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Evaluation of Water Quality Around an Industrial Setup in Odisha, India

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***Abstract*: Water being one of the basic necessities of life needs conservation and protection owing to its global demand. Industrialization has been an age old agent responsible for water depletion both quantitatively and qualitatively. This study aimed to evaluate the spatial and temporal scale variations in the surface and ground water quality around an alumina refinery in Odisha state of India. The results suggest that the surface water experience organic load from the surrounding medium (COD = 8.6 to 34.2 mg/L) while the ground water received dissolved salts from the soil medium (TDS = 79.64 to 470.1 mg/L). Although the water quality has not been seriously impacted by the industrial activity, the surface water and ground water receive pollution load from the soil storage and surrounding medium. This may have serious cumulative consequences in near future, if the controlling and management strategies are not adopted both at the industrial and local level.**

***Keywords*: Water quality, Physico-chemical parameters, Alumina refractory.**

1. Introduction

Water is a basic necessity of life and is present in a very small amount in freshwater and consumable form. The vitality of freshwater therefore needs to be protected that is often put under stress due to anthropogenic and pollution issues [1]. Over the years, due to growing population coupled with rapid sprawl in urban setup and industrial activities, surface and ground water quality has been depleted to a large extent [2]. In addition to this, developmental activities and modernization have led to extinction of many surface water sources. This has resulted in a stressed water scenario in most of the developing nations including India.

Several health hazards including chronic and acute disorders are associated with poor water quality [3]. Water contaminated with fecal coliforms and heavy metals are precarious to human and animal health. Besides the anthropogenic sources, potable water quality is also depleted due to the natural sources that includes floods, cyclones etc., [4]. Although several initiatives are taken up by the regulatory bodies to improve the water quality of an urban area, frequent cases of pollution compel the residents to depend on unimproved water sources for living [5]. Therefore, water quality should be regularly evaluated with physicochemical and biological parameters to avoid any health and environmental concerns [6].

Previous studies on water quality have not addressed the impact of industrial activities and seasonal change on the surrounding water. The present work was therefore intended to assess (i) the surface and ground water quality and (ii) evaluate the spatial and seasonal impact on the water quality around an industrial setup (alumina refinery) in Lanjigarh of Odisha, India.

2. Materials and Methods

A. Study Area

The present study was carried out in an industrial operating area i.e., Lanjigarh in Kalahandi district of Odisha state in India. The area witnesses the operation of an alumina refinery with a capacity of 1.4 MTPA. Water forms a major raw material used in different units of operation during the processing and conversion of bauxite ore into alumina powder. Therefore, wastewater is a major byproduct of this industrial operation.

Table 1
Details of the sampling locations

Station Code	Name of the Site	Distance from the plant site (km)	Direction from the plant site	Geographical Coordinates
Surface Water Sampling Stations				
SW1	Vansadhara river near Lanjigarh	4	W	19.70º NL, 83.37º EL
SW2	Vansadhara river near Chatrapur	1.6	N	19.72º NL, 83.41º EL
SW3	Stream near Rengopali	2	S	19.69º NL, 83.39º EL
SW4	Stream near Kenduguda	2	W	19.72º NL, 83.38º EL
SW5	Stream near Bundel	4	E	19.71º NL, 83.39º EL
Ground Water Sampling Stations				
GW1	Bore well at Lanjigarh	4	W	19.71º NL, 83.36º EL
GW2	Bore well at Rengopali	2	S	19.70º NL, 83.39º EL
GW3	Bore well at Chatrapur	2	N	19.72º NL, 83.40º EL
GW4	Bore well at Chanalima	1.7	WNW	19.71º NL, 83.39º EL

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B. Sampling and Analysis

Water analysis comprised of both ground water and surface water samples obtained from strategic locations situated in and around of the alumina refinery. The details of the sampling locations are described in Table 1. The locations were identified as per the protocol of given by the State Pollution Control Board (SPCB), Odisha.

Water sampling was done during three season viz. pre

Table 2
Surface water quality parameters around refinery plant in Lanjigarh during 2018-2019

	Stations	Post-monsoon	Pre-monsoon	Monsoon
pH	SW1	7.80±1.23	7.52±1.33	7.05±1.29
	SW2	8.40±1.90	8.82±1.79	7.58±1.89
	SW3	7.30±1.98	7.15±1.99	6.92±1.20
	SW4	6.99±1.20	7.56±1.10	6.75±1.34
	SW5	6.98±1.71	7.89±1.34	6.86±1.01
EC (µs/cm)	SW1	180±4.20	120.8±5.56	202±5.67
	SW2	152±4.89	199.5±4.90	174±4.23
	SW3	139±4.29	111.3±4.78	112±4.20
	SW4	149±4.78	187.6±4.25	132±4.12
	SW5	135±4.19	108.6±4.78	91±5.37
TURBIDITY (NTU)	SW1	25±1.34	36.8±1.98	57±1.78
	SW2	24±1.28	38±2.10	52±1.98
	SW3	20±1.34	18±1.89	29±1.34
	SW4	18±1.90	28±1.78	31±1.78
	SW5	19±1.78	10±1.20	27±1.67
TDS (mg/L)	SW1	96±4.98	68.32±4.78	106±4.20
	SW2	80±4.19	111.5±4.10	102±4.02
	SW3	106±3.39	62.34±4.10	94±4.98
	SW4	98±4.29	104.5±4.38	90±4.21
	SW5	93±4.89	60.4±4.89	84±4.78
COD	SW1	25.1±2.34	34.2±2.39	22.4±2.10
	SW2	26.1±3.40	23.2±3.23	22.2±2.20
	SW3	12.7±2.10	8.6±2.20	14.6±1.89
	SW4	13.1±3.29	9.2±2.18	14.2±2.34
	SW5	10.9±2.98	8.8±2.55	12±2.00
Ca (mg/L)	SW1	16.2±1.34	11.2±1.95	15.6±1.85
	SW2	11±1.11	14.4±1.25	8±1.34
	SW3	10±1.70	9.6±1.73	8±1.36
	SW4	8±1.11	11.2±1.20	8±1.09
	SW5	6±1.01	9.6±1.21	4±1.00
Mg (mg/L)	SW1	5.8±1.01	5.8±1.21	4.3±0.92
	SW2	6±1.10	4.8±1.00	3.8±0.98
	SW3	4.8±0.98	8.6±1.00	4.8±1.21
	SW4	4.8±1.38	3.4±1.02	4.8±1.11
	SW5	3.6±1.02	3.8±1.10	4.3±1.09
Cl (mg/L)	SW1	19±1.34	20±1.98	15±1.38
	SW2	20±1.59	30±1.92	14±1.58
	SW3	7±1.98	22±1.23	4±1.59
	SW4	15±1.98	24±1.29	10±1.57
	SW5	14±1.34	18±1.78	10±1.98
SO_4 (mg/L)	SW1	1.7±0.34	0.5±0.31	2±0.21
	SW2	1.5±0.12	0.7±0.23	1.8±0.32
	SW3	0.3±0.21	0.5±0.42	0.4±0.23
	SW4	0.5±0.054	0.6±0.23	0.5±0.01
	SW5	0.4±0.02	0.4±0.01	0.5±0.26
Fe(mg/L)	SW1	0.03±0.01	0.04±0.02	0.03±0.02
	SW2	0.02±0.01	0.06±0.01	0.02±0.01
	SW3	0.03±0.01	0.04±0.01	0.03±0.01
	SW4	0.04±0.01	0.04±0.01	0.04±0.01
	SW5	0.01±0.001	0.02±0.001	0.01±0.001
PO_4(mg/L)	SW1	0.005±0.00045	0.006±0.00045	0.003±0.00045
	SW2	0.004±0.00047	0.008±0.00041	0.004±0.00048
	SW3	0.004±0.00043	0.005±0.00044	0.002±0.00046
	SW4	0.008±0.00045	0.008±0.00043	0.003±0.00043
	SW5	0.004±0.00044	0.008±0.00046	0.001±0.00041
NO_3(mg/L)	SW1	0.1±0.04	0.3±0.05	0.2±0.03
	SW2	0.5±0.04	0.9±0.01	0.5±0.03
	SW3	0.3±0.03	0.5±0.04	0.3±0.04
	SW4	0.3±0.01	0.9±0.01	0.4±0.02
	SW5	0.2±0.01	0.4±0.02	0.2±0.01
F (mg/L)	SW1	0.2±0.01	0.3±0.07	0.2±0.05
	SW2	0.3±0.08	0.5±0.06	0.3±0.017
	SW3	0.2±0.09	0.3±0.06	0.3±0.03
	SW4	0.1±0.06	0.4±0.07	0.2±0.01
	SW5	0.1±0.05	0.2±0.05	0.1±0.05
Cu (mg/L)	SW1	0.005±0.0001	0.006±0.0003	0.003±0.0002
	SW2	0.009±0.0003	0.008±0.0003	0.004±0.0004
	SW3	0.007±0.0002	0.007±0.0001	0.002±0.0001
	SW4	0.008±0.0003	0.008±0.0001	0.003±0.0001
	SW5	0.004±0.0002	0.009±0.0001	0.001±0.0003
Pb (mg/L)	SW1	0.008±0.0001	0.009±0.0003	0.009±0.0004
	SW2	0.009±0.0004	0.008±0.0006	0.008±0.0001
	SW3	0.007±0.0004	0.007±0.0001	0.007±0.0005
	SW4	0.008±0.0003	0.008±0.0005	0.008±0.0003
	SW5	0.009±0.0005	0.009±0.0003	0.009±0.0001

monsoon, monsoon and post monsoon season of 2018-2019. Water samples (both ground water and surface water) collected from the identified locations were quickly transported to the laboratory under cool and insulated conditions for analysis of the physicochemical parameters. All analysis were conducted as per the protocol mentioned in Indian Standard (IS: 10500) derived from American Public Health Association [7].

3. Results

A. Surface Water Quality

Table 2 depicts the physicochemical characteristics of the surface water quality around the operating alumina refinery. It is evident from the table that, while the pH varied from 6.98±1.71 to 8.4±1.90 in post-monsoon, 7.15±1.99 to 8.82±1.79 in pre-monsoon and 6.75±1.34 to 7.58±1.89 in the monsoon season; the EC (µs/cm) in the same seasons ranged from 180±4.20 to 135±4.19, 199.5±4.90 to 108.6±4.78 and 202±5.67 to 91±5.37 respectively. Station SW2 (Chatrapur) showcased the highest pH irrespective of seasons and the same was true for station SW1 (Lanjigarh) in case of EC. Similarly, the lowest pH and EC values were observed in SW4 (Kenduguda) station and SW5 (Bundel) station respectively. pH displayed significant variations concerning both stations and seasons ($F \geq 8.23$, $p < 0.05$; Table 3). On the other hand, EC did not exhibit any significant variations with respect to both stations and seasons ($F \leq 2.57$, $p > 0.05$; Table 3).

The Turbidity (NTU) and TDS (mg/L) ranged from 25±1.34 to 18±1.90 and 106±3.39 to 80±4.19 in the post-monsoon, 38±2.10 to 10±1.20 and 111.5±4.10 to 60.4±4.89 in pre monsoon and 57±1.78 to 27±1.67 and 106±4.20 to 84±4.78 in the monsoon season respectively. While Station SW1 (Lanjigarh) showcased the highest Turbidity irrespective of seasons, the same was true for SW2 (Chatrapur) station in case of TDS. Similarly, the lowest value of turbidity was observed in SW5 (Bundel) Station and the lowest TDS value was observed in SW4 (Kenduguda) stations (Table 2). Turbidity displayed significant variations concerning both stations and seasons ($F \geq 5.97$, $p < 0.05$; Table 3), but TDS did not exhibit any significant variations either in seasons or in stations ($F \leq 1.03$, $p > 0.05$; Table 3).

The COD, on the other hand, ranged between 26.1±3.40 and 12.7±2.10, 34.2±2.39 and 8.6±2.20, and 22.4±2.10 and 12±2.00 in the post-monsoon, pre-monsoon, and monsoon seasons respectively (Table 2). While Station SW1 (Lanjigarh) showcased the highest COD value irrespective of seasons, the lowest value was observed in SW3 (Rengopali) Station. COD displayed a significant variation concerning stations only ($F = 11.97$, $p < 0.05$; Table 3).

Calcium and magnesium concentration (mg/L) in the surface water of the studied area ranged from 16.2±1.34 to 6±1.01 and 6±1.10 to 3.6±1.02 in the post-monsoon, 14.4±1.25 to 9.6±1.21 and 8.6±1.00 to 3.4±1.02 in the pre monsoon, and 15.6±1.85 to 4±1.00 and 4.8±1.21 to 3.8±0.98 in the monsoon season respectively (Table 2). While Station SW1 (Lanjigarh) showcased the highest value for both calcium and magnesium concentrations irrespective of seasons, the lowest values for the same were observed in station SW5 (Bundel). Calcium displayed a significant variation concerning stations only ($F=4.48$, $p < 0.05$; Table 3) but magnesium did not display any significant variations with respect to both stations and seasons ($F \leq 1.30$, $p > 0.05$; Table 3).

The chloride and sulphate concentrations ranged from

Table 3
ANOVA for various surface water parameters in different stations and seasons

Parameter	Source of Variation	SS	df	MS	F	P-value	F crit	S/ NS
pH	Stations	2.81	4.00	0.70	8.23	0.01	3.84	S
	Seasons	1.45	2.00	0.73	8.49	0.01	4.46	S
EC	Stations	9736.94	4.00	2434.23	2.57	0.12	3.84	NS
	Seasons	197.21	2.00	98.60	0.10	0.90	4.46	NS
TURBIDITY	Stations	1066.76	4.00	266.69	5.97	0.02	3.84	S
	Seasons	864.41	2.00	432.20	9.68	0.01	4.46	S
TDS	Stations	724.23	4.00	181.06	0.61	0.67	3.84	NS
	Seasons	607.32	2.00	303.66	1.03	0.40	4.46	NS
COD	Stations	724.14	4.00	181.04	11.97	0.00	3.84	S
	Seasons	1.56	2.00	0.78	0.05	0.95	4.46	NS
Ca	Stations	100.73	4.00	25.18	4.48	0.03	3.84	S
	Seasons	15.64	2.00	7.82	1.39	0.30	4.46	NS
Mg	Stations	8.53	4.00	2.13	1.30	0.35	3.84	NS
	Seasons	2.02	2.00	1.01	0.62	0.56	4.46	NS
Cl	Stations	184.40	4.00	46.10	4.52	0.03	3.84	S
	Seasons	381.73	2.00	190.87	18.71	0.00	4.46	S
SO_4	Stations	3.02	4.00	0.76	4.70	0.03	3.84	S
	Seasons	0.65	2.00	0.33	2.02	0.19	4.46	NS
Fe	Stations	0.00	4.00	0.00	4.00	0.05	3.84	S
	Seasons	0.00	2.00	0.00	4.26	0.05	4.46	S
PO_4	Stations	0.00001	4.00	0.00	1.94	0.20	3.84	NS
	Seasons	0.00005	2.00	0.00	15.17	0.00	4.46	S
NO_3	Stations	0.39	4.00	0.10	9.52	0.00	3.84	S
	Seasons	0.30	2.00	0.15	14.71	0.00	4.46	S
F	Stations	0.08	4.00	0.02	7.00	0.01	3.84	S
	Seasons	0.07	2.00	0.03	11.56	0.00	4.46	S
Cu	Stations	0.00001	4.00	0.00	1.76	0.23	3.84	NS
	Seasons	0.00007	2.00	0.00	19.09	0.00	4.46	S
Pb	Stations	0.000007	4.00	0.00	10.6	0.00	3.84	S
	Seasons	0.000	2.00	0.00	0.00006	1.00	4.46	NS

20±1.59 to 7±1.98 and 1.7±0.34 to 0.3±0.21 in the post-monsoon, 30±1.92 to 18±1.78 and 0.7±0.23to 0.4±0.01 in the pre monsoon, and 15±1.38 to 4±1.59 and 2±0.21 to 0.4±0.23 in the monsoon season respectively (Table 2). While Station SW2 (Chatrapur) showcased the highest chloride concentration irrespective of seasons, the same was true for SW1 (Lanjigarh) station concerning sulphate concentration. The lowest value on the other hand for chloride and sulphate concentrations were observed in station SW3 (Rengopali). Chloride displayed significant variations concerning both stations and seasons ($F \geq 4.52$, $p < 0.05$; Table 3), but sulphate exhibited significant variations concerning stations only ($F=4.70$, $p < 0.05$; Table 3).

Iron on the other hand, ranged between 0.04±0.01 and 0.01±0.001, 0.06±0.01 and 0.02±0.01, and 0.04±0.01 and 0.01±0.001 in the post-monsoon, pre-monsoon, and monsoon seasons respectively. While Station SW2 (Chatrapur) showcased the highest iron concentration irrespective of seasons, the lowest value was observed in SW4 (Kenduguda) Station (Table 2). Iron displayed significant variations concerning both stations and seasons ($F \geq 4.00$, $p < 0.05$; Table 3).

The nitrate and phosphate ranged from 0.5±0.04 to 0.1±0.04 and 0.004±0.00043 to 0.008±0.00045 in the post-monsoon, 0.9±0.01 to 0.3±0.05 and 0.005±0.00044 to 0.008±0.00046 in the pre monsoon, and 0.5±0.03 to 0.2±0.01 and 0.001±0.00041 to 0.001±0.00041 in the monsoon season respectively (Table 2). While Station SW2 (Chatrapur) and SW4 (Kenduguda) showcased the highest nitrate and phosphate concentration irrespective of seasons, the lowest value was observed in station SW1 (Lanjigarh) and SW3 (Rengopali). Nitrate displayed significant variations concerning stations and seasons ($F \geq 9.52$, $p < 0.05$; Table 3), but phosphate exhibited significant variation concerning stations only ($F=15.17$, $p < 0.05$; Table 3).

Fluoride ranged from 0.3±0.08 to 0.1±0.05 in the post-monsoon, 0.5±0.06 to 0.2±0.05 in the pre monsoon and 0.3±0.03 to 0.1±0.05 in the monsoon season (Table 2). While Station SW2 (Chatrapur) showcased the highest fluoride concentration irrespective of seasons, the lowest value was observed in station SW5 (Bundel). Fluoride displayed significant variations concerning both stations and seasons ($F \geq 7.00$, $p < 0.05$; Table 3).

The copper and lead concentrations in the surface water of the studied area varied from 0.004±0.0002 to 0.009±0.0003 and 0.007±0.0004 to 0.009±0.0004 in the post monsoon, 0.006±0.0003 to 0.009±0.0001 and 0.007±0.0001 to 0.009±0.0003 in the pre monsoon, and 0.001±0.0003 to

Table 4
Correlation between different surface water parameters irrespective of seasons

	Rainfall	Temp	WS	RH	pH	EC	TUR	TDS	COD
Rainfall	1								
Temp	0.624*	1							
WS	0.288	0.928*	1						
RH	0.742*	-0.062	-0.428	1					
pH	-0.631*	0.213	0.561*	-0.988*	1				
EC	-0.985*	-0.749*	-0.449	-0.615*	0.487	1			
TUR	0.985*	0.751*	0.451	0.613*	-0.485	-1.000*	1		
TDS	0.076	-0.732*	-0.933*	0.725*	-0.822*	0.097	-0.099	1	
COD	-0.603*	-1.000*	-0.938*	0.088	-0.239	0.732*	-0.733*	0.750*	1
Ca	-0.150	0.680*	0.904*	-0.774*	0.862*	-0.023	0.025	-0.997*	-0.700*
Mg	-0.695*	0.129	0.488	-0.998*	0.996*	0.560*	-0.559*	-0.770*	-0.150
Cl	-0.391	0.475	0.769*	-0.907*	0.961*	0.227	-0.224	-0.947*	-0.500
SO_4	0.936*	0.309	-0.067	0.930*	-0.863*	-0.862*	0.860*	0.422	-0.280
Fe	-0.038	0.757*	0.946*	-0.698*	0.799*	-0.135	0.137	-0.999*	-0.770*
PO_4	0.038	-0.757*	-0.946*	0.698*	-0.799*	0.135	-0.137	0.999*	0.770*
NO_3	0.077	0.827*	0.977*	-0.612*	0.725*	-0.248	0.250	-0.988*	-0.840*
F	0.241	0.909*	0.999*	-0.472	0.601*	-0.405	0.407	-0.949*	-0.920*
Cu	-0.487	-0.654*	-0.313	-0.611*	0.677*	-0.597*	-0.038	-0.901*	-0.784*
Pb	-0.231	-0.575*	-0.478	-0.598*	-0.712*	0.634*	-0.842*	-0.018	-0.319

	Ca	Mg	Cl	SO_4	Fe	PO_4	NO_3	F	Cu	Pb
Rainfall										
Temp										
WS										
RH										
pH										
EC										
TUR										
TDS										
COD										
Ca	1									
Mg	0.815*	1								
Cl	0.968*	0.934*	1							
SO_4	-0.488	-0.903*	-0.690*	1						
Fe	0.994*	0.745*	0.935*	-0.390	1					
PO_4	-0.994*	-0.745*	-0.934*	0.387	-1.000*	1				
NO_3	0.974*	0.663*	0.887*	-0.280	0.990*	-0.990*	1			
F	0.924*	0.531*	0.799*	-0.120	0.960*	-0.960*	0.990*	1		
Cu	-0.033	0.722*	0.552*	-0.231	0.231	0.231	0.799*	0.700*	1	
Pb	-0.854*	-0.719*	0.596*	0.994*	0.990*	-0.994*	0.494	0.647*	-0.311	1

'*' – $p < 0.05$

Table 5
Ground water quality parameters around refinery plant in Lanjigarh during 2018-2019

Parameters	Stations	Post-monsoon	Pre-monsoon	Monsoon
pH	GW1	7.58±0.21	7.04±0.11	7.64±0.11
	GW2	7.24±0.08	7.86±0.10	7.13±0.12
	GW3	7.61±0.10	7.52±0.11	7.68±0.12
	GW4	7.42±0.13	7.12±0.13	7.17±0.08
EC (μs/cm)	GW1	482±6.23	923.8±4.23	746±6.23
	GW2	173±4.56	144.3±6.89	198±6.89
	GW3	486±5.78	219.2±6.10	419±6.10
	GW4	169±6.67	352.8±6.20	133±5.23
TURBIDITY (NTU)	GW1	3.6±0.91	0.74±0.81	5±0.80
	GW2	3±0.10	0.48±0.99	4±0.78
	GW3	4.2±1.12	0.67±0.96	3±0.91
	GW4	3.6±0.92	0.71±0.34	5±0.91
TDS (mg/L)	GW1	248±6.82	470.1±6.65	436±6.21
	GW2	86±6.10	79.64±6.02	114±6.99
	GW3	282±6.01	121.4±6.08	243±6.12
	GW4	102±6.18	199.7±6.19	235±6.10
Ca (mg/L)	GW1	48±2.82	74±2.98	280±2.98
	GW2	19±2.99	20±2.10	84±2.11
	GW3	53±3.82	12±2.89	240±2.80
	GW4	25±2.11	53.6±2.32	60±2.13
Mg (mg/L)	GW1	22±1.12	24.9±1.98	24±1.65
	GW2	7.1±1.72	8±1.23	7.2±1.34
	GW3	23±1.45	6.3±1.34	19.7±1.12
	GW4	7.1±1.34	9.5±1.67	10.1±1.23
Cl (mg/L)	GW1	41.3±2.34	44±2.21	46±2.27
	GW2	13.9±1.34	8±2.99	10±2.28
	GW3	18.6±3.34	12±2.87	14±2.65
	GW4	11.7±2.67	8±2.76	8±2.98
SO4 (mg/L)	GW1	6.1±1.56	3.4±1.87	4±1.34
	GW2	2.2±1.34	0.3±0.01	1.4±0.23
	GW3	2.4±0.98	0.5±0.67	2.1±0.43
	GW4	1.8±0.23	0.7±0.12	1.6±0.23
Fe(mg/L)	GW1	0.04±0.03	0.05±0.06	0.04±0.05
	GW2	0.05±0.02	0.02±0.01	0.04±0.02
	GW3	0.05±0.06	0.16±0.02	0.06±0.03
	GW4	0.05±0.02	0.12±0.02	0.05±0.05
PO_4(mg/L)	GW1	2.34±0.56	5.21±1.92	2.02±0.39
	GW2	3.12±1.11	6.22±2.06	2.88±0.91
	GW3	4.65±1.67	5.96±2.39	3.21±1.20
	GW4	3.63±0.99	4.82±1.72	3.01±1.53
NO_3 (mg/L)	GW1	0.5±0.02	0.4±0.05	0.6±0.02
	GW2	0.3±0.04	0.2±0.06	0.3±0.05
	GW3	0.4±0.05	0.3±0.02	0.3±0.07
	GW4	0.4±0.02	0.2±0.04	0.4±0.06
F (mg/L)	GW1	0.4±0.01	0.9±0.02	0.4±0.02
	GW2	0.5±0.05	0.3±0.06	0.5±0.02
	GW3	0.7±0.02	0.4±0.02	0.2±0.06
	GW4	0.3±0.05	0.3±0.08	0.1±0.09
Cu (mg/L)	GW1	0.01±0.004	0.01±0.005	0.008±0.002
	GW2	0.01±0.009	0.01±0.005	0.008±0.003
	GW3	0.02±0.007	0.01±0.003	0.007±0.002
	GW4	0.01±0.003	0.01±0.008	0.009±0.004
Pb (mg/L)	GW1	0.002±0.0008	0.003±0.0003	0.002±0.0003
	GW2	0.003±0.0009	0.006±0.0004	0.002±0.0007
	GW3	0.002±0.0005	0.006±0.0007	0.002±0.0008
	GW4	0.003±0.0007	0.008±0.0004	0.004±0.0005

0.004±0.0004 and 0.007±0.0005 to 0.009±0.0001 in the monsoon season respectively. Stations SW2 and SW5 had highest concentrations for copper and lead irrespective of seasons while stations SW5 and SW3 had the lowest concentration of the same (Table 2). While copper displayed a significant variation concerning season only ($F=19.09$, $p < 0.05$; Table 3), lead exhibited significant variation concerning stations only ($F=10.60$, $p < 0.05$; Table 3).

When a Pearson's correlation matrix was plotted (at $\alpha=0.05$) between parameters to test the interrelationships, significant positive correlations were noted between pH and Ca, Mg, Cl, F, Cu ($r \geq 0.601$, $p < 0.05$; Table 4); between EC and COD, Mg, Pb ($r \geq +0.560$, $p < 0.05$; Table 4); between turbidity and sulphate ($r = +0.860$, $p < 0.05$; Table 4); between TDS and COD, phosphate ($r \geq +0.750$, $p < 0.05$; Table 4); between COD and phosphate ($r = +0.770$, $p < 0.05$; Table 4); between Ca and Mg, Cl, Fe, nitrate and F ($r \geq +0.815$, $p < 0.05$; Table 4); between Mg and Cl, Fe, nitrate, F, Cu ($r \geq +0.531$, $p < 0.05$; Table 4); between Cl and Fe, nitrate, F, Cu and Pb ($r \geq +0.552$, $p < 0.05$; Table 4); between Fe and nitrate, F, Pb ($r \geq +0.960$, $p < 0.05$; Table 4); between nitrate and F, Cu ($r \geq +0.799$, $p < 0.05$; Table 4). Similarly, significant negative correlations were

Table 6
ANOVA for various ground water parameters in different stations and seasons

Parameter	Source of Variation	SS	df	MS	F	P-value	F crit	S/ NS
pH	Stations	0.20	3.00	0.07	0.70	0.59	4.76	NS
	Seasons	0.01	2.00	0.01	0.07	0.94	5.14	NS
EC	Stations	548804.90	3.00	182934.97	7.18	0.02	4.76	S
	Seasons	13693.90	2.00	6846.95	0.27	0.77	5.14	NS
TURBIDITY	Stations	0.93	3.00	0.31	0.72	0.57	4.76	NS
	Seasons	29.45	2.00	14.72	34.27	0.00	5.14	S
TDS	Stations	134687.43	3.00	44895.81	6.60	0.02	4.76	S
	Seasons	12013.28	2.00	6006.64	0.88	0.46	5.14	NS
Ca	Stations	18140.49	3.00	6046.83	1.68	0.27	4.76	NS
	Seasons	43666.13	2.00	21833.06	6.05	0.04	5.14	S
Mg	Stations	502.06	3.00	167.35	6.96	0.02	4.76	S
	Seasons	22.06	2.00	11.03	0.46	0.65	5.14	NS
Cl	Stations	2382.90	3.00	794.30	124.46	0.00	4.76	S
	Seasons	22.88	2.00	11.44	1.79	0.25	5.14	NS
SO_4	Stations	21.24	3.00	7.08	31.08	0.00	4.76	S
	Seasons	7.25	2.00	3.62	15.91	0.00	5.14	S
Fe	Stations	0.01	3.00	0.00	1.64	0.28	4.76	NS
	Seasons	0.00	2.00	0.00	1.85	0.24	5.14	NS
PO4	Stations	3.11	3.00	1.04	3.48	0.09	4.76	NS
	Seasons	16.80	2.00	8.40	28.16	0.00	5.14	S
NO_3	Stations	0.09	3.00	0.03	9.73	0.01	4.76	S
	Seasons	0.04	2.00	0.02	6.82	0.03	5.14	S
F	Stations	0.17	3.00	0.06	1.28	0.36	4.76	NS
	Seasons	0.08	2.00	0.04	0.92	0.45	5.14	NS
Cu	Stations	0.000019	3.00	0.000006	0.66	0.61	4.76	NS
	Seasons	0.000041	2.00	0.000020	2.10	0.20	5.14	NS
Pb	Stations	0.000011	3.00	0.000003	3.74	0.08	4.76	NS
	Seasons	0.000028	2.00	0.00001	14.49	0.01	5.14	S

observed between pH and TDS, sulphate, phosphate, Pb ($r \geq -0.712$, $p < 0.05$; Table 4); between EC and turbidity, sulphate, Cu ($r \geq -0.597$, $p < 0.05$; Table 4); between turbidity and COD, Mg, Pb ($r \geq -0.559$, $p < 0.05$; Table 4); between TDS and Ca, Mg, Cl, Fe, nitrate, F, Cu ($r \geq -0.770$, $p < 0.05$; Table 4); between COD and Ca, Fe, nitrate, fluoride, Cu ($r \geq -0.700$, $p < 0.05$; Table 4); between Ca and phosphate, Pb ($r \geq -0.854$, $p < 0.05$; Table 4); between Mg and sulphate, phosphate, Pb ($r \geq -0.745$, $p < 0.05$; Table 4); between Cl and sulphate, phosphate ($r \geq -0.690$, $p < 0.05$; Table 4); between iron and phosphate ($r = -1.000$, $p < 0.05$; Table 4); between phosphate and nitrate, fluoride, Pb ($r \geq -0.960$, $p < 0.05$; Table 4).

B. Ground Water Quality

Table 5 depicts the physicochemical characteristics of the ground water quality around the operating alumina refinery. It is evident from the table that, while the pH varied from 7.24±0.08 to 7.61±0.10 in post-monsoon, 7.04±0.11 to 7.86±0.10 in pre-monsoon and 7.13±0.12 to 7.68±0.12 in the monsoon season; the EC (µs/cm) in the same seasons ranged from 169±6.67 to 486±5.78, 144.3±6.89 to 923.8±4.23 and 133±5.23 to 746±6.23 respectively. Station GW3 (Chatrapur) showcased the highest pH irrespective of seasons and the same was true for station GW1 (Lanjigarh) in case of EC. Similarly, the lowest pH and EC values were observed in GW4 (Chanalima) station and GW2 (Rengopali) station respectively. pH did not display any significant variations concerning both stations and seasons ($F \leq 0.70$, $p > 0.05$; Table 6). On the other hand, EC exhibited significant variations concerning stations only ($F = 7.18$, $p < 0.05$; Table 6).

The Turbidity (NTU) and TDS (mg/L) ranged from 3.0±0.10 to 4.2±1.12 and 86±6.10 to 282±6.01 in the post-monsoon, 0.48±0.99 to 0.74±0.81 and 79.64±6.02 to 470.1±6.65 in pre monsoon and 3.0±0.91 to 5.0±0.80 and 114±6.99 to 436±6.21 in the monsoon season respectively. While Station GW1 (Lanjigarh) showcased the highest Turbidity and TDS, the lowest value of turbidity and TDS was observed in GW2 (Rengopali) station irrespective of seasons. (Table 5). Turbidity displayed significant variation concerning seasons only ($F = 34.27$, $p < 0.05$; Table 6). On the other hand, TDS exhibited significant variation concerning stations only ($F = 6.60$, $p < 0.05$; Table 6).

Calcium and magnesium concentration (mg/L) in the ground water of the studied area ranged from 19±2.99 to 53±3.82 and 7.1±1.34 to 23±1.45 in the post-monsoon, 12±2.89 to 74±2.98 and 6.3±1.34 to 24.9±1.98 in the pre monsoon, and 60±2.13 to 280±2.98 and 7.2±1.34 to 24±1.65 in the monsoon season respectively (Table 5). While Station GW1 (Lanjigarh) showcased the highest value for both calcium and magnesium concentrations irrespective of seasons, the lowest values for the same were observed in station GW2 (Rengopali). Calcium displayed a significant variation concerning seasons only ($F=6.05$, $p < 0.05$; Table 6) but magnesium displayed significant variations concerning stations only ($F=6.96$, $p < 0.05$; Table 6).

The chloride and sulphate concentrations ranged from 11.7±2.67 to 41.3±2.34 and 1.8±0.23 to 6.1±1.56 in the post-monsoon, 8±2.76 to 44±2.21 and 0.3±0.01 to 3.4±1.87 in the pre monsoon, and 8±2.98 to 46±2.27 and 1.4±0.23 to 4±1.34 in the monsoon season respectively. While station GW1 (Lanjigarh) showcased the highest chloride and sulphate concentrations irrespective of seasons, the lowest value on the other hand for chloride and sulphate concentrations were observed in stations GW4 (Chanalima) and GW2 (Rengopali) respectively (Table 5). Chloride displayed significant variations concerning stations only ($F=124.46$, $p < 0.05$; Table 6), where

Table 7
Correlation between different ground water parameters irrespective of seasons

	Rainfall	Temp.	WS	RH	pH	EC	Turb	TDS	Ca	Mg
Rainfall	1.000									
Temp.	0.624*	1.000								
WS	0.288	0.928*	1.000							
RH	0.742*	-0.062	-0.428	1.000						
pH	-0.687*	-0.996*	-0.893*	-0.023	1.000					
EC	0.530*	0.993*	0.965*	-0.175	-0.980*	1.000				
Turb	0.207	-0.636*	-0.877*	0.809*	0.568*	-0.720*	1.000			
TDS	1.000*	0.647*	0.317	0.721*	-0.709*	0.555*	0.177	1.000		
Ca	0.896*	0.211	-0.168	0.963*	-0.293	0.098	0.620*	0.882*	1.000	
Mg	0.173	-0.662*	-0.893*	0.789*	0.596*	-0.743*	0.999*	0.143	0.593*	1.000
Cl	-0.522*	-0.992*	-0.967*	0.184	0.978*	-1.000*	0.726*	-0.548*	-0.089	0.749*
SO_4	-0.412	-0.969*	-0.991*	0.305	0.945*	-0.991*	0.806*	-0.439	0.036	0.826*
Fe	-0.038	0.757*	0.946*	-0.698*	-0.700*	0.827*	-0.986*	-0.008	-0.478	-0.991*
PO_4	-0.265	0.589*	0.847*	-0.843*	-0.518*	0.677*	-0.998*	-0.236	-0.666*	-0.996*
NO_3	0.038	-0.757*	-0.946*	0.698*	0.700*	-0.827*	0.986*	0.008	0.478	0.991*
F	-0.884*	-0.187	0.192	-0.969*	0.269	-0.073	-0.639*	-0.870*	-1.000*	-0.613*
Cu	-0.988*	-0.735*	-0.431	-0.631*	0.790*	-0.653*	-0.055	-0.992*	-0.817*	-0.021
Pb	-0.038	0.757*	0.946*	-0.698*	-0.700*	0.827*	-0.986*	-0.008	-0.478	-0.991*

	Cl	SO_4	Fe	PO_4	NO_3	F	Cu	Pb
Rainfall								
Temp.								
WS								
RH								
pH								
EC								
Turb								
TDS								
Ca								
Mg								
Cl	1.000							
SO_4	0.992*	1.000						
Fe	-0.832*	-0.895*	1.000					
PO_4	-0.684*	-0.769*	0.974*	1.000				
NO_3	0.832*	0.895*	-1.000*	-0.974*	1.000			
F	0.064	-0.061	0.500	0.684*	-0.500	1.000		
Cu	0.646*	0.546*	-0.115	0.115	0.115	0.803*	1.000	
Pb	-0.832*	-0.895*	1.000*	0.974*	-1.000*	0.500	-0.115	1.000

'*' – $p < 0.05$

as sulphate exhibited significant variations concerning both stations and seasons ($F \geq 15.91$, $p < 0.05$; Table 6).

Iron on the other hand, ranged between 0.04±0.03 and 0.05±0.02, 0.02±0.01 and 0.16±0.02, and 0.04±0.02 and 0.06±0.03 in the post-monsoon, pre-monsoon, and monsoon seasons respectively. While Station GW2 (Rengopali) showcased the lowest iron concentration irrespective of seasons, the highest value was observed in GW3 (Chatrapur) station (Table 5). Iron did not display any significant variation concerning both stations and seasons ($F \leq 1.85$, $p > 0.05$; Table 6).

The nitrate and phosphate ranged from 0.3±0.04 to 0.5±0.02 and 2.34±0.56 to 4.65±1.67 in the post-monsoon, 0.2±0.04 to 0.4±0.05 and 4.82±1.72 to 6.22±2.06 in the pre monsoon, and 0.3±0.05 to 0.6±0.02 and 2.02±0.39 to 3.21±1.20 in the monsoon season respectively (Table 5). While Station GW1 (Lanjigarh) and GW3 (Chatrapur) showcased the highest nitrate and phosphate concentration irrespective of seasons, the lowest value was observed in station GW2 (Rengopali) and GW1 (Lanjigarh). Nitrate displayed significant variations concerning stations and seasons ($F \geq 6.82$, $p < 0.05$; Table 6), but phosphate exhibited significant variation concerning seasons only ($F=28.16$, $p < 0.05$; Table 6).

Fluoride ranged from 0.3±0.05 to 0.7±0.02 in the post-monsoon, 0.3±0.06 to 0.9±0.02 in the pre monsoon and 0.1±0.09 to 0.4±0.02 in the monsoon season (Table 5). While Station GW1 (Lanjigarh) showcased the highest fluoride concentration irrespective of seasons, the lowest value was observed in station GW4 (Chanalima). Fluoride did not display any significant variations concerning both stations and seasons ($F \leq 1.28$, $p > 0.05$; Table 6).

The copper and lead concentrations in the surface water of the studied area varied from 0.01±0.003 to 0.02±0.007 and 0.02±0.0005 to 0.03±0.0007 in the post monsoon, 0.01±0.003 to 0.01±0.008 and 0.003±0.0003 to 0.008±0.0004 in the pre monsoon, and 0.007±0.002 to 0.009±0.004 and 0.002±0.0003 to 0.004±0.0005 in the monsoon season respectively. Station GW4 (Chanalima) had highest concentrations for copper and lead irrespective of seasons while station GW1 (Lanjigarh) had the lowest concentrations for the same (Table 5). While copper did not display any significant variations concerning both stations and seasons ($F \leq 2.10$, $p > 0.05$; Table 6), lead exhibited significant variation concerning seasons only ($F=14.49$, $p < 0.05$; Table 6).

When a Pearson's correlation matrix was plotted (at $\alpha=0.05$) between parameters to test the interrelationships, significant positive correlations were noted between pH and Mg, Cl, sulphate, nitrate, Cu ($r \geq +0.568$, $p < 0.05$; Table 7); between

EC and TDS, phosphate, Fe, Pb ($r \geq +0.555$, $p < 0.05$; Table 7); between turbidity and Ca, Mg, Cl, sulphate, nitrate ($r \geq +0.620$, $p < 0.05$; Table 7); between TDS and Ca ($r = +0.882$, $p < 0.05$; Table 7); between Ca and Mg ($r \geq +0.593$, $p < 0.05$; Table 7); between Mg and Cl, sulphate, nitrate ($r \geq +0.749$, $p < 0.05$; Table 7); between Cl and sulphate, nitrate, Cu ($r \geq +0.646$, $p < 0.05$; Table 7); between sulphate and nitrate, Cu ($r \geq +0.546$, $p < 0.05$; Table 7); between Fe and phosphate, Pb ($r \geq +0.974$, $p < 0.05$; Table 7); between phosphate and fluoride, Pb ($r \geq +0.684$, $p < 0.05$; Table 7); between F and Cu ($r \geq +0.803$, $p < 0.05$; Table 7). Similarly, significant negative correlations were noted between pH and EC, TDS, Fe, phosphate, Pb ($r \geq -0.518$, $p < 0.05$; Table 7); between EC and turbidity, Mg, Cl, sulphate, nitrate, Cu ($r \geq -0.653$, $p < 0.05$; Table 7); between turbidity and Fe, phosphate, F, Pb ($r \geq -0.639$, $p < 0.05$; Table 7); between TDS and Cl, F, Cu ($r \geq -0.548$, $p < 0.05$; Table 7); between Ca and phosphate, Cu ($r \geq -0.666$, $p < 0.05$; Table 7); between Mg and Fe, phosphate, F, Pb ($r \geq -0.613$, $p < 0.05$; Table 7); between Cl and Fe, phosphate, Pb ($r \geq -0.684$, $p < 0.05$; Table 7); between sulphate and Fe, phosphate, Pb ($r \geq -0.769$, $p < 0.05$; Table 7); between Fe and nitrate ($r = -1.000$, $p < 0.05$; Table 7); between phosphate and nitrate ($r = -0.974$, $p < 0.05$; Table 7); and between nitrate and Pb ($r = -1.000$, $p < 0.05$; Table 7).

4. Discussion

Water quality is the most vulnerable entity to pollution especially around an industrial operation. While, the most important pollutant of the surface water is organic matter and nutrients, the ground water is mostly impacted by the dissolved salts due its movements through various pores and channels inside the soil. Our study observed low organic concentration in surface water which is indicated by a low COD value. This suggests negligible industrial contribution in organic matter load on the nearby water bodies. However, a significant spatial variation in the COD suggests variable source of organic matter into the water body. Basti et al. [8] opined that the organic load to the water body gets diluted with rainfall events. Our results also reveal that the organic load in water was diluted due to natural events

On the other hand, this study also observed that the ground water showed considerable spatial scale variations in TDS indicating the contribution of industrial byproducts through underground leaching. Although, the TDS value was well within the permissible value (500 ppm) of the drinking water standard, the industrial impact on altering the water quality cannot be denied. Further, it was also found that the ground water was with greater EC value as compared to the surface water which also indicates the likelihood of presence of salts in soils that might have reached to the ground water.

When surface and ground water quality concerning the presence of Ca, Mg, Cl, SO_4 were analyzed, no significant variation was noted suggesting the non-disturbance of the water quality and negligible industrial impact on it. However, when the results of PO_4 and NO_3 were compared, significant difference concerning the nutrient concentrations were observed both in surface and ground waters. This suggests that the probability of ground water leaching of nutrients from soil is more than the surface runoff. Heavy metals and F concentration were however found to be in low concentrations in both the surface and ground water samples again indicating low industrial influence on the surrounding water quality. Enhanced nutrient (PO_4 and NO_3) contents can cause biological pollution in water [9], while presence of Ca and Mg can harden the water. The chloride content on one hand increases the salinity of water [10], heavy metals on the other hand can cause neuropsychological disorders [11].

It is evident from this study that although the industrial impact on altering the water quality of the nearby surface and ground water source is negligible as of now, the growing long-term impact and seasonal influence cannot be discarded. Therefore, not only the potable water alternative is to be identified and provided by the industry to the local people, but also the waste water discharge should be regulated in a more stringent manner to eliminate likely chances of future contamination. Our results were in line with the results reported by Kumar et al. [12] who observed similar seasonal influence on physicochemical characteristics of reservoir water in India. Further, the concept of zero discharge which is in practice should be more vigilantly monitored by the industry authorities and regulatory bodies.

5. Conclusion

This study presents an insight on the water quality around an industrial operation (an alumina refinery) in Odisha, India. The results suggest that the surface and ground water quality is impacted due to the surrounding areas and background soil conditions which might be due to industrial activities. Further, significant spatial and temporal scale variations in the physicochemical parameters reveal the seasonal and other human influence on changing water quality. Therefore, controlling measures at the industrial level and management strategies both at the industrial and local level must be adopted to maintain the water quality of both surface and ground waters in the future days.

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