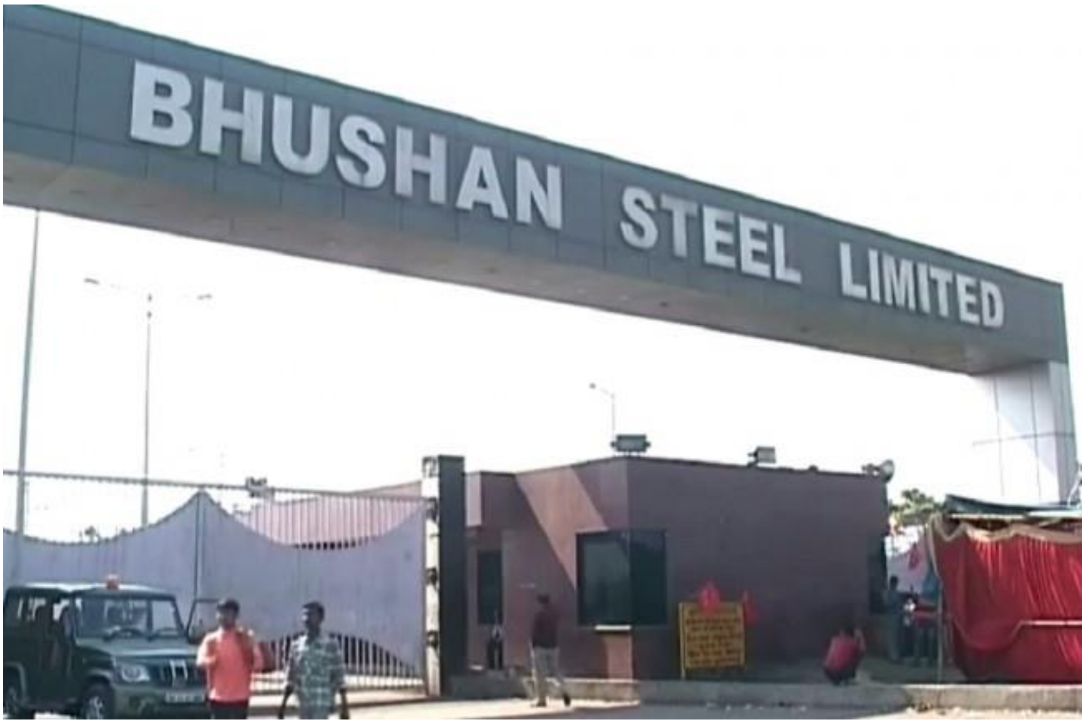
Final Report

Impact Assessment Studies of Fly Ash Disposal into mine void Quarry No. 04 of Jagannath OCP of M/s. Mahanadi Coalfields Limited, Talcher

Submitted to

M/s Bhushan Steel Limited
Meramandli, Dhenkanal District, Odisha



CSIR-National Environmental Engineering Research Institute
Under Council of Scientific & Industrial Research
Nehru Marg, Nagpur – 440 020

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PROJECT LEADERS

Dr. Paras R. Pujari
Er. Ramya Sanam

TEAM MEMBERS

Dr.P.K.Labhasetwar
Mrs. V. Jyothi
Mr. R. Balakrushna Reddy
Mr. Pandurang Balwant
Dr. C. Padmakar
Dr. (Mrs). L N Sangolkar
Mr. Rafat Quamar
Mr. Dileep Meshram
Dr. (Mrs.) Leena Deshpande
Mr. Chandrakant Jangam
Mr. J. Ramesh

SECRETARIAL SUPPORT

Mrs. P. Vandana

PROJECT COORDINATOR

Dr. R. Kumar (Director, CSIR-NEERI, Nagpur)

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ABBREVIATIONS

AERB	*Atomic Energy Regulatory Board*
AMSL	*Above Mean Sea Level*
BA	*Bottom ash*
BDL	*Below Detection Limit*
BEL	*Bhushan Energy Limited*
BGL	*Below Ground Level*
BIS	*Bureau of Indian Standards*
BSL	*Bhushan Steel Limited*
BRIT	*Board of Radiation and Isotope Technology*
DAE	*Department of Atomic Energy*
Des	*Desirable Limit*
DW	*Dug Well*
EC	*Electrical Conductivity*
EPA	*Environment Protection Agency*
FA	*Fly ash*
GPS	*Global Positioning System*
HP	*Hand Pump*
IBM	*Indian Bureau of Mines*
ICP-OES	*Inductively Coupled Plasma-Optical Emission Spectroscopy*
ICP-MS	*Inductively Coupled Plasma-Mass Spectroscopy*
LHS	*Left Hand Side*
ND	*Not Detected*
NR	*No Relaxation*
Per	*Permissible Limit*
RHS	*Right Hand Side*
RL	*Reduced Level*
SW	*Surface Water*

Executive Summary

Impact Assessment Studies of Fly Ash Disposal into mine void Quarry No. 04 of Jagannath OCP of M/s. Mahanadi Coalfields Limited, Talcher

The plant has captive thermal power plant (TPP) generating 883 MW of electricity (both BSL & BEL). The Power plant is located approximately 140 km from Bhubaneswar in Dhenkanal district of Odisha. The Steel Plant has an annual capacity of 5.6 MTPA. BSL and BEL generate about 5000 tons per day of ash (1.65 MTPA). MoEF has accorded permission for disposal of the ash at the disused Quarry No 4 of the Jagannath Opencast Mines of the Mahanadi Coal Fields Limited (MCL). The Quarry is located at an approximate distance of 25 km from the TPP. The mine void (Quarry No.4) covers an area of 119 Ha. The ash is brought to the disposal site by covered vehicles (bulkers) in dry form. At the disposal site, the ash is conditioned and slurrified by mixing the ash and water in the ratio of 60% and 40%. The disposal of ash in the mine pit started in March 2014.

The present study aims at assessing the impact of ash disposal on groundwater quality in the watershed surrounding the Jagannath mine pit. An integrated approach has been adopted in this study by utilizing various tools like hydrogeology, groundwater chemistry, fly ash characterization, soil, groundwater flow and solute transport modeling studies. A network of observation wells has been set up and monitoring of the wells has been carried out in the post-monsoon and pre-monsoon seasons for the major cations, anions and trace elements. The analysis has also been carried out for mine pit water and groundwater samples at various depths of the hand pumps in the study area. Soil sampling has been carried out at representative locations around the mine area and analysis for the major physical and chemical properties viz., exchangeable cations. Bio-assay test, bio-magnification and bio-accumulation tests have also been carried out for the study area. Leachability studies of fly ash have been carried out using the TCLP, SPLP and Water Elution test. Petrographic study has been carried out for rock samples collected in the study area.

The study based on the ground water level (above mean sea level) contours indicates that the groundwater flow direction is towards Brahmani river. Groundwater quality in the study area indicates that few observation wells have higher nitrate concentration in both post and pre monsoon seasons. Fluoride concentration above the permissible limit of BIS has been observed in both the seasons. Except for these two parameters, all the other major cations/anions are within the permissible limits of BIS standards. Petrographic study indicated the presence of fluoride and aluminium bearing minerals in the study area. The trace element concentration of trace elements namely (As, Pb and Hg) in the Mine Pit water does not show any increasing trend with time in the sampling campaign undertaken in January 2016, April 2016 and June 2016.

The possible impact of the mine pit on the groundwater sources was also studied by attempting the solute transport simulation using the Mass Transport Modeling (MT3D). The modeling of the solute transport for the Jagannath mine pit indicate that the plumes will move to a maximum distance of 700 m over a 30 year period starting from March 2014. The prediction is only for advection dominated transport for conservative elements. The movement of trace elements will be considerably less as compared to conservative elements. It is essential that stringent monitoring of trace elements and pH in the pit water be carried out quarterly. The piezometers installed in the upstream and downstream of the mine pit should be used for monitoring of major cations, anions and trace elements (including As, Pb and Hg).

The trace element concentration in the plant species has been found to be within limits. The Bioassay tests also indicated that mortalities were not observed in the test samples.

Based on the comprehensive study starting from May 2014 and sampling spread over the last 2 years, it is concluded that the trace element in the Mine Pit has not increased with time and the concentration in the wells close to the Mine Pit is also not increasing. The leaching tests also confirm the insignificant leaching and the radioactive activity is also within the limits. The flow and solute transport model prediction for trace element will be considerably less that that predicted for conservative elements (700m over a 30 yr period). As there is no adverse impact on the environment, the ash disposal may be continued further and EC may be accorded.

It is desired that the BSL may continue with the monitoring as recommended below.

Chapter I

Introduction

1.1 Preamble

The plant has captive thermal power plant (TPP) generating 883 MW of electricity (both BSL and BEL). The Power plant is located approximately 140 km from Bhubaneswar in Dhenkanal district of Odisha. The Steel Plant has an annual capacity of 5.6 MTPA. BSL and BEL generate about 5000 tons per day of ash (1.65 MTPA). MoEF has accorded permission for disposal of the ash at the disused Quarry No 4 of the Jagannath Opencast Mines of the Mahanadi Coal Fields Limited (MCL). The Quarry is located at an approximate distance of 25 km from the TPP. The mine void (Quarry No.4) covers an area of 119 Ha. The ash is brought to the disposal site by covered vehicles (bulkers) in dry form. At the disposal site, the ash is conditioned and slurrified by mixing the ash and water in the ratio of 60% and 40%. The disposal of ash in the mine pit started in March 2014. In view of the large quantity of ash dumping in the mine void, it is essential to assess the impact of the ash disposal on the groundwater and surface water quality in the vicinity of the mine void and surrounding villages. M/S Bhushan Steel Limited desires CSIR-NEERI to carry out an impact assessment of the ash disposal at the disused Quarry No.4 of Jagannath Opencast mines on the groundwater resources surrounding the Mine Void.

The task has been assigned with the following objectives:

Assessment of the groundwater and surface water quality of the existing sources in the vicinity of the ash fill sites at Jagannath Open cast mine pit (Quarry No:4) along with the impact assessment on flora and fauna.

1.2 Approach of the study

Keeping in view the objectives of the study, maximum primary data have been collected from the study area. Secondary data have also been collected for the purpose.

- Delineation of the study area on the basis of watershed principle.
- A network of observation wells has been set up for water level measurement and groundwater sampling. The monitoring has been carried out for both the post-monsoon (November 2014) and pre-monsoon seasons (May 2015). The samples have been analyzed for major cations, anions and trace elements.

- Mine Pit samples have been collected and analysed for trace elements in May 2015, January 2016, April 2016 and June 2016 to study the trend of concentration of key trace elements.
- Petrographic and geochemical analysis of the rock samples
- Chemical characterization of the fly ash for parameters namely SiO_2, Al_2O_3, Fe_2O_3, CaO, K_2O, P_2O_5, NiO etc.
- Trace elements in the fly ash for parameters namely Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, B
- Concentration of radioactive elements namely U, Th, Pb, K and Cs.
- Analysis of soil samples for parameters namely EC, Organic carbon, fluoride, exchangeable cations (Na, K, Mg, Ca), heavy metals
- Bioassay test in the mine pit water to study the toxicity on the aquatic life
- Bio-magnification of the biota like herbs, shrubs etc.
- TCLP and SPLP analysis to study the hazardous nature of fly ash and bottom ash
- Water extraction test and Water elution test to study the leaching of trace elements from fly ash
- Particle Size Analysis of the fly ash samples
- Development of the groundwater flow and solute transport model

As suggested by the Environmental Appraisal Committee (EAC) of the Ministry of Environmental and Forest (MoEF) vide letter dated Z-11013/43/2011/IA-II(M) dated 19.04.16, various issues recommended by the EAC have been addressed in the study. The conditions stipulated in the previous EC dated…………………were complied with.

1.3 Tasks Undertaken

The present study is based on the extensive primary and secondary data.

- Delineation of the study area has been carried out on the basis of watershed principle
- A network of observation wells has been set up for water level measurement in the pre-monsoon and post-monsoon seasons. It was also attempted that samples are located in 500 m, 1000 m, 2000 m, 5000 m and 10,000 m buffer zone.
- Few samples were also collected in the upstream of the mine pit
- Hydrogeological studies has been carried out in the study area
- Groundwater sampling and analysis has been carried in the observation well network

- Toxicity Characteristic Leaching Procedure (TCLP) and Synthetic Precipitation Leaching Procedure (SPLP) have been attempted
- Water extraction and Water elution test for the fly ash sample have been carried out
- Mine pit water has been collected and analyzed for major cations/anions and trace elements
- Particle Size Analysis of the fly ash samples has been carried out.
- Analysis of flora and fauna has also been carried out
- Bio-assay test has been carried out to assess the heavy metals toxicity on the aquatic life
- Flow and Solute transport modelling has been carried out assuming the conservative ion as the contaminant source

1.4 Report Layout

The report is presented as follows:

Chapter 2: It gives brief introduction to the study area

Chapter 3: The methodology of data collection is presented. A detailed description is provided about the methodology of sampling groundwater, mine water, surfacewater, leachability studies, Bioassay studies and Groundwater flow and solute transport modelling study.

Chapter 4: The results and discussions in respect of Hydrogeology, Hydrochemistry, Leachability, Ash characterization and Flow and Solute Transport modelling are presented in Chapter 4.

Chapter 5: The results and discussions in pertaining to Bioassay test and Biomagnification are presented in Chapter 5.

Chapter 6: The findings and recommendations are presented in Chapter 6.

Chapter II

Study Area

2.1 Location

The Bhushan steel Limited (BSL) is located at Narendrapur village in Meramandi which is under the jurisdiction of Dhenkanal district in Odisha. It is approximately 18 km from the Angul town (Figure 2.1.1). However, the ash disposal site is located in the microwatershed covered between latitudes 20° 52’ 00” N to 20° 59’ 00” N and longitudes 85° 07’ 30” E and 85° 15’ 30” E. It is covered by Survey of India Toposheet (F45 T/1 and F45 T/5 on 1:50,000 scale).

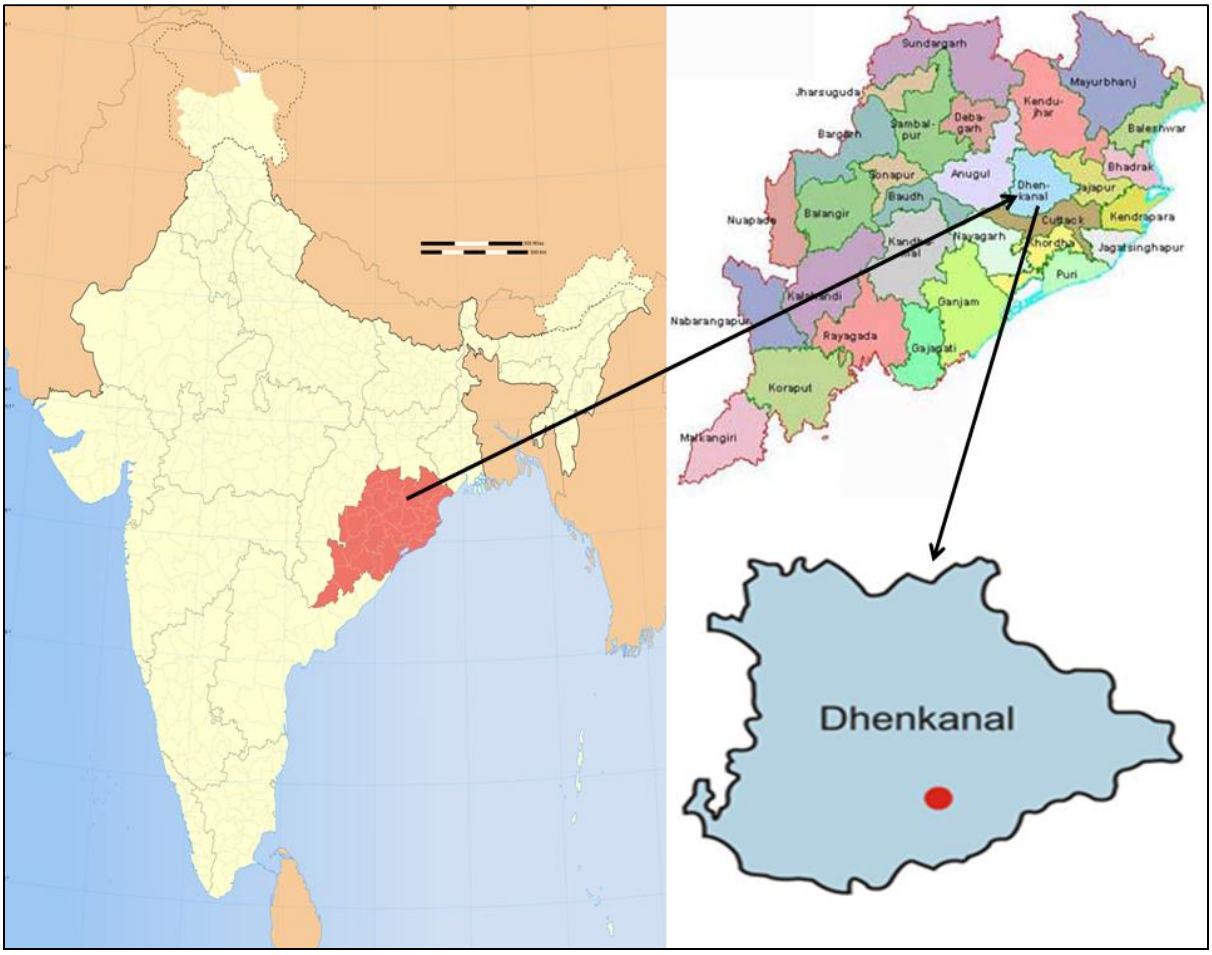


Figure 2.1.1 Location map of the study area

2.2 Climate

The study area experiences tropical monsoon climate with mild winter and hot summer. The average annual rainfall of the study area is approximately 1250 mm of which major amount is received during the four months extending from June to September.

2.3 Physiography and Landuse

The study area constitutes northern part of Angul district. The area is mainly drained by the river Brahmani. The area constitutes various physiographic features such as alluvial plain, mountain ranges, flood plains and water bodies. The slope is towards the southeast direction.

2.4 Geological set up

The study area is mostly characterized by the rocks of the Gondwana Super Group (Figure 2.1.1). The Gondwanas comprise of sandstone, carbonaceous shale and coal bands with pink clay and pebbly sandstones. Gondwana rocks are overlain by recent alluvium and valley fill materials at places. It is observed that granitoids of Precambrian age appeared in South East and South West patches of the study area (Figure 2.4.1). In addition, the laterites occur as patches capping over the country rocks and attain a limited thickness.

2.5 Hydrogeology

The area falls in the Brahmani tributary. The principal ground water reservoir in the area is consolidated crystalline rock of Precambrian age and semi consolidated Gondwana formations comprising of mainly sandstone and shale. The weathered and fractured sandstone form a good aquifer. Groundwater occurs under water table conditions in the weathered zone and under semi-confined to confined condition in the fracture zone.

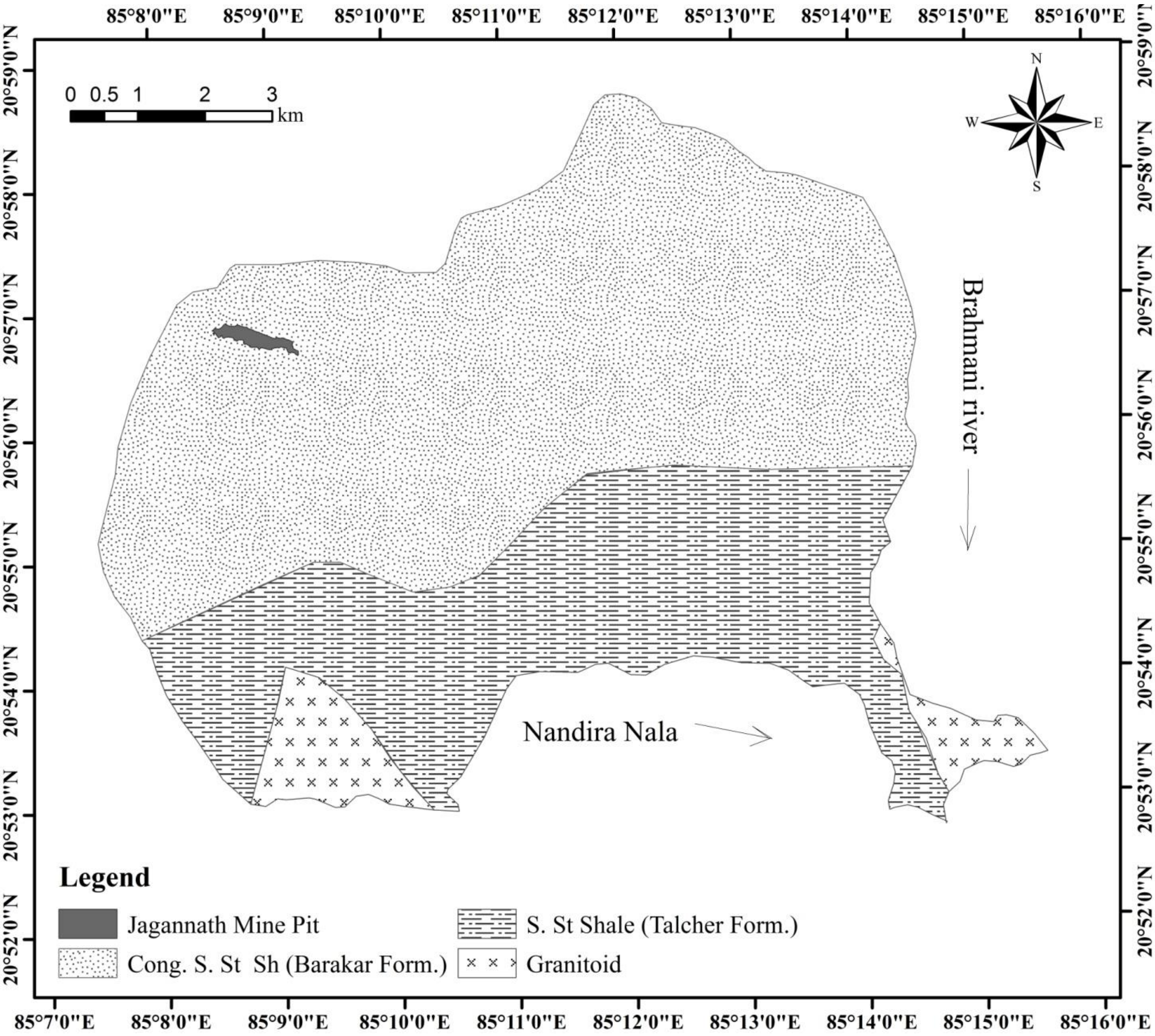


Figure 2.4.1 Geological map of the study area (after GSI, 2010)

Chapter III

Methodology for data collection

3.1 General

The study envisages addressing the objectives by a holistic approach integrating the following aspects:

- Delineation of Watershed and setting up the observation well network
- Hydrogeology
- Hydrochemistry
- Analysis of Mine Pit water at different period
- TCLP tests, Water extraction tests, Water Elution test and Total concentration of trace elements in ash matrix
- Chemical Characterization of the fly ash
- Soil analysis
- Radioactivity content in the fly ash samples
- Flow and Solute Transport Modelling
- Bioassay, Biomagnification and Bioaccumulation tests

Accordingly, primary data has been generated by undertaking extensive field survey in the months of August 2014, November 2014, May 2015, January 2016, April 2016 and June 2016. Secondary data has been collected through interaction with Bhushan Steel Limited officials, Officials of the Rural Water supply and sanitation Department, Odisha and the local villagers in and around the study area.

3.2 Delineation of the watershed and observation well network

The study area has been delineated on the basis of watershed principle (Figure 3.2.1). The delineated watershed covers an area of 89.35 sq. km. A network of observation wells (24 nos.) has been set up in the study area. The observation well network consisted of India Mark II hand-pumps as well as open wells (Table 3.2.1). The observation wells were distributed in a representative manner in the study area. Due care was taken to ensure that the observation wells are spread over different land use pattern in the study area. The nearest observation wells are at a distance varying from 0.28 km to 2.33 km (Table 3.2.2, Figure 3.2.2). The distance of the control samples varied from 3.15 km to 4.5 km. Control Samples at a distance less than 3 km were not found in the study area.

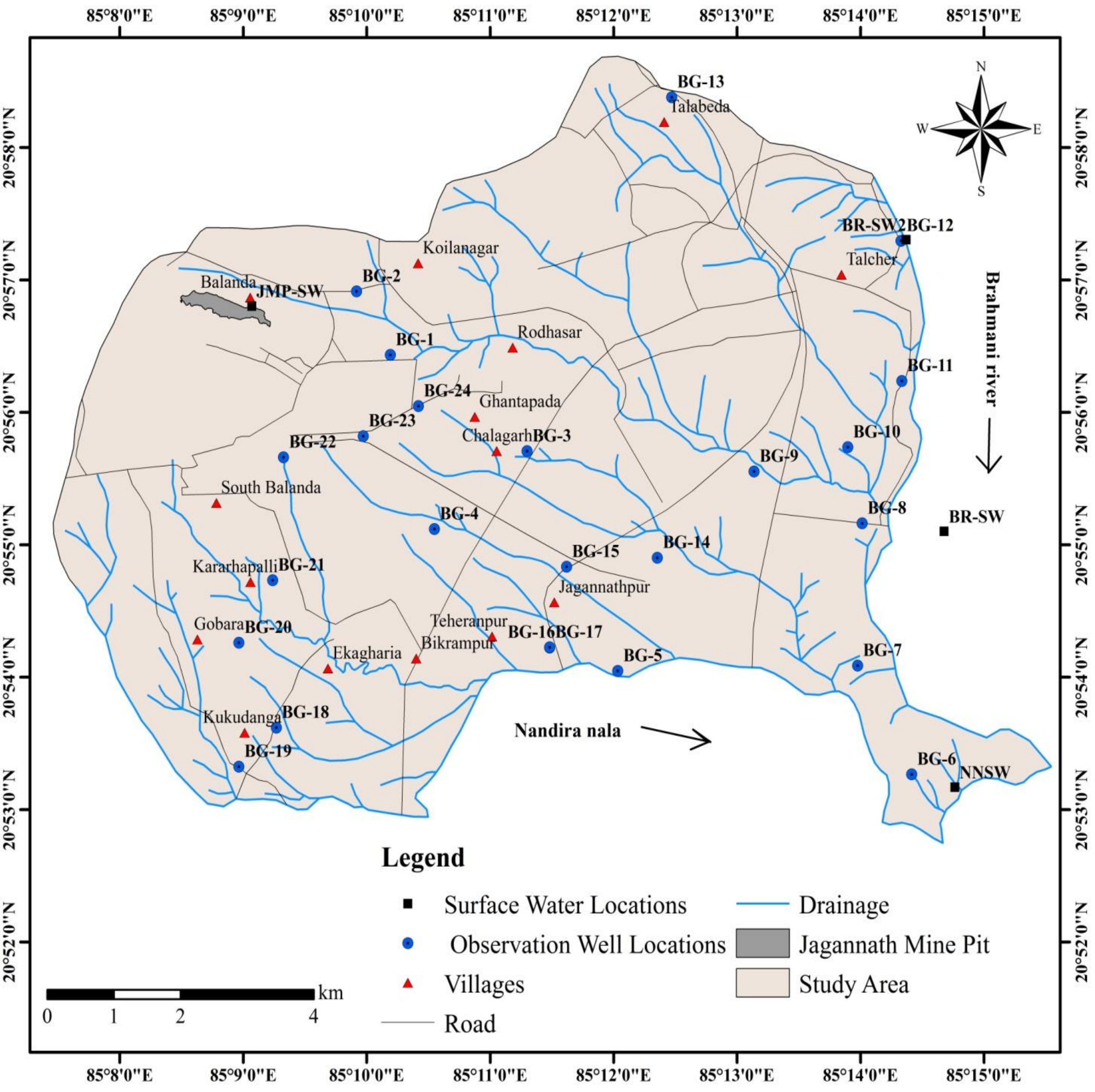


Figure 3.2.1 Basemap of the study area

Table 3.2.1 Observation well network locations in the study area

Sample Code	Longitude	Latitude	Well Type	Description
BG-1	85° 10′ 11.5″	20° 56′ 26″	HP	Panihating village, beside Anganwadi Kendra, downstream of the Jagannath mine pit
BG-2	85° 9′ 55.1″	20° 56′ 54.8″	HP	Dera village, inside primary school, LHS of the road towards Jagannath mine pit
BG-3	85° 11′ 17.9″	20° 55′ 42.4″	HP	Inside Chalagarh village, Das sahi street, beside praful dheera house
BG-4	85° 10′ 32.9″	20° 55′ 7.1″	HP	Inside Tentulei village, opposite naresh Chandra 26eioniz house, RHS of the road towards NALCO
BG-5	85° 12′ 2″	20° 54′ 2.8″	HP	Inside Jagannathpur village, Abhimanyupur, beside madan mahapatra house
BG-6	85° 14′ 24.9″	20° 53′ 16″	HP	Tolkulendi village, LHS of the road, near to old ash pond, opposite to dayanidhi naik house
BG-7	85° 13′ 58.6″	20° 54′ 5.2″	HP	Santhapada village, beside Hingula temple
BG-8	85° 14′ 0.8″	20° 55′ 9.7″	HP	Santhapada village, below the road, towards Brahmani bridge
BG-9	85° 13′ 8.3″	20° 55′ 33.2″	HP	Balhar village, LHS of the road towards Kukudanga village, opposite to rajan kumar bal house
BG-10	85° 13′ 53.8″	20° 55′ 44.2″	HP	Bebastamunda village, Talcher, opposite to primary school
BG-11	85° 14′ 20.1″	20° 56′ 14.2″	HP	Gopinathpur, near Brahmani river, opposite to neekuna beher house and kirana shop
BG-12	85° 14′ 19.7″	20° 57′ 17.7″	HP	Talcher town, beside jagannath mandir, LHS of the road towards talabeda village
BG-13	85° 12′ 28.2″	20° 58′ 22.8″	HP	Talabeda village, LHS of the road towards kaniha, opposite to maheswar behera house
BG-14	85° 12′ 21.2″	20° 54′ 54.1″	HP	RHS of the road, towards Talcher station, Bantol village, beside slum huts
BG-15	85° 11′ 37.1″	20° 54′ 50″	HP	Jagannathpur village, RHS of the road towards bikrampur, beside kuna bhai house, slum huts, after canal
BG-16	85° 11′ 28.9″	20° 54′ 13.4″	HP	Jagannathpur, opposite to cowshed, LHS of the road towards Teherenpur, opposite to biju biswal house
BG-17	85° 9′ 39.4″	20° 54′ 13.5″	HP	Ekagharia village, LHS of the road towards kukudanga village, beside ekagharia upper primary school
BG-18	85° 9′ 16.1″	20° 53′ 37.1″	HP	Kukudanga village, opposite cowshed, LHS of the road towards gobara, beside slum huts
BG-19	85° 8′ 57.9″	20° 53′ 19.5″	HP	Kukudanga village, beside transformer, LHS of the road towards gobara, beside grinding mill
BG-20	85° 8′ 27.4″	20° 54′ 15.6″	HP	Gobara village, LHS of the road towards kanhapur, beside drainage
BG-21	85° 9′ 14.3″	20° 54′ 43.9″	HP	Karadapali village, LHS of the road, opposite to

				gadadhar nayak house
BG-22	85° 9′ 19.6″	20° 55′ 39.6″	HP	South Balanda village, near Binsa munda square, near Balanda dispensary, LHS of the road
BG-23	85° 9′ 58.3″	20° 55′ 49.2″	HP	In front of Maa shibani hotel, beside conveyor belt, central colony, LHS of the road towards talcher
BG-24	85° 10′ 25.1″	20° 56′ 2.8″	HP	Beside kali mandir, in front of Nehru shatabdi hospital, LHs of the road towards ghantapada village
NNSW	85° 14′ 15.9″	20° 53′ 10.2″	SW	Nandir Nala water sample
BR-SW	85° 14′ 40.6″	20° 55′ 6.1″	SW	Brahmani river water sample in the downstream
BR-SW2	85° 14′ 22.9″	20° 57′ 18.3″	SW	Brahmani river water sample in the upstream
JMP-SW	85° 09′ 04.2″	20° 56′ 48.2″	SW	Jagannath mine pit water sample
JMP-DA	85° 09′ 9.0″	20° 56′ 47.6″	Ash Sample	Ash sample collected directly from the conditioning unit
CP-1*	85° 10′ 1.6″	20° 58′ 21.1″	DW	In Naraharipur village, in the residence of Mr. Bhaskar Ochayyi (mukhi), besides road
CP-2*	85° 08′ 15.4″	20° 59′ 30.5″	HP	In Hiloi village, entrance of the village, LHS of the road, corner hand pump
CP-3*	85° 07′ 21.8″	20° 58′ 11.5″	HP	In Padmavathipur village, upper primary school premises, entrance of the village, RHS of the road
CP-4*	85° 09′ 45.8″	20° 59′ 9.8″	DW	In Zilinda village (kadolipal), besides open cast coal seam, CMPDI dug well

*Control sample

Table 3.2.2: Distance between Mine void periphery & nearest sampling locations.

Sr. No.	Sample Locations	Distance from the mine void (km)
1	BG-1	1.71 km
2	BG-2	1.26 km
3	BG-22	1.81 km
4	BG-23	1.98 km
5	BG-24	2.33 km
6	BPZ-1	0.18 km
7	BPZ-2	0.28 km

8	CP-1	3.37 km
9	CP-2	4.92 km
10	CP-3	3.15 km
11	CP-4	4.50 km

Note: BG – Bhushan Groundwater sample, BPZ – Bhushan Piezometer, CP – Control Point.

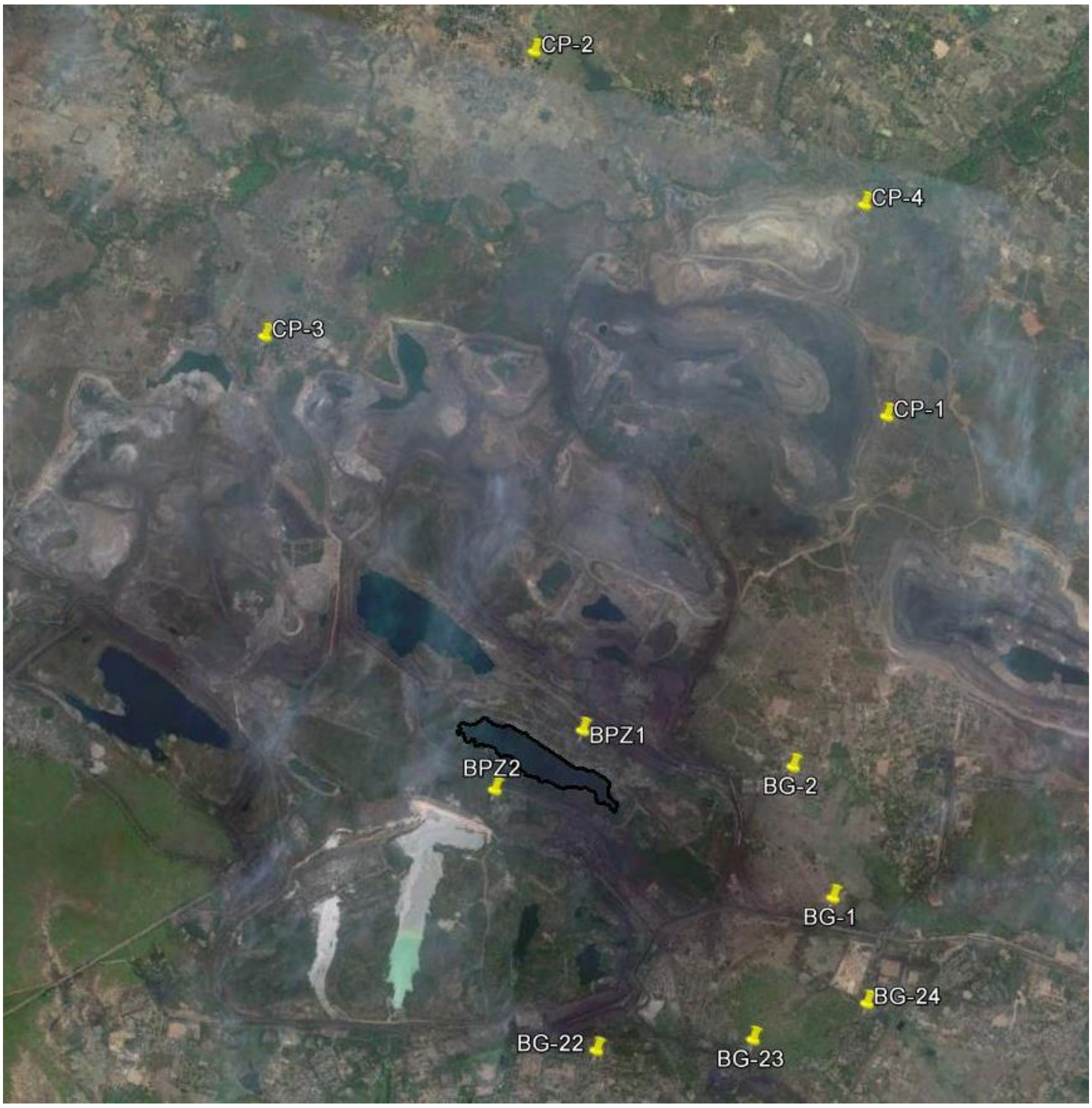


Fig. 3.2.2: Location map of sampling locations near by Jagannath mine pit.

3.3 Groundwater sampling and analysis

Groundwater samples and few surface water samples have been collected from the identified sources (Figures 3.3.1, 3.3.2. 3.3.3) in the study area. The co-ordinates (latitude/longitude) of the observation wells were noted with the help of hand held GPS of Garmin make (Figures 3.3.4, 3.3.5).

For physico-chemical parameters and heavy metal analysis, the samples were collected in pre-cleaned 500 ml and 100 ml polyethylene bottles respectively. Concentrated HNO_3 was added to the heavy metal samples for preservation. Parameters namely, pH and temperature were measured in the field itself.

Samples (4 nos) have been collected from the upstream location (Figure 3.3.6) in the pre-monsoon season (May 2015). Depth sampling (collecting samples at different depth) has been attempted at groundwater sources (3 nos) by dismantling the Mark-II hand pumps and collecting groundwater samples at different depths.

Figure 3.3.1 Groundwater sample collection

The surface water samples were also collected (Table 3.2.1). The surface water samples include the samples from Nandira Nala, Brahmani River and Jagannath Mine Pit. The physico-chemical parameters were analyzed by following the standard protocols (APHA, 2012). The heavy metal analysis was done by using ICP-OES (Model: iCAP 6300 DUO, Make: Thermo Fischer). The detection limit for Fe, Mn, Zn, Pb, Cd, Cr and Cu are 0.0062 ppm, 0.0014 ppm, 0.005 ppm, 0.05 ppm, 0.002 ppm, 0.02 ppm and 0.005 ppm respectively. The parameters namely Na and K were analyzed by Flame Photometer (Model: CL361, Make: ELICO).

Figure 3.3.2 Surface water sampling at Brahmani river

Figure 3.3.3 Surface water sampling at Brahmani river

Figure 3.3.4 GPS measurement of observation wells in the study area

Figure 3.3.5 GPS measurement of observation wells in the study area

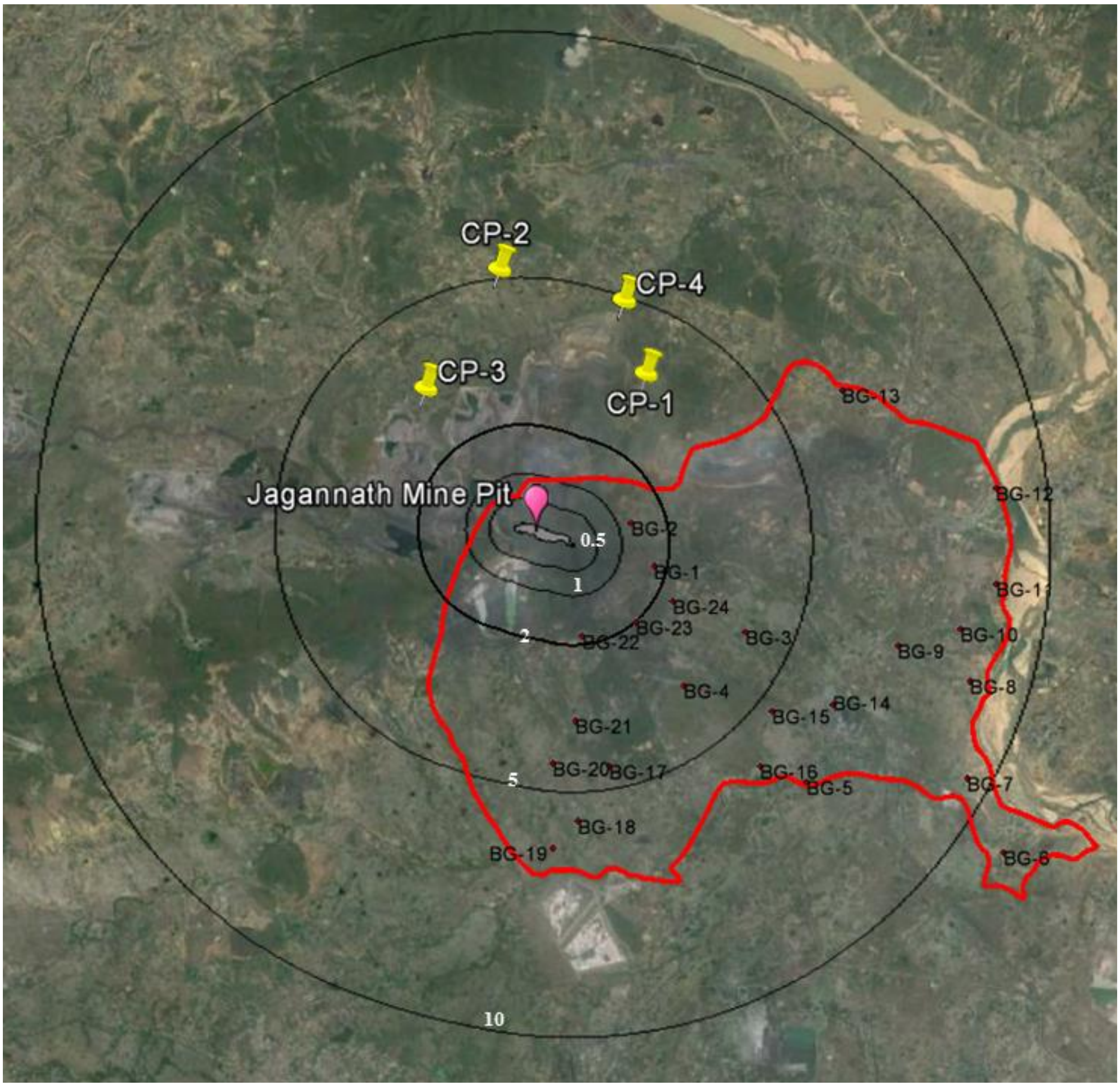


Figure 3.3.6: Study area with 0.1 km, 5 km, 10 km buffer zone with control samples (CP1, CP2, CP3, CP4)

3.4 Groundwater Level Measurement

The water level from observation well network was obtained using Electric Contact Gauze (KL010) manufactured by M/S OTT Pvt. Ltd (Germany). The groundwater level has been obtained with respect to below ground level (bgl). Subsequently, RL survey is undertaken in the study area at the observation wells and other control locations (Figure 3.4.1). The water level (bgl) is converted to water level (amsl) subsequently.

Figure 3.4.1: Reduced Level (RL) survey in the study area

3.5 Mine Pit water Sampling

Mine pit water samples (2 nos) were collected in the post-monsoon sampling (November 2014) while a systematic and extensive sampling campaign was undertaken in the pre-monsoon (May 2015) season for collection of water samples at different depth from the mine pit (Figure 3.5.1). Pit water samples were subsequently collected in the months of January 2016, April 2016 and June 2016 to study the trend of the concentration of trace elements. The samples were collected from different points at different depths (Table 3.5.1) by using a depth sampler (Figures 3.5.2, 3.5.3).

Table 3.5.1 Water samples collected at different depths from Jagannath Mine pit

S.No.	Sample Code	Depth (in m)*
1.	JMP-A1	0
2.	JMP-A2	6
3.	JMP-B1	0
4.	JMP-C1	0
5.	JMP-C2	6
6.	JMP-D1	0
7.	JMP-D2	18
8.	JMP-E1	0
9.	JMP-E2	10
10.	JMP-F1	0
11.	JMP-G1	0
12.	JMP-G2	15

*Depth at which the sample was taken

Figure 3.5.1: Different sampling locations in the Jagannath Mine Pit (Quarry No. 4)

Figure 3.5.2 Mine pit water sampling at Jagannath Mine pit (Quarry No. 4)

Figure 3.5.3 Mine pit water sampling at Jagannath Mine pit (Quarry No. 4)

3.6 Petrographic analysis

Petrographic study has been attempted to study the presence of any fluoride and aluminium bearing mineral in the rock samples. Rock samples (4 nos) have been collected from locations as mentioned in Table 3.6.1 (Figure 3.6.1). The samples were analyzed for mineral characterization.

Table 3.6.1 Rock Sample locations in the study area

S.No.	Sample Code	Latitude	Longitude
1.	BR-1	20° 56’ 49.5”	85° 09’ 06.5”
2.	BR-2	20° 54’ 07.6”	85° 11’ 45.6”

3.	BR-3	20° 54’ 51.7”	85° 11’ 43.8”
4.	BR-4	20° 57’ 18.1”	85° 14’ 22.2”

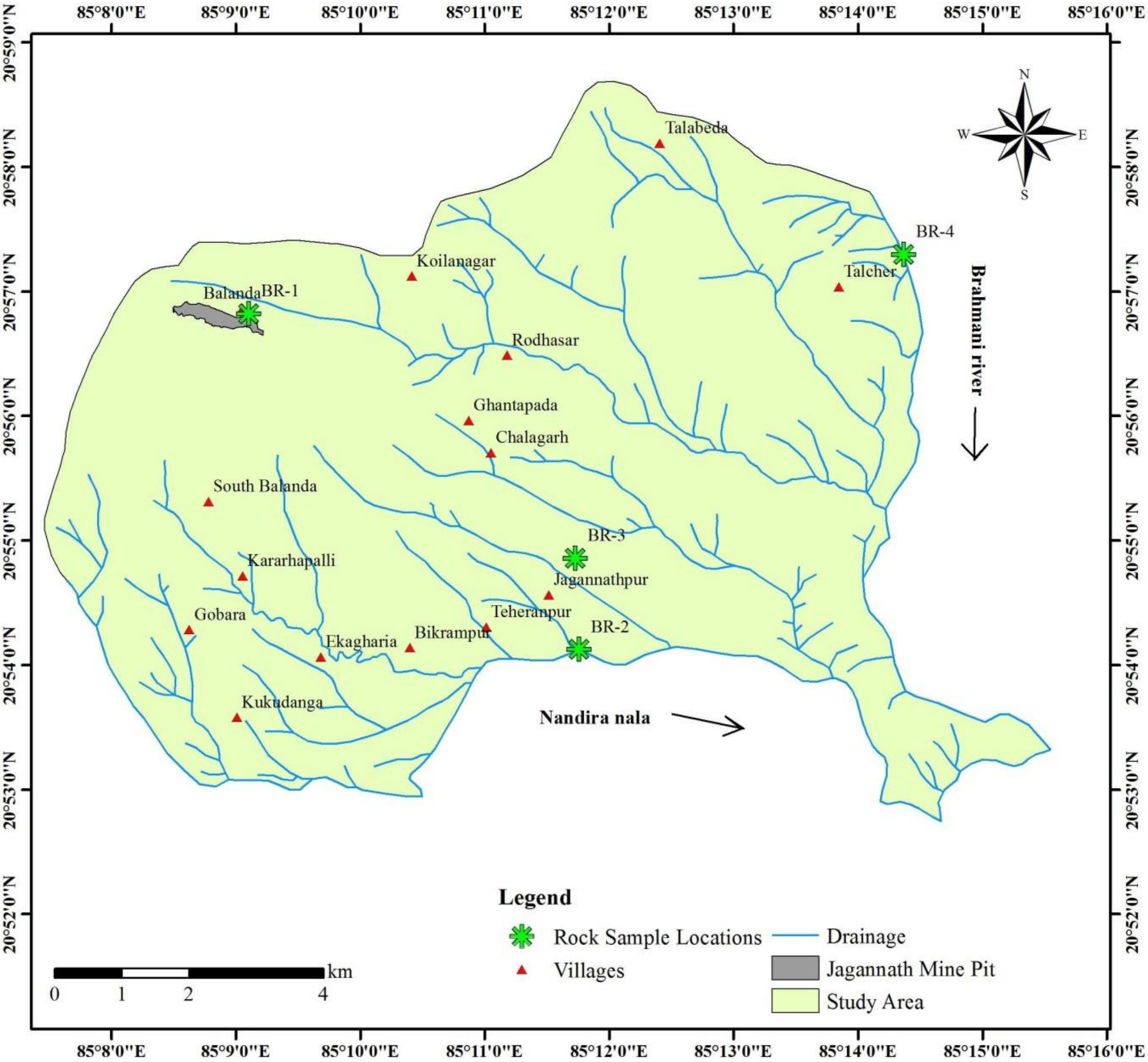


Figure 3.6.1 Rock sampling locations in the study area

3.7 Toxicity Characteristic Leaching Procedure (TCLP)

The fly ash and bottom ash samples were collected at the four ash generation units and analyzed using the TCLP test (Figure 3.7.1). A commonly used test for the determination of the leaching characteristics of fly ash is the **Toxicity Characteristic Leaching Procedure (TCLP)** established by the US Environmental Protection Agency (US EPA, 1992). The TCLP is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid and multiphase wastes. The procedure is carried out in an assembly (Figure 3.7.2) which has an orbital shaker with fixed rotations per minute (RPM). This procedure provides a uniform method to compare the tendency of inorganic elements to leach out from fly ash samples into ***moderate-to-highly acidic aqueous environments.*** The testing methodology is used to determine if ash is characteristically hazardous (D-List) or not. The extract is analyzed for substances appropriate to the protocol. The toxicity characteristic leaching procedure (TCLP) was conducted as per United States Environmental Protection Agency protocol (US EPA SW-846 method, 1311), where 10 gram of ash samples was taken with extraction fluid in 1:20 ratio (m/v). The extraction assembly at room temperature was tightly closed and kept in orbital shaker at 30±2 rpm for 18 hours. The suspension was filtered and filtrates for heavy metals were analyzed by ICP-MS. The TCLP extraction fluid was prepared by mixing 5.7 ml of glacial acetic acid, 500 ml of deionized water and later 64.3 ml of 1N NaOH was added and the volume was made up to 1 Liter. The pH of extraction fluid was maintained at 4.9.

Figure 3.7.1: Fly ash sample collection

Figure 3.7.2: Orbital shaker for TCLP

3.8 Water extraction test

The test is performed to determine the leachable elemental concentration in water using ASTM D 3987 (Table 3.8.1). It is carried out by taking 10 gm of fly ash and 200 ml of deionized water. They are mixed and put on a stirrer for 18 hours at 30 RPM. Subsequently, they are filtered by ordinary filter papers to remove the ash particles. The fine ash particles left in the water are removed by filtering through 0.2µm syringe filter. The sample is then acidified with HNO_3 and kept in refrigerator for preservation. All the samples treated in triplicate manner to avoid errors. The samples were analysed on ICP-MS for heavy metal concentration.

Table 3.8.1 Description of leaching test

Tests Condition	EPA 3050B (Total concentration of trace elements)	ASTM D 3987 (Water extraction test)
Heavy metal concentration	Leachable + Non-leachable	Leachable
Leaching Solution	Nitric acid+ Hydrogen peroxide	Deionized Water
Liquid to solid ratio	100:1	20:1
pH	< 2	6.5 – 7.0

Digestion/ Leaching time(h)	6 hrs	18 hrs
Temperature(˚C)	95	25-30
Number of samples	3	3

3.9 Total concentration of trace elements in ash matrix

The total leachable and non-leachable heavy metal concentration was determined by acid digestion method by EPA3050B (Table 3.8.1). It is carried out by taking 1 gm of ash (after sieving) in a digestion vessel. After adding 1:1 10 ml of HNO3, it is kept on hot plate for digestion. After 30 minutes, another 5 ml of HNO3 is added. HNO3 is added after some time till the brown fumes subside. It is cooled and then 2 ml of Hydrogen peroxide is added. It is again heated for 2 hours and cooled. Then few drops of HCl are added and heated for 15-20 minutes and cooled to room temperature. It is now filtered through ordinary filter paper to remove the ash particles. The filtrate is now diluted up to 100 ml with the help of deionized water. The fine ash particles left in the water are removed by filtering through 0.2µm syringe filter. All the samples treated in triplicate manner to avoid errors. The sample is preserved and analyzed by ICP-MS.

3.10 Water Elution Test

Leachable concentration of trace elements in ash matrix was estimated for the fly ash samples collected from the ESP hopper of Bhushan Steel. The total leachable heavy metal concentration was estimated by Water Elution test. The test is undertaken by following the procedures outlined in ASTM D 4874 (2001b). Acrylic material made column is used for the test to avoid the possible contamination from the other materials like glass, metals etc. The column with 50mm dia and 600mm height and having opening at both ends is used for test. Approximately 500g of air dried fly ash sample is weighed and transferred in the vertical column and an ordinary filter paper is kept on both ends to spread the water uniformly throughout the column and filter the particles (Figures 3.10.1, 3.10.2). Initial pH of the deionised water is maintained pH:2, pH:5 pH:7, pH:10 with the help of 10% acetic acid and 0.5 N NaOH To identify the leaching behaviour of fly ash according to the initial pH of leaching

Figure 3.10.1: Water elution test for the fly ash sample

Figure 3.10.2: Water elution test for different pH condition

medium. Raw water collected from the plant is used as it is for the leaching experiment. All the fix pH deionised water and raw water reservoirs are kept in such a way that the flow of water should be maintained gravitationally. The Samples are coded according to the pH of the leaching medium which is A, B, C, D and E for pH2, pH5, pH7, pH10 and raw water respectively.

As the fly ash is very poor permeable material, the water flow is maintained at 25ml/hr throughout the leaching period to avoid the overflow and maintain the same contact time for throughout the experiment. Water flow is maintained by the knob on the pipeline which connects column to the deionised water reservoir. The beaker is kept at the other end of the column to collect the leachate. Samples are collected for particular time interval and transferred the pre-cleaned containers. The fine ash particles left in the water are removed by filtering through 0.2µm syringe filter. For the preservation of the sample 10% HNO_3 is added to maintain the pH below 2 and kept in refrigerator at 4°C. The concentration of the elute trace metals are determined by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). Elements measured in samples are Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Se and Zn.

3.11 Chemical characterization of ash samples

The fly ash and bottom ash samples were collected from the four sources of ash generation units in Bhushan steel. They were analyzed for major elements i.e. SiO_2, Al_2O_3, Fe_2O_3, TiO_2 and minor elements i.e. K_2O, CaO, MgO, Na_2O, P_2O_5, SO_3. The analysis was carried out at IBM (Indian Bureau of Mines), Nagpur.

3.12 Particle Size Analysis of the ash samples

The fly ash and bottom ash samples were collected from the four sources of ash generation units in Bhushan steel. Composite sample was prepared for particle size analysis using Mastersizer 2000.

3.13 Soil sampling

Soil sampling has been carried out at representative locations in the study area (Figure 3.13.1). The samples were packed in air tight sampling bags for their safe transportation to the laboratory. Sampling locations were selected with reference to the mine pit. The coordinates of soil sampling locations (Table 3.13.1) have been noted with the help of hand-held GPS. A soil profile of 1 m × 1 m× 1 m (Figure 3.13.2) was made at each of the sampling site. The soil sampling is done as per Soil Survey Manual (1971). The soil samples were analyzed for various parameters viz., hydraulic conductivity, pH, EC, organic carbon (%), exchangeable cations (Ca, Mg, Na, K) in 100 meq/gm, total fluoride (mg/kg) etc (Jackson 1967; Black 1965).

Table 3.13.1 Soil Sampling Locations

S.No.	Sample Code	Latitude	Longitude
1	BS-1	20° 54′ 6.3″	85° 13′ 58.2″
2	BS-2	20° 55′ 48.5″	85° 09′ 56.7″
3	BS-3	20° 56′ 50.1″	85° 09′ 57.0″

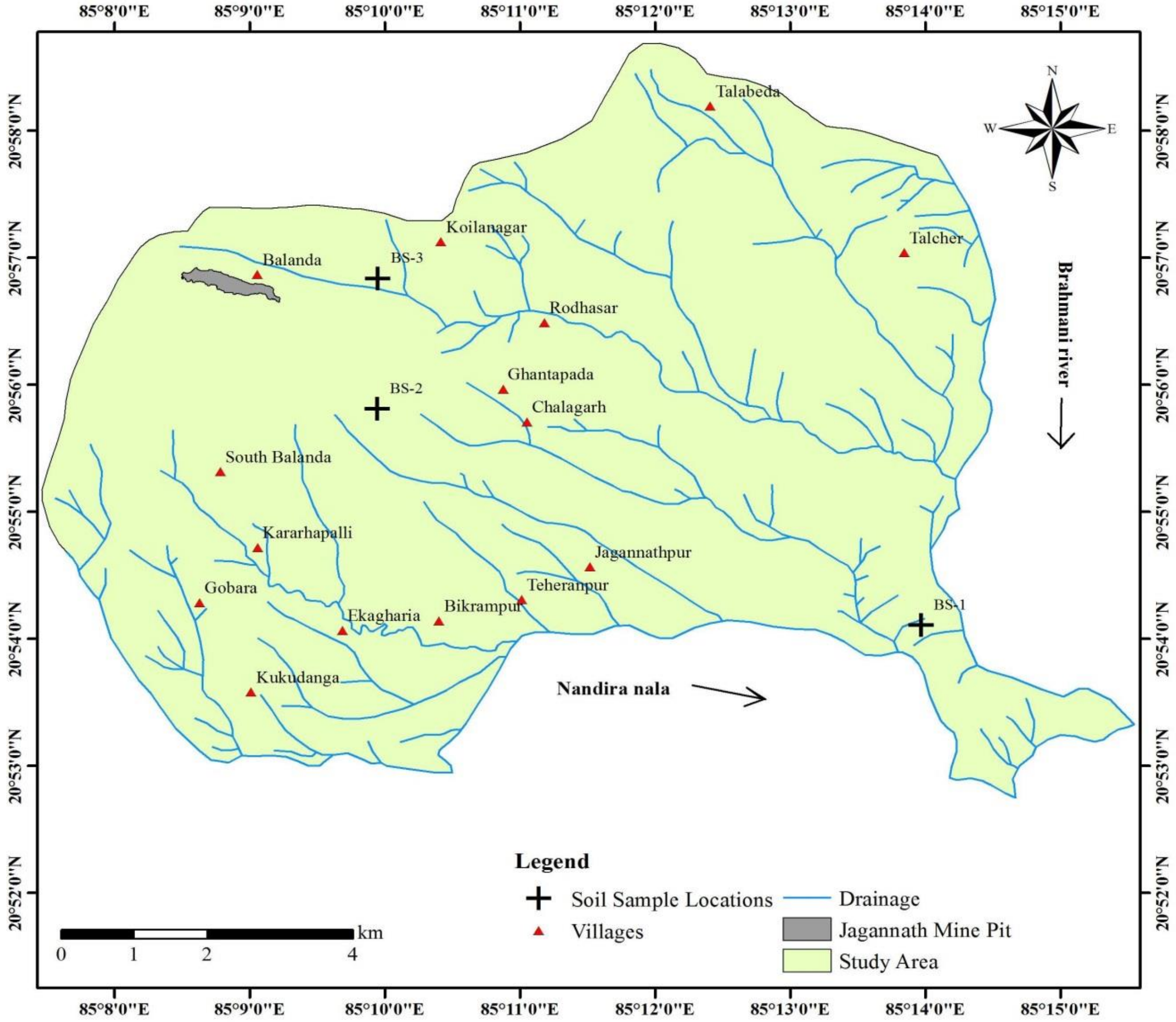


Figure 3.13.1 Soil sampling locations in the study area

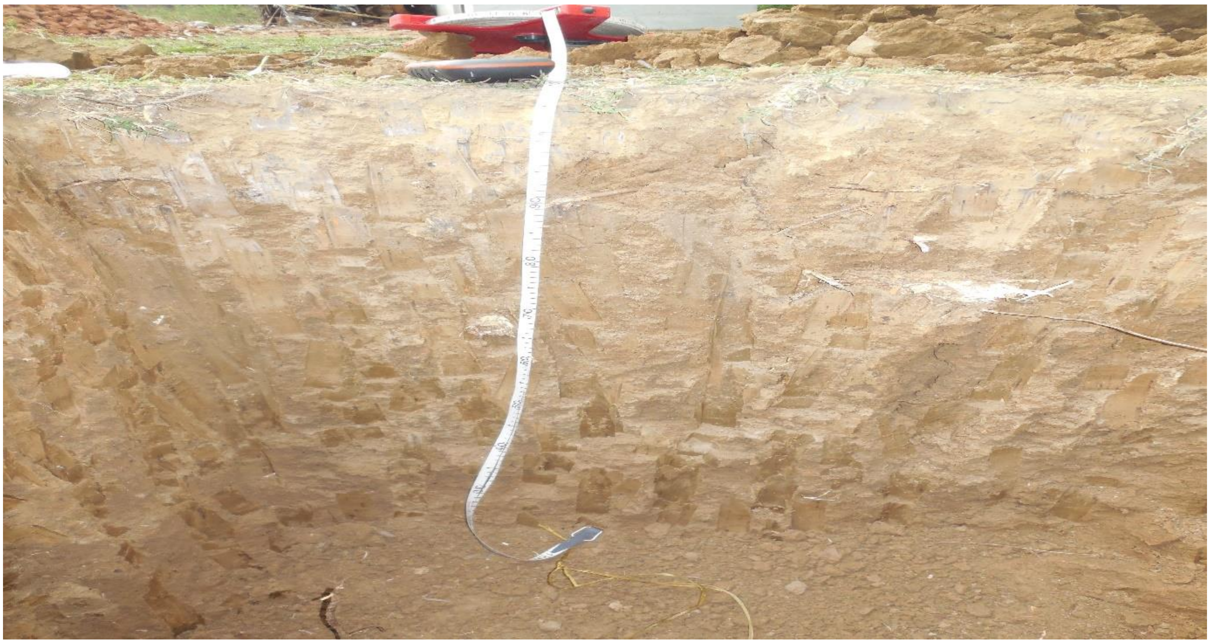


Figure 3.13.2 Soil profile in the study area

3.14 Bio-assay, bio-magnification and bio-accumulation tests

Environmental bioassay is an experimental process wherein the assessment of toxicity on biological organisms is tested. . The purpose of this test is to determine the acute toxicity of substances (toxicants) to fish in fresh water. Acute toxicity is an exposure test of short duration (days). Aquatic ecosystems are affected by numerous natural and chemical substances. These substances may be responsible for possible impacts on the structure and function of aquatic organisms. Since chemical analysis of pollutants does not cover all toxic substances, bioassays have been developed for bio-monitoring and evaluation of toxic substances in freshwater and natural ecosystems. Bioassays assess the potential harm of toxicants and are based on the response of living organisms to the toxicants in the water.

Test Procedure: The zebra fishes were obtained from a local aquarium. All fishes were transferred directly into a glass aquarium of 30 litres capacity for acclimatization (Figure 3.14.1). The fishes were acclimatized in uncontaminated (dilution) water (normal tape water) for seven days before they were used. The test was performed using five glass aquariums filled with different test solution concentrations by mixing the sample and normal tape water One control experiment i.e with normal tape water was run and measurements of pH and temperature were carried out during the test. In the remaining four aquariums, six fishes were transferred directly into each glass aquariums filled with 1 liter of test water samples with minimum handling. No food was offered during the exposure period i.e. 96 hours. Fish behavior and mortality were observed and recorded as frequently as possible during the exposure period.

The Bioassay test has been carried out on the pit water in post-monsoon (2014) season. However, the test has been carried out in Pre-monsoon (2015) season by considering the pit water as well as the slurry which is directly disposed on the mine void.

Dilution/control water: Drinking-water supply, good-quality, uncontaminated natural water.
Test fish: Zebra fish (*Danio rerio*), in good health and free from any apparent malformation.

Figure 3.14.1 Fish Bioassay test

Test type: Static (test solutions remain unchanged throught test duration). The test was performed without pH adjustment because pH of test solutions were within the range 6.5-8.5
Test duration: 96 hours
Feeding: No food supplied to the test fishes during exposure period.
Aeration: None

3.15 Groundwater Flow and Solute Transport Modelling

A steady state Groundwater Flow and Solute Transport mode has been attempted for the study area. The Groundwater flow is attempted using the Visual Modflow (2011.1) version whereas the Solute transport model is attempted using the MT3D engine (Zheng, 1990).

The Groundwater Flow provides the hydraulic head and the velocity field which is subsequently used by the solute transport engine MT3D to estimate the concentration of solute at different time and space.

MT3D is a Modular 3-Dimensional solute Transport model for simulating changes in concentration of single species miscible contaminants in groundwater considering advection, dispersion and some simple chemical reactions with various types of boundary conditions and external sources or sinks in ground water systems. **MT3D** is based on a modular structure to permit simulation of transport components independently or jointly. It interfaces directly with the USGS finite-difference groundwater flow model MODFLOW, for the head solution, and supports all the hydrologic and discretization features of MODFLOW. The modular structure of the MT3D transport model makes it possible to simulate processes like advection, dispersion, source/sink mixing and chemical reactions independently.

A brief account on flow and solute transport modelling is as follows:

3.15.1 Groundwater Flow Equations

The groundwater flow is governed by the Darcy's law and the conservation of mass. The governing mathematical equations for groundwater flow are developed from the fundamental principle of conservation of mass of fluid and the Darcy's law.
A general equation for conservation of mass may be expressed as:

Rate of mass inflow – rate of mass outflow + rate of mass reduction/consumption
= rate of mass accumulation

The Darcy's law states that the flow per unit area per unit time is directly proportional to the change in head and inversely proportional to the length of the flow path.

$$\mathbf{V= K\ (\partial h/\partial x)} \quad \text{. . . . . (3.1)}$$

Where,

V = flow per unit area per unit time

K = hydraulic conductivity

$\partial h/\partial x$ = hydraulic gradient

In steady state condition, the groundwater flow equation is given by:

$$\frac{\partial}{\partial x}\left(\frac{K_{xx}\,\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{K_{yy}\,\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{K_{zz}\,\partial h}{\partial z}\right)+W=0 \quad \text{. . . . . (3.2)}$$

Where,

K_{xx} = hydraulic conductivity in the x-direction

K_{yy} = hydraulic conductivity in the y-direction

K_{zz} = hydraulic conductivity in the z-direction

W is the source or sink term

h is the hydraulic head

3.15.2 Solute Transport Equations

The governing equations for the transport of solute in groundwater can be derived by taking the mass balance of the dissolved pollutant over a static elementary volume, $\Delta V= \Delta x\Delta y\Delta z$. The transport equations were developed by Zheng (1990).

It can be written as follows:

Change in solute mass stored = excess solute mass diffusion into volume

+ excess solute mass inflow over outflow or mass transport by convection

+ solute mass added by injection/filtration

- solute mass lost by withdrawal

- solute mass lost by decay

- solute mass lost by reaction

- solute mass adsorbed on solid interface

$$-\frac{\partial(v_iC)}{\partial x_j}+\frac{\partial}{\partial x_i}\left(D_{ij}\,\frac{\partial C}{\partial x_j}\right)\pm q_s\,\frac{C_s}{\theta}-\lambda\left(C+p_b\,\frac{S}{\theta}\right)=R\frac{\partial C}{\partial t} \quad \text{. . . . . (3.3)}$$

The first term represents the **advection term**, second term is the **dispersion**, third term is the **sink/source**, fourth is the **reactions term** and last (R) is the retardation term.

Where,

C: dissolved concentration of species k

θ: porosity of the subsurface medium

t: time

x_i: distance along the respective Cartesian coordinate axis.

D_{ij}: hydrodynamic dispersion coefficient tensor

v_i: seepage or linear pore water velocity

q_s: volumetric flow rate per unit volume of aquifer representing source/sink

C_s: concentration of the source or sink for species k

ΣR_n: chemical reaction term

It need to be mentioned that the solute transport model is based on the **advection and dispersion transport.** It does not assume reactions and retardation which require a separated study and it can not be achieved within the scope of the present study. Hence, the prediction from the flow and solute transport will be valid for conservative elements in the solute. Any prediction for trace elements like As, Pb and Hg would depend on the retardation factor (R), which can vary over a range 10^2 to 10^4 (EPA, 1999). ***Hence, any prediction for movement of trace elements mentioned above will be considerably less than the movement for conservative elements.***

Chapter IV

Results & Discussion

(Hydrogeology, Hydrochemistry, Leachability, Radioactive studies & Solute transport modelling)

4.1 Groundwater Level

Groundwater level conveys useful information about the groundwater system. The temporal variation of the groundwater level conveys the characteristics like its recharge potential due to precipitation. The groundwater level has been measured in the observation well (24 nos) network during post-monsoon (November 2014) and pre-monsoon (May 2015). It is observed (Table 4.1.1) that the post-monsoon water level (bgl) varied from 1.04 m (BG-3) to 14.91 m (BG-9) and the pre-monsoon water level (bgl) varied from 2.35 m (BG-17) to 27.85 m (BG-2). It is also indicated that the water level is at a deeper level in pre-monsoon as compared to the post-monsoon level. The pre-monsoon to post-monsoon varied from less than 1m (BG-1) to 12.2m (BG-13). Reduced level survey has been carried out in the study area to reduce the water level (bgl) to a common datum (amsl). The broad topography as deciphered by the RL survey (Figure 4.1.1) indicates that the general topographic gradient is in the south east direction. The water level (amsl) contours (Figures 4.1.2 & 4.1.3) indicate that the groundwater flow direction is in the south east direction. The groundwater flow direction broadly follows the topography.

Table 4.1.1 Water level (bgl-m) in observation well network – Post monsoon (November 2014) and Pre monsoon (May 2015)

Sample ID	Longitude	Latitude	RL (in m)	Post 2014	Pre 2015	Post 2014	Pre 2015
				BGL (m)		AMSL (m)	
BG-1	85° 10′ 11.5″	20° 56′ 26.0″	101.98	4.75	5.05	97.23	96.93
BG-2	85° 09′ 55.1″	20° 56′ 54.8″	103.05	17.48	27.85	85.57	75.2
BG-3	85° 11′ 17.9″	20° 55′ 42.4″	83.75	1.04	2.56	82.71	81.19
BG-4	85° 10′ 32.9″	20° 55′ 07.1″	88.83	2.82	5.99	86.01	82.84
BG-5	85° 12′ 02.0″	20° 54′ 02.8″	67.91	4.6	8.02	63.31	59.89
BG-6	85° 14′ 24.9″	20° 53′ 16.0″	61.05	6.57	8.5	54.48	52.55
BG-7	85° 13′ 58.6″	20° 54′ 05.2″	62.53	3.73	6.78	58.8	55.75
BG-8	85° 14′ 0.8″	20° 55′ 09.7″	64.82	12.6	14.15	52.22	50.67
BG-9	85° 13′ 08.3″	20° 55′ 33.2″	69.99	14.91	19.38	55.08	50.61
BG-10	85° 13′ 53.8″	20° 55′ 44.2″	63.25	6.18	8.98	57.07	54.27
BG-11	85° 14′ 20.1″	20° 56′ 14.2″	70.38	13.94	13.41	56.44	56.97
BG-12	85° 14′ 19.7″	20° 57′ 17.7″	66.81	10.61	10.75	56.2	56.06
BG-13	85° 12′ 28.2″	20° 58′ 22.8″	95.89	2.09	14.29	93.8	81.6
BG-14	85° 12′ 21.2″	20° 54′ 54.1″	70.08	----	20.24	----	49.84
BG-15	85° 11′ 37.1″	20° 54′ 50.0″	73.91	4.74	6.99	69.17	66.92
BG-16	85° 11′ 28.9″	20° 54′ 13.4″	72.73	4.54	7.3	68.19	65.43
BG-17	85° 09′ 39.4″	20° 54′ 13.5″	83.52	1.77	2.35	81.75	81.17

BG-18	85° 09′ 16.1″	20° 53′ 37.1″	84.31	2.98	8.05	81.33	76.26
BG-19	85° 08′ 57.9″	20° 53′ 19.5″	85.05	3.79	8.43	81.26	76.62
BG-20	85° 08′ 27.4″	20° 54′ 15.6″	97.93	3.04	5.76	94.89	92.17
BG-21	85° 09′ 14.3″	20° 54′ 43.9″	93.97	6.71	14.83	87.26	79.14
BG-22	85° 09′ 19.6″	20° 55′ 39.6″	119.01	----	----	----	----
BG-23	85° 09′ 58.3″	20° 55′ 49.2″	115.32	3.44	----	111.88	----
BG-24	85° 10′ 25.1″	20° 56′ 02.8″	109.87	7.81	8.64	102.06	101.23

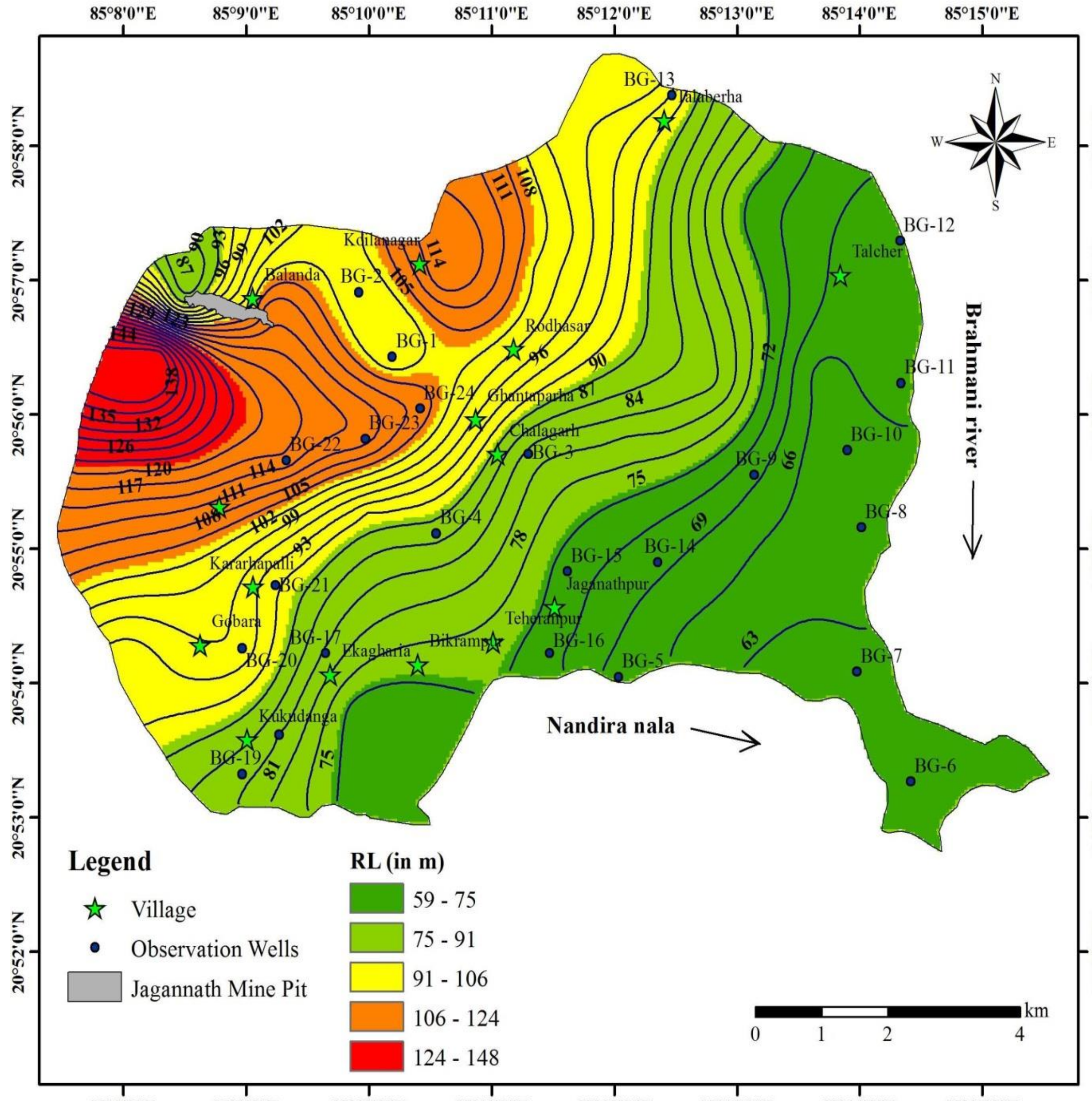


Figure 4.1.1 Topography (from Reduced Level Survey) of the study area

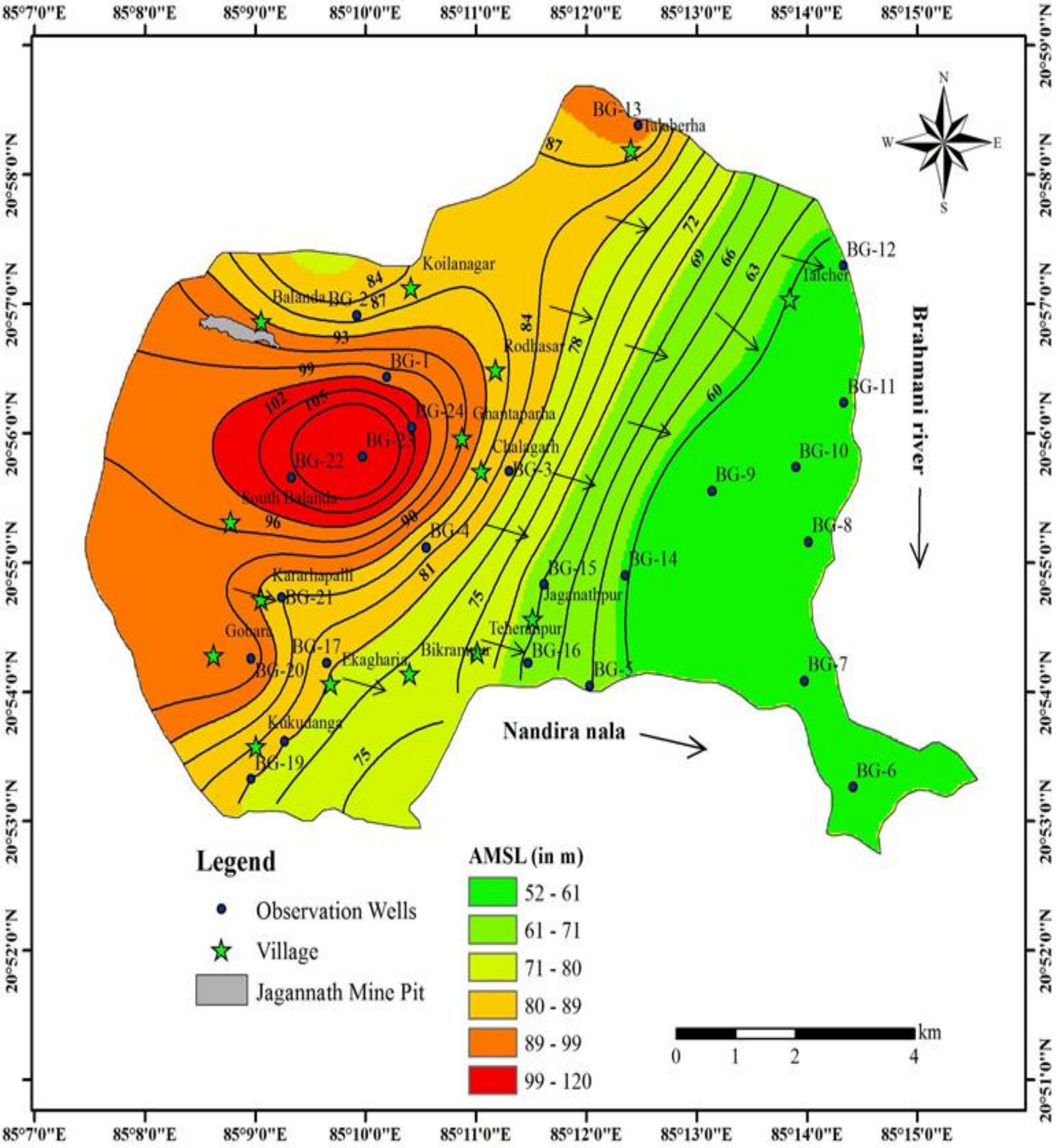


Figure 4.1.2 Water level (AMSL) contours in the study area during post monsoon 2014

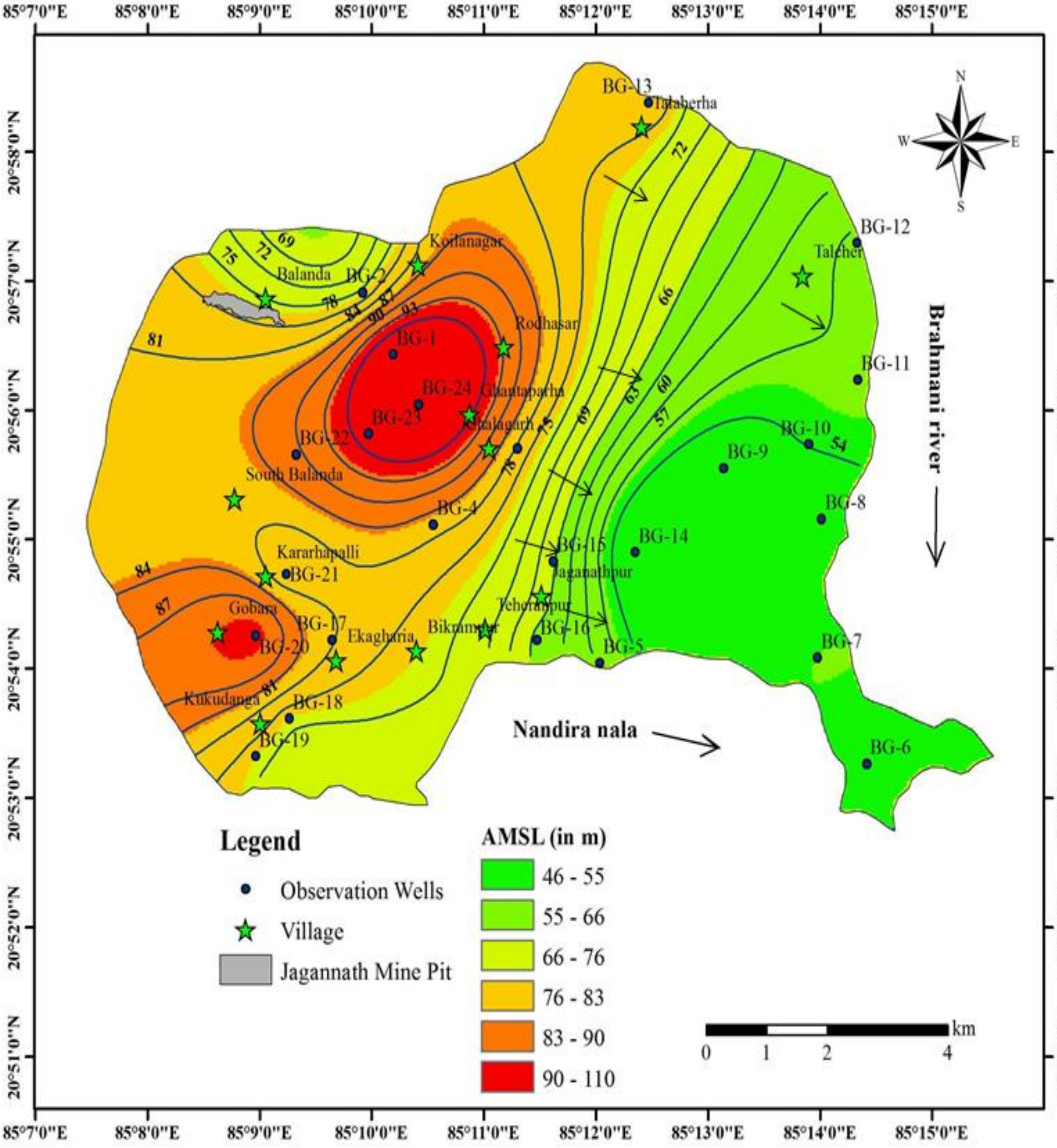


Figure 4.1.3 Water level (amsl) contours of the study area during pre-monsoon 2015

4.2 Groundwater Quality (Physico-chemical Parameters)

The analysis of major cations, anions and trace elements of the groundwater samples (Tables 4.2.1, 4.2.2 and 4.2.3) indicate the temporal variability of the different parameters in the post-monsoon season (November 2014) and pre-monsoon season (May 2015). The key parameters like TDS, Cl, NO_3, F and SO_4 (Table 4.2.1 & 4.2.2) were taken into consideration for the analysis which show significant impact on groundwater quality. The physico-chemical parameters (Table 4.2.1 & 4.2.2) were also analyzed and compared with the Bureau of Indian Standards (BIS 10500:1991) (Table 4.2.3).

pH: pH is an important parameter for water quality assessment to know the acidic or basic nature of water. The pH of the samples was found in between 6.0 (BG-2) to 8.1 (BG-10) during post monsoon season and was found in the range of 6.59 (BG-1) to 8.3 (BG-10) during pre-monsoon season. Hence pH is found to be within acceptable range of 6.5 to 8.5 as per BIS standards (10500:1991).

TDS (Total Dissolved Solids): The estimation of TDS reveals that values varied in the range 76.67 mg/L (BG-1) to 1806 mg/L (BG-5) during post-monsoon (Table 4.2.1) and in the range of 64 mg/L (BG-1) to 1160 mg/L (BG-18) during pre-monsoon season (Table 4.2.2). It was observed that the TDS values (Figures 4.2.1 & 4.2.2) of all the sources are within the permissible limit as per BIS standard (1991:10500).

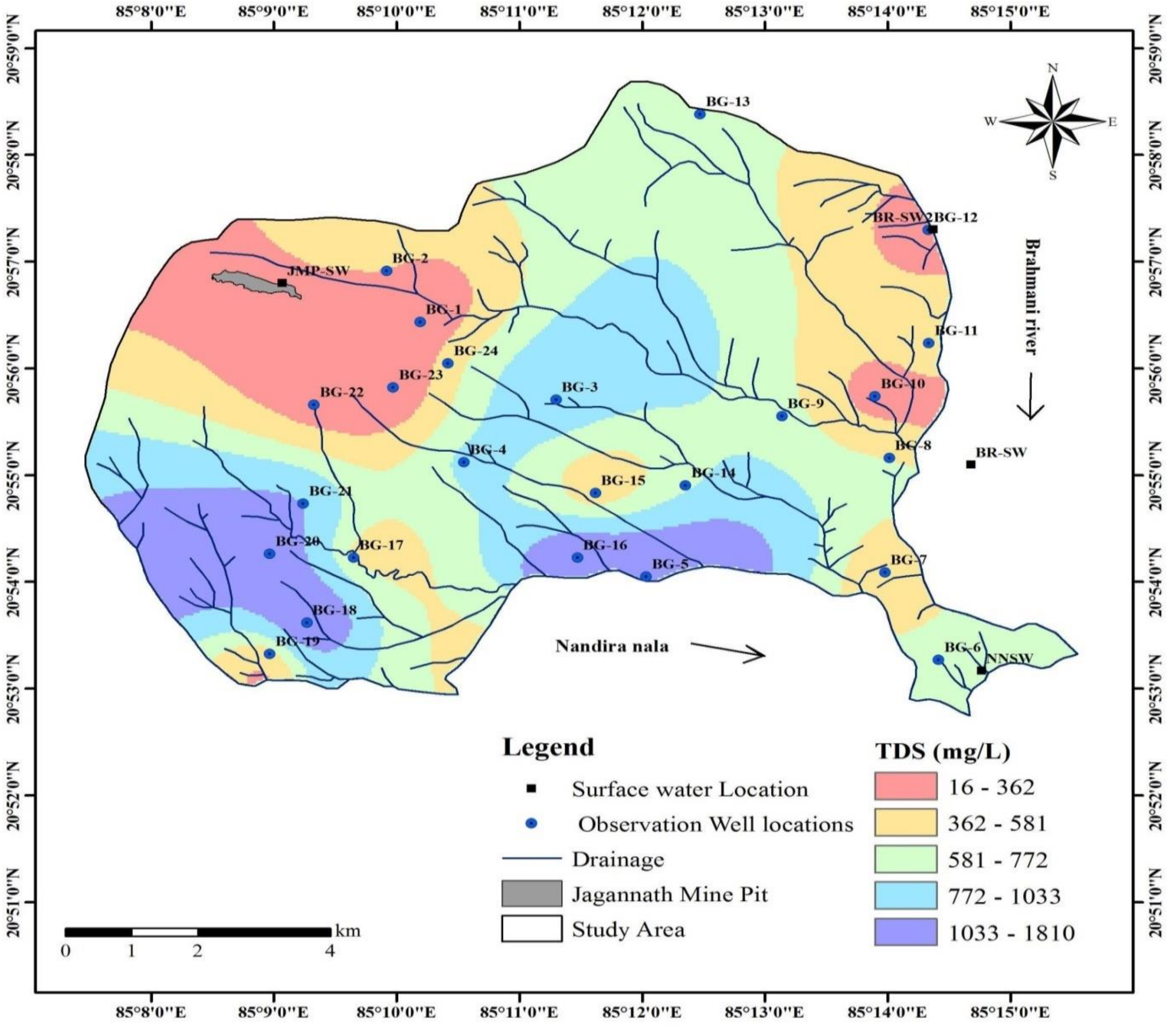


Figure 4.2.1 TDS concentration (mg/L) in the study area-post monsoon 2014

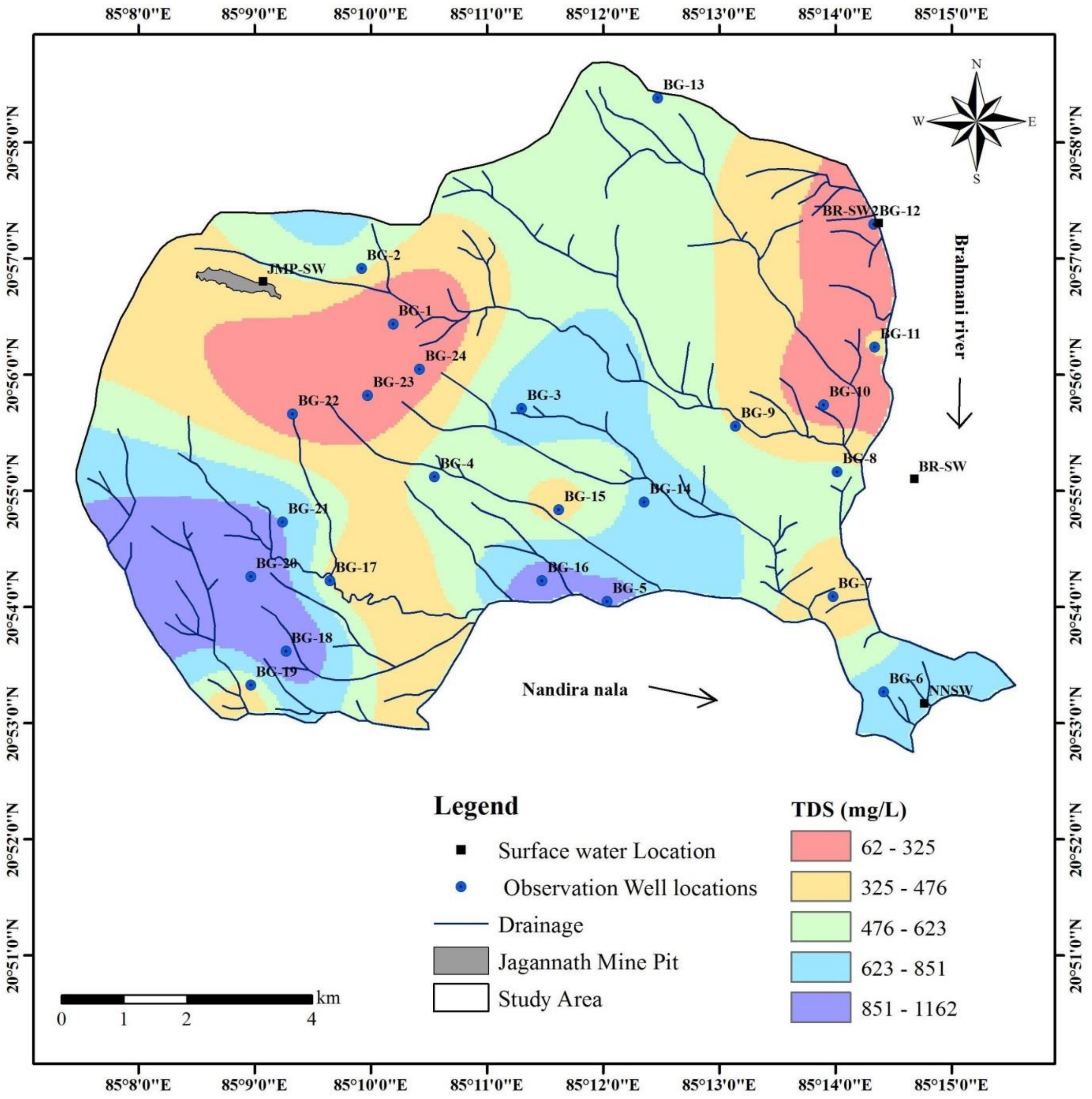


Figure 4.2.2 TDS concentration (mg/L) in the study area-pre monsoon 2015

Sulphate: Sulphate concentration varied in the range 1.02 mg/L (BG-1) to 338.78 mg/L (BG-5) in the period of post-monsoon 2014 (Figure 4.2.3) and in the range of 9 mg/L (BG-1) to 130 mg/L (BG-14) during pre-monsoon season (Figure 4.2.4). The average concentration was observed to be approximately 72.76 mg/L and 67.6 mg/L during post-monsoon and pre-monsoon season respectively. The sulphate concentration in all the samples was within the permissible limit of BIS standard (Table 4.2.1 & 4.2.2).

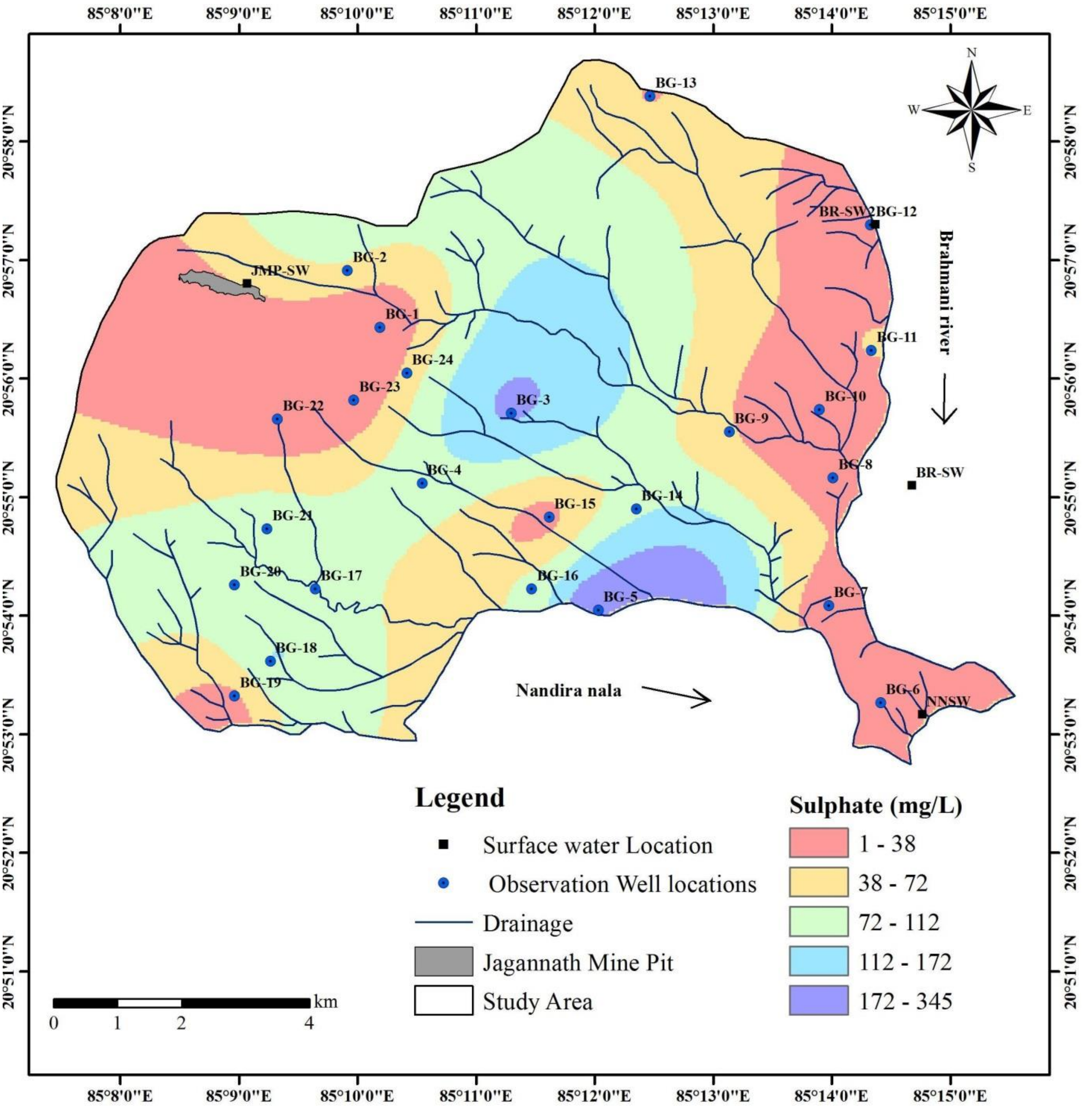


Figure 4.2.3 Sulphate concentration (mg/L) in the study area-post monsoon 2014

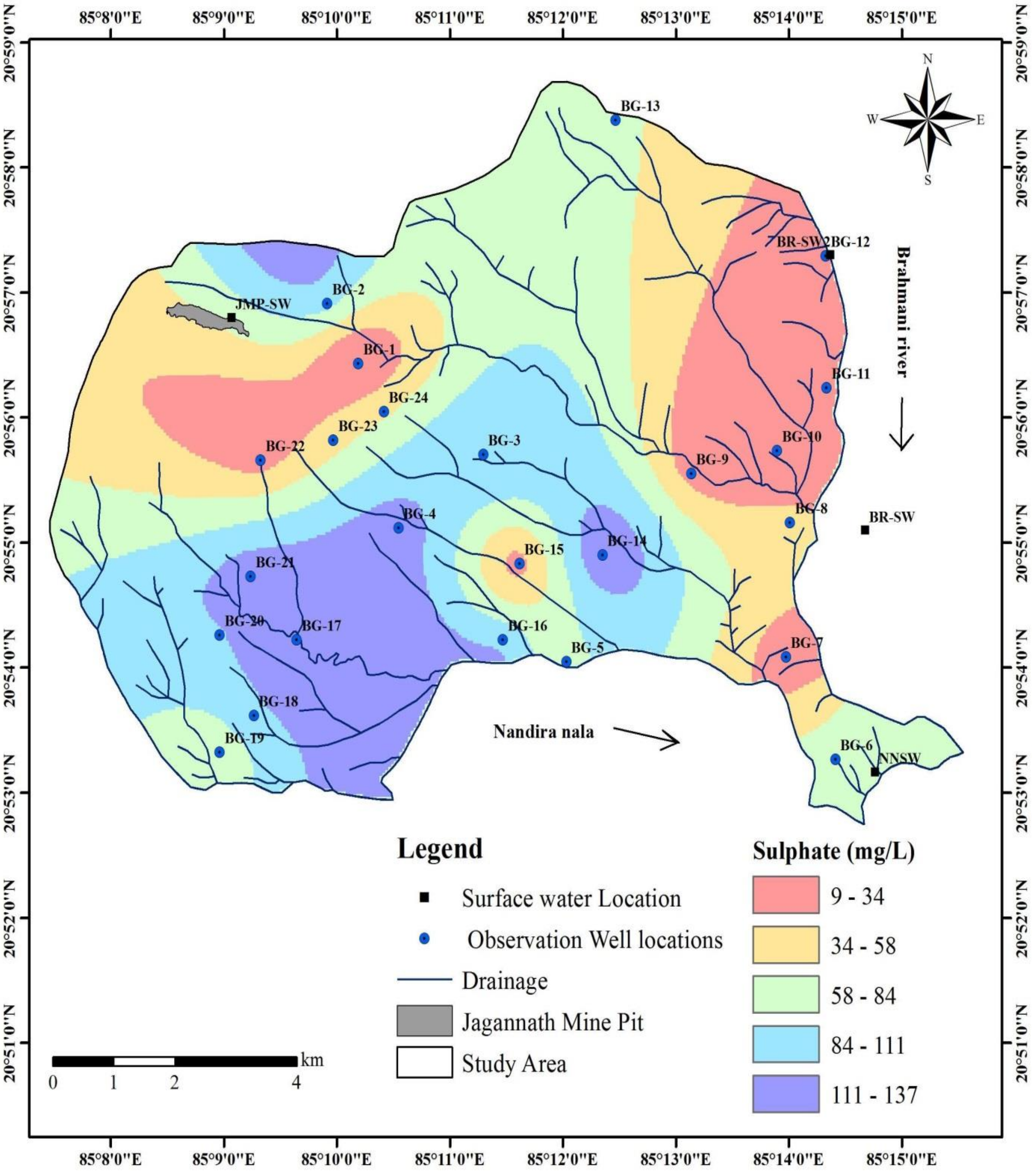


Figure 4.2.4 Sulphate concentration (mg/L) in the study area-pre monsoon 2015

Nitrate: Nitrate concentration varied in the range ND (BG-23 & BG-24) to 298.04 mg/L (BG-5) during post-monsoon season (Figure 4.2.5) and in the range of 0.3 mg/L (BG-7) – 153 mg/L (BG-20) during pre-monsoon season (Figure 4.2.6). The average nitrate concentration was observed to be 51.64 mg/L and 34.45 mg/L during post-monsoon and pre-monsoon seasons respectively. Seven groundwater samples and five groundwater samples showed higher concentration of nitrate during post-monsoon and pre-monsoon seasons respectively. The major source for nitrate contamination may be due to the land use and land cover pattern i.e., local habitation without proper sewerage and agricultural practices in the study area.

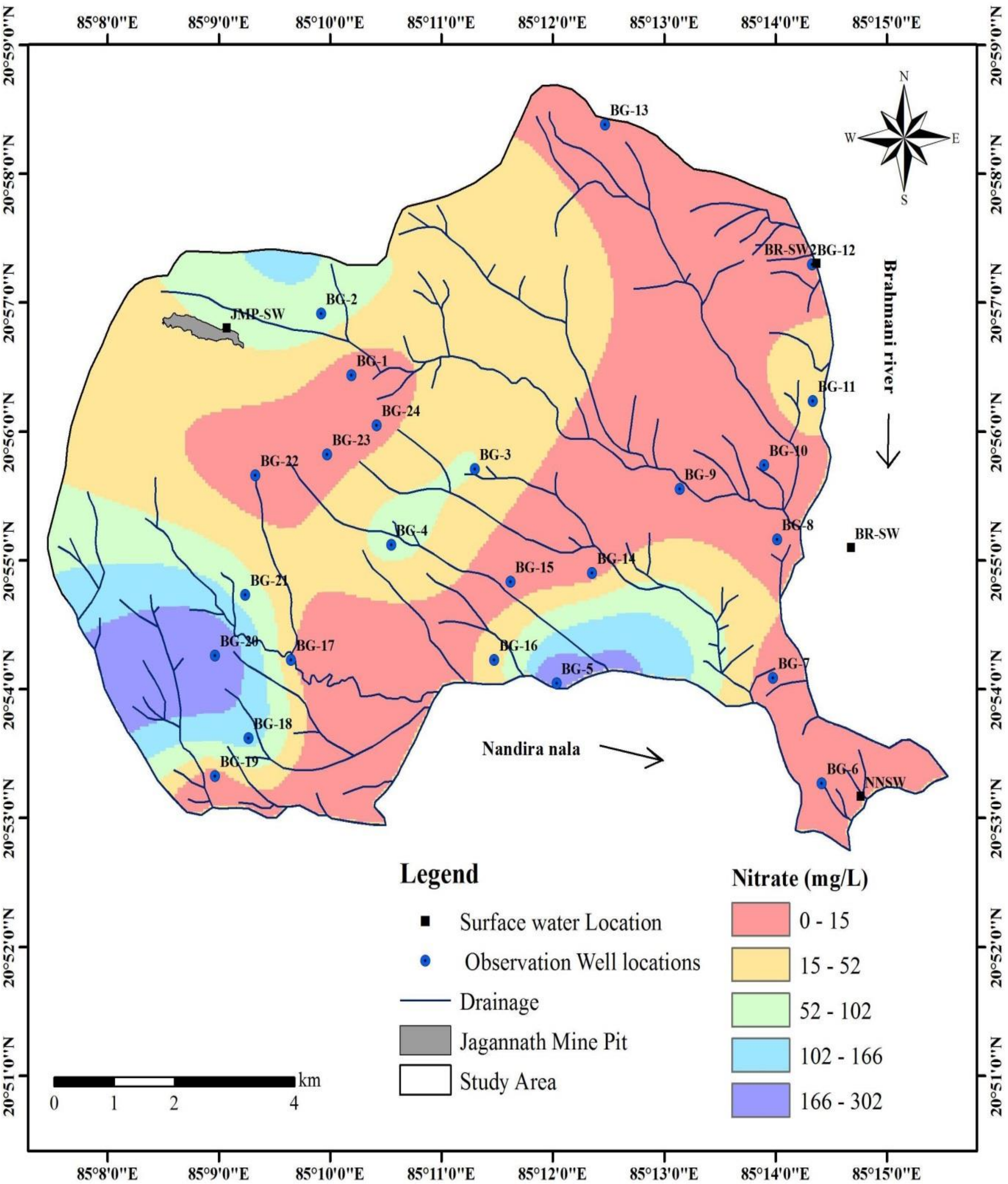


Figure 4.2.5 Nitrate concentration (mg/L) in the study area-post monsoon 2014

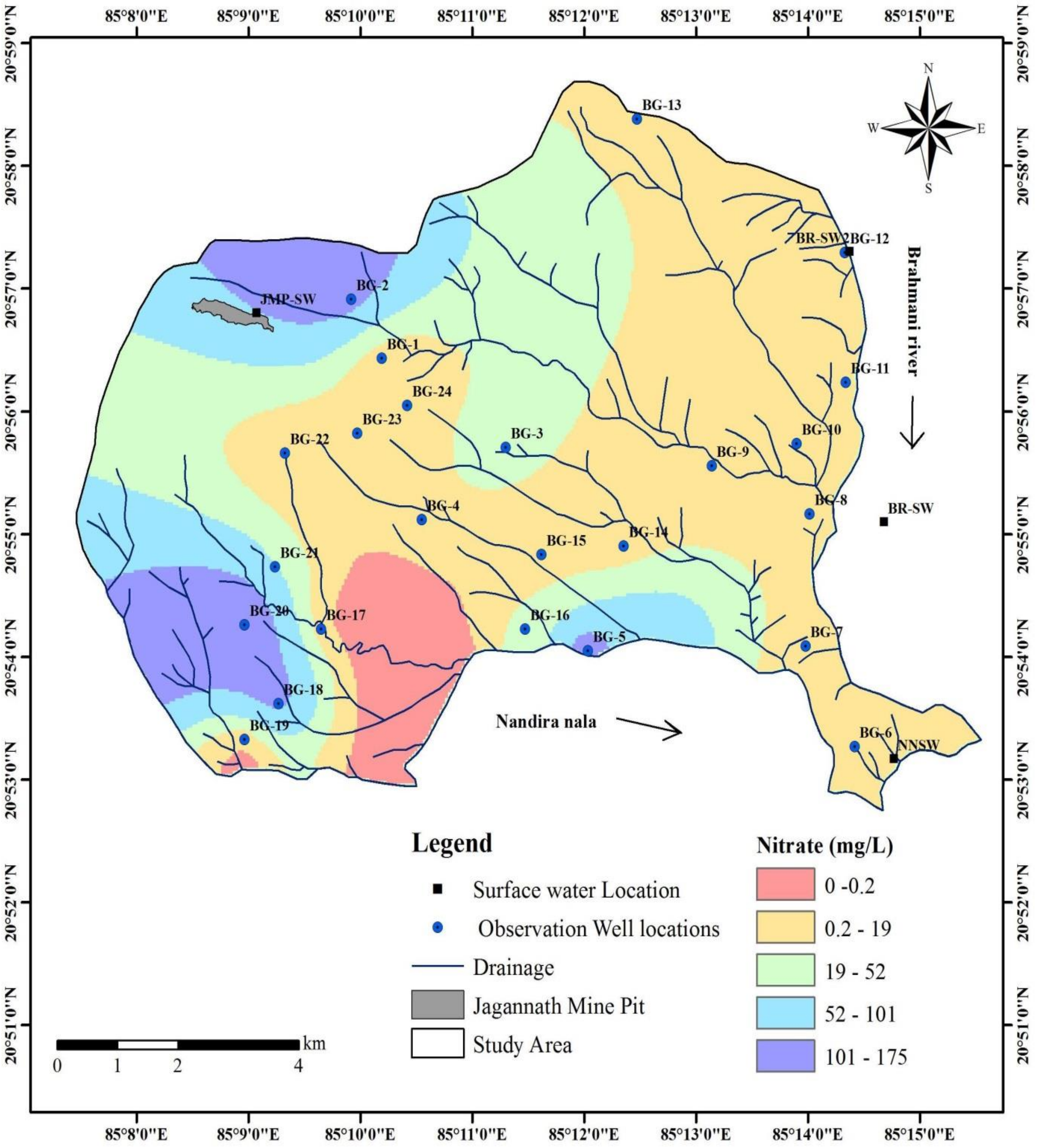


Figure 4.2.6 Nitrate concentration (mg/L) in the study area-pre monsoon 2015

Fluoride: The Fluoride concentration varied in the range 0.23 mg/L (BG-22) to 7.9 mg/L (BG-10) during post-monsoon and in the range 0.096 mg/L (BG-22) to 7 mg/L (BG-10) during pre-monsoon season (Table 4.2.1 & 4.2.2). The average concentration is estimated at approximately 1.78 mg/L and 1.36 mg/L during post-monsoon and pre-monsoon seasons respectively. The samples namely BG-6, BG-7, BG-10 and BG-21 during post-monsoon and samples namely BG-6, BG-10 and BG-21 during pre-monsoon season showed higher values of fluoride (Figure 4.2.7 & 4.2.8). Excluding above mentioned samples, all the other samples have fluoride concentration within the permissible limits as per BIS standards. It is revealed from various studies carried out in past that the occurrence of high level of fluoride in the ground water is in this region is lying in the basement crystalline and in the Gondwana sedimentaries (Talcher Coal Field).

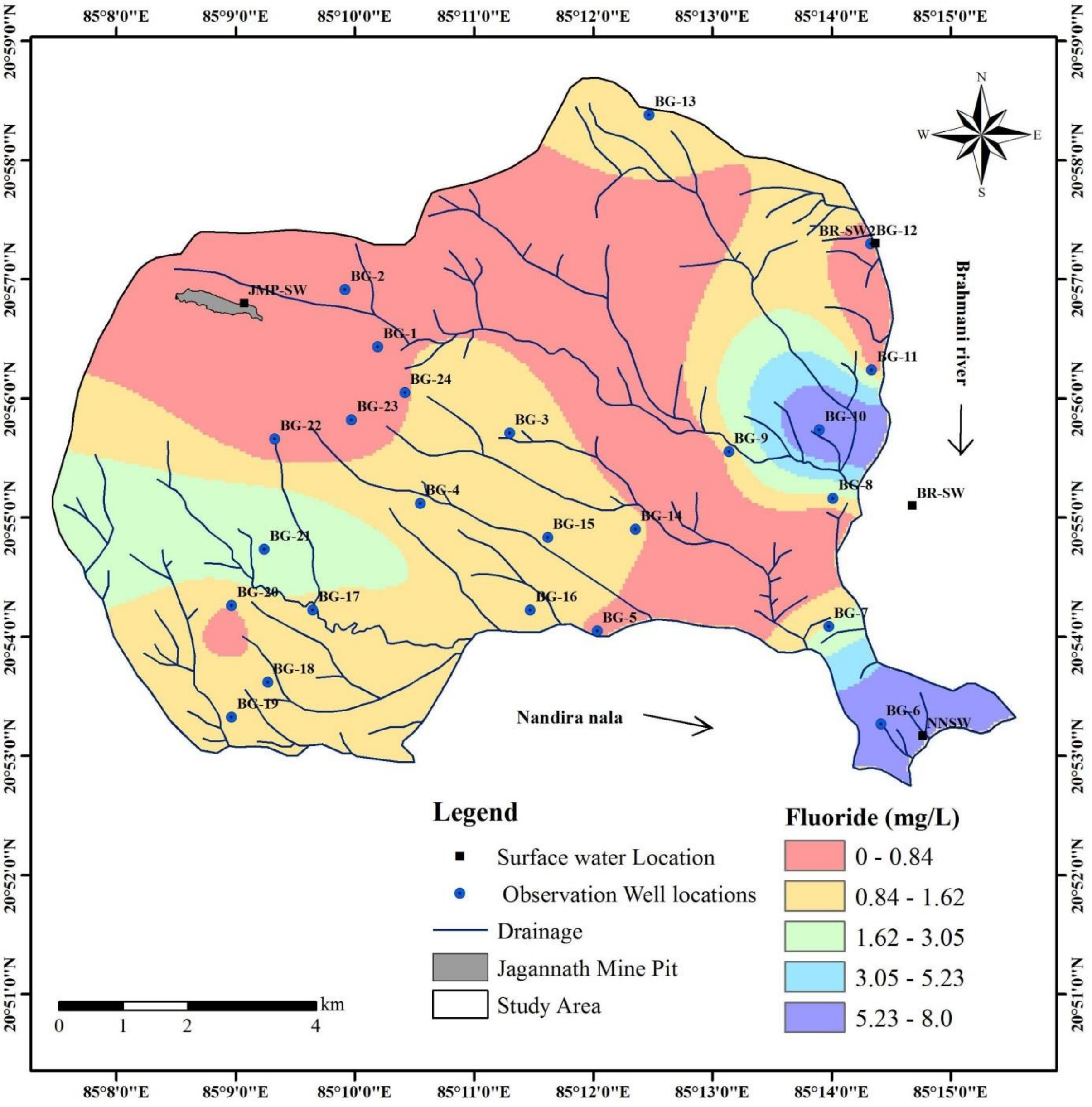


Figure 4.2.7 Fluoride concentration (mg/L) in the study area-post monsoon 2014

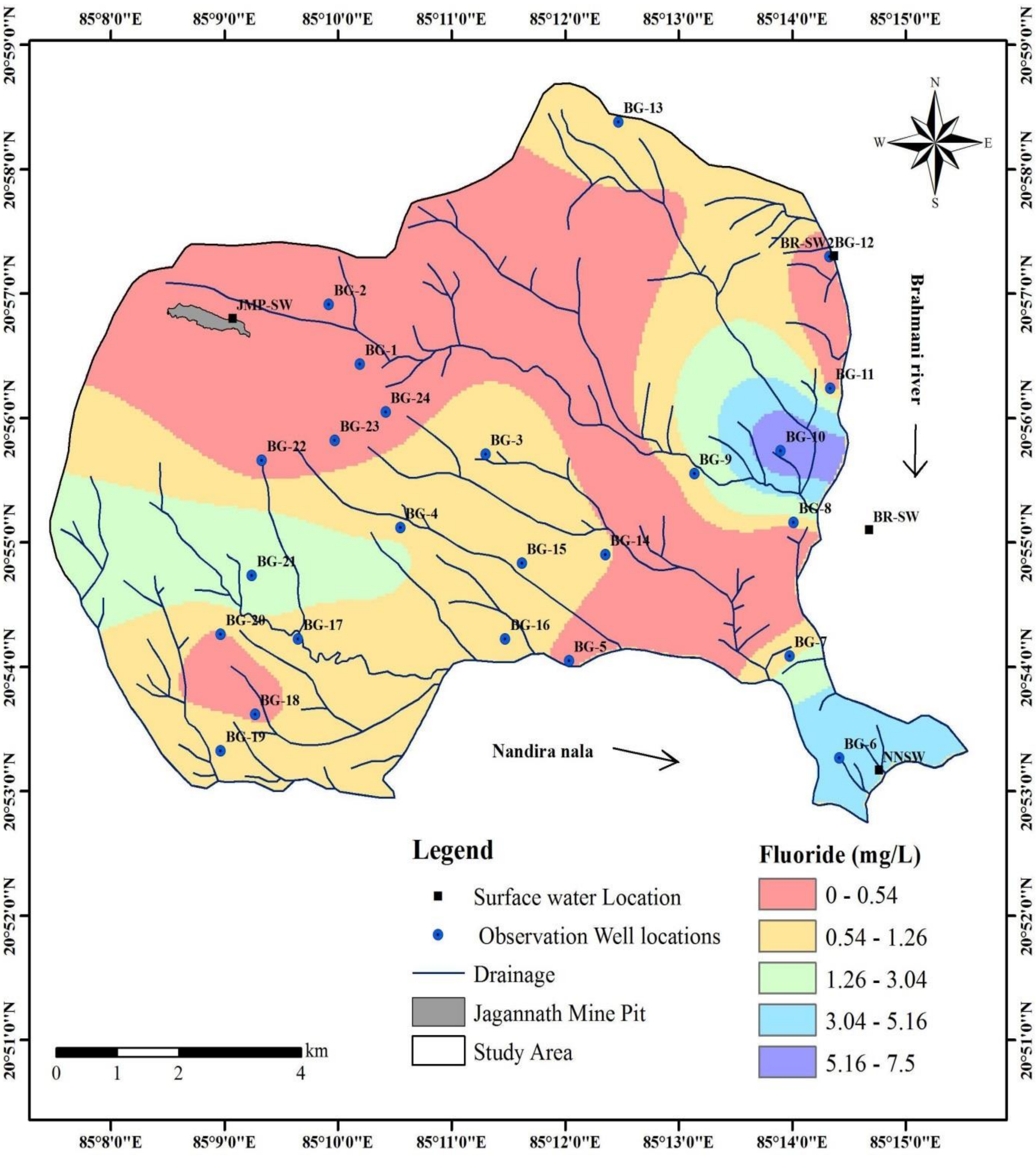


Figure 4.2.8 Fluoride concentration (mg/L) in the study area-pre monsoon 2015

Chloride: Chloride concentration varied in the range 8 mg/L (BG-23) to 480 mg/L (BG-18) in the period of post-monsoon 2014 (Figure 4.2.9) and in the range of 14 mg/L (BG-1) – 482 mg/L (BG-18) during pre-monsoon season (Figure 4.2.10). The average concentration was observed to be approximately 135 mg/L and 120.96 mg/L during post-monsoon and pre-monsoon season respectively. The chloride concentration in all the samples was within the permissible limit of BIS standard (Table 4.2.1 & 4.2.2).

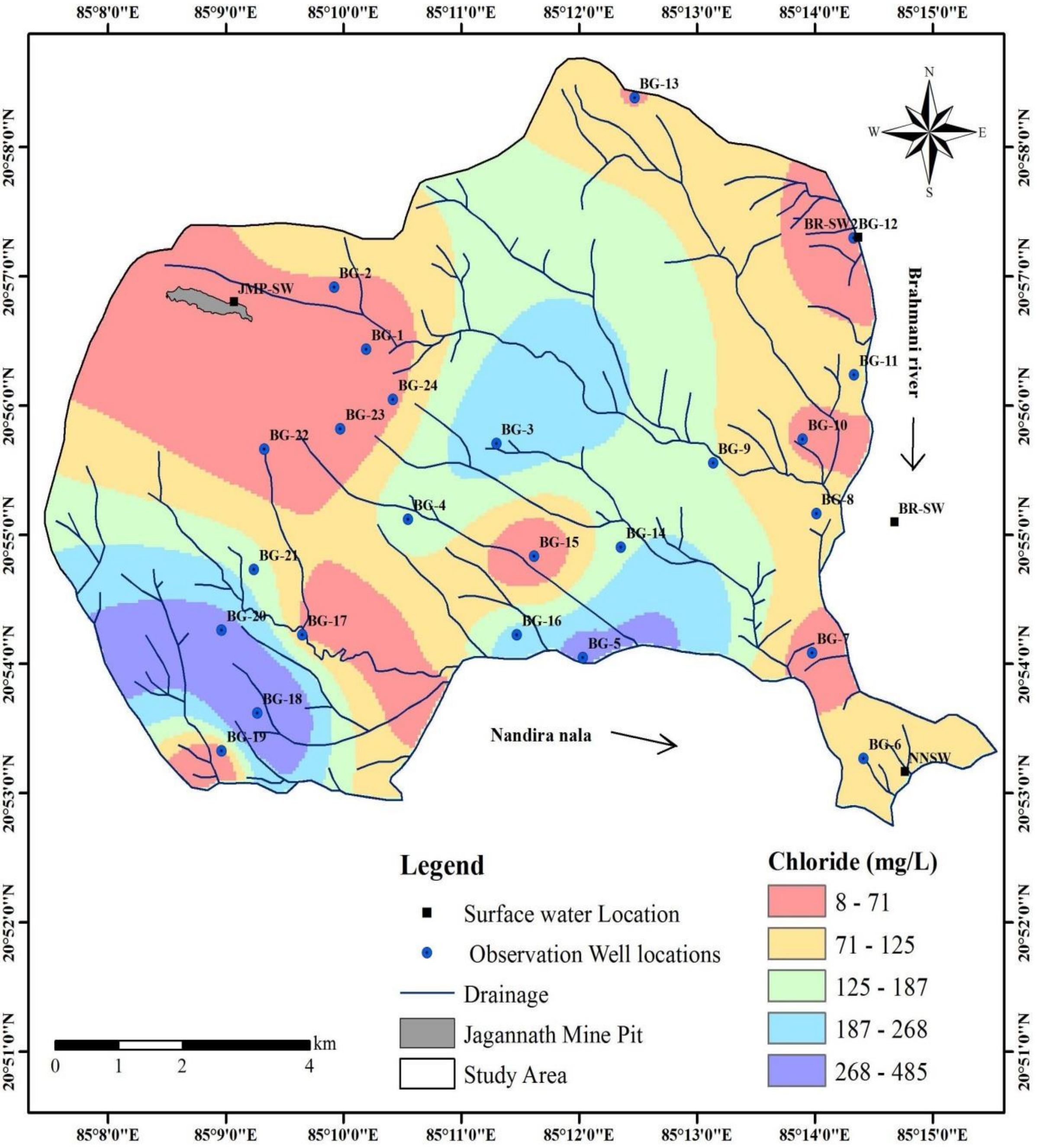


Figure 4.2.9 Chloride concentration (mg/L) in the study area-post monsoon 2014

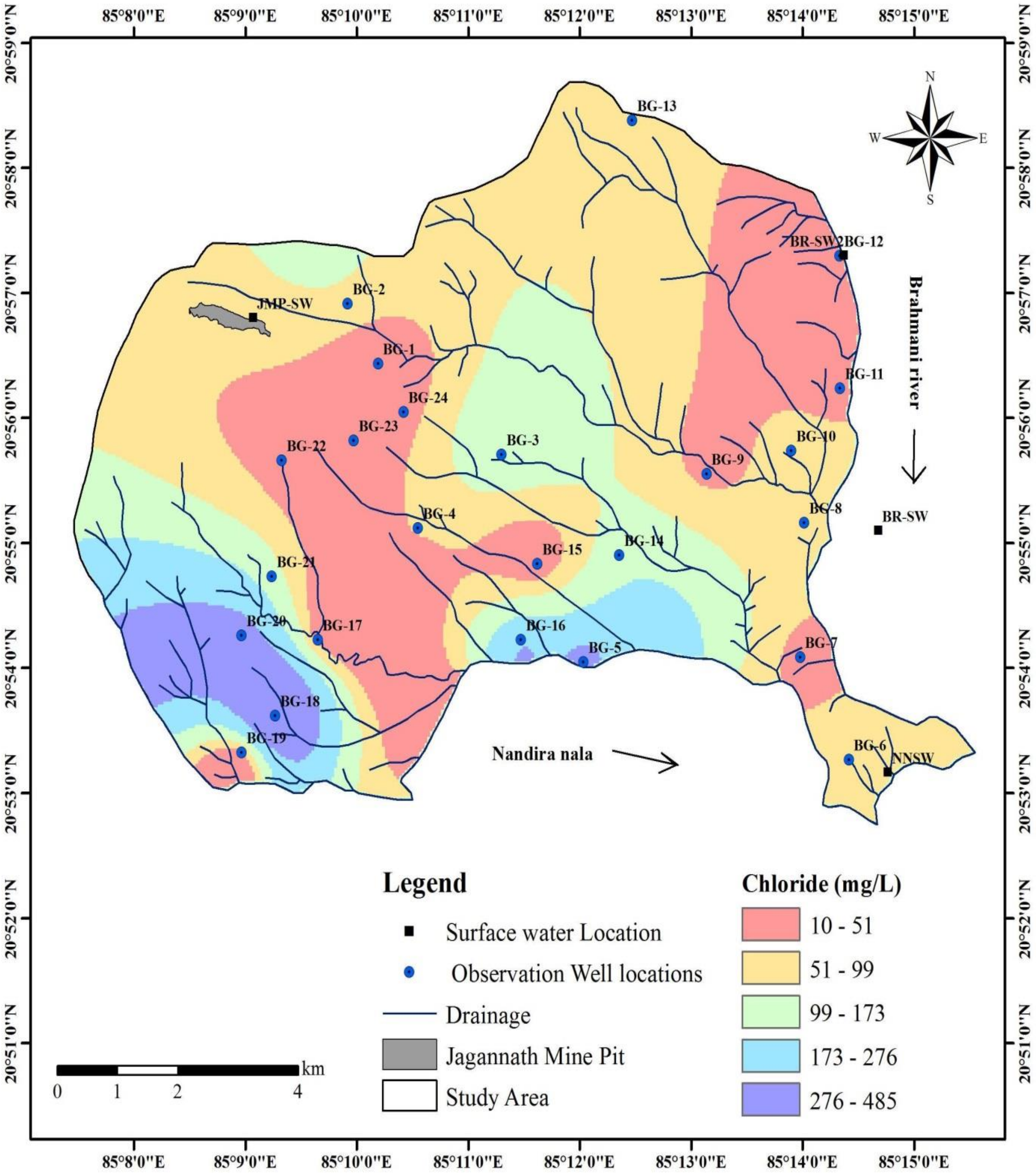


Figure 4.2.10 Chloride concentration (mg/L) in the study area-pre monsoon 2015

Table 4.2.1 Concentration of major cations / anions in observation well network – post-monsoon (November) 2014

Sample ID	**pH**	**Turbidity (NTU)**	**EC (µs/cm)**	**TDS (mg/L)**	**T.Hard as $CaCO_3$ (mg/L)**	**Ca^{++}(mg/L)**	**Mg^{++}(mg/L)**	**Na^{+}(mg/L)**	**K^{+}(mg/L)**	**T. Alk (mg/L)**	**Cl^{-} (mg/L)**	**SO^{-2}_{4} (mg/L)**	**NO^{-}_{3}(mg/L)**	**F – (mg/L)**
Des	**6.5-8.5**	**1**	**--**	**500**	**200**	**75**	**30**	**--**	**--**	**200**	**250**	**200**	**45**	**1**
Per	**6.5-8.5**	**5**	**--**	**2000**	**600**	**200**	**100**	**--**	**--**	**600**	**1000**	**400**	**NR**	**1.5**
BG-1	6.6	116	120	76.672	40	11.2	2.9	4.4	5.7	40	10	1.02	0.14	0.65
BG-2	6	3.87	575	368	132.02	36.2	10.1	80.6	18.4	56	66	67.86	80.78	0.28
BG-3	7.1	0.26	1517	970.88	533.85	99.4	69.3	154.1	39.4	304	248	182.14	54.71	1.2
BG-4	7.1	4.88	1258	805.12	491.91	98.0	60.0	112.8	3.3	312	164	96.43	66.18	1.4
BG-5	6.7	1.69	2580	1806	1004.7	278.0	75.3	213.9	4	320	388	338.78	298.04	0.69
BG-6	7.4	1.16	1048	670.72	113.85	25.2	12.4	126.5	1.7	260	108	18.98	9.22	6.6
BG-7	7.3	14.09	652	417.28	120	24.8	9.2	92.3	1.5	264	44	8.78	0.1	1.6
BG-8	7.1	1.45	890	569.6	206.96	52.8	18.2	146.8	1.8	328	96	19.90	3.04	1.5
BG-9	7.5	2.02	1067	682.88	192	41.6	21.4	129	2.7	300	134	43.57	0.51	1
BG-10	8.1	1.24	411	263.04	28	8.0	1.9	73.3	1.3	52	64	6.84	0.55	7.9
BG-11	6.9	4.82	845	540.8	268.46	58.0	30.0	96.8	7.9	246	90	40.61	29.88	0.94
BG-12	6.3	108	234	149.76	96	20.8	10.7	12.4	10.5	88	14	2.04	0.04	0.71
BG-13	7.2	115	949	607.36	352	51.2	54.4	52.7	32	368	64	35.41	0.18	1.6
BG-14	7.3	33.8	1139	728.96	352	67.2	44.7	119.3	3.3	288	164	96.12	0.35	0.95
BG-15	7.2	20.1	711	455.04	184	38.4	21.4	90.3	2.5	328	14	29.39	0.33	1.2
BG-16	7.1	2.68	2350	1504	376.8	75.0	46.0	235.8	5	452	210	90.71	41	1.4
BG-17	7.4	0.98	862	551.68	335	71.6	37.9	101.8	1.7	332	68	87.14	18.24	1.4
BG-18	7	2.08	2150	1376	896.5	220.0	84.2	138.8	3.3	280	480	110.00	122.94	0.97
BG-19	7.4	0.5	774	495.36	220	43.2	27.2	84.3	3	276	58	33.06	2.16	1.3
BG-20	6.8	4.5	1921	1229.44	648	156.8	62.2	141.8	48.1	304	308	87.55	238.82	0.89
BG-21	7.4	0.53	1613	1032.32	312	64.0	36.9	212.1	2.8	416	156	98.37	77.25	2.8
BG-22	6.2	81.9	281	179.84	28	8.0	1.9	20	3.8	36	28	4.90	0.31	0.23
BG-23	6.2	81.8	128	81.856	60	17.6	3.9	7.9	2.6	60	8	7.45	ND	0.35
BG-24	7.2	29	698	446.72	212	46.4	23.3	76.3	7.6	304	50	45.00	ND	0.8

Table 4.2.2 Concentration of major cations / anions in observation well network – pre-monsoon (May) 2015

Sample ID	pH	Turbidity (NTU)	EC (µs/cm)	TDS (mg/L)	T.Hard as $CaCO_3$ (mg/L)	Ca^{++}(mg/L)	Mg^{++}(mg/L)	Na^{+}(mg/L)	K^{+}(mg/L)	T. Alk (mg/L)	Cl^{-} (mg/L)	SO^{-2}_{4} (mg/L)	NO^{-}_{3}(mg/L)	F – (mg/L)
Des	**6.5**	**1**	**--**	**500**	**200**	**75**	**30**	**--**	**--**	**200**	**250**	**200**	**45**	**1**
Per	**8.5**	**5**	**--**	**2000**	**600**	**200**	**100**	**--**	**--**	**600**	**1000**	**400**	**NR**	**1.5**
BG-1	6.6	1.57	106	64	60	24	36	20	5.2	40	14	9	7	0.17
BG-2	7.13	12.4	860	516	280	196	84	90	14	132	86	95	124	0.14
BG-3	7.7	0.06	1208	725	432	48	384	102	15	300	152	111	35	0.95
BG-4	7.8	0.23	890	534	404	208	196	60	3	280	56	122	8.1	1.2
BG-5	7.4	0.17	1640	984	616	240	376	125	25	284	328	75	139.2	0.36
BG-6	7.9	0.01	1119	671	244	112	132	130	26	360	80	69	5.4	4.9
BG-7	7.8	6.92	599	359	128	44	84	95	2	240	38	24	0.3	1
BG-8	7.7	0.1	839	503	328	80	248	70	0.3	288	68	40	4	0.89
BG-9	7.8	0	780	468	196	84	112	88	2.2	340	42	27	0.3	0.94
BG-10	8.3	0.21	419	251	28	20	8	94	0.1	72	68	13	1.5	7
BG-11	7.7	0	557	334	148	32	116	76	7	200	28	19	12.2	0.56
BG-12	6.8	74.2	257	154	123	51	72	29.1	6.2	96	22	15	1.5	0.35
BG-13	7.2	41.5	929	557	400	104	296	83	1	388	56	61	5	1.1
BG-14	7.7	4.89	1109	665	300	100	200	138.5	27	300	136	130	2	0.61
BG-15	7.8	2.34	695	417	132	92	40	94	3	332	16	29	1	0.79
BG-16	7.6	0.41	1715	1029	364	116	248	222	25	416	262	101	38.2	0.87
BG-17	7.8	1.35	711	427	264	68	196	75	1.3	200	28	130	1.5	0.84
BG-18	7.4	0.44	1934	1160	904	188	716	102	2.4	256	482	103	110	0.51
BG-19	8.2	0	805	483	144	44	100	101	7	280	48	68	3	0.79
BG-20	7.3	0.14	1852	1111	460	260	200	265	10	380	332	109	153	0.51
BG-21	8.1	0	1402	841	288	64	224	180	20	356	128	127	54.4	2.2
BG-22	7.1	4.51	342	205	140	88	52	33	8	144	32	23	1	0.096
BG-23	Sample could not be collected due to malfunctioning of the hand pump													
BG-24	7.2	7.66	312	191	104	84	20	40	6	84	26	51	0.5	0.18

Table 4.2.3 Range and Average of key parameters of observation wells in the study area

S.No	Parameters (mg/L)	BIS Limit	Post Monsoon 2014			Pre Monsoon 2015		
			Range (mg/L)	Average	Samples*	Range (mg/L)	Average	Samples*
1.	Total Dissolved Solid (TDS)	2000	76.67 mg/L (BG-1) to 1806 mg/L (BG-5)	667.05	0	64 mg/L (BG-1) to 1160 mg/L (BG-18)	554.92	0
2.	Chloride (Cl-)	1000	8 mg/L (BG-23) to 480 mg/L (BG-18)	135	0	14 mg/L (BG-1) – 482 mg/L (BG-18)	120.96	0
3.	Sulphate (SO4-)	400	1.02 mg/L (BG-1) to 338.78 mg/L (BG-5)	72.76	0	9 mg/L (BG-1) – 130 mg/L (BG-14)	67.6	0
4.	Fluoride (F-)	1.5	0.23 mg/L (BG-22) to 7.9 mg/L (BG-10)	1.78	4	0.096 mg/L (BG-22) – 7 mg/L (BG-10)	1.36	3
5.	Nitrate (NO3-)	45	0.0 mg/L (BG-23 & BG-24) – 298.04 mg/L (BG-5)	51.64	7	0.3 mg/L (BG-7) – 153 mg/L (BG-20)	34.45	5

*Number of samples above BIS limits

4.3 Groundwater quality (Trace Elements)

The concentration of iron in the study period i.e., post-monsoon (2014) varied from 0.13 mg/L (BG-10) to 46.19 mg/L (BG-22) during pre-monsoon (2015) it varied from 0.46 mg/L (BG-19) to 79.3 (BG-22). It was observed that most of the samples have higher concentration of iron i.e. beyond the permissible limits as per BIS (10500:1991) standard (Tables 4.3.1 & 4.3.2).

Arsenic was within the permissible limits of BIS for all the samples in both the seasons. The concentration of other heavy metals (Tables 4.3.1 & 4.3.2) such as Cd, Ni, Co, Cr and Cu were also within the permissible limit as per BIS standard (1991:10500) except for Al, Mn. The concentration of all other heavy metals was within the limits of BIS limits except for Al, B, Mn, and Ni. Samples (4 nos) namely CP1, CP2 , CP3, CP4 were considered to serve as control samples and were analysed for trace elements (Table 4.3.3) and it is observed that trace elements of concern like As, Pb, Hg were either not detected or were below the detection limit. ***It need to be mentioned that Pb and Hg were not detected in both May 2015 and June 2016.*** It was observed that poor O & M has led to rusting in the pipes in most of the hand pumps (Figure 4.3.1) which may be partially responsible for the high iron concentration in the identified sources.

Table 4.3.1 Concentration of trace elements in observation wells, post-monsoon (November) 2014

Sample ID	Al	As	B	Cd	Co	Cr	Cu	Fe	Mn	Ni	Zn
Des	**0.03**	**0.01**	**0.5**	**0.01**	**0.04**	**0.05**	**0.05**	**0.3**	**0.1**	**0.02**	**5.0**
Per	**0.2**	**NR**	**1**	**NR**	**NR**	**NR**	**1.5**	**1**	**0.3**	**NR**	**15.0**
BG-1	0.030	0.010	0.030	BDL	0.005	0.007	0.006	19.85	0.510	0.003	0.200
BG-2	0.011	0.01	0.018	BDL	BDL	0.006	0.014	2.31	0.030	0.005	8.576
BG-3	0.060	0.006	0.051	BDL	BDL	0.003	0.008	0.45	0.060	BDL	0.324
BG-4	0.132	0.007	0.018	BDL	BDL	0.002	0.007	0.49	0.050	BDL	1.463
BG-5	0.011	0.006	0.030	BDL	BDL	0.003	0.006	0.49	0.360	BDL	0.843
BG-6	0.343	0.006	0.012	BDL	BDL	0.002	0.004	1.55	0.060	BDL	0.490
BG-7	0.049	BDL	0.010	BDL	BDL	0.007	0.008	4.00	0.060	BDL	2.081
BG-8	0.032	0.004	0.035	BDL	BDL	0.006	0.006	0.89	0.010	BDL	1.222
BG-9	0.111	0.006	0.167	BDL	BDL	0.002	0.003	0.42	0.070	BDL	1.566
BG-10	0.045	0.002	0.121	BDL	BDL	BDL	0.002	0.13	0.003	BDL	0.057
BG-11	0.037	0.001	0.043	BDL	BDL	0.006	0.007	2.37	0.129	BDL	0.635
BG-12	0.049	BDL	0.096	BDL	0.002	0.051	0.060	44.05	0.474	0.016	3.051
BG-13	0.014	BDL	0.083	BDL	0.002	0.013	0.018	8.19	0.108	0.003	5.213
BG-14	0.061	0.008	0.088	BDL	BDL	0.023	0.044	12.00	0.142	0.008	1.448
BG-15	0.029	0.009	0.084	BDL	BDL	0.011	0.003	15.55	0.107	0.002	4.342
BG-16	0.069	0.003	0.124	BDL	BDL	0.015	0.016	1.61	0.054	BDL	0.915
BG-17	0.009	0.008	0.036	BDL	BDL	0.002	0.002	0.92	0.104	BDL	0.223
BG-18	0.011	0.001	0.024	BDL	BDL	0.002	0.010	3.38	0.077	BDL	0.154
BG-19	0.041	0.004	0.054	BDL	BDL	0.004	0.002	0.29	0.021	BDL	1.240
BG-20	0.081	0.003	0.119	BDL	BDL	0.007	0.006	1.16	0.018	BDL	0.079
BG-21	0.178	0.003	0.024	BDL	BDL	0.002	0.002	0.57	0.089	BDL	0.444
BG-22	0.086	BDL	0.075	BDL	BDL	0.003	0.002	46.19	0.461	BDL	0.751
BG-23	0.043	BDL	0.057	BDL	0.004	0.006	0.008	31.21	0.345	0.003	2.185
BG-24	0.023	0.001	0.146	BDL	BDL	0.004	0.003	4.09	0.087	BDL	1.799

*All units in mg/L

Table 4.3.2 Concentration of trace elements in observation wells, pre-monsoon (May) 2015

Sample ID	Al	As	B	Cd	Co	Cr	Cu	Fe	Mn	Ni	Zn	Pb	Hg
Des	**0.03**	**0.01**	**0.5**	**0.01**	**0.04**	**0.05**	**0.05**	**0.3**	**0.1**	**0.02**	**5.0**		**0.001**
Per	**0.2**	**NR**	**1**	**NR**	**NR**	**NR**	**1.5**	**1**	**0.3**	**NR**	**15.0**		
BG-1	0.20	0.004	0.13	0.0003	0.022	0.036	0.039	42.31	0.408	0.0708	1.59	BDL	BDL
BG-2	0.025	0.0009	2.88	0.0003	0.0012	0.007	0.085	35.44	0.172	0.0313	7.15	BDL	BDL
BG-3	0.052	0.001	0.48	0.00005	0.0002	0.0015	0.003	3.031	0.056	0.004	0.30	BDL	BDL
BG-4	0.148	0.0007	0.22	0.001	0.0002	0.001	0.005	1.55	0.021	0.003	1.078	BDL	BDL
BG-5	0.015	0.004	0.27	0.0001	0.0006	0.0009	0.003	1.15	0.226	0.008	0.176	BDL	BDL
BG-6	0.034	0.001	0.16	0.00009	0.0002	0.0234	0.009	0.82	0.062	0.002	0.17	BDL	BDL
BG-7	0.062	0.0009	0.085	0.0001	0.0002	0.044	0.11	5.55	0.055	0.0019	0.745	BDL	BDL
BG-8	0.467	0.0006	0.25	0.0003	0.0003	0.004	0.007	2.75	0.0149	0.004	1.262	BDL	BDL
BG-9	0.228	0.0015	3.85	0.0001	0.0002	0.0024	0.022	3.76	0.045	0.002	0.86	BDL	BDL
BG-10	0.07	0.0007	1.30	0.0001	0.00005	0.0178	0.008	0.61	0.004	0.001	0.1108	BDL	BDL
BG-11	0.015	0.0005	1.45	0.00007	0.0005	0.0013	0.006	1.97	0.11	0.0033	0.579	BDL	BDL
BG-12	0.007	0.0012	0.34	0.0001	0.001	0.017	0.028	63.87	0.363	0.008	3.468	BDL	BDL
BG-13	0.04	0.0009	0.55	0.0001	0.0018	0.007	0.0212	28.22	0.122	0.007	6.0576	BDL	BDL
BG-14	0.047	0.003	0.67	0.0001	0.0007	0.012	0.044	19.08	0.311	0.007	1.565	BDL	BDL
BG-15	0.017	0.0019	0.57	0.0001	0.0002	0.003	0.0201	15.59	0.0658	0.002	0.981	BDL	BDL
BG-16	0.0407	0.0022	1.14	0.00007	0.0002	0.002	0.0424	2.98	0.024	0.0036	0.6004	BDL	BDL
BG-17	0.007	0.0007	0.52	0.00014	0.0001	0.0006	0.002	1.01	0.042	0.003	0.245	BDL	BDL
BG-18	0.225	0.005	0.26	0.00006	0.0006	0.0017	0.007	2.43	0.073	0.008	0.26	BDL	BDL
BG-19	0.023	0.001	0.63	0.0002	0.0002	0.002	0.007	0.46	0.024	0.002	1.053	BDL	BDL
BG-20	0.323	0.007	6.64	0.0003	0.0015	0.0019	0.011	2.98	0.17	0.012	0.9	BDL	BDL
BG-21	0.012	0.0012	0.24	0.0002	0.0001	0.0018	0.0098	1.68	0.043	0.002	1.271	BDL	BDL
BG-22	0.022	0.0004	0.07	0.0001	0.0004	0.0026	0.0249	79.30	0.428	0.002	1.902	BDL	BDL
BG-23	Sample could not be collected due to malfunctioning of the hand pump												
BG-24	0.087	0.0005	0.63	0.0019	0.0008	0.0139	0.204	76.68	0.388	0.004	21.305	BDL	BDL

Table 4.3.3 Concentration of trace elements in targeted samples (June 2016)

Sample ID	Al	As	B	Cd	Co	Cr	Cu	Fe	Mn	Ni	Zn	Pb	Hg
Des	**0.03**	**0.01**	**0.5**	**0.01**	**0.04**	**0.05**	**0.05**	**0.3**	**0.1**	**0.02**	**5.0**		**0.001**
Per	**0.2**	**NR**	**1**	**NR**	**NR**	**NR**	**1.5**	**1**	**0.3**	**NR**	**15.0**		
CP-1	0.20	0.004	0.13	0.0003	0.022	0.036	0.039	42.31	0.408	0.0708	1.59	BDL	BDL
CP-2	0.025	0.0009	2.88	0.0003	0.0012	0.007	0.085	35.44	0.172	0.0313	7.15	BDL	BDL
CP3-3	0.052	0.001	0.48	0.00005	0.0002	0.0015	0.003	3.031	0.056	0.004	0.30	BDL	BDL
CP-4	0.148	0.0007	0.22	0.001	0.0002	0.001	0.005	1.55	0.021	0.003	1.078	BDL	BDL
BG-1	0.136	ND	0.052	ND	0.001	0.010	0.010	42.989	0.653	BDL	0.354	BDL	BDL
BG-2	0.076	ND	0.051	ND	0.001	0.016	0.041	18.497	0.350	0.009	1.949	BDL	BDL
BG-3	0.032	ND	0.045	ND	ND	BDL	0.010	2.959	0.036	BDL	0.504	ND	BDL
BG-4	0.136	ND	0.013	ND	ND	ND	0.002	0.201	0.014	ND	0.612	ND	BDL
BG-9	0.071	ND	0.156	ND	ND	ND	0.002	ND	0.048	ND	0.861	ND	BDL
BG-15	0.016	ND	0.063	ND	ND	ND	ND	5.803	0.102	ND	0.640	ND	BDL
BG-17	0.019	ND	0.035	ND	ND	ND	ND	1.207	0.059	ND	0.316	ND	BDL
BG-21	BDL	ND	0.006	ND	ND	ND	ND	ND	0.078	ND	0.570	ND	BDL
BG-22	0.016	ND	0.036	0.001	ND	ND	0.017	59.384	0.459	BDL	0.666	BDL	BDL
BG-24	0.106	ND	0.115	ND	ND	BDL	0.004	12.567	0.247	BDL	5.512	0.010	BDL

Figure 4.3.1 Rusting of iron pipes (indicated by red arrow) in the observation wells

4.4 Surface water samples

The surface water samples have been collected from Nandira Nala and Brahmani river and analysed for major cations, anions and trace elements in post monsoon 2014 and pre monsoon 2015 seasons. The results of the parameters (Tables 4.4.1 & 4.4.2) are as follows:

pH: pH was found to be within the BIS limits of drinking water i.e., 6.5 to 8.5 during both the seasons.

TDS: TDS was found to be within the range of 71.616 mg/L to 282.88 during post monsoon season and in the range of 66 mg/L to 332 mg/L during pre-monsoon season.

All the other parameters were within the permissible limits of BIS standards except for fluoride which was high for NNSW sample (Nandira Nala) as 1.9 mg/L in post monsoon season and 3 mg/L during pre-monsoon season. It need to be mentioned that a stream connected to the South Balanda Mine joins the Nandira Nala and since the Mine Pit water has fluoride concentration, fluoride is also observed in the Nandira Nala. The lesser concentration in post-monsoon may be attributed to dilution.

Table 4.4.1 Physico-chemical parameters of the surface water samples-post monsoon 2014

Sample ID	**pH**	**Turbidity (NTU)**	**EC (µs/cm)**	**TDS (mg/L)**	**T.Hard as $CaCO_3$ (mg/L)**	**Ca^{++}(mg/L)**	**Mg^{++}(mg/L)**	**Na^{+}(mg/L)**	**K^{+}(mg/L)**	**T. Alk (mg/L)**	**Cl^{-} (mg/L)**	**SO^{-2}_{4} (mg/L)**	**NO^{-}_{3}(mg/L)**	**F - (mg/L)**
Des	**6.5-8.5**	**1**	**--**	**500**	**200**	**75**	**30**	**--**	**--**	**200**	**250**	**200**	**45**	**1**
Per	**6.5-8.5**	**5**	**--**	**2000**	**600**	**200**	**100**	**--**	**--**	**600**	**1000**	**400**	**NR**	**1.5**
NNSW	7.8	3.75	442	282.88	170.78	41.2	16.5	23	2	46	46	62.76	6.57	1.9
BR-SW	8.5	5.26	149	95.168	56	14.4	4.9	5.1	1.3	10	12	6.53	0.88	0.26
BR-SW2	7.9	7.99	112	71.616	63.98	14.4	6.8	4.7	1.2	18	10	10.82	0.53	0.21

Table 4.4.2 Physico-chemical parameters of the surface water samples-pre monsoon 2015

Sample ID	**pH**	**Turbidity (NTU)**	**EC (µs/cm)**	**TDS (mg/L)**	**T.Hard as $CaCO_3$ (mg/L)**	**Ca^{++}(mg/L)**	**Mg^{++}(mg/L)**	**Na^{+}(mg/L)**	**K^{+}(mg/L)**	**T. Alk (mg/L)**	**Cl^{-} (mg/L)**	**SO^{-2}_{4} (mg/L)**	**NO^{-}_{3}(mg/L)**	**F - (mg/L)**
Des	**6.5**	**1**	**--**	**500**	**200**	**75**	**30**	**--**	**--**	**200**	**250**	**200**	**45**	**1**
Per	**8.5**	**5**	**--**	**2000**	**600**	**200**	**100**	**--**	**--**	**600**	**1000**	**400**	**NR**	**1.5**
NNSW	7.9	0.15	553	332	168	96	72	50	7	108	32	90	3.4	3
BR-SW	7.6	0.66	148	89	84	68	16	6	2.3	60	12	17	1.5	0.22
BR-SW2	7.3	0.71	109	66	60	28	32	6.3	2.3	44	14	19	0.5	0.16

Heavy Metals:

It was found that all the heavy metals were within the permissible limits of BIS standards (Tables 4.4.3 & 4.4.4).

Table 4.4.3 **Concentration of trace elements in surface water samples, post-monsoon (November) 2014**

Sample ID	Al	As	B	Cd	Co	Cr	Cu	Fe	Mn	Ni	Zn
Des	**0.03**	**0.01**	**0.5**	**0.01**	**0.04**	**0.05**	**0.05**	**0.3**	**0.1**	**0.02**	**5.0**
Per	**0.2**	**NR**	**1**	**NR**	**NR**	**NR**	**1.5**	**1**	**0.3**	**NR**	**15.0**
NN-SW	0.226	0.003	0.130	BDL	BDL	0.002	0.003	0.17	0.061	BDL	0.193
BR-SW	0.215	0.003	0.014	BDL	BDL	0.004	0.002	0.50	0.012	BDL	0.008
BR-SW2	0.144	BDL	0.013	BDL	BDL	0.018	0.001	0.28	0.015	BDL	0.015

Table 4.4.4 **Concentration of trace elements of surface water samples, pre-monsoon (May) 2015**

Sample ID	Al	As	B	Cd	Co	Cr	Cu	Fe	Mn	Ni	Zn
Des	**0.03**	**0.01**	**0.5**	**0.01**	**0.04**	**0.05**	**0.05**	**0.3**	**0.1**	**0.02**	**5.0**
Per	**0.2**	**NR**	**1**	**NR**	**NR**	**NR**	**1.5**	**1**	**0.3**	**NR**	**15.0**
NN-SW	0.13	0.0046	2.7423	0.0003	0.0003	0.0012	0.0027	0.5997	0.028	0.0026	0.1685
BR-SW	0.17	0.0003	0.1248	0.0001	0.0008	0.002	0.0021	0.9667	0.0548	0.0022	0.1987
BR-SW2	0.19	0.0006	0.0966	0.0001	0.0003	0.0079	0.0011	0.3578	0.0361	0.0011	0.1011

4.5 Depth sampling of the hand pumps

The groundwater samples were collected at various depths at 3 wells locations namely BG-1, BG-2, BG-24 during pre-monsoon 2015. The hand pumps were dismantled (Figure 4.14) and the groundwater samples were collected using the depth sampler at various depths as mentioned in the Table 4.5.1.

The groundwater quality data of the groundwater samples revealed that none of the physic-chemical parameters exceeded the BIS limits of drinking water standards. All the parameters were well within the limits of BIS. The heavy metals analysis revealed that all the heavy metals were within the BIS limits of drinking water standards except for Al, Fe, B, Mn, Ni (Table 4.5.2). It is already noted that significant rusting was observed in the wells (Figure 4.14). It is observed that for the same well, the samples collected at different depth have almost the same composition as far as physico-chemical parameters and trace elements are concerned.

Table 4.5.1 Physico-chemical parameters of the depth samples of the hand pumps

Sample ID	**Depth (in m)**	**pH**	**Turbidity (NTU)**	**EC (µs/cm)**	**TDS (mg/L)**	**T.Hard as $CaCO_3$ (mg/L)**	**Ca^{++}(mg/L)**	**Mg^{++}(mg/L)**	**Na^+(mg/L)**	**K^+(mg/L)**	**T. Alk (mg/L)**	**Cl^- (mg/L)**	**SO^{-2}_4 (mg/L)**	**NO^-_3(mg/L)**	**F - (mg/L)**
Des		**6.5-8.5**	**1**	**--**	**500**	**200**	**75**	**30**	**--**	**--**	**200**	**250**	**200**	**45**	**1**
Per		**6.5-8.5**	**5**	**--**	**2000**	**600**	**200**	**100**	**--**	**--**	**600**	**1000**	**400**	**NR**	**1.5**
BG-1	7	6.6	1.57	106	64	60	24	36	20	5.2	40	14	9	7	0.17
BG-1	17	6.7	0.34	104	62	52	40	12	16	4	40	24	9	4.5	0.19
BG-1	30	6.43	0.8	93	56	32	20	12	9.2	4	40	14	9	2.3	0.16
BG-2	30	7.13	12.4	860	516	280	196	84	90	14	132	86	95	124	0.14
BG-24	20	7.2	7.66	312	191	104	84	20	40	6	84	26	51	0.5	0.18
BG-24	30	7.1	20.3	332	199	109	45	64	54	6	120	20	32	0.4	0.29

Table 4.5.2 Concentration of trace metals of the depth groundwater samples of hand pumps

Sample ID	**Depth**	**Al**	**As**	**B**	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Zn**
Des	**(in m)**	**0.03**	**0.01**	**0.5**	**0.003**	**0.04**	**0.05**	**0.05**	**0.3**	**0.1**	**0.02**	**5.0**
Per		**0.2**	**0.05**	**1**	**NR**	**NR**	**NR**	**1.5**	**NR**	**0.3**	**NR**	**15.0**
BG-1	7	0.20	0.0046	0.138	0.0003	0.022	0.036	0.039	42.309	0.408	0.07	1.598
BG-1	17	0.0509	0.001	0.127	0.0001	0.004	0.048	0.0107	26.832	0.355	0.01	0.7625
BG-1	30	0.097	0.0019	0.297	0.0002	0.007	0.059	0.0202	34.322	0.465	0.012	0.839
BG-2	30	0.0257	0.0009	2.886	0.0003	0.001	0.007	0.085	35.444	0.172	0.031	7.153
BG-24	20	0.087	0.0005	0.631	0.0019	0.0008	0.013	0.204	76.686	0.388	0.004	21.305
BG-24	30	0.072	0.0002	0.861	0.0013	0.0005	0.007	0.14	70.431	0.154	0.003	19.144

4.6 Control samples

The control samples for groundwater sampling were taken in the buffer zone of 0.5 km, 1 km, 2 km, 5 km and 10 km around the Jagannath mine pit. The samples were mostly found within the 5 km zone.

The groundwater samples were collected at control locations namely CP-1, CP-2, CP-3, CP-4 during pre-monsoon 2015 and analysed for major cations, anions and trace elements (Tables 4.6.1 and 4.6.2)

The groundwater quality data of the control samples revealed that some of the physic-chemical parameters like pH, Turbidity, Total Hardness, Ca, Mg and sulphate exceeded the BIS limits of drinking water. All the other parameters were within the limits of BIS. The heavy metals analysis revealed that all the concentration was within the BIS limits of drinking water standards except for Fe, Mn, and Ni (Table 4.6.2).

Table 4.6.1 Physico-chemical parameters of control samples around the Jagannath Mine Pit

Sample ID	**pH**	**Turbidity (NTU)**	**EC (µs/cm)**	**TDS (mg/L)**	**T.Hard as $CaCO_3$ (mg/L)**	**Ca^{++}(mg/L)**	**Mg^{++}(mg/L)**	**Na^{+}(mg/L)**	**K^{+}(mg/L)**	**T. Alk (mg/L)**	**Cl^{-} (mg/L)**	**SO^{-2}_{4} (mg/L)**	**NO^{-}_{3}(mg/L)**	**F - (mg/L)**
Des	**6.5**	**1**	**--**	**500**	**200**	**75**	**30**	**--**	**--**	**200**	**250**	**200**	**45**	**1**
Per	**8.5**	**5**	**--**	**2000**	**600**	**200**	**100**	**--**	**--**	**600**	**1000**	**400**	**NR**	**1.5**
CP-1	7.8	1	992	595	216	104	112	101	8	180	150	84	11.2	0.51
CP-2	8.7	3.15	547	328	200	76	124	80	10.2	244	60	12	5	0.67
CP-3	4.8	6.9	1927	1156	888	580	308	16	3.3	16	42	777	2.4	0.31
CP-4	8.1	0.145	343	206	168	108	60	33	2	128	26	26	17.3	0.45

Table 4.6.2 Concentration of trace metals of the control samples of the Jagannath Mine Pit

Sample ID	**Al**	**As**	**B**	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Zn**	**Hg**
Des	**0.03**	**0.01**	**0.5**	**0.003**	**0.04**	**0.05**	**0.05**	**0.3**	**0.1**	**0.02**	**5.0**	
Per	**0.2**	**0.05**	**1**	**NR**	**NR**	**NR**	**1.5**	**NR**	**0.3**	**NR**	**15.0**	
DL												
CP-1	0.112	0.003	0.451	0.0001	0.001	0.0019	0.003	0.666	0.253	0.007	0.044	BDL
CP-2	0.013	0.001	0.484	0.00004	0.0004	0.0021	0.0016	6.222	0.089	0.002	BDL	BDL
CP-3	0.148	0.0002	0.234	0.0001	0.0056	0.0018	0.063	58.587	0.591	0.038	0.201	BDL
CP-4	0.082	0.0005	0.44	0.0001	0.0003	0.001	0.0006	0.28	0.044	0.003	0.069	BDL

4.7 Mine Pit water analysis

The mine pit water samples have been collected at various locations and at various depths of the mine pit and analyzed in the laboratory for major physico-chemical parameters and heavy metals in the pre-monsoon season (Tables 4.7.1, 4.7.2). Samples were also collected in the months of January, April and June 2016 to examine the trend of the concentration of heavy metal (Tables 4.7.3, 4.7.4 & 4.7.5). The major cations, anions and trace elements were also analyzed and compared with the Bureau of Indian Standards (BIS 10500:1991).

pH: The pH of the samples were found in between 6.2 (JMP-E1) to 8.2 (JMP-E2). pH is found to be within acceptable range of 6.5 to 8.5 as per BIS standards for all the samples during pre-monsoon.

TDS (Total Dissolved Solids): TDS results show that it varies in the range 711 mg/L (JMP-D1) to 915 mg/L (JMP-B1) during pre-monsoon (Table 4.7.1). The TDS values ranges within the permissible limit as per BIS standard (1991:10500) for all the samples.

Chloride: Chloride varies in the range of 18 mg/L (JMP-D1) to 192 mg/L (JMP-G2) during pre-monsoon season (Table 4.7.1). It was observed that the chloride concentration in all the samples was within the permissible limit of BIS standard (1991:10500).

Sulphate: Sulphate concentration varies in the range 381 mg/L (JMP-G2) to 731 mg/L (JMP-B1). The sulphate concentration in all the samples was above the permissible limit of BIS standard (1991:10500) except for JMP-G2.

Nitrate: Nitrate concentration varies in the range 2.3 mg/L (JMP-G1) to 8.2 mg/L (JMP-D2) (Table 4.7.1). The nitrate concentration was found to be within the permissible limits of BIS standards.

Fluoride: The Fluoride concentration varies in the range 7.8 mg/L (JMP-A1) to 8.7 mg/L (JMP-C2) (Table 4.7.1). The fluoride concentration in all the samples exceeded the BIS limits.

Table 4.7.1 Concentration of physico-chemical parameters of mine pit water, pre-monsoon (May) 2015

Sample ID	Depth (in m)	pH	Turbidity (NTU)	EC (µs/cm)	TDS (mg/L)	T.Hard as $CaCO_3$ (mg/L)	Ca^{++}(mg/L)	Mg^{++}(mg/L)	Na^{+}(mg/L)	K^{+}(mg/L)	T. Alk (mg/L)	Cl^{-} (mg/L)	SO^{-2}_{4} (mg/L)	NO^{-}_{3}(mg/L)	F - (mg/L)

Des		**6.5-8.5**	**1**	**--**	**500**	**200**	**75**	**30**	**--**	**--**	**200**	**250**	**200**	**45**	**1**
Per		**6.5-8.5**	**5**	**--**	**2000**	**600**	**200**	**100**	**--**	**--**	**600**	**1000**	**400**	**NR**	**1.5**
JMP-A1	0	7.1	0.6	1418	851	548	444	104	63.4	12	48	26	582	4.4	7.8
JMP-A2	6	7.1	0.45	1458	875	512	400	112	65.1	12.2	56	30	586	6.3	8.2
JMP-B1	2	7.2	0.86	1525	915	472	340	132	64.2	12	48	26	731	3.1	8
JMP-C1	0	7.1	0.41	1299	779	500	340	160	64	12	56	22	500	4	8.1
JMP-C2	6	6.9	0.14	1296	778	511	344	167	64	12	80	22	482	8	8.7
JMP-D1	0	7.1	0.64	1183	711	512	364	148	64.4	12	48	18	552	4	8.5
JMP-D2	18	7.4	0.11	1321	793	500	350	150	63	12	44	20	550	8.2	8.5
JMP-E1	0	6.2	0.87	1345	807	520	400	120	64	12	44	24	531	4	8
JMP-E2	10	8.2	0.02	1355	813	532	388	144	64	12	56	22	531	6.2	8.2
JMP-F1	3.5	8.1	0.34	1385	831	556	392	164	64	12	52	24	597	3.5	8
JMP-G1	0	7.9	0.95	1446	868	500	304	196	77	12	48	22	601	2.3	8.1
JMP-G2	15	7.8	0.28	1272	763	480	312	168	80	13	52	192	381	7	8.2
JMP-DA	-	5.7	7.67	1840	1104	992	704	288	70	24	20	22	849	39	15
JMP-DA1	-	5.6	0.5	2514	1508	1000	720	280	70.1	24	20	28	1100	35	16
JMP-DA2	-	5.7	40.8	1869	1121	872	600	272	25.3	81	20	36	848	44	17

Heavy Metals

The concentration of iron in the study period i.e., pre-monsoon (May 2015) varied from 0.252 mg/L (JMP-C1) to 6.262 mg/L (JMP-A2). All the samples except for JMP-A2, JMP-C2, JMP-D1, JMP-E2, JMP-F1, and JMP-G2 were beyond the permissible limits of BIS standards (Table 4.7.2). It is observed that As is within limit at all the sampling locations. All the other heavy metals except for Al, B, and Fe were within the permissible limits of BIS standards. Al and Fe show elevated concentration at the bottom as compared to the top surface. The points near the ash disposal have very high concentration of Al and Mn.

Table 4.7.2 Trace elements of the samples of mine pit water, pre monsoon (May) 2015

Sample ID	Depth (m)	Al	As	B	Cd	Co	Cr	Cu	Fe	Mn	Ni	Zn
Des		**0.03**	**0.01**	**0.5**	**0.003**	**0.04**	**0.05**	**0.05**	**0.3**	**0.1**	**0.02**	**5.0**
Per		**0.2**	**0.05**	**1**	**NR**	**NR**	**NR**	**1.5**	**NR**	**0.3**	**NR**	**15.0**
JMP-A1	0	0.4	0.009	21.166	0.0004	0.001	0.0049	0.0017	0.447	0.079	0.014	0.033
JMP-A2	6	0.302	0.007	6.221	0.0003	0.001	0.0017	0.0108	6.262	0.159	0.011	0.332
JMP-B1	2	0.325	0.007	21.107	0.0002	0.0009	0.0031	0.002	0.938	0.082	0.013	0.019
JMP-C1	0	0.191	0.007	6.175	0.0002	0.0007	0.0043	0.0014	0.253	0.073	0.0102	0.0195
JMP-C2	6	0.922	0.011	7.014	0.0002	0.0019	0.0082	0.0059	2.729	0.222	0.012	0.115
JMP-D1	0	0.267	0.006	6.306	0.0002	0.0007	0.002	0.0013	1.119	0.069	0.0108	0.023

JMP-D2	18	0.813	0.009	6.783	0.0002	0.002	0.001	0.0025	0.583	0.232	0.0127	0.062
JMP-E1	0	0.173	0.006	6.516	0.0002	0.0007	0.0006	0.0012	0.79	0.069	0.0108	0.012
JMP-E2	10	0.412	0.009	6.382	0.0005	0.0013	0.0012	0.0026	1.39	0.17	0.011	0.051
JMP-F1	3.5	0.225	0.005	6.028	0.0002	0.0007	0.0016	0.0013	1.157	0.073	0.0101	0.094
JMP-G1	0	0.173	0.007	6.656	0.0002	0.0008	0.0009	0.001	0.484	0.064	0.0118	0.086
JMP-G2	15	0.288	0.008	6.75	0.0002	0.0015	0.0009	0.003	1.785	0.208	0.0123	0.088
JMP-DA	-	54.395	BDL	16.42	0.058	1.215	0.041	8.927	0.918	34.307	4.598	4.816
JMP-DA1	-	59.284	BDL	16.306	0.056	1.194	0.043	8.45	1.073	34.128	4.568	4.69
JMP-DA2	-	60.275	BDL	16.43	0.058	1.211	0.062	9.669	1.906	34.353	4.582	4.76

Table 4.7.3: Heavy Metals concentration in water samples collected from the Jagannath Mine pit (Quarry No.4), Talcher, Orissa (January 2016)

Sr.No.	**Sample Code**		**Al**	**As**	**Ba**	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Hg**	**Mn**	**Ni**	**Pb**	**Zn**
BIS Limits(mg/L)		**Depth of sampling (m)**	**0.03-0.2**	**0.01-0.05**	**0.7**	**0.003**	**--**	**0.05**	**0.05-1.5**	**0.30**	**0.001**	**0.10-0.30**	**0.02**	**0.01**	**5.0-15.0**
Detection Limits (ICP-OES)			**0.01**	**0.007**	**0.0001**	**0.0006**	**0.003**	**0.0045**	**0.0004**	**0.001**	**0.001**	**0.018**	**0.005**	**0.009**	**0.001**
1	JMP-A1	0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
2	JMP-A2	5	0.41	BDL	0.23	0.003	0.007	0.006	0.008	19.30	BDL	0.40	0.01	BDL	1.79
3	JMP-B	0	0.68	0.008	0.10	BDL	BDL	BDL	0.001	0.40	BDL	0.29	0.03	BDL	0.07
4	JMP-C1	0	2.43	0.010	0.10	BDL	BDL	0.02	0.003	0.27	BDL	0.30	0.01	BDL	0.08
5	JMP-C2	5	1.01	0.009	0.10	BDL	BDL	BDL	0.002	BDL	BDL	0.32	0.01	BDL	0.03
6	JMP-D1	0	0.84	BDL	0.10	BDL	BDL	BDL	0.001	BDL	BDL	0.29	0.01	BDL	0.04
7	JMP-D2	8	0.93	0.01	0.12	BDL	BDL	BDL	0.002	BDL	BDL	0.30	0.03	BDL	0.06
8	JMP-D3	17	0.86	0.01	0.11	BDL	BDL	BDL	0.002	BDL	BDL	0.29	0.01	BDL	0.03
9	JMP-E1	0	0.98	BDL	0.11	BDL	BDL	BDL	0.003	BDL	BDL	0.32	0.01	BDL	0.05
10	JMP-E2	9	0.80	BDL	0.11	BDL	BDL	BDL	0.003	BDL	BDL	0.31	0.01	BDL	0.03
11	JMP-F1	0	0.83	BDL	0.12	BDL	BDL	BDL	0.001	BDL	BDL	0.31	0.01	BDL	0.04
12	JMP-F2	4	0.75	BDL	0.11	BDL	BDL	BDL	0.003	BDL	BDL	0.30	0.01	BDL	0.01
13	JMP-G1	0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.32	0.02	BDL	0.08
14	JMP-G2	14	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.29	0.01	BDL	0.03
15	JMP-H1	0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.30	0.01	BDL	0.04
16	JMP-H2	10	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.29	0.01	BDL	0.06
17	JMP-I1	0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.32	0.03	BDL	0.03
18	JMP-I2	12	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.31	0.01	BDL	0.05
19	JMP-J1	0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.31	0.01	BDL	0.03
20	JMP-J2	16	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.30	0.01	BDL	0.04
21	JMP-SW	0	BDL	0.008	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.32	0.01	BDL	0.01
22	JMP-DA	-	36.81	0.001	0.29	0.002	0.14	0.01	0.04	1.43	BDL	2.94	0.33	0.02	1.54

Note: BDL-Below Detection Limit,

Table 4.7.4: Heavy Metals concentration in water samples collected from the Jagannath Mine pit (Quarry No.4), Talcher ,Orissa (April, 2016)

Sr. No.	**Sample Code**		**Al**	**As**	**B**	**Ba**	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Hg**	**Mn**	**Ni**	**Pb**	**Zn**
BIS limits mg/L		**Depth of sampling (m)**	**0.03 - 0.20**	**0.01 - 0.05**	**0.5 - 1.0**	**0.70**	**0.003**	**--**	**0.05**	**0.05 - 1.50**	**0.30**	**0.001**	**0.10 - 0.30**	**0.02**	**0.01**	**5.0 - 15.0**
Detection Limits (ICP-OES)			**0.01**	**0.007**		**0.0001**	**0.0006**	**0.003**	**0.0045**	**0.0004**	**0.001**	**0.001**	**0.018**	**0.005**	**0.009**	**0.001**
1	JMP- A1	0	0.36	BDL	1.06	0.15	BDL	0.001	0.001	0.001	1.23	BDL	0.12	0.010	BDL	0.92
2	JMP- A 2	5	0.27	BDL	1.08	0.21	BDL	0.001	0.001	BDL	0.31	BDL	0.13	0.011	BDL	0.03
3	JMP- B	0	1.04	0.009	1.14	0.15	BDL	BDL	0.013	0.001	0.42	BDL	0.07	0.009	BDL	0.04
4	JMP- C1	0	0.37	0.010	1.11	0.15	BDL	BDL	0.001	BDL	0.28	BDL	0.05	0.008	BDL	0.04
5	JMP- C2	5	0.36	0.008	1.13	0.15	BDL	0.001	0.001	BDL	BDL	BDL	0.06	0.009	BDL	0.04
6	JMP- D1	0	0.33	0.009	1.14	0.16	BDL	BDL	0.001	BDL	BDL	BDL	0.05	0.009	BDL	0.03
7	JMP- D2	18	0.35	0.008	1.15	0.16	BDL	BDL	0.010	BDL	BDL	BDL	0.05	0.009	BDL	0.03
8	JMP- E1	0	0.31	BDL	1.20	0.15	BDL	BDL	0.001	BDL	BDL	BDL	0.06	0.009	BDL	0.03
9	JMP- E2	10	0.34	BDL	1.13	0.15	BDL	BDL	0.001	BDL	BDL	BDL	0.06	0.008	BDL	0.02
10	JMP- F1	0	0.34	BDL	1.11	0.14	BDL	0.001	0.001	BDL	BDL	BDL	0.10	0.010	BDL	0.03
11	JMP- F2	5	0.27	BDL	1.13	0.14	BDL	0.001	0.001	BDL	BDL	BDL	0.11	0.010	BDL	0.03
12	JMP- G1	0	0.31	BDL	1.14	0.15	BDL	0.001	0.01	BDL	BDL	BDL	0.09	0.008	BDL	0.07
13	JMP- G2	18	0.29	BDL	1.16	0.14	BDL	BDL	0.001	BDL	BDL	BDL	0.09	0.009	BDL	0.04

Sr. No.	Sample Code		Al	As	B	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
BIS limits mg/L		**Depth of sampling (m)**	**0.03 - 0.20**	**0.01 - 0.05**	**0.5 - 1.0**	**0.70**	**0.003**	**--**	**0.05**	**0.05 - 1.50**	**0.30**	**0.001**	**0.10 - 0.30**	**0.02**	**0.01**	**5.0 - 15.0**
Detection Limits (ICP-OES)			**0.01**	**0.007**		**0.0001**	**0.0006**	**0.003**	**0.0045**	**0.0004**	**0.001**	**0.001**	**0.018**	**0.005**	**0.009**	**0.001**
14	JMP- H1	0	0.38	BDL	1.21	0.15	BDL	BDL	0.001	BDL	BDL	BDL	0.06	0.008	BDL	0.04
15	JMP- H2	8	0.49	BDL	1.20	0.15	BDL	0.001	0.001	0.001	BDL	BDL	0.06	0.009	BDL	0.06
16	JMP- I1	0	0.32	BDL	1.26	0.15	BDL	BDL	0.001	BDL	BDL	BDL	0.06	0.008	BDL	0.05
17	JMP-I2	12	0.25	BDL	1.15	0.15	BDL	BDL	0.001	BDL	BDL	BDL	0.05	0.008	BDL	0.03
18	JMP-J 1	0	0.39	BDL	1.17	0.15	BDL	BDL	0.003	BDL	BDL	BDL	0.05	0.008	BDL	0.04
19	JMP- J 2	10	0.34	BDL	1.15	0.15	BDL	BDL	0.001	BDL	BDL	BDL	0.05	0.008	BDL	0.04
20	JMPSW	0	0.31	0.008	1.15	0.15	BDL	BDL	0.001	BDL	0.30	BDL	0.05	0.008	BDL	0.06

Note: BDL-Below Detection Limit, ND: Not Detected

Table 4.7.5: Heavy Metals concentration in water samples collected from the Jagannath Mine pit (Quarry No.4), Talcher, Orissa (June 2016)

Sr.No	Sample code		Al	As	B	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
BIS limit(ppm)		**Depth of sampling (m)**	**0.03-0.20**	**0.01-0.05**	**0.5-1.0**	**0.7**	**0.003**		**0.05**	**0.05-1.5**	**0.3**	**0.001**	**0.10-0.30**	**0.02**	**0.01**	**5.0-15**
Detection limit(ppm)			**0.002**	**0.007**	**-**	**0.0001**	**0.0001**	**0.003**	**0.0045**	**0.0004**	**0.001**	**0.001**	**0.0001**	**0.005**	**0.009**	**0.001**
1	**JMP-A1**	0	0.139	BDL	0.941	0.161	BDL	0.001	BDL	0.002	3.14	BDL	0.088	0.007	BDL	0.147
2	**JMP-A2**	6	0.134	BDL	1.005	0.067	BDL	BDL	BDL	BDL	1.027	BDL	0.089	0.007	BDL	0.164

Sr.No	Sample code		Al	As	B	Ba	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
BIS limit(ppm)		**Depth of sampling (m)**	**0.03-0.20**	**0.01-0.05**	**0.5-1.0**	**0.7**	**0.003**		**0.05**	**0.05-1.5**	**0.3**	**0.001**	**0.10-0.30**	**0.02**	**0.01**	**5.0-15**
Detection limit(ppm)			**0.002**	**0.007**	**-**	**0.0001**	**0.0001**	**0.003**	**0.0045**	**0.0004**	**0.001**	**0.001**	**0.0001**	**0.005**	**0.009**	**0.001**
3	**JMP-B**	0	0.107	0.009	1.017	0.069	BDL	BDL	BDL	BDL	0.476	BDL	0.072	0.006	BDL	0.173
4	**JMP-C1**	0	0.107	0.008	0.989	0.071	BDL	BDL	BDL	BDL	0.228	BDL	0.071	0.006	BDL	0.206
5	**JMP-C2**	7	0.126	0.007	1.011	0.062	BDL	BDL	BDL	BDL	BDL	BDL	0.074	0.006	BDL	0.13
6	**JMP-D1**	0	0.101	0.008	0.997	0.066	BDL	BDL	BDL	BDL	BDL	BDL	0.075	0.007	BDL	0.184
7	**JMP-D2**	17	0.15	0.008	1.03	0.084	BDL	0.001	BDL	0.002	BDL	BDL	0.076	0.007	BDL	0.154
8	**JMP-E1**	0	0.119	BDL	1.043	0.085	BDL	0.001	BDL	BDL	BDL	BDL	0.076	0.007	BDL	0.143
9	**JMP-E2**	9	0.143	BDL	1.011	0.085	0.007	0.001	BDL	BDL	BDL	BDL	0.074	0.014	BDL	0.135
10	**JMP-F1**	0	0.184	BDL	1	0.082	BDL	0.001	BDL	0.001	BDL	BDL	0.082	0.007	BDL	0.194
11	**JMP-F2**	5	0.122	BDL	1.046	0.087	BDL	0.001	BDL	0.001	BDL	BDL	0.081	0.007	BDL	0.149
12	**JMP-G1**	0	0.164	BDL	1.012	0.083	BDL	0.001	BDL	0.001	BDL	BDL	0.091	0.008	BDL	0.109
13	**JMP-G2**	19	0.211	BDL	1.019	0.085	BDL	0.001	BDL	0.001	BDL	BDL	0.094	0.008	BDL	0.196
14	**JMP-H1**	0	0.16	BDL	1.017	0.085	BDL	0.001	BDL	BDL	BDL	BDL	0.073	0.007	BDL	0.229
15	**JMP-H2**	9	0.13	BDL	1.014	0.084	BDL	0.001	BDL	BDL	BDL	BDL	0.072	0.007	BDL	0.335
16	**JMP-I1**	0	0.14	BDL	1.013	0.085	BDL	0.001	BDL	0.001	BDL	BDL	0.075	0.007	BDL	0.125
17	**JMP-I2**	14	0.156	BDL	1.015	0.084	BDL	0.001	BDL	0.001	BDL	BDL	0.082	0.007	BDL	0.159
18	**JMP-J1**	0	0.135	BDL	1.127	0.076	BDL	BDL	BDL	BDL	BDL	BDL	0.072	0.006	BDL	0.397
19	**JMP-J2**	11	0.136	BDL	1.153	0.076	BDL	BDL	BDL	BDL	BDL	BDL	0.075	0.007	BDL	0.255
20	**JMPSW**	0	0.245	0.007	1.063	0.074	BDL	BDL	BDL	0.001	BDL	BDL	0.076	0.006	BDL	0.135

Note: BDL-Below Detection Limit, ND: Not Detected

The sampling carried out in the months of January, April and June (Tables 4.73, 4.7.4, 4.7.5) indicate that Aluminium concentration has come down with respect to the concentration in May 2015. The concentration of As, Pb and Hg is also within the BIS limit and most of the samples are below BDL. The Arsenic concentration also indicates that the trend does not increase with time (Figure 4.16).

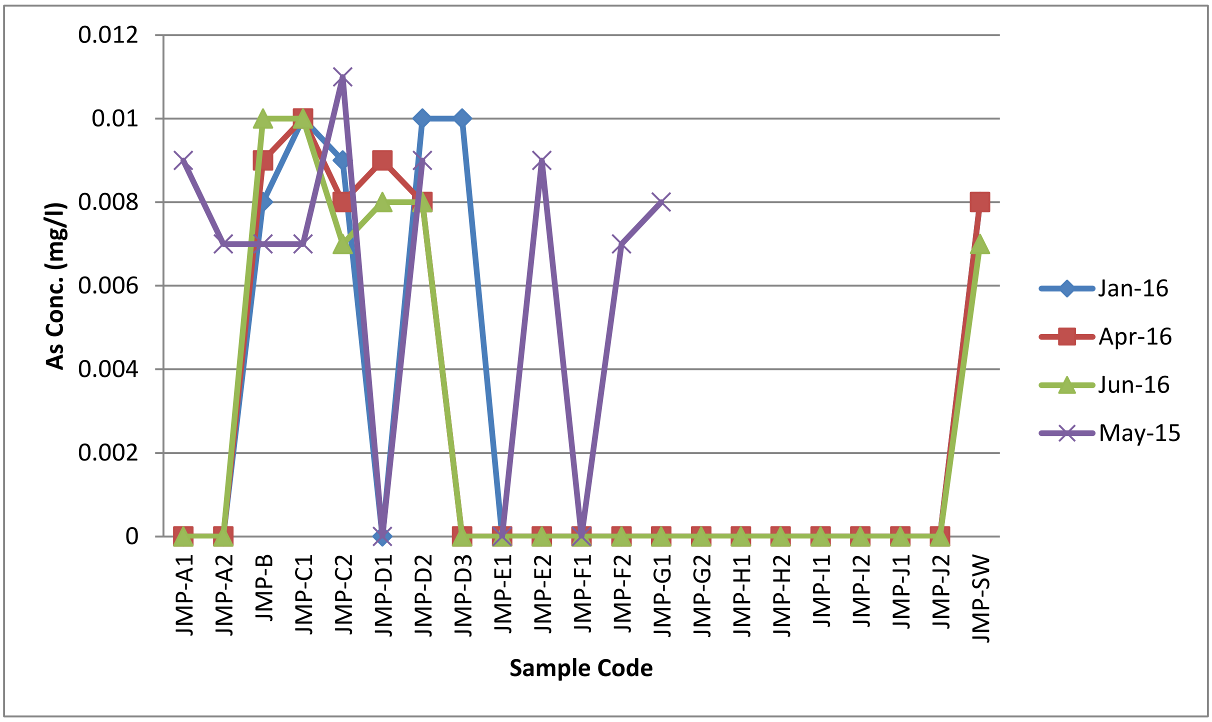


Figure 4.7.1: Trend of Arsenic concentration in the Mine Pit samples

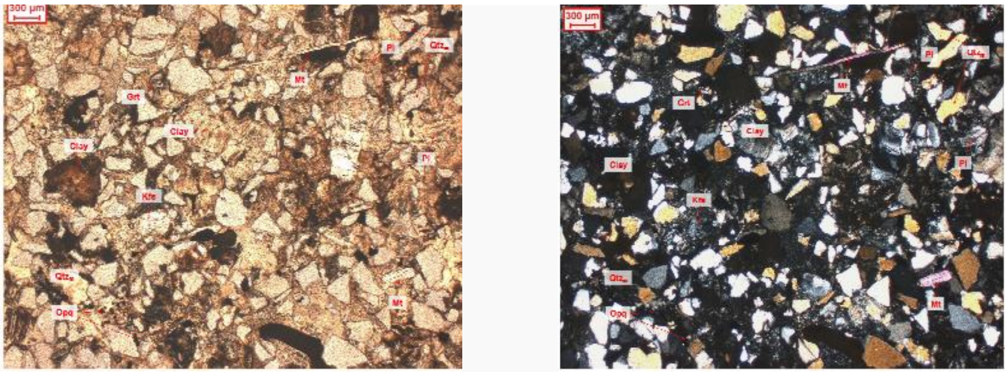
4.8 Petrographic analysis

The present study deals with the petrographic interpretation of the rocks of Gondwana Super Group of Mahanadi Coal fields around the ash disposal site (Jagannath Quarry No: 4). The Gondwanas comprise of sandstone, carbonaceous shale and coal bands with pink clay and pebbly sandstones. Gondwana rocks are overlain by recent alluvium and valley fill materials at places. It is observed that granitoids of Precambrian age appeared in South East and South West patches of the study area. In addition, the laterites occur as patches capping over the country rocks and attain a limited thickness. The Talcher formation is marked by uniformly deposited olive green sandstone, conglomerate, thinly laminated shales, siltstone, and varves with typical glacigene facies tillite mostly at the base.

The petrographic study is attempted to study the presence of any fluoride and aluminium bearing minerals in the study area. This assumes importance as few groundwater samples have elevated concentration of fluoride and aluminium. Rock samples (4 nos) have been collected along Nandira nala and Brahmini river cuttings and adjoining areas in the study area.

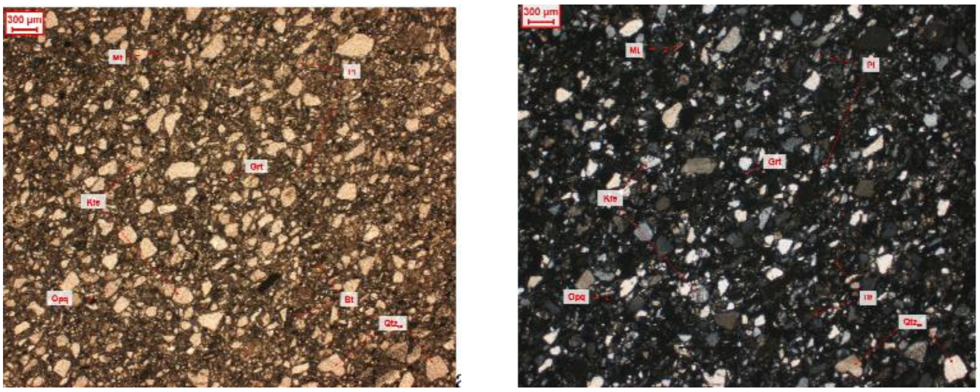
Thin sections of the above selected samples were prepared for petrographic analysis by standard techniques. The thin sections indicate that Quartz (SiO_2) is the principal component and it occurs in monocrystalline and polycrystalline forms (Photo micrographs presented in Figures 4.8.1 to 4.8.4). It has both straight to slightly undulatory extinction with angular to sub rounded grains. This is followed by feldspar, which appears in angular to sub angular forms and is mostly decomposed to clay. It occurs in the varieties of k-feldspars (microcline-$KAlSi_3O_8$, perthite) and plagioclase feldspars (albite-$NaAlSi_3O_8$) which have been evidenced by rock fragments. The clay material is pale yellow to brown and is probably kaolinite ($Al_4Si_4O_{10}OH_8$). In addition, the accessory minerals muscovite **(KAl_2 $(AlSi_3)O_{10}$ $(OHF)_2$, Biotite ($K(MgFe)_3$ Al Si_3 O_{10} $(FOH)_2$, Zircon ($ZrSiO_4$)** are also observed in the thin sections (Photo micrographs presented in Figures 4.8.1 to 4.8.4).

It is identified from the thin section study that the rock samples BR-1 and BR-4 are named as Arksoic Sandstone wherein the rock is cemented with kaolinitic / ferruginous cementing material and the rest of BR-2 and BR-3 are Subarkosic Sandstone category wherein the rock is cemented with ferruginous/kalonitic cementing material. ***As the rock samples have fluoride and aluminum bearing minerals, the elevated concentration of fluoride and aluminium is geogenic in nature.***



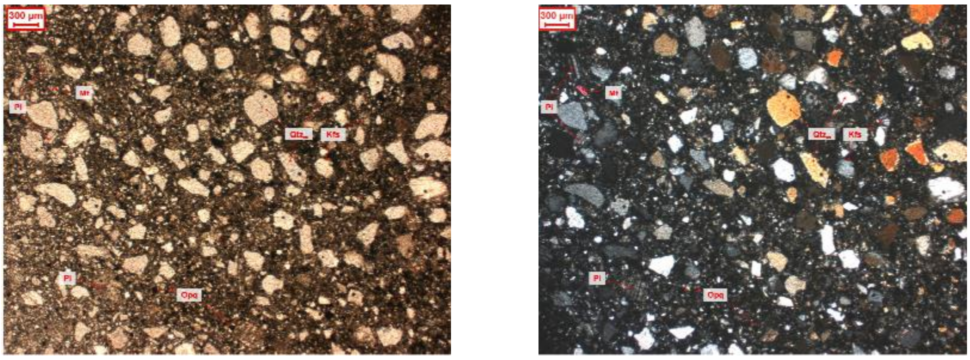
(a)PPL (BR-1) **(b) CPL (BR-1)**

Figure 4.8.1 (a) In Plane Polarised Light (PPL), monocrystalline quartz (Qtzm) stands out clear compared to feldspars which appears pitted. Grain boundaries appear stained. Muscovite (Mt) is colourless & has perfect one set of cleavage. Clay is pale yellow to brown has scale like form. Garnet (Grt) shows high relief. Opaques (Opq) are in irregular form. (b) In Cross Polarised Light (CPL), Tartan twinning in microcline (Kfs) results in a cross-hatched pattern, Plagioclase (Pl) shows albite twins. Muscovite (Mt) shows straight extinction and upper 2nd order interference colours. Garnet (Grt) is isotropic.



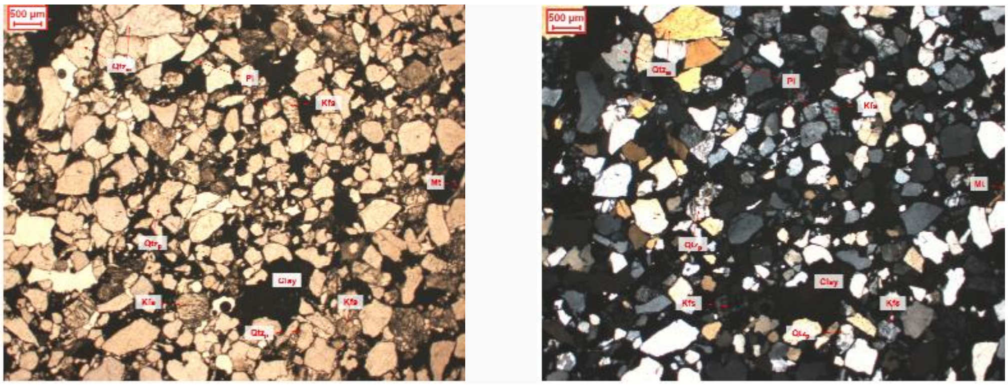
(a) PPL (BR-2) **(b) CPL (BR-2)**

Figure 4.8.2 (a) In Plane Polarised Light (PPL), monocrystalline quartz (Qtzm) stands out clear compared to feldspars which appears pitted. Grain boundaries appear stained. Muscovite (Mt) is colourless & has perfect one set of cleavage. Clay is pale yellow to brown. Garnet (Grt) shows high relief. Opaques (Opq) are in irregular form (b) In Cross Polarised Light (CPL), Tartan twinning in microcline (Kfs) results in a crosshatched pattern, Plagioclase (Pl) shows albite twins. Muscovite (Mt) is colourless & biotite (Bt) is brown and pleochroic. These shows straight extinction and upper 2nd order interference colours. Garnet (Grt) is isotropic.



(a) PPL (BR-3) **(b) CPL (BR-3)**

Figure 4.8.3 (a) In Plane Polarised Light (PPL), monocrystalline quartz (Qtzm) stands out clear compared to cloudy feldspars (Kfs & Pl). Muscovite is colourless with perfect one set of cleavage. Opaques (Opq) are irregular in form (b) In Cross Polarised Light (CPL), monocrystalline quartz (Qtzm) shows wavy extinction. K-feldspar (Kfs) includes microcline (cross hatched twins) and perhites. Plagioclase shows albite twins. Muscovite (Mt) shows straight extinction and upper 2nd order interference colour.



(a) PPL (BR-4) **(b) CPL (BR-4)**

Figure 4.8.4 (a) In Plane Polarised Light (PPL), monocrystalline quartz (Qtzm) as well as polycrystalline quartz (Qtzp) stands out clear compared to cloudy feldspars (Kfs & Pl). Clay is pale yellow to brown in colour. Muscovite is colourless with perfect one set of cleavage. Opaques (Opq) are irregular in form (b) In Cross Polarised Light (CPL), monocrystalline quartz (Qtzm) and polycrystalline quartz (Qtzp) shows wavy extinction & 1st order grey interference colour. K-feldspar (Kfs) includes microcline (cross-hatched twins) and perhites. Plagioclase shows polysynthetic albite twins. Muscovite (Mt) shows straight extinction and upper 2nd order interference colours.

4.9 Toxicity Characteristic Leaching Procedure (TCLP)

The TCLP test was conducted as per US EPA SW-846, method-1311. The trace element concentration (Table 4.9.1) indicates that the leaching is within the Regulatory level of USAEPA-RCRA-D list. Based upon this leaching studies, none of the ash samples would fail the TCLP for high As, B, Cd, Cr, and Pb, as they were all well below the regulatory level of 5 mg/L for As, Cr, Pb, 100 mg/L for B and 1 mg/L for Cd respectively. These leaching studies reveal that collected fly ash and bottom ash samples were non-hazardous in nature as per RCRA guidelines (U.S. EPA, 1986).

Table 4.9.1 TCLP Trace metal concentrations-post monsoon (November) 2014

Sample Code	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	B
RL*	**- - -**	**5**	**1**	**- - -**	**5**	**- - -**	**- - -**	**- - -**	**- - -**	**5**	**100**
AFBC- BA	12.04	0.0021	0.0024	0.002	0.0269	0.6915	0.4428	0.0839	0.0045	0.0026	0.1412
AFBC-FA	23.87	0.005	0.0063	0.007	0.0371	0.7259	0.3564	0.0917	0.0225	0.0025	0.1367
BEL- BA	0.04	0.0019	0.0095	0.0004	0.0183	0.5946	0.183	0.0553	0.0014	0.0003	0.219
BEL- FA	0.49	0.0078	0.0003	0.0012	0.0344	0.6866	0.0644	0.0368	0.0067	0.0003	0.22
BFPP1- BA	0.2	0.005	0.0022	0.0008	0.0306	1.0954	0.288	0.0814	0.0035	0.0015	0.0531

BFPP1- FA	7.83	0.0108	0.0018	0.0032	0.03	1.1356	0.1138	0.0571	0.0148	0.0108	0.0783
BFPP2- BA	19.36	0.0045	0.0006	0.0048	0.032	1.0349	0.3157	0.0718	0.0141	0.0045	0.2187
BFPP2- FA	12.4	0.0028	0.0036	0.0041	0.0264	0.324	0.1354	0.0684	0.0123	0.0018	0.2343

***RL: Regulatory level by USEPA-RCRA-D List (mg/L)**

AFBC, BFPP1, BFPP2 are the ash generation units of BSL and BEL is the ash generation units of Bhushan Energy Limited.

4.10 Chemical characterization of the ash samples

The chemical characterization of the fly ash and bottom ash samples were analyzed at IBM (Indian Bureau of Mines), Nagpur. The ash characterization results indicate that the fly ash and bottom ash samples comes under the class F with the percentage of SiO_2 (63.29% - 53.68%) followed by Al_2O_3 (20.71% - 29.6%), Fe_2O_3 (4.04% - 11.57%), TiO_2 (0.8% - 1.54%) respectively (Tables 4.10.1 & 4.10.2). As per the results, the major constituents in the pond ash are Si, Al, Fe and Ti as prominent elements in the form of oxides, silicates and alumino-silicates.

Table 4.10.1 Chemical composition of fly ash and bottom ash samples

Sample Code	Na_2O	MgO	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	K_2O	P_2O_5	SO_3	Cr_2O_3	MnO_2
	(%)											
AFBC - BA	0.21	0.6	53.68	23.84	9.28	1.08	1.08	0.95	0.36	0.68	0.02	0.2
AFBC -FA	0.14	0.5	57.68	27.52	4.43	1.2	0.65	0.88	0.4	0.32	0.02	0.06
BEL-BA	0.22	0.52	63.29	26.79	4.87	1.11	0.65	1.07	0.25	0.1	0.02	0.09
BEL-FA	0.18	0.61	60.83	29.6	3.35	1.54	0.8	0.99	0.46	0.18	0.03	0.04
BFPP1 - BA	0.25	0.55	61.92	20.71	11.57	0.8	1.26	0.76	0.25	0.6	0.02	0.33
BFPP1 - FA	0.21	0.55	55.48	26.63	4.04	1.42	0.79	0.96	0.35	0.56	0.02	0.05
BFPP2 - BA	0.22	0.55	60.65	25.27	6.71	1.03	0.49	1.03	0.2	0.1	0.02	0.19
BFPP2 - FA	0.22	0.59	59.73	29.48	4.17	1.53	0.87	0.92	0.46	0.2	0.02	0.05

Table 4.10.2 Chemical composition of fly ash and bottom ash samples

Sample Code	NiO	CuO	ZnO	Rb_2O	SrO	Y_2O_3	ZrO_2	Nb_2O_5	BaO	Cl	Co_3O_4	F
	(%)											
AFBC - BA	0.01	0.01	- - -	0.004	0.005	0.002	0.02	0.002	0.02	0.02	- - -	- - -
AFBC -FA	0.007	0.01	- - -	0.004	0.007	0.003	0.03	0.003	0.02	0.03	- - -	- - -
BEL-BA	0.01	0.01	0.008	0.005	0.004	0.001	0.02	0.002	0.02	0.01	- - -	- - -
BEL-FA	0.01	0.01	- - -	0.006	0.008	0.002	0.03	0.003	0.02	0.01	0.003	- - -
BFPP1 - BA	0.008	0.006	- - -	0.002	0.004	0.002	0.01	0.001	0.02	0.01	- - -	- - -
BFPP1 - FA	0.01	0.01	- - -	0.005	0.007	0.003	0.03	0.003	0.02	0.04	0.006	- - -
BFPP2 - BA	0.006	0.008	- - -	0.004	0.004	0.001	0.02	0.002	0.02	0.01	0.007	- - -
BFPP2 - FA	0.01	0.01	0.007	0.004	0.009	0.002	0.03	0.003	0.03	0.02	0.004	0.1

4.11 Particle Size Analysis

The particle size analysis of the fly ash and bottom ash sample was analysed. The particle size range and the respective % volume (Table 4.11.1) indicates that the fly ash has particle size predominantly below 100 μm whereas 70% of the bottom ash has particle size exceeding 100 μm.

Table 4.11.1: Particle size analysis of fly ash (BFPP-FA) and bottom ash (BFPP-BA)

BFPP-2BA		BFPP-2FA	
Size (μm)	Volume in %	Size (μm)	Volume in %
0- 0.1	0	0-0.1	0
0.1 - 1	1.09	0.1-1	4.39
1-10	7.97	1-10	35.11
10-100	17.81	10-100	55.93
100-1000	73.09	100-1000	4.56

4.12 Trace elements in fly ash and bottom ash and water extraction test

It is observed that the principal constituents in the fly ash and bottom ash are Fe and Al. Concentration of Fe is observed in the range of 15111 mg/kg (BEL-FA) to 31197 mg/kg (BFPP2-BA) which is more than the other elements (Table 4.12.1). Al concentration is detected in the range of 1628 mg/kg (BFPP2-BA) to 2024 mg/kg (BFPP1-BA).

It is indicated (Table 4.12.1) that though the concentration of Fe and Al is substantial in the ash matrix, the leaching by water extraction test is very less than the total amount of ash content present in the sample after digestion.

A close analysis indicates that the leaching percentage of Fe is 0.01% - 0.05% in Water extraction from the total concentration in acid digestion. The leaching percentage of Al by water extraction in fly ash is 0.39 % - 2.9 %. However, the leaching percentage of boron (3.36% - 12.52 %) is found more than any other element in test. According to results it is observed that the leaching percentage in fly ash samples is more than the bottom ash samples. It is observed that none of the sample shows leaching characteristic for Cu and in case of Cd only two samples namely BEL-FA (0.03%) and BEL-BA (0.1%) shows minimal leaching characteristic.

On the basis of obtained result it is concluded that the leaching percentage is very less in water extraction test. The metals present in the ash are in complex form and cannot mix with water at natural conditions.

Table 4.12.1 Heavy metal concentration in total and leachable form in fly ash (in mg/kg)

Sample Code/ Element	BFPP1 -FA		BFPP1- BA		BFPP2 -FA		BFPP2- BA		BEL -FA		BEL BA	
	Total	**Leach***	**Total**	**Leach***	**Total**	**Leach***	**Total**	**Leach***	**Total**	**Leach***	**Total**	**Leach***
Al	1801	6.94	2024	18.98	1730	7.74	1628	47.18	1658	33.7	1935	22.14
Cd	0.23	ND	0.29	ND	0.26	ND	0.31	ND	0.29	0.0001	0.2	0.0002
Co	7.83	0.058	6.31	ND	9.81	0.017	5.09	ND	7.12	0.034	2.83	ND
Cu	33.9	ND	16.8	ND	46.2	ND	14.5	ND	37.7	ND	18.2	ND
Mn	283	2.53	102	0.04	259	1.5	914	0.19	174	2.27	406	0.01
Ni	23.83	0.12	13.4	0	27.28	0.04	17.27	ND	23.66	0.07	9.66	ND
Pb	13.12	ND	7.23	0.001	19.58	0.002	5.88	ND	12.64	0.001	2.68	0.001
Cr	57.57	ND	42.07	0.021	95.26	0.037	48.04	ND	53.54	ND	30.99	ND
B	54.5	1.83	10.6	0.51	56	4.56	13.2	1.34	30.1	3.59	11.9	1.49
Fe	23130	10.96	26655	4.54	20061	1.58	31197	3.79	15111	2.74	22514	4.52
Zn	295	0.16	142	0.33	189	ND	136	ND	108	0.12	93	0.23

*Total – Total heavy metal concentration after acid digestion, *Leachable- Leachable heavy metal concentration after water extraction test

4.13 Water Elution Test

A close analysis of the results (Tables 4.13.1, 4.13.2, 4.13.3 & 4.13.4) indicates that the leaching percentage of Al, As, Mn and Fe is more than the any other element. It is observed that leaching concentration of trace elements decreases with increase in time. The concentration of trace elements in first sample (24hr) is more than the concentration of every fly ash sample collected after 48 hrs. In the sample collected after 96 hrs, many samples show concentration of trace metal Below Detection Limit (BDL). The high concentration of As (0.16 & 0.1 mg/l), Al (23.28 & 10.48 mg/l) and B (12.49 & 4.91mg/l) are observed in the first (24hrs) sample collected from A (pH:2) and D (pH: 10) leaching medium respectively. Leaching concentration of fly ash mixtures at pH:2 and pH:10 is higher than the concentration leached at pH:5, pH:7 and raw water due to the dissolution of metal bearing phases. Elements namely Cr, Hg and Pb did not show any leachability with raw water and at pH 7. Elements namely As, B, Mn and Al show the concentration above permissible limit of BIS for first sample (24hr) while at last samples after 96hrs the concentration is very less or below detection limit.

On the basis of obtained results, it is concluded that the leaching concentration of trace metals from fly ash is closely associated with the initial pH of the leaching medium. The leaching percentage is very less in water elution test. The metals present in the ash are in complex form and cannot mix with water at natural conditions. Although the initial concentration of

Table 4.13.1: Water Elution Test concentration of trace metals in sample A having initial pH 2.

Sample Code	Time in Hrs	Al	As	B	Ba	Cd	CO	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Zn
BIS Limits(mg/L)	**--**	**0.03-0.2**	**0.01-0.05**	**0.5-1**	**0.7**	**0.003**	**--**	**0.05**	**0.05-1.5**	**0.3-1**	**0.001**	**0.10-0.30**	**0.02**	**0.01**	**0.01**	**5.0-15.0**
Detection Limits (ICP-OES)	**--**	**0.01**	**0.007**	**0.0015**	**0.0001**	**0.0006**	**0.003**	**0.0045**	**0.0004**	**0.001**	**0.000074**	**0.018**	**0.005**	**0.009**	**0.03**	**0.001**
A1	24 hrs	23.28	0.16	12.49	1.60	0.0012	0.076	0.019	0.190	1.19		2.20	0.17	0.06	0.07	2.110
A2	36 hrs	11.07	0.06	2.18	0.10	0.0011	0.050	0.007	0.043	0.60		2.19	0.11	0.01	BDL	1.532
A3	48 hrs	6.63	0.03	1.24	0.08	BDL	0.030	BDL	0.016	0.58		1.60	0.08	BDL	BDL	0.861
A4	72 hrs	3.23	0.02	0.95	BDL	BDL	0.013	BDL	0.006	0.26		0.45	0.03	BDL	BDL	0.270
A5	96 hrs	0.02	BDL	0.22	BDL	BDL	BDL	BDL	0.004	0.60		0.19	0.01	BDL	BDL	0.045

ND-Not Detected, BDL- Below Detection Limit

Table 4.13.2: Water Elution Test concentration of trace metals in sample B having initial pH 5

Sample Code	Time in Hrs	Al	As	B	Ba	Cd	CO	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Zn
BIS Limits(mg/L)	**--**	**0.03-0.2**	**0.01-0.05**	**0.5-1**	**0.7**	**0.003**	**--**	**0.05**	**0.05-1.5**	**0.3-1**	**0.001**	**0.10-0.30**	**0.02**	**0.01**	**0.01**	**5.0-15.0**
Detection Limits (ICP-OES)	**--**	**0.01**	**0.007**	**0.0015**	**0.0001**	**0.0006**	**0.003**	**0.0045**	**0.0004**	**0.001**	**0.000074**	**0.018**	**0.005**	**0.009**	**0.03**	**0.001**
B1	24 hrs	0.94	0.14	3.86	0.258	BDL	BDL	BDL	0.0041	0.56		0.05	0.03	BDL	BDL	0.138
B2	36 hrs	0.87	0.03	0.28	0.014	BDL	BDL	BDL	0.0021	0.19		0.03	BDL	BDL	BDL	0.054
B3	48 hrs	0.19	0.02	0.18	0.010	BDL	BDL	BDL	0.0013	0.28		BDL	BDL	BDL	BDL	0.028
B4	72 hrs	0.20	0.02	0.03	0.008	BDL	BDL	BDL	BDL	0.90		BDL	BDL	BDL	BDL	0.060
B5	96 hrs	0.10	0.01	BDL	0.005	BDL	BDL	BDL	BDL	0.28		BDL	BDL	BDL	BDL	0.015

ND-Not Detected, BDL- Below Detection Limit

Table 4.13.3: Water Elution Test concentration of trace metals in samples C having initial pH 7.

Sample Code	Time in Hrs	Al	As	B	Ba	Cd	CO	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Zn
BIS Limits(mg/L)	**--**	**0.03-0.2**	**0.01-0.05**	**0.5-1**	**0.7**	**0.003**	**--**	**0.05**	**0.05-1.5**	**0.3-1**	**0.001**	**0.10-0.30**	**0.02**	**0.01**	**0.01**	**5.0-15.0**
Detection Limits (ICP-OES)	**--**	**0.01**	**0.007**	**0.0015**	**0.0001**	**0.0006**	**0.003**	**0.0045**	**0.0004**	**0.001**	**0.000074**	**0.018**	**0.005**	**0.009**	**0.03**	**0.001**
C1	24 hrs	0.59	0.09	5.81	0.030	BDL	BDL	BDL	0.0010	0.42		0.07	BDL	BDL	BDL	0.015
C2	36 hrs	0.19	0.05	0.31	0.070	BDL	BDL	BDL	0.0027	0.32		BDL	BDL	BDL	BDL	0.020
C3	48 hrs	0.14	0.03	0.17	0.003	BDL	BDL	BDL	0.0006	0.23		BDL	BDL	BDL	BDL	0.012
C4	72 hrs	BDL	0.02	0.13	0.003	BDL	BDL	BDL	0.0007	0.12		BDL	BDL	BDL	BDL	0.008
C5	96 hrs	BDL	0.02	0.07	0.003	BDL	BDL	BDL	0.0011	0.12		0.81	BDL	BDL	BDL	0.013

ND-Not Detected, BDL- Below Detection Limit

Table 4.13.4: Water Elution Test concentration of trace metals in sample D having initial pH 10.

Sample Code	Time in Hrs	Al	As	B	Ba	Cd	CO	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Se	Zn
BIS Limits(mg/L)	**--**	**0.03-0.2**	**0.01-0.05**	**0.5-1**	**0.7**	**0.003**	**--**	**0.05**	**0.05-1.5**	**0.3-1**	**0.001**	**0.10-0.30**	**0.02**	**0.01**	**0.01**	**5.0-15.0**
Detection Limits (ICP-OES)	**--**	**0.01**	**0.007**	**0.0015**	**0.0001**	**0.0006**	**0.003**	**0.0045**	**0.0004**	**0.001**	**0.000074**	**0.018**	**0.005**	**0.009**	**0.03**	**0.001**
D1	24 hrs	10.48	0.10	4.91	0.032	BDL	BDL	BDL	0.0018	0.48		0.33	BDL	BDL	BDL	0.035
D2	36 hrs	4.95	0.05	0.22	0.006	BDL	BDL	BDL	0.0023	0.19		BDL	BDL	BDL	BDL	0.141
D3	48 hrs	1.67	0.04	0.15	0.006	BDL	BDL	BDL	0.0025	0.10		BDL	BDL	BDL	BDL	0.015
D4	72 hrs	0.37	0.04	0.11	0.006	BDL	BDL	BDL	0.0011	0.11		BDL	BDL	BDL	BDL	0.010
D5	96 hrs	BDL	0.03	0.06	0.004	BDL	BDL	BDL	0.0013	0.14		BDL	BDL	BDL	BDL	0.004

ND-Not Detected, BDL- Below Detection Limit

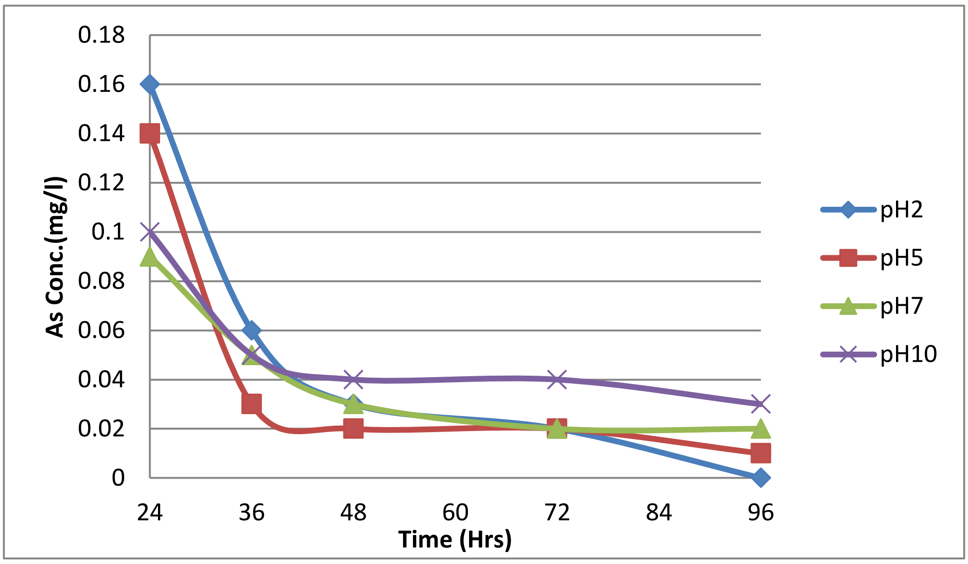


Figure.4.13.1. As concentration (mg/l) with respect to Time (Hrs)

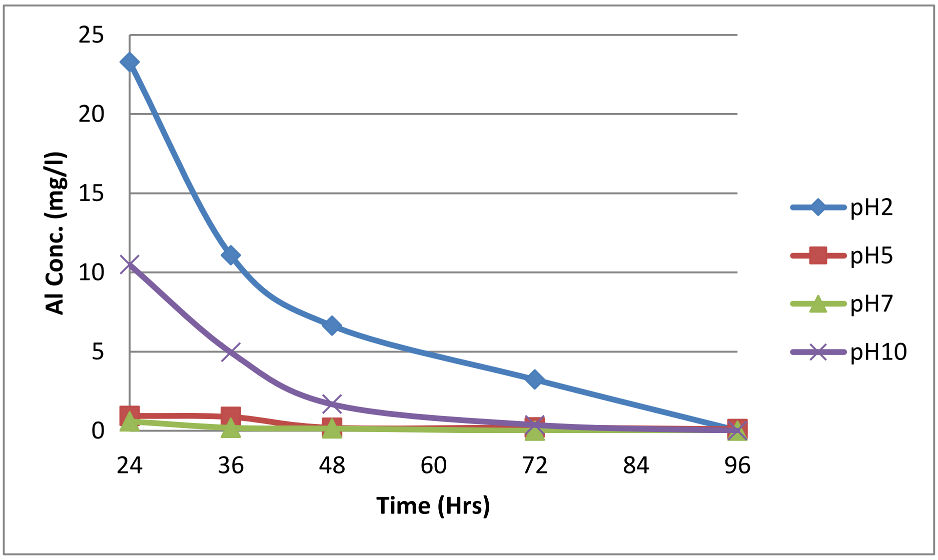


Figure.4.13.2. Al concentration (mg/l) with respect to Time (Hrs)

some of the elements is above the BIS limits, the concentration is getting decreased with respect to time and which can be diluted further (Figure 4.13.1, 4.13.2).

4.14 Radioactivity of ash samples

The radioactivity of the ash samples has been carried out for fly ash and bottom ash samples of Bhushan Steel Limited (BSL) and Bhushan Energy Limited (BEL). The results are presented in Table 4.14.1.

Table 4.14.1 Radioactivity of ash samples (Source: Certificate issued by BRIT, DAE)

Sample	U-238 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	K-40 (Bq/kg)
BEL-FA	< 7.1	56 ± 2.2	67.5 ± 4.6	48.5 ± 5.9
BEL-BA	< 7.1	29.3 ± 0.6	33.5 ± 1.2	43.1 ± 5.9
BSL-FA	111.1 ± 7.6	103.0 ± 3.2	105.8 ± 4.0	255.4 ± 25.3
BSL-BA	< 7.1	43.6 ± 1.5	50.8 ± 2.8	149.5 ± 13.9

The results of the radioactivity analysis of ash samples indicate that all the values are well below the clearance level for radionuclides of natural origin in bulk solid materials as per the AERB directive 01/2013 (Table 3) dated 26.11.2010.

4.15 Litholog Data of the drilling site

Drilling was carried out at two points upstream and downstream of the Mine pit for installation of piezometers (Figures 4.15.1 & 4.15.2). The well BW-1 (upstream of the pit) stuck water at 108 m whereas the well BW-2 (downstream of the pit) stuck water at 18 m. The water level at BW-1 monitored in July 2016 was 26m. The lithology (Table 4.15.1) at BW-1 indicates that the aquifer is very deep (confined nature) and it extends from 108 m (bgl) and continues deeper till 162 m depth or it may be further. However, in case of well-BW2, water was stuck at 18 m below the coal seam (Table 4.15.2) which indicates that the aquifer was semi confined to confined water occurred at semi confined to confined nature. The drilling indicated that in both the cases, the aquifer behaved as a single aquifer upto the depth drilled (150 m in case of BW1 and 110 m in case of BW-2).

Figure 4.15.1 Piezometer at Bore well BW-1   Figure 4.15.2 Piezometer at Bore well BW-2

Table 4.15.1 Lithology at BW-1 (upstream of the pit)

Depth Range (m)		**Log data description**
From	**To**	
1	14	Clay :dark, grey black color
14	20	Clay: yellow, very sticky.
20	22	Clay: brownish sticky.
22	24	Sand stone: dull white very fine to fine grained.
24	26	Clay: dark grey, black sticky.
26	30	Sand stone: Very fine grained, dark grey, carbonaceous matrix.
30	36	Sand stone: light grey color fine to medium grain.
36	38	Sand stone: quartzo-feldspathicc, clear transparent, dark grey, arenaceous.
38	40	Sandstone: Fine grained
40	42	Sand stone: dark grey fire to medium grained, carbonaceous
42	44	Sand stone: quartzo- feldpathic, clear transparent, dark grey, fine to coarse grained, arenaceous
44	46	Sand stone: quartzo-feldspathic, clear.
46	52	Silt stone: light gray greenish grey, dull white tending to very fine grain sand stone.
52	54	Sand stone: quartz
54	56	Sand stone: dulll white ,Quartz clear transparent very fine to coarse
56	62	Carbonaceous shale
62	64	Sand stone: clear transparent fine to pore grain, quartz.
64	66	Carbonaceous shale
66	102	Sand stone clear transparent grey fine to medium grain.
102	110	Sand stone: very fine grain light grey transparent clear. (Water stuck at 108m)
110	120	Sand stone grey dark grey clear transparent medium to large gain sub rounded.
120	138	Sand stone grey dark grey fine to medium grain. occasionally coarse grained
138	144	Sand stone grey dark grey very fine to fine grain.
144	150	Sand stone grey clear transparent medium grain surrounded well sorted.

Table 4.15.2 Lithology at BW-2 (downstream of the pit)

Depth Range (m)		**Log data description**
From	**To**	
0	16	Clay: brown in color, sticky
16	18	Coal
18	36	Sand stone: grey color very fire to very fire grained
36	42	Sand stone: quartzo-feldspathic, fine to very coarse ,angular
42	48	Boulder of quartz
48	54	Sand stone: grey brownish fire to medium grain
54	66	Sand stone: dark grey clear transparent gravel to pebbly.
66	90	Sand stone: dark grey, brownish, clear, transparent fine to very coarse, angular
90	108	Sand stone: grey clear transparent fine to medium grain occasional coarse grained

4.16 Soil Analysis

Physico-chemical characteristics of soils: Generally, the soil testing laboratories use organic carbon as an index of available N, Olsen's and Bray's method for available P and neutral normal ammonium acetate for K. In semiarid tropics, nitrate as nitrogen is also used as an index of available N in soil. The soil samples were analysed for various physicochemical parameter (Table 4.16.1) viz., pH, EC, organic carbon, fluoride, exchangeable cations (Ca^{++}, Mg^{++},Na^{+}, K^{+}), following standard procedure given in Soil Testing Manual of Ministry of Agriculture, Government of India, 2011.

Table 4.16.1 Physico-chemical characteristics of soil samples

S.No	Sample ID	pH	EC	Org.C	F	Exchangeable Cations in (meq/100gm)			
			µS/cm	%	mg/kg	Ca	Mg	Na	K
1	BS-1A	6.5	139	1.26	0.2	13.2	14.2	0.19	0.11
2	BS-1B	6.5	145	1.18	0.15	14.8	14.4	0.16	0.09
3	BS-1C	6.4	159	1.12	0.1	14.5	16.7	0.24	0.05
4	BS-1D	6.2	137	0.93	0.6	12.1	19.4	0.22	0.05
5	BS-1E	6.4	55	0.90	0.5	4.8	18.2	0.22	0.04
6	BS-2A	6.5	282	1.18	0.3	3.3	3.7	0.23	0.11
7	BS-2B	5	187	2.40	0.02	1.8	2.5	0.4	0.03
8	BS-2C	4	59	0.36	0.01	2.3	1.2	0.5	0.01
9	BS-2D	6	57.6	0.23	0.1	2.8	1.2	0.55	0.01
10	BS-2E	5.3	103	0.26	0.4	1.9	2.7	0.52	0.01
11	BS-3A	6.1	89	1.14	0.4	1.4	1.9	0.04	0.01
12	BS-3B	6.1	81	0.10	0.2	2.1	2.6	0.50	0.01
13	BS-3C	6.4	42	0.25	0.2	2	2.8	0.55	0.01
14	BS-3D	6.5	43	1.23	0.3	1.9	2.5	0.55	0.01
15	BS-3E	6.5	44	1.11	0.1	1.6	2.7	0.53	0.01

pH: The soil reaction (pH) indicates the acidity or alkalinity of a soil. Soil pH influences availability of plant nutrients, soil physical condition and plant growth. pH of the soil depends upon soil forming materials, leaching of bases, CaCO3 content, vegetation and land management. The soils of the study area are acidic in nature where pH ranges between 4.0 and 6.5. In general, the pH values indicate that the soil is good for plant growth or agriculture.

Electrical Conductivity (EC): Electrical conductivity of the soil depends upon concentration of soluble salts in soil solution. The higher the EC, the less water is available to plants, even though the soil may appear wet. Because plants can only transpire “pure” water, usable plant water in the soil solution decreases dramatically as EC increases (Bauder T.A. 2014). The electrical conductivity of the soil ranged between 39 µS/cm to 282 µS/cm. The soil EC is good for plant life.

Organic Carbon: Soil organic carbon is an indication of organic fraction of the soil which has a great influence on soil chemical properties. Soil organic matter is composed chiefly of carbon, hydrogen, oxygen, nitrogen and smaller quantities of sulphur and other elements. The organic fraction serves as a reservoir for the plant essential nutrients and increases soil water holding and cations exchange capacities (CEC), and enhances soil aggregation and structure. Soils of all the four sites are low in organic carbon content, which ranged between 0.2% and 1.2%.

Fluoride: Fluorine is widely dispersed in nature and is estimated to be the 13th most abundant element on our planet (Mason & Moore, 1982). Native F in soils is generally contained within the minerals apatite (specifically fluorapatite ($Ca_5(PO_4)3F$)), fluorite (CaF_2), cryolite (Na_3AlF_6), forms of topaz ($Al_2(SiO_4)F_2$), and within micaeous clay minerals. Fluoride in soil was found in the range of 0.1 to 0.6 mg/L. It will not have any adverse impact on plant growth.

Exchangeable Bases: Most of the soils have high concentration of Magnesium (1.2 to 19.4 meq/100g), followed by Calcium (1.4 to 14.8 meq/100g), Sodium (0.16 to 0.55 meq/100g), and Potassium (0.01 to 0.11 meq/100g) indicating dominance of cations in order of Mg^{++}, Na^{+}& Ca^{++}, K^{+}.

Heavy Metals in Soil

Soil is the unconsolidated mineral matter that has been subjected to, and influenced by genetic and environmental factors – parent material, climate, organisms and topography all acting over a period of time. Soil differs from the parent material in the morphological, physical, chemical and biological properties (Soil Testing Manual, 2011). According to USDA (United States Department of Agriculture), Mining, manufacturing, and the use of synthetic products (e.g. pesticides, paints, batteries, industrial waste, and land application of industrial or domestic sludge) can result in heavy metal contamination of urban and agricultural soils (Table 4.16.2). Heavy metals also occur naturally, but rarely at toxic levels. Furthermore, potentially contaminated soils may occur at old landfill sites (particularly those that accepted industrial wastes), old orchards that used insecticides containing arsenic as an active ingredient, fields that had past applications of waste water or municipal sludge, areas in or around mining waste piles and tailings, industrial areas where chemicals may have been dumped on the ground, or in areas downwind from industrial sites (Technical Note, 2000).

Table 4.16.2 Content of Various Elements in Soils (Lindsay, 1979)

Metal	Selected Average for Soils mg/kg	Common range for Soils mg/kg
Al	71000	10,000-3,000,000
Fe	38000	7,000-550,000
Mn	600	20-3,000
Cu	30	2-100
Cr	100	1-1,000
Cd	0.06	0.01-0.70
Zn	50	10-300
Ni	40	5-500
Pb	10	2-200

Source: Ground Water Issue, EPA/540/S-92/018 Oct 1992

The concentration of metals in soil is primarily related to the geology of the parent material from which the soil was formed. Depending on the local geology, the concentration of metals in a soil may exceed the ranges listed in Table 4.15.2. Soil samples from the study area were analyzed by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) for Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn (Table 4.16.3) Analysis data shows that all elements were within average and common range given under Table 4.15.2. It was observed that the Al and Cd ranged between 2732.5 mg/kg to 5542.5 mg/kg and 0.27 to 0.65 mg/kg respectively. However, Cadmium was found below detection limit in many samples. Chromium ranged between 0.5 mg/kg to 60.20 mg/kg, while Cobalt ranged 0.10 mg/kg to 17.99 mg/l. It was observed that Fe, Mn and Ni ranged between 2073.12 mg/kg to 33125.4 mg/kg, 1.89 mg/kg to 572.2 mg/kg and 1.4 to 49.58 mg/kg respectively. The Pb and Zn ranged between BDL to 26.5 mg/kg, 2.21 to 56.1 mg/kg respectively, whereas Cu was found in the range of 2.95 mg/kg to 54.0 mg/kg.

Table 4.16.3 Heavy metal content of soils (mg/kg) in the study area

Sample ID	Heavy Metals in mg/kg									
	Al	**Cd**	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Pb**	**Zn**
BS-1A	4,130.45	0.65	11.81	60.20	54.0	30,278.4	415.4	49.58	8.8	56.1
BS-1B	4,418.32	0.32	17.99	38.34	26.2	29,940.59	572.2	38.23	BDL	38.5
BS-1C	4,659.78	0.40	10.77	50.6	25.4	31,215.2	382.7	32.4	BDL	40.4
BS-1D	5,213.3	0.25	11.36	46.45	29.2	28,957.68	401.16	31.6	BDL	39.0
BS-1E	5,542.5	0.48	10.07	42.10	28.2	28,145.35	382.1	31.9	BDL	32.40
BS-2A	4,590.63	BDL	3.21	31.34	10.1	11,073.4	157.21	11.3	BDL	28.27
BS-2B	3,012.92	BDL	0.10	22.78	40.1	4,930.67	68.69	5.4	23.9	12.92
BS-2C	2,718.5	BDL	2.10	1.78	48.0	3,924.5	81.40	3.9	26.5	2.21
BS-2D	2,013.7	BDL	1.71	0.5	3.2	2,645.28	60.52	1.4	BDL	24.3
BS-2E	3,685.4	BDL	3.76	28.6	8.1	7,900.2	121.4	4.40	BDL	20.1
BS-3A	3,020.55	BDL	0.74	3.23	5.1	1872.5	1.89	1.95	0.12	7.6
BS-3B	3,695.97	BDL	0.89	3.5	3.4	2,391.54	7.4	4.30	BDL	14.1
BS-3C	4,012.49	BDL	0.96	4.6	2.95	3,545.44	4.3	4.14	BDL	4.1
BS-3D	3,595.96	BDL	0.67	32.28	3.0	3,178.33	10.33	5.4	BDL	11.12
BS-3E	4,008.99	BDL	0.94	5.14	3.4	3,500.37	10.1	4.37	BDL	12.43

The results were compared to regulatory limits given by U.S. EPA (1993) shows that all metals analyzed are within the regulatory limits. The prescribed limit given by U.S. EPA is depicted in Table 4.27.

Table 4.16.4 Regulatory limits on heavy metals as per US EPA (1993)

Heavy metal	Maximum concentration in sludge (mg/kg or ppm)
Cadmium	85
Chromium	3000
Copper	4300
Lead	420
Nickel	75
Zinc	7500

4.17 Development of the Groundwater flow and Solute Transport Model

4.17.1 Development of the conceptual model

Development of the conceptual model is the most important aspect in the groundwater modeling exercise. The calibration of the model is to a large extent dependent on the conceptual model. The primary data and the secondary data are relied heavily to develop the conceptual model. The conceptual model entails defining the model area, defining the aquifer system, identification of the appropriate model boundary, assigning the appropriate boundary conditions and assigning the reliable input stresses like the recharge, groundwater withdrawal through the pumping wells.

One of the key aspects in conceptual modeling is the assignment of appropriate values of the aquifer properties like the hydraulic conductivity and storativity. The aquifer geometry has to be conceptualized with the help of available lithologs. In the present study, the data from the observation wells, Geophysical soundings, pumping pattern in the villages has been used partly in the conceptualization of the system.

In the present study, the study area has been delineated on the basis of the sub water shed principle. The hydraulic conductivity of the study area has been assigned on the basis of the existing reports. It is subsequently refined during the manual calibration.

4.17.2 Design of the model grid

The study area was discretized into 79 rows and 100 columns. The cells outside the watershed were marked inactive as they do not contribute to the groundwater system of the model area under consideration (Figure 4.17.1). A two layer groundwater system was conceptualized by taking into account the hydrogeology of the study area.

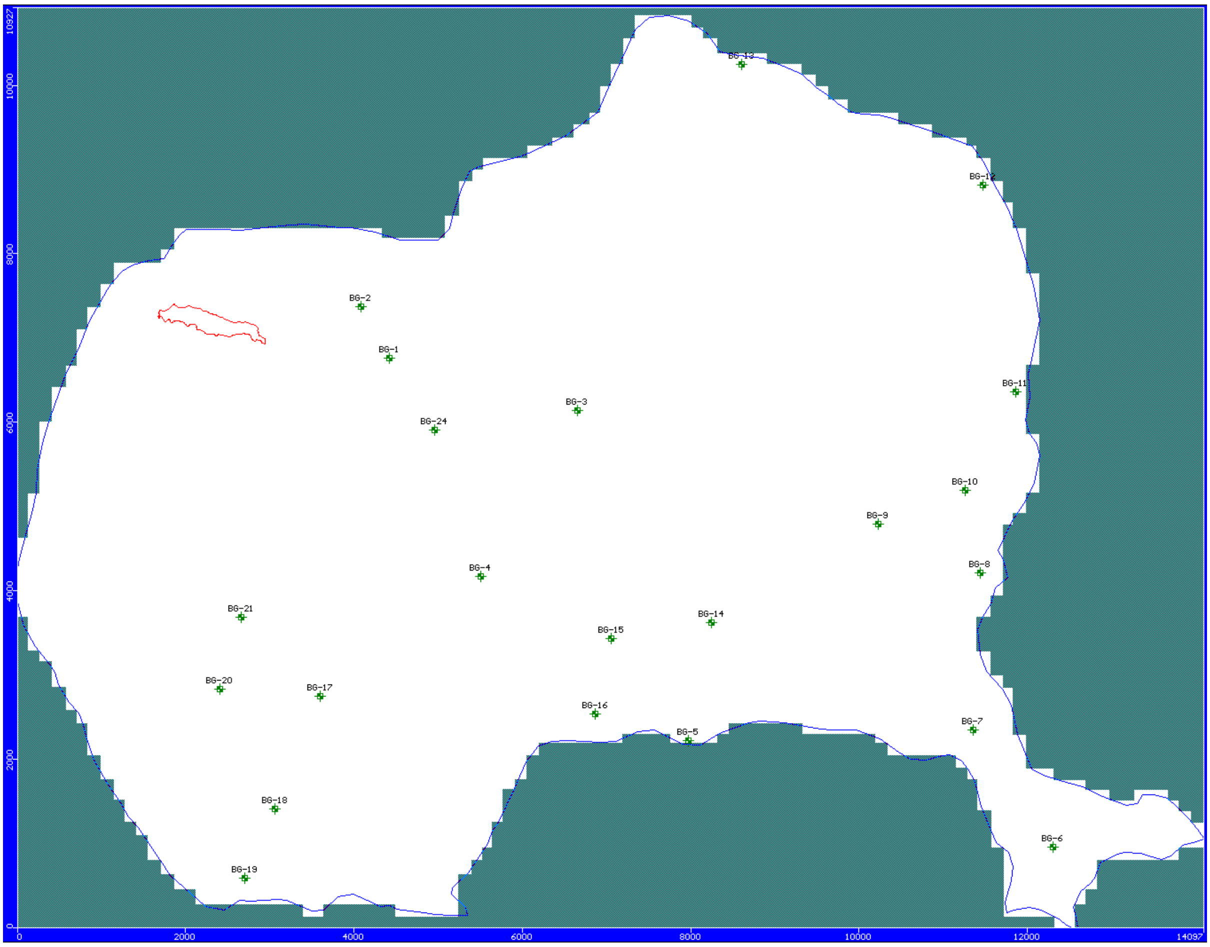


Figure 4.17.1 Model boundary with mine pit (red polygon) and observation wells(green circles)

4.17.3 Modflow Input values

The various input values to the MODFLOW are shown in the following sections:

4.17.3.1 Hydraulic conductivity

The hydraulic conductivity values (Figure 4.17.2, Table 4.17.1) have been assigned for the two layer model based on the transmissivity values from the existing literature and the subsequent manual calibration. The values assigned are as follows:

Table 4.17.1 Hydraulic conductivity values in the model

Zone	**Kx (m/s)**	**Ky (m/s)**	**Kz (m/s)**
Green	1.14E-4	1.14E-4	1.14E-5
Navy Blue	1.59E-4	1.59E-4	1.59E-5
Dark cyan	1.59E-4	1.59E-4	1.59E-5
Red	1.04E-4	1.04E-4	1.04E-5

Pink	1.04E-4	1.04E-4	1.04E-5
Gold	1.04E-4	1.04E-4	1.04E-5

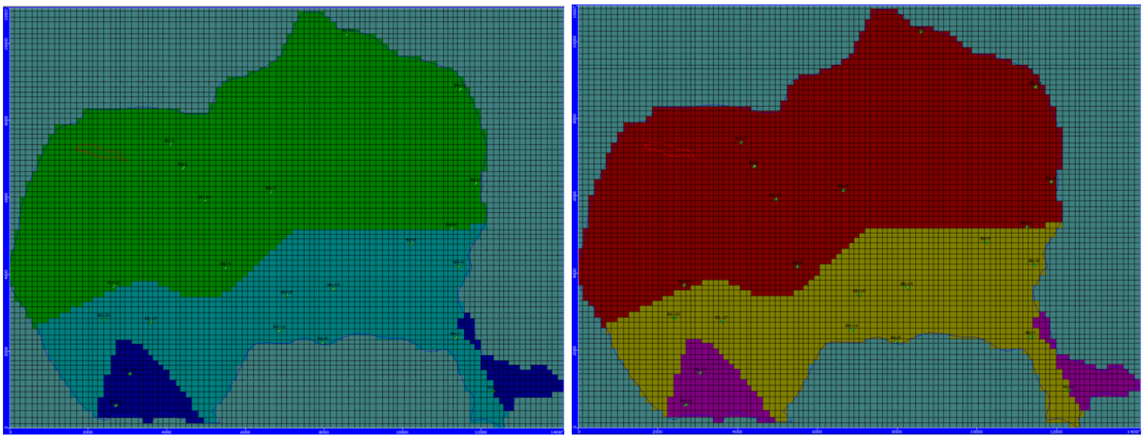


Figure 4.17.2 Hydraulic conductivity of the study area (layer 1 and layer 2)

4.17.3.2 Wells

Initially, 24 key observation wells have been selected in the study area. The wells are the Indian Mark II hand pumps. Besides, all the Indian Mark II wells used for supplying water to the villages have been included in the pumping well network. Based on the village population, as per CGWB norms, 40 lpcd has been assigned as the approximate draft which is estimated for each well.

4.17.3.4 Initial Heads

To start solving the groundwater flow simulation, MODFLOW requires an initial guess for the head values in the model. The initial head values are also used to calculate the drawdown values, as measured by the difference between starting head and the calculated head. An initial head of value 141.503 m has been assigned to start with the simulation

4.17.3.5 Boundary conditions

Every model requires an appropriate set of boundary conditions to represent the system’s relationship with the surrounding systems. In the case of the groundwater flow model, boundary conditions will describe the exchange of flow between the different components in the model.

Flow Boundary conditions

Constant head boundary conditions

The constant head boundary condition is used to fix the head value in selected grid cells regardless of the system conditions in the surrounding grid cell, thus acting as an infinite source of water entering the system or as an infinite sink for water leaving the system. Therefore, constant head boundary conditions have significant influence on the results of the simulation. The existing groundwater level data in the study area have been considered in assigning the constant head boundary conditions.

The western part has the highest head value and the eastern part has the lowest head value. Hence, the groundwater flow direction is from western part towards the eastern part (towards Brahmini river). Hence, constant heads have been defined in the western part of the study area to constrain the groundwater flow within the upper limit of the heads obtained in the field (Figure 4.17.3).

River boundary conditions

The river package simulates the surface water/ groundwater interaction via a seepage layer separating the surface water body from the groundwater system. In the present study, the Brahmini river and Nandira Nala serves as a river boundary condition (Figure 4.20.3).

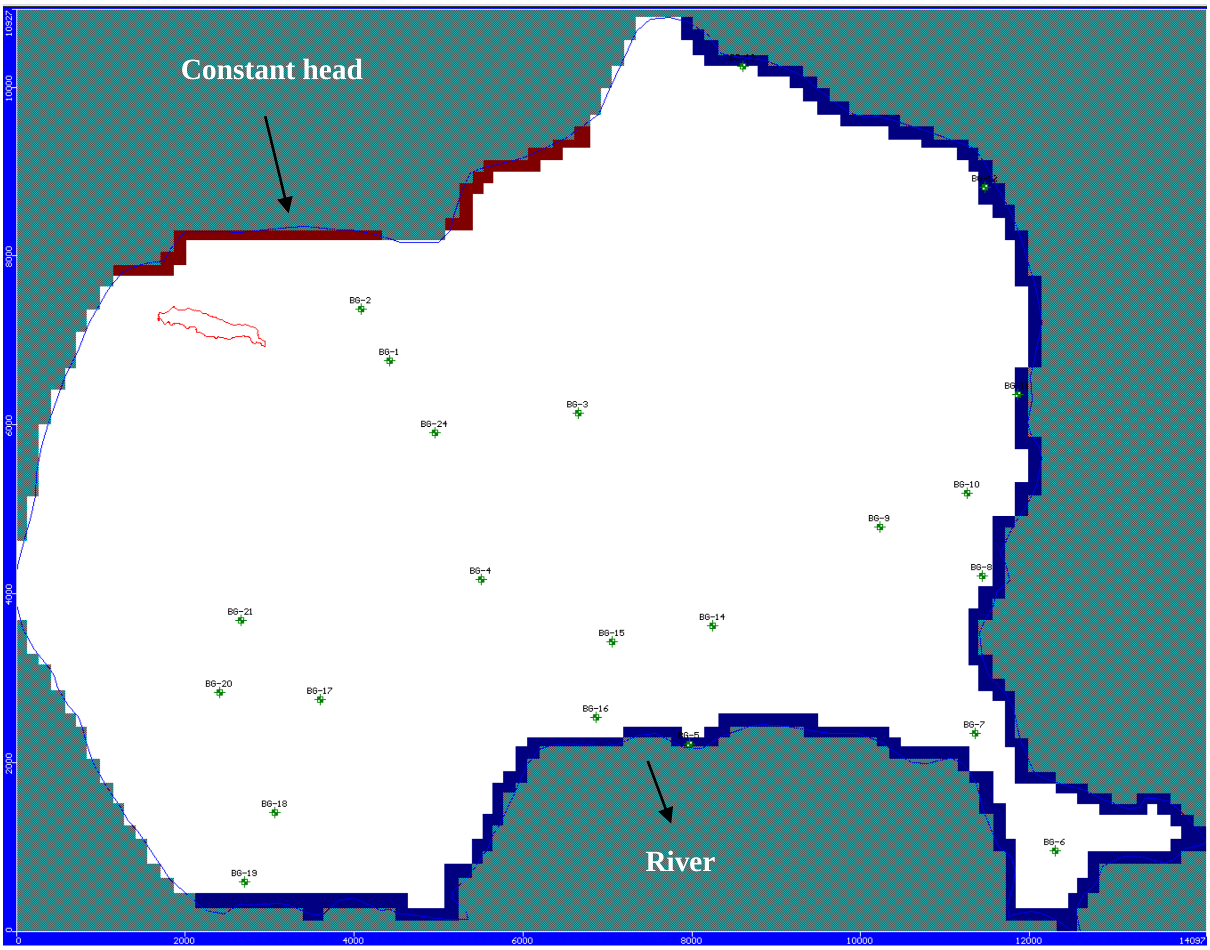


Figure 4.17.3 Constant head and River boundary condition

Recharge boundary condition

The recharge package is typically used to simulate the distributed recharge to the groundwater system. As the aquifer is basically unconfined, the recharge occurs as a result of precipitation percolating into the groundwater system. However, recharge package can be used to simulate the recharge from sources other than precipitation, such as irrigation, artificial recharge or seepage from a pond. It is generally assumed to be a percentage of precipitation. This percentage ranges from 10% to 13% depending on many factors that include:

- the predominant land use and vegetation type
- the surface topography (slope)
- the soil cover material

In the present study, the established norm of 10%-13% of the precipitation is considered in assigning the recharge to the study area (NABARD, 2006). Based on the rainfall data, the recharge assigned has been assigned depending on the topography and geology of the study area. However, the blue zone has been assigned the recharge of 210 mm/year, the green and cyan zones have been assigned the recharge of 80 mm/year and red zone has been assigned a recharge of 800 mm/yr in the study area (Figure 4.17.4) and the manual adjustment during the calibration procedure.

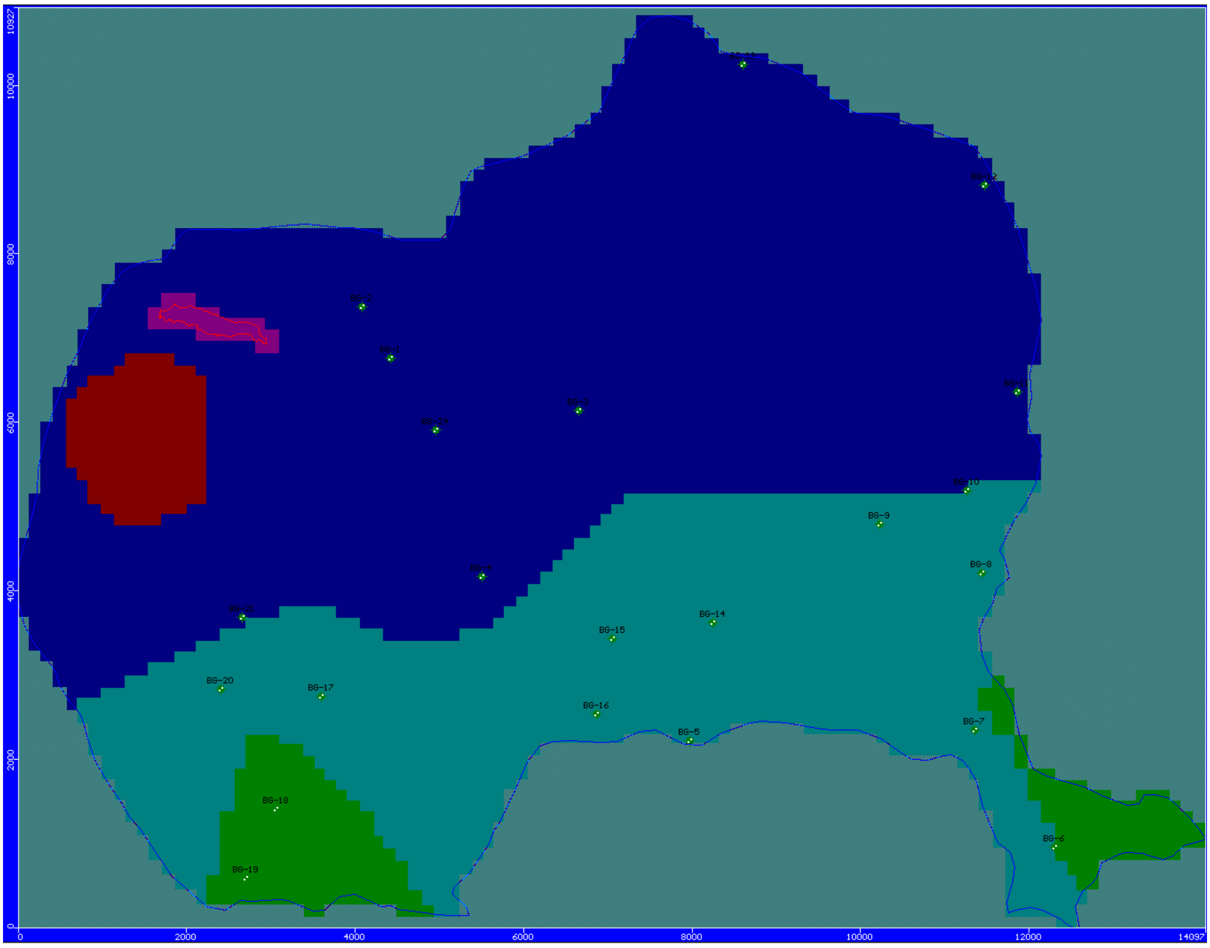


Figure 4.17.4 Recharge boundary condition

4.17.4 MT3D Input values

The hydrochemical data have been considered in assigning the input values in the mass transport model.

Initial concentration

In view of lack of historical groundwater quality data, assigning the background concentration had to be done with caution. The initial concentration for the study area is taken as 200 mg/L for which is the value obtained from the analysis data.

Mass transport boundary conditions

The solution of the governing equations for mass transport requires the specification of the boundary conditions.

4.17.5 Constant concentration boundary condition

The constant concentration boundary condition acts as a contaminant source providing solute mass to the model domain in the form of a known concentration. Constant concentration zone is assigned only in the Jagganath mine pit. Hence, the loading at the pit is simulated for the prediction scenario for 30 years. The solutes are concentrated initially in this zone before they eventually advance to the aquifer system. The approximate concentration of the TDS obtained from the water samples collected from pit is 500 mg/L which is input to the model as the constant concentration (Figure 4.17.5).

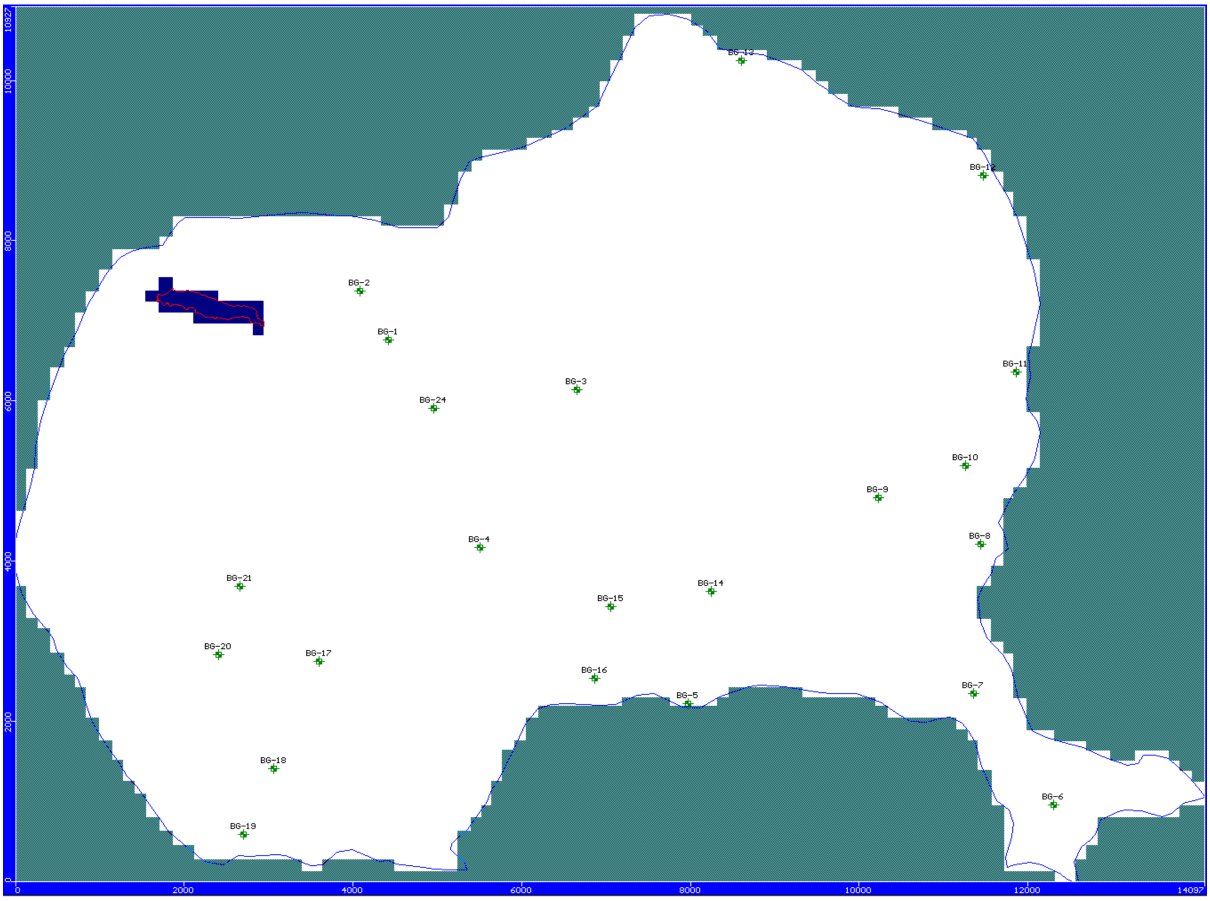


Figure 4.17.5 Constant concentration boundary condition

4.17.6 Modeling Results

4.17.6.1 Flow Modeling

A steady state model has been developed using the groundwater level data of the study area. As long time water level data is not available in the study area, steady state model has been attempted. The calculated head contours (Figure 4.17.6) were obtained after the simulation of the groundwater flow model.

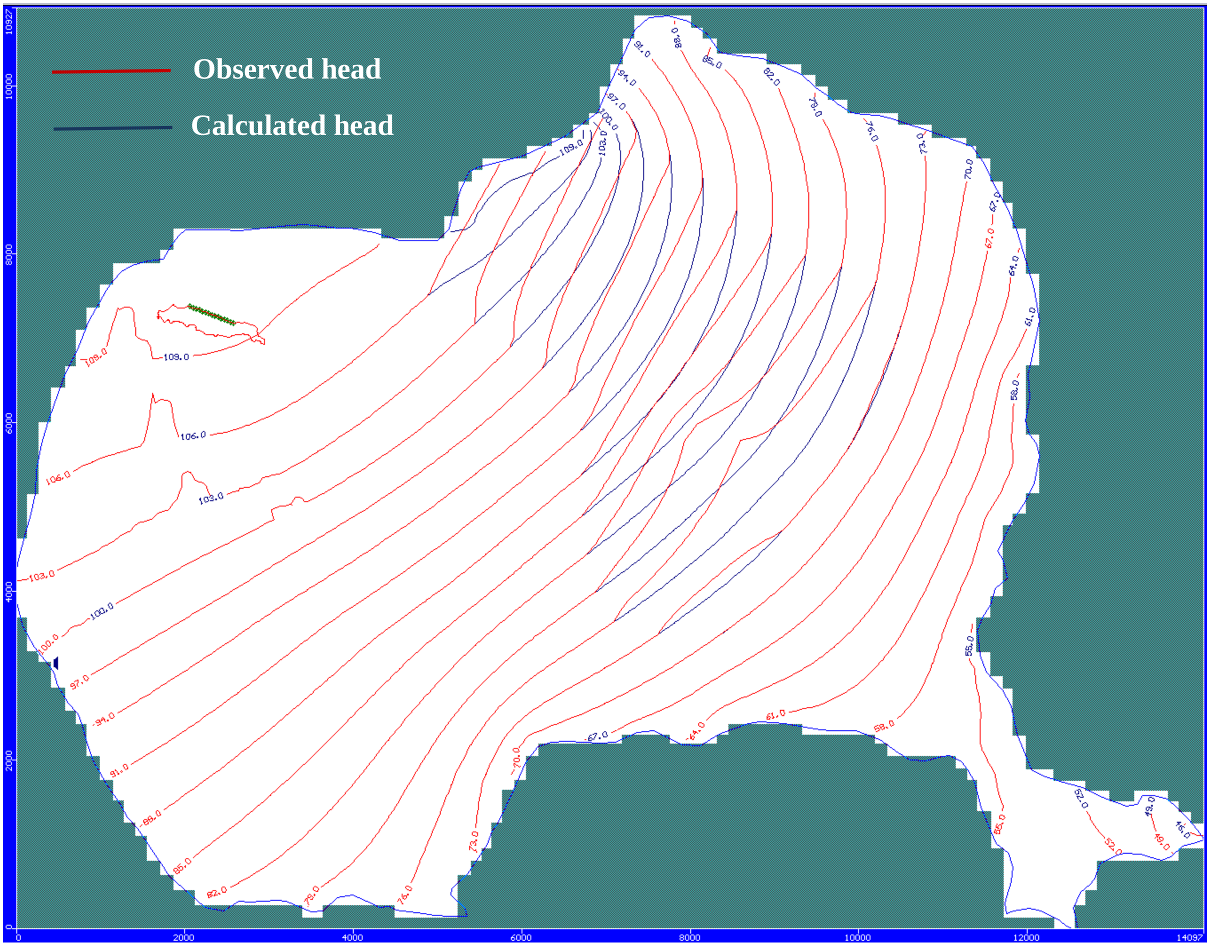
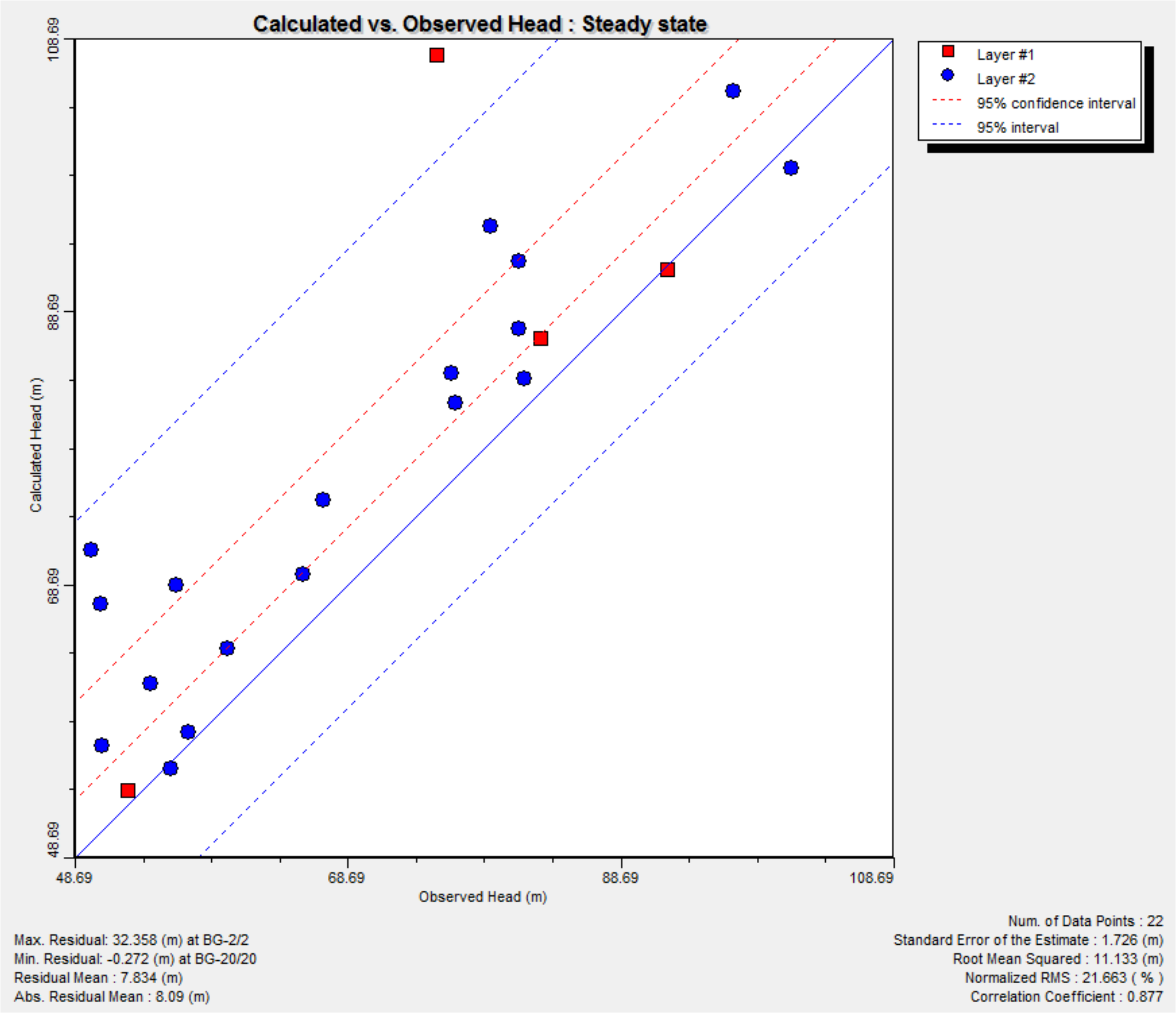


Figure 4.17.6 Computed water level contours

The calibration plot (Figure 4.17.7) shows that most of the observation wells follow 95% confidence interval except for very few observation wells. It can also be observed that most of the wells fall in the 95% confidence interval line which shows that the calculated head results simulated from the groundwater flow model (Figure 4.17.8) are in line with the observed head obtained from the field data. The deviations can be from uncertainties in the pumping rates. However, a correlation of 0.877 was observed between the observed head and the calculated head.



Max. Residual: 32.358 (m) at BG-2/2
Min. Residual: -0.272 (m) at BG-20/20
Residual Mean : 7.834 (m)
Abs. Residual Mean : 8.09 (m)

Num. of Data Points : 22
Standard Error of the Estimate : 1.726 (m)
Root Mean Squared : 11.133 (m)
Normalized RMS : 21.663 (%)
Correlation Coefficient : 0.877

Figure 4.17.7 Calibration plot

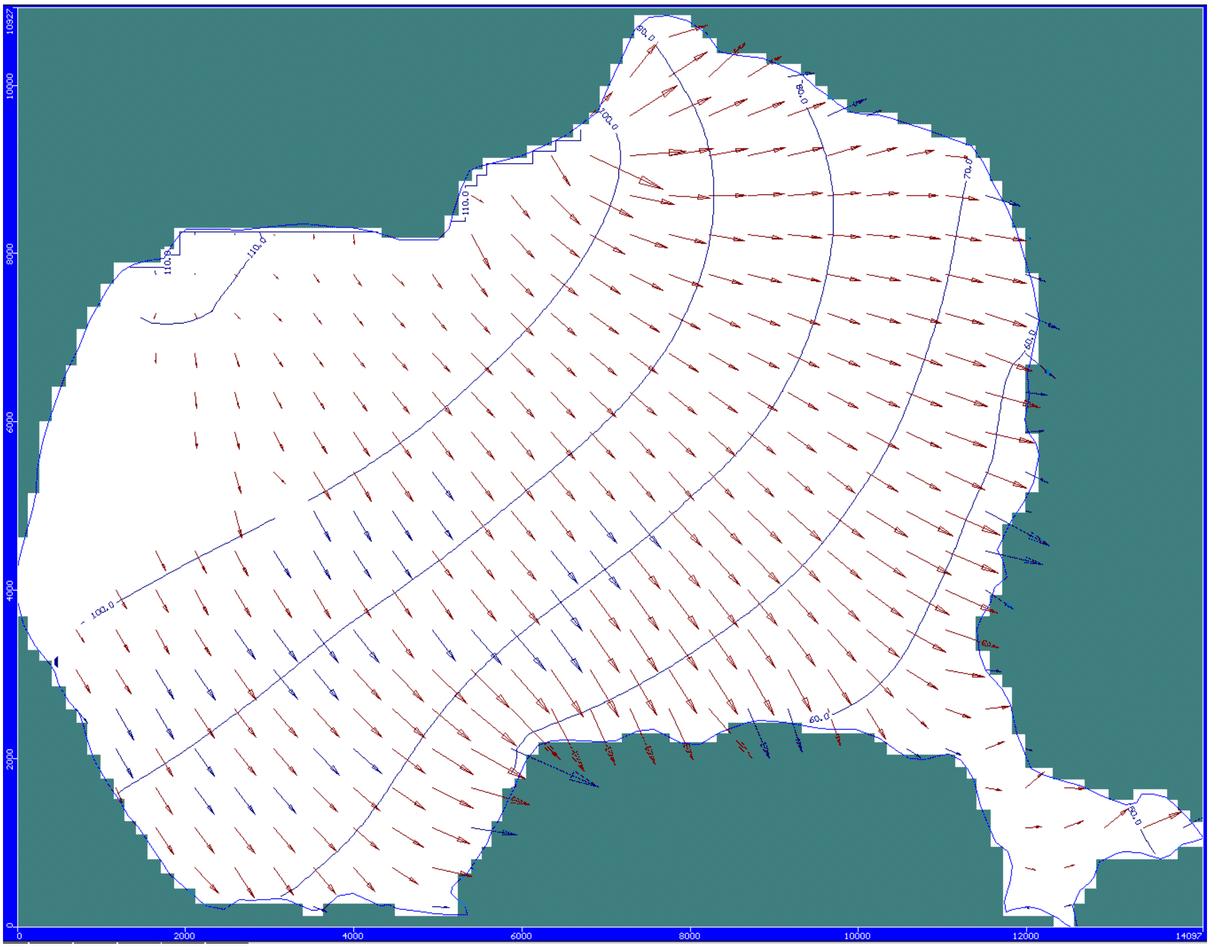


Figure 4.17.8 Groundwater flow direction in the study area

4.17.6.2 Mass Transport Modeling

The calibrated flow model constitutes the input for mass transport modeling. A constant concentration of 500 mg/L has been assigned for the Jagganath mine pit which is identified as the constant concentration zone (Figure 4.17.5).

A background concentration of 200 mg/L has been assumed for the model. The mass transport model has been developed for prediction of the contaminant's migration over the next 30 years starting from March 2014 assuming that the loading at the mine pit continues for another 30 years. The predicted concentration after 5 years, 10 years, 15 years, 20 years, 25 years and 30 years indicates that the plume will move by nearly by 432 m (Figure 4.17.9), 532 m (Figure 4.17.10), 625 m (Figure 4.17.11), 650 m (Figure 4.17.12), 715 m (Figure 4.17.13) and 798 m (Figure 4.17.14) respectively (approx) and the maximum concentration in the plume will be less than 200 mg/L. The migration pattern indicates that the plumes will have high concentration (close to 500 mg/L) in the pond and the concentration outside the pond reduces with distance. This indicates that the contamination due to plume from the mine pit on the wells is not very significant. None of the observation wells surrounding the mine pit are likely to be affected due to the migration of the plume in the coming 30 years starting from March 2014 subjected to the prevailing hydrological stresses. This scenario is valid for conservative parameters assuming that the present hydrological stresses do not vary.

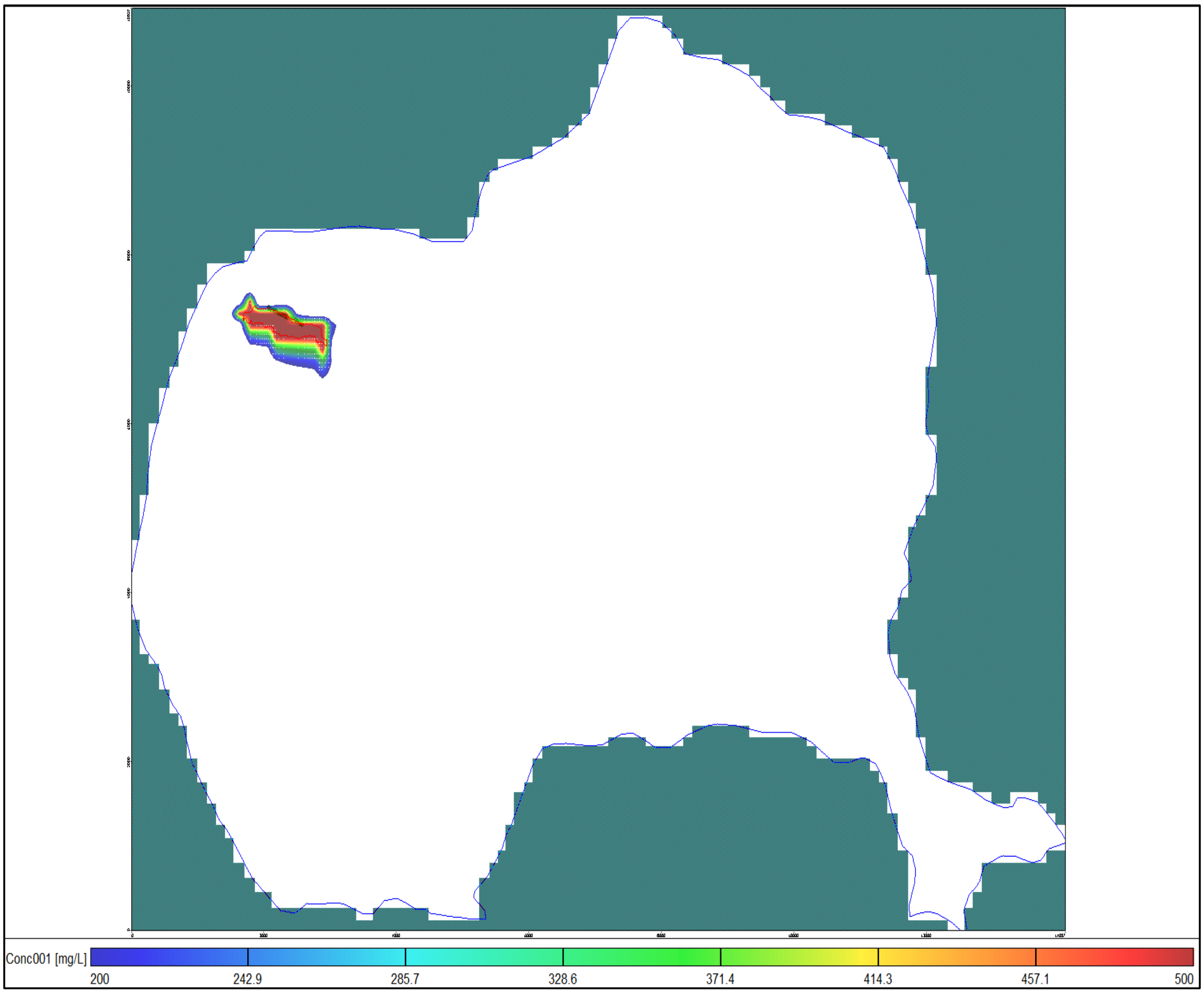


Figure 4.17.9 Migration of contaminant after 5 years

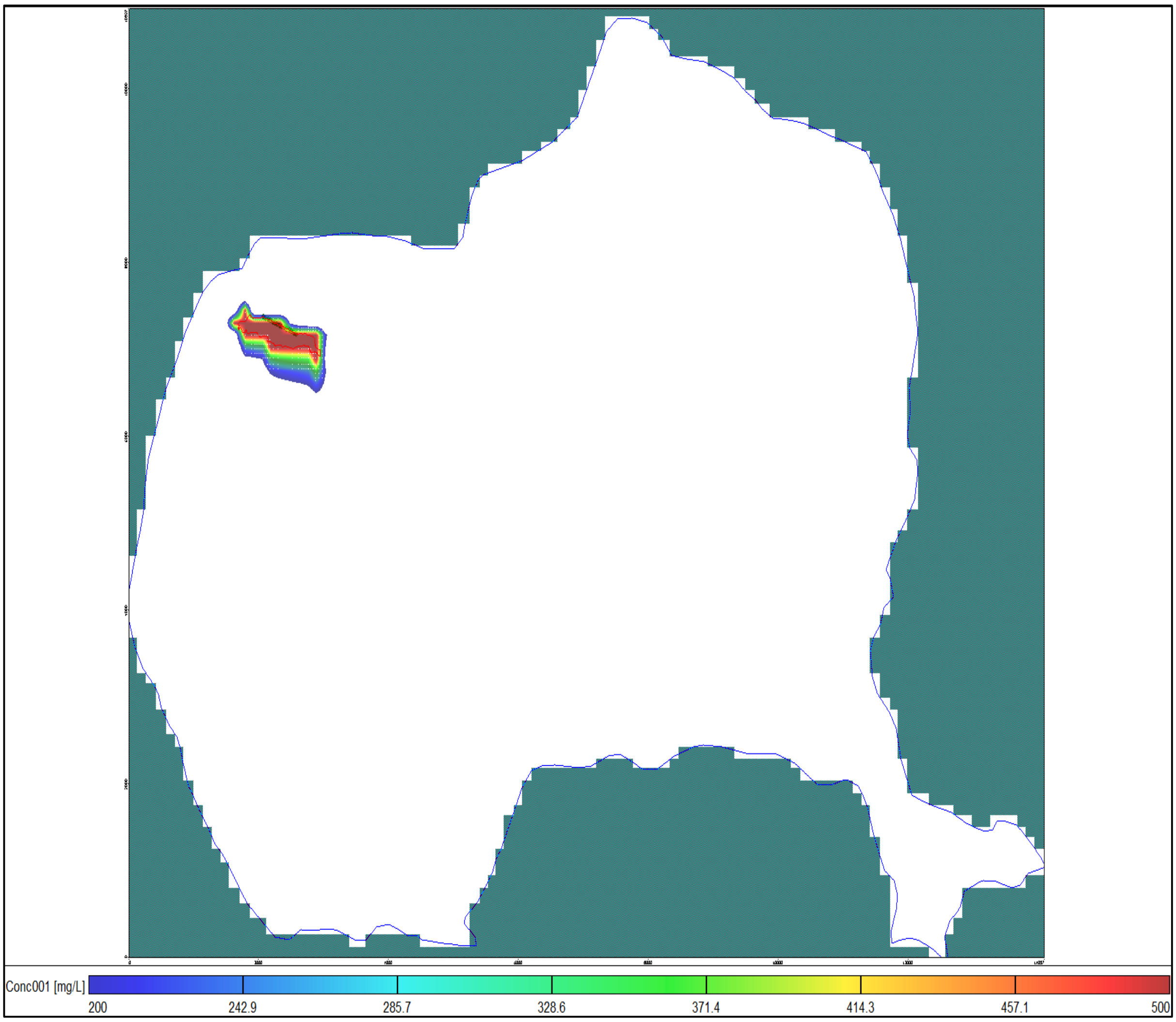


Figure 4.17.10 Migration of contaminant after 10 years

Figure 4.17.11 Migration of contaminant after 15 years

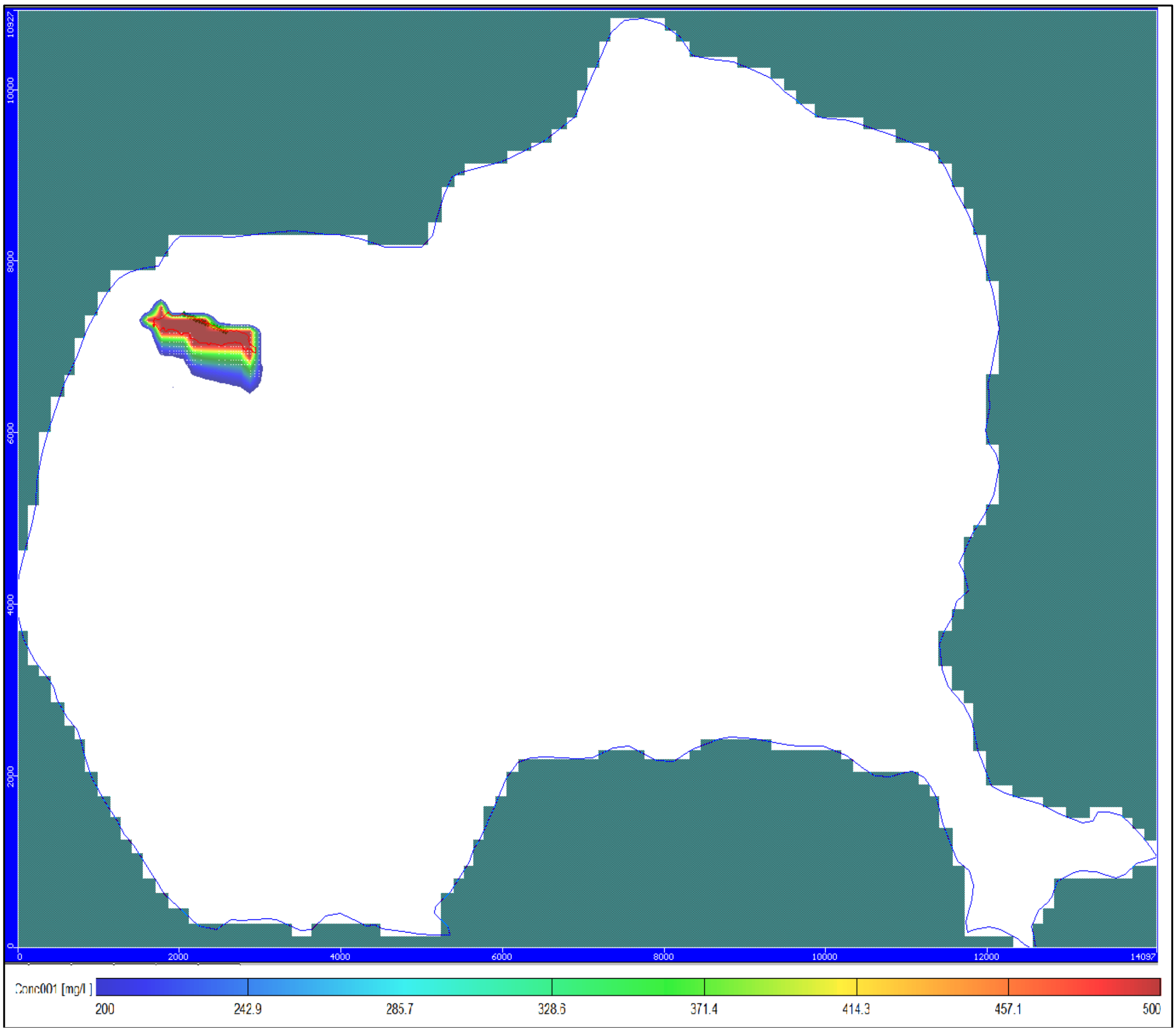


Figure 4.17.12 Migration of contaminant after 20 years

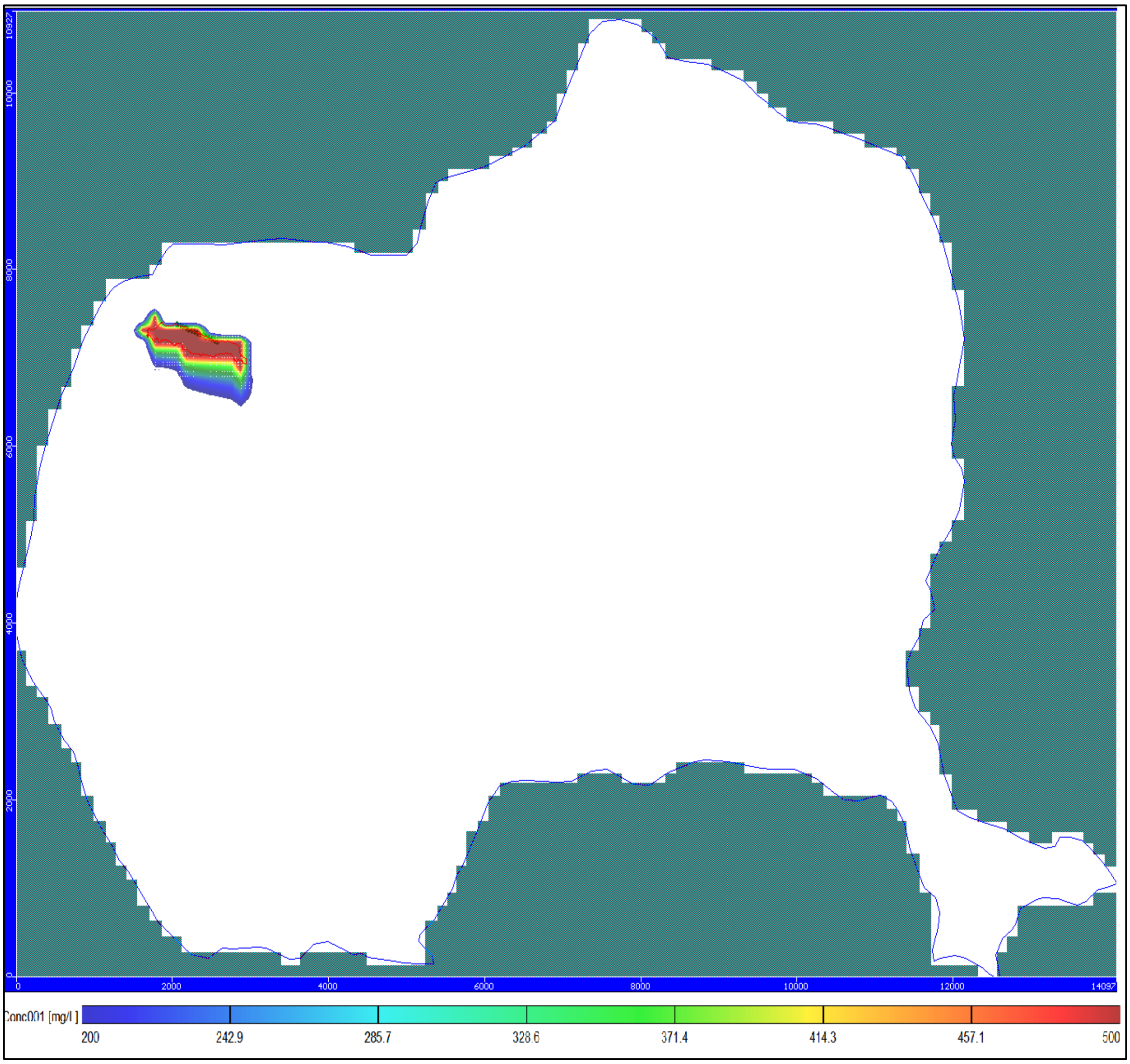


Figure 4.17.13 Migration of contaminant after 25 years

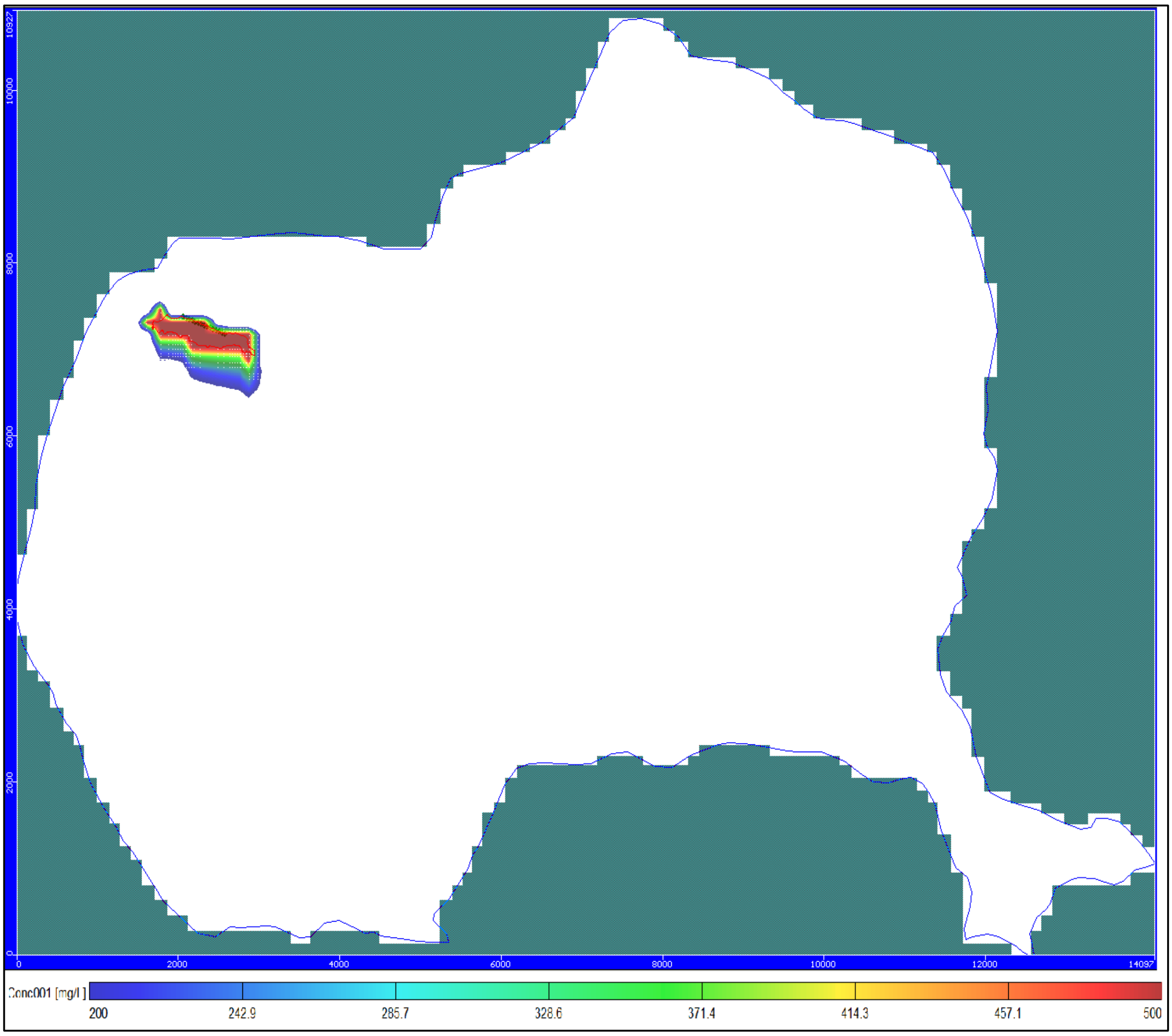


Figure 4.17.14 Migration of contaminant after 30 years

4.17.7 Findings

The groundwater flow and mass transport modelling indicate that concentration of 200 mg/L will have plumes travelling approximately 798 m (approx) over a period of 30 years starting from March 2014. The scenario is valid for conservative parameters assuming that the hydrological stresses do not vary. The presence of significant clay in the soil medium and the Gondwana formations of the study area may be one of the reasons responsible for retarding the movement of the plumes. The solute transport model in the present study is only simulated for advection and dispersion processes. Reaction mechanism has not been incorporated in the present study and is likely to introduce uncertainty in the predictions of the solute transport model. In fact, the movement of reactive species will be still less as compared to the prediction for conservative elements.

Chapter V

Biotic Studies

5.1 Bio-assay test

The bio-assay test has been carried out during post monsoon season (November 2014) and pre monsoon seasons (May 2015). The results are presented as follows:

Post Monsoon (November 2014)

The fishes were inspected after the first 2 to 6 hours and at 12, 24, 48, 72 and 96 hour for fish mortality and behaviour (Table 4.17.1). In the control test (using normal tape water), fish movement, swimming behaviour, respiratory functions were normal. As compared to the respective control tests, in all test samples, the movement and swimming behaviour were fast initially and slowed as the exposure time increased. In sample concentrations 100% and 70% of JMPSW (surface water from Jagannath Mine pit) and NNSW (surface water from Nandira Nala), irregular swimming activity and frequent surfacing were observed at 72 and 96 hr exposure time. At low concentrations (50%, 30%) fish activities were observed normal during the entire test period. In case of samples BRSW-1 (water from Brahmani river) and BRSW-2, fish movement, swimming activity, opercula movements were observed normal. As compared to control test, in sample Mine Water Quary-4, changes in swimming behaviour were observed after 48 hr in all concentration(100%, 70%, 50%, 30% v/v) during 72 and 96 hr exposure. Besides, frequent loss of equilibrium, surfacing, sinking to the bottom, irregular swimming activity was observed but no mortalities were recorded.

In the present test, based on the results no mortalities were occurred during the exposure time i.e., 96 hr. Highest test concentration (100% v/v) caused no mortality within the period of the test. Fishes in this concentration were found under stress, but that was not fatal. In all the test samples, no fish mortality and 100% control survival indicate valid testing.

Mortality: 0% in control and all test samples
Effect measured: Survival
Test acceptability: 100% survival in the laboratory water control.

Table 5.1.1 Test sample concentrations with important physicochemical parameters and fish mortalities during exposure period (November 2014-post monsoon)

Sample ID	Concentration of test sample (% v/v)	pH	Temp (^0C)	No. of fish tested	Mortality percentage during exposure period						
					2 hr	6 hr	12 hr	24 hr	48 hr	72 hr	96 hr
Control-1	0	7.9	21.8	6	0	0	0	0	0	0	0
JMPSW	100	6.9	22.3	6	0	0	0	0	0	0	0
	70	7.2	23.9	6	0	0	0	0	0	0	0
	50	7.5	23.0	6	0	0	0	0	0	0	0
	30	7.7	22.6	6	0	0	0	0	0	0	0
NNSW	100	7.6	22.2	6	0	0	0	0	0	0	0
	70	7.6	22.7	6	0	0	0	0	0	0	0
	50	7.7	22.0	6	0	0	0	0	0	0	0
	30	7.8	21.9	6	0	0	0	0	0	0	0
Control-2	0	7.9	22.2	6	0	0	0	0	0	0	0
BRSW-1	100	7.8	22.4	6	0	0	0	0	0	0	0
	70	7.8	24.3	6	0	0	0	0	0	0	0
	50	7.8	22.2	6	0	0	0	0	0	0	0
	30	8	22.2	6	0	0	0	0	0	0	0
BRSW-2	100	7.4	22.4	6	0	0	0	0	0	0	0
	70	7.7	22.3	6	0	0	0	0	0	0	0
	50	7.8	22.2	6	0	0	0	0	0	0	0
	30	8	22.2	6	0	0	0	0	0	0	0
Control-3	0	7.9	18.7	6	0	0	0	0	0	0	0
Mine Water Quary-04	100	6.9	18.6	6	0	0	0	0	0	0	0
	70	7.3	18.7	6	0	0	0	0	0	0	0
	50	7.6	18.5	6	0	0	0	0	0	0	0
	30	7.9	18.4	6	0	0	0	0	0	0	0

Pre Monsoon (May 2015)

The fishes were inspected after the first 2 to 6 hours and at least 12, 24, 48, 72 and 96 hours for fish mortality and behaviour. In all control tests, fish movement, swimming behaviour, respiratory functions were normal. As compared to the respective controls, in all test samples, the movement and swimming behaviour were fast initially and slowed as the exposure time increased. At low concentrations (50%, 30%), fish activities were observed normal during the entire test period. In case of sample MQW -1, MQW -2 and BRSW-2, the fish movement, swimming activity, opercula movements were observed normal and no mortalities were recorded at the end of test. In case of sample NNSW, fish movement, swimming activity, opercula movements were observed normal initially, however frequent surfacing and sinking were observed after 12 hours of test period in all test solution concentrations. As compared to the respective control, the swimming activity was observed slow with frequent surfacing in all test concentrations during 24 hr, 48 hr, 72 hr and 96 hr test period but no mortalities were recorded at the end of test in this sample. In case of sample JMPDA (supernatant from the slurry at disposal site), fish movement and swimming activity were observed normal initially. However, after 2 hours of test period, frequent surfacing and sinking was observed in all test solution concentrations. As compared to the respective control, after 6 hours of test period, 100% mortality was recorded in 100% v/v test concentration. The mortality may be related to ***low pH and dissolved oxygen*** in this sample. In other concentrations (70%, 50%, 30%), frequent surfacing, irregular swimming activity, slow movement and sinking were observed at 12 hr, 24 hr, 48 hr, 72 hr, 96 hr exposure time but no mortalities were recorded in these test concentrations.

In case of sample MQW-1, MQW-2, BRSW-2 and NNSW highest test concentration (100% v/v) caused no mortality within the period of the test. In all these test samples, no fish mortality and 100% control survival indicate valid testing (Table 5.1.2). Fishes in this concentration were found under stress, but that was not fatal. However, 100% v/v test concentration of sample JMPDA was found highly toxic.

Mortality: 0% in control and all test sample concentrations except 100% v/v test concentration of sample JMPDA in which mortality was 100%.

Effect measured: Survival

Test acceptability: 100% survival in the laboratory water control.

Table 5.1.2 Test sample concentrations with important physicochemical parameters and fish mortalities during exposure period

Sample ID	Concentration of test sample (% v/v)	pH	Temp (°C)	DO (mg/L)	Number of fish tested	Mortality percentage during exposure period						
						2 hr	6 hr	12 hr	24 hr	48 hr	72 hr	96 hr
Control-1	0	8.2	27.6	6.6	6	0	0	0	0	0	0	0
MQW- 1	100	7.6	27.5	7.0	6	0	0	0	0	0	0	0
	70	7.7	27.4	7.3	6	0	0	0	0	0	0	0
	50	7.8	27.4	7.1	6	0	0	0	0	0	0	0

	30	7.9	27.4	7.0	6	0	0	0	0	0	0	0
MQW-2	100	7.6	27.4	7.5	6	0	0	0	0	0	0	0
	70	7.8	27.4	7.5	6	0	0	0	0	0	0	0
	50	7.9	27.4	7.4	6	0	0	0	0	0	0	0
	30	7.9	27.3	7.3	6	0	0	0	0	0	0	0
Control-2	0	8.1	27.2	7.9	6	0	0	0	0	0	0	0
BRSW-2	100	8.2	27.3	7.4	6	0	0	0	0	0	0	0
	70	8.1	27.3	7.5	6	0	0	0	0	0	0	0
	50	8.1	27.3	7.3	6	0	0	0	0	0	0	0
	30	8.1	27.2	7.1	6	0	0	0	0	0	0	0
NNSW	100	7.9	28.2	7.2	6	0	0	0	0	0	0	0
	70	7.9	28.2	7.4	6	0	0	0	0	0	0	0
	50	8.0	28.2	7.6	6	0	0	0	0	0	0	0
	30	8.1	28.1	7.8	6	0	0	0	0	0	0	0
Control-3	0	8.2	28.0	7.9	6	0	0	0	0	0	0	0
JMP-DA	100	5.4	28.1	5.8	6	0	100	0	0	0	0	0
	70	5.8	28.1	7.1	6	0	0	0	0	0	0	0
	50	6.0	28.1	7.0	6	0	0	0	0	0	0	0
	30	6.2	28.1	7.3	6	0	0	0	0	0	0	0

*MQW: Mine Quary Water, BRSW: Brahmani River Surface Water, NNSW: Nandira Nala Surface Water, JMP-DA: Jagannath Mine Pit -Dumping Ash

5.2 Concentration of heavy metals in fishes

The concentrations of heavy metals in two fish samples viz. tilapia and dwarf snakehead are shown in table (Table 4.2.1). The results showed that the concentration of heavy metals in tilapia was more than in dwarf snakehead. The concentration of Cr, Fe and Mn was more than the guideline values indicated higher metal accumulating tendency in both the fish samples. Also the concentration of Ni and Zn was more than the guideline values indicated higher metal accumulating tendency in tilapia. The other metal such as Cd, Co, Cu and Pb has no accumulating tendency in both the fish samples. In case of dwarf snakehead, Cr and Ni have no accumulating tendency.

Table 5.2.1 Heavy Metals concentrations in fish samples from Jagannath Mine Pit Odisha (August 2015)

Heavy Metals concentrations (mg/kg dry weight)	**Fish species**		**FAO / WHO Guidelines (mg/kg)**
	***Oreochromis mossambicus* (Tilapia)**	***Channa gachua* (Dwarf snakehead)**	
Cd	0.35	0.22	-
Co	3.33	0.55	-
Cr	1.59	1.42	2

Cu	17.84	5.18	30
Fe	73.69	76.44	100
Mn	0.95	0.78	1
Ni	0.57	0.31	0.6
Pb	2.27	1.44	4
Zn	62.97	92.20	100

5.3 Bio-diversity observed in and around the study area

The following are the species observed in the study area.

Phytoplankton Phytoplankton counts (Table 5.3.1) in water samples from Jagannath Mine Pit, indicate that the total algal count ranged between 233/mL and 583/mL. In general 4 groups comprising 6 genera were observed in water samples (Table 5.3.2). The members of Chlorophyceae, Cyanophyceae and Cryptophyceae were most common. The group Chlorophyceae was represented by 2 genera viz. *Chlorella* and *Coelastrum*. Cyanophyceae was represented by 2 genera viz. *Oscillatoria* and *Microcystis*. The group Bacillariophyceae and Cryptophyceae were represented by single genera viz. *Nitzschia* and *Cryptomonas* respectively.

Palmer Index: According to Palmer (1969), a total score of 20 or more in a sample is an indicator of organic pollution. The PPI values ranged between 9 and 12 indicates ***no evidence of organic pollution*** (Table 5.3.3).

Shannon - Wiener Diversity Index (SWI): During the study, the SWI values ranged between 1.87 and 2.24 (Table 5.3.4). The values of SWI indicated moderate levels of plankton biodiversity with medium impact of adverse factors for plankton growth.

Table 5.3.1 Density, Diversity & Species composition of phytoplankton observed in water samples from Jagannath Mine Pit, Orissa (May 2015)

S. No.	Sample ID	Count /mL	Composition of algal groups (%)				SWI	PPI
			Chloro phyceae	Cyano phyceae	Bacillario phyceae	Cryptophyceae		
1	A-1	292	29	47	-	24	2.24	9
2	B-1	583	16	28	10	46	2.21	12
3	C-1	233	30	55	-	15	1.87	9
4	D-1	350	24	26	9	41	2.09	12
5	E-1	233	19	27	12	42	2.12	12

6	F-1	408	8	53	10	29	2.08	12
7	G-1	525	19	30	8	43	2.23	12

***- : absence of genera concerned.**

Table 5.3.2 List of Phytoplankton genera identified in water samples from Jagannath Mine Pit, Orissa (May 2015)

S.No.	**Algal group**	**Genera**
1	Chlorophyceae	*Chlorella sp.*
		Coelastrum sp.
2	Cyanophyceae	*Oscillatoria sp.*
		Microcystis sp.
3	Bacillariophyceae	*Nitzschia sp.*
4	Cryptophyceae	*Cryptomonas sp.*

Table 5.3.3 Ranges of Palmer's Pollution Index (PPI)

< 15	Indicate **absence** of organic pollution
<15-20	Indicate **presence** of organic pollution
>20	Indicate **presence of high** organic pollution

Table 5.3.4 Ranges of Shannon-Wiener Diversity Index (SWI)

Range	**Impact of pollution or Adverse factors**
<1	**Maximum**
1-<3	**Medium**
≥3	**Minimum**

Zooplankton: Zooplankton counts observed in water samples from Jagannath Mine Pit, Orissa at different sampling locations are shown in Table 5.3.5. Density of zooplankton during study period varied between 6867/ m^3 and 24733/ m^3. Total 2 groups comprising 5 genera and 1 nauplius stage of copepods were observed (Table 5.3.5). Copepoda was the most abundant group as compared to Rotifera (Table 5.3.5). Rotifera was represented by 3 genera viz. *Keratella, Brachionus* and *Filinia*. Copepoda was represented by 2 genera with one nauplius stage viz. *Cyclops* and *Diaptomus* (Table 5.3.6).

Shannon - Wiener Diversity Index (SWI) : Generally "Shannon Wiener index" values between 1 and 3 are believed to indicate semi productivity of the water body, while the values above 3 are considered to represent lowest or minimum impact of pollution or adverse factors. The SWI values varied from 2.07 to 2.36 (Table 5.3.5) indicated medium levels of plankton biodiversity with medium impact of adverse factors for plankton growth.

Table 5.3.5 Density, Diversity & Species composition of zooplankton observed in water samples from Jagannath Mine Pit, Orissa (May 2015)

S. No.	Sample ID	Zooplankton/ m^3	Composition of zooplankton groups (%)		SWI
			Rotifera	Copepoda	
1	A-1	16133	59	41	2.07
2	B-1	6867	46	54	2.36
3	C-1	11333	48	52	2.26
4	D-1	24733	46	54	2.14
5	E-1	16667	44	56	2.12
6	F-1	23933	46	54	2.21
7	G-1	10800	56	44	2.16

Table 5.3.6 List of zooplankton genera identified in water samples from Jagannath Mine Pit, Orissa (May 2015)

S.No.	Zooplankton group	Genera
1	Rotifera	*Keratella* sp.
		Brachionus sp.
		Filinia sp.
2	Copepoda	*Cyclops* sp.
		Diaptomus sp.
		Nauplius larva

5.4 Heavy metals concentration in plants

The results of analysis for heavy metals concentration in the vegetables, shrubs and trees are presented in Table 5.4.1.

Cadmium (Cd): The concentration of cadmium was ranged between 0.01 and 16.14 mg/kg dry weight. The average concentration was 1.02 mg/kg dry weight in all the plant species. It was found that all studied plants have cadmium below the normal limit set by WHO. The high concentration of cadmium was found in leaves of *Citrus aurantifolia* may be due to maximum level of cadmium in soil.

Cobalt (Co): The average concentration level of cobalt was 1.65 mg/kg dry weight. The highest and lowest concentrations were 33.09 and 0.05 mg/kg dry weight respectively. For cobalt content in plants, there are no standard limits set by WHO/FAO.

Chromium (Cr): The concentration of chromium was ranged between 0 and 8.11 mg/kg dry weight. The average concentration was 2.43 mg/kg dry weight. It needs to be mentioned that the soil has higher chromium concentration.

Copper (Cu): It is an essential trace element which is necessary for many enzymes. It play important role in normal growth and development. The highest and lowest concentration of copper was 35.27 and 3.1 mg/kg dry weight. The average concentration was 11.57 mg/kg dry weight. It was found below the permissible limit set by WHO (Table 5.4.2).

Iron (Fe): It is the most abundant metal. It is an essential constituent for all plants and animals. The results showed that highest concentration of iron was 2825.74 mg/kg dry weight and lowest concentration was 73.79 mg/kg dry weight. The average iron concentration was more may be due to high level of iron content in soil as the study area has lateritic soil .

Manganese (Mn): It is a trace heavy metal and very essential for plants and animals growth. Results revealed that manganese concentration was found high in all plant samples. The concentration of manganese was found in the range between 3.4 to 2781.22 mg/kg dry weight. The average concentration of manganese was 194.56 mg/kg dry weight. It was found below the permissible limit set by WHO (Table 5.4.2).

Nickel (Ni): It is an essential element needed for plants and animals. The maximum and minimum concentration of nickel was 66.16 and 0.83 mg/kg dry weight. The average concentration was 6.84 mg/kg dry weight. It was found below the permissible limit set by WHO.

Lead (Pb): It is a non-essential trace metal. The concentration of lead was ranged between 0.02 and 57.24 mg/kg dry weight. The average concentration was 5.14 mg/kg dry weight. It was found below the permissible limit set by WHO. It need to be mentioned that Pb is present in soil in the study area.

Zinc (Zn): The zinc concentration was ranged between 1.57 and 323.38 mg/kg dry weight. The average zinc concentration was 55.47 mg/kg dry weight. It was found below the permissible limit set by WHO.

Table 5.4.1 Heavy Metals concentrations in vegetables, shrubs, trees samples from Bhushan steel study area in Odisha (May 2015)

Sample code	Plants	Parts	Heavy Metals concentrations (mg/kg)								
			Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
BG-2	*Azadirachta indica*	Leaves	0.10	0.26	1.89	35.27	570.00	33.06	2.70	57.24	23.81
	Cassia siamea	Leaves	0.06	0.36	2.01	7.41	521.48	29.12	4.41	0.42	11.82
	Tridax procumbens	Leaves	0.52	1.96	6.39	21.73	2623.68	103.65	7.57	7.90	57.07
	Calotropis gigantea	Leaves	3.51	0.81	5.16	12.78	1254.99	70.73	2.24	3.36	103.67
	Lantana camara	Leaves	0.58	1.59	5.10	15.11	1668.84	80.07	3.72	2.35	46.26
BG-3	*Ipomoea carnea*	Leaves	0.05	0.95	2.57	17.77	922.46	40.10	2.46	5.00	25.72
	Andrographis paniculata	Leaves	0.11	0.68	2.17	19.32	1127.69	39.59	1.67	12.62	40.87
BG-7	*Azadirachta indica*	Leaves	0.05	0.17	0.52	7.74	345.01	68.43	2.93	1.57	30.05
	Mangifera indica	Leaves	0.17	0.17	0.37	8.52	266.87	179.78	4.63	12.75	37.00
BG-11	*Azadirachta indica*	Leaves	0.22	0.09	0.00	4.18	135.12	18.07	2.06	19.13	20.12
	Ipomoea carnea	Leaves	0.05	0.22	0.32	9.34	393.77	79.77	3.35	3.10	18.61
	Cassia siamea	Leaves	0.06	0.10	0.27	4.62	193.48	31.08	2.22	5.15	11.70
	Andrographis paniculata	Leaves	0.32	0.59	5.26	10.33	389.29	106.26	9.50	6.93	27.48
BG-19	*Eucalyptus citriodora*	Leaves	0.06	0.32	0.37	7.84	399.95	122.23	5.90	1.70	290.54
	Cassia siamea	Leaves	0.05	0.23	0.19	6.95	213.04	34.16	3.20	15.93	19.25
Near JMP	*Ipomoea carnea*	Leaves	0.04	0.53	1.75	10.75	776.38	102.05	2.98	1.65	20.86
	Andrographis paniculata	Leaves	0.14	0.88	3.85	16.65	1382.04	99.01	5.96	3.28	46.13
	Cassia siamea	Leaves	0.08	0.57	0.89	6.43	485.75	167.54	1.87	4.59	20.78
	Acacia farnesiana	Leaves	0.06	0.63	2.98	11.69	1188.95	64.88	2.84	1.74	28.62
CP-1	*Citrus aurantifolia*	Leaves	0.07	0.27	3.05	6.67	697.40	27.69	6.61	1.64	19.83

	Psidium guajava	Leaves	0.05	0.26	2.35	7.78	363.69	45.78	4.03	1.59	15.91
	Aegle marmalos	Leaves	BDL	0.10	0.58	11.59	184.23	28.83	4.15	0.02	19.47
	Azadirachta indica	Leaves	0.06	0.18	1.27	6.31	285.19	17.84	2.44	1.47	18.91
	Cassia siamea	Leaves	0.03	0.40	0.25	5.96	212.43	52.48	2.85	0.53	15.05
JMP-A	*Nymphaea* sp.	Leaves	0.44	33.09	4.82	15.63	1580.55	2781.22	66.16	1.80	122.67
JMP-B	*Nymphaea* sp.	Leaves	0.59	19.20	7.67	19.60	2825.74	2052.13	57.26	4.49	107.02
Ash dumping point	*Cassia siamea*	Leaves	0.09	0.52	8.11	8.48	619.23	55.98	6.29	5.29	33.14
	Calotropis gigantea	Leaves	0.08	0.94	2.45	8.25	1309.46	120.19	3.57	1.29	30.83
	Azadirachta indica	Leaves	0.04	0.43	3.20	8.73	566.83	61.75	4.43	1.91	60.99
	Acacia farnesiana	Leaves	0.06	0.79	2.20	13.71	894.93	138.17	3.36	0.92	33.02
BG-24	*Solanum melongena*	Fruits	0.18	1.52	2.17	23.18	200.02	29.34	2.16	18.37	199.36
	Momordica charantia	Fruits	0.40	0.13	2.73	11.82	164.92	15.41	2.84	0.47	58.44
	Luffa acutangula	Fruits	0.11	0.33	2.01	22.95	136.34	21.64	7.95	6.16	39.97
	Vigna unguiculata	Fruits	0.18	0.18	5.02	8.78	164.38	60.15	11.46	4.72	34.95
	Abelomoschus esculentus	Fruits	0.23	0.17	0.58	13.66	145.50	62.39	5.66	0.31	59.51
	Cyamopsis tetragonoloba	Fruits	0.05	0.24	0.92	9.07	268.34	70.60	11.07	0.27	38.96
	Citrus aurantifolia	Fruits	BDL	0.05	0.08	3.10	89.35	3.40	0.83	BDL	BDL
	Mangifera indica	Fruits	0.01	BDL	0.13	6.80	73.79	24.51	1.84	0.37	BDL
	Solanum melongena	Leaves	0.20	0.87	3.54	24.15	1365.23	142.16	5.29	1.73	14.40
	Vigna unguiculata	Leaves	0.07	0.47	2.49	12.29	839.47	185.40	3.51	1.58	71.15
	Citrus aurantifolia	Leaves	15.56	0.20	1.80	5.03	394.45	40.75	3.59	0.42	323.38
	Mangifera indica	Leaves	0.15	0.22	1.27	8.74	499.15	451.05	3.71	1.31	1.57
BG-24 Farm-2	*Citrus aurantifolia*	Leaves	16.14	0.40	3.64	8.53	1029.71	46.64	6.80	1.37	88.82
	Psidium guajava	Leaves	2.86	0.37	2.82	10.02	601.25	77.94	4.95	0.75	79.87
	Musa paradisiaca	Leaves	0.11	0.25	2.18	5.68	533.04	672.61	2.93	1.15	17.93

Table 5.4.2 Guidelines for Metals in foods, Vegetables and plants

Metals (mg/kg)	WHO/FAO	EC/CODEX	Normal range in plants
Cd	1	0.2	<2.4
Co	-	-	-
Cr	1.30	-	-
Cu	30	0.3	2.5
Fe	48	-	400-500
Mn	500	-	-
Ni	10	-	0.02-50
Pb	2	0.3	0.5-30
Zn	60	<50	20-100

Chapter VI

Findings & Recommendations

6.1 Findings

Based on the water level measurements, groundwater quality analysis for major cations /anions, trace elements, Leachability studies (TCLP, SPLP, Water Elution test), particle size analysis for ash samples and the Biotic studies, the following findings emerge from the study:

i. The samples namely BG-6, BG-7, BG-10 and BG-21 show higher values of fluoride. The presence of high fluoride concentration gives the reasons whether it is due to geogenic nature or anthropogenic stresses. Petrographic study indicated the presence of fluoride bearing minerals in the study area

ii. The Petrographic study also indicated the presence of minerals having alumimum.

iii. It is revealed from various studies carried out in past that the occurrence of high level of fluoride in the ground water in this region is in the basement crystalline and in the Gondwana sedimentaries near the Talcher Coal Field (Das et al. 2000).

iv. The fluoride content in the ground water within 2.5 km of the ash dumping area is <1.0mg/L which is well within the norms.

v. The concentration of TDS in all the samples is within the BIS limits

vi. The higher concentration of iron is observed in some of the groundwater samples which may be due to the presence of laterite geological nature. Iron levels in the fly ash <0.1 mg/L and in bottom ash <0.3 mg/L indicates very low level of iron which may not be a contributing factor

vii. The other physico-chemical parameters were within the permissible limits of BIS standards

viii. It is noted that arsenic was within the permissible limits of BIS standards in all the samples

ix. The TCLP test for fly ash and bottom ash samples reveal that the ash is non-hazardous in nature as per RCRA guidelines.

x. The water extraction test indicated that the leaching of trace elements from the fly ash and bottom ash is very less. It is less than 1% for the different trace elements.

xi. The water elution test also indicates that the leaching of trace elements from the ash matrix decreases with time. At pH:7, the leaching of Pb is below the detection limit whereas the leaching of As is also <0.02 m/L). As the pH in the Jagannath Mine Pit is approximately 7, leaching at concentration likely to affect the groundwater is not expected.

xii. The analysis of Mine Pit samples in the Jagannath Mine Pit from the sampling campaign in January 2016, April 2016 and June 2016 also does not indicate any increase in the concentration of trace elements with time. There is no impact of the ash disposal at the Mine Void on the water quality in the Pit.

xiii. The particle size analysis of the fly ash sample also indicates that 35.11% and 55.53% of the ash particles are in the size range 0-10 µm and 10-100 µm respectively. These fine particles lead to very low permeability in the ash matrix which can retard the movement of trace elements.

xiv. The radio activity analysis of the radio nuclides indicates that the activity is below the limits set by the AERB guidelines.

xv. The solute transport modelling for conservative parameters indicate the plumes moving approximately 700m over a 30 year period (starting from March 2014). The movement will be significantly less for trace elements since they undergo retardation. Depending on the retardation factor of the particular trace element in the given hydrogeological setting, the movement of the trace element will vary.

xvi. The trace element concentration in the plant species has been found to be within limits. The Bioassay tests also indicated that mortalities were not observed in the test samples.

Based on the comprehensive study starting from May 2014 and sampling spread over the last 2 years, it is concluded that the trace element in the Mine Pit has not increased with time and the concentration in the wells close to the Mine Pit is also not increasing. The leaching tests also confirm the insignificant leaching and the radioactive activity is also within the limits. The flow and solute transport model prediction for trace element will be considerably less that that predicted for conservative elements (700m over a 30 yr period). As there is no adverse impact on the environment, the ash disposal may be continued further and EC may be accorded.

It is desired that the BSL may continue with the monitoring as recommended below.

6.2 Recommendations

i) It is essential that stringent monitoring of trace elements and pH in the pit water be carried out quarterly.

ii) The piezometers installed in the upstream and downstream of the mine pit should be used for monitoring of major cations, anions and trace elements (including As, Pb, Hg). The monitoring should also be carried out in pre-monsoon and post-monsoon.

iii) The water level in the piezometers should also be monitored quarterly to see whether the ash disposal is leading to any head build up in the immediate vicinity of the pit.

iv) BSL need to have a systematic repository of the water chemistry data from the mine pit and key observation wells in the study area which should include the two piezometers installed.

v) BSL need to have a systematic repository of the water chemistry data from the mine pit and key observation wells in the study area which should include the piezometers/wells installed by BSL.

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