investigations on water quality assessment on of Kolong River was done by [24], [25] and [26]. Their observations highlight the concentration of fluoride in groundwater samples collected from Kolong river basin which ranged between 0.03 mg/l and 5.68 mg/l. [26] reported the causes of increased pollution level of Kolong's water to be mainly discharge of various domestic and commercial wastewater, sewage and effluents. Moreover, the truncated river flow accompanied with diminished flow velocity have reduced the self-assimilation and self-purification capacity of Kolong river [27].

Besides these, [24] worked on the analysis of Water Quality Index (WQI) parameters and its seasonal variations along the Kolong River. They concluded that there are variations in water quality in different seasons in a same site. Moreover, variations in water quality in different sites along the river were also witnessed. However, studies assessing the ecological health of the Kolong river with regard to physico-chemical parameters and phytoplankton composition, and their interrelationships, are very scanty.

Therefore, the present study aims to determine the influence of physico-chemical parameters and abundance of plankton community in different seasons and their interrelationships on ecological health of the river Kolong, which is prone to anthropogenic pressures. Th year 2018 has been taken as the study period. The study also includes a brief analytical discussion on the economics of its water quality and associated management strategies.

2. Materials and Method

2.1. Study Area

Kolong river is located in the Nagaon District of Assam, India. It has a total length of about 230 km. and is a distributary (*suti* in local language) of the Brahmaputra which branches out near Jakhalabandha, about 77 Km upstream of Nagaon and meets again at Kajalimukh near Guwahati in a joint channel with the Kopili river, a major South bank tributary of Brahmaputra. During its course, the river meets with several smaller rivers viz. Diju, Misa, Haria and Digaru. The total basin area of the river is about 5300 sq. km. which lies in the northern plain region of Nagaon and Morigaon Districts. The geographical coordinates of the origin point are 92º 59' 38" East and 26º35'21" North, whereas those of the confluence point with Brahmaputra are 91º57'51" E and 26º14'41" N.

Four sampling stations were selected as part of the study, namely, Jakhalabandha, Samoguri, Nagaon Town and Roha for the investigation. The distance between Station 1 (Jakhalabandha) and Station 2 (Samoguri) is 33.6 km; between Station 2 (Samoguri) to Station 3 (Nagaon Town) is 21.6 km and between Station 3 (Nagaon Town) to Station 4 (Roha) is 20 km. Except Station 3, all the stations are located in rural areas. Station 1 is located at 92° 59" E and 26° 35" N, Station 2 is at 92° 50" E and 26° 24" N, Station 3 is at 92° 40" E and 26° 21" N, and Station 4 is at 92° 31" E and 23° 13" N.

Based on the distribution of rainfall, the year has been climatologically classified into four seasons [28], namely, pre-monsoon (March, April and May), monsoon (June, July, August and September), retreating monsoon (October and November) and winter (December, January and February). Data has been collected for each station for the four seasons, for the year 2018.

2.2. Physico-Chemical Parameters

Thirteen water quality parameters were considered for the present study which are water temperature (WT), transparency (Trans.), pH, total alkalinity (TA), total hardness (TH), conductivity (Cond.), chloride (Cl), magnesium (Mg), phosphate (PO_4), sulphate (SO_4), dissolved oxygen (DO), biological oxygen demand (BOD) and chemical oxygen demand (COD) were analysed following standard procedures recommended by the American Public Health Association (APHA) [29]. Water temperatures were recorded for all the stations which were measured immediately after the collection of samples.

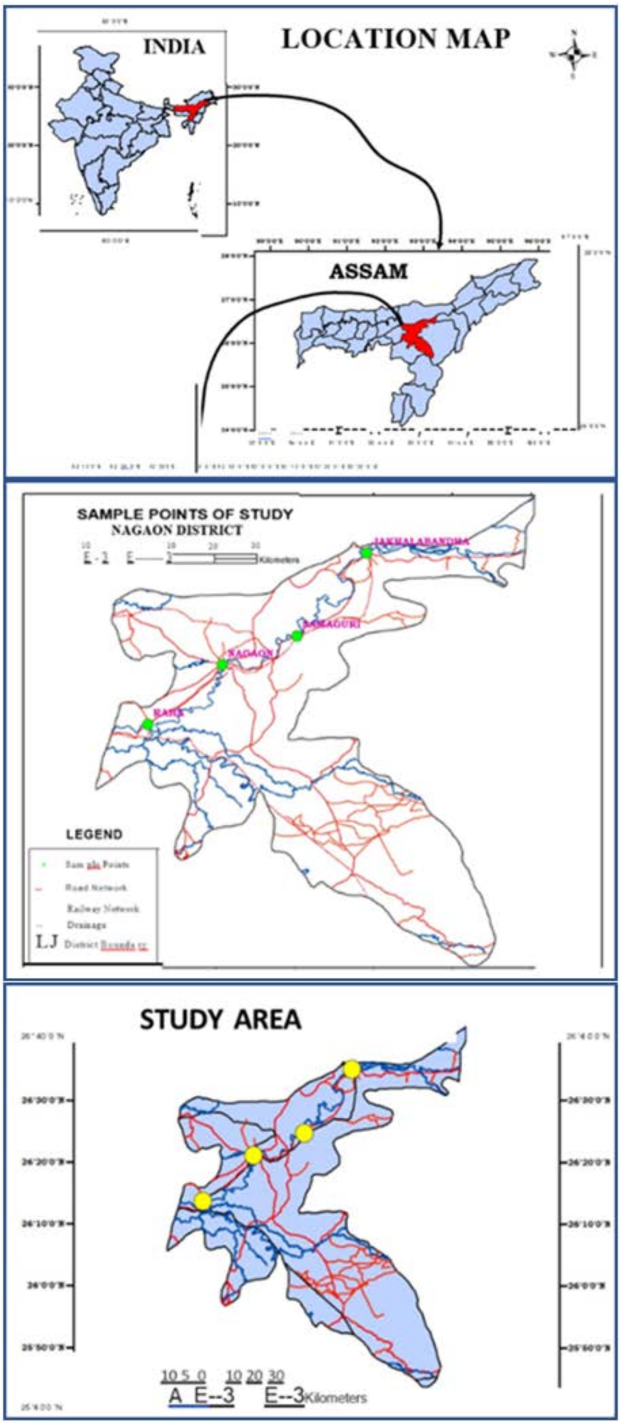

Figure 1. Location and map of sampling sites

2.3. Plankton

Monthly plankton samples were collected from the four stations for all the four seasons. Collection was done by filtering 100 litre of water through a plankton net made of bolting silk (standard grade No.25 with a mesh size of 60 microns). Samples were collected in early hours of the day and preserved in 4% formaldehyde for analysis. These were later transferred to a 100 ml. borosil graduated centrifuge tube and kept for about 24 hours so as to allow the organic elements to settle, following which, the volume was noted. Macro plankton were removed from the sample. The sample was then stirred to ensure even distribution of the organism and from each, 1 ml was transferred with a narrow-mouthed pipette to a Sedgwick Rafter counting cell and the phytoplankton number were calculated [30]. Identification of plankton was made as per guidelines of [31,32].

2.4. Statistical Interpretation

The data relating to thirteen physico-chemical parameters and plankton were subjected to statistical interpretation after the analysis of water samples. The IBM SPSS (v20.0) package was used for this purpose. Besides this, Pearson's correlation coefficient (r) was calculated to find out the relationship among the thirteen variables. The significance of correlation was reported at 5% level and 1% level based on the probability value. Regression model for inter-relationship of different physico-chemical parameters and that of plankton population was derived for further analysis.

The regression model is of the form:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_n X_n + \varepsilon \qquad (1)$$

where, β, β_1 ... β_n = Constants to be determined, Y = Plankton abundance (U/l), X_1 = Water temperature (ºC), X_2 =pH, X_3 = Transparency (cm), X_4 = Alkalinity (mg/l), X_5 = Hardness (mg/l), X_6 = Conductivity (µmhos/cm), X_7 = Chloride (mg/l), X_8 = Magnesium (mg/l), X_9 = Phosphate (mg/l), X_{10} = Sulphate (mg/l), X_{11} = Dissolved oxygen (mg/l), X_{12} = B.O.D. (mg/l), X_{13} = C.O.D. (mg/l), ε = Error component

2.5. Economics of Water Quality

The idea of analysing the economic implications of water quality or ecological health of a river body, traditionally relates to the economic efficiency associated with it. The methodology of the present study includes a discussion on the economic implications of Kolong's water quality subject to the investigation of its ecological health within a broader perspective, rather than a quantitative analysis of treatment costs and other relevant externalities.

3. Discussion

For evaluating the ecological health of a river or any aquatic ecosystem, the essential pre-requisites include estimating the status of various water quality parameters and their analyses. In the present study, thirteen physico-chemical parameters comprising of temperature, pH, conductivity, alkalinity, hardness, transparency, chloride, magnesium, sulphate, phosphate, DO, BOD and COD of water were analysed. Mean values of the data with standard deviations have been reported in Table 1a, Table 1b, Table 1c, and Table 1d. Karl Pearson's correlation coefficients of the thirteen physico-chemical parameters have been presented in Table 2a, Table 2b, Table 2c and Table 2d. The correlation between plankton and various parameters in all the four stations have been calculated (raw data is not shown here) and the trend of plankton abundance have been presented in Figure 2a, Figure 2b, Figure 2c, Figure 2d, Figure2e for phytoplankton and Figure 3a, Figure 3b, Figure 3c, Figure 3d, Figure 3e for zooplankton.

Table 1a. Mean value and Standard Deviation of Physico-Chemical parameters in Station 1 (2018)

	Pre-Monsoon		Monsoon		Retreating Monsoon		Winter	
Water Parameters	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Water Temperature (^{0}C)	28.43	±0.51	29.58	±1.51	25.9	±1.38	20.98	±1.41
pH	7.05	±0.31	6.92	±0.43	7.53	±0.17	7.7	±0.18
Transparency (cm)	49.25	±3.66	38.7	±5.52	53.78	±5.02	51.75	±4.34
Total Alkalinity (mg/l)	70.08	±3.24	85.1	±5.34	74.9	±3.32	72.53	±5.18
Total Hardness (mg/l)	111.6	±9.61	82.65	±5.70	89.9	±6.55	98.4	±3.80
Conductivity (µmhos/cm)	156.25	±9.18	180.75	±6.70	145.25	±6.45	134.25	±6.99
Chloride (mg/l)	55.55	±4.62	41.35	±4.78	37.78	±4.52	32.48	±4.85
Magnesium (mg/l)	35.75	±4.86	40.8	±3.63	31.5	±5.32	28.53	±1.86
Phosphate (mg/l)	1.1	±0.22	1.53	±0.31	1.35	±0.24	0.75	±0.26
Sulphate (mg/l)	6.73	±1.42	8.33	±1.43	5.33	±1.99	4.03	±0.99
Dissolved Oxygen (mg/l)	5.9	±0.43	6.6	±0.53	6.15	±0.21	5.75	±0.39
B.O.D (mg/l)	4.85	±0.26	3.43	±0.62	4.68	±0.40	6.05	±0.91
C.O.D. (mg/l)	10.03	±0.99	10.95	±1.12	11.88	±1.16	16.28	±1.58

Table 1b. Mean value and Standard Deviation of Physico-Chemical parameters in Station 2 (2018)

	Pre-Monsoon		Monsoon		Retreating Monsoon		Winter	
Water Parameters	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Water Temperature (^{0}C)	25.78	±1.29	28.23	±2.32	23.33	±2.01	21.53	±2.15
pH	7.23	±0.25	7.05	±0.31	7.58	±0.46	7.63	±0.43
Transparency (cm)	59.03	±5.72	40.5	±4.88	67.08	±4.81	51.85	±4.86
Total Alkalinity (mg/l)	70.7	±10.71	92.58	±7.90	76.9	±12.76	84.55	±8.29
Total Hardness (mg/l)	158.45	±23.68	125.25	±6.04	127.93	±10.15	131.68	±13.23
Conductivity (µmhos/cm)	211.25	±25.94	264.5	±18.16	200	±13.29	155.75	±17.35
Chloride (mg/l)	57.43	±14.14	57.15	±13.71	43.7	±16.98	37.43	±11.72
Magnesium (mg/l)	48.05	±13.78	52.13	±14.52	41.4	±8.64	34.93	±6.69
Phosphate (mg/l)	1.15	±0.37	2.08	±0.46	1.93	±0.53	0.95	±0.42
Sulphate (mg/l)	8	±2.84	11.63	±4.86	6.93	±2.89	4.85	±2.09
Dissolved Oxygen (mg/l)	7.28	±0.75	7.55	±0.70	6.93	±0.46	6.43	±0.88
B.O.D (mg/l)	4.4	±0.80	3.63	±1.00	4.28	±0.87	4.53	±0.76
C.O.D. (mg/l)	10	±1.04	10.95	±1.20	13	±1.60	15.15	±1.71

Table 1c. Mean value and Standard Deviation of Physico-Chemical parameters in Station 3 (2018)

	Pre-Monsoon		Monsoon		Retreating Monsoon		Winter	
Water Parameters	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Water Temperature (^{0}C)	24.93	±1.10	28.83	±1.15	21	±1.60	19.03	±1.42
pH	6.95	±0.34	6.88	±0.40	6.98	±0.35	6.95	±0.24
Transparency (cm)	45.95	±5.69	37.43	±4.95	59.05	±5.07	52.93	±3.30
Total Alkalinity (mg/l)	83.25	±8.11	75.93	±8.63	86.03	±7.01	108.68	±13.32
Total Hardness (mg/l)	127.75	±13.15	89.13	±11.92	95.18	±18.63	123.33	±9.93
Conductivity (µmhos/cm)	123	±16.39	140.5	±11.96	111	±10.74	107.25	±13.23
Chloride (mg/l)	67.63	±13.95	68.13	±9.53	64.88	±6.63	45.08	±6.18
Magnesium (mg/l)	35.8	±6.31	44.4	±6.80	34.35	±6.12	29.73	±6.08
Phosphate (mg/l)	1.05	±0.42	2.18	±0.51	1.75	±0.62	1.05	±0.34
Sulphate (mg/l)	9.6	±1.57	12.13	±1.24	7.93	±1.54	5.73	±1.36
Dissolved Oxygen (mg/l)	5.33	±0.80	6.05	±0.83	5.28	±0.82	5.1	±0.83
B.O.D (mg/l)	5.65	±0.77	5.23	±0.96	5.48	±0.64	5.85	±0.88
C.O.D. (mg/l)	12.8	±1.85	13.45	±2.07	15.05	±1.78	19.18	±2.30

Table 1d. Mean value and Standard Deviation of Physico-Chemical parameters in Station 4 (2018)

	Pre-Monsoon		Monsoon		Retreating Monsoon		Winter	
Water Parameters	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Water Temperature (^{0}C)	24.93	±1.15	28.4	±2.09	20.75	±1.19	18.85	±1.01
pH	7.1	±0.22	6.98	±0.28	7.18	±0.30	7.25	±0.29
Transparency (cm)	52.6	±7.92	43.3	±6.07	71.6	±7.49	65.73	±6.32
Total Alkalinity (mg/l)	85.08	±7.85	65.18	±7.85	71.55	±7.86	94.53	±9.86
Total Hardness (mg/l)	141.85	±9.50	121.23	±5.57	125.15	±5.83	131.73	±7.76
Conductivity (µmhos/cm)	220	±14.83	263.75	±9.29	188	±18.09	162	±12.99
Chloride (mg/l)	61.83	±8.17	57.6	±9.13	51.3	±6.83	40.3	±7.37
Magnesium (mg/l)	40.68	±5.13	50.23	±7.51	39.28	±6.35	33.75	±4.82
Phosphate (mg/l)	1.08	±0.28	1.95	±0.31	1.3	±0.39	0.88	±0.25
Sulphate (mg/l)	7	±0.91	9.93	±1.03	5.98	±0.81	3.95	±0.60
Dissolved Oxygen (mg/l)	7.13	±0.25	7.33	±0.35	6.33	±0.68	6.1	±0.65
B.O.D (mg/l)	4.2	±0.29	3.45	±0.58	4.43	±0.51	4.95	±0.50
C.O.D. (mg/l)	9.78	±1.21	11.45	±1.94	12.35	±1.85	16.5	±1.64

Table 2a. Correlation between various physico-chemical parameters for Station 1 (2018)

	W.T.	p^H	Trans.	T.A.	T.H.	Cond.	Cl.	Mg.	PO_4	SO_4	D.O.	B.O.D	C.O.D
W.T.	1												
p^H	-0.91983	1											
Trans.	-0.65042	0.867336	1										
T.A.	0.476723	-0.59179	-0.83512	1									
T.H.	-0.14762	0.166414	0.471444	-0.87727	1								
Cond.	0.882579	-0.96312	-0.92634	0.783203	-0.42556	1							
Cl.	0.698662	-0.622	-0.18538	-0.24935	0.604464	0.404435	1						
Mg.	0.919224	-0.98916	-0.89627	0.69537	-0.30716	0.991446	0.519559	1					
PO_4	0.826176	-0.68655	-0.58255	0.739247	-0.63134	0.799945	0.20787	0.767966	1				
SO_4	0.943566	-0.98711	-0.86512	0.67236	-0.29303	0.985396	0.549154	0.997678	0.792798	1			
D.O.	0.717419	-0.71878	-0.79165	0.936338	-0.78835	0.874013	0.007943	0.812997	0.92617	0.812235	1		
B.O.D	-0.89567	0.85607	0.781549	-0.80323	0.569569	-0.9397	-0.30959	-0.91671	-0.95691	-0.9277	0.95223	1	
C.O.D	-0.95455	0.783839	0.398544	-0.2222	-0.05193	-0.70239	-0.80554	-0.76396	-0.7397	-0.80446	0.52866	0.758079	1

Table 2b. Correlation between various physico-chemical parameters for Station 2 (2018)

	W.T.	p^H	Trans.	T.A.	T.H.	Cond.	Cl.	Mg.	PO_4	SO_4	D.O.	B.O.D	C.O.D
W.T.	1												
p^H	-0.97882	1											
Trans.	-0.54048	0.610655	1										
T.A.	0.290338	-0.27223	-0.84127	1									
T.H.	0.082678	-0.2022	0.312867	-0.77606	1								
Cond.	0.969627	-0.90153	-0.48812	0.368169	-0.11877	1							
Cl.	0.935459	-0.94711	-0.33109	-0.04137	0.42345	0.846988	1						
Mg.	0.987672	-0.95981	-0.40707	0.142781	0.184031	0.953862	0.967349	1					
PO_4	0.575536	-0.40149	-0.15062	0.412858	-0.58822	0.757718	0.35037	0.563332	1				
SO_4	0.977241	-0.9263	-0.58209	0.437787	-0.12872	0.993523	0.843007	0.946937	0.711035	1			
D.O.	0.979166	-0.93577	-0.35896	0.128165	0.151799	0.96212	0.953132	0.996864	0.615505	0.947315	1		
B.O.D	-0.84004	0.760152	0.666338	-0.69125	0.47071	-0.91941	-0.59604	-0.77124	-0.81727	-0.93421	0.77955	1	
C.O.D	-0.86019	0.859245	0.125927	0.235561	-0.52415	-0.77599	-0.97771	-0.92359	-0.3233	-0.75158	0.91855	0.470784	1

Table 2c. Correlation between various physico-chemical parameters for Station 3 (2018)

	W.T.	p^H	Trans.	T.A.	T.H.	Cond.	Cl.	Mg.	PO_4	SO_4	D.O.	B.O.D	C.O.D
W.T.	1												
p^H	-0.82557	1											
Trans.	-0.89645	0.817918	1										
T.A.	-0.8608	0.591888	0.54749	1									
T.H.	-0.42718	0.673535	0.165328	0.573811	1								
Cond.	0.989619	-0.89362	-0.92571	-0.80146	-0.46685	1							
Cl.	0.760951	-0.40631	-0.4106	-0.97692	-0.46424	0.675352	1						
Mg.	0.959587	-0.90627	-0.80565	-0.8742	-0.6625	0.96785	0.751751	1					
PO_4	0.600658	-0.80378	-0.36762	-0.67301	-0.97765	0.640988	0.544066	0.801091	1				
SO_4	0.987902	-0.80946	-0.81896	-0.92435	-0.5246	0.968886	0.835847	0.976074	0.677873	1			
D.O.	0.91738	-0.97321	-0.82882	-0.76015	-0.68672	0.954613	0.60443	0.979162	0.824028	0.919148	1		
B.O.D	-0.79296	0.816497	0.524038	0.871305	0.879715	-0.79836	-0.76801	-0.92414	-0.94692	-0.86341	-0.89629	1	
C.O.D	-0.80787	0.38835	0.520597	0.948459	0.290613	-0.71729	-0.97499	-0.73844	-0.40393	-0.85325	-0.58768	0.671993	1

Table 2d. Correlation between various physico-chemical parameters for Station 4 (2018)

	W.T.	p^H	Trans.	T.A.	T.H.	Cond.	Cl.	Mg.	PO_4	SO_4	D.O.	B.O.D	C.O.D
W.T.	1												
p^H	-0.98937	1											
Trans.	-0.93127	0.886959	1										
T.A.	-0.65213	0.750283	0.372855	1									
T.H.	-0.17976	0.313089	0.035837	0.71631	1								
Cond.	0.994249	-0.99925	-0.90001	-0.72623	-0.27767	1							
Cl.	0.820181	-0.78428	-0.65833	-0.52343	0.199534	0.796542	1						
Mg.	0.945912	-0.98283	-0.81262	-0.84359	-0.48003	0.975003	0.699401	1					
PO_4	0.807726	-0.88298	-0.64973	-0.91539	-0.72088	0.86457	0.488245	0.953963	1				
SO_4	0.971125	-0.99524	-0.84043	-0.81101	-0.3858	0.99096	0.767578	0.994283	0.917495	1			
D.O.	0.979252	-0.94285	-0.92789	-0.53115	0.020828	0.954666	0.88813	0.865686	0.676139	0.911323	1		
B.O.D	-0.96593	0.993032	0.830264	0.822636	0.402941	-0.98795	-0.76066	-0.99581	-0.92466	-0.99978	-0.90283	1	
C.O.D	-0.74054	0.713624	0.538092	0.539082	-0.19965	-0.72359	-0.98824	-0.63866	-0.44167	-0.70687	-0.81141	0.701737	1

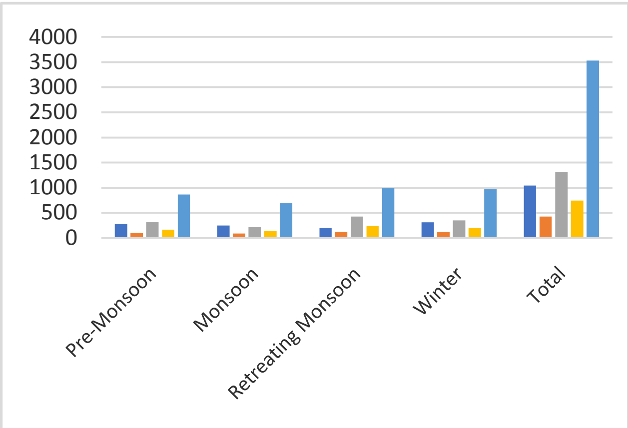

Figure 2a. Phytoplankton in Station 1

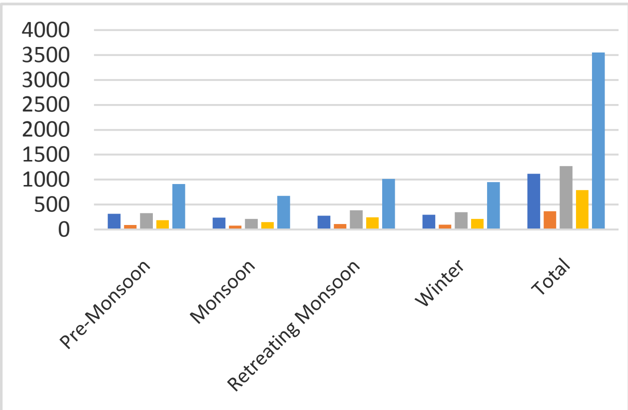

Figure 2b. Phytoplankton in Station 2

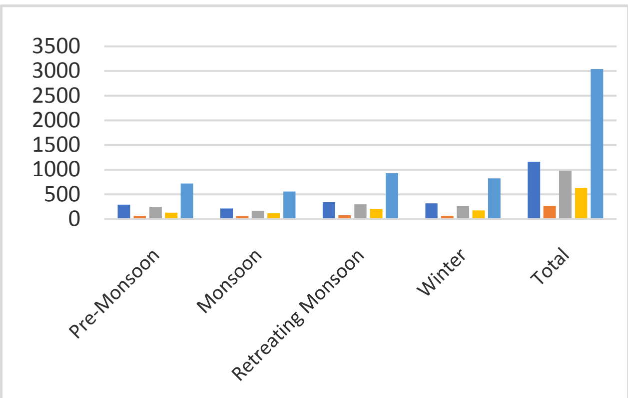

Figure 2c. Phytoplankton in Station 3

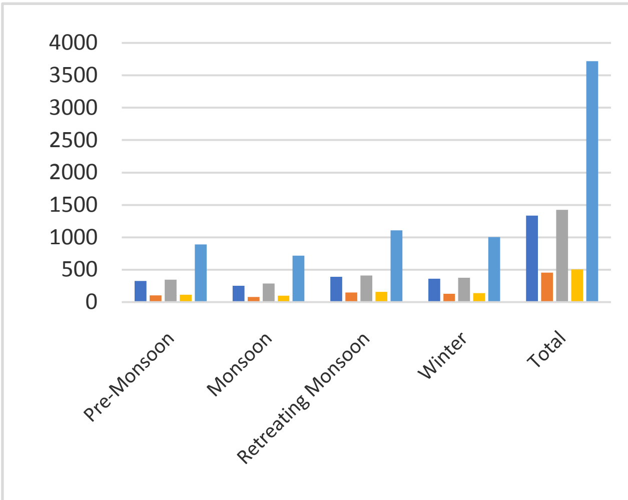

Figure 2d. Phytoplankton in Station 4

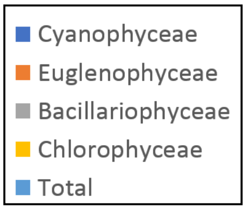

Figure 2e. Phytoplankton legend

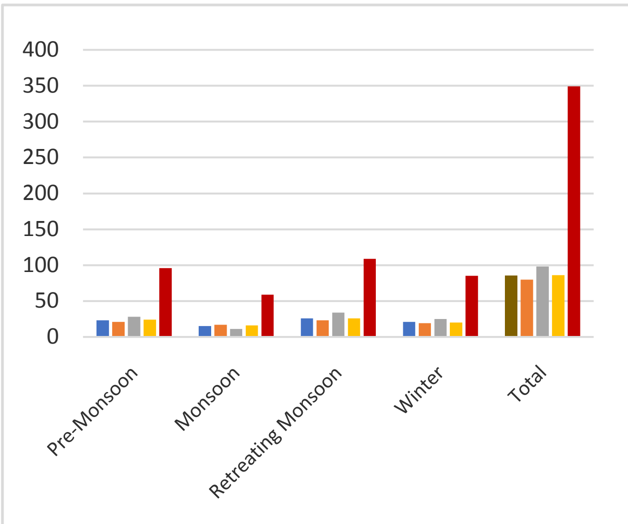

Figure 3a. Zooplankton in Station 1

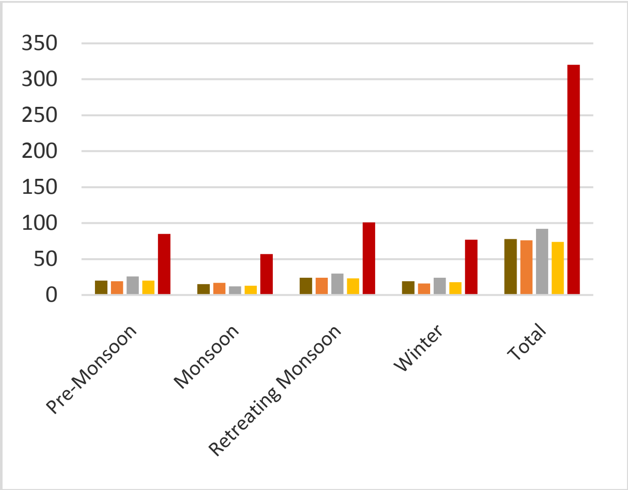

Figure 3b. Zooplankton in Station 2

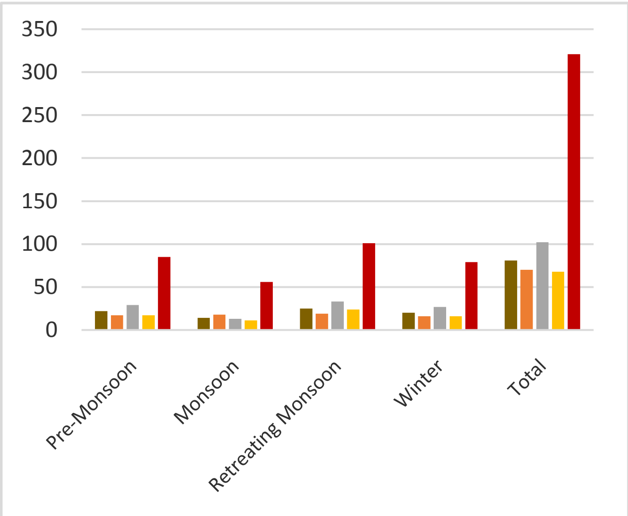

Figure 3c. Zooplankton in Station 3

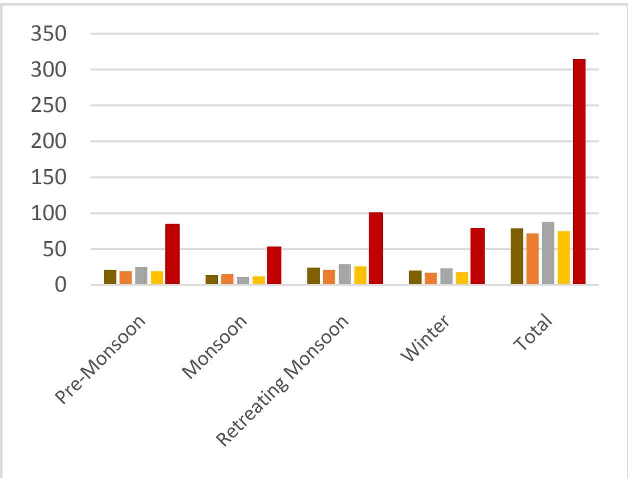

Figure 3d. Zooplankton in Station 4

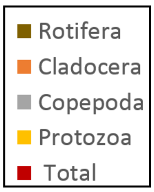

Figure 3e. Zooplankton legend

3.1. Water Temperature, pH, Transparency and Alkalinity

Temperature plays an important role for controlling the physico-chemical and biological parameters of water and is considered to be one of the most important factors in an aquatic environment, particularly for freshwater. As regards water temperature of the Kolong river during 2018, values recorded in the present study corroborates with already published works for tropical areas [33,34]. The mean value of temperature for Station 1 ranged from 20.98 ± 1.41 in the winter season to 29.58 ± 1.51 in the monsoon season. In case of Station 2, mean value ranged from 21.53 ± 2.15 (winter) to 28.23 ± 2.32 (monsoon); from 19.03 ± 2.15 (winter) 28.83 ± 1.15 (monsoon) in Station 3, and 18.85 ± 1.01 (winter) to 28.40 ± 2.09 (monsoon) in Station 4. In general, higher temperatures were observed during the monsoon season while low temperatures were observed during the winter season. The findings of the present study corroborate with those of [33] for Nila River and [34] for Pennar River of India.

The balance of pH in ecosystems is essential for the well-being of all organisms. Generally, pH affects the way in which an organism functions and, while it may be monitored in public drinking water, it is especially important in natural aquatic ecosystems since it affects the efficiency of enzymes to carry out their respective processes. The delicate balance of pH not only affects an individual organism, but all organisms that are interconnected in an ecosystem. In the present study, low pH values were recorded during the monsoon season and marginally high values during the retreating monsoon, winter and pre-monsoon season. In particular, the mean value for pH ranged from 6.92 ± 0.43 (monsoon) to 7.70 ± 0.18 (winter) in Station 1; from 7.05 ± 0.31 (monsoon) to 7.63 ± 0.43 (winter) in Station 2; from 6.88 ± 0.40 (monsoon) to 6.95 ± 0.24 (winter) and 6.95 ± 0.34 (pre-monsoon) in Station 3, and 6.98 ± 0.28 (monsoon) to 7.25 ± 0.29 (winter) in Station 4. The mean values were found to be comparatively higher in Station 2 due to it being a major tourist spot, corroborating the study of [35] and also due to the addition of seasonal rain water. The pH trend increased from Station 1 to Station 2 which again lowered in Station 3. This is because Station 3 is an urban area where the river is highly exposed to municipal sewage and other industrial discharges from small-scale industries that have developed in the vicinity of the river. The increasing value of pH towards Station 4 could be attributed to the dilution of impurities in the river's due course.

Transparency measures how far light can penetrate a body of water. Sunlight provides the energy for photosynthesis and determines the depth at which algae and other plants can grow, defining the ecological make-up of a water body. Heavy rains may bring a change in water clarity due to deposition of silt and debris. As per the present analysis, mean value of transparency ranged from 38.7 ± 5.52 (monsoon) to 53.78 ± 5.02 (retreating monsoon) in Station 1; from 40.50 ± 4.88 (monsoon) to 67.08 ± 4.81 (retreating monsoon) in Station 2; from 37.43 ± 4.95 (monsoon) to 59.05 ± 5.07 (retreating monsoon) in Station 3, and from 43.3 ± 6.07 (monsoon) to 71.6 ± 7.49 (retreating monsoon) in Station 4. In general, highest transparency was observed during retreating monsoon season in all stations. All the stations had low transparency during monsoon season which may be due to higher sediments added to the river by the seasonal rainwater, which corroborates with the findings of [33,34].

Alkalinity is considered to be an index of aquatic productivity [36]. In the investigated sites, considerable differences in alkalinity were recorded, indicating notable variations in their water chemistry. The mean value of alkalinity ranged from 70.08 ± 3.24 (pre-monsoon) to 85.1 ± 5.34 (monsoon) in Station 1; from 70.7 ± 10.71 (pre-monsoon) to 92.58 ± 7.90 (monsoon) in Station 2; from 75.93 ± 8.93 (monsoon) to 108.68 ± 13.32 in Station 3, and from 65.18 ± 7.85 (monsoon) to 94.53 ± 9.86 (winter) in Station 4. Alkalinity values were found to be mostly higher in monsoon season, similar to findings reported by [37].

3.2. Hardness and Conductivity

Hardness is imparted to water by the presence of certain cations, mainly calcium and magnesium. It is the property of water which prevents lather formation with soap and increases boiling point. In the present analysis, seasonal variation of hardness revealed comparatively low values during monsoon months. It gradually increased and the maximum recorded value was observed in pre-monsoon season. The values were comparatively higher at Station 2 during the study period. High rate of evaporation and absence of fresh water influx by rain is the reason for high hardness values during the pre-monsoon season. The low values of total hardness during a monsoon season may be due to the dilution effect of rainwater. [38] has classified water bodies on the basis of hardness values as (0 – 60) soft, (61 – 120) moderately hard, (121 – 60) hard and (> 180) as very hard. Kolong river falls under the second category. In particular, the mean values of hardness ranged from 82.65 ± 5.70 (monsoon) to 111.60 ± 9.61 (pre-monsoon) in Station 1; from 125.25 ± 6.04 (monsoon) to 158.45 ± 23.68 (pre-monsoon) in Station 2; from 891.3 ± 11.92 (monsoon) to 127.75 ± 13.15 (pre-monsoon) in Station 3, and 121.23 ± 5.57 (monsoon) to 141.85 ± 9.50 (pre-monsoon) in Station 4.

Conductivity represents the amount of total dissolved substances present in water and is a measure of the resistance offered by them to electric flow. It is regarded as a valuable indicator of water quality and a parameter to assess the trophic status of aquatic ecosystem [39]. In all the four sampling sites, the mean values ranged from 134.25 ± 6.99 (winter) to 180.75 ± 6.70 (monsoon) in Station 1; from 155.75 ± 17.35 (winter) to 264.50 ± 18.16 (monsoon) in Station 2; from 107.25 ± 13.23 (winter) to 140.5 ± 11.96 (monsoon) in Station 3, and from 162 ± 12.99 (winter) to 263.75 ± 9.29 (monsoon) in Station 4. The values were maximum during the monsoon season and minimum during winter. This can be attributed to greater ionic concentration of the inlet flow. Conductivity at Station 3 was low compared to the other stations. Similar results have been observed by [40].

3.3. Chloride, Magnesium, Phosphate and Sulphate

The concentration of chloride is considered an index of organic pollution caused due to inflow of domestic waste waters. The mean values in our study ranged from 32.48 ± 4.85 (winter) to 55.55 ± 4.62 (pre-monsoon) in Station 1; from 37.43 ± 11.72 to 57.43 ± 14.14 (pre-monsoon) in Station 2; from 45.08 ± 6.18 (winter) to 68.13 ± 9.53 (monsoon) in Station 3 and from 40.3 ± 7.37 (pre-monsoon) to 61.83 ± 8.17 (winter) in Station 4. While the chloride content was found to be the most in Station 3, it was observed to be high in the monsoon season across all the sites. This could be attributed to its import from the catchment area with the rain water. Moreover, the slight increase in chloride levels in Station 3 was because of the high inflow of washing residues, industrial, biomedical and similar kind of wastes.

The concentration of magnesium in Kolong was found to be high in the monsoon season, and low in winter and pre-monsoon season. The mean values ranged from 28.53 ± 1.86 (winter) to 40.8 ± 3.63 (monsoon) in Station 1; from 34.93 ± 6.69 (winter) to 52.13 ± 14.52 (monsoon) in Station 2; from 29.73 ± 6.08 (winter) to 44.4 ± 6.80 (monsoon) in Station 3 and from 33.75 ± 4.82 (winter) to 50.23 ± 7.51 (monsoon) in Station 4. Such variations may be attributed to the inflow of rain water during monsoon. These findings are in conformity with the findings of [41].

Phosphorus is an essential micro-nutrient and critical abiotic factor which was known to limit the productivity in fresh waters [39]. The present investigation shows that concentration of phosphorus was found to be maximum during monsoon and minimum during winter. The mean values ranged from 0.75 ± 0.26 (winter) to 1.53 ± 0.31 (monsoon) in Station 1; from 0.95 ± 0.42 (winter) to 2.08 ± 046 (monsoon) in Station 2; from 1.05 ± 0.34 (winter) and 1.05 ± 0.42 (pre-monsoon) to 2.18 ± 0.51 (monsoon) in Station 3 and 0.88 ± 0.25 (winter) to 1.95 ± 0.31 (monsoon) in Station 4. Phosphate concentration was found to be maximum in Station 3 during monsoon season corroborating the findings of [42].

Besides phosphate, sulphate present in fertilizers and domestic sewage immensely contribute to water pollution, leading to eutrophication in water bodies. During the study period, sulphate value was found to be maximum in monsoon season and minimum in winter season. Similar result had been observed by [43]. The mean values for sulphate ranged from 4.03 ± 0.99 (winter) to 8.33 ± 1.43 (monsoon) in Station 1; from 4.85 ± 2.09 to 11.63 ± 4.86 (monsoon) in Station 2; from 5.73 ± 1.36 (winter) to 12.13 ± 1.24 (monsoon) in Station 3, and from 3.95 ± 0.60 (winter) to 9.93 ± 1.03 (monsoon) in Station 2. Maximum values were found at Station 3 during monsoon and lowest values were observed at Station 2. High sulphate concentration at Station 3 indicates high agricultural runoff and discharges of large quantities of organic compounds from industrial settlements as well as tanneries set up in the vicinity of Station 3.

3.4. Dissolved Oxygen

DO is considered to be one of the most important parameters essential for the survival and existence of a water body and its constituents. Lower the DO value of a water body, the more polluted it is. In the present study, DO was maximum during the monsoon season and very low in winter season. Mean values ranged from 5.75 ± 0.39 (winter) to 6.6 ± 0.53 (monsoon) in Station 1; from

6.43 ± 0.88 (winter) to 7.55 ± 0.70 (monsoon) in Station 2; from 5.1 ± 0.83 (winter) to 6.05 ± 0.83 (monsoon) in Station 3, and 6.1 ± 0.65 (winter) to 7.33 ± 0.35 (monsoon) in Station 4. In general, maximum values were recorded in Station 2 and minimum values at Station 3. It must be noted that the Bureau of Indian Standards (BIS) permissible limit for DO is 6 mg/l. The lower value during winter could be attributed to low water flow while the higher value pertains to seasonal flow of rainwater. The higher values in Stations 1 and 2 is due to the low pollution load in upstream areas while the high value in Nagaon town (Station 3) is obviated by the inflow of wastewater, effluents and other run-offs that adversely impact DO levels. Similar, result was also observed by [42].

3.5. BOD and COD

BOD and COD were found to be maximum in winter and minimum in monsoon season, corroborating the findings of [44]. BOD value was observed to be maximum at Station 3 and minimum at Station 2, validating the findings of [42]. During the monsoon season, BOD values were observed to be low as because temperature retards the rate of reproduction of organisms. Besides this, COD value was found to be maximum at Station 3 and minimum at Station 4, while being high in winter season and minimum in pre-monsoon season. In particular, the mean values of BOD ranged from 3.43 ± 0.62 (monsoon) to 6.05 ± 0.91 (winter) in Station 1; from 3.63 ± 1.00 (monsoon) to 4.53 ± 0.76 (winter) in Station 2; from 5.23 ± 0.96 (monsoon) to 5.85 ± 0.88 (winter) in Station 3, and from 3.45 ± 0.58 (monsoon) to 4.95 ± 0.50 (winter) in Station 4. Similarly, the mean values of COD ranged from 10.03 ± 0.99 (pre-monsoon) to 16.28 ± 1.58 (winter) in Station 1; from 10 ± 1.04 (pre-monsoon) to 15.15 ± 1.71 (monsoon) in Station 2; from 12.8 ± 1.85 (pre-monsoon) to 19.18 ± 2.30 (winter) in Station 3, and from 9.78 ± 1.21 (pre-monsoon) to 16.5 ± 1.64 (winter) in Station 4. The higher values of BOD and COD in Station 3 reiterate the fact that it is an urban area wherein the river is highly exposed to municipality and household wastes as well as washing and other residues. Lower values observed in Station 4 could be attributed to the further dilution effect of the river flow.

3.6. Analysis of Pearson's Correlation Coefficients

Recent studies such as [45] have inferred from their research that positive correlation occurs when one parameter increases as other parameters also increase, while negative correlation means that as one parameter increases, other parameters decrease.

Water temperature showed direct relation with TA (r = 0.47, r = 0.28), Cond. (r = 0.88, r = 0.96), Cl (r = 0.69, r = 0.82), Mg (r = 0.91, r = 0.96), PO_4 (r = 0.82, r = 0.54), SO_4 (r = 0.94, r = 0.89) and DO (r = 0.71, r = 0.85). On the other hand, inverse relation is seen with pH (r = - 0.91, r = - 0.98), BOD (r = - 0.89, r = - 0.97) and COD (r = - 0.95, r = - 0.84). This implies that alkalinity, conductivity and dissolved oxygen would increase with the rise in water temperature while the pH, BOD and COD levels of the river would decrease.

pH had direct correlation with Trans. (r = 0.86, r = 0.68), TH (r = 0.31, r = 0.30), BOD (r = 0.85, r = 0.95) and COD (r = 0.78, r = 0.88) but inversely related with Cond. (r = - 0.96, r = - 0.93), Mg (r = - 0.98, r = - 0.92), SO_4 (r - 0.98, r = - 0.88) and DO (r = - 0.71, r = - 0.87). This indicates that transparency, total hardness, BOD and COD levels will increase with a rise in the pH level, while conductivity and DO will decrease.

Transparency showed direct relation with BOD (r = 0.83, r = 0.58), COD (r = 0.53, r = 0.48) while showing inverse relation with TA (r = - 0.83, r = - 0.68) and Cond. (r = - .0.92, r = - 0.87). But in Station 3, Trans. showed direct relation with TA (r = 0.54, r = 0.71). As such, an increase transparency would lead to increased BOD and COD levels, while alkalinity and conductivity of the water will decrease.

Alkalinity showed direct relation with Mg (r = 0.69, r = 0.51), DO (r = 0.93, r = 0.55), PO_4 (r = 0.73, r = 0.49) and SO_4 (r = 0.67, r = 0.60), whereas, showing inverse relation with BOD (r = – 0.80, r = - 0.47) and COD (r = - 0.22, r = - 0.26). But in Station 3, Alkalinity showed direct relation with BOD (r = 0.87, r = 0.91) and COD (r = 0.94, r = 0.90) and inverse relation with DO (r = - 0.76, r = - 0.62). As such, a rise in alkalinity would result in higher DO along with magnesium, phosphate and sulphate concentration, while BOD and COD of the river would decrease.

Total hardness showed direct relation with BOD (r = 0.87, r = 0.57) and Cl (r = 0.60, r = 0.53) and inverse relation with Mg. (r = - 0.30, r = - 0.21) and COD (r = - 0.52, r = - 0.53). This implies that as the hardness of the river increases, BOD and chlorine concentration would also increase, while magnesium and COD level would decrease.

Conductivity directly correlated with WT (r = 0.88, r = 0.96), Cl (r = 0.69, r = 0.82), DO (r = 0.87, r = 0.93) but inversely correlated with TH (r = - 0.42, r = -0.28) and BOD (r = - 0.93, r = - 0.99). As such, a rise in conductivity could be attributed to higher water temperature, along with a rise in chlorine, DO, while total hardness and BOD decrease.

Chloride showed direct correlation with Mg (r = 0.51, r = 0.70), SO_4 (r = 0.54, r = 0.49), DO (r = 0.95, r = 0.60) but inverse relation with BOD (r = - 0.76, r = - 0.86) and COD (r = - 0.97, r = - 0.99). Magnesium had direct relation with TA (r = 0.69, r = 0.51) and Cond. (r = 0.99, r = 0.99) but inverse relation with BOD (r = - 0.91, r = - 0.99) and COD (r = - 0.76, r = - 0.68).

Besides, Phosphate had direct relation with WT (r = 0.82, r = 0.54), Cond. (r = 0.79, r = 0.66), Cl (r = 0.35, r = 0.20), Mg (r = 0.51, r = 0.70) and DO (r = 0.95, r = 0.60). while showing inverse relation with pH (r = - 0.40, r = - 0.78), TA (r = - 0.91, r = - 0.94), TH (r = - 0.63, r = - 0.74), BOD (r = - 0.81, r = - 0.91) and COD (r = - 0.44, r = - 0.47). Further, SO_4 had direct relation with WT (r = 0.94, r = 0.89), Cl (r = 0.84, r = 0.44), Mg (r = 0.94, r = 0.86) and DO (r = 0.94, r = 0.92), but inverse relation with BOD (r = - 0.93, r = - 0.97) and COD (r = - 0.75, r = - 0.61).

Dissolved Oxygen had direct relation with PO_4 (r = 0.61, r = 0.90), Cond. (r = 0.96, r = 0.88), Cl (r = 0.95, r = 0.60), SO_4 (r = 0.94, r = 0.92) and inverse relation with BOD (r = - 0.77, r = - 0.98) and COD (r = - 0.91, r = -0.84). Besides this, BOD and COD directly correlated with pH (r = 0.76, r = 0.96; r = 0.85, r = 0.78) and inversely with DO (r = - 0.95, r = - 0.93; r = - 0.91, r = - 0.84). BOD and COD showed direct relation with each other (r = 0.67, r = 0.81). This clearly indicates that a rise in DO invariably leads to an increase in the conductivity of water as well as concentration of chorine and sulphate, while leading to a decrease in BOD and COD levels. Furthermore, an increase in BOD and COD levels would lead to a rise in pH level of the water body,

From the analysis of the correlation coefficients, it may be observed that the ecological health of Kolong in all the Stations, especially Station 3 (Nagaon town), is extremely poor. The DO, BOD and COD levels as well as their correlations clearly indicated degraded levels of oxygen in the present study.

3.7. Plankton

It is well established that the plankton community, on which the whole aquatic population of a river depends, is largely influenced by the interaction of a number of physico-chemical factors. Results for Kolong showed that in all four stations phytoplankton dominated over zooplankton. Bacillariophyceae showed its dominance in retreating monsoon and again it showed its decline from pre-monsoon onwards, reaching the minimum in monsoon. Cyanophyceae was observed to be maximum in pre-monsoon and minimum in retreating monsoon. Chlorophyceae and Euglenophyceae showed its dominance in retreating monsoon and minimum in monsoon months. The dominance of Bacillariophyceae at the Kolong river was also observed by [46]. Similar trend was observed with regard to other phytoplankton groups.

The relationship between plankton and different physico-chemical parameters have been observed through regression models and the findings are as follows:

For Station 1 in 2018:

$$\begin{aligned} Y = {} & 7483.0511 - 70.1905\,X_1 - 401.1643\,X_2 \\ & - 11.9104\,X_3 + 19.4631\,X_4 + 4.8879\,X_5 \\ & - 19.0779\,X_6 + 4.7104\,X_7 + 34.1628\,X_8 \\ & + 372.6581\,X_9 - 104.3392\,X_{10} - 156.6034\,X_{11} \\ & - 108.8408\,X_{12} - 49.2747\,X_{13} \end{aligned} \tag{2}$$

$$R^2 = 0.9224\,(Significant).$$

For Station 2 in 2018:

$$\begin{aligned} Y = {} & 1449.7145 - 6.6737\,X_1 - 111.6452\,X_2 \\ & + 5.7264\,X_3 - 5.4698\,X_4 - 0.8763\,X_5 \\ & + 0.0900\,X_6 - 1.4689\,X_7 + 1.5508\,X_8 \\ & - 14.8726\,X_9 - 2.6696\,X_{10} + 10.0170\,X_{11} \\ & - 11.9379\,X_{12} + 3.1014\,X_{13} \end{aligned} \tag{3}$$

R^2 = 0.9433 (Significant)

For Station 3 in 2018:

$$\begin{aligned} Y = {} & 2862.3577 - 32.0392\,X_1 - 159.6706\,X_2 \\ & - 4.0775\,X_3 + 1.7623\,X_4 + 1.9306\,X_5 \\ & - 4.6900\,X_6 + 6.7569\,X_7 - 0.3533\,X_8 \\ & - 79.5085\,X_9 + 29.9258\,X_{10} - 31.0346\,X_{11} \\ & - 52.8129\,X_{12} - 30.5351\,X_{13} \end{aligned} \tag{4}$$

$$R^2 = 0.8997\,(Significant).$$

For Station 4 in 2018:

$$\begin{aligned} Y = {} & 5653.1878 + 34.3076\,X_1 - 24.2788\,X_2 \\ & + 10.4043\,X_3 + 11.4308\,X_4 - 17.0781\,X_5 \\ & - 1.0195\,X_6 + 12.7060\,X_7 - 19.1159\,X_8 \\ & - 474.3060\,X_9 + 76.6778\,X_{10} - 404.1799\,X_{11} \\ & - 371.5118\,X_{12} - 47.2183\,X_{13} \end{aligned} \tag{5}$$

R^2 = 0.9410 (Significant).

The results of the statistical analysis clearly indicate that different ecological parameters have influence on the plankton abundance. The study ensures that the variation in abundance of plankton can be best explained when environmental parameters jointly influence. In multiple regression, the fact that two variables tend to increase or decrease together does not necessarily imply that one variable has direct or indirect effect on the other, as both may be influenced by other variables in such a manner so as to give a strong mathematical relationship. The thirteen physico-chemical parameters show the coefficient of determination (R^2) to be 92% in Station 1; 94% in Station 2; 89% in Station 3 and 94% in Station 4. The remaining percentage of variation is not explained by the regression model perhaps due to non-inclusion of certain parameters.

Results indicate the plankton abundance to be low in monsoon compared to the other seasons. The pH value was also low in monsoon season and highly coincided with the heavy phytoplanktonic population as also reported by [47].

Temperature did not appear to be responsible for the seasonal fluctuations of plankton as there were two peaks in almost all groups, generally one in the retreating monsoons and the other in the winter. [44] stated that the variations in the abundance of algae cannot be correlated with variation in the temperature of the water. However, in the present study different plankton were found to thrive well in changing temperatures. Bacillariophyceae among phytoplankton was abundant during the low temperature period while Cyanophyceae were more abundant in relatively higher water temperature.

Transparency had negative correlation with the plankton abundance in some stations of Kolong river. Because when the water is clear, there does not appear to be any relationship between plankton abundance and transparency of water. Even though light is necessary for photosynthesis, there is a limit at which plants become light saturated [44].

DO content was found to be considerably high in monsoon season. [48] stated that the solubility of oxygen in water is increased by lowering the temperature, which may be due to rain water. DO had shown negative relationship with plankton in three stations except station 2. On the other hand, the minimum DO values coincided with low plankton concentrations in monsoon months.

In this study, positive correlation was seen in case of alkalinity. It was low in monsoon, when the water level was high while it increased, when the water level subsided in winter. Again, with the onset of monsoon rains, the alkalinity level reduced. This seems to indicate that alkalinity is inversely related to the water level. [49] pointed out the influence of alkalinity on loricate rotifers.

But in the present study, the relation was inverse in some stations.

The importance of nutrient salts in the growth and abundance of plankton is well established. In the present study, phosphate showed a direct relationship with plankton in some stations, as the plankton flourished during the period of high concentration of phosphate. The reduction in phosphate immediately after the phytoplankton peak shows its utilisation by the phytoplankton community.

In the present investigation, high abundance of Cyanophyceae, Bacillariophyceae and Chlorophyceae have been observed in all the Stations, especially in Station 3, which indicates heavy pollution as these phytoplankton are considered to be major indicators of pollution. Similar observations have also been reported by [50]. With regard to zooplankton, the abundant occurrence of Rotifers was expected as all the sites were eutrophic in nature as derived from the previous observations. Copepods were observed to be larger in size compared to Rotifers, indicating high pollution as they have higher tolerance with respect to eutrophicated water.

3.8. Economic Implications of Kolong's Water Quality

Deriving from the physico-chemical parametric analysis, it has been observed that the average temperature ranges around 23-26^0 C in the Kolong river. This is a moderately good temperature for agricultural production. However, the temperature during summer and monsoon is relatively high. This can invariably result in crop loss. Studies state that high temperature (due to climate change and other variables) affects about 4-9% of India's agricultural production annually, which has resulted in an approximate loss of 1.5% of gross domestic product (GDP) [51]. Given the threat of climate change, it can be expected that the temperature will rise in future. Statistics show that with another 1^0 C rise in temperature, agricultural production will decline by 13.72% in 2050. In Assam's context, agricultural production is sensitive to increase in temperatures [52]. Interestingly, tea garden production has already taken a hit with 10-15% crop loss. The same has been noticed with communities living on the Kolong river bank, where increased flood activities and associated water temperatures have dampened crop production and has severely impacted household incomes.

Alkalinity levels have been found to be high in the river. The sources can be both industrial and agricultural. Its impact upon crop production depends upon the crop type and also the amount of salinity in the water. It is important to note here that alkaline nature of water is preferred to acidic. However, alkalinity with a high pH level can adversely affect health of humans and may inhibit the growth of specific plants. Similar is the case with the chloride and phosphorus content. Concerning the economic implication of it, efforts to abate and treat these can result in large expenditure both on treatment plants and household costs. The operating cost for chloride removal is very high and can amount to thousands of dollars [53,54]. The economic cost on households might be even larger, if they get exposed to life-threatening diseases.

Several meta-analyses of water treatment processes in terms of BOD and COD cite the existence of complicacies in treating water and estimates the costs to be approximately USD 500,000 per capita to USD 1.5 million per one treatment station, which include the equipment, design, engineering, installation and project implementation costs [55].

3.9. Economics of Managing Water Quality

Pertaining to our analysis of the physico-chemical parameters of Kolong river and its associated economic impacts, it becomes pertinent to discuss on economic strategies that can assist with the mitigation process. It should be noted that the primary idea of designing water quality management policies is to attain economic efficiency [56]. Following strategies could be employed to achieve this objective:

I. Development of a water management firm that operates specifically for the Kolong river basin, so as to assist in internalising externalities. This can be done by designing and implementing policies that can nudge polluting units to adopt cleaner practices or release wastewater after it is treated into the river [57]. A public-private partnership can also be envisaged for managing the firm. However, India has been spending approximately $5 billion every year in the water business [58]. Corporatising such ventures may put an increased expenditure incidence on the polluters, which even if necessary, can make stakeholders rebellious and render them non-participative in the entire process. Government interventions to an extent of viability funding will be most crucial in this case.

II. Imposing effluent charges on each polluter has been a sought-after policy instrument worldwide. With the banks of Kolong getting urbanised and industrialised day-by-day, this policy instrument has become all the more necessary. However, identification of polluting sources becomes a major hindrance. It is indeed obvious with industries, but charging agricultural estates is not an easy task, considering the ambiguity of their run-off. Nevertheless, polluters should be charged equivalent to the marginal damages associated with the discharged water. If the cost of damages vis-à-vis discharged water quality could be assessed, the water management firm could effectively implement and collect associated penalties which could then be used to invest in treatment plants or mitigate health costs.

III. Application of stream standards is another important strategy that could be implemented. This policy was originally undertaken in the United States under its Water Quality Control Act (1965) wherein maximum and minimum water quality standards were set for each physico-chemical parameter of water. This was considered easier to implement than effluent charges since assessing marginal damages was difficult and could be a long-drawn process. In the context of Kolong, stream standards should be deployed which could vary across stretches, with stringent standards along the Nagaon town. It should be noted that the Central and State governments have several standards in place, but timely monitoring has been lacking. Bringing uniformity in all standards and engaging greater scholastic and non-governmental participation can critically help in keeping the water quality on track.

IV. Treating water quality is undoubtedly associated with large costs. Minimising them could start at the sources itself. For instance, if industries implement in-plant alterations in their mechanics, raw material use, water use and re-use patterns, the society would have to spend less on treatment methods. Government's industrial policies should also focus on making it mandatory for industries to imbibe upgraded and built-in treatment plants, that will decrease the unit cost of treating pollution.

V. Treating river water at a municipal level will be very expensive with respect to both implementation and surveillance costs. Joint municipal industrial treatment plants, however, could be set up that can take advantage of the economies of scale, thereby reducing costs of all stakeholders in the system.

VI. Imposition of a fertiliser tax combined with a charge for irrigation water may be done. This is being practiced in most nations as its importance policy is gaining immense traction.

In summary, little is known regarding the quantum of costs associated with individuals, groups and governments with respect to the water quality of a particular water resource, which is Kolong, in our case. Needles to say, an extensive study on the distributive aspect of such costs should be conducted which will induce efficient water quality management and help government policymaking in negating the magnitude of adverse impacts. In this study, the economic analysis of water quality management may be termed crude but has made an effort to address certain fresh and key points.

4. Conclusion

In the present study, an assessment of the ecological health and a discussion on the economics of water quality have been conducted for the Kolong river, located in Assam, India. A number of observations were derived from analysing water from four stations on different stretches of the river, collected for the year 2018. The discussion on its economics pertained to a briefing on the need for maintaining water quality and the necessity of management strategies for maintenance of Kolong's ecological health. It can be concluded from the study that the water quality of the river in all the Stations is considerably poor, especially Nagaon town (Station 3) which is an urban area. Furthermore, phytoplankton were observed to be dominating over zooplankton. High abundance of Bacillariophyceae, in case of phytoplankton, and Copepods, in case of zooplankton, were encountered, indicating poor ecological health of the Kolong river. As such, there should be a policy for proper management and restoration of the dynamic nature of Kolong river. Anthropogenic disturbances should be minimised while public consciousness should be generated through mass awareness campaigns. There should be strict legislation, which can help in minimising any source of pollution and prevent threats to the health of the river. Drainage treatment and necessary sanitation techniques may also help in restoration of water quality of the Kolong river.

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