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Iron-Ore Mining, Water Quality and Health: An Investigation into their Relationships

Minati Sahoo*, Dharmabrata Mohapatra[1] and Dukhabandhu Sahoo[2]

Department of Economics, Central University of Orissa, Landiguda, Dist. Koraput, Odisha, India
[1]Department of Economics, Ravenshaw University, Cuttack, Odisha, India
[2]School of HSS&M, Indian Institute of Technology Bhubaneswar, Odisha, India
✉ minati.sahoo@gmail.com

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Abstract: The present study has made an attempt to investigate and estimate the relationship of water quality and health of the inhabitants living in the iron-ore mining region of Odisha. For this, the study has used a comparative analysis (with and without mining) and techniques like t-test, Principal Component Analysis and Regression analysis. It has been found that mining activities have deteriorated the water quality (both surface and ground water) in the region. Even the occurrence of water-borne diseases is positively and significantly related to water parameter index for water-borne disease in the mining region. Similarly, number of persons suffering from skin diseases is positively and significantly related to water parameter index for skin disease also. Therefore, a mechanism should be developed that will ensure mining to be environmentally acceptable by the local community.

Key words: Disease, environment, health, mining, water parameter index.

Introduction

Exploration of mineral deposits can pave the way for the growth of a nation (Ofosu-Mensah, 2011). However, mining activities cannot be done without disturbing and interfering environment (Aswathanarayana, 2005). Numerous studies have shown the adverse impact of mining on different elements of environment (Chauhan, 2010; Panwar et al., 2011; Adetayo, 2012). And some of the environmental effects are also irreversible (Knight, 2001). Additionally, people living adjacent to the mines have to suffer adverse health effects that result from degradation in environmental quality. And some of these effects in the form of disease are chronic in nature (Stephens and Ahern, 2001). This necessitates an investigation into the relationship between mining, environment and health of local population and an assessment of their relationship that can pave the way to arrest the adverse impact of mining.

India is one of the world's most naturally endowed lands and is home to numerous minerals. And among all mining states, Odisha holds a key position in the Indian mining sector (Federation of Indian Chambers of Commerce and Industry, 2013). It is renowned as the largest mineral producing state in the country and its contribution to the production of iron ore is substantial. The state is having a lion share of 40 percent of all India iron ore production and 37 percent of all India value of iron ore in 2014-15 (Indian Bureau of Mines, 2017a). Its iron-ore extraction is mostly confined to Keonjhar district which accounts for 67.4 percent of total extraction (Economic Survey of Odisha, 2016-17). Additionally, National Steel Policy 2005 projected the production of steel at 180 million tonnes by 2019-20.

*Corresponding Author

To meet the projected steel production, around 500 million tonnes of iron ore will be required (Indian Bureau of Mines, 2011). This will result in the vigorous exploration of iron ore and will contribute significant pressures on the land, air, water, forest and bio-diversity and consequently, may affect the health of the people living in the surrounding region. Thus the present paper has following objectives:

1. To analyze the impact of iron ore mining activities on the water quality in the region.
2. To investigate and estimate the relationship between the water quality and health in iron ore mining region.

Research Design

Keonjhar is one of the premier mineral producing districts in Odisha. Its main mineral production activity is iron ore. The district contributed 352 lakh tonnes of iron ore which was 27 percent of the country's production and 67 percent of the state's production during 2014-15 (Indian Bureau of Mines Report, 2017a). It has also minerals like manganese, chromite, limestone, dolomite, quartz, asbestos, pyroxenite, china clay, pynophyllite and quartzite (Indian Bureau of Mines Report, 2017b).

The district has thirteen blocks out of which seven are mining blocks. Existence of mining activity in a region is used as criteria in the present study to designate a block to be a mining block. Joda block has been selected by simple random sampling technique. There were six operational iron ore mines, of which Balda Block iron mine of M/s Serajuddin & Co. has been selected for the present study by the same method. And then, randomly four villages adjacent to this mine namely Balda, Kundaposi, Bada Kalimati and Uchaballi are selected and would be referred as mining villages in this study. As this iron-ore mine is in continuous operation since 1962, it is difficult to go for a before and after comparison. Therefore, to assess the impact of iron ore mine on environment and health of people, with and without comparison approach has been used. So, out of six non-mining blocks, Ghatagaon has been selected by simple random method. From this non-mining block, Dhangardiha, Suneriposi, Banachakulia and Sanajiuli are selected and would be referred as non-mining villages in this study.

With regard to selection of households from mining and non-mining villages, proportionate stratified simple random sampling technique according to the level of income of the households has been adopted so that selected households are the proper representative of entire population. The sample size of the present study consists of 180 households from mining villages (50 households each from Balda and Kundaposi villages and 40 households each from Kalimati and Uchaballi villages) and 180 households from non-mining villages (45 household each from Dhangardiha, Suneriposi, Sanajiuli and Banachakulia villages). Since the villages closer to mines are affected more by the mining activities, a greater number of households have been chosen from villages like Balda and Kundaposi which are closer to mines. The total sample size of current study is 360 households. The sample units of the present study are the households.

Data have been collected and analysed from both the primary and secondary sources. Primary data were collected by administering a structured surveyed schedule on the households of mining and non-mining villages during June to December 2014. Besides, ground and surface water samples and soil samples of mining and non-mining villages have been collected and tested in Cleenviron Private Limited, Rourkela and R.V. Briggs & Co. Private Limited, Barbil to analyse the impact of mining on environment. Data collected from survey then is summarized and portrayed in tables. Beside this, mathematical and statistical techniques such as averages, t-test, Regression analysis, Principal Component Analysis have also been used in the present study.

Results and Discussion

Impact of Iron Ore Mining on Water Quality

Though mining affects water, air, soil, forest, but the present study focuses the discussion on water as it has a direct influence on human health. Clean water is crucial for health, economic and social well-being, and quality of life. Any undesirable changes in water quality directly affect human beings. As evident from literature, mining profoundly affects the hydrosphere. So, to what extent operation of Serajuddin & Co. has affected the water quality in mining villages is analysed by making a comparison with non-mining villages.

Surface Water Quality

In mining areas, surface water is affected by contamination of acid mines drainage, originating from mines and spoils, leaching of heavy metals, organic enrichment and silting of iron ore particles etc. This water is generally used by the households for bathing, washing clothes and utensils. In mining villages, surface water consists of river, ponds and 'nalas'. But, households in all the non-mining villages use pond for the same purpose. Table 1 depicts the water quality status of inland surface water of mining and non-mining villages. Degradation of water quality in the mining area is evidenced by high concentration of iron, low DO (dissolved oxygen) and presence of total coliform. In non-mining area, surface water is characterised by high BOD (bio-chemical oxygen demand), high sulfate, high conductivity and some toxic metals. This is because surface water in non-mining villages is in stock form i.e. ponds. Further to know whether these differences are significant or not, *t*-test has been done. The result shows that the difference is significant for iron at 1% level of significance, nitrate, magnesium and total coliform at 5% level and total dissolved solids (TDS) and DO at 10% level of significance.

Table 1: Average value of surface water quality parameters in mining and non-mining villages

Surface water parameter	*Mining villages*	*Non-mining villages*
pH	6.8	6.8
EC (µS/cm)	128.6	217.7
TDS (in mg/L)	64.7	142.0
DO (in mg/L)	4.7	5.2
BOD (in mg/L)	1.4	1.5
Oil and grease (in mg/L)	2.3	1.6
Total hardness (in mg/L)	45.6	68.7
Chloride (in mg/L)	11.8	24.3
Sulfate (in mg/L)	5.6	11.9
Total Nitrate (in mg/L)	0.1	1.7
Magnesium (in mg/L)	9.5	4.6
Iron (in mg/L)	0.6	0.2
Manganese (in mg/L)	0.08	0.15
Total Coliform (MPN/100 ml)	7.9	0.0

Source: Compiled by author from primary sources

Groundwater Quality

Groundwater is mostly used for drinking purposes for it is safe and potable. Once groundwater is contaminated, its quality cannot be restored back easily. Suitability of groundwater used for drinking purpose can be examined by comparing it with the standards framed by Bureau of Indian Standards. Besides, in order to know the impact of iron ore mine on groundwater, a comparative analysis based on certain parameters as shown in Table 2 in mining and non-mining is done.

The pH of drinking water must be between 6.5 and 8.5. But it can be seen that pH value of water in both mining and non-mining villages is less than 6.5. This means water is little acidic in nature in both the villages. Besides, pH value is little higher in mining than in non-mining villages. With regard to turbidity,

Table 2: Average value of drinking water quality parameters in mining and non-mining villages

Ground water parameter	*Mining villages*	*Non-mining villages*	*Standard limit*	
			Desirable limit	*Permissible limit*
Turbidity (in NTU)	2.5	3.8	1	5
pH	6.4	6.1	6.5-8.5	NR
TDS (in mg/L)	119.3	322.5	500	2000
EC (in µS/cm)	243.3	490.8	-	-
Total Hardness (in mg/L)	86.1	211.3	200	600
Iron (in mg/L)	0.5	0.0	0.3	NR
Chloride (in mg/L)	10.4	87.3	250	1000
Residual-free chlorine (in mg/L)	0.1	0.3	0.2	1
Calcium (in mg/L)	23.3	63.7	75	200
Magnesium (in mg/L)	6.8	12.7	30	100
Sulfate (in mg/L)	3.1	18.9	200	400
Total nitrate (in mg/L)	0.9	14.3	45	NR
Fluoride (in mg/L)	0.0	0.4	1	1.5
Alkalinity (in mg/L)	87.5	135.0	200	600
Sodium (in mg/L)	10.3	26.5	-	-
Potassium (in mg/L)	4.4	8.4	-	-

Source: Compiled by author from primary sources and Bureau of Indian Standard, 2012.
Note: NR is No Relaxation

the concentration is more than the desirable level in both the villages but is within permissible limit. Further, it is seen that turbidity is more in non-mining than in mining villages. Even TDS is more in non-mining villages than in mining villages. This may be because of agricultural operation in non-mining villages. But they are within the desirable limit in both mining and non-mining villages. Besides, EC (Electrical conductivity) is found to be higher in non-mining than in mining villages. Apart from physical parameter, analysis of groundwater with regard to chemical parameters is also necessary. This is done by measuring the concentration of different metals, like calcium, magnesium, iron, manganese, lead, cadmium, fluoride, nitrate, zinc, potassium, sodium, chloride, residual chlorine etc. Groundwater in mining villages is ‘moderately hard’, whereas in non-mining villages, it is ‘hard’. This is because of low level of calcium and magnesium present in groundwater of mining villages.

Almost all natural waters contain chloride and sulfate ions. Excessive concentrations of either can make water unpleasant to drink. It can be seen that both chloride and sulphate are much within permissible limit in both mining and non-mining region. But these are higher in non-mining villages than in mining villages. The presence of iron and manganese in groundwater are naturally occurring, for example from weathering of iron and manganese bearing minerals and rocks. Industrial effluent, acid-mine drainage, sewage etc. may also contribute iron and manganese to local groundwater. We could find a high concentration level of iron in mining villages due to operation of iron ore mine in the region. A high level of nitrate is also seen in the groundwater of non-mining villages. Such condition is due to excess use of fertilizer in agricultural operation in the region. Also because of this the level of sodium and potassium is found to be more in non-mining villages than mining villages. We could also find concentration of fluoride and residual-free chlorine only in non-mining villages. Thus, pH and iron is higher and residual-free chlorine is lower in mining villages than non-mining villages. Whereas EC, TDS, turbidity, nitrate, sulfate, chloride and fluoride is higher in non-mining than mining villages. But by doing *t*-tests, it is found that these differences are significant only for iron, nitrate, fluoride and residual-free chlorine.

Iron Ore Mining, Water Quality and Health: An Investigation of Their Relationship

It is known from literature (Fawell and Nieuwenhuijsen, 2003; English et al., 2003; Mohsin et al., 2013) that water-borne diseases and skin diseases are basically caused due to contaminated water used by the people for drinking and other purposes. A comparative analysis of occurrences of these diseases along with the concentration level of different water parameters has been done for mining and non-mining villages. Table 3 depicts this with respect to water-borne disease. This table shows significant variation in the nine water parameters that lead to water-borne diseases in mining and non-mining villages.

It is known that a high level of turbidity, magnesium, BOD, total coliform bacteria, TDS and iron of both ground and surface water and a low level of residual free chlorine would cause water-borne disease (Nwidu et al., 2008; Parihar et al., 2012; Javed et al., 2014). However, the table shows that some water parameters like TDS of ground and surface water are high in non-mining villages. Thus conducting a test to find out the impact of all these variables on water-borne diseases in mining and non-mining region independently may give misleading results as other water parameters also affect the disease. In order to get rid of this problem, an index comprising eight water parameters[1] is created through Principal Component Analysis (PCA). This index is called water parameter index for water-borne diseases and is supposed to have positive effect on the number of persons having water-borne diseases. The water parameter index for water-borne diseases has been constructed taking the weighted average of all the principal components and the expression is given in Equation (1):

$$\mathrm{WPI}_w = (\lambda_1 P_1 + \ldots + \lambda_k P_k)/(\lambda_1 + \ldots + \lambda_k) \qquad (1)$$

where WPI_w represents water parameter index for water-borne diseases, k is the number of water parameters, λ_1 to λ_k are Eigen values of the 8×8 correlation matrix of the water parameters and P_1 to P_k are factor loadings of variables on component. Here, $\lambda_1 > \lambda_2 > \lambda_3 > \ldots \lambda_8$ and $\mathrm{var}P_1 = \lambda_1 \ldots \mathrm{var}P_8 = \lambda_8$

Factor loadings of each variable on the component are shown in Table 4. The factor loadings are the strength of each variable in defining factor and can be thought

[1] Water parameter index for water-borne diseases has been estimated using the principal component analysis taking eight water parameters i.e. four surface water parameters (TDS, turbidity, iron and magnesium) and four groundwater parameters (TDS, BOD, iron and total coliform).

Table 3: Number of persons suffering from water-borne diseases and concentration of its related water parameters in mining and non-mining villages

Villages	*Ground water parameters*					*Surface water parameters*				*Incidence of water-borne diseases*[*]	*Water parameter index for water-borne diseases*
	TDS	*Residual-free chlorine*	*Turbidity*	*Iron*	*Magnesium*	*TDS*	*BOD*	*Iron*	*Total coliform*		
Balda	94.2	0.0	1.2	0.53	4.37	74.3	1.65	0.66	10.7	196	0.97
Kundaposi	74.0	0.25	2.6	0.53	8.09	84	1.0	0.46	0.0	188	0.35
Kalimati	83.9	0.0	3.1	0.48	3.89	25.4	1.33	0.59	10.6	167	1.11
Uchaballi	225	0.0	3.2	0.62	10.69	75.2	1.65	0.69	10.1	149	0.78
Dhangardiha	230	0.25	9.8	0.0	3.04	50	1.0	0.30	0.0	141	0.06
Banachakulia	236	0.23	1.4	0.013	19.23	170	2.0	0.02	0.0	145	-1.20
Suneriposi	710	0.46	1.8	0.0	22.26	214	1.0	0.35	0.0	120	-1.54
Sanajiuli	114	0.19	2.2	0.0	6.07	134	2.0	0.12	0.0	121	-0.52

Source: Compiled by author from primary sources.
Note: * shows the number of people suffering from water-borne diseases.

Table 4: Component matrix of water parameter index for water-borne diseases

Variables	*Component*
TDS_g	-0.708
Turbidity	0.151
$Iron_g$	0.839
Magnesium	-0.798
TDS_s	-0.924
BOD	-0.071
$Iron_s$	0.802
Coliform	0.792

Source: Compiled by author from primary sources

of as the coefficient of the correlation between the component (factor) and the variable. Higher the loading (positive/negative), the more important it is to that factor. Iron in ground and surface water and coliform have a strong loading for the component as its value is greater than 0.5 and is positive. Similarly variables like TDS in ground and surface water and magnesium too have strong loadings for the component but values are negative which indicate that these variables have inverse relationship with the rest of the factor. Eigen values for Water Parameter Index for water-borne diseases can be seen from Table 5.

Since the index has some negative values, taking logarithmic will not be possible. Therefore hundred is added to all the values of this index. After doing so, a regression is run with the following equation:

$$\log(NP) = \beta_1 \log(WPI_w) + \beta_2 \log(RFC) + \beta_3 D + \varepsilon \quad (2)$$

where NP is the number of persons suffering from water-borne diseases, WPI_w is the water parameter index for water-borne disease plus 100, RFC is the residual-free chlorine, *D* is the dummy variable with 1 for mining and 0 otherwise and ε is the random error term that satisfy all the assumption of the classical linear regression model.

Now if we run the regression by taking all the three variables, that is water parameter index for water-borne diseases, dummy variable (mining/non-mining) and residual-free chlorine together given in Equation (2), we could find that number of persons suffering from water-borne diseases is positively and significantly related to water parameter indexes for water-borne diseases, mining and negatively related to residual-free chlorine (Table 6. Besides, the table also shows that 1% increase in water parameter index for water-borne diseases will significantly increase 1.04% of occurrence of water-borne diseases whereas 1% increase in residual-free chlorine will decrease 0.08%. Even occurrence of water-borne diseases is positive and significant for mining villages.

Similarly, skin problems mainly occur due to contamination of surface water. Table 7 shows that TDS and coliform of surface water are considered here to be two important water parameters that cause this disease and high level of these parameters will lead to more skin problems.

Since skin problem may be due to more than one parameter, an index based on TDS and total coliform of surface water is constructed through PCA as it was constructed for index of water-borne diseases. And this index is called water parameter index for skin disease. This index is supposed to have positive effect on the number of people having skin problems. The factor loadings of each variable on component and Eigen values are shown in Tables 8 and 9 respectively.

This index too has some negative values, so taking logarithmic will not be possible. Therefore, hundred is added to all the values of this index. After doing so, Equation (3) is regressed and the result is shown in Table 10.

Table 5: Eigen values of water parameter index for water-borne diseases

Component	*Initial Eigen values*			*Extraction sums of squared loadings*		
	Total	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*
1	3.993	49.914	49.914	3.993	49.914	49.914
2	1.868	23.348	73.262			
3	1.49	18.631	91.892			
4	0.425	5.31	97.203			
5	0.153	1.918	99.121			
6	0.067	0.842	99.963			
7	0.003	0.037	100			
8	1.19E-16	1.48E-15	100			

Source: Compiled by author from primary sources

Table 6: Regression result for water parameter index for water-borne diseases, residual-free chlorine and dummy variable

Dependent variable: log (number of persons suffering from water-borne disease)	
Independent variable	*Coefficient*
Log (water parameter index for water-borne disease)	1.04* (66.53)
Log (Residual-free chlorine)	-0.08 (-1.43)
Dummy variable	0.34* (7.95)

Source: Compiled by author from primary sources.
Note: * implies coefficient is significant at 1% level and Figure in the parenthesis shows '*t*' value.

$$\log (NP) = \beta_1 \log (SI) + \varepsilon \quad (3)$$

where NP is the number of persons suffering from skin disease. SI is the water parameter index for skin disease plus 100 and ε is the random error term that satisfy all the assumption of the classical linear regression model.

Table 10 shows that 1% increase in water parameter index for skin disease will cause 0.67% increase in the number of persons suffering from skin diseases. Thus the above discussion shows that high occurrences of diseases in mining villages are due to the adverse impact of mining activities on ground and surface water quality.

Findings and Implications

It is evident from the present study that iron ore mining is having an adverse impact on water (surface and ground) quality. Degradation of surface water quality in the mining area is evidenced by significantly higher concentration of iron, magnesium, coliform bacteria and lower dissolved oxygen than in non-mining villages. Even the groundwater in mining villages is characterised by significantly higher iron concentration and lower residual-free chlorine than in non-mining villages. Thus mining operation has deteriorated the quality of surface as well as groundwater in mining villages. And it has been found that occurrence of water-borne diseases is positively and significantly related to water parameter index for water-borne diseases and negatively related to residual-free chlorine. It is also significant for mining region. Similarly, number of persons suffering from skin diseases is positively and significantly related to water parameter index for skin disease also. Thus the findings of the present study extend its support to those studies that established the adverse impact of mining activities on the water quality (Krishnaswamy et al., 2006; Delgado, 2009) and consequently leads to harmful effect on health (Yeboah, 2008; Mohapatra et al., 2010).

Therefore, mining company should take some measures to address environment and health issues in the region. First of all, eco-friendly technology should be used to minimise the adverse impact of mining operation on environment in general and water bodies in particular. With regard to health, mobile dispensary could be provided by the mining company to the peripheral villages on a regular basis. Even company could also appoint some health workers in these villages. There should be increase in the frequency of medical camps that are organised by mining company for the nearby villages. The planning and delivery

Table 7: Number of persons suffering from skin diseases and concentration of its related water parameters in mining and non-mining villages

Villages	*Surface water parameters*		*Incidence of skin diseases**	*Water parameter index for skin diseases*
	TDS	*Total coliform*		
Balda	74.3	10.7	55.0	-0.957
Kundaposi	84.0	0.0	57.0	0.236
Bada Kalimati	25.4	10.6	16.0	-1.377
Uchaballi	75.2	10.1	28.0	-0.887
Dhangardiha	50.0	0.0	14.0	-0.062
Banachakulia	170.0	0.0	20.0	0.992
Suneriposi	214.0	0.0	14.0	1.379
Sanajiuli	134.0	0.0	11.0	0.676

Source: Compiled by author from primary sources.
Note: * shows the number of people suffering from skin diseases.

of health programmes and sanitation programmes around the mine-sites should be based on a partnership approach with a strong role for the local community in their design and implementation. Besides, Government should improve regulations and independent monitoring teams should be commissioned to intervene before environmental and health problems goes out of control so that local community could gain from development that takes place on their land.

Table 8: Component matrix of water parameter index for skin diseases

Variables	*Component*
TDS	0.891
Coliform	-0.891

Source: Compiled by author from primary sources.

Table 9: Eigen values of water parameter index for skin diseases

Component	*Initial Eigen values*			*Extraction sums of squared loadings*		
	Total	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*
1	1.587	79.337	79.337	1.587	79.337	79.337
2	0.413	20.663	100			

Source: Compiled by author from primary sources.

Table 10: Regression result of water parameter indexes for skin disease

Dependent variable: log (number of persons suffering from skin disease)	
Independent variable	*Coefficient*
log (SI)	0.67*
	(13.94)

Source: Compiled by author from primary sources.

Note: * implies coefficient is significant at 1% level and figure in the parenthesis shows '*t*' value.

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