Spatial Interpolation of Iron Contamination Around the Industrial Belts of Eastern Odisha: A GIS Approach

Dattatreya Sundaray*, Tarun Sahoo*, Sailazanandini Biswal*, Prabhu Prasad Das*, Sudarsan Sahoo**
*Department of Civil Engineering, ITER, SOA University, Bhubaneswar, Odisha, India
**Department of Chemistry, ITER, SOA University, Bhubaneswar, Odisha, India

***Abstract* - The present research looks at the spatial variation of iron contamination in groundwater around three of the major industrial hubs of eastern Odisha, India. Accordingly 52 samples of groundwater from these three regions were collected and analyzed for the determination of Iron contamination as well as the other influencing parameters including pH, Electrical Conductance, Total Dissolved Solids and the Dissolved Oxygen Level. Almost 36% of the samples had detectable level of Iron contamination as well as 63% had >10ppm of dissolved Oxygen concentration. The statistical analysis as well as the GIS spatial interpolation indicates no significant interrelationship between the analyzed parameters. However, the GIS interpolation indicates a close proximity of the contamination plumes to the various industry locations.**

Keywords - Heavy Metal, GIS, Groundwater, Dissolved Oxygen, Electrical Conductance, AAS

I. INTRODUCTION

Among the natural resources, water is considered as one of the most essential and precious one. About 97% of Globe's water is saline and only 2.5% belong to fresh water category [1]. That is the reason why water assumes a vital role in the development as well as depletion of any human activity. It can hence be considered as the cardinal natural resource supporting economic development and ecological diversity as well [7]. Groundwater utilization dates back to ancient times, although an understanding of the occurrence and movement of this as part of the hydrologic cycle is relatively recent [1]. Groundwater is part of the earth's water circulatory system known as hydrologic cycle and is that part of precipitation that percolates downward until it reaches the water table [1]. In various ways it is the reason behind the sustainment of rivers, wetlands, lakes, as well as subterranean ecosystems with karst or alluvial aquifers [8].

Natural waters have varying levels of material wastes and suspended solid particles [9]. Owing to its property of being a universal solvent, water dissolves minerals, rocks and soil that come in contact with it [1]. Groundwater pollution by various pollutants from the earth's surface create contaminant plume within an aquifer [4]. Hence, *"groundwater pollution may be defined as the artificially induced degradation of natural ground water quality"* [1]. This impairs the use of water and creates hazards to human health [2][3]. Waste water is the cardinal source of groundwater pollution coming from a variety of uses. In contrast to surface water pollution, sub-surface water pollution is hard to detect and is even harder to control and manage [1].

Heavy metals (those elements having atomic weight more than 63 and four times denser than water) can leach into groundwater from a verity of natural or anthropogenic sources, resulting in concentrations exceeding regulatory standards for drinking water [4]. Iron is one of the common heavy metals found on the surface of the earth. Although iron is not as toxic as other heavy metals such as lead, arsenic etc., higher concentration of this metal is undesirable in potable water. Primary natural iron minerals are magnetite, hematite, goethite and siderite [4]. Weathering releases this element into subsurface waters naturally. As the groundwater movement through the subsurface is very slow, the higher iron concentration is directly proportional to longer residence time [1].Dissolved iron content in groundwater varies seasonally for a given well. This in turn corresponds to the influx of oxygenated water from the surface during periods of recharge which prevents metal from dissolving. If the oxygen within this recharge water depletes, iron dissolves and the groundwater will have higher iron contamination. Deep aquifers typically have lower dissolved oxygen levels, particularly, if it contains organic particles. However, the dissolution of Fe^{2+} in groundwater do depend, to a lesser extent, upon the pH of the concerned subsurface water [5].

Elementary iron can dissolve under normal conditions whereas, naturally found iron oxide, iron hydroxide, iron carbide and iron penta-carbonyl are very much water insoluble [5]. The solubility of some of its compounds do increase at lower pH values [6]. Iron carbonate, iron sulfide and iron vitriol have water solubility of approximately 60 mg/l, 6 mg/l and 295 mg/l respectively. Also, many Fe chelation complexes are water soluble [5]. There does exist a noticeable difference between the Fe^{2+} and Fe^{3+} compounds. The latter are water soluble in strongly acidic environment and solubility increases after they reduce to Fe^{2+} under favorable conditions. The desirable concentration level of iron is 0.3 mg/l which is based on discoloration of laundry and typical metallic taste that becomes noticeable between 0.1 to 1.0 mg/l [5].

Ferrous iron (Fe^{2+}) is the common form found in wells and aquifers and has negative health effect for both higher and lower concentrations [4]. Generally, people not ingesting enough iron are anemic which causes tiredness, headaches and concentration loss. In contrast, those ingesting too much iron, get it accumulated in the pancreas, liver, spleen and heart causing major damage. Also, inhaling iron dust can lead to lung infection. Mining activity also causes iron to enter the soil contaminating the ground water [5].

The present study focuses on the iron contamination around three of the major industrial belts of eastern Odisha including the Jajpur Industrial Belt, Jagatpur Industrial Estate and the Paradeep Industrial region and its spatial variation through the geographic information system.

II. STUDY SITES

A. *Jajpur Industrial Belt*

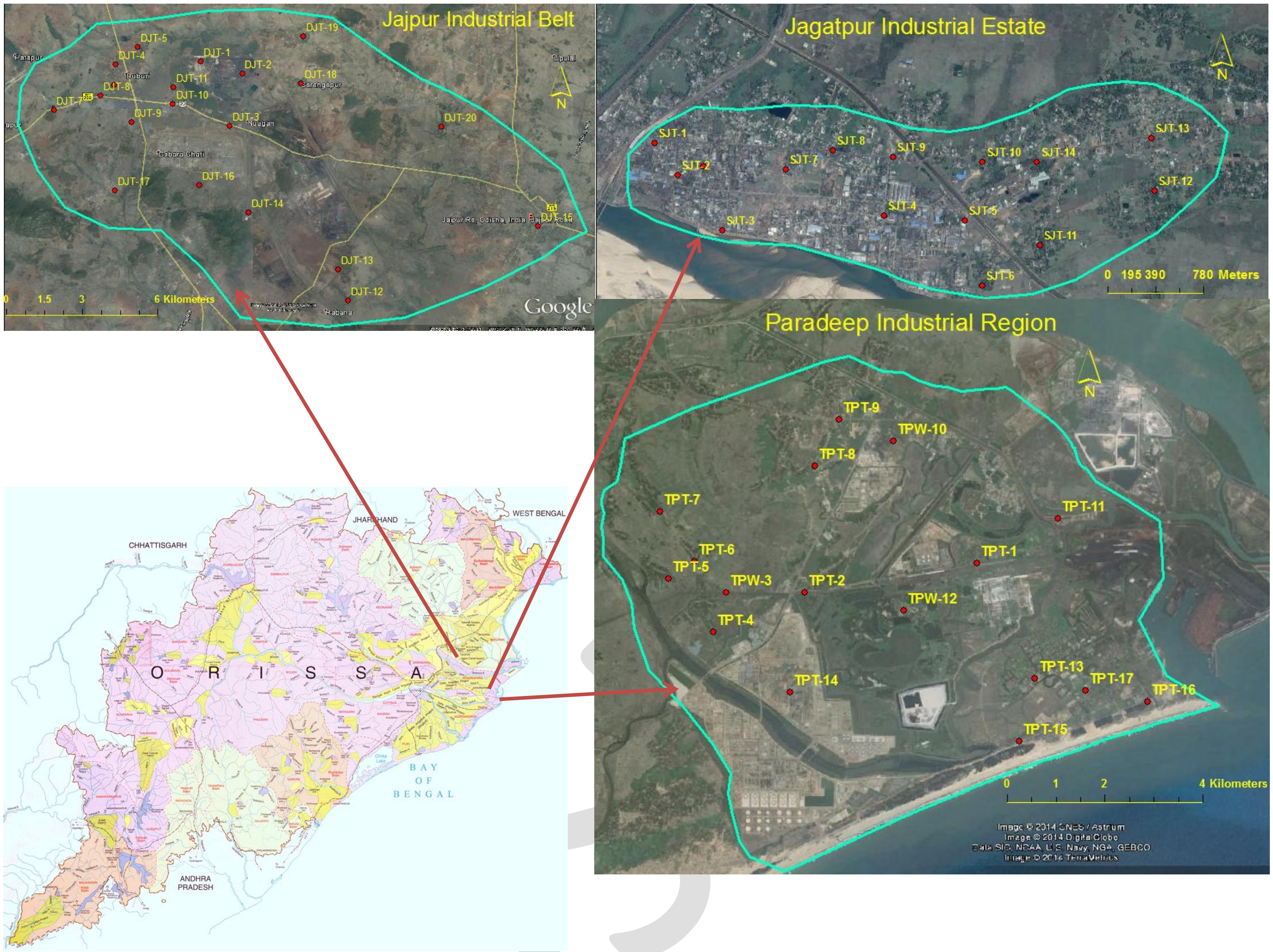
Jajpur is located in the eastern part of Odisha with geographical area of 2888 Sq. kms. Keonjhar and Bhadrak districts bound it on the North, Kendrapara and Cuttack district on the South, Dhenkanal on the West and Kendrapara and Bhadrak on the East. Historically, the district has been treated as a major producer of Paddy, pulses and oil seeds [13] [14]. The district fall under two agro-climatic zones- (1) Mid Central table land and (2) North East Coastal Plain. But the district has a network of no. of rivers such as the Baitarani, Brahmani, Kharsorta, Birupa and Budhabalanga providing potential water resources. Kalinganagar situated in Danagadi Block is a planned industrial and modern town in Jajpur [13][14]. Recently because of high global demand for steel, it is becoming a major global hub in steel, power and ancillary products. Major steel plants such as Neelachal Ispat Nigam Limited, Jindal Stainless Limited, Maithan Ispat, Tata Steel, VISA, MESCO and production units such as Brahmani River Pellets etc. are main components of this area. The city has been a main contributor to odisha's economy, human resource and fast growing urbanization. The present research dealing on the Fe contamination focuses on industries that are concentrated between latitudes of 20.9073^0N to 21.0208^0N and longitudes of 85.9467^0E to 86.1499^0E.

B. Paradeep Industrial Region

Paradeep is one of the major ports of India situated in Jagatsinghpur district, Odisha. The study site for the present research lies between 86.57° E to 86.68^0 E longitudes & 20.32° N to 20.28^0 N latitudes and is a very low lying with an average elevation of 1m. The temperature varies between 42^0C to 9^0C and average annual rain fall is about 1480^0C. Many industries have grown up due to port facilities, land availability, transportation facility & water availability [12]. The main source of water for drinking and industrial use is Taladanda Canal (a subsidiary canal of river Mahanadi) but as the population and industries are growing in a rapid pace the surface water is not enough for some of the nearby villages and Industries and they have to depend upon the ground water for their daily use and for irrigation [12]. The cardinal source of livelihood for nearby city and village population is this industrial hub of Paradeep. But still, many depend largely on agriculture to earn their livelihood and exploit the subsurface water resource for irrigation as the reach of surface water to each village cannot be maintained and supplied. Within Paradeep there are a variety of industries and the product varies from steel, fertilizers, Petroleum, Chemicals to Plastic, and Breweries etc. As many as 15 major industries are located in and around Paradeep including giant ones such as IOCL Oil Refinery, IFFCO & PPL, Fertilizer Manufacturing Unit, ESSAR Steel manufacturing plant, Cargill Edible oil refinery plant, Deppak Chemical manufacturing plant etc. [15]. One very big Steel manufacturing plant named POSCO is also going to set its unit near Paradeep. The population of the city is growing rapidly [16]. According to census 2001, the population of Paradeep stood at 73,633 but exploded to about 1,50,000 by 2009. This rapid growth is linked to the migration of workers following the expansion of the port and establishment of major projects such as Indian Oil's Paradeep Refinery [15][16]. Until recently the prime source of water for the city is canal water which many of the nearby villages and cities lack due to non-supply of treated water from water treatment plant of Paradeep port trust. Hence, groundwater is primarily explored by means of tube wells, Dug wells or bore wells. While, almost all industries use the canal water for their industrial needs, there are some such as KKSEPL who have their own bore wells for their needs as the canal water becomes scarce by the time it reaches the end users. In summer the situation becomes worse when the treatment plant of Paradeep port trust gets less water and the city residents suffer for domestic water and largely depend upon the tube wells. As there is intrusion of saline water to the ground water, normally the depth of tube wells and bore wells are more than 700ft.

C. Jagatpur Industrial Estate

Jagatpur lies in Cuttack district of Odisha, India and lies beside the Jobra barrage of Mahanadi river. The study site for the present research extends from 20.50^0N to 20.48^0N latitude and 85.92^0E to 85.96^0E longitude. The average



Fig, 1 Study areas around the three industrial regions of Jajpur, Paradeep and Jagatpur and the corresponding sampling locations. Source – Google Earth

elevation of the study site is about 31m from Mean Sea Level. Jagatpur experiences a tropical wet and dry climate and the average annual rainfall is around 144 cm with a temperature range of 45^0C in summer to 10^0C in winter.

With time the number of industries has manifolded due to its proximity to the capital of the state and Cuttack, the major business hub of Odisha, water availability, land availability and availability of raw materials for the industries. There exists more than 40 industries in and around Jagatpur with products varying from Ferro alloys, Steel, Animal feeds, Bakery etc. some of the major industries are PasupatiIspat, Kalinga Steel, R.P Steel Manufacturers, Pasupati animal feeds etc.. Industries as well as the nearby village population explore groundwater for their for their specific needs by tube wells, bore wells and some dug wells. The current population of Jagatpur is about 60,000 (2011 census) and as it continues to increase due to the expanding industrialization, groundwater is getting depleted and contaminated by this over utilization.

III. MATERIALS AND METHODOLOGY

Water sample collection for the present study has been done in accordance with the standard methods of 1060, APHA, 1995 from the various places within the above mentioned three industrial areas of interest. Sincere effort was made to collect the water samples from places around the various industries present within the concerned study site. This was followed so as to find out any specific spatial pattern that exists with respect to the industrial activity. A total of 52 ground water samples, 20 from Jajpur Industrial belt, 17 from Paradeep Industrial region and 15 from Jagatpur industrial estate were collected in September 2014.

The samples were collected in 250ml low density poly-ethyle4ne wide mouth bottle (conforming to USP Class IV) with leak-proof and air tight lid. Before collecting the samples from the required source, certain amount of water was first pumped out so that we should get fresh ground water (not stored water). Collector's hand was properly washed and the sampling bottles were rinsed with same water for few seconds before collecting the water samples. During the collection of water samples the location of the site was identified by GPS device (GARMIN NUVI 250). The labeling of the samples was done in such a manner so that it clearly demonstrates the system (e.g. well or tube-well or bore well), sampling site and sample number. The date and time of the sampling was also noted down during the collection of the samples. As soon as the sample were collected, they were labeled and capped and packaged in foam box that was used exclusively for this purpose.

Physical parameters like PH, Electrical Conductance (EC) were measured on the spot by Systronics Water analyzer 371 and Total dissolved Solid (TDS) was calculated from the obtained EC by multiplying a factor of 0.64 to the EC value. Determination of the concentration of Dissolved Oxygen (DO) in samples was calculated by oxidation of KI by nascent oxygen obtained from the DO using $Mn(OH)_2$. The liberated iodine was titrated against standard $Na_2S_2O_3$ solution using starch as indicator.

Fe^{2+} concentration of the collected samples was done by Atomic Absorption Spectroscopy (AAS). The AAS has been in use since the 1950s and is based on the principle that a specific electron configuration of a specific element produces a unique line spectrum when excited [13]. The concentration of a metal is determined by applying the Beer-Lambert Law to light absorbed by the concerned sample. The Beer-Lambert Law is an empirical relationship that represents the inter-relationship between absorption and concentration. In the present research the Fe^{2+} concentration was determined by the Microprocessor Based Doubled Beam Atomic Absorption Spectrometer (AAS), SL: 176 Model (ELICO) with a lamp Current of 8.0 mA and Air-Acetylene (Oxidizing) flame. The amount of iron in natural water samples was found to be higher than the detection limits. Therefore, the determination of iron was performed directly without pre-concentration and the wavelength was set to 248 nm as optimum working range was in between 2ppm to 9ppm.(sensitivity 0.05ppm).

IV. RESULTS AND DISCUSSION

The present study focused on the spatial distribution of Fe around the three major industrial hubs of eastern Odisha. As explained earlier, Fe^{2+} concentration is influenced by the pH and DO levels in the corresponding groundwater zone. Therefore, the physico-chemical parameters including pH, EC, TDS and DO were studied along with the contamination of Fe^{2+}. The concentration of the above factors as estimated from the *in situ* as well as laboratory experiments is given in Table I,II,III. The corresponding statistical correlation between the various physico-chemical elements is given in Table IV. From the statistical analysis it is hard to find out any significant relationship between Fe^{2+} and other parameters. The noticeable relationship which is displayed by this statistical analysis is between pH and EC where they vary linearly for Jajpur and Paradeep industrial belts, but, show a markedly negative correlation for the Jagatpur industrial area. Fe^{2+} conspicuously displays a linear relationship with DO for Jajpur industrial area, although albiet very weakly. This is markedly different from the established theories of negative relationship between the Fe^{2+} and DO. Fe displays a weak negative relationship with pH in Jajpur and Paradeep industrial sites but shows almost no correlation in Jagatpur area. The DO does display a

TABLE I
GROUNDWATER QUALITY ANALYSIS OF
JAJPUR INDUSTRIAL BELT

Jajpur Industrial Belt							
FID	Longitude (^0E)	Latitude (^0N)	PH	EC (µs)	TDS (ppm)	Fe^{2+} (ppm)	DO (ppm)
DJT-1	86.01	21.00	6.99	758	485.12	0.17	8.0
DJT-2	86.03	21.00	5.80	234	149.76	0.09	10.2
DJT-3	86.02	20.98	6.65	316	202.24	0.77	11.2
DJT-4	85.98	21.00	7.08	703	449.92	0.11	9.2
DJT-5	85.99	21.01	5.55	57	36.67	0.40	10.8
DJT-6	85.98	20.99	7.16	862	551.68	0.17	8.4
DJT-7	85.96	20.98	6.68	312	199.68	0.32	9.6
DJT-8	85.98	20.99	6.65	572	366.08	0.45	10.8
DJT-9	85.99	20.98	7.05	695	444.80	0.13	9.2
DJT-10	86.00	20.99	6.04	313	200.32	0.53	13.0
DJT-11	86.00	20.99	7.00	595	380.80	0.87	8.0
DJT-12	86.06	20.92	6.47	453	289.92	1.07	10.4
DJT-13	86.06	20.93	6.30	231	147.84	0.55	10.8
DJT-14	86.03	20.95	6.30	428	273.92	0.65	9.2
DJT-15	86.13	20.94	6.77	848	542.72	0.15	8.4
DJT-16	86.01	20.96	6.20	350	224.00	0.40	10.7
DJT-17	85.98	20.96	6.50	518	331.52	0.18	9.1
DJT-18	86.05	20.99	5.90	242	154.88	0.45	11.1
DJT-19	86.05	21.01	6.10	490	313.60	0.39	9.6
DJT-20	86.10	20.98	6.58	510	326.40	0.32	9.8

TABLE II
GROUNDWATER QUALITY ANALYSIS OF
PARADEEP INDUSTRIAL REGION

Paradeep Industrial Region							
FID	Longitude (^0E)	Latitude (^0N)	PH	EC (µs)	TDS (ppm)	Fe^{2+} (ppm)	DO (ppm)
TPT-1	86.64	20.28	7.70	1430	915.20	0.19	11.0
TPT-2	86.60	20.28	6.37	1410	902.40	0.06	11.4
TPW-3	86.59	20.28	7.50	2740	1753.60	0.26	9.8
TPT-4	86.59	20.27	7.74	1690	1081.60	0.09	10.0
TPT-5	86.58	20.28	7.70	1540	985.60	0.00	10.6
TPT-6	86.58	20.28	7.76	1470	940.80	0.11	9.8
TPT-7	86.58	20.29	7.65	1340	857.60	0.17	11.8
TPT-8	86.61	20.30	7.50	2780	1779.20	0.60	11.2
TPT-9	86.61	20.31	6.26	484	309.76	0.53	10.6
TPW-10	86.62	20.31	6.70	507	324.48	0.26	8.6
TPT-11	86.65	20.29	7.89	1140	729.60	0.11	10.2
TPW-12	86.62	20.28	6.80	992	634.88	0.36	7.6
TPT-13	86.65	20.26	8.23	1550	992.00	0.15	8.4
TPT-14	86.60	20.26	7.30	939	600.96	0.11	9.4
TPT-15	86.64	20.25	7.70	1390	889.60	0.21	8.8
TPT-16	86.67	20.26	7.50	1360	870.40	0.30	10.8
TPT-17	86.66	20.26	8.13	1680	1075.20	0.11	7.2

TABLE III
GROUNDWATER QUALITY ANALYSIS OF JAGATPUR INDUSTRIAL ESTATE

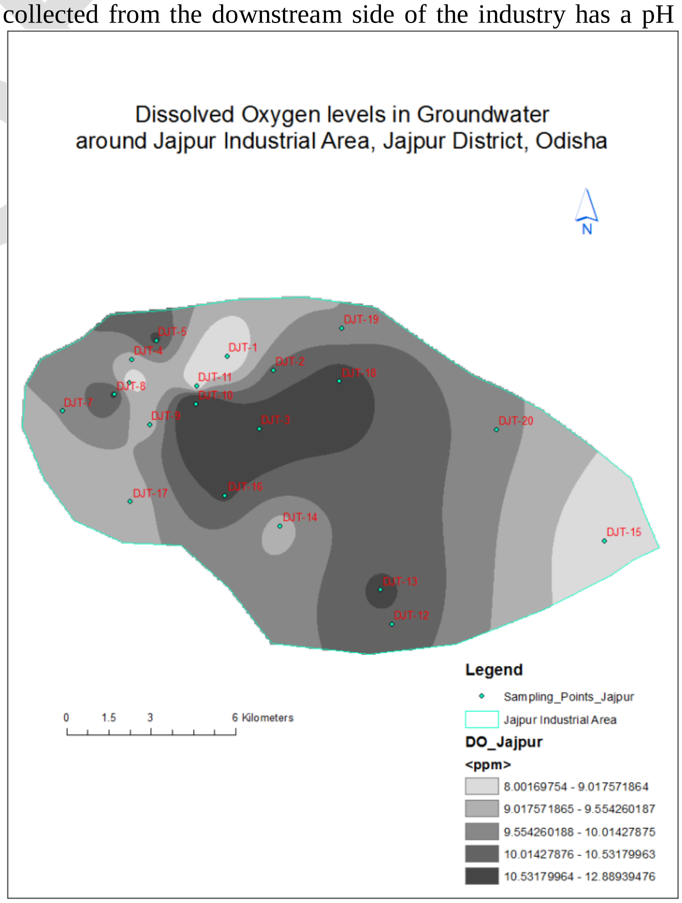
Jagatpur Industrial Estate							
FID	Longitude (^{0}E)	Latitude (^{0}N)	PH	EC (µs)	TDS (ppm)	Fe^{2+} (ppm)	DO (ppm)
SJT-1	85.92	20.50	6.16	486	311.04	0.24	10.4
SJT-2	85.92	20.49	6.58	687	439.68	0.17	10.4
SJT-3	85.93	20.49	6.39	771	493.44	0.45	11.2
SJT-4	85.94	20.49	6.53	627	401.28	0.09	10.8
SJT-5	85.94	20.49	7.26	177	113.28	0.06	11.2
SJT-6	85.95	20.49	5.97	1070	684.80	0.28	10.2
SJT-7	85.93	20.49	6.48	375	240.00	0.15	10.8
SJT-8	85.94	20.49	6.63	243	155.52	0.21	10.8
SJT-9	85.94	20.49	6.72	678	433.92	0.13	10.4
SJT-10	85.95	20.49	6.72	363	232.32	0.19	11.0
SJT-11	85.95	20.49	7.43	299	191.36	0.45	10.8
SJT-12	85.96	20.49	6.41	234	149.76	0.15	11.2
SJT-13	85.96	20.50	6.16	248	158.72	0.15	13.4
SJT-14	85.95	20.49	7.04	229	146.56	0.17	10.2
SJT-15	85.93	20.49	6.21	653	417.92	0.17	10.4

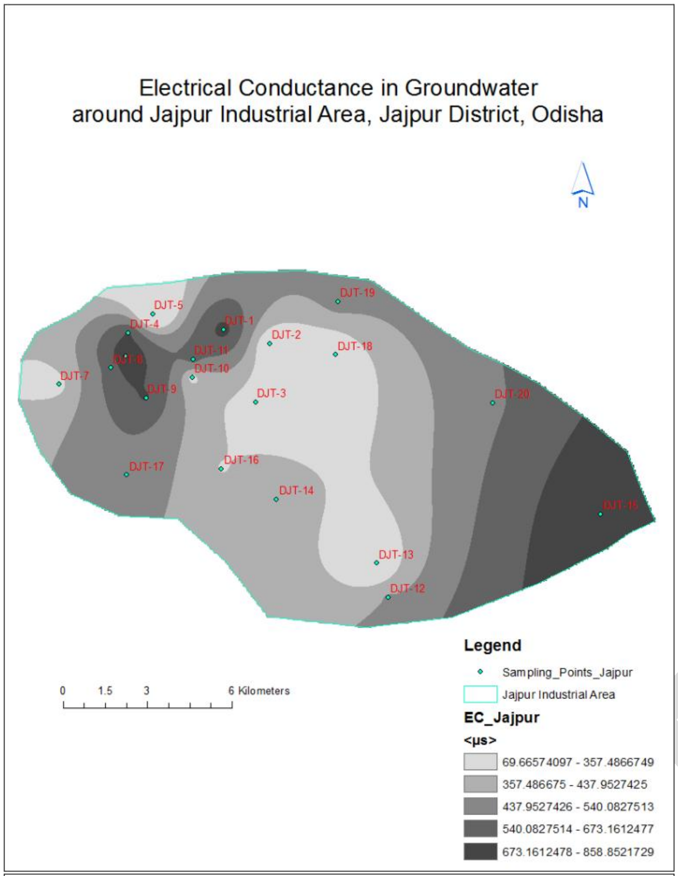
TABLE IV
CORRELATION BETWEEN VARIOUS GROUNDWATER QUALITY PARAMETERS

Jajpur Industrial Belt					
	PH	EC	TDS	Fe^{2+}	DO
PH	1.00				
EC	0.85	1.00			
TDS	0.85	1.00	1.00		
Fe2+	-0.14	-0.34	-0.34	1.00	
DO	-0.65	-0.73	-0.73	0.32	1.00
Jagatpur Industrial Estate					
	PH	EC	TDS	Fe^{2+}	DO
PH	1.00				
EC	-0.54	1.00			
TDS	-0.54	1.00	1.00		
Fe2+	0.05	0.27	0.27	1.00	
DO	-0.13	-0.41	-0.41	-0.09	1.00
Paradeep Industrial Region					
	PH	EC	TDS	Fe^{2+}	DO
PH	1.00				
EC	0.46	1.00			
TDS	0.46	1.00	1.00		
Fe2+	-0.41	0.10	0.10	1.00	
DO	-0.17	0.18	0.18	0.09	1.00

negative correlationship with EC for Jajpur and Jagatpur industrial areas but contrastingly shows a positive relationship in Paradeep area. From the above characteristics it can be assumed that there exists no specific interrelationship between the various groundwater quality measuring parameters. This absence of correlation between the various factors may be attributed to the timing of the sampling. The sampling was carried out immediately after few weeks of heavy rain along the eastern tracts of the state of Odisha due to low pressure storms formed over the Bay-of-Bengal. This indicates chaotic intermixing of various elements within the groundwater zone which can be very close to the ground surface during the monsoonal period.

However, to determine the areal distribution of the physico-chemical parameters and to find out the epicenters of contamination plumes, the above data set was analyzed in a GIS environment (Fig. 2). Arc GIS 10 was used to spatially interpolate the analyzed concentrations of various water pollutants. Digital Elevation Models (DEMs) were created for each parameter (where the concentration is displayed as elevation) to know the lateral variation of the groundwater pollution. The spatial interpolation of Fe^{2+}, EC, TDS, DO and pH are also in accordance with the statistical findings. The contamination plumes which is displayed by the DEMs of the concerned elements do not show any kind of interrelationship. However, the epicenters of these plumes do correspond to the locations of the various industries situated within the study sites. Of particular mention is the study site DJT 1 and DJT 2, where the former collected from the canteen tube well displays a pH value of 6.9 (upstream of the industry) whereas the later collected from the downstream side of the industry has a pH




Electrical Conductance in Groundwater
around Jajpur Industrial Area, Jajpur District, Odisha
N
0 1.5 3 6 Kilometers
Legend
Sampling_Points_Jajpur
Jajpur Industrial Area
EC_Jajpur
<μs>
69.66574097 - 357.4866749
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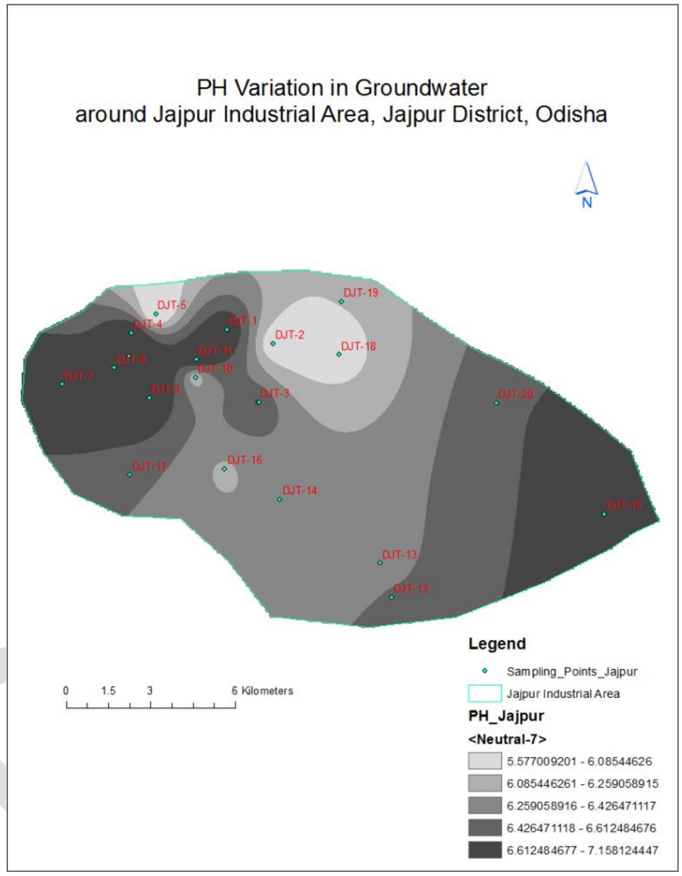
673.1612478 - 858.8521729


PH Variation in Groundwater
around Jajpur Industrial Area, Jajpur District, Odisha
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0 1.5 3 6 Kilometers
Legend
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Jajpur Industrial Area
PH_Jajpur
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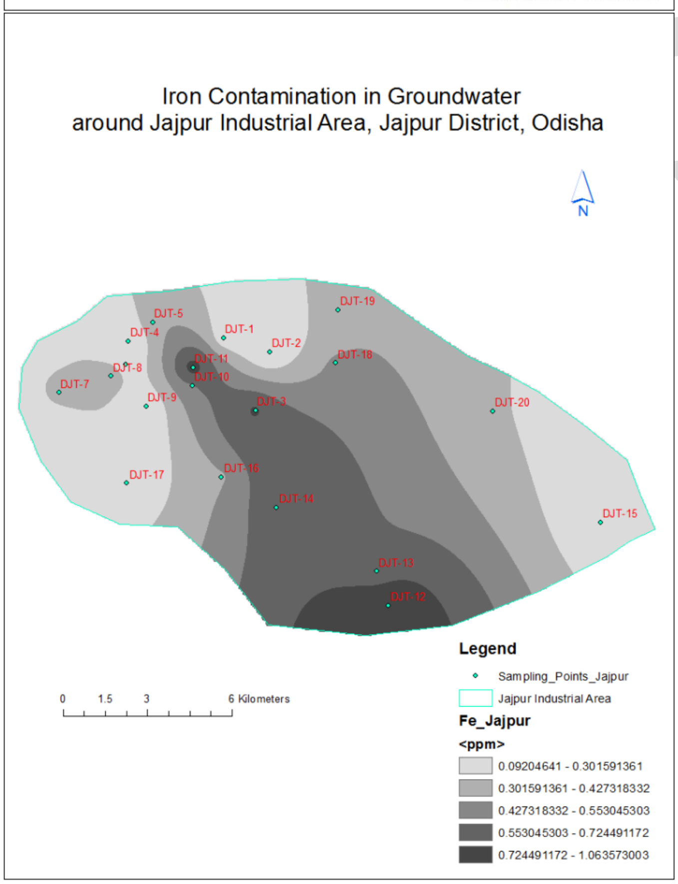
Iron Contamination in Groundwater
around Jajpur Industrial Area, Jajpur District, Odisha
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0 1.5 3 6 Kilometers
Legend
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Jajpur Industrial Area
Fe_Jajpur
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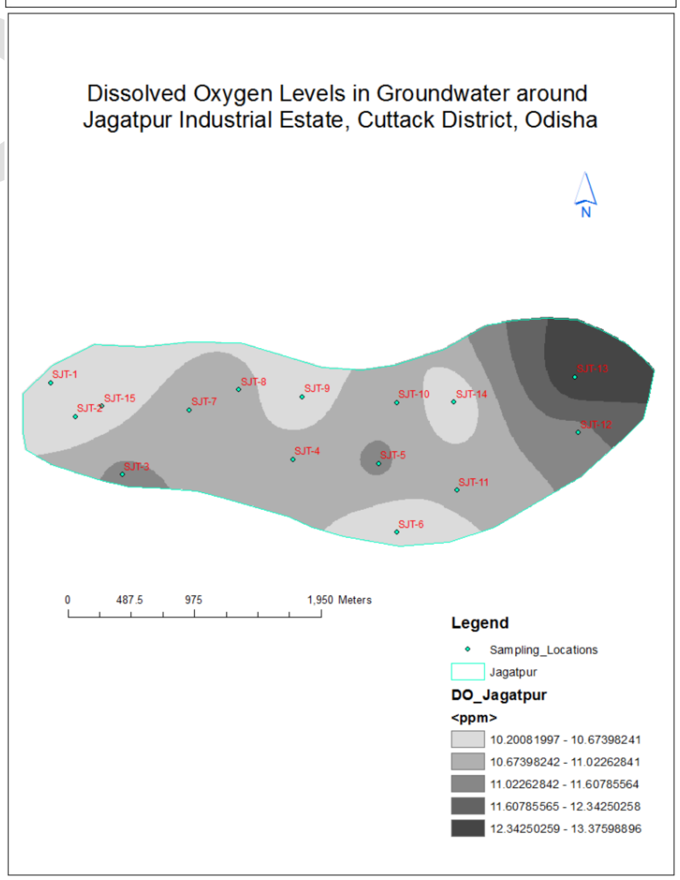
Dissolved Oxygen Levels in Groundwater around
Jagatpur Industrial Estate, Cuttack District, Odisha
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0 487.5 975 1,950 Meters
Legend
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Jagatpur
DO_Jagatpur
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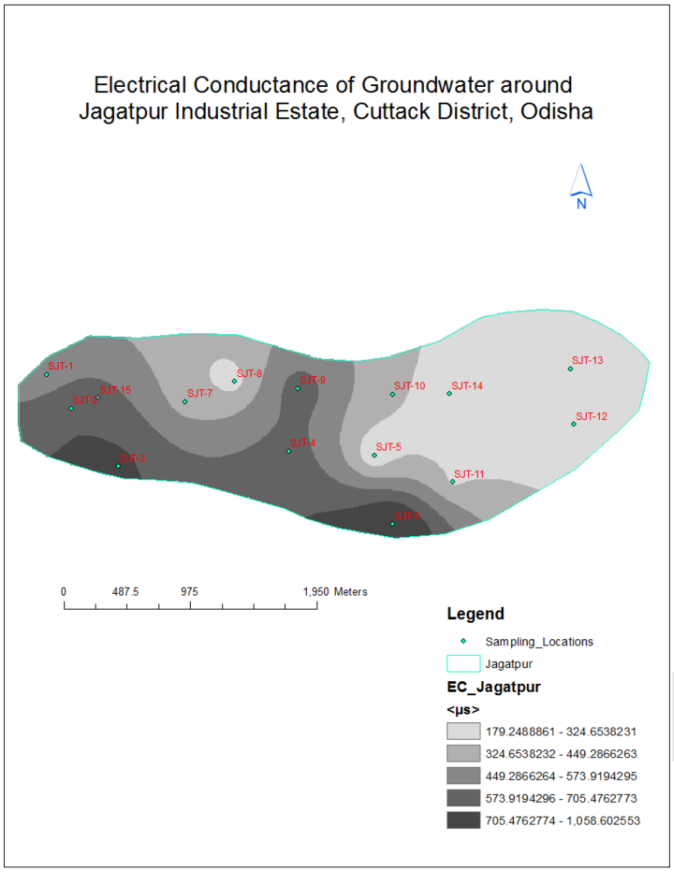
Electrical Conductance of Groundwater around
Jagatpur Industrial Estate, Cuttack District, Odisha
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SJT-2
SJT-15
SJT-7
SJT-8
SJT-9
SJT-10
SJT-14
SJT-13
SJT-12
SJT-3
SJT-4
SJT-5
SJT-11
SJT-6
0 487.5 975 1,950 Meters
Legend
Sampling_Locations
Jagatpur
EC_Jagatpur
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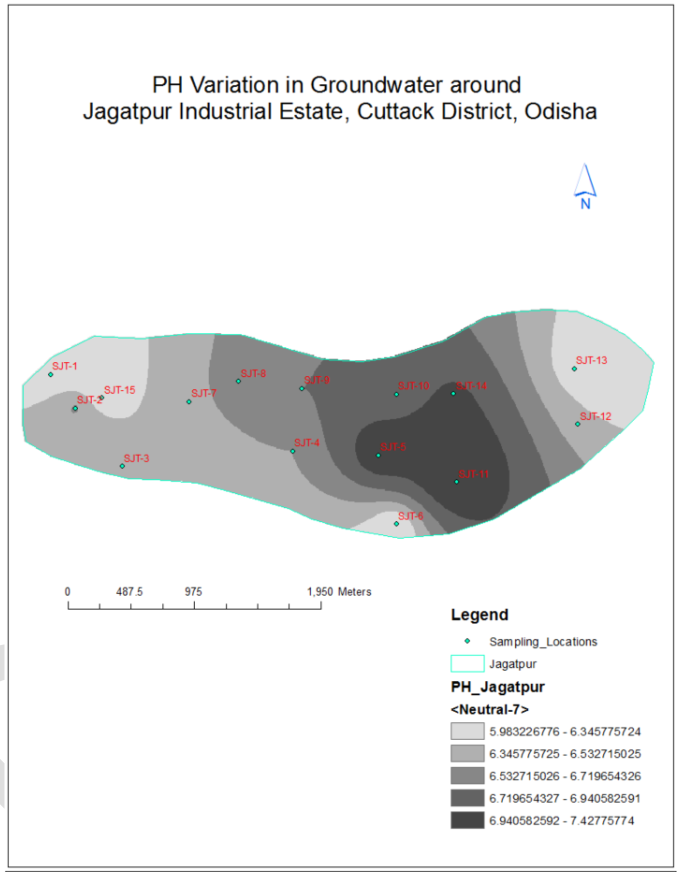
PH Variation in Groundwater around
Jagatpur Industrial Estate, Cuttack District, Odisha
N
SJT-1
SJT-2
SJT-15
SJT-7
SJT-8
SJT-9
SJT-10
SJT-14
SJT-13
SJT-12
SJT-3
SJT-4
SJT-5
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SJT-6
0 487.5 975 1,950 Meters
Legend
Sampling_Locations
Jagatpur
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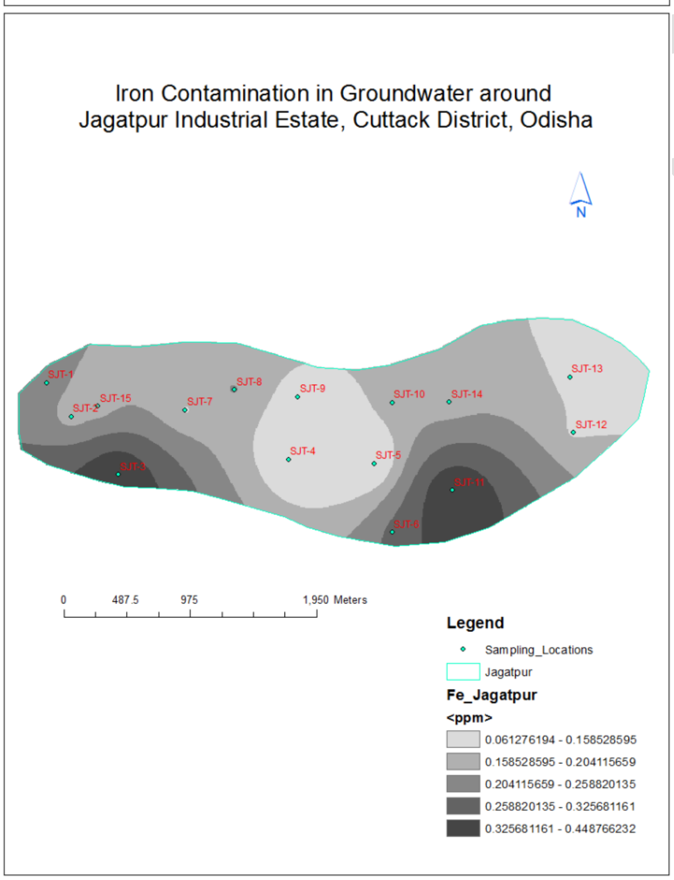
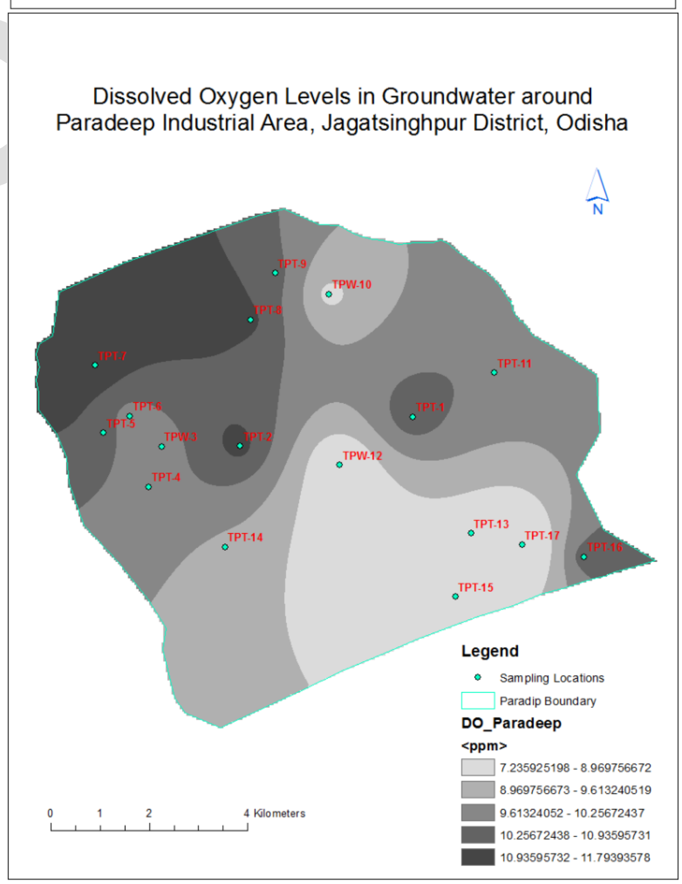
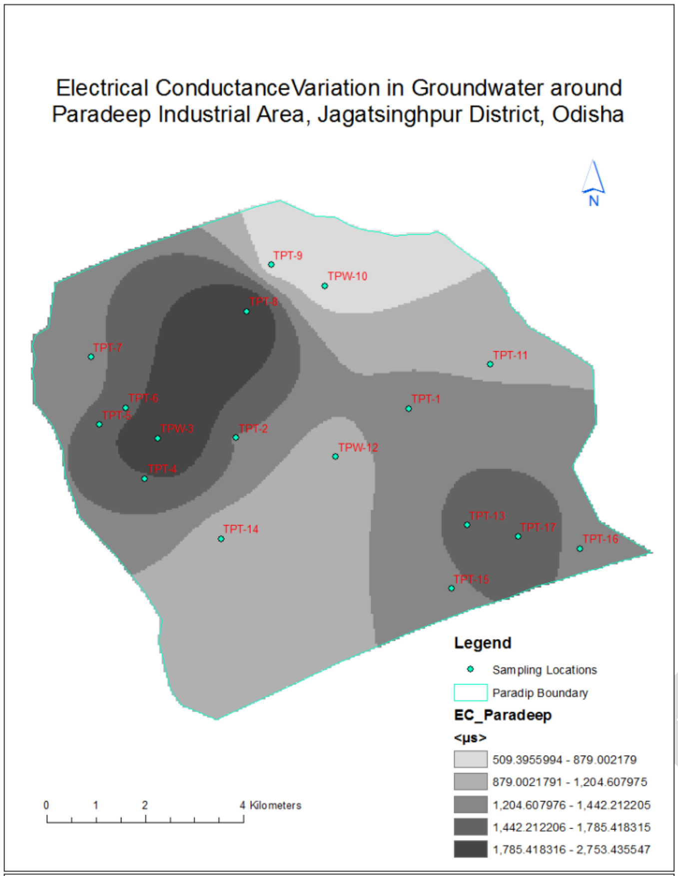
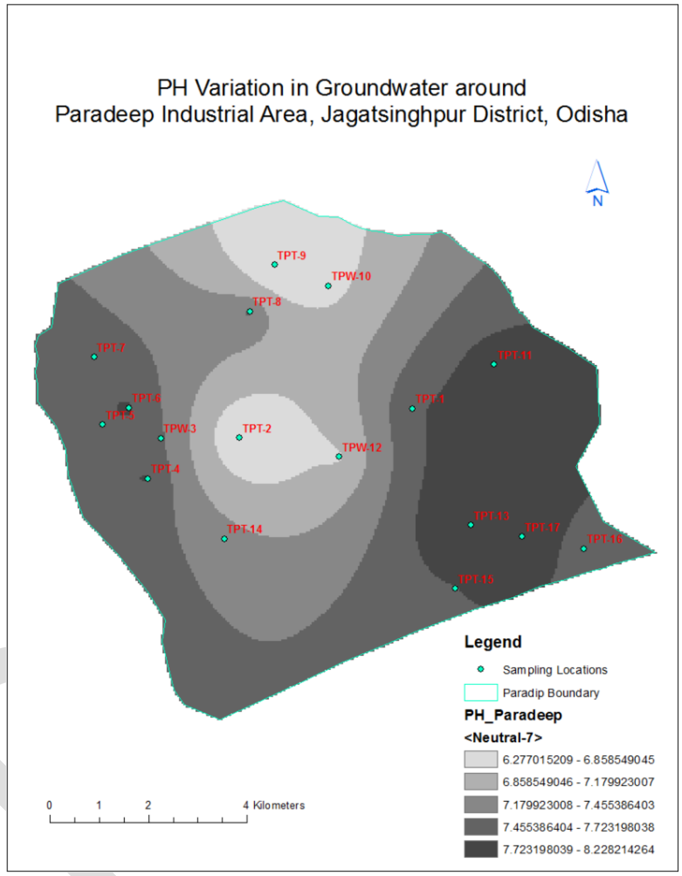
6.719654327 - 6.940582591
6.940582592 - 7.42775774


Iron Contamination in Groundwater around
Jagatpur Industrial Estate, Cuttack District, Odisha
N
SJT-1
SJT-2
SJT-15
SJT-7
SJT-8
SJT-9
SJT-10
SJT-14
SJT-13
SJT-12
SJT-3
SJT-4
SJT-5
SJT-11
SJT-6
0 487.5 975 1,950 Meters
Legend
Sampling_Locations
Jagatpur
Fe_Jagatpur
<ppm>
0.061276194 - 0.158528595
0.158528595 - 0.204115659
0.204115659 - 0.258820135
0.258820135 - 0.325681161
0.325681161 - 0.448766232


Dissolved Oxygen Levels in Groundwater around
Paradeep Industrial Area, Jagatsinghpur District, Odisha
N
TPT-9
TPW-10
TPT-8
TPT-7
TPT-11
TPT-6
TPT-5
TPW-3
TPT-2
TPT-1
TPW-12
TPT-4
TPT-14
TPT-13
TPT-17
TPT-16
TPT-15
0 1 2 4 Kilometers
Legend
Sampling Locations
Paradip Boundary
DO_Paradeep
<ppm>
7.235925198 - 8.969756672
8.969756673 - 9.613240519
9.61324052 - 10.25672437
10.25672438 - 10.93595731
10.93595732 - 11.79393578





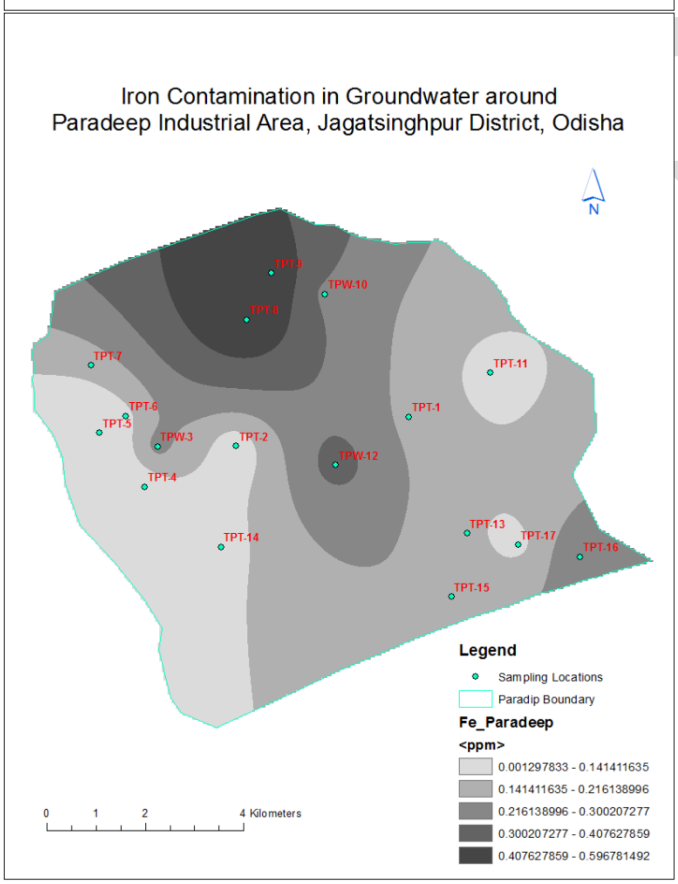


Fig. 2 DEMs of various quality parameters of study sites

value of 5.8 (correspond to the industry's coke dumping zone). But, contrastingly the same sample has a very low iron concentration of 0.09ppm. Out of the 52 groundwater samples collected from the three industrial belts 19 samples have Fe^{2+} contamination i.e. the samples have Fe^{2+} concentration more than 0.3mg/l and also the same no. of samples do have pH values less than 6.5 which is acidic. This points to an approximately 36.5% of acidic water as well as iron contamination. However, 65% of samples from Jajpur industrial belt have Fe concentration more than the desirable limit of 0.3ppm. This indicates toward the Fe^{2+} contamination of groundwater from the concentrated iron industry within the belt as well as towards the possible contaminating mining areas upstream of the study site. About 63.46% of samples have DO levels more than 10ppm which is the highest desirable limit. This high level of DO is not appropriate for specific industrial operation and also it points to the immediate previous rain fall wherein oxygenated water have percolated underground. As TDS was calculated with a multiplication factor of 0.64 from EC, the spatial interpolation came identical to that of the EC. While the groundwater samples of Jajpur and Jagatpur industrial areas displayed normal EC values (except SJT-6 sampling location of Jagatpur belt), all the samples of Paradeep region gave very high values of EC indicating higher salinity and possible indication towards the saline water intrusion along the coast.

V. CONCLUSION

The present research carried out the *in situ* as well as laboratory investigation of Fe^{2+} contamination in the groundwater zones around three of the major industrial belts of eastern Odisha. The analysis displays no significant interrelationship between the water chemical parameters investigated. This indicates to the possible chaotic intermixing of water elements after the heavy monsoonal rainfall due to low pressure storms over the Bay-of-Bengal. The higher EC values of Paradeep industrial belt also points to the possible saline water intrusion along the coast as well as the higher Fe values of Jajpur industrial area points to the concentrated iron industry within the region as well as possible source of contamination from the exploratory Fe mines upstream. The higher DO levels found out throughout the industrial belts are not appropriate for certain boiler operations and also points towards the oxygenated water influx after the heavy storm showers.

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