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Influence of Monsoon on quality of water in lakes of Chota Nagpur plateau, North Eastern India.

Influencia del monzón en la calidad del agua en los lagos de la meseta de Chota Nagpur, noreste de la India.

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ABSTRACT

Indian agricultural, political and social structure is hugely impacted by the variability in monsoon. In recent times, unprecedented irregularities have been witnessed by Indian Metrological Department (IMD). Lakes and natural reservoirs in plateau are extremely dependent on monsoon, therefore, minimum alteration also translates in huge deviation in quality of water. In this study, an attempt has been made to examine alteration in quality of water during pre-monsoon, monsoon and post-monsoon. It was also assured that how population and urbanization impact monsoon runoff and change in physicochemical characteristics. Two lakes, namely Kanke lake and Ranchi lake were selected due to its urban and semi-urban localization, respectively. Physicochemical characteristics were examined according to APHA guidelines. Our results indicated significant alteration ($p<0.05$) in pH (7.32 ± 0.17), DO (4.27 ± 0.47 mg/l), and phosphate (0.19 ± 0.01 mg/l) of Kanke lake post-monsoon. Whereas, minimum significant alteration was observed in Ranchi lake post-monsoon. Level of DO (10.39 ± 0.44) significantly changed ($p<0.05$) in Ranchi lake following depletion in monsoon. However, level of hardness and BOD altered significantly ($p<0.05$) comparing to pre-monsoon during both monsoon and post-monsoon. Monsoon impacted physicochemical properties of both lakes, however, more alteration was evident in Kanke lake comparing to Ranchi lake. Eutrophication in both lakes were observed due to potential anthropogenic acidification. This study observed that semi-urban lakes are more vulnerable to encroachment and eutrophication comparing to urban lakes.

Key Words: Monsoon, Eutrophication, Plateau lakes, Lake encroachment

RESUMEN

La estructura agrícola, política y social de la India se ve enormemente afectada por la variabilidad del monzón. En los últimos tiempos, el Departamento de Metrología de la India (IMD) ha sido testigo de irregularidades sin precedentes. Los lagos y embalses naturales en la meseta dependen en gran medida del monzón, por lo tanto, una alteración mínima también se traduce en una gran desviación en la calidad del agua. En este estudio, se ha intentado examinar la alteración en la calidad del agua durante el premonzón, el monzón y el posmonzón. También se aseguró que cómo la población y la urbanización impactan la escorrentía del monzón y el cambio en las características fisicoquímicas. Se seleccionaron dos lagos, a saber, el lago Kanke y el lago Ranchi debido a su localización urbana y semiurbana, respectivamente. Las características fisicoquímicas se examinaron de acuerdo con las pautas de la APHA. Nuestros resultados indicaron una alteración significativa ($p < 0.05$) en el pH (7.32 ± 0.17), OD (4.27 ± 0.47 mg / l) y fosfato (0.19 ± 0.01 mg / l) del lago Kanke después del monzón. Considerando que, se observó una alteración mínima significativa en el lago Ranchi después del monzón. El nivel de OD (10,39 ± 0,44) cambió significativamente ($p < 0,05$) en el lago Ranchi tras el agotamiento del monzón. Sin embargo, el nivel de dureza y DBO se alteraron significativamente ($p < 0.05$) en comparación con antes del monzón tanto durante el monzón como después del monzón. El monzón impactó las propiedades fisicoquímicas de ambos lagos, sin embargo, fue evidente una mayor alteración en el lago Kanke en comparación con el lago Ranchi. Se observó eutrofización en ambos lagos debido a una posible acidificación antropogénica. Este estudio observó que los lagos semiurbanos son más vulnerables a la invasión y la eutrofización en comparación con los lagos urbanos.

Palabras clave: monzón, eutrofización, lagos de meseta, invasión de lago.

INTRODUCTION

Although many factors can influence climate change, such as; solar activity, orbital shifts, volcanic eruptions, ocean currents etc., strikingly in recent times, inconsistency related to weather pattern in most parts of the world is scarcely linked to these natural factors. The current global climate change is identified by two variables, one, it leads to a long-term progressive increase in temperature, and two, unpredictable variation in the weather pattern (Joshi et al., 2020). Present trend of irregularities in global weather indicate similarities with both variables. Natural water reservoirs and lakes also dictate early signs of any potential long-term alterations in local weather (Adrian et al., 2009). Sustenance of lakes and natural water reservoirs depends largely on adequate summer, balanced recycling of water, and normal rainy season (IPCC, 2013; Jeppesen et al., 2014).

Freshwater amounts to almost 7% of the global biodiversity and in recent times regarded as the most endangered (Dudgeon et al., 2006). Many studies have reported that climate change is affecting both physicochemical and biological properties of lakes around the world (Jackson et al., 2007; Kosten et al., 2012; Shurin et al., 2012). Continued weather repression of lakes, reduce ability to provide habitat to existing species. This disproportionation causes severe threats to the future of lakes and water reservoirs (Jeppesen et al., 2014). Other factors that influence lakes and water reservoirs are population, urbanization, and pollution (Liyanage and Yamada, 2017). Human activities and ever-increasing urban cites greatly affect river basins and water bodies (Sabry, 2015; International Decade for Action 'Water for Life'). Municipal wastes are one of the leading causes of high BOD and low DO in many South Asian countries (Karn and Harada, 2001). Anthropogenic activities drastically affect lakes in the urban areas. Degradation of water bodies in urban locations have been reported from pollution and encroachment from ever growing population (Neelakantan and Ramakrishnan, 2017).

One of the major source of water recycle in the lakes is rainy season. Monsoon in India is a huge built-up of moisture during summer in Indian Ocean. It is driven by large area of land-ocean-atmosphere system, which begin precipitating from Southern India reaching to far north to Himalayas and Southern Pakistan (Webster et al., 1998). With almost 70% of population dependent on agriculture, India hugely depend on normal monsoon (Gadgil and Gadgil, 2016; Sinha et al., 2011). Recent studies have noted significant shifts in monsoon rainfall linking it to hydro-climatic changes (Kathayat et al., 2017; Ali et al., 2018). In India, monsoon is expected from month of mid of May to first week of September, with an average precipitation of 1100 mm (CWC, 2015). Irregularities in monsoon leads to significant alteration in properties and existence of Lakes (Gaury et al., 2018). Lakes in plateau are more vulnerable to abnormal weather thus dependent greatly on monsoon precipitation. A study by Yang and Lu, (2014) reported disappearance of lakes due to alteration in monsoon activities. The same study claimed such alteration as indicator of climate change due to excessive plundering of water resources. Plateau lakes are being studied extensively in most parts of the world for enumeration of climate change around the globe (Yi and Zhang, 2015; Tang et al., 2018; Adrian et al., 2010; Tao et al., 2015). In addition to monsoon, factors such as urbanization (Glińska-Lewczuk et al., 2016), pollution (Shi et al., 2020), and population (Juma et al., 2014) also affect the quality of water in lakes.

In this study, attempt was made to evaluate monsoon related changes through quality of water in lakes of Chota Nagpur Plateau. It is located in the state of Jharkhand, Eastern India, spread over 25000 miles^2 with lowest point 1000 ft and highest 3819 ft above sea level. Chota Nagpur Plateau is formed through continental uplift and originate from Gondwana supercontinent (Singh, 2013). It consisted of three steps, among which highest step measured at 3500 ft above sea level, next step consists of Ranchi and Hazaribagh districts (2000 ft), and the third step consist of Manbhum and Singhbhum districts (1000 ft). The plateau contains many lakes and falls, awkwardly, number of published paper on lakes and its surveillances are very limited. Inappropriately, extremely low number of papers were found on quality of water in lakes of comparatively denser populated ‘second step’ of this plateau. In Ranchi monsoon begin in mid of June and decline significantly in last week of August. This study investigated the physicochemical properties of water in lakes of urban and semi-urban area of Ranchi (23.36°N 85.33°E - Chota Nagpur Plateau) during pre-monsoon, monsoon, and post-monsoon.

MATERIALS AND METHODS

Collection of water sample: Kanke Lake (23.4018 °N, 85.3126 °E) and Ranchi Lake (23.3684 °N, 85.3181 °E) were selected based on residential built-up encroachments, thus, regarded as semi-urban and urban, respectively (Figure 1). Three sites were selected based on specific significance. Water was collected between 10:00 AM to 12:00 PM, by a 12 ft long aluminium rod, containing bottle holder at one end. Collection bottles were rinsed three times without agitating the water sediments. Afterwards 1 l water was collected by dipping the bottle at least 12 inches straight down. This process was repeated at three distinctly separate places with specific significance. Water samples were collected at three points of time 12.05.2020, 12.07.2020, and 12.09.2020, labelled as pre-monsoon, monsoon and post-monsoon, respectively. Once sample was collected it was immediately stored at 4 °C and transported to laboratory for physicochemical characteristics.

Physicochemical parameters: Characterization of collected water sample was conducted. Physicochemical (APHA, 2005) and biological analysis was conducted.

Temperature and pH of water sample: Temperature of water sample was measured by using a centigrade thermometer, along with transparency was measured by Secchi disk. A digital pH meter was used to assess neutrality of sample (pH 211, HANNA).

Turbidity: Turbidity was measured by a nephelometer (Equiptronics, Digital Turbimeter, MH, India) through estimating propensity of suspended particles. The value of

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turbidity was expressed in NTU (Nephelometric Turbidity Units).

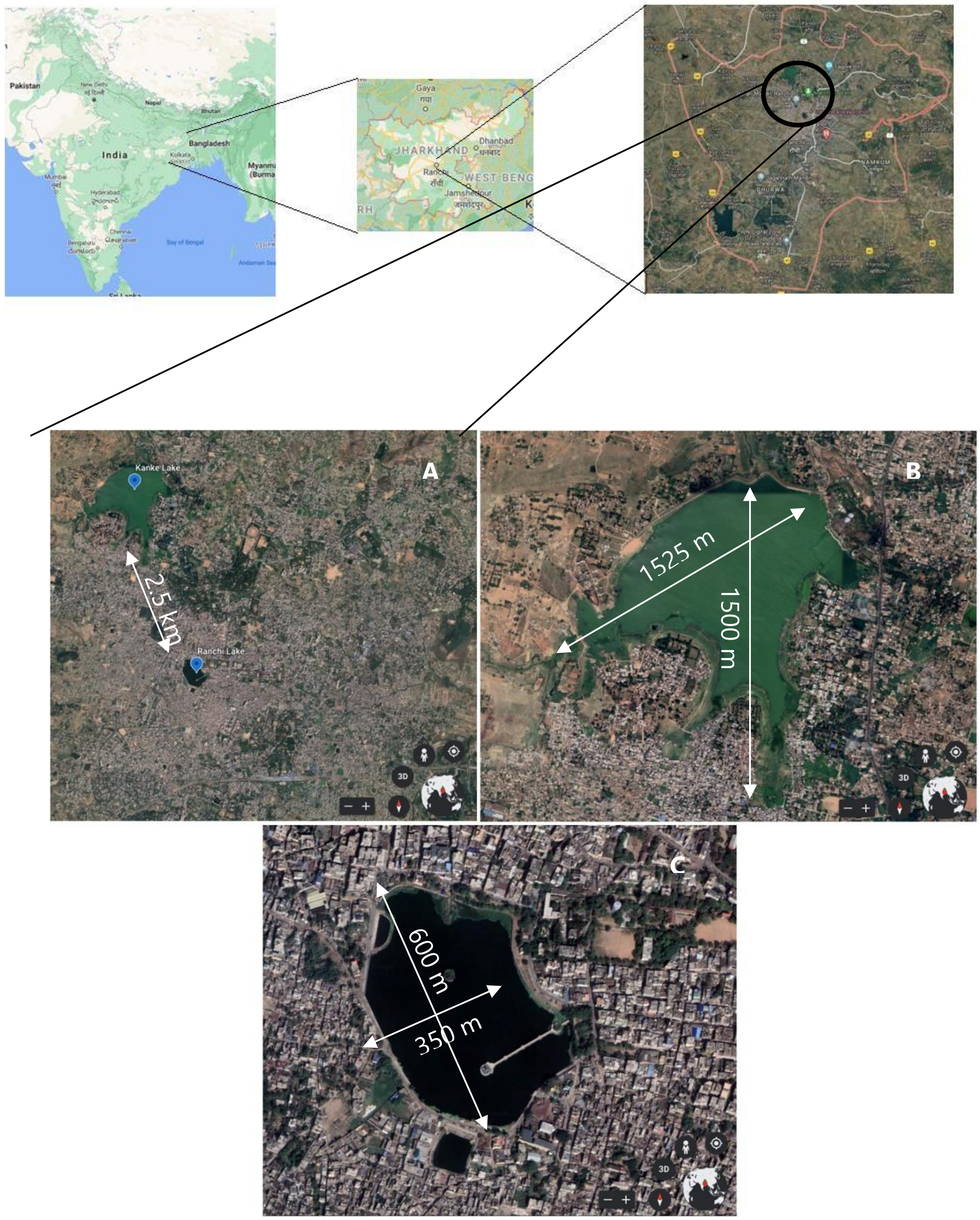

Figure 1: Location and size of Kanke and Ranchi lakes. A. Distance between both lakes are shown with arrows. B. Residential encroachment alongside of Kanke lake. C. Residential built up alongside of Ranchi lake. Satellite images are available at Google Maps.

Alkalinity: Measurement of bicarbonate was carried out by acid base titration method (Xing et al., 2019). Briefly, burette was filled with N/50 sulfuric acid (H_2SO_4). In 100 ml of water sample 3 drops of phenolphthalein indicator if the orange colour developed it was titrated against H_2SO_4. Initial reading was noted final reading was noted until the pink colour disappeared. Afterwards, in the same sample one drop of methyl orange was added, which was titrated again till appearance of light orange colour. Initial and final reading for methyl orange was noted. This experiment was repeated thrice to find concordant reading. Total alkalinity was calculated as follows:

$$T = H_2SO_4\ (PI_T) + H_2SO_4\ (MO_T)$$

$$\text{Total alkalinity} = \frac{T\ X\ 1000}{Total\ sample}\ \text{mg/l}$$

Where;

T = Total H_2SO_4 used during first titration (PI_T) and total H_2SO_4 used during second titration (MO_T)

PI_T = Phenolphthalein indicator titration

MO_T = Methyl orange indicator titration

Hardness: Temporary hardness was measured in the collected samples by volumetric EDTA titrimetric method (Xing et al., 2019). In short, EDTA standard solution was prepared by dissolving 4g of sodium salt of EDTA 0.1 g of magnesium chloride 800 ml of water. The Erichrome black T indicator was prepared by adding .4 g of indicator powder and 4.5 g of hydroxyl amine hydrochloride in 100 ml of 95% ethanol. A 100 ml of water sample was added with 1 ml of ammonia buffer and 5 drops of EDTA indicator, mixed properly. Thereafter, burette was filled with EDTA standard solution and initial reading was noted. Dilution was initiated by adding EDTA standard solution in the sample, volumetric change in burette for change in colour of sample from purple to blue is noted. This experiment was repeated thrice to find concordant reading. Total hardness was calculated as follows:

$$\text{Total Hardness} = \frac{ml\ of\ EDTA\ Standard\ Soln.used}{ml\ of\ sample}\ \text{mg/l}$$

Dissolved oxygen: Dissolved oxygen (DO) in water sample was enumerated by membrane electrode method by dissolved oxygen meter (NDO24, Okhla, New Delhi). Briefly, KCl (7.5 %) solution was filled in the electrode tube. Membrane was activated by submerging into cold and hot water alternatively. Calibration was carried out against deionized water and sodium sulphide (Na_2SO_4) (2% w/v). Water sample was then taken in to a beaker and electrode was stirred in the water until final value become stable.

Biological oxygen demand (BOD): BOD in water sample was determined by method described in Lenore et al. (2005). BOD bottle and aerated water samples were prepared. Dissolved oxygen was estimated by incubating bottles in dark for five days at 20 °C. The difference between final dissolved oxygen content and initial dissolved oxygen content is measured on the fifth day of incubation. Any decrease in dissolved oxygen was identified as biological demand of the sample.

Phosphate: Orthophosphate was calibrated in the water sample by MH-3536 Phosphate test kit (APHA, 2005). Phosphate reagent (HANNA) was added in to 10 ml of water sample, and mixed thoroughly, and allowed to react for 1 min. Colour change in the water sample was observed. The colour change was calibrated against the measuring cuvette, and appropriate amount of phosphate was noted. This experiment was repeated thrice for accuracy.

Nitrate: Nitrate was calibrated in the water sample by MH-3536 Nitrate test kit (APHA guideline). Nitrate reagent was added in to 10 ml of water sample, mixed thoroughly. The solution was allowed to settle for 4 min. Colour change in the water sample was observed. The colour change was calibrated against the measuring cuvette, and appropriate amount of phosphate was noted. This experiment was repeated thrice for accuracy.

Chemical oxygen demand: Water sample was taken into a flask and added with 1 ml of $HgSO_4$ solution. Solution was mixed well by spinning for few minutes. Glass beads were added to the flask to avoid over-boiling. Once adequately mixed 5 ml of $K_2Cr_2O_7$ solution was added in to the solution. Later 15 ml of Ag_2SO_4 and H_2SO_4 solution were slowly poured in. Once the solution is prepared it was digested using hot plate for two hours with condenser connected to it. Distilled water was applied to cool down the flask. Once temperature fall back to room temperature 2-4 drops of ferroin indicator was added and titrated with ferrous sulphate (0.025 M). All endpoints were noted and later calculated for total COD.

$$COD = \frac{8 \times 1000 \times DF \times M \times (Vb - Vs)}{Volume\ of\ sample} \quad \text{mg/l}$$

DF – Dilution factor

M – Molarity of ferrous ammonium sulphate

Vb – Volume consumed in titration with blank

Vs – Volume consumed in titration with sample

Statistical analysis: Experiments done in multiple series were present in Mean±SD. All paired analyses were compared through Student-*t* test (MINITAB, US), for which any value below 95% CI was considered significant. Pearson's correlation test (r) (MS-EXCEL, US) was applied to enumerate cause and effect analysis between pre-monsoon, monsoon, and post-monsoon. Strength of relatedness (R^2) between values of physicochemical characteristics of Ranchi and Kanke lakes were determined through linear regression analysis.

RESULTS

Physicochemical properties of Kanke and Ranchi lakes: Temperature in the water samples of Kanke lake were recorded as 17.57±0.71, 19±0.62, and 18.33±0.31 ℃ during pre-monsoon, monsoon, and post-monsoon, respectively. Whereas, 23.37±0.64, 21.82±0.51, and 21.62±0.78 ℃ were recorded in Ranchi lake during pre-monsoon, monsoon, and post-monsoon, respectively. Significant change in temperature of Ranchi lake was noted during pre-monsoon comparing to monsoon. Likewise, significant change in pH was observed in Kanke lake during post-monsoon season comparing to monsoon. Water pH in Kanke lake was measured as 8.04±0.08, 7.83±0.13, and 7.32±0.17, during pre-monsoon, monsoon, and post-monsoon, respectively. No significant alteration in pH was noted in Ranchi lake and were measured in range of 7-7.5. Significantly higher level of hardness in Ranchi lake was noted during pre-monsoon season comparing to monsoon. Whereas, no notable dependence was noted in hardness of water of Kanke lake on monsoon (Table 1; Figure 2).

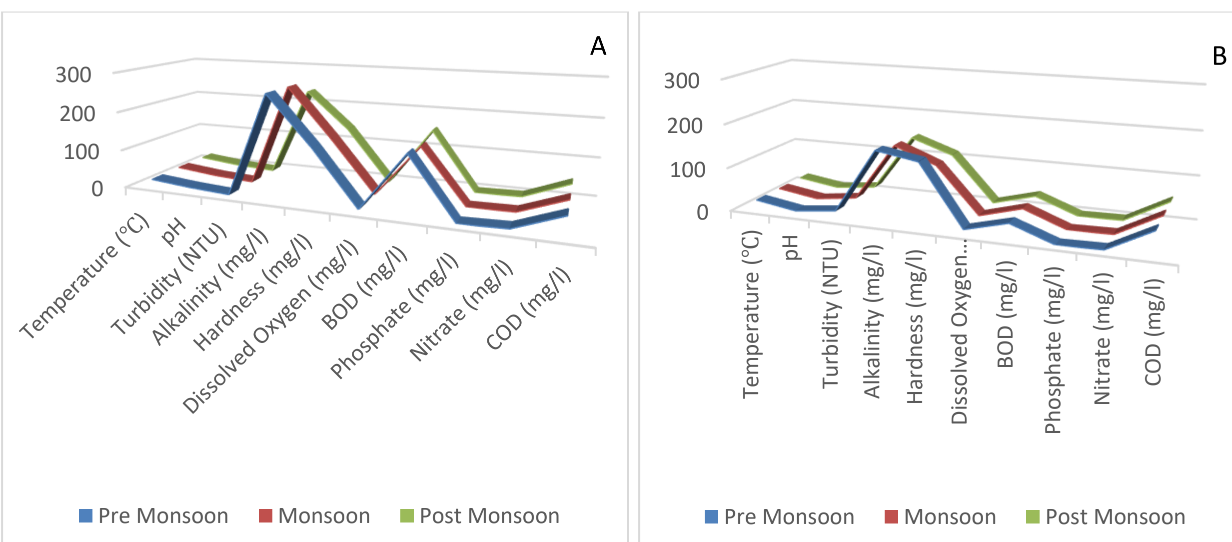

Figure 2: Physicochemical properties of A. Kanke Lake and B. Ranchi Lake during pre-monsoon, monsoon, and post-monsoon.

Table 1: Physicochemical characteristics of Kanke and Ranchi lakes during summer, monsoon and winter. Values are in Mean±SD.

	Kanke Lake		
Variables	Pre Monsoon	Monsoon	Post Monsoon
Temperature (℃)	17.57±0.71	19.00±0.62	18.33±0.31
pH	8.04±0.08	7.83±0.13	7.32±0.17*
Turbidity (NTU)	1.70±0.36	1.57±0.33	1.63±0.33
Alkalinity (mg/l)	265.33±16.65	264.00±14.42	234.53±11.98
Hardness (mg/l)	143.33±5.03	139.33±1.15	139.33±2.72
Dissolved Oxygen (mg/l)	5.17±0.45*	5.80±0.62	4.27±0.47*
BOD (mg/l)	151.11±5.09	139.67±13.23	153.56±7.78
Phosphate (mg/l)	0.16±0.01	0.16±0.01	0.19±0.01*
Nitrate (mg/l)	3.95±1.23	2.42±0.20	2.98±0.24
COD (mg/l)	48.78±3.69	46.20±2.33	48.72±1.90
		Ranchi Lake	
Variables	Pre Monsoon	Monsoon	Post Monsoon
Temperature (℃)	22.37±0.64*	21.82±0.51	21.62±0.78
pH	7.43±0.42	7.27±0.21	7.42±0.32
Turbidity (NTU)	18.16±7.47	19.28±5.28	17.86±4.00
Alkalinity (mg/l)	163.67±25.58	151.33±24.01	146.33±21.96
Hardness (mg/l)	147.33±7.64*	114.33±7.57	113.67±7.37
Dissolved Oxygen (mg/l)	9.95±0.66	10.09±0.55	10.39±0.44*
BOD (mg/l)	35.22±6.05*	36.78±5.96	36.44±5.35
Phosphate (mg/l)	0.25±0.10	0.20±0.07	0.20±0.04
Nitrate (mg/l)	2.27±0.86	2.21±0.84	2.07±0.63
COD (mg/l)	54.38±10.38	54.71±12.42	54.87±10.88

*p<0.05 against values observed during monsoon

Level of dissolved oxygen (DO) in Kanke lake was noted as 5.17±0.45, 5.8±0.62, and 4.27±0.47 mg/l, during pre-monsoon, monsoon, and post-monsoon, respectively. Significant decline in DO was observed during post monsoon, whereas, substantial increase ($p<0.05$) was noted during pre-monsoon. DO in Ranchi lake responded slightly differently and no significant change was noted during pre-monsoon comparing to monsoon, however, a substantial increase was noted post-monsoon, which was noted as 10.39±0.44 mg/l. Level of BOD during pre-monsoon season was noted as 35.22±6.05 mg/l, which was significantly lower comparing to monsoon season. No alteration in BOD level was noted in Kanke lake before or after monsoon. However, substantial ($p<0.05$) increase was noted in concentration pf phosphate during post-monsoon season in Kanke lake, which was uninterrupted in Ranchi lake through the period of investigation (Table 1; Figure 2).

Between both lakes substantial difference in physiochemical characteristics was noted. Except for pH, nearly all parameters reflected huge differences, such as; at least 2 ℃ increase in temperature of water was observed in Ranchi lake comparing to Kanke lake. Similarly, almost 10-11 folds increase in turbidity of Ranchi lake was noted comparing to Kanke lake. Lower alkalinity and overall hardness in Ranchi lake was observed comparing alkalinity and hardness of Kanke lake. Although DO was only slightly higher in Ranchi lake the BOD was extremely lower comparing to Kanke lake (Table 1).

Correlation and relatedness of physicochemical characteristics: This study observed influence of monsoon on physicochemical characteristics of water before arrival and after departure. Therefore, respective association between each physicochemical parameter and among each physicochemical parameter were examined. Degree of association between parameters in Ranchi lake between pre-monsoon and monsoon season reflected almost no effect on quality of water based on temperature, pH, turbidity, alkalinity, DO, BOD, phosphate, nitrate, and COD. However, level of hardness was affected greatly during both seasons. Lowest association for hardness was observed when estimated against turbidity ($r=-0.018$), temperature ($r=-0.372$), and pH ($r=-0.402$). To some extent lower association was also observed in alkalinity, hardness when estimated against hardness. Similarly, slightly lower association between nitrate and phosphate was calculated (Table 3).

Deflection in degree of association between physicochemical parameter between monsoon and post monsoon seasons reflected slightly higher comparing to pre-monsoon and monsoon. Lowest association was noted for BOD ($r=0.061$), DO ($r=-0.070$), and nitrate ($r=-0.077$) when calculated against hardness. Likewise, lowest association was also observed for turbidity ($r=-0.076$), and hardness ($r=-0.076$) when estimated against pH. Similarly, lower association was noted between temperature and hardness ($r=-0.162$). Weak deflected association was observed between temperature-turbidity, temperature-alkalinity, hardness-phosphate, and hardness-alkalinity (Table 4).

Table 3 Pearson's correlation test (r) for alteration in physicochemical characteristics of Ranchi lake between pre-monsoon and monsoon.

	Temperature	pH	Turbidity	Alkalinity	Hardness	DO	BOD	Phosphate	Nitrate	COD
Temperature	0.993	0.999	0.923	0.823	-0.372	-0.929	-0.896	0.991	0.837	0.923
pH		1.000	0.910	0.804	-0.402	-0.916	-0.881	0.995	0.819	0.910
Turbidity			0.999	0.971	-0.018	-1.000	-0.995	0.880	0.977	0.999
Alkalinity				0.962	-0.053	-0.999	-0.991	0.896	0.968	0.998
Hardness					0.058	-0.998	-1.000	0.842	0.990	0.999
DO						1.000	0.998	-0.863	-0.984	-1.000
BOD							0.997	-0.873	-0.980	-1.000
Phosphate								0.996	0.695	0.815
Nitrate									1.000	0.980
COD										0.999

Table 4: Pearson's correlation test (r) for alteration in physicochemical characteristics of Ranchi lake between monsoon and post monsoon.

Monsoon-Post Monsoon	Temperature	pH	Turbidity	Alkalinity	Hardness	DO	BOD	Phosphate	Nitrate	COD
Temperature	0.994	0.986	0.689	0.593	-0.162	-0.842	-0.905	0.996	0.912	0.859
pH		0.997	0.749	-0.076	-0.076	-0.885	-0.938	1.000	0.944	0.900
Turbidity			0.956	0.912	0.344	-0.998	-0.997	0.910	0.996	1.000
Alkalinity				0.977	0.532	-0.988	-0.960	0.804	0.955	0.983
Hardness					0.944	-0.070	0.061	-0.402	-0.077	0.037
DO						0.997	0.998	-0.916	-0.997	-0.999
BOD							0.990	-0.881	-0.988	-0.999
Phosphate								0.995	0.907	0.853
Nitrate									0.962	0.987
COD										1.000

Extremely associated, **Highly associated**, **Weakly associated**, **No association**

Table 5: Pearson's correlation test (r) for alteration in physicochemical characteristics of Kanke lake between pre-monsoon and monsoon.

	Temperature	pH	Turbidity	Alkalinity	Hardness	DO	BOD	Phosphate	Nitrate	COD
Temperature	0.291	0.979	0.819	0.117	-0.163	0.130	0.639	0.163	0.088	0.904
pH		-0.226	-0.864	-0.951	-0.828	-0.955	-0.966	0.828	0.868	-0.767
Turbidity			0.979	0.500	0.240	0.511	0.891	-0.240	-0.312	0.999
Alkalinity				0.533	0.277	0.544	0.908	-0.277	-0.349	1.000
Hardness					-0.115	0.178	0.676	0.115	0.040	0.924
DO						0.986	0.922	-0.896	-0.927	0.673
BOD							-0.619	-0.188	-0.114	-0.892
Phosphate								-0.971	-0.950	0.036
Nitrate									-0.990	0.212
COD										0.067

Table 6: Pearson's correlation test (r) for alteration in physicochemical characteristics of Kanke lake between monsoon and post-monsoon.

	Temperature	pH	Turbidity	Alkalinity	Hardness	DO	BOD	Phosphate	Nitrate	COD
Temperature	0.979	0.680	0.728	-0.653	-0.999	0.275	-0.281	-0.832	-0.695	0.961
pH		0.792	0.749	-0.050	-0.050	-0.933	-0.981	-0.629	-0.779	0.362
Turbidity			0.996	-0.981	-0.761	-0.376	-0.812	-0.997	-0.990	0.927
Alkalinity				-0.509	-0.991	0.440	-0.107	-0.721	-0.558	0.898
Hardness					-0.914	0.672	0.173	-0.500	-0.305	0.740
DO						0.429	-0.120	-0.729	-0.568	0.903
BOD							-0.631	-0.982	-0.920	0.993
Phosphate								0.500	0.305	-0.740
Nitrate									0.376	-0.789
COD										0.850

Extremely associated, **Highly associated**, **Weakly associated**, **No association**

Huge dependence on monsoon was observed in quality of water in Kanke lake based on degree of association between physicochemical parameter. Comparatively most parameters of pre-monsoon revealed low association with values observed during monsoon respective to Ranchi lake. Table 5 shows high number of dark blue cells and relatively lower green cells comparing to Ranchi lake. Where dark blue cells denote weak association and green cells denote strong association. Hardness of water showed strong association with temperature (r=-0.163), turbidity (r=0.240), alkalinity (r=0.277), and hardness (r=-0.115). Besides hardness, phosphate also showed maximum weak associations with temperature (r=0.163), turbidity (r=-0.240), alkalinity (r=-0.277), hardness (r=0.115), and BOD (r=-0.188).

Between monsoon and post monsoon, associations between parameters were slightly strengthen comparing to pre-monsoon. However, more deviation in association was observed and minimum numbers of strong associations (green cells) were observed between parameters (Table 6). Association of values were highly affected for pH and nitrate against rest of the parameters. Though number of associations were higher in this segment of cause and effects analysis, most association were weak comparing to pre-monsoon. Weakest association were observed for BOD when estimated against temperature (r=-0.281), alkalinity (r=-107), hardness (r=0.173), and DO (r=-0.120).

Between both lakes variation in values were examined for relatedness (R^2). During all three collection periods, strong relatedness was observed, these were estimated as R^2=0.772 (pre-monsoon), R^2=0.838 (monsoon), and R^2=0.794 (post-monsoon). Observed degree of relatedness indicate similar weather pattern in the area (Figure 3 A-C).

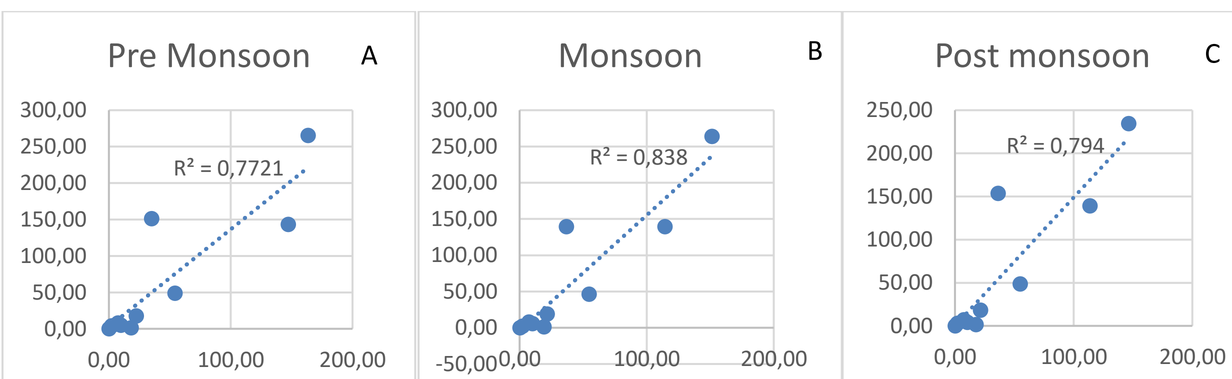

Figure 3: Linear regression analysis of physicochemical characteristics during each investigated season.

DISCUSSION

Monsoon rainfall is primary source of water in lakes of this plateau. Rivers in these areas are only active during monsoon season and on remaining months of a year only contain city wastewater drainage. This study investigated two lakes from Ranchi district, one, from city center (Ranchi lake) and another, from semi-urban area Kanke lake. Volume of both lake vary significantly as Kanke lake is almost 4 times larger to that of Ranchi lake. Monsoon rains changes physicochemical characteristics of urban and semi-urban areas invariably (Sharma and Tiwari, 2018; Vajravelu et al., 2018; Chaudhuri et al., 2012). This study also observed alteration in both lakes pre- and post- monsoon however, the changes were limited to few parameters only. Comparing to monsoon only significant alteration was noted in dissolved oxygen of Kanke lake during both pre- and post-monsoon. A pattern of decline was noted in DO following monsoon. In general, high inflows during heavy rain significantly increase the DO (Li et al., 2015), however, in this case significant decline in the DO of Kanke lake indicate extensive urban sewer overflows causing hypoxic events (Gaulke et al., 2015). In an urban system, aquatic hypoxia is common if the municipal pre-management of sewer drainage before monsoon is incomplete or improper. Local newspapers have noticed neglected encroachment and inappropriate sewer inflow in Kanke lake by local municipal authorities (The Telegraph, Published on 29/09/2018). Interestingly, level of DO in Ranchi lake was contrasting to that of Kanke lake. Completely reverse pattern was observed, level of DO increased expectedly through monsoon and post-monsoon, comparing to pre-monsoon. During post-monsoon DO was significantly higher than that of monsoon. As discussed earlier heavy rainfall increases DO of lakes, however, blocked sewer overflow and better wastewater management may have contributed to high DO. In addition to that the overall level of DO in Ranchi lake was higher than Kanke lake. According Pandey and Kumar (2015), level of DO in Kanke lake was between 5-10 mg/l, whereas, Kerketta et al. (2013) reported 2-3 mg/l. Despite, previous studies indicated a gradual increase in the DO of Kanke lake, it was observed that Kanke lake was more vulnerable to DO recycle due to encroachment and municipal mismanagement.

This study noted significant increase in temperature of water in Ranchi lake during pre-monsoon, comparing to monsoon. Which was apparent due to long dry summer days, previous study has noted change in temperature of lakes during summer at high altitude (Woolway and Merchant, 2017). However, the same was not evident in Kanke lake, as no significant change in temperature was evident when compared against monsoon. It could possibly be due to its large size comparing to Ranchi lake. Large lakes reduce the maximum temperature during summer as they absorb more energy for temperature change (Wen et al., 2015). It is to be noted that with increase in temperature, solubility of oxygen decreases (Walczynska and Sobczyk, 2017). Dissolved oxygen stratification is common during autumn and summer (Zhang et al., 2015). Likewise, similar pattern was observed in Ranchi lake. Nonetheless, DO in Kanke lake were found in contrast to temperature as no significant alteration was observed. It confirms earlier assumption in this study that variability in DO of Kanke lake was majorly contributed by sewer overflows and wastewater mismanagement.

Temperature also impact phosphate in water system. Previous study reported that increase in temperature support release of phosphorus and decrease in level of DO (Li et al., 2013). Phosphates were not affected by monsoon rainfall in Ranchi lake, though significant increase in Kanke lake was observed during post-monsoon. It is to be noted that phosphates enter into lakes through wastewater from industries, laundries, fertilizer runoff etc. (Water Research Center-Phosphate; Kroiss et al., 2011), that is very common in the investigated Kanke area. Although no alteration in phosphate level was observed in Ranchi lake the concentration was significantly higher than Kanke lake. The level of phosphate in Ranchi lake was above acceptable range (> 0.1 mg/l) (Water Research Center), potentially harmful for human use and suitable for eutrophication. According to a study by Mukharjee et al. (2010) Ranchi lake is predominantly eutrophic, phosphate in water was measured as 2.37 mg/l during period of 2007-2008. Based on this study recent rejuvenation of Ranchi lake by local municipal corporation between 2017-2019 under Atal Mission for Rejuvenation and Urban Transformation (AMRUT), may have contributed immensely in reducing concentration of phosphate in the water.

Comparing to earlier study on Kanke lake, high alkalinity and pH was recorded in this study (Kerketta et al., 2013; Pandey and Kumar, 2015). Similarly, high alkalinity in Ranchi lake was also evident, although it was lower than Kanke lake. One of the potential reasons for such a high value of alkalinity in both lakes could be due to calcium carbonate buffering and low acidic precipitation or drainage (Muller et al., 2016). During post-monsoon season, significant decrease in pH was noted in Kanke lake comparing to monsoon and pre-monsoon. It is to be noted that on average Kanke lake was more alkaline than Ranchi lake. It was also evident in concentration of alkalinity, which was almost 2-3 times higher in Kanke lake than that of the Ranchi lake. Significant change in pH during post monsoon could be due to neutralization of acidic runoff during heavy rain. Many unattended sewer discharges of acidic wastewater can induce reduction in alkalinity and thus overall pH. Current result also showed lowering of alkalinity during post-monsoon season however, this change was not significant. In general, lakes usually have pH between 6-8 which was also evident in this study, however, weathering of lakes maintain homeostasis bicarbonate and carbonate ions (Kalff, 2002). However, due to anthropogenic acidification depletion of carbonate buffering system occur (Weyhenmeyer et al., 2019), causing subsequent lowering of pH.

This study observed strength of association between individual parameters to establish linkage of monsoon related changes in the variation of results. This study noted low influence of monsoon on quality of water in Ranchi lake. Most parameters such as; temperature, pH, DO, BOD, phosphate, nitrate and COD remained strongly associated. Lack of association or weak association was only evident in hardness of the water when examined between pre-monsoon and monsoon. Rain water has zero hardness, thus high precipitation may lead to reduction in total hardness (Risner, 2008). Similar result was observed post-monsoon also, hardness indicated weakest association with each parameter which indicated inflow of runoff from heavy rainfall. No other weak association indicate least influence of monsoon on the quality of water. It is to be noted that although multiple steps taken to renovate and rejuvenate Ranchi lake, it remains mostly eutrophic and not considered safe for use (TOI, Published on 26/02/2014).

On the other hand, Kanke lake indicated more activity in relation to monsoon comparing to Ranchi lake. Various parameters indicated weak associations between pre-monsoon and monsoon results. For instance, hardness, temperature, phosphate, DO and nitrate indicated weakest associations with most of the parameters. This reflects that monsoon creates instability in physicochemical properties of water, before, during, and after excessive rainfall. It also reflects that physicochemical characteristics of Kanke lake is responsive to seasonal change, thus, this study hypothesizes that better care of this lake can rejuvenate its health significantly.

As conclusion this study reveals that both lakes are eutrophic with high level of alkalinity and hardness. Eutrophication of lake water was potentially contributed by anthropogenic acidification. The physiochemical state of both lakes revealed consequential effect of multiple stressors. It concludes combinatorial effect of sewage pollution and inadequate monsoon in the investigated area. This study confirmed that monsoon have low effect in modulating physicochemical properties of urban lake, whereas, semi-urban lake reflected broad adjustments during both pre- and post- monsoon seasons. Which also confirms that monsoon can rejuvenate lakes in the plateau area. However, rejuvenation of lakes through monsoon precipitation is also dependent on level of encroachments and amount of wastewater discharge. This study observed that Kanke lake is more vulnerable to encroachment and eutrophication comparing to Ranchi lake.

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