एनटीपीसी
NTPC

एनटीपीसीलिमिटेड
(भारत सरकार का उद्यम)

NTPC LIMITED

(A Govt. of India Enterprise)

तालचेर थर्मल / Talcher Thermal

Ref. : TTPS/EMG/C-9/61
Date : 28.10.2020

To

Additional Principal Chief Conservator of Forests (C),
Ministry of Environment, Forest and Climate Change,
Regional Office (EZ), A/3, Chandersekharpur,
Bhubaneswar – 751023
Tel. No. 0674- 2301213, 2302432
Fax No.0674- 2302432
Email: roez.bsr-mef@nic.in

Sub: Half yearly Compliance of MoEF&CC Permission letter no.J-11015/276/2011-IA.II(M) dated. 19.04.2017.

Dear Sir,

Please find enclosed herewith Half yearly Compliance of MoEF& CC letter no. J-11015/276/2011-IA.II(M) dated. 19.04.2017 regarding permission for disposal of fly ash (1.2 MTPA) generated from 460 MW Talcher TPP of M/s. NTPC Ltd. into mine void of South Balanda OCP of M/s. Mahanadi Coalfields Ltd., in Talcher Coalfields, District, Angul, Odisha. Compliance period from April 2020 to September 2020.

Thanking you,

Yours faithfully,

28.10.2020

(Sujit Mukherjee)
AGM (EMG/AU)
NTPC/TTPS

Encl : As above.

CC:

1. **Central Pollution Control Board**
   Kasba New Market, Sector E, East Kolkata Twp, Kolkata, West Bengal -700107
2. **The Member Secretary,**
   SPCB, Odisha, Paribesh Bhawan,
   A/118, Nilakantha Nagar, Unit- VIII, Bhubaneswar -751 012

Half yearly Compliance of MOEF&CC Environmental Clearance letter no. J-11015 / 276 /2011-IA.II (M) dated 19.04.2017

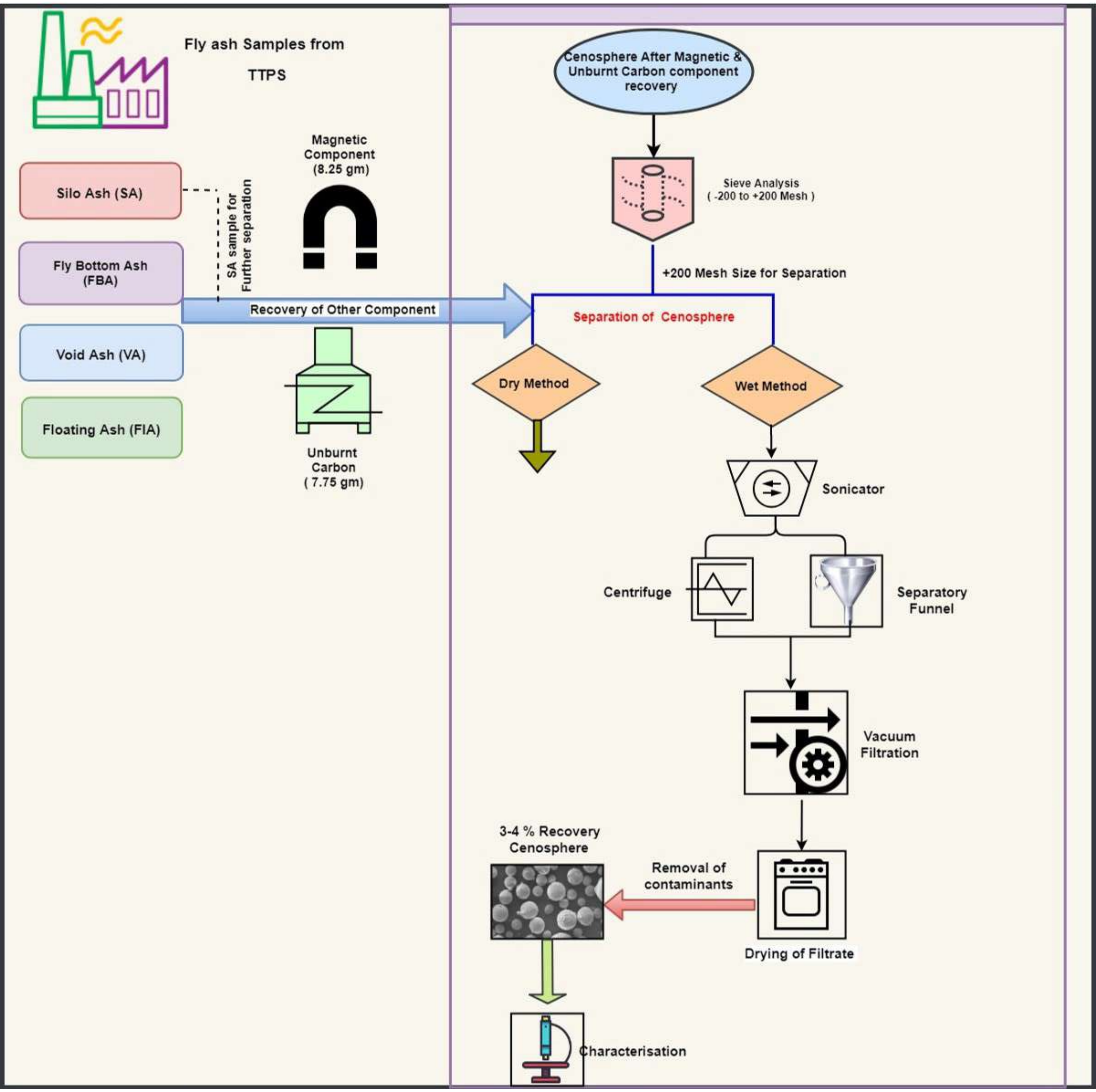
Compliance Period: October 2019 to March 2020

Half Yearly Compliance of Environmental Clearance dated 19.04.2017 for permission of disposal of fly ash (1.2 MTPA) generated from 460 MW Talcher TPP of M/s NTPC Ltd. into mine void of South Balanda OPC of M/s Mahanadi Coalfields Ltd., in Talcher Coalfields, District, Angul, Odisha.

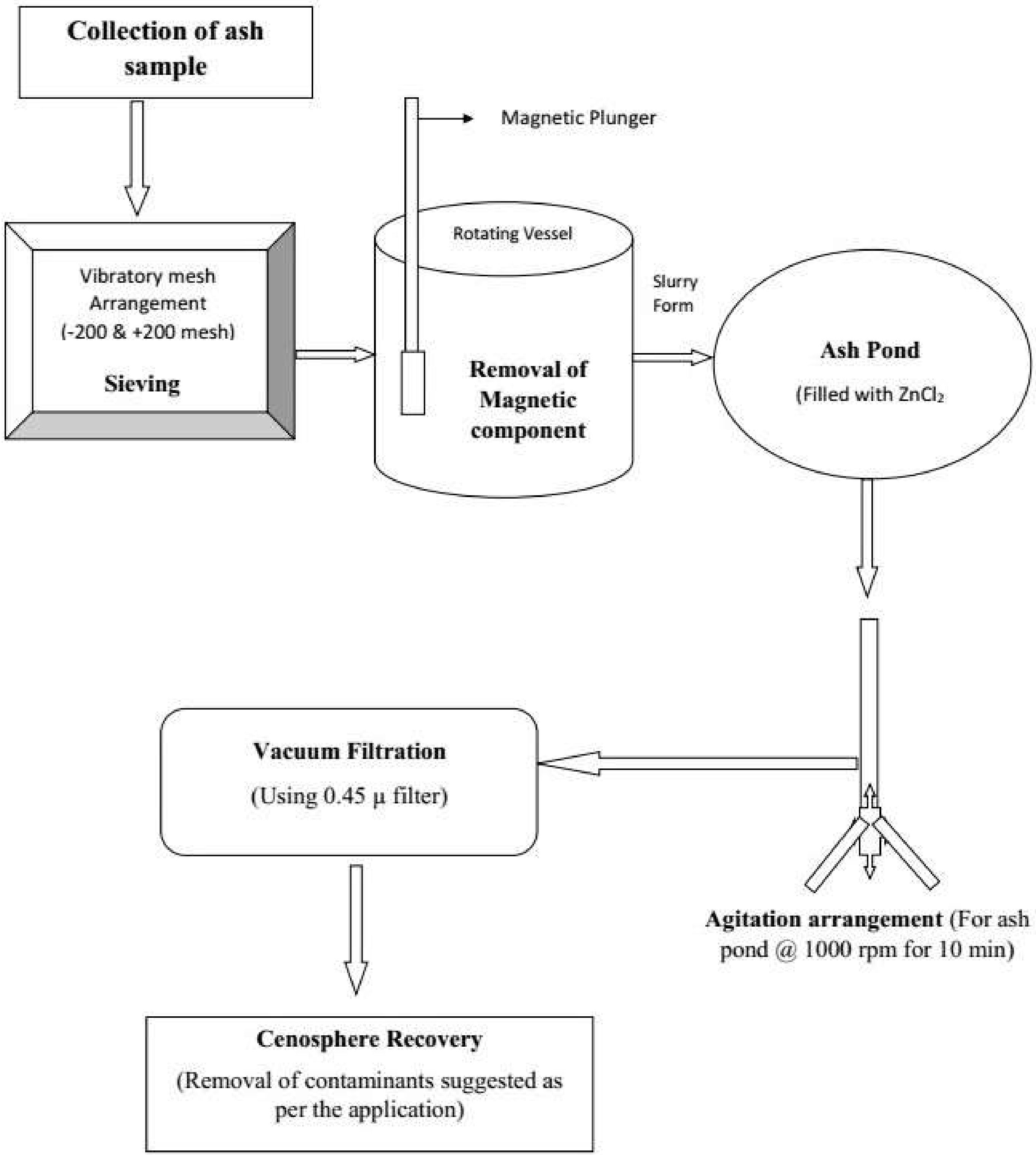
S. No.	EC Stipulation in EC letter dated 19.04.2017	NTPC Talcher TPP response as on 31.03.2020
10	The matter was placed before the Re-constituted Expert Appraisal Committee (Thermal Power) in its 4th Meeting held on 16.03.2017. In acceptance of the recommendation of the Re-constituted Expert Appraisal Committee (Thermal Power) and in view of the information / clarification furnished by you, with respect to the above project, the **Ministry hereby accords the permission to continue the disposal of fly ash for the maximum quantity of 1.2 MTPA on temporary basis for a further period of five years w.e.f. from 10.04.2017** subject to following conditions.	
i.	A pilot project shall be explored for implementation for Cenosphere extraction from flyash and manufacturing of by-products in consultation with organizations like CSIR, ISM (IIT) Dhanbad.	Awarded to M/s NEERI, Nagpur. A Prototype unit of 10 Kg ash capacity has been fabricated by M/s NEERI. Details are enclosed as **Annex-I**.
ii.	As recommended by NEERI, Ash characterisation, hydro-geological studies, leachability of trace metals, monitoring of trace elements in the supernatant, pH of the water and the piezometers on a quarterly basis and reports shall be submitted to the Ministry and it's regional office annually.	Awarded to M/s NEERI, Nagpur. 3rd year Interim Report is enclosed as **Annex-II**
iii.	Radio tracer studies shall be continued once in six months and the findings of the study shall be submitted to the Ministry and its Regional office annually.	Awarded to BRIT, Mumbai. The report submitted by M/s BRIT is enclosed as **Annex- III.**
iv.	Bioaccumulation and bio-magnification tests shall be conducted on surrounding flora and fauna (tree leaves, vegetation, crop yields and cattle population etc) during pre-monsoon and post monsoon to find out any trace metals escaped through groundwater or runoff and the reports shall be submitted to the Ministry annually.	Awarded to NBRI, Lucknow second Year interim report enclosed as **Annex-IV.**
v.	Surface runoff and supernatant water, in any case shall not be let into surroundings. It shall be collected by providing adequate drains around the mine. As proposed the supernatant water along with surface runoff shall be	The supernatant water along with surface runoff is being treated and re-used for ash mixing and plant operations. Surface runoff and supernatant water are not being discharged outside.

S. No.	EC Stipulation in EC letter dated 19.04.2017	NTPC Talcher TPP response as on 31.03.2020
	treated and re-used for ash mixing and plant operations. Surface and ground water quality along with existing piezometric wells shall be monitored quarterly and the reports shall be submitted to the Ministry annually.	As mentioned in (ii) above, Awarded to M/s NEERI, Nagpur. 2nd year Interim Report is enclosed as **Annex-II**
vi.	After the mine void reaches its full capacity, 30 cm sweet soil lining and proper compacting be provided on the top to avoid any wash off during rainy season. Reclamation activities along with greenbelt development shall be carried out in consultation with M / s MCL in accordance with approved Mine Closure Plan. An action plan in this regard shall be submitted to the Ministry and its Regional Office.	As the mine void reached its full capacity, 1 m top soil followed by green cover will be provided
vii	Only decanted water from mine, make up water from treated effluents such as cooling tower blow down and treated sewage water shall be used from making ash slurry. Raw water withdrawal from Brahmani river for purpose of making ash slurry shall be minimized. Downstream impacts of water withdrawal from Brahmani River shall be studied and report submitted to the Ministry.	Decanted water from mine, make up water from treated effluents such as cooling tower blow down and treated sewage water are being used for making ash slurry. Raw water withdrawal from Brahmani river for purpose of making ash slurry has already been minimized/optimized. Study on downstream impacts of water withdrawal from Brahmani River. Awarded to NIH, Roorkee. Final report enclosed as **Annex-V**
viii.	Mercury in fly ash shall be periodically monitored by Inductively Coupled Plasma Mass Spectrometry (ICP-MS)	Being studied with Sr. No. ii under Ash characterisation, hydro-geological studies, leachability of trace metals, monitoring of trace elements in the supernatant.
ix.	Details of month-wise quantity of fly ash disposed and water consumption along with nature of water shall be submitted to Ministry.	Annual report of Ash utilization is being submitted to MOEF&CC. Besides this, Annual Environmental Statement containing ash utilization and Water consumption for various purposes is being submitted to SPCB, Odisha.
x.	Half-yearly Compliance report for all the stipulated condition in this permission shall be submitted to the Ministry and its Regional Office	Being complied.
xi.	The fly ash utilization shall be in compliance with Fly ash Notification and	Fly ash is being used in preparation fly ash bricks and supply to other user industries. Balance ash is being

S. No.	EC Stipulation in EC letter dated 19.04.2017	NTPC Talcher TPP response as on 31.03.2020
	its amendments issued from time to time by the Ministry.	utilized in filling of abandoned South Balanda Mine Voids of MCL.
xii.	Third party evaluation / Environment Audit shall be conducted annually form reviewing the compliance conditions stipulated in the clearances along with the baseline data / studies to be carried out during the period of temporary permission.	Third party Audit is carried out and report enclosed as **Annex-VI.**
xiii.	Compliance of EC / amendment conditions, Environment (Protection) Act. 1986, Rules and MoEF&CC Notifications issued time to time shall be done by an Environment Officer to be nominated by the Project Head of the Company who shall be responsible from implementation and necessary compliance timely.	Head (Env. Management Group/Ash Utilization) department is responsible for implementation & necessary compliance timely.
11.	All other studies & conditions prescribed in the earlier permissions dated 05.09.2013, 02.03.2015 and 11.04.2016 shall also be complied with by NTPC and other concerned, as applicable.	All other studies & conditions prescribed in the earlier permissions dated 05.09.2013, 02.03.2015 and 11.04.2016 are being complied.
12.	Any appeal against this permission shall lie with the National Green Tribunal, of preferred, within 30 days as prescribed under Section 16 of the National Green Tribunal Act. 2010.	Noted.



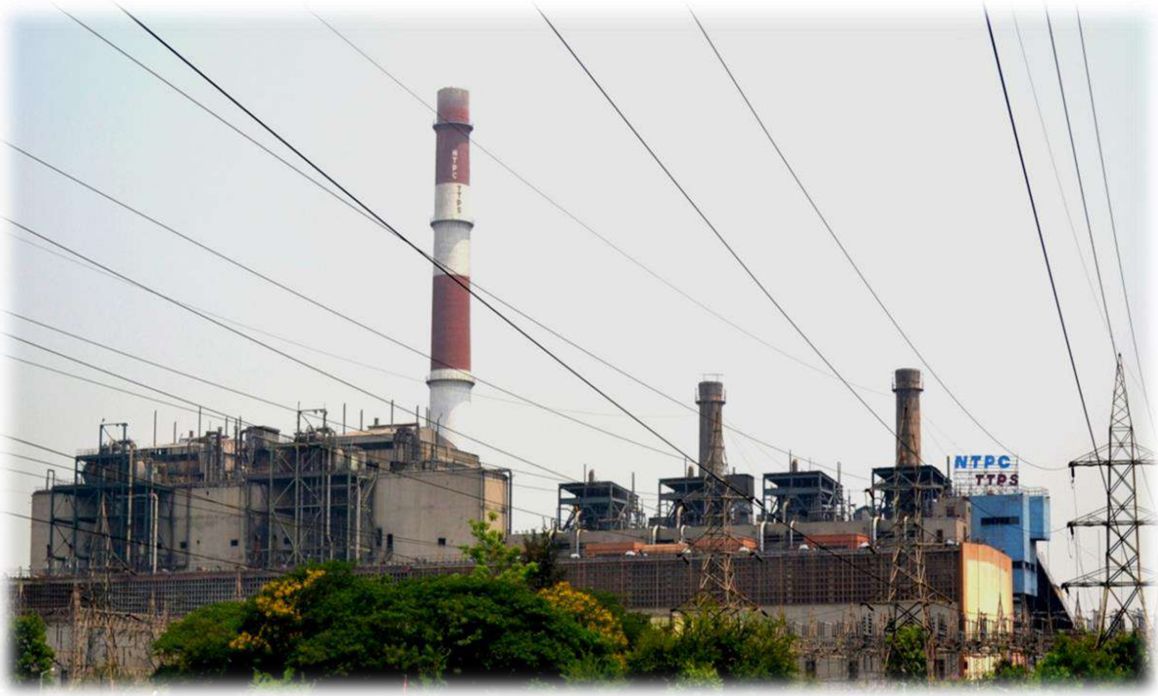
Fly ash Samples from
TTPS
Silo Ash (SA)
Fly Bottom Ash (FBA)
Void Ash (VA)
Floating Ash (FIA)
SA sample for Further separation
Magnetic Component (8.25 gm)
Recovery of Other Component
Unburnt Carbon (7.75 gm)
Cenosphere After Magnetic & Unburnt Carbon component recovery
Sieve Analysis (-200 to +200 Mesh)
+200 Mesh Size for Separation
Separation of Cenosphere
Dry Method
Wet Method
Sonicator
Centrifuge
Separatory Funnel
Vacuum Filtration
Drying of Filtrate
Removal of contaminants
3-4 % Recovery Cenosphere
Characterisation



Collection of ash sample
Magnetic Plunger
Vibratory mesh Arrangement (-200 & +200 mesh)
Sieving
Rotating Vessel
Removal of Magnetic component
Slurry Form
Ash Pond
(Filled with $ZnCl_2$
Vacuum Filtration
(Using 0.45 µ filter)
Agitation arrangement (For ash pond @ 1000 rpm for 10 min)
Cenosphere Recovery
(Removal of contaminants suggested as per the application)

Interim Report-III

Ash Characterization, its Leachability, Hydrogeological and Water Quality in and around Ash Filled South Balanda Mine Void



Submitted to

M/s. NTPC Limited, Talcher
Angul District, Odisha

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

NEERI
ISO 9001:2008

May 2020

Chapter 1: Introduction

1.1. Preamble

The NTPC-Talcher Thermal Power Station (TTPS) is a (4 × 60 MW and 2 × 110 MW) coal based power station situated about 15 km from the Angul town in Odisha. The power station was established by Odisha Power Generation Corporation Limited in the year of 1968. However, it was taken over by NTPC in the year of 1995.

The TTPS generates approximately 3500 tons of ash is generated per day. The potential use of fly ash for brick making in the region is insignificant. Only 1% of the fly ash is used for brick making and the rest is used for back filling of abandoned mine voids of South Balanda Open Cast Mines of Mahanadi Coalfields Limited since September 2005.

The unused fly ash and the bottom ash (in a ratio of about 80:20) are mixed with water in the ratio of 1:6 and the resultant slurry is brought to the abandoned South Balanda Mine void by large pipelines. After decantation, the supernatant water is recycled back to the project for further use in ash slurry making.

The South Balanda Mine void is spread over an area of 92.82 ha (**Figure 1.1**). The Mine void consists of three quarries, known as Quarry 2, 3A and 3B.

Figure 1.1: Ash disposal at the abandoned mine void (Quarry 3A) by Talcher Thermal Power Station (TTPS)

Before start of the ash filling, NTPC had undertaken various studies through The Central Mine Planning and Design Institute (CMPDI) in 2003. However, since intervention by Ministry of Environment, Forest and Climate Change (MOEF&CC) in 2011, NTPC engaged National Environmental Engineering Research Institute (NEERI) to undertake various studies related to Environmental Impacts of ash filling in mine voids. NEERI started studies in the South Balanda area in 2012 and since then, the study has been continuing every year during pre-monsoon and post-monsoon seasons. The studies have been undertaken in five phases as follows:

1. Impact assessment of ash fill sites of NTPC Ltd.,/ Talcher Thermal Power Station on water resources in the surrounding villages of South Balanda Mine Void and old ash pond area of Talcher Thermal Power Station (April 2012-March 2013),
2. Study of fly ash characterization of ash fill sites of Talcher Thermal Power Plant and leaching characteristics of mine void water at South Balanda mine void (October 2012-October 2013),
3. Impact Assessment of Ash Pond on Groundwater Quality in the Surrounding Area of South Balanda Mine Void of Talcher Thermal Power Station (November 2013-November 2014),
4. Monitoring of groundwater, surface water and soil in the vicinity of South Balanda Mine and old ash pond (May 2015-May 2016),
5. Integrated Hydrogeological, Geophysical, Hydrochemical and Groundwater flow and solute transport modelling studies around the ash filled South Balanda Mine Voids in Angul District, Odisha (May 2015-May 2016).

In addition, NTPC has also undertaken studies pertaining to impact on Flora, Fauna and Bio-accumulation & Bio-magnification of trace metals through NEERI and a Tracer Study through Bhabha Atomic Research Center (BARC), Mumbai. These reports were presented separately. Based on the above mentioned studies, the TTPS got Environmental Clearance to continue with the ash disposal at the mine void for a period of 5 years vide letter No: J-11015/276/2011-IA.II (M) dated 19.4.2017. The MoEF&CC has accord the permission to TTPS to continue disposal of fly ash for the maximum quantity of 1.2 MTPA on temporary basis for a further period of five years w.e.f. 10.04.2017 and directed to carry out certain studies. TTPS desired CSIR-NEERI to continue with the studies with the following scope of work for periods of 4 years vide Purchase order No4000197484-037-1027 dated 20.01.2018.

1.2. Objectives of the study

The broad objectives of the study are as follows:

- Ash characterization, hydro-geological studies, leachability of trace metals
- Periodical monitoring of Mercury in fly ash by inductively coupled Plasma Mass Spectrometry (ICP-MS)
- Monitoring of trace elements in the supernatant /decanted water, surface and ground water from nearby sources along with network of piezometric wells
- Monitoring of water quality (Physico-chemical) in the supernatant/decanted water, surface and ground water along with existing network of piezometric wells
- Nature of water used for ash slurry makeup

1.3. Scope of the work

The scope of the study includes the following aspects:

- Quarterly every year (including Pre and Post monsoon seasons) monitoring of Groundwater and Surface water quality for Physico-chemical Properties (pH, EC, TDS, Total Alkalinity, Ca, Mg, Na, K, Cl, SO_4, NO_3, and PO_4) and Trace metals (As, Ba, Cd, Co, Cr, Cu, F, Fe, Hg, Mn, Ni, Pb and Zn)
- Quarterly (every year) monitoring of chemical constituents of Fly Ash: SiO_2, Al_2O_3, Fe_2O_3, K_2O, TiO_2, CaO, MgO, Na_2O, P_2O_5, SO_3, Cr_2O_3, MnO_2, CuO, Rb_2O, SrO, Y_2O_3, Nb_2O_5 and BaO on percentage basis.
- Quarterly (every year) monitoring of Trace Elements in Fly Ash : As, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn (mg/kg, using TCLP Test)
- Quarterly (every year) monitoring of Mercury in Fly Ash using ICP-MS

1.4. Approach of the Study

The study includes the collection of Primary data (Field observations, sample collections, laboratory analysis and experiments) and secondary data (from different Govt. agencies, Reports and literature) keeping in view of the broader objectives of the project. The proposed methodology/approach for the study is described below:

a) Field visit to the study area and selection of observation wells.

b) A network of observation wells for water level measurement and groundwater sampling. The monitoring has to be done on quarterly basis which will also include the pre-monsoon and post-monsoon seasons.

c) Collection and analysis of groundwater samples of the study area for physico-chemical properties and trace metals.

d) Collection and analysis of surface water samples including samples of Mine Void supernatant/decanted water for physico-chemical properties and trace metals

e) Characterization of Ash – Analysis of chemical parameters, analysis of trace elements using Toxicity Characteristic Leaching Procedure (TCLP) test, and Mercury analysis on Inductive Coupled Plasma Mass Spectroscopy (ICP-MS)

f) Leachability studies through TCLP method

1.5. Layout of the report

The entire report has been presented in four chapters; the details of each chapter are given below:

Chapter 2: The study area details are presented.

Chapter 3: The methodology for data collection is discussed.

Chapter 4: The results for monitoring carried out in April 2018, June 2018 and November 2018, February 2019, June 2019, October 2019, February 2020 are presented in this Interim report-III.

Chapter 2: The Study Area

2.1. Location

The NTPC-Talcher Thermal Power Station (TTPS) lies in the study area 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). It is located in Talcher town in the Angul district of Odisha which is approximately 15 km from Angul city (**Figure 2.1**).

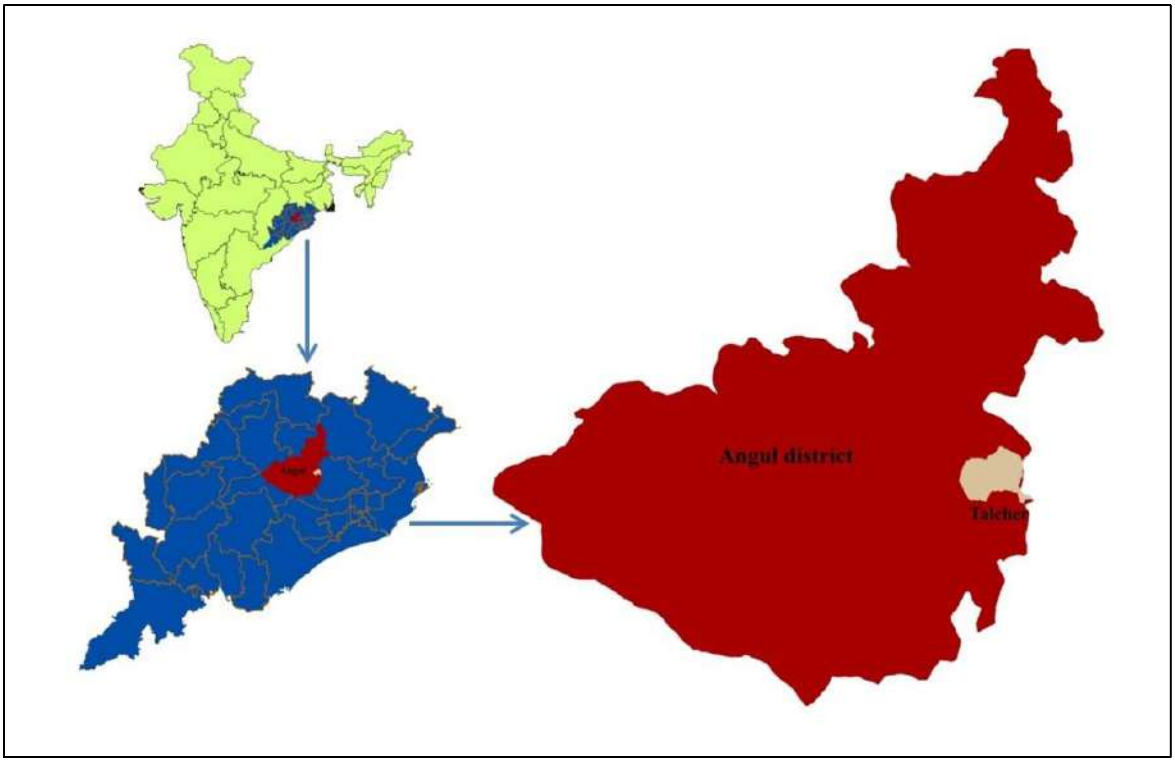


Figure 2.1: Location map of the study area

2.2. Climate

The study area experiences tropical monsoon climate with mild winter and hot summer. The average annual rainfall in the study area is approximately 1250 mm of which major amount is received during south west monsoon which is active during the period June to September.

2.3. Physiography and Land use

The study area constitutes northern part of Angul district. The area is mainly drained by the Brahmani River. The area constitutes various physiographic features such as alluvial plain, mountain ranges, flood plains and water bodies. The elevation of the area above mean sea

level (amsl) ranges from 49 m to 119 m and the slope is towards the south-east direction (**Figure 2.2**).

2.4. Geological setup

The study area is predominantly characterized by rocks of the Gondwana Super Group (**Figure 2.3**). The rock comprises 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. The abandoned South Balanda Mine is characterized by the Barakar formations underlain by pebbly sandstones and then the Karhabari formation (**Table 2.1**). The coal seams were found in the Barakar formations and the Karhabari formations. It is observed that granitoids appeared in South East and South West patches of the study area. Sandstone and Shale underlie the Karhabari formations (**Table 2.1**).

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 mantle, recent alluvium and the laterites and under semi-confined to confined condition in the fracture zone. The groundwater abstraction sources are mainly the open wells and India Mark-II hand pumps which are used to meet the domestic and drinking water requirements in the study area. The groundwater abstraction for agricultural requirement is almost insignificant.

Table 2.1: Local geology of South Balanda Block (CMPDI Report, 2003)

Age	Formation	Lithology	Thickness
Quaternary	Recent	Soil and sub-soil	0.86 m
Lower Permian	Baraker	Sandstone	6.1 m - 15.25 m
		Seam II	7.38 m - 48.92 m
		Pebbly sandstone	60 m (approx.)
Lower Permian	Karharbari	Sandstone	60 m -75 m
		Seam I	0.61 m - 18.16 m
		Sandstone	About 135m
Upper carboniferous to Lower Permian	Talchir	Sandstone and Shale	-

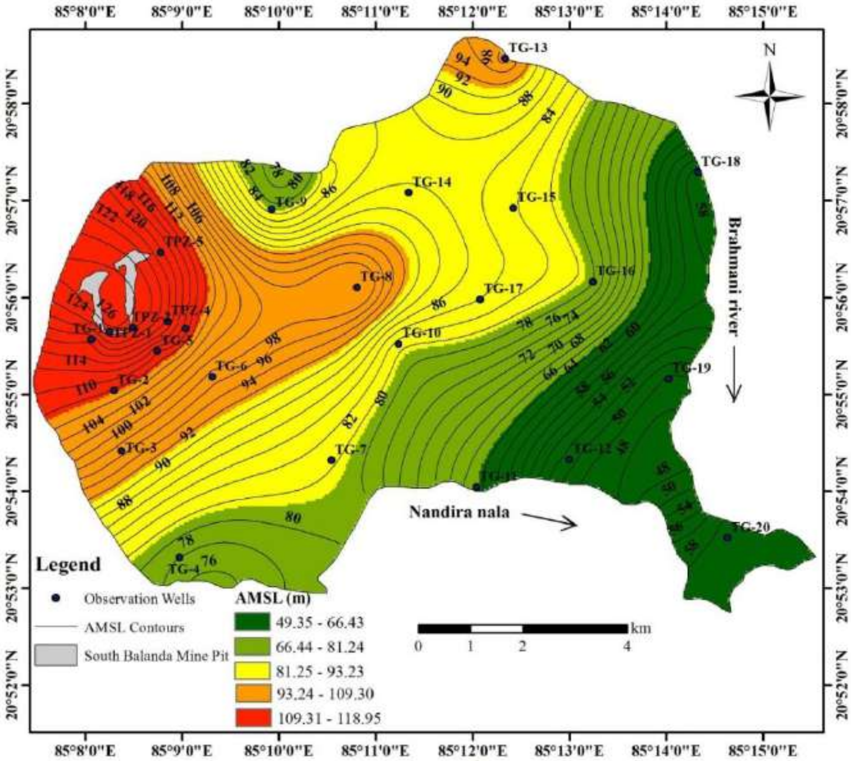


Figure 2.2: Elevation, location of observation wells and Mine Pits in the study area

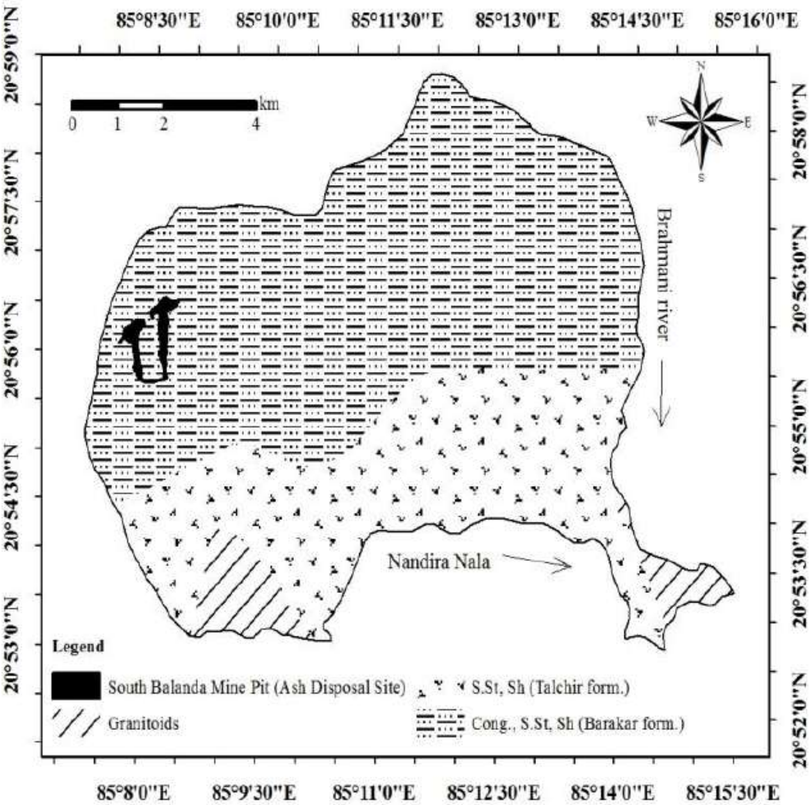


Figure 2.3: Geology map of the study area (after GSI, 2010)

Chapter 3: Methodology

3.1. General

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

- Delineation of the study area on the basis of watershed principle and setting up a network of observation wells
- Measurement of groundwater levels in the study area
- Collection and analysis of groundwater samples in the study area
- Collection and analysis of Mine Void water samples
- Chemical characterization of fly ash (SiO_2, Al_2O_3, Fe_2O_3, K_2O, TiO_2, CaO, MgO, Na_2O, P_2O_5, SO_3, Cr_2O_3, MnO_2, CuO, Rb_2O, SrO, Y_2O_3, Nb_2O_5 and BaO**)**
- Mercury in fly ash
- Leachability studies through TCLP

3.2. Delineation of the study area and establishing observation well network

The study area has been delineated on the basis of watershed principle (**Figure 3.1**). The delineation is carried out by using the Survey of India Toposheet (F45 T/1 and F45 T/5 on 1:50,000 scale). A network of observation wells has been set up in the study area (Table 3.1). The observation well network includes India Mark-II hand pumps, open wells and piezometers installed by the TTPS. The study area covers an area of 89.52 sq. km. The co-ordinates (latitude/longitude) of the observation wells were noted with the help of hand held GPS of Garmin make. The details of the wells are presented in **Table 3.1**. It is ensured that the observation wells are located within 0.5 km, 1.0 km, 5.0 km and 10 km radius buffer zone (**Figure 3.1**). The Piezometers are located at a distance of 70m to 500m (**Figure 3.1**) from the Mine Void (

Table 3.2). The observation wells were identified in the study area in well representative manner so that the observation wells falls in all the land use pattern of the study area and during selection of observation wells it was also ensured that observation wells must cover the upstream and downstream area of the Ash ponds. Some of the sampling points were identified close to the disposal site i.e. the South Balanda Mine Void.

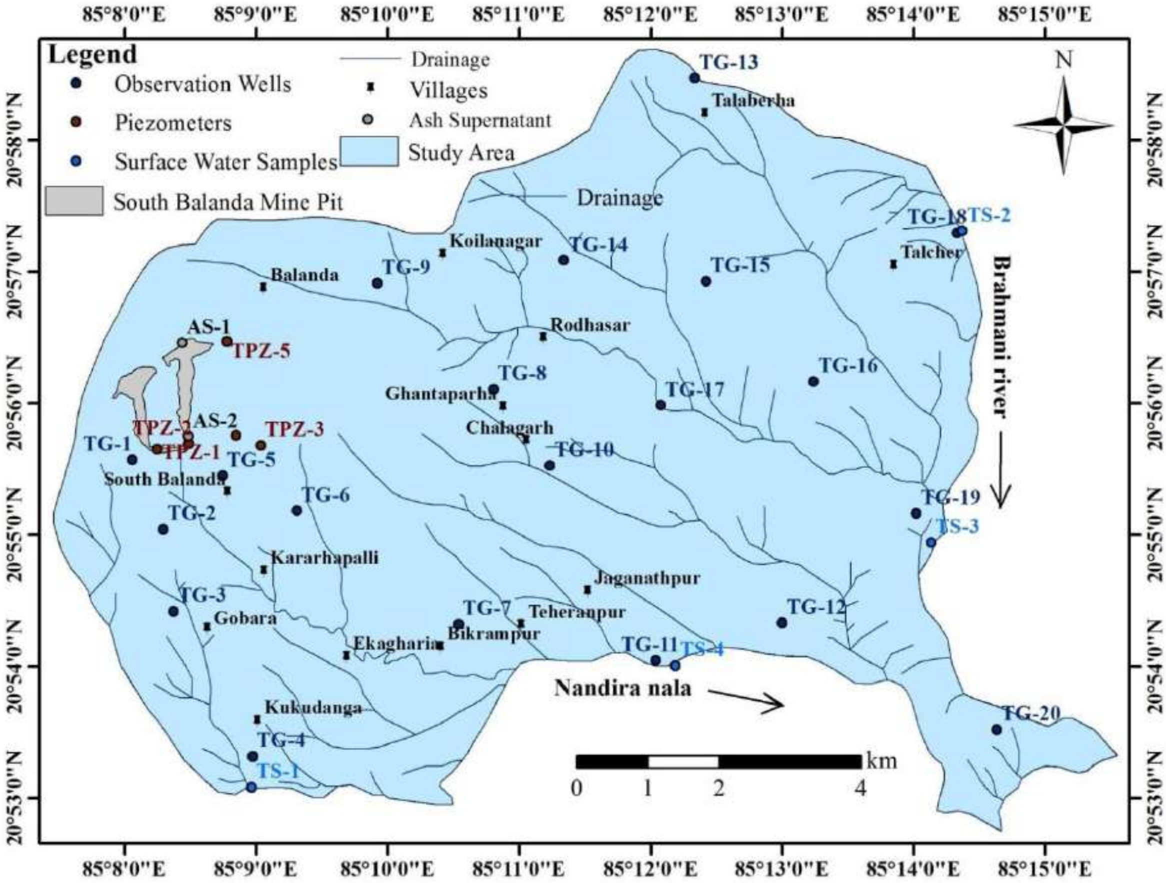


Figure 3.1: Base map of the study area

Table 3.1: Details of observation well network and surface water sampling locations in the study area

Source ID	Latitude	Longitude	Source	Description
TG-1	20° 55' 34.1"	85° 08' 03.6"	HP	Bharatpur gobara chowk, near truck garage, Temple
TG-2	20° 55' 02.2"	85° 08' 17.7"	HP	Chikkamunda village, Badasinghada, on the RHS of road from Bharatpur to Gobara
TG-3	20° 54' 25.2"	85° 08' 22.1"	HP	Gobara village center, after temple
TG-4	20° 53' 19.5"	85° 08' 57.9"	HP	Kukudanga village, LHS of the road towards Gobara, beside grinding mill

Source ID	Latitude	Longitude	Source	Description
TG-5	20° 55' 27.1"	85° 08' 44.6"	HP	MCL staff quarters, near Maa Tarini temple, south Balanda
TG-6	20° 55′ 11.0″	85° 09′ 18.4″	HP	Laxmanpur village near Balanda village, RHS of the road, beside the temple
TG-7	20° 54′ 19.4″	85° 10′ 32.0″	HP	RHS of the road towards NALCO, opposite to Shri Ganesh petrol pump, Bidyuth colony, Bikrampur
TG-8	20° 56′ 06.3″	85° 10′ 48.4″	HP	Ghantapada village, LHS of the road towards Chalagarh village, beside Pawan Biswal house
TG-9	20° 56′ 54.8″	85° 09′ 55.1″	HP	Dera village, inside primary school, LHS of the road towards Jagannath mine pit
TG-10	20° 55' 31.5"	85° 11' 14.1"	DW	On the Talcher-Chalagada road
TG-11	20° 54' 2.8"	85° 12' 02.0"	HP	Jagannathpur village, beside Madan Mahaparta village
TG-12	20° 54′ 19.5″	85° 12′ 59.5″	HP	LHS of the road towards TTPS, beside Talcher Thermal railway station
TG-13	20° 58′ 28.3″	85° 12′ 20.2″	HP	Talabeda village, RHS of the road towards Talcher road
TG-14	20° 57' 05.4"	85° 11' 20.1"	HP	Langida village, near Giridhar Maharana house
TG-15	20° 56' 56.2"	85° 12' 25.4"	HP	Deulabeda, in chouk near Shani Temple
TG-16	20° 56' 08.6"	85° 13' 20.7"	DW	Baghuabol village
TG-17	20° 55' 58.9"	85° 12' 04.9"	HP	On LHS of the road from Talcher station to Hatatota
TG-18	20° 57′ 17.7″	85° 14′ 19.7″	HP	Talcher town, beside Jagannath Mandir, LHS of the road towards Talabeda village
TG-19	20° 55′ 09.7″	85° 14′ 00.8″	HP	Santhapada village, RHS of the road towards Brahmani River
TG-20	20° 53' 30.9"	85° 14' 37.4"	HP	Village Jhadianba, near cowshed, besides drainage
TS-1	20° 53' 3.33"	85° 9′ 36.00″	SW	Upstream of Nandra Nala
TS-2	20° 57' 18.56"	85° 14′ 22.16″	SW	Upstream of Brahmani River
TS-3	20° 54' 56.47"	85° 14′ 7.98″	SW	Downstream of Brahmani River
TS-4	20° 54' 0.46"	85° 12′ 11.28″	SW	Downstream of Nandra Nala

* LHS-left hand side; RHS-right hand side; DW-dug well; HP-hand pump, SW-Surface water; NA-Not Available

Table 3.2: Piezometer locations near the South Balanda Mine Void

Piezometer ID	Latitude	Longitude
TPZ-1	20°55'38.90"N	85° 8'14.90"E
TPZ-2	20°55'41.40"N	85° 8'29.25"E
TPZ-3	20°55'40.70"N	85° 9'2.10"E
TPZ-4	20°55'45.30"N	85° 8'51.00"E
TPZ-5	20°56'28.10"N	85° 8'46.60"E

3.3. Groundwater level measurement

The water level from observation well network (**Figure 3.2**) 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).

Figure 3.2: Water level measurements in the study area

3.4. Groundwater and surface water sampling and analysis

The groundwater and surface water samples are collected from all the selected observation wells, piezometers and from surface water bodies (Brahmani River and Nandra Nala) (**Figure 3.3**). For physico-chemical parameters and metal analysis, samples were collected in pre-cleaned 500 ml and 100 ml polyethylene bottles respectively. Concentrated HNO_3 was added in the metal samples for preservation. Onsite parameters like pH, water temperature and Electrical Conductivity was measured in the field using probes. The physico-chemical parameters were analyzed by following the standard protocols (APHA, 2012). The trace metals (Fe, Mn, Zn, Pb, Cd, Cr and Cu) analysis was done by using ICP-OES (Model iCAP 6300 DUO, Make: Thermo Scientific). The detection limit for Fe, Mn, Zn, Pb, Cd, Cr and

Cu is 0.0003 ppm, 0.018 ppm, 0.0002 ppm, 0.05 ppm, 0.009 ppm, 0.0006 ppm and 0.0004 ppm respectively. The parameters namely Na and K are analyzed by Flame Photometer (Model- CL361, Make: ELICO). The samples are also analyzed for the major cations and anions.

Figure 3.3: Surface water sampling from the Nandra Nala

3.5. Mine void water sampling

Supernatant samples were collected from the Mine void i.e. Quarry 2 and 3B. The samples were analyzed for the major cations, anions and trace metals.

3.6. Characterization of Ash

The fly ash samples were analyzed for the Toxicity Characteristic Leaching Procedure (TCLP) and total mercury concentration by digestion method.

3.6.1. Trace elements

The total leachable and non-leachable heavy metal concentration was determined by acid digestion method of EPA 3050B. The samples were taken in triplicates to avoid errors. After digestion the sample was filtered and analyzed by ICP-MS.

3.6.2. TCLP test

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 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). The fly ash and bottom ash sample was collected from the ash generation unit of NTPC-TTPS and analyzed using the TCLP test. Standard leaching procedure has been developed for the assessment of the mobility of hazardous substances into an aqueous phase and for the evaluation of their environmental impacts.

Table 3.3: Description of leaching test

Tests Condition	**EPA 3050B (Total concentration of trace elements)**
Heavy metal concentration	Leachable + Non-leachable
Leaching Solution	Nitric acid+ Hydrogen peroxide
Liquid to solid ratio	100:1
pH	< 2
Digestion/ Leaching time(h)	6 hrs
Temperature (˚C)	95
Number of samples	1

4.1. Groundwater Level

The groundwater level was monitored in the study area, from the identified hand pumps, dug wells and piezometers, in the month of April 2018, June 2018 and November 2018. The groundwater level in the study area ranges from **1.37 to 26.23 m BGL, 0.7 to 24.61 m BGL, 0.74 to 21.82 m BGL, 1.78 to 42.78 m BGL, 2.13 to 25.7 m BGL, 0.44 to 34.92 m BGL and 1.04 m to 31.85 m BGL** in the month of April 2018, June 2018, November 2018, Feb 2019, June 2019, October 2019 and February 2020 respectively (**Table 4.1)**.

Table 4.1: Groundwater level data in the study area

Source ID	Well Type	BGL (m) April 2018	BGL (m) June 2018	BGL (m) November 2018	BGL(m) Feb 2019	BGL (M) June 2019	BGL (m) October 2019	BGL (m) Feb 2020
TG-1	HP	9.4	9.87	8.53	7.68	13.56	10.37	14.12
TG-2	HP	NA	NA	NA	11.13	6.74	4.92	NA
TG-3	HP	4.52	1.76	1.69	2.81	4.19	1.53	8.45
TG-4	HP	7.55	6.39	3.09	7.2	6.7	2.64	7.9
TG-5	HP	2.1	1.53	2.2	2.09	2.3	1.73	1.8
TG-6	HP	3.24	3.48	3.4	2.33	4.78	1.92	2.1
TG-7	HP	NA	24.61	21.82	18.45	22.46	19.8	17.4
TG-8	HP	9.32	8.4	4.88	6.55	8	3.31	5.6
TG-9	HP	26.23	20.23	12.97	18.98	21.76	NA	16.4
TG-10	DW	2.83	0.7	0.91	1.78	2.45	0.84	1.4
TG-11	HP	NA	NA	NA	23.77	22.32	17.5	21.2
TG-12	HP	11.23	11.6	9.81	10.39	16.06	16.76	8.7
TG-13	HP	5.07	21.15	15.06	17.08	20.15	15.55	19.4
TG-14	HP	NA	NA	NA	42.78	4.21	34.92	40.1

Source ID	Well Type	BGL (m) April 2018	BGL (m) June 2018	BGL (m) November 2018	BGL(m) Feb 2019	BGL (M) June 2019	BGL (m) October 2019	BGL (m) Feb 2020
TG-15	HP	9.96	3.91	4.7	4.35	3.93	4.3	4.2
TG-16	DW	2.65	1.02	0.74	1.79	2.13	0.44	1.56
TG-17	HP	1.37	2.15	2.4	5.73	4.45	2.54	5.6
TG-18	HP	12.77	14.02	9.55	4.98	5.35	3.27	4.6
TG-19	HP	18.30	14.85	14.61	5.97	25.7	12.04	31.85
TG-20	HP	11.19	10.9	8.55	9.97	9.65	9.34	16.43

* DW – dug well; HP – hand pump; NA-Not Available

The piezometers installed in the study area had the groundwater level in the range of **0.73 to 7.69 m BGL, 0.71 to 6.23 m BGL and 0.45 to 4.23 m BGL, 0.6 to 5.44 m BGL, 0.43 to 4.11 m BGL, 0.18 to 4.35 m BGL** in the month of April 2018, June 2018, November 2018, Feb 2019, June 2019 and October 2019 respectively **(Table 4.2)**.

Table 4.2: Groundwater level data of Piezometers installed in the study area

Piezometer ID	BGL (m) April 2018	BGL (m) June 2018	BGL (m) November 2018	BGL (m) Feb 2019	BGL (m) June 2019	BGL (m) October 2019	BGL (m) Feb 2020
TPZ-1	0.73	0.95	0.45	0.6	0.43	2.22	0.5
TPZ-2	1.21	NA	NA	0.74	1.08	0.18	0.6
TPZ-3	2.95	0.71	0.89	4.35	4.11	3.51	4.4
TPZ-4	5.13	4.83	4.23	5.44	3.46	4.35	5.23
TPZ-5	7.69	6.23	3.82	*	*	*	*

*****measurement could not be taken due to collapse of the Piezometre

4.2. Ground water and Surface water quality

A total of 31 water samples were collected from nearby groundwater sources, surface water and from piezometers installed in the study area for the analysis of physico-chemical properties and trace metal concentrations. The water quality results were compared with the acceptable and permissible limits of drinking water specification BIS 10500:2012.

4.2.3. Physico-chemical Analysis

The physicochemical results of the water samples collected in the month of April 2018 **(Table 4.3 (a))**, June 2018 **(Table 4.3 (b))** and November 2018 **(Table 4.3 (c))** shows that some of the collected samples do not meet the overall drinking water specification BIS 10500:2012. The results of physico-chemical analysis for each parameter are as follows:

pH-

pH in April 2018

The pH **(Table 4.3 (a))** of all the collected groundwater and surface water samples taken in the month of April 2018 was found well within acceptable limits of BIS 10500:2012 drinking water specification.

pH in June 2018

The pH **(Table 4.3 (b))** for samples TG-17, TG-19 and TG-20 taken in the month of June 2018 were more than acceptable limit of BIS 10500:2012.

pH in November 2018

The pH **(Table 4.3 (c))** for the samples TG-9, TG-17 and TPZ-2 taken in the month of November 2018 showed below acceptable limit of BIS 10500;2012.

pH in February 2019

The pH **(Table 4.3 (d))** of all the water samples taken in the month of February 2019 were found above acceptable limits but well within the permissible limits 10500:2012 drinking water specification.

pH in June 2019

The pH **(Table 4.3 (e))** of all the water samples taken in the month of June 2019, accept for TG-8 & TG-9 were found above acceptable limits but all samples were well within the permissible limits 10500:2012 drinking water specification.

pH in October 2019

The pH **(Table 4.3 (f))** of all the water samples taken in the month of October 2019 were found above acceptable limits but well within the permissible limits 10500:2012 drinking water specification.

Total Dissolved Solids (TDS)-

April 2018

The TDS **(Table 4.3 (a) & Figure 4.3 (a))** in water samples collected in the month of April 2018 with code: TG-3, TG-4, TG-3, TG-6, TG-7, TG-11, TG-12, TG-17, TG-19, TPZ-3-T and TPZ-8-T were found above acceptable limit whereas all other samples were well within acceptable and permissible limits of BIS 10500:2012 drinking water specification.

June 2018

The TDS **(Table 4.3 (b) & Figure 4.3 (b))** in water samples with code: TG-3, TG-4, TG-6, TG-7, TG-11, TG-12, TG-13, TG-17, TG-19, TG-20, TPZ-3 and TPZ-5 were found above acceptable limit of BIS 10500:2012, whereas all other samples were well within the permissible limits of BIS 10500:2012 drinking water specification.

November 2018

The TDS **(Table 4.3 (c) & Figure 4.3 (c))** in water samples with code: TG-2 was the only one found to be above acceptable limit of BIS 10500:2012, whereas all other samples were well within acceptable and permissible limits of BIS 10500:2012 drinking water specification.

February 2019

The TDS **(Table 4.3 (d) & Figure 4.3 (d))** in water samples with code: TG-3, TG-4, TG-6, TG-16, TG-17, TG-19 & TPZ-4 was found to be above acceptable limit of BIS 10500:2012. However, rest of the samples were well within permissible limits of BIS 10500:2012 drinking water specification.

June 2019

The TDS **(Table 4.3 (e) & Figure 4.3 (e))** in water samples with code: TG-3, TG-4, TG-6, TG-13, TG-14, TG-19, TPZ-2 & TPZ-4 was found to be above acceptable limit of BIS 10500:2012. However, rest of the samples were well within permissible limits of BIS 10500:2012 drinking water specification.

October 2019

The TDS **(Table 4.3 (f) & Figure 4.3 (f))** in water samples with code: TG-3, TG-4, TG-6, TG-9, TG-11, TG-12, TG-13, TG-17, TG-19, & TPZ-4 was found to be above acceptable limit of BIS 10500:2012. However, rest of the samples were well within permissible limits of BIS 10500:2012 drinking water specification.

Turbidity-

April 2018

The turbidity **(Table 4.3 (a))** in most of the samples was found above acceptable/permissible limit of BIS 10500:2012 drinking water specification. The turbidity in samples with sample code: TG-4, TG-12, TG-13, TPZ-2B, TPZ-2T, TPZ-4T, TPZ-5T were found above acceptable limit.

June 2018

The turbidity **(Table 4.3 (b))** in all of the samples was found above acceptable limit of BIS 10500:2012 and most of them were above the permissible limit of BIS 10500:2012 drinking water specification. The only two samples that were below the permissible are TG-3 and TG-12, remaining all were above the permissible limit.

November 2018

The turbidity **(Table 4.3 (c))** in all of the samples was found above acceptable limit of BIS 10500:2012 and the samples TG-1, TG-2, TG-3, TG-4, TG-5, TG-6, TG-7, TG-8, TG 9, TG 13, TG 14, TG 15, TG 18, TG 20, TPZ-1, TPZ-4 and TPZ-5 was found above the permissible limit of BIS 10500:2012 drinking water.

February 2019

The turbidity **(Table 4.3 (d))** in all of the samples was found above the permissible limit of BIS 10500:2012 drinking water specification.

June 2019

The turbidity **(Table 4.3 (e))** in the samples TG-7, TG-8, TG-20, TPZ-2 and TPZ-3 was found above acceptable limit of BIS 10500:2012 and in the samples TG-1, TG-5, TG-9, TG-12, TG-18, TPZ-1 & TPZ-4 was found above the permissible limit of BIS 10500:2012 drinking water.

October 2019

The turbidity **(Table 4.3 (f))** in the samples TG-7, TG-8, TG-18, TG-20 & TPZ-2 was found above acceptable limit of BIS 10500:2012 and in the samples TG-1, TG-5, TG-9, TG-12, TPZ-1 & TPZ-4 was found above the permissible limit of BIS 10500:2012 drinking water.

Total Hardness as $CaCO_3$-

April 2018

The total hardness **(Table 4.3 (a))** in the samples (TG-1, TG-8, TG-12, TG-14, TG-15, TG-16, TG-19, TG-20, TPZ-4T, and TPZ-4B) was under acceptable limit. All other samples were detected with higher total hardness as compared to BIS 10500:2012 drinking water specification. All the surface water samples were found well within acceptable limit of BIS 10500:2012 drinking water specification for total hardness.

June 2018

The total hardness **(Table 4.3 (b))** of the samples TG2, TG3, TG 4, TG 6, TG 11, TG 13, TPZ 4 and TPZ 5 were above the acceptable limit of BIS 10500:2012. However, all the samples were well within the permissible limit as prescribed in 10500:2012.

November 2018

The total hardness **(Table 4.3 (c))** of the samples TG 2, TG3, TG 6, TG 9, TG 10, TG 13, TG 19, TPZ-4 and TPZ-5 were above the acceptable limit of BIS 10500:2012. However, all the samples except TG 13 were well within the permissible limit as prescribed in 10500:2012.

February 2019

The total hardness **(Table 4.3 (d))** of the samples TG-2, TG-3, TG-4, TG-10, TG-17, TPZ-2, TPZ-3, and TPZ-4 were above the acceptable limit of BIS 10500:2012. However, all the samples except TPZ-4 were well within the permissible limit as prescribed in 10500:2012.

June 2019

The total hardness **(Table 4.3 (e))** of the samples TG-2, TG-3, TG-4, TG-5, TG-6, TG-9, TG-10, TG-13, TG-15, TPZ-2, TPZ-3, and TPZ-4 were above the acceptable limit of BIS 10500:2012. However, all the samples were well within the permissible limit as prescribed in 10500:2012.

October 2019

The total hardness **(Table 4.3 (f))** of the samples TG-2, TG-4, TG-6, TG-9, TG-12, TG-13, TG-16, TG-19, TG-20 and TPZ-2 were above the acceptable limit of BIS 10500:2012. However, all the samples were well within the permissible limit as prescribed in 10500:2012.

Total alkalinity as $CaCO_3$-

April 2018

The total alkalinity **(Table 4.3 (a))** in samples (TG-2, TG-3, TG-4, TG-6, TG-7, TG-11, TG-12, TG-13, TG-17, TG-19, TG-20, TPZ-2T, and TPZ-4T) was exceeding the acceptable limit of drinking water specification BIS: 10500:2012. However, all the surface water samples were found well within acceptable limit of BIS 10500:2012 drinking water specifications for total alkalinity.

June 2018

The total alkalinity **(Table 4.3 (b))** in the samples (TG-2, TG-3, TG-4, TG-6, TG-7, TG-11, TG-12, TG-13, TG-17, TG-19, TG-20 and TPZ-2) was exceeding the acceptable limit of drinking water specification BIS: 10500:2012. However, all the surface water samples were found well within acceptable limit of BIS 10500:2012 drinking water specifications for total alkalinity.

November 2018

The total alkalinity samples **(Table 4.3 (c))** TG-2, TG-3, TG-4, TG-6, TG-12, TG-13, TG-17 & TG-19 were above the acceptable limit of BIS 10500:2012. However, rest if the samples were well within the permissible limit as prescribed in 10500:2012.

February 2019

The total alkalinity samples **(Table 4.3 (d))** TG-2, TG-3, TG-4, TG-12, TG-17, TG-19 & TG-20 were above the acceptable limit of BIS 10500:2012. However, rest of the the samples were well within the permissible limit as prescribed in 10500:2012.

June 2019

The total alkalinity samples **(Table 4.3 (e))** TG-2, TG-3, TG-4, TG-6, TG-12, TG-13, TG-19 & TG-20 were above the acceptable limit of BIS 10500:2012. However, rest of the the samples were well within the permissible limit as prescribed in 10500:2012.

October 2019

The total alkalinity samples **(Table 4.3 (f))** TG-3, TG-4, TG-6, TG-12, TG-13, TG-19 & TG-20 were above the acceptable limit of BIS 10500:2012. However, rest of the the samples were well within the permissible limit as prescribed in 10500:2012.

Fluoride-

April 2018

Fluoride **(Table 4.3 (a) & Figure 4.3 (a))** concentration was analyzed and the samples TG-7, TG-19, and TG-20 detected with higher fluoride concentration than the acceptable limit of BIS 10500:2012 drinking water specification.

Fluoride concentration in two surface water samples (TS-1 and TS-4) were also found above acceptable limit of drinking water specification BIS 10500:2012. Whereas all other surface water samples were under acceptable limit of drinking water specification BIS 10500:2012.

June 2018

Fluoride **(Table 4.3 (b) & Figure 4.3 (b))** concentration was analyzed in all of the samples and all of them had a result below the acceptable limit as prescribed by the BIS 10500:2012.

November 2018

Fluoride **(Table 4.3 (c) & Figure 4.3 (c))** concentration for samples TG 7, TG 11, TG-20 was above the permissible limit set in BIS: 10500:2012 All the other samples were within the permissible limit.

February 2019

Fluoride **(Table 4.3 (d) & Figure 4.3 (d))** concentration for samples other than TG-20 were well within the permissible limit as prescribed in 10500:2012.

June 2019

Fluoride **(Table 4.3 (e) & Figure 4.3 (e))** concentration for samples TG-3 & TG-4 was above acceptable limits and all samples other than TG-7, TG 11, TG-19 & TG-20 were within the permissible limit as prescribed in 10500:2012.

October 2019

Fluoride **(Table 4.3 (f) & Figure 4.3 (f))** concentration for samples TG-3 & TG-4 was above acceptable limits and all samples other than TG-7, TG 11, TG-19 & TG-20 were within the permissible limit as prescribed in 10500:2012.

Nitrate-

April 2018

The concentration of Nitrate **(Table 4.3 (a) & Figure 4.3 (a))** in all the collected samples (groundwater sources, piezometers, and surface water) was found well within acceptable limit of drinking water specification BIS 10500:2012.

June 2018

The concentration of Nitrate **(Table 4.3 (b) & Figure 4.3 (b))** in all the collected samples (groundwater sources, piezometers, and surface water) was found well within acceptable limit of drinking water specification BIS 10500:2012.

November 2018

The concentration of Nitrate **(Table 4.3 (c) & Figure 4.3 (c))** in all the collected samples (groundwater sources, piezometers, and surface water) was except samples, namely TG 9 and TG 17 found well within acceptable limit of drinking water specification BIS 10500:2012.

February 2019

The concentration of Nitrate **(Table 4.3 (d) & Figure 4.3 (d))** in all the collected samples except for TG-6, TG-9 was found well within acceptable limit of drinking water specification BIS 10500:2012.

June 2019

The concentration of Nitrate **(Table 4.3 (e) & Figure 4.3 (e))** in all the collected samples except for TG-3, TG-6, TG-8, TG-9 & TG-15 was found well within acceptable limit of drinking water specification BIS 10500:2012.

October 2019

The concentration of Nitrate **(Table 4.3 (f) & Figure 4.3 (f))** in all the collected samples was found well within acceptable limit of drinking water specification BIS 10500:2012.

Sulphate-

April 2018

The sulphate **(Table 4.3 (a) & Figure 4.4 (a))** concentration in all the samples were well within acceptable limit of drinking water specification BIS 10500:2012 except samples with sample code TG-11 and TPZ-5T. The predicted Sulphate concentration within the study area (based on Sulphate concentration analyzed in collected groundwater sources including piezometers) is presented in **Figure 4.19**. Sulphate concentration in all the surface water samples was well within acceptable limits of drinking water specification BIS 10500:2012.

June 2018

The sulphate **(Table 4.3 (b) & Figure 4.4 (b))** concentration in the samples was well within acceptable limit of drinking water specification BIS 10500:2012 except samples namely, TG 11, TPZ-3, TPZ-4 and TPZ-5.

November 2018

The sulphate **(Table 4.3 (c) & Figure 4.4 (c))** concentration in the samples was well within acceptable limit of drinking water specification BIS 10500:2012 except samples namely, TG 19, Q2S, TPZ-3, TPZ-4 and TPZ-5.

February 2019

The sulphate **(Table 4.3 (d) & Figure 4.4 (d))** concentration in all the samples except for TPZ-4 was well within acceptable limit of drinking water specification BIS 10500:2012.

June 2019

The sulphate **(Table 4.3 (e) & Figure 4.4 (e))** concentration in all the samples except for TPZ-4 was well within acceptable limit of drinking water specification BIS 10500:2012.

October 2019

The sulphate **(Table 4.3 (f) & Figure 4.4 (f))** concentration in all the samples except for TPZ-4 was well within acceptable limit of drinking water specification BIS 10500:2012.

Chloride-

April 2018

The concentration of chloride **(Table 4.3 (a) & Figure 4.5 (a))** in all the samples was also well within acceptable limit drinking water specification BIS 10500:2012 except sample TG-11. The predicted Chloride concentration within the study area (based on Chloride concentration measured in collected samples) is presented in **Figure 4.25**.

June 2018

The concentration of chloride **(Table 4.3 (b) & Figure 4.5 (b))** in all the samples was also well within acceptable limit drinking water specification BIS 10500:2012.

November 2018

The concentration of chloride **(Table 4.3 (c) & Figure 4.5 (c))** in all the samples was also well within acceptable limit drinking water specification BIS 10500:2012.

February 2019

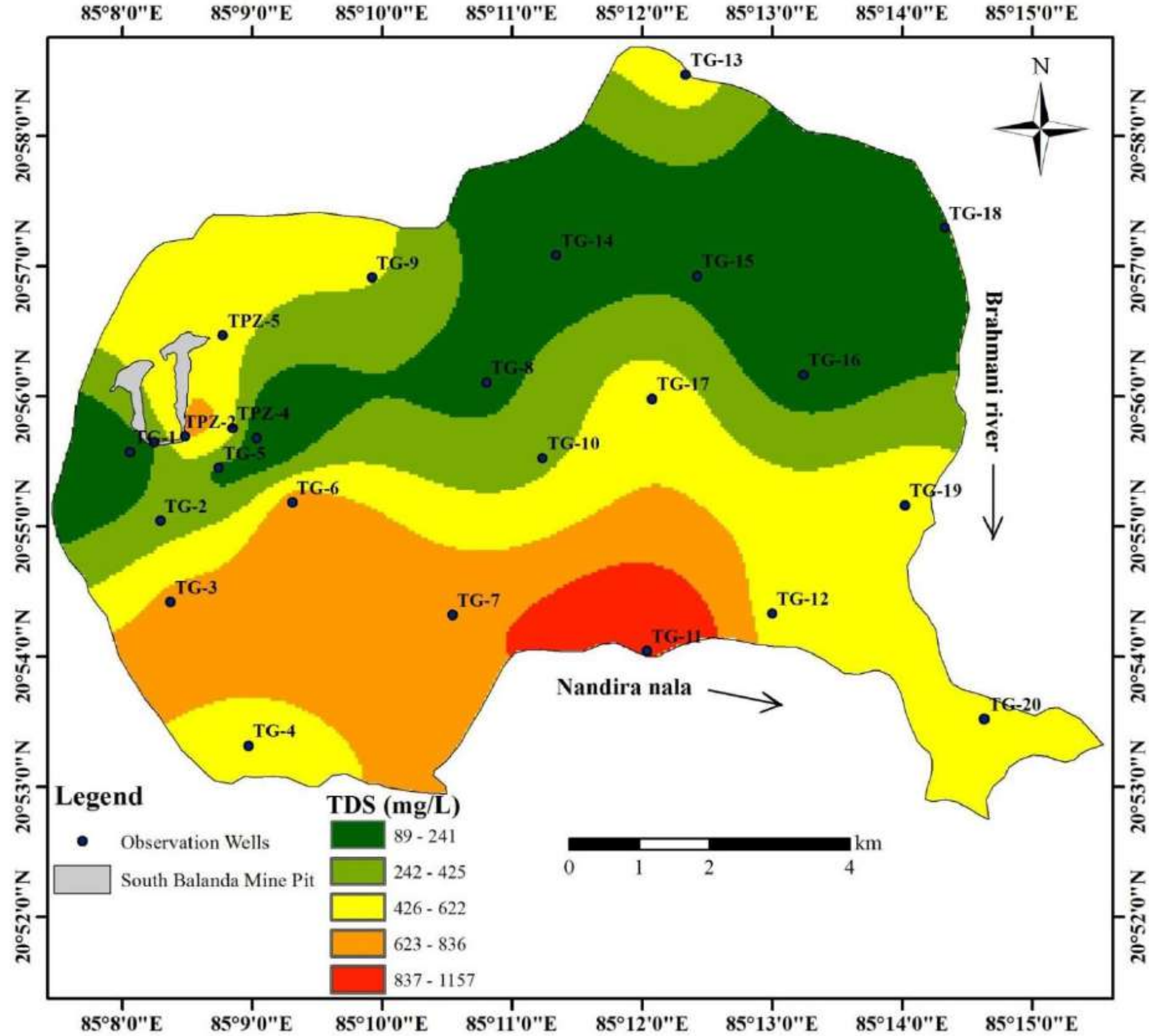
The concentration of chloride **(Table 4.3 (d) & Figure 4.5 (d))** in all the samples was also well within acceptable limit drinking water specification BIS 10500:2012.

June 2019

The concentration of chloride **(Table 4.3 (e) & Figure 4.5 (e))** in all the samples was also well within acceptable limit drinking water specification BIS 10500:2012.

October 2019

The concentration of chloride **(Table 4.3 (f) & Figure 4.5 (f))** in all the samples was also well within acceptable limit drinking water specification BIS 10500:2012.



85°8'0"E
85°9'0"E
85°10'0"E
85°11'0"E
85°12'0"E
85°13'0"E
85°14'0"E
85°15'0"E
20°58'0"N
20°57'0"N
20°56'0"N
20°55'0"N
20°54'0"N
20°53'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-15
TG-9
TPZ-5
TG-8
TG-16
TG-17
TPZ-2
TPZ-4
TG-1
TG-5
TG-10
TG-6
TG-19
TG-2
TG-3
TG-7
TG-12
TG-11
Nandira nala
TG-20
TG-4
Brahmani river
Legend
Observation Wells
South Balanda Mine Pit
TDS (mg/L)
89 - 241
242 - 425
426 - 622
623 - 836
837 - 1157
km
0
1
2
4

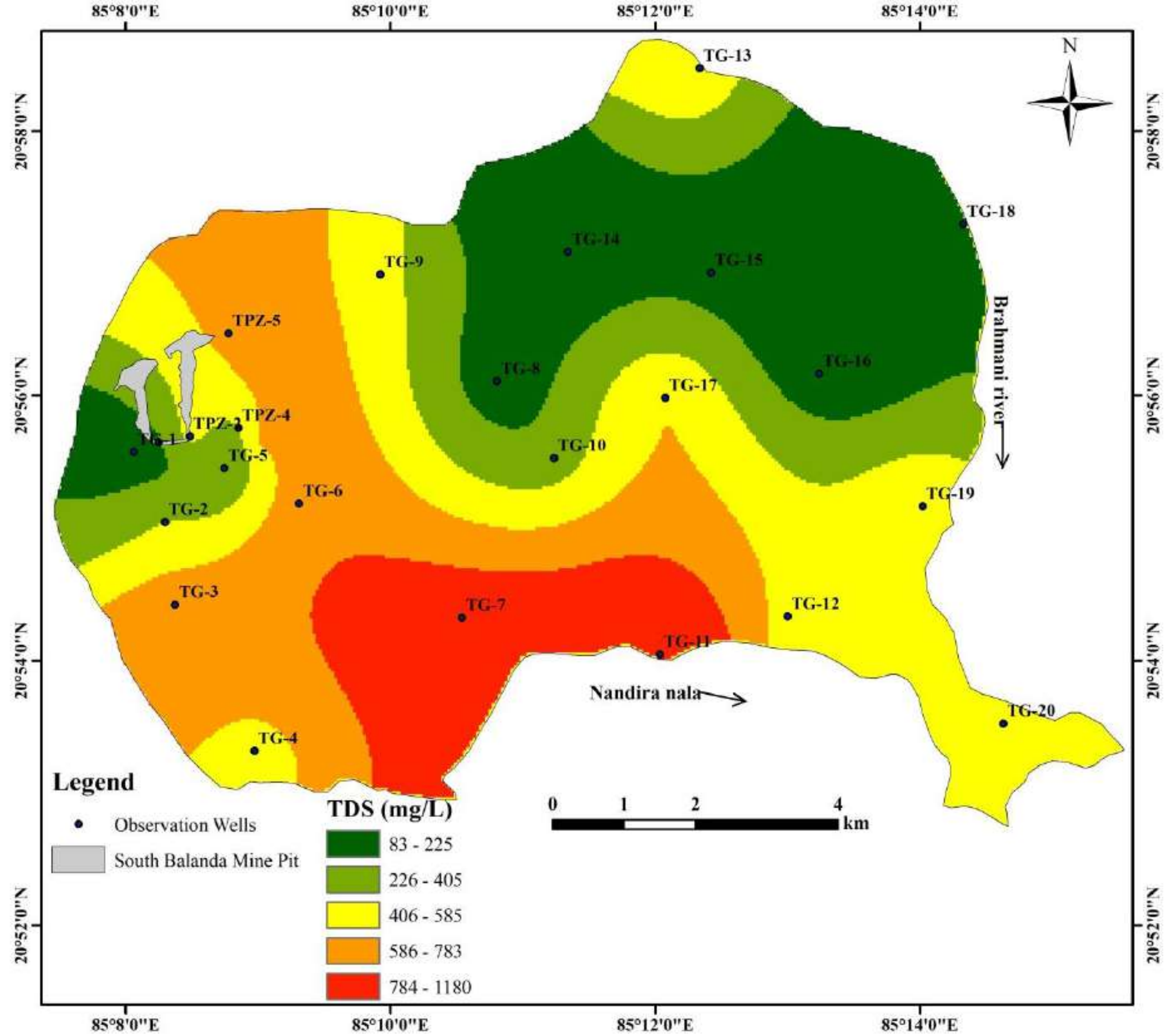
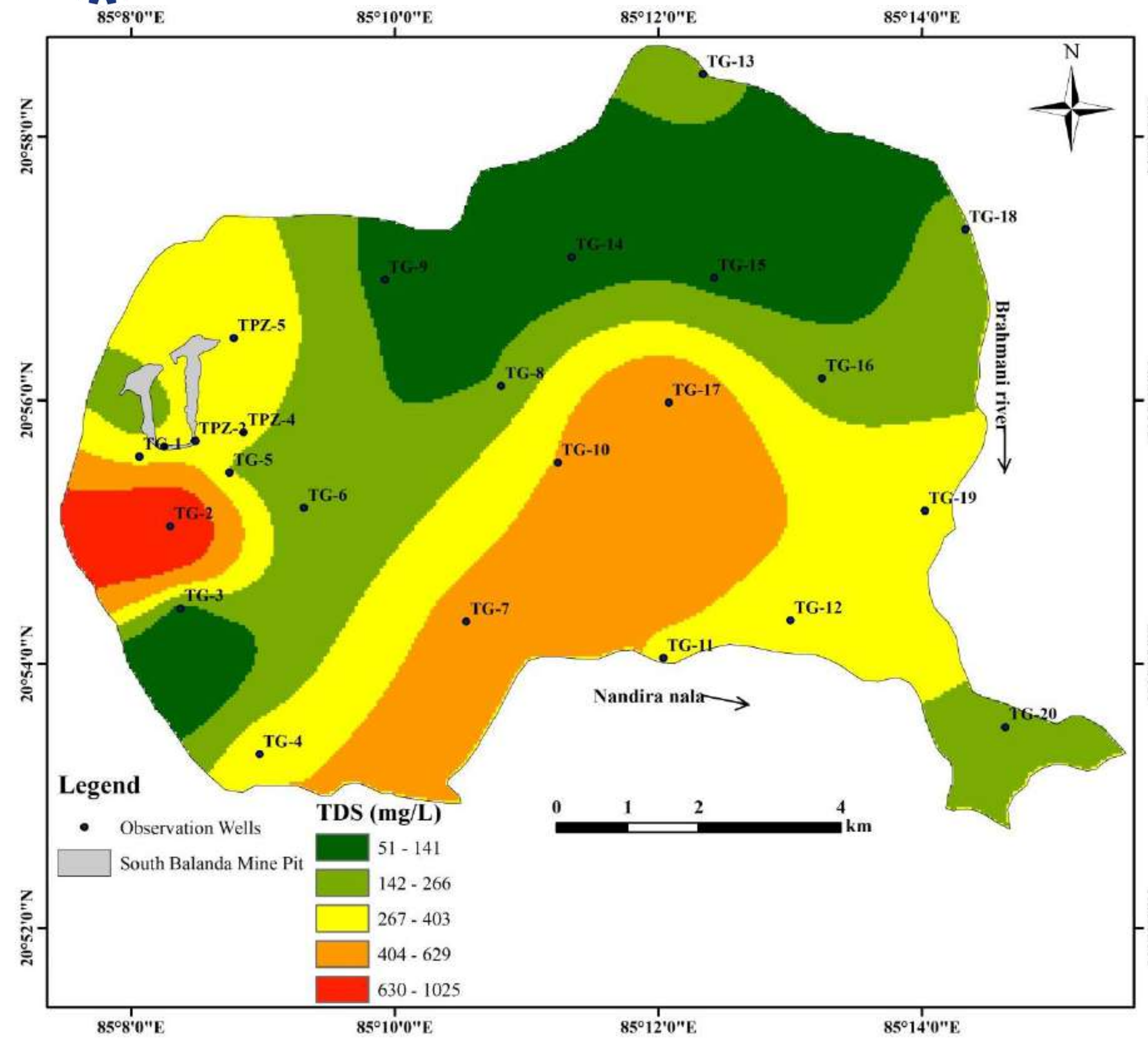


Figure 4.2 (b): TDS concentration in groundwater of the study area in June 2018


85°8'0"E
85°10'0"E
85°12'0"E
85°14'0"E
20°58'0"N
20°56'0"N
20°54'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-9
TG-15
Brahmani river
TPZ-5
TG-16
TG-8
TG-17
TPZ-2
TPZ-4
TG-1
TG-10
TG-5
TG-6
TG-19
TG-2
TG-3
TG-7
TG-12
TG-11
Nandira nala
TG-20
TG-4
Legend
Observation Wells
South Balanda Mine Pit
TDS (mg/L)
51 - 141
142 - 266
267 - 403
404 - 629
630 - 1025
0 1 2 4
km

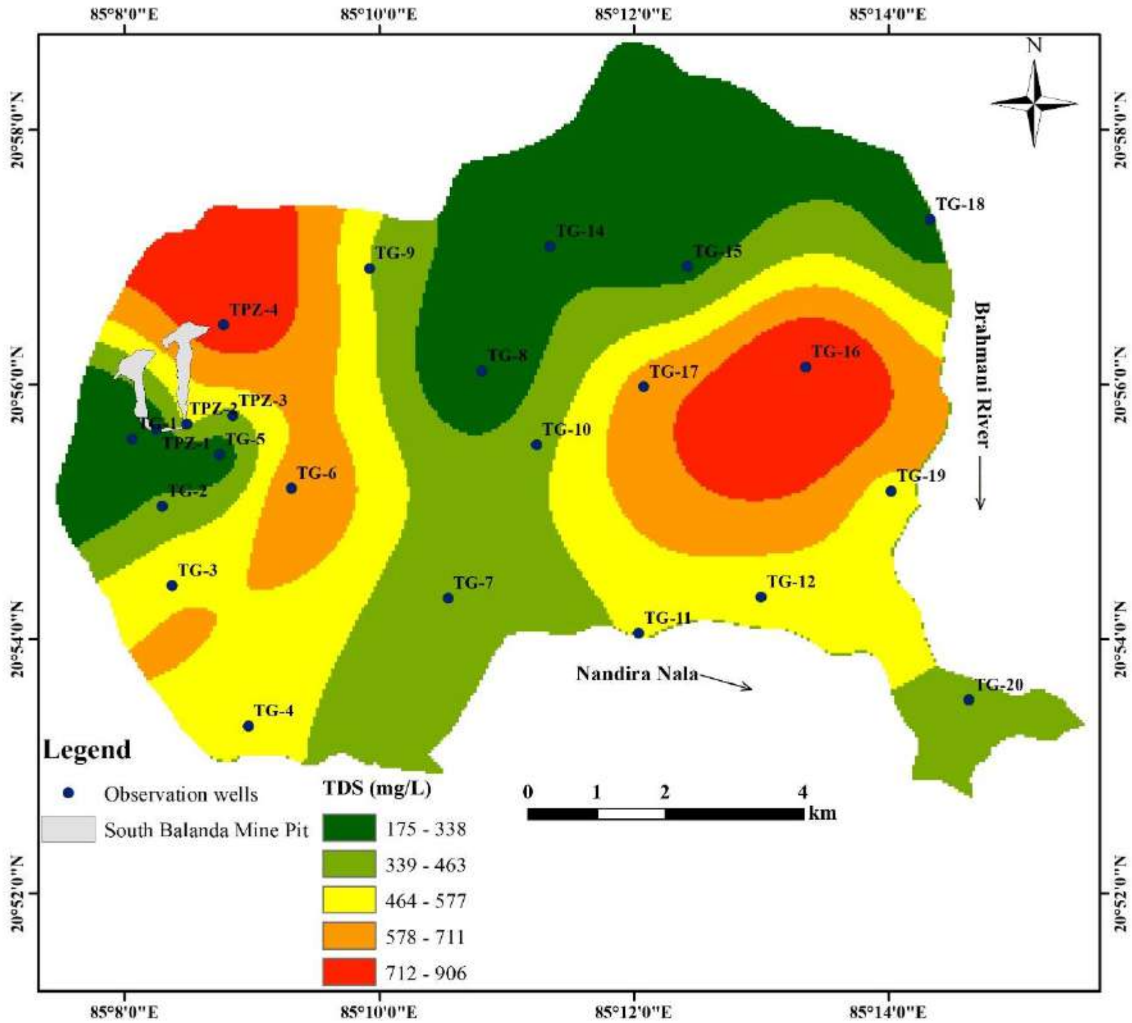
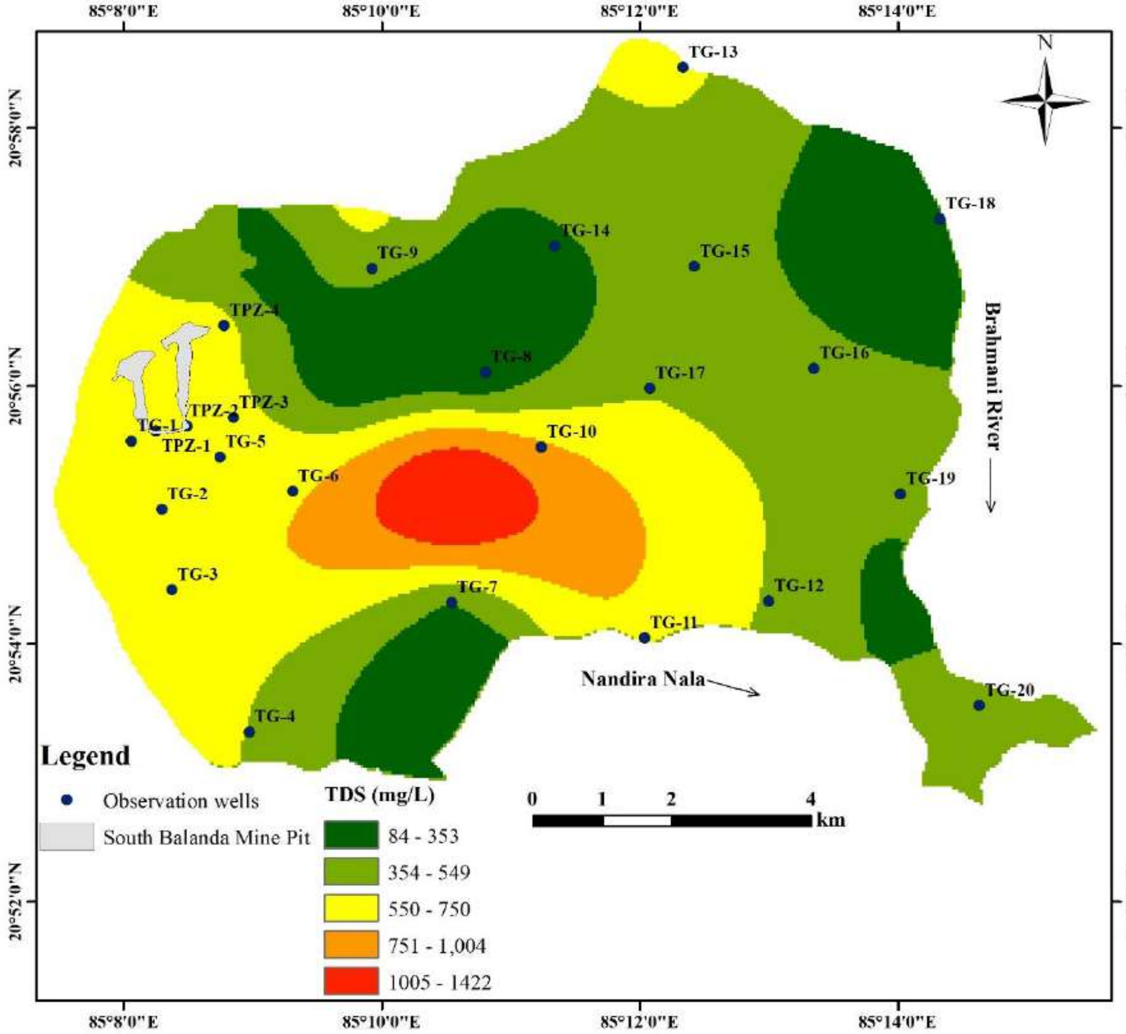


Figure 4.4 (d): TDS concentration in groundwater of the study area in February 2019



85°8'0"E
85°10'0"E
85°12'0"E
85°14'0"E
20°58'0"N
20°56'0"N
20°54'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-9
TG-15
TPZ-4
TG-16
TG-8
TG-17
TPZ-2
TPZ-3
TG-1
TPZ-1
TG-5
TG-10
TG-6
TG-19
TG-2
TG-3
TG-7
TG-12
TG-11
Nandira Nala
TG-4
TG-20
Brahmani River
Legend
Observation wells
South Balanda Mine Pit
TDS (mg/L)
84 - 353
354 - 549
550 - 750
751 - 1,004
1005 - 1422
0 1 2 4
km

Figure 4.5 (e): TDS concentration in groundwater of the study area in June 2019

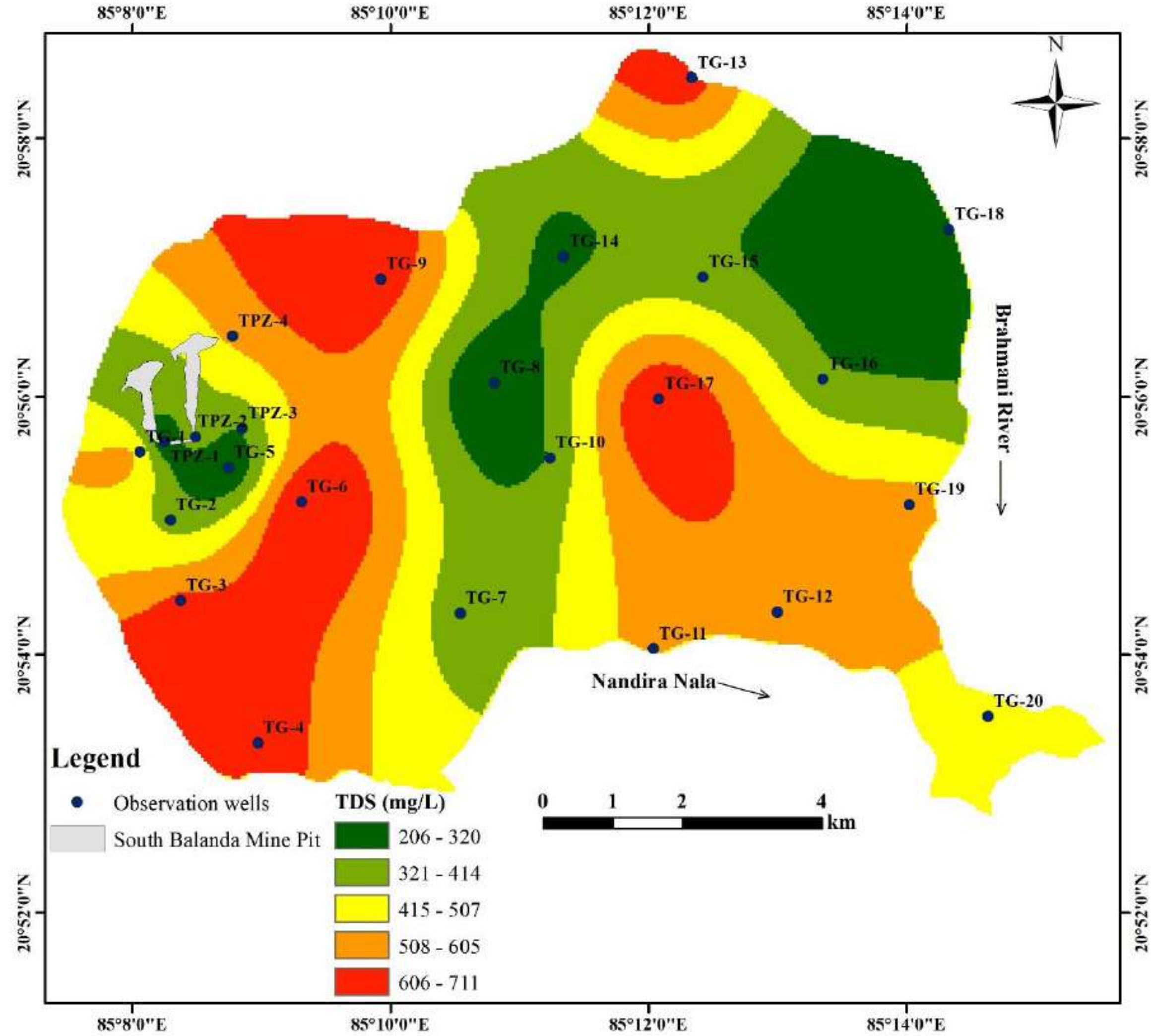
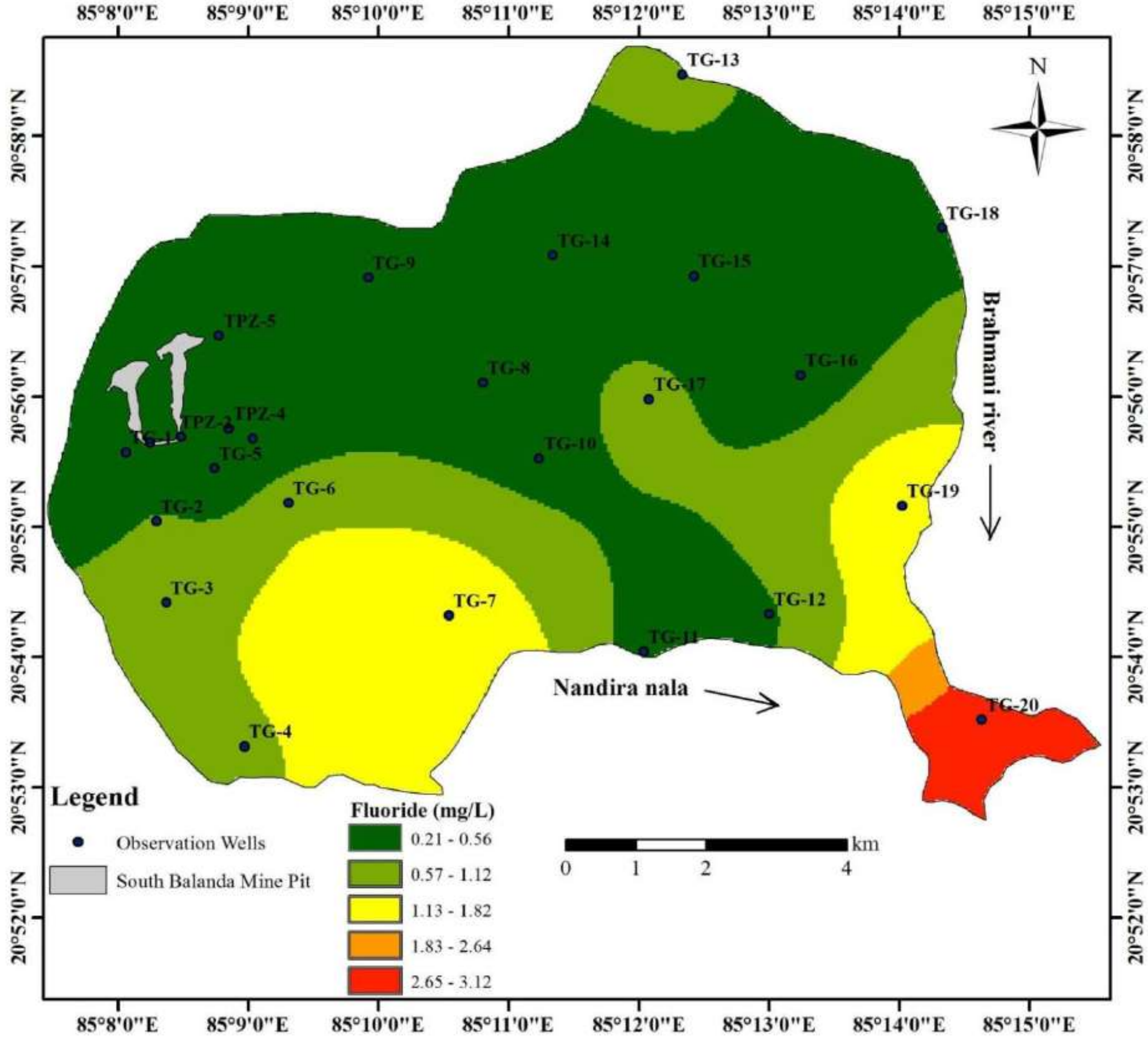


Figure 4.6 (f): TDS concentration in groundwater of the study area in October 2019


85°8'0"E
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20°58'0"N
20°57'0"N
20°56'0"N
20°55'0"N
20°54'0"N
20°53'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-15
TG-9
TPZ-5
TG-8
TG-16
TG-17
TPZ-2
TPZ-4
TG-1
TG-5
TG-10
TG-6
TG-2
TG-19
TG-3
TG-7
TG-12
TG-11
TG-4
TG-20
Brahmani river
Nandira nala
Legend
Observation Wells
South Balanda Mine Pit
Fluoride (mg/L)
0.21 - 0.56
0.57 - 1.12
1.13 - 1.82
1.83 - 2.64
2.65 - 3.12
0
1
2
4
km

Figure 4.7 (a): Fluoride concentration in the groundwater of the study area in April 2018

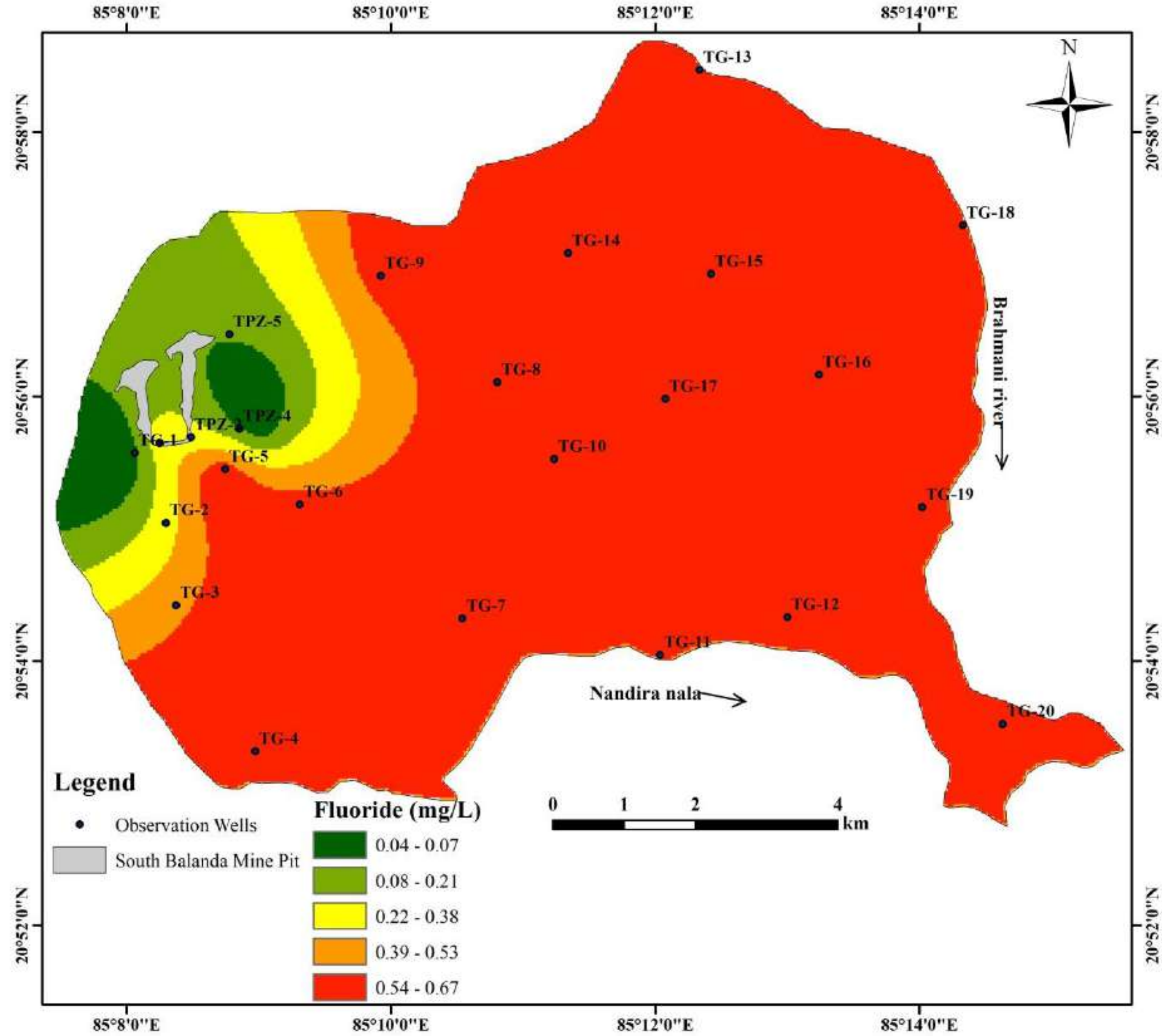
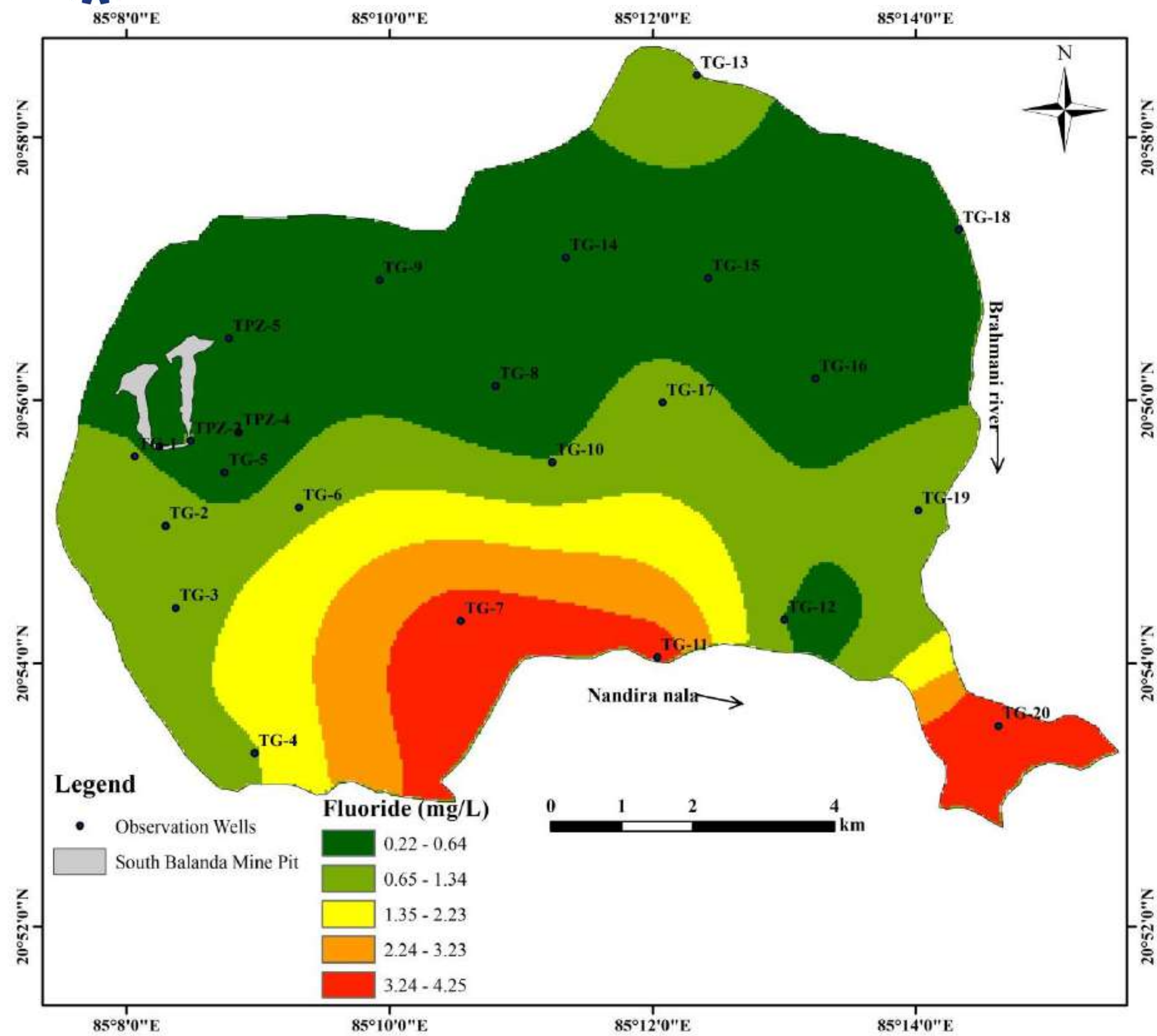


Figure 4.8 (b): Fluoride concentration in the groundwater of the study area in June 2018



85°8'0"E
85°10'0"E
85°12'0"E
85°14'0"E
20°58'0"N
20°56'0"N
20°54'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-9
TG-15
TPZ-5
Brahmani river
TG-8
TG-16
TG-17
TPZ-4
TPZ-2
TG-1
TG-10
TG-5
TG-6
TG-19
TG-2
TG-3
TG-7
TG-12
TG-11
Nandira nala
TG-20
TG-4
Legend
Observation Wells
South Balanda Mine Pit
Fluoride (mg/L)
0.22 - 0.64
0.65 - 1.34
1.35 - 2.23
2.24 - 3.23
3.24 - 4.25
0 1 2 4
km

Figure 4.9 (c): Fluoride concentration in the groundwater of the study area in November 2018

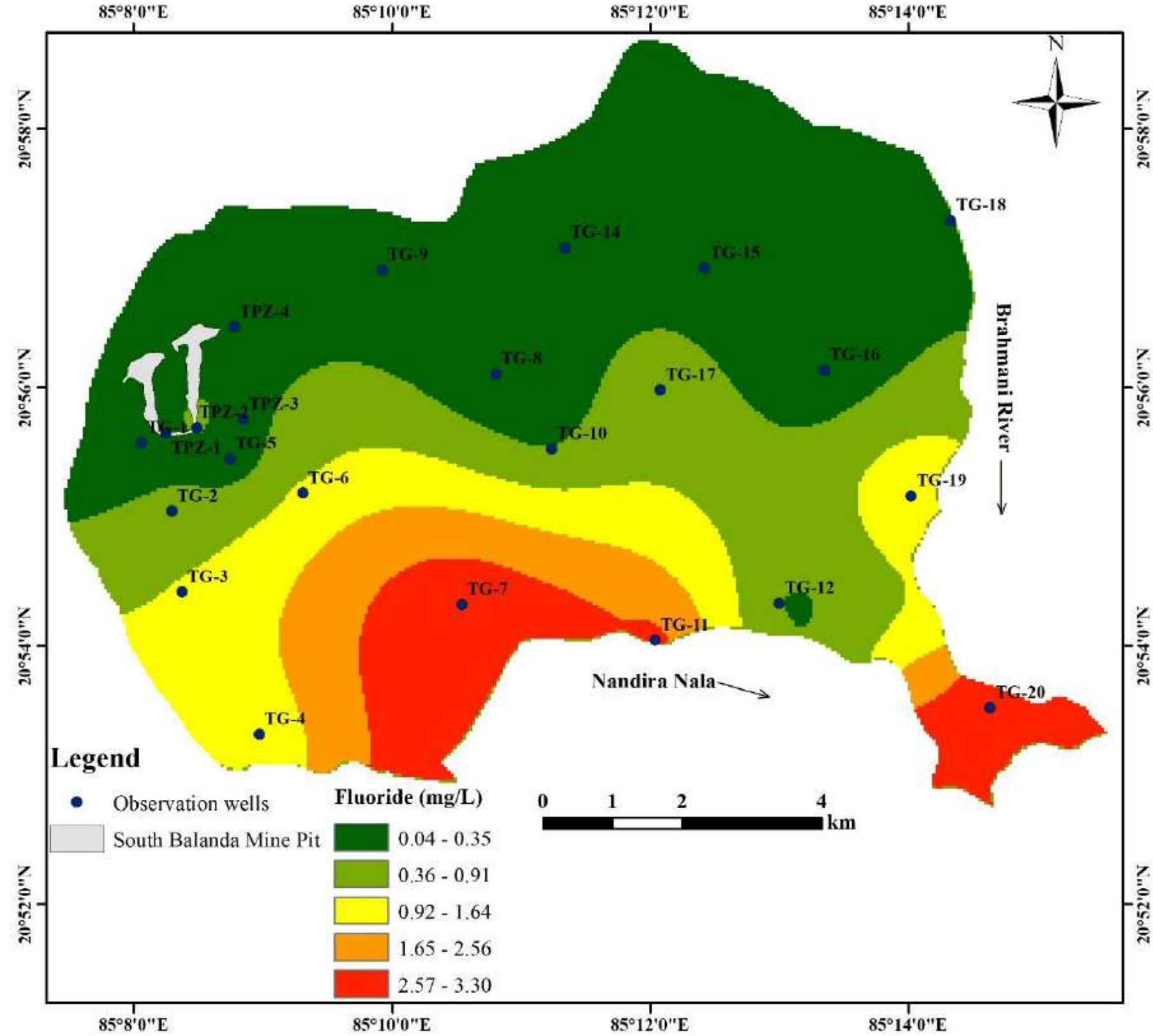


Figure 4.10 (d): Fluoride concentration in the groundwater of the study area in February 2019

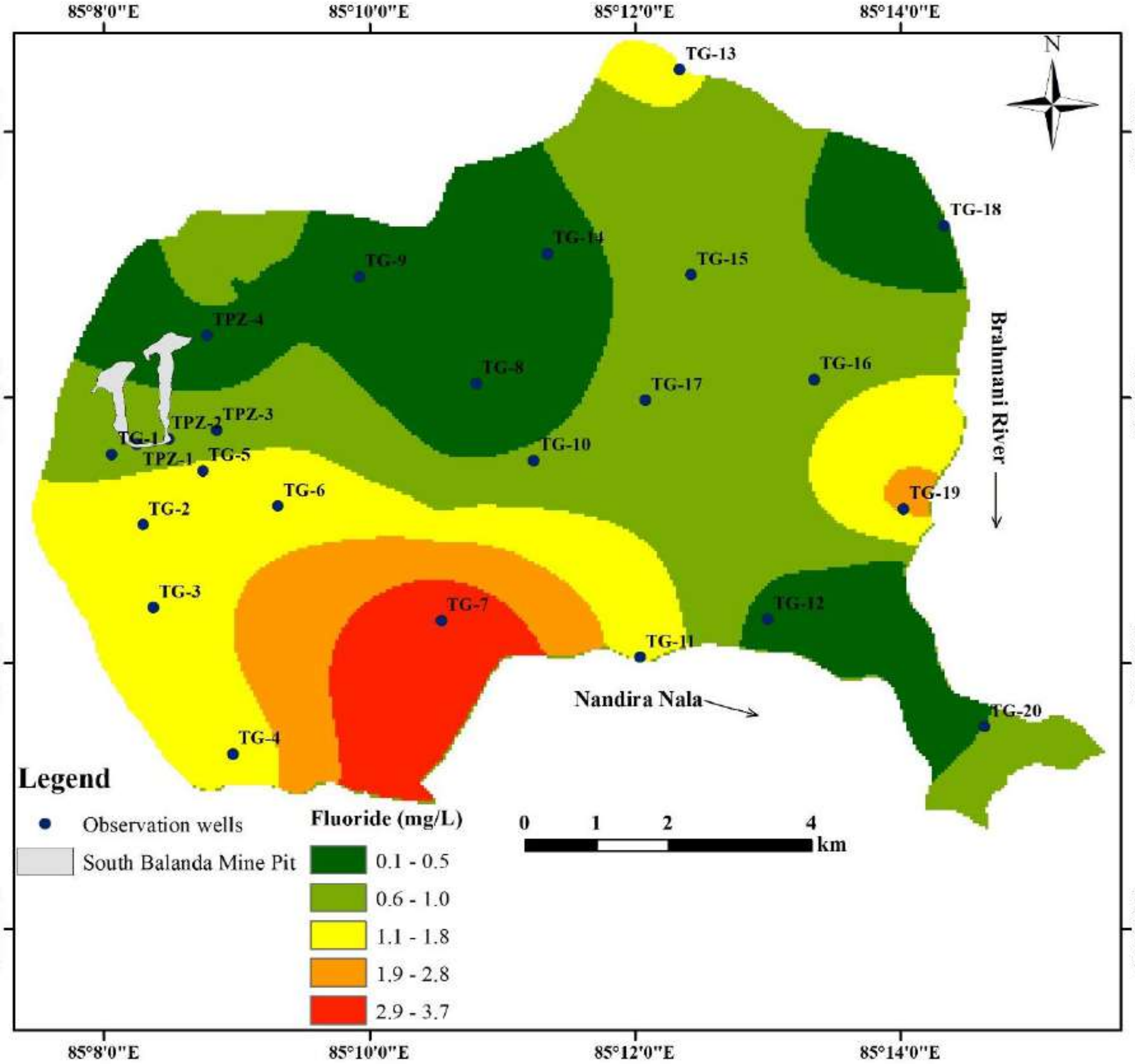

85°8'0"E
85°10'0"E
85°12'0"E
85°14'0"E
20°58'0"N
20°56'0"N
20°54'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-15
TG-9
TPZ-4
TG-8
TG-17
TG-16
TPZ-2
TPZ-3
TG-1
TPZ-1
TG-5
TG-10
TG-6
TG-2
TG-19
TG-3
TG-7
TG-12
TG-11
TG-4
TG-20
Brahmani River
Nandira Nala
Legend
Observation wells
South Balanda Mine Pit
Fluoride (mg/L)
0.1 - 0.5
0.6 - 1.0
1.1 - 1.8
1.9 - 2.8
2.9 - 3.7
0
1
2
4
km

Figure 4.11 (e): Fluoride concentration in the groundwater of the study area in June 2019

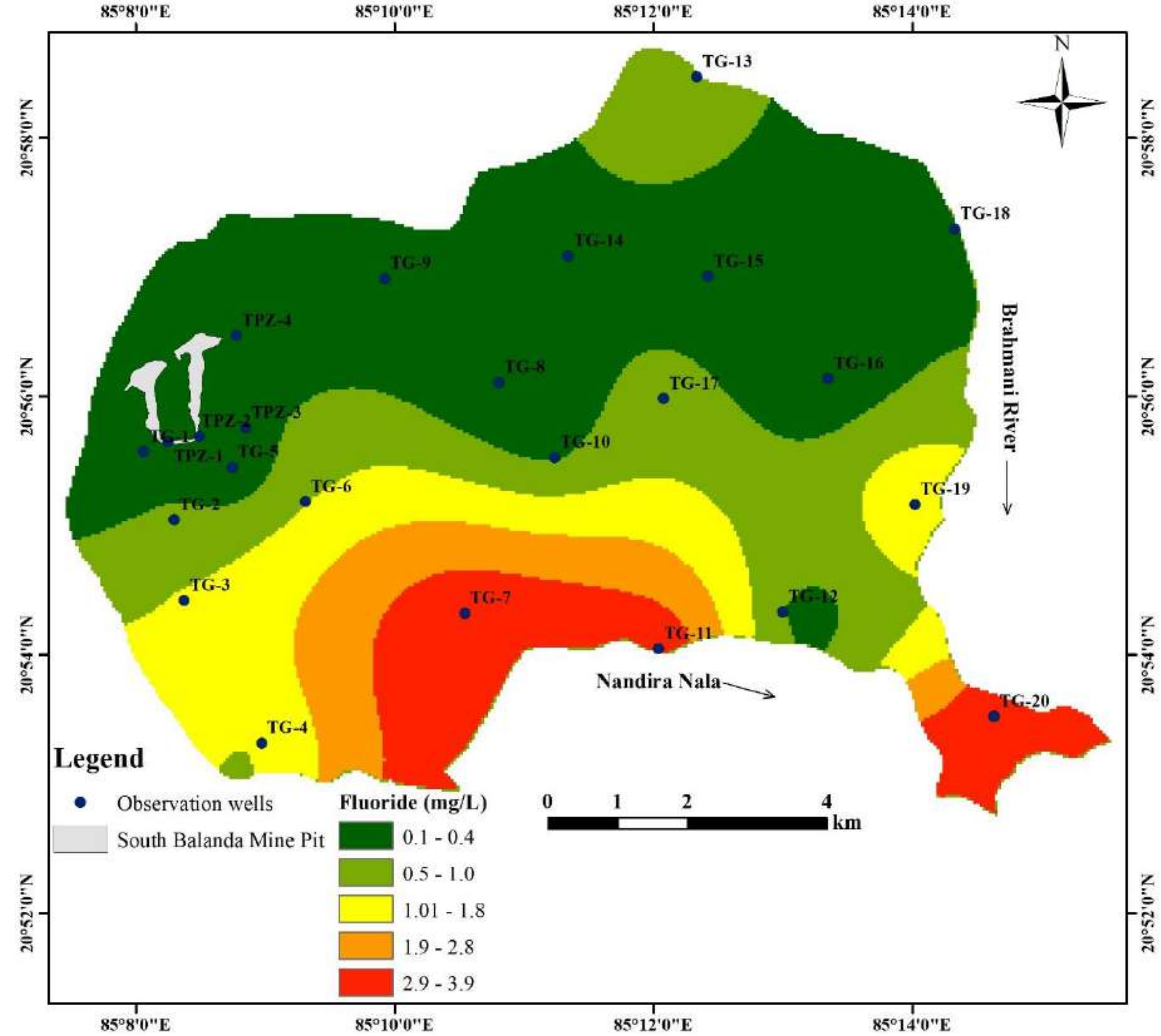


Figure 4.12 (f): Fluoride concentration in the groundwater of the study area in October 2019

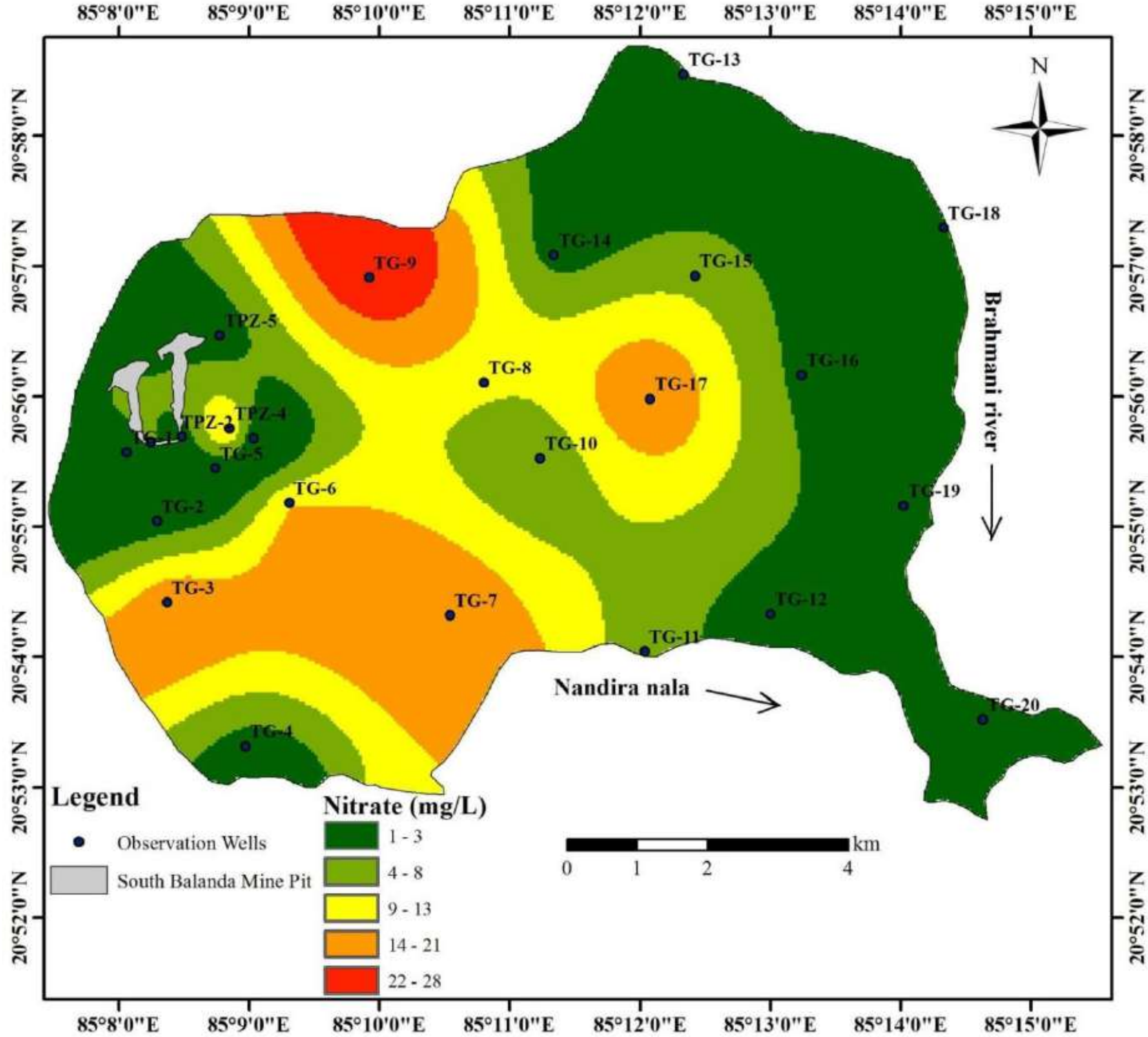

85°8'0"E
85°9'0"E
85°10'0"E
85°11'0"E
85°12'0"E
85°13'0"E
85°14'0"E
85°15'0"E
20°58'0"N
20°57'0"N
20°56'0"N
20°55'0"N
20°54'0"N
20°53'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-15
TG-9
TPZ-5
TG-8
TG-16
TG-17
TPZ-2
TPZ-4
TG-1
TG-5
TG-10
TG-6
TG-2
TG-19
TG-3
TG-7
TG-12
TG-11
TG-20
TG-4
Brahmani river
Nandira nala
Legend
Observation Wells
South Balanda Mine Pit
Nitrate (mg/L)
1 - 3
4 - 8
9 - 13
14 - 21
22 - 28
0
1
2
4
km

Figure 4.13 (a): Nitrate concentration in the groundwater of study area in April 2018

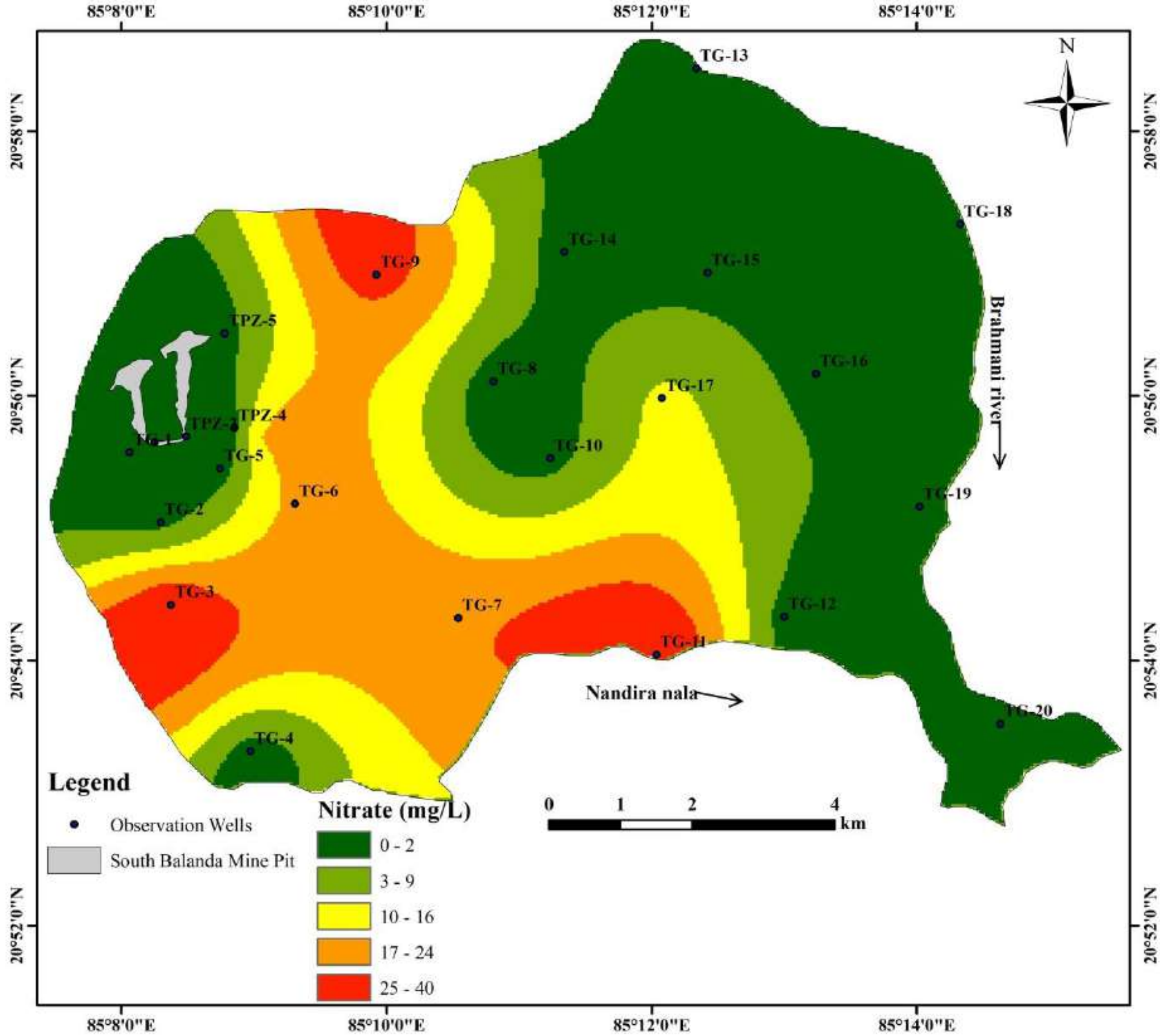
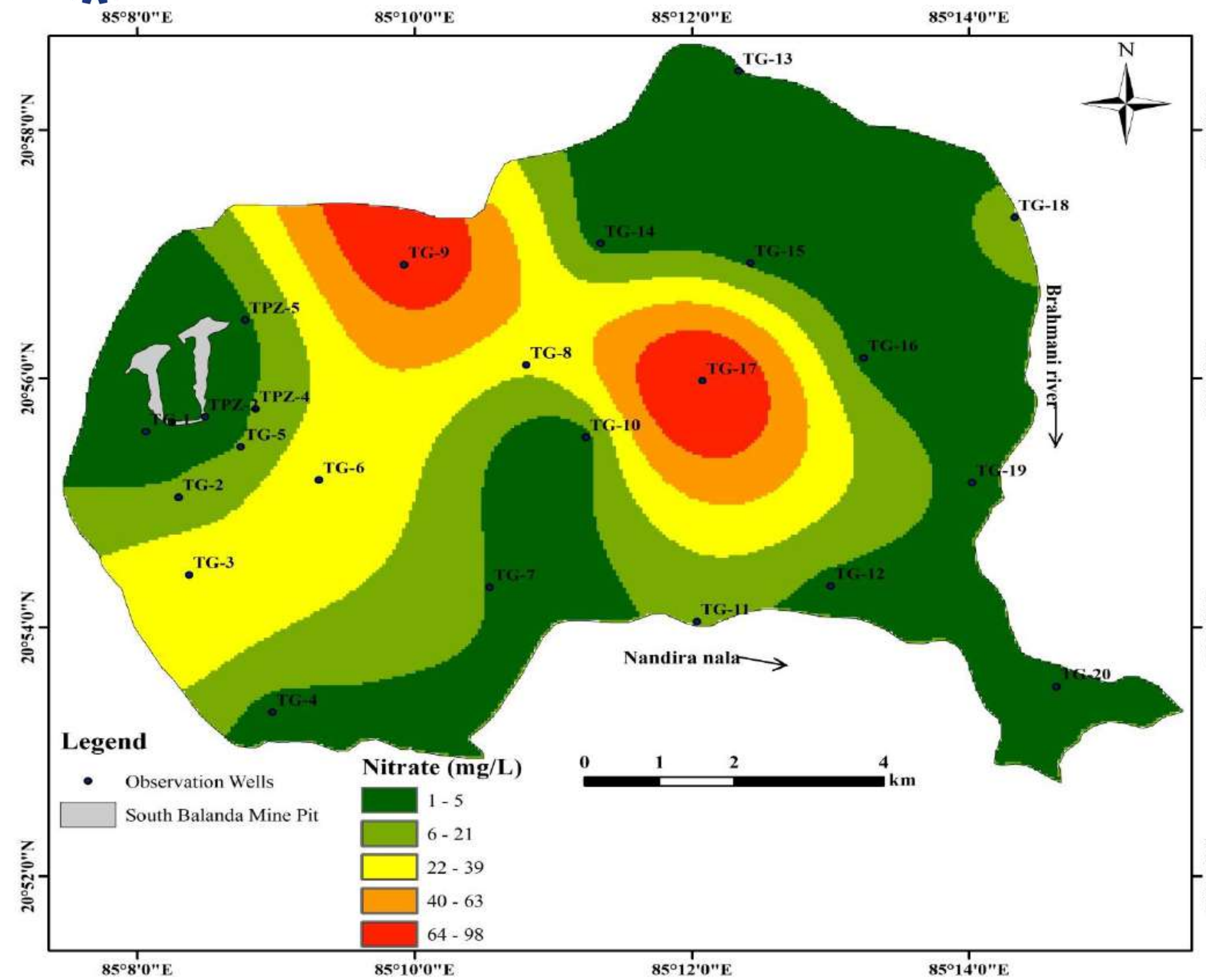


Figure 4.14 (b): Nitrate concentration in the groundwater of study area in June 2018


85°8'0"E
85°10'0"E
85°12'0"E
85°14'0"E
20°58'0"N
20°56'0"N
20°54'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-9
TG-15
TPZ-5
TG-16
TG-8
TG-17
TPZ-4
TG-10
TG-5
TG-6
TG-2
TG-19
TG-3
TG-7
TG-12
TG-11
Nandira nala
TG-20
TG-4
Brahmani river
Legend
Observation Wells
South Balanda Mine Pit
Nitrate (mg/L)
1 - 5
6 - 21
22 - 39
40 - 63
64 - 98
0 1 2 4 km

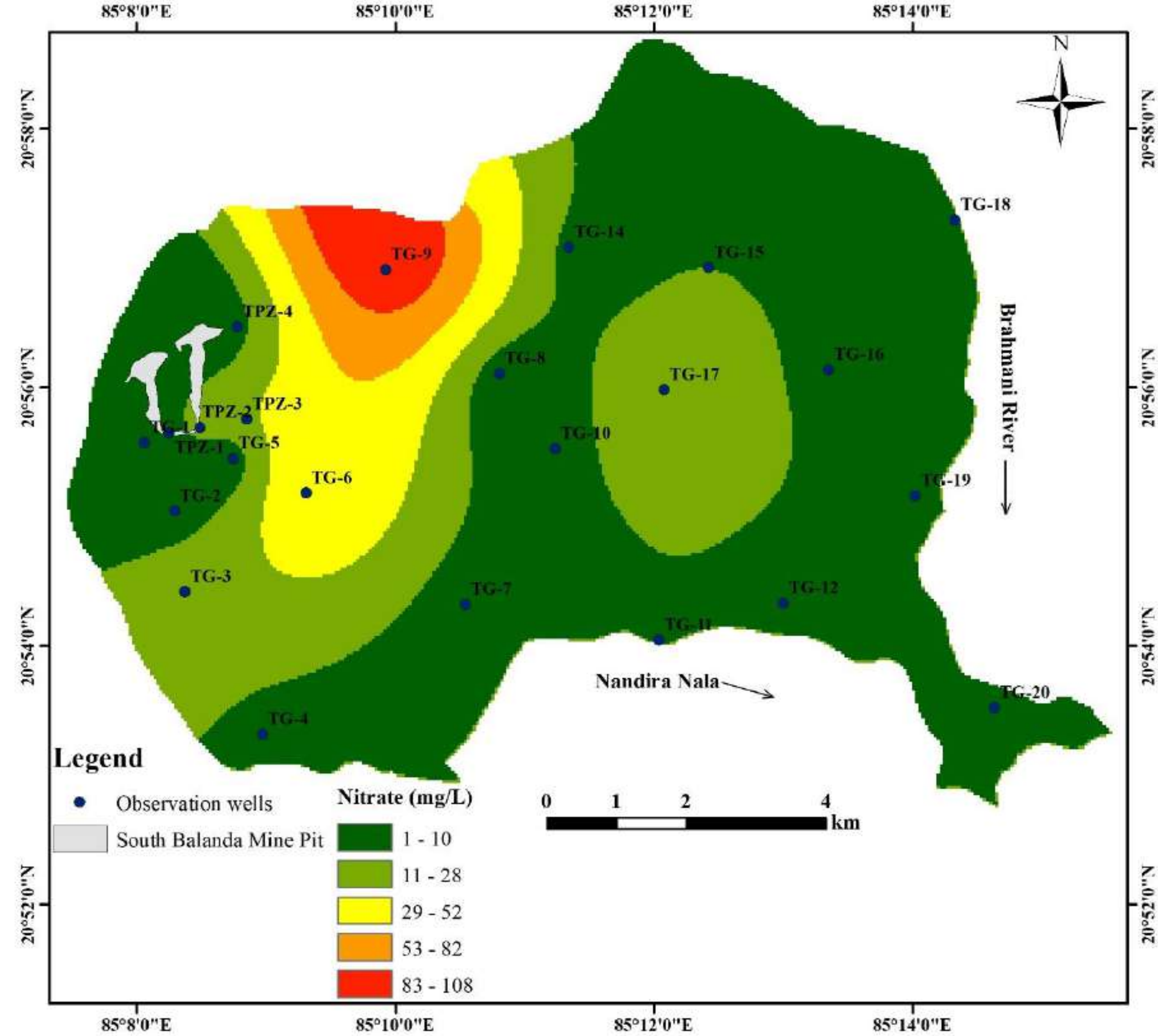
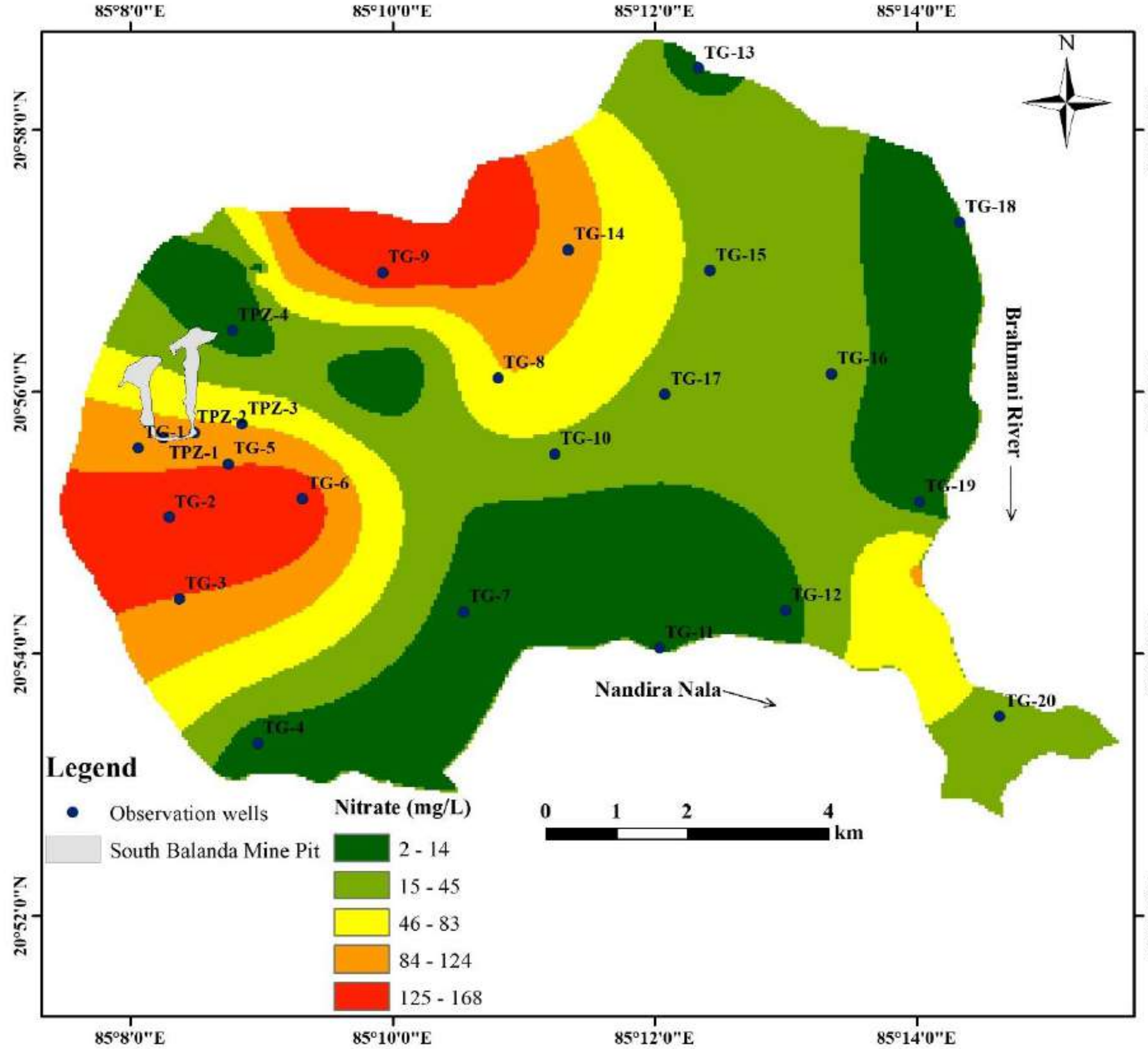


Figure 4.16 (d): Nitrate concentration in the groundwater of study area in February 2019



85°8'0"E
85°10'0"E
85°12'0"E
85°14'0"E
20°58'0"N
20°56'0"N
20°54'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-15
TG-9
TPZ-4
TG-8
TG-17
TG-16
TPZ-2
TPZ-3
TG-1
TPZ-1
TG-5
TG-10
TG-6
TG-19
TG-2
TG-3
TG-7
TG-12
TG-11
Nandira Nala
TG-20
TG-4
Brahmani River
Legend
Observation wells
South Balanda Mine Pit
Nitrate (mg/L)
2 - 14
15 - 45
46 - 83
84 - 124
125 - 168
0
1
2
4
km

Figure 4.17 (e): Nitrate concentration in the groundwater of study area in June 2019

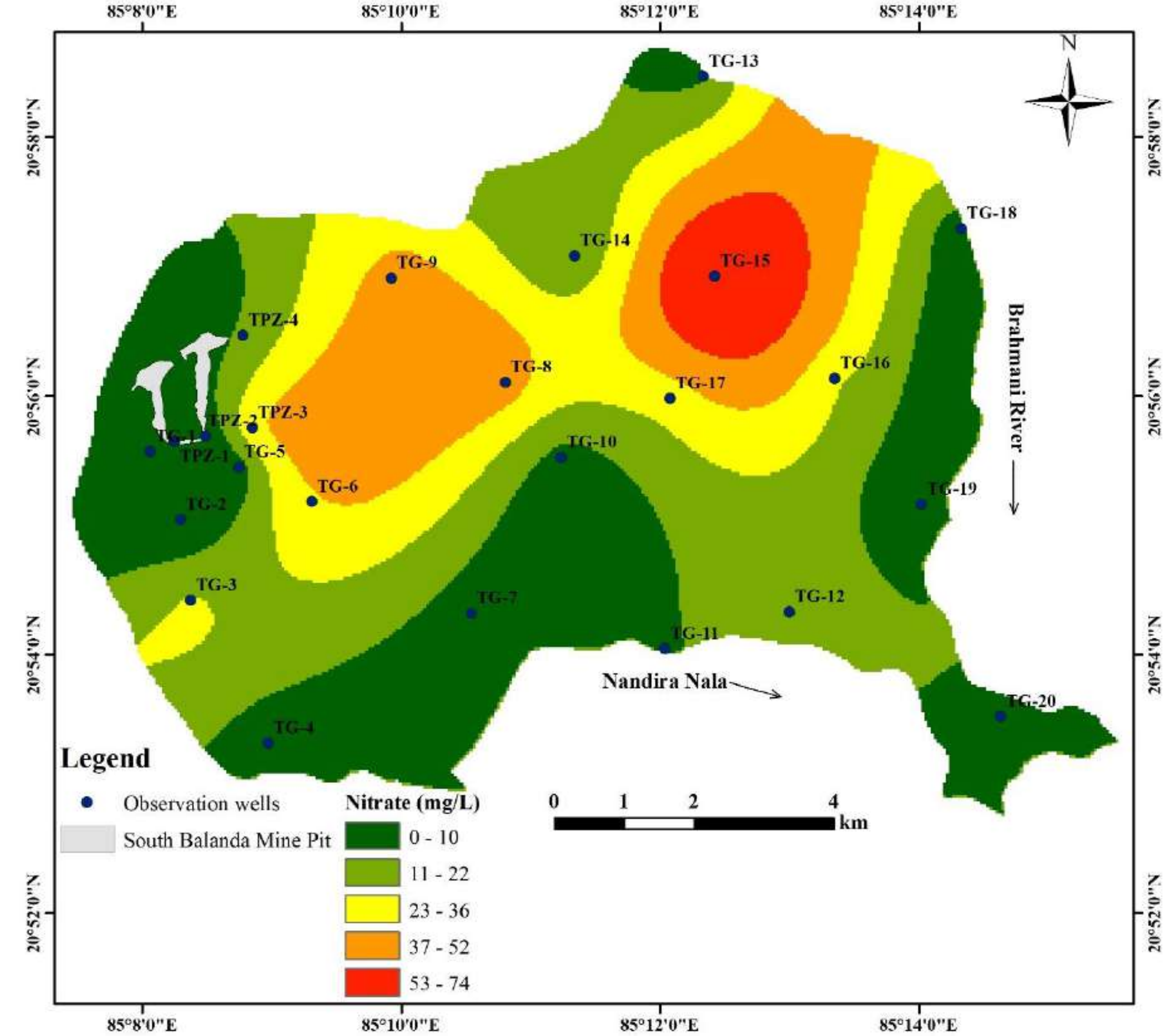


Figure 4.18 (f): Nitrate concentration in the groundwater of study area in October 2019

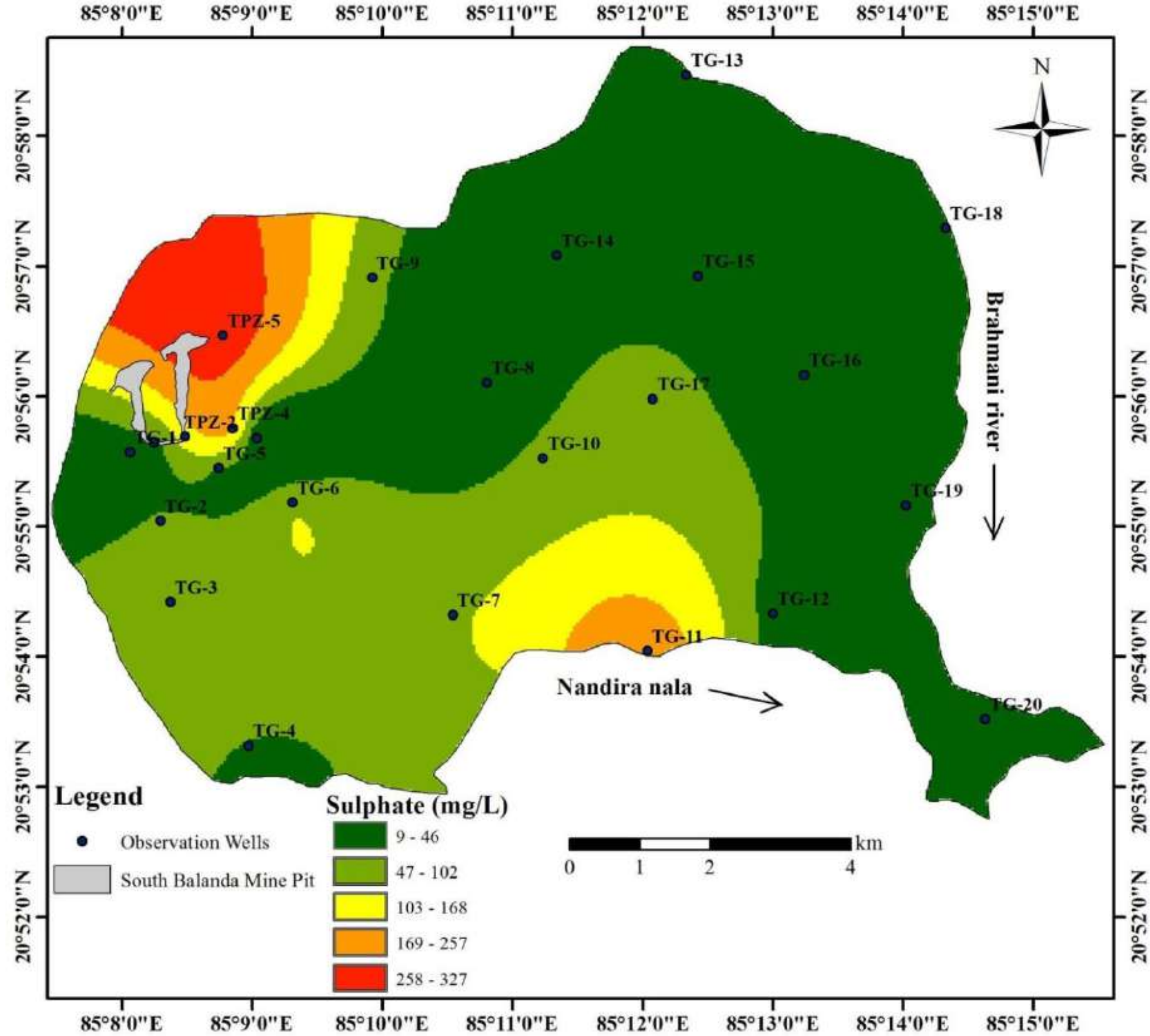

85°8'0"E
85°9'0"E
85°10'0"E
85°11'0"E
85°12'0"E
85°13'0"E
85°14'0"E
85°15'0"E
20°58'0"N
20°57'0"N
20°56'0"N
20°55'0"N
20°54'0"N
20°53'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-15
TG-9
TPZ-5
TG-8
TG-16
TG-17
TPZ-2
TPZ-4
TG-1
TG-5
TG-10
TG-6
TG-2
TG-19
TG-3
TG-7
TG-12
TG-11
Nandira nala
TG-20
TG-4
Brahmani river
Legend
Observation Wells
South Balanda Mine Pit
Sulphate (mg/L)
9 - 46
47 - 102
103 - 168
169 - 257
258 - 327
km
0
1
2
4

Figure 4.19 (a): Sulphate concentration in groundwater of the study area in April 2018

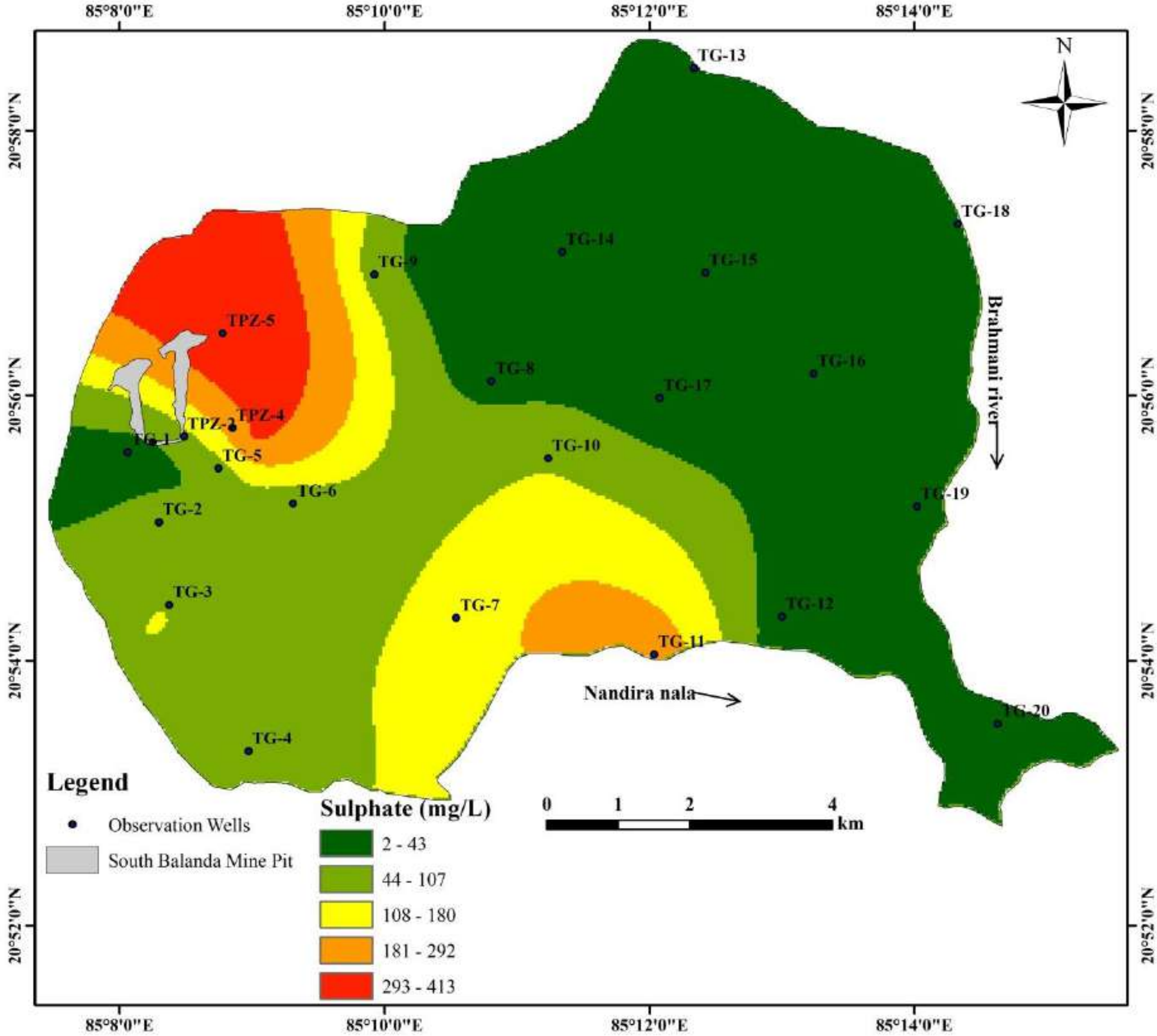


Figure 4.20 (b): Sulphate concentration in groundwater of the study area in June 2018

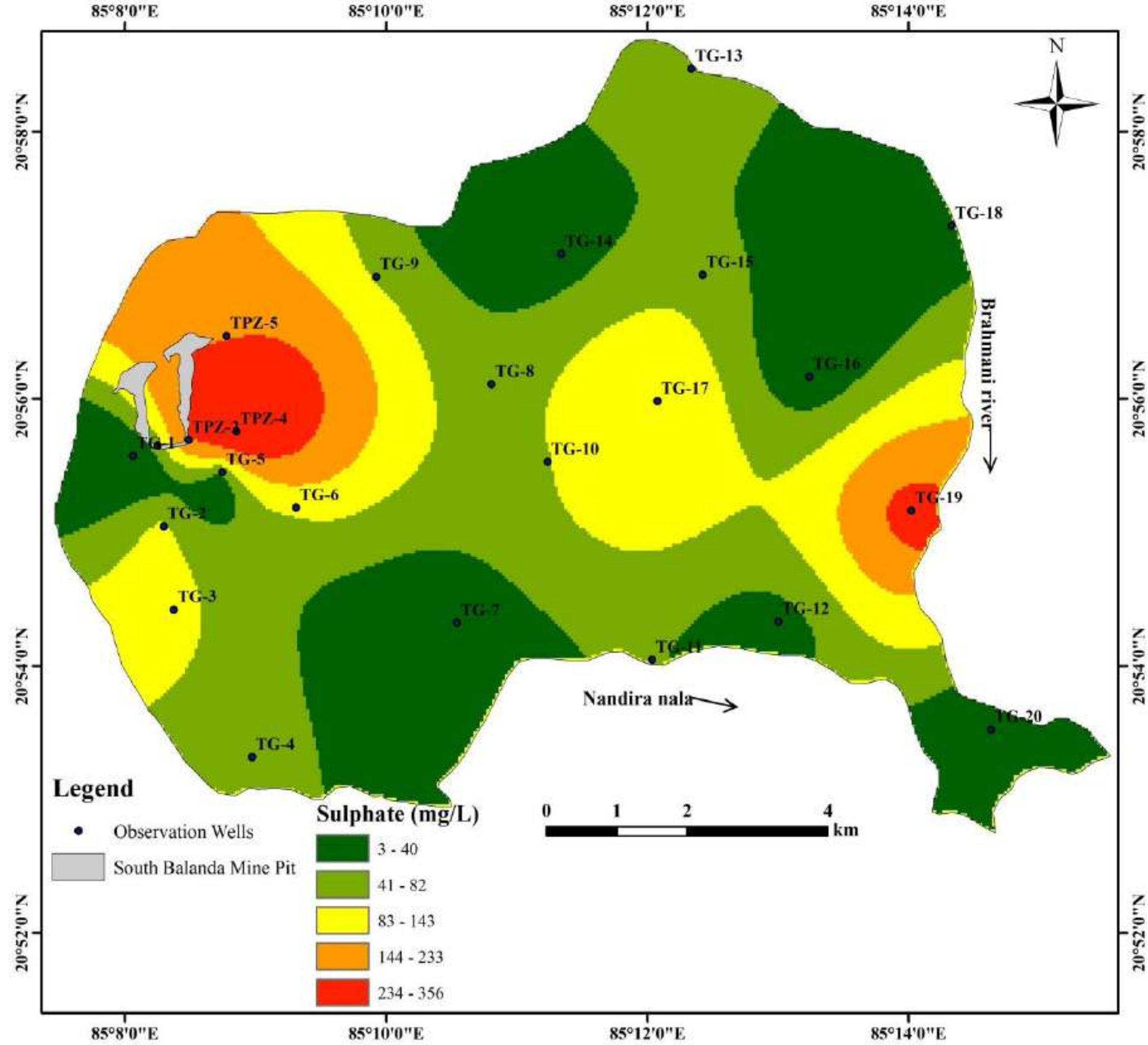

85°8'0"E
85°10'0"E
85°12'0"E
85°14'0"E
20°58'0"N
20°56'0"N
20°54'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-15
TG-9
TPZ-5
TG-16
TG-8
TG-17
TPZ-4
TG-1
TG-5
TG-10
TG-19
TG-6
TG-2
TG-3
TG-7
TG-12
TG-11
TG-4
TG-20
Brahmani river
Nandira nala
Legend
Observation Wells
South Balanda Mine Pit
Sulphate (mg/L)
3 - 40
41 - 82
83 - 143
144 - 233
234 - 356
0 1 2 4 km

Figure 4.21 (c): Sulphate concentration in groundwater of the study area in November 2018

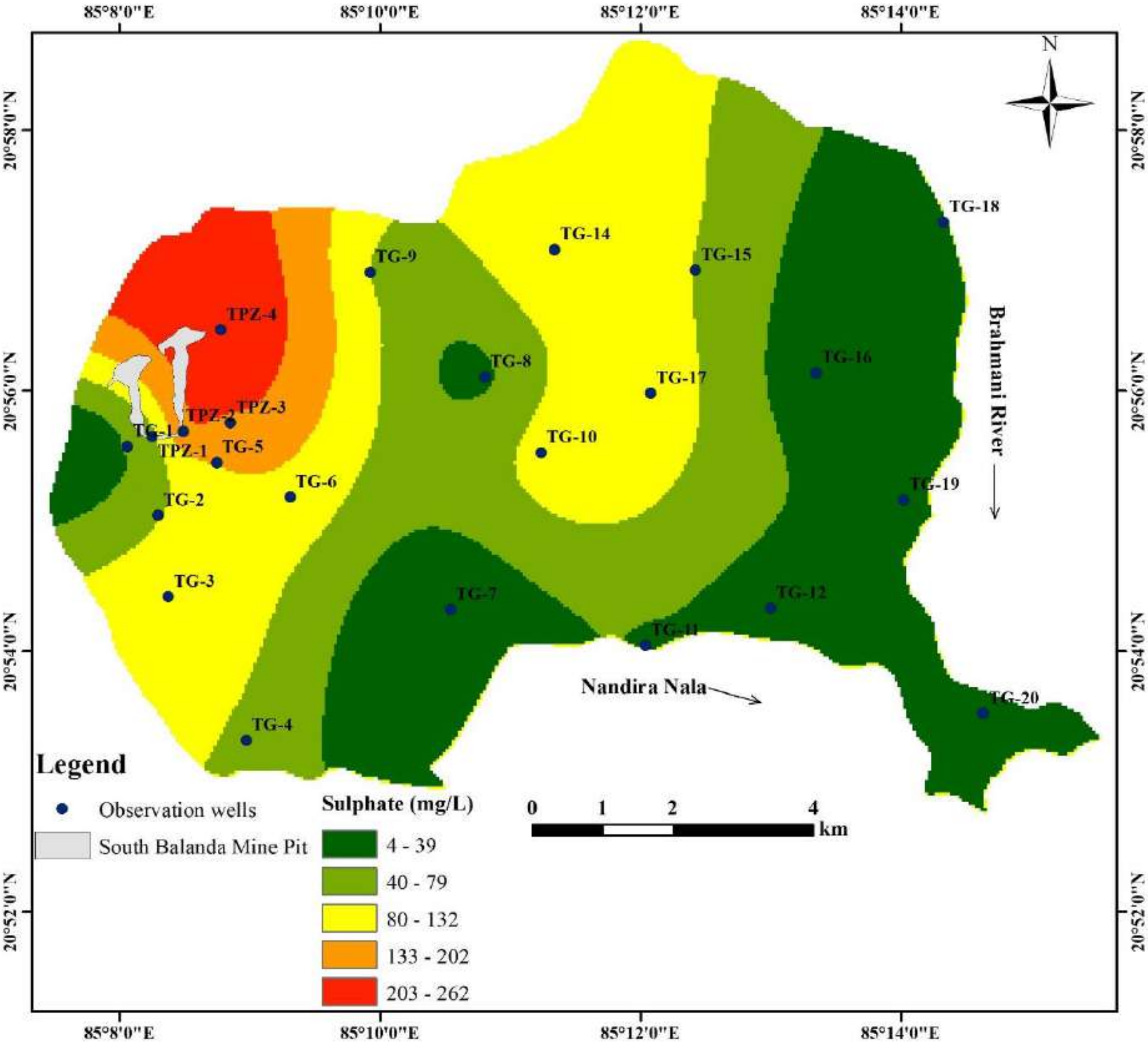
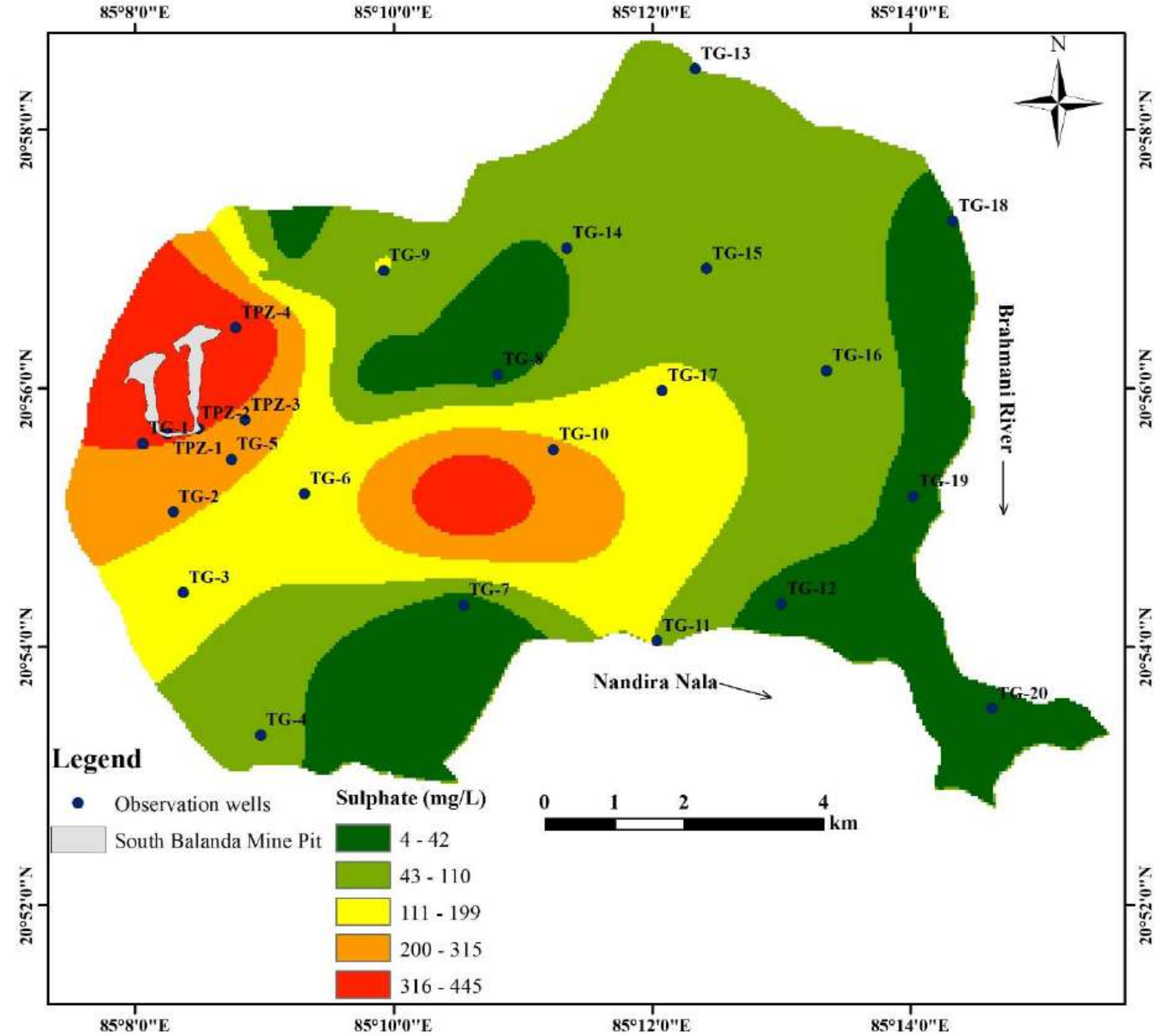


Figure 4.22 (d): Sulphate concentration in groundwater of the study area in February 2019



85°8'0"E
85°10'0"E
85°12'0"E
85°14'0"E
20°58'0"N
20°56'0"N
20°54'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-15
TG-9
TPZ-4
TG-8
TG-16
TG-17
Brahmani River
TPZ-2
TPZ-3
TG-1
TPZ-1
TG-5
TG-10
TG-6
TG-19
TG-2
TG-3
TG-7
TG-12
TG-11
Nandira Nala
TG-20
TG-4
Legend
Observation wells
South Balanda Mine Pit
Sulphate (mg/L)
4 - 42
43 - 110
111 - 199
200 - 315
316 - 445
0 1 2 4
km

Figure 4.23 (e): Sulphate concentration in groundwater of the study area in June 2019

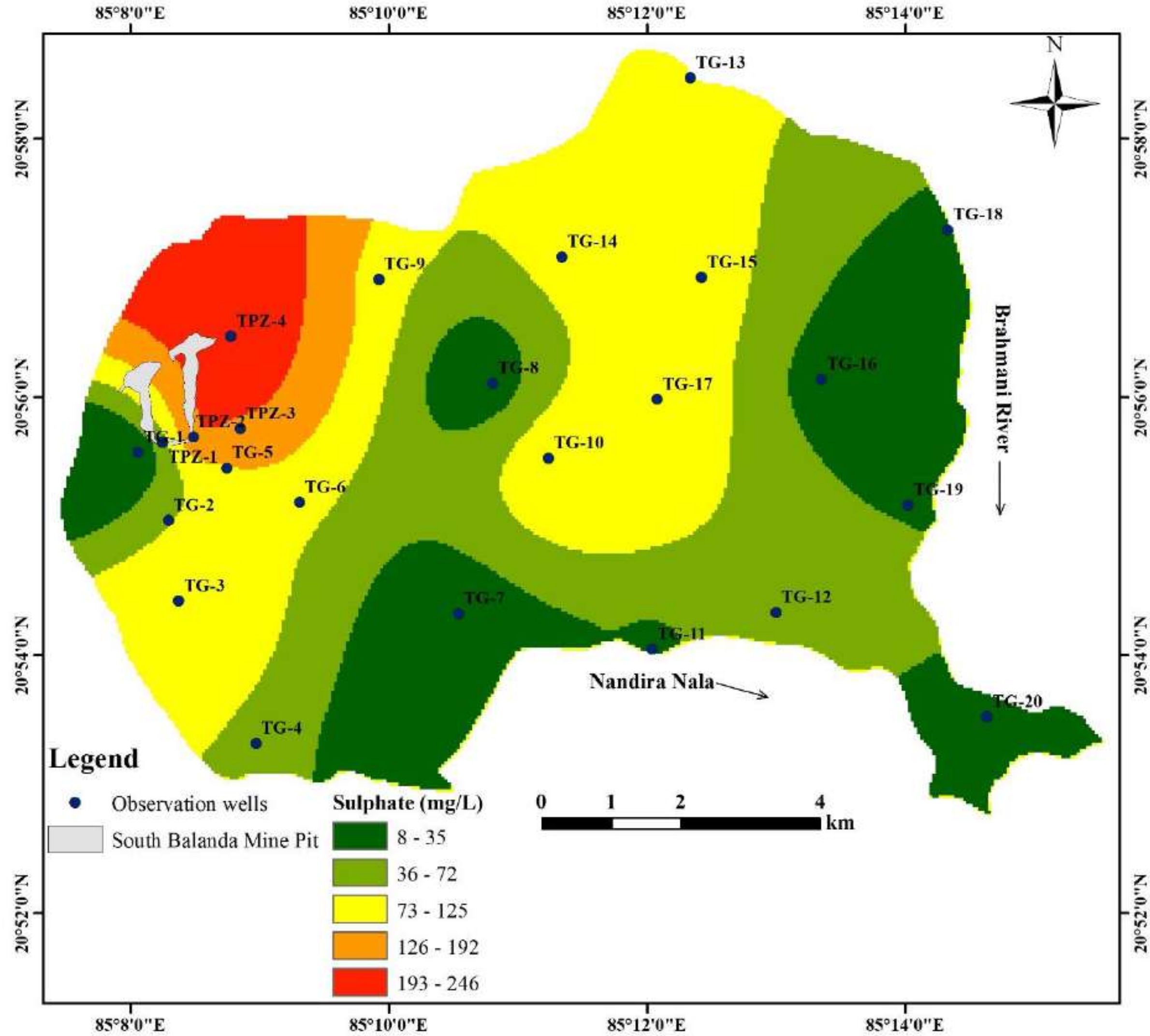
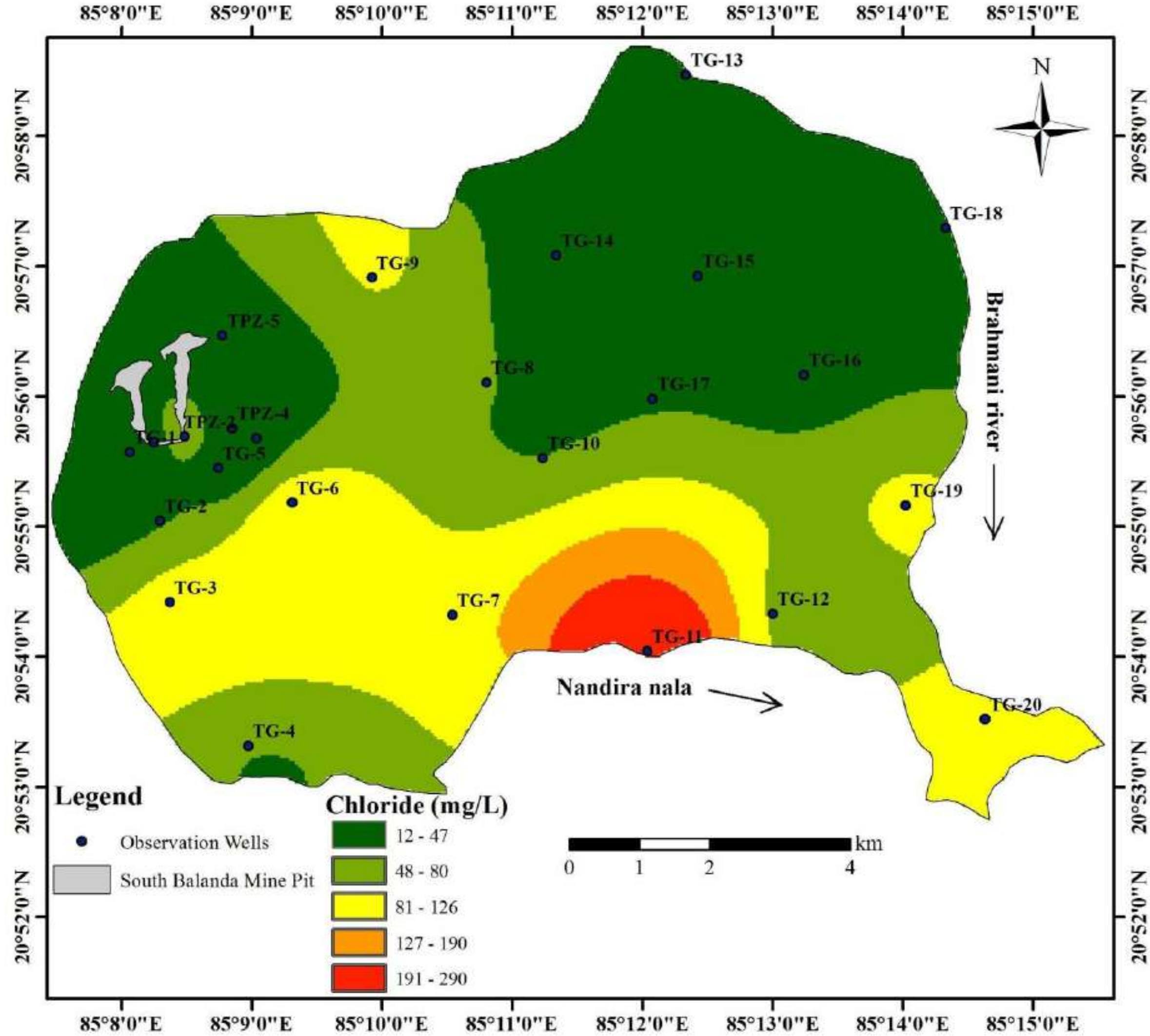


Figure 4.24 (f): Sulphate concentration in groundwater of the study area in October 2019


85°8'0"E
85°9'0"E
85°10'0"E
85°11'0"E
85°12'0"E
85°13'0"E
85°14'0"E
85°15'0"E
20°58'0"N
20°57'0"N
20°56'0"N
20°55'0"N
20°54'0"N
20°53'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-15
TG-9
TPZ-5
TG-8
TG-17
TG-16
TPZ-2
TPZ-4
TG-1
TG-5
TG-10
TG-6
TG-19
TG-2
TG-3
TG-7
TG-12
TG-11
Brahmani river
Nandira nala
TG-20
TG-4
Legend
Observation Wells
South Balanda Mine Pit
Chloride (mg/L)
12 - 47
48 - 80
81 - 126
127 - 190
191 - 290
0
1
2
4
km

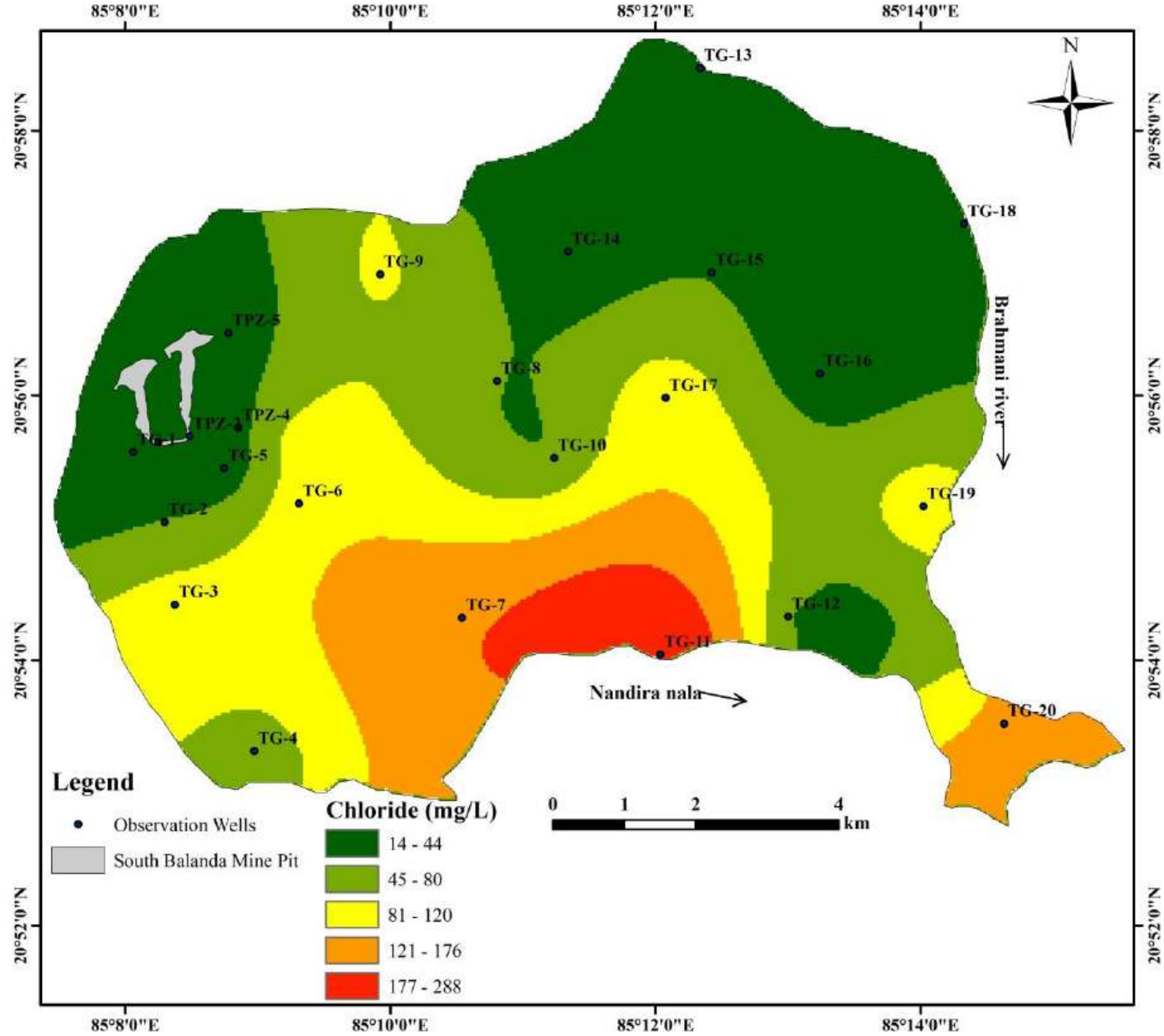
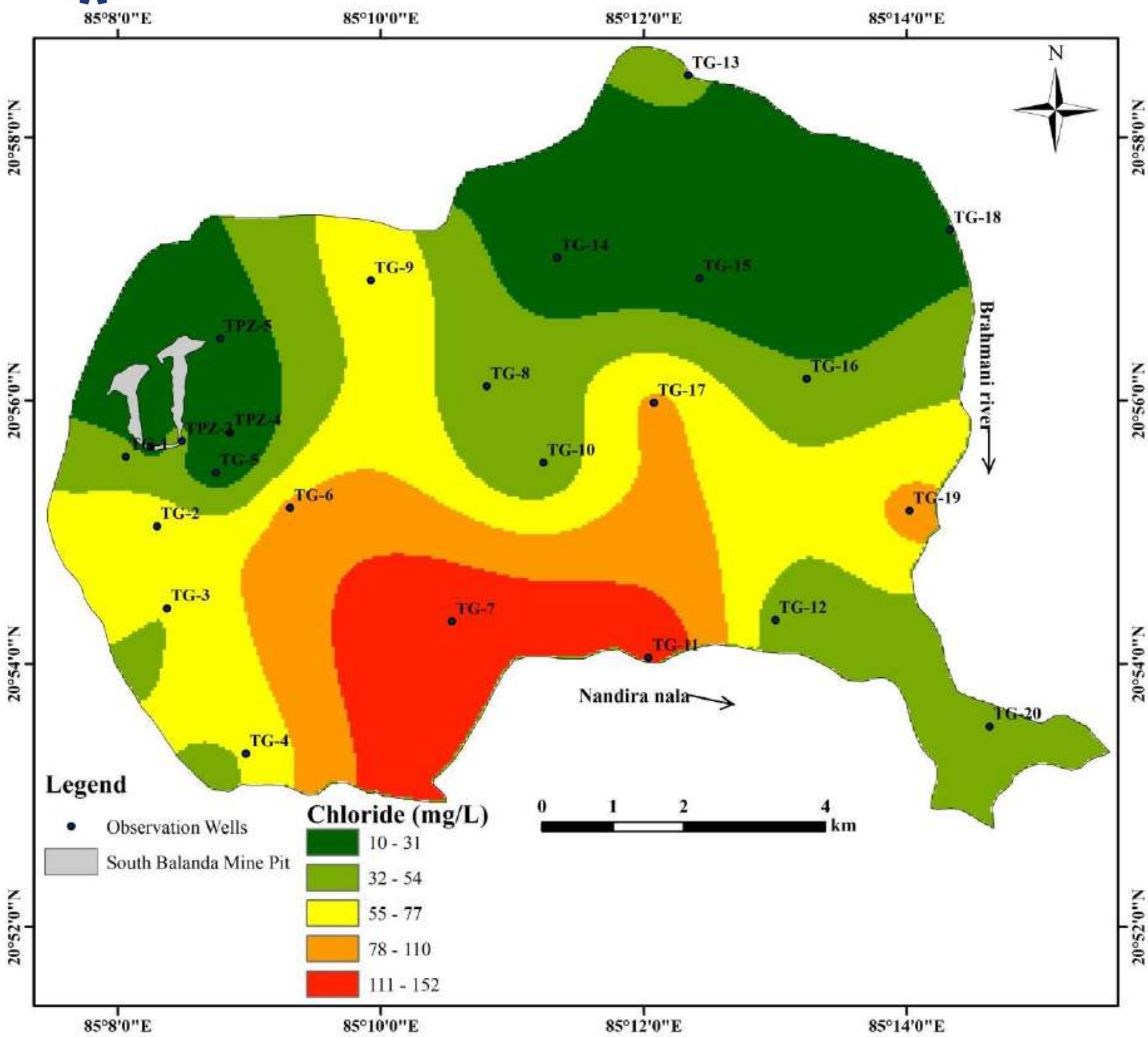


Figure 4.26 (b): Chloride concentration in groundwater of the study area in June 2018



85°8'0"E
85°10'0"E
85°12'0"E
85°14'0"E
20°58'0"N
20°56'0"N
20°54'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-15
TG-9
TPZ-5
TG-8
TG-16
TG-17
TPZ-3
TPZ-4
TG-1
TG-5
TG-10
TG-6
TG-19
TG-2
TG-3
TG-7
TG-12
TG-11
TG-20
TG-4
Brahmani river
Nandira nala
Legend
Observation Wells
South Balanda Mine Pit
Chloride (mg/L)
10 - 31
32 - 54
55 - 77
78 - 110
111 - 152
0
1
2
4
km

Figure 4.27 (c): Chloride concentration in groundwater of the study area in November 2018

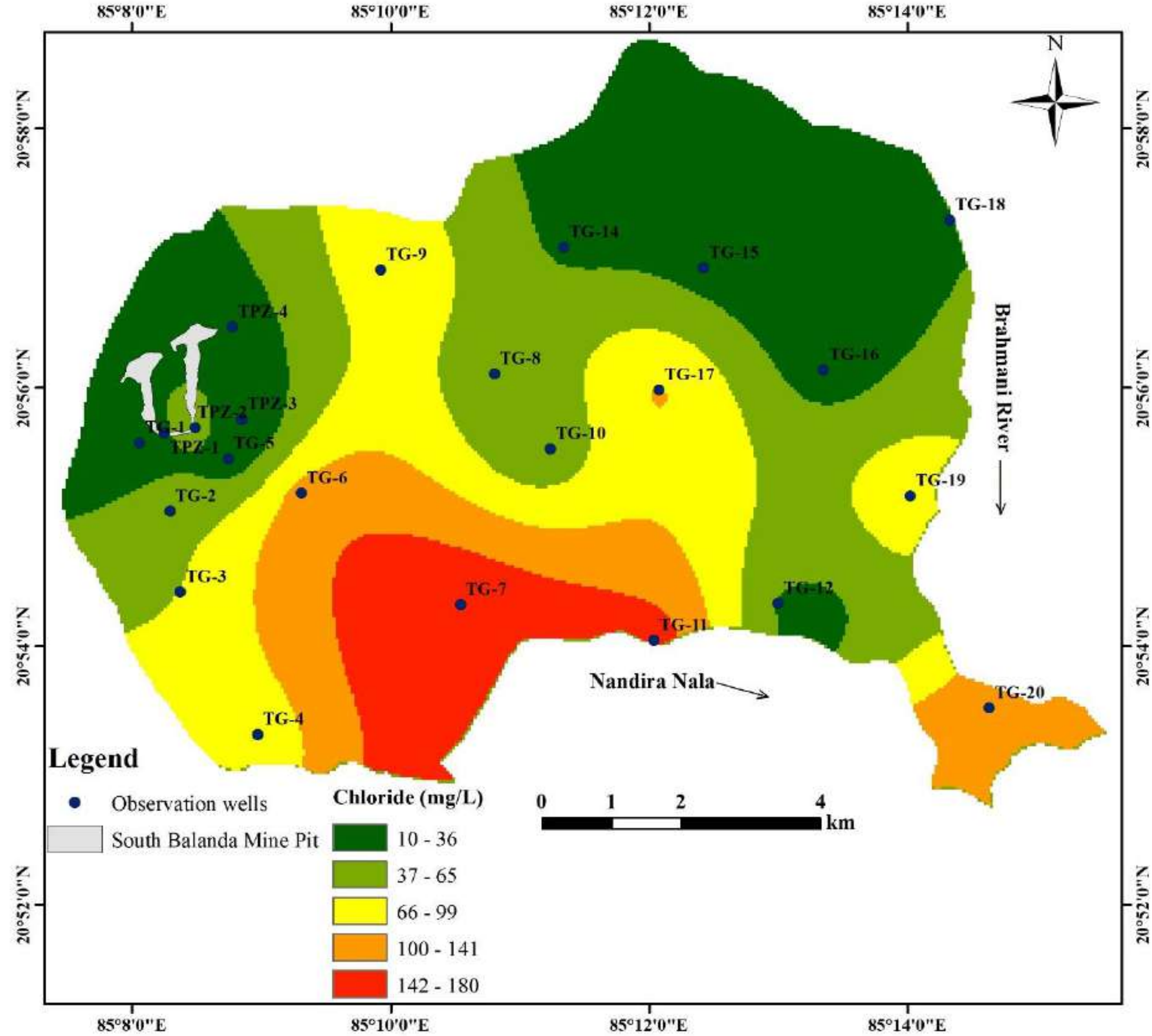
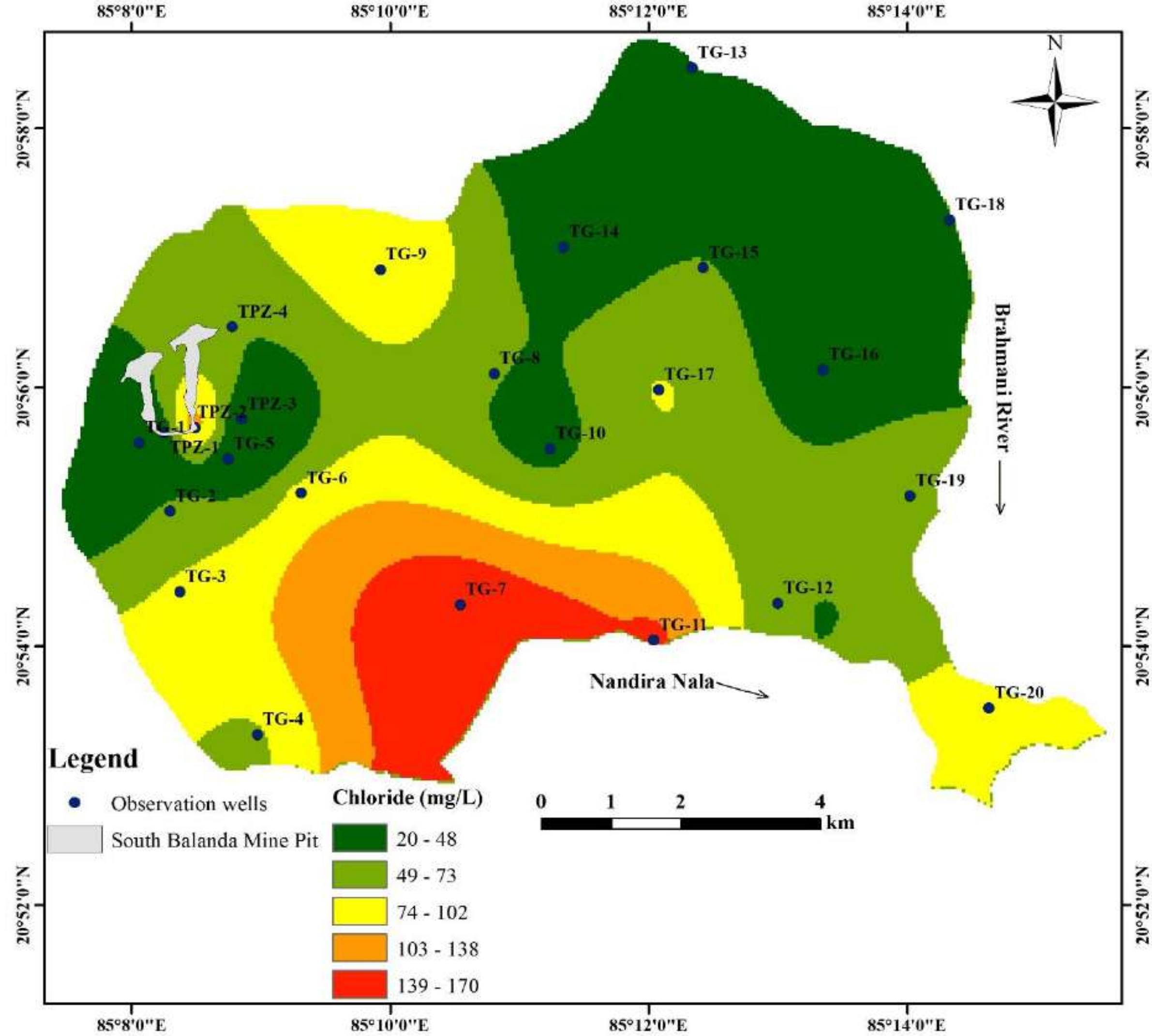


Figure 4.28 (d): Chloride concentration in groundwater of the study area in February 2019



85°8'0"E
85°10'0"E
85°12'0"E
85°14'0"E
20°58'0"N
20°56'0"N
20°54'0"N
20°52'0"N
N
TG-13
TG-18
TG-14
TG-15
TG-9
TPZ-4
TG-8
TG-16
TG-17
TPZ-2
TPZ-3
TG-1
TPZ-1
TG-5
TG-10
TG-6
TG-19
TG-2
TG-3
TG-7
TG-12
TG-11
Nandira Nala
TG-20
TG-4
Brahmani River
Legend
Observation wells
South Balanda Mine Pit
Chloride (mg/L)
20 - 48
49 - 73
74 - 102
103 - 138
139 - 170
0
1
2
4
km

Figure 4.29 (e): Chloride concentration in groundwater of the study area in June 2019

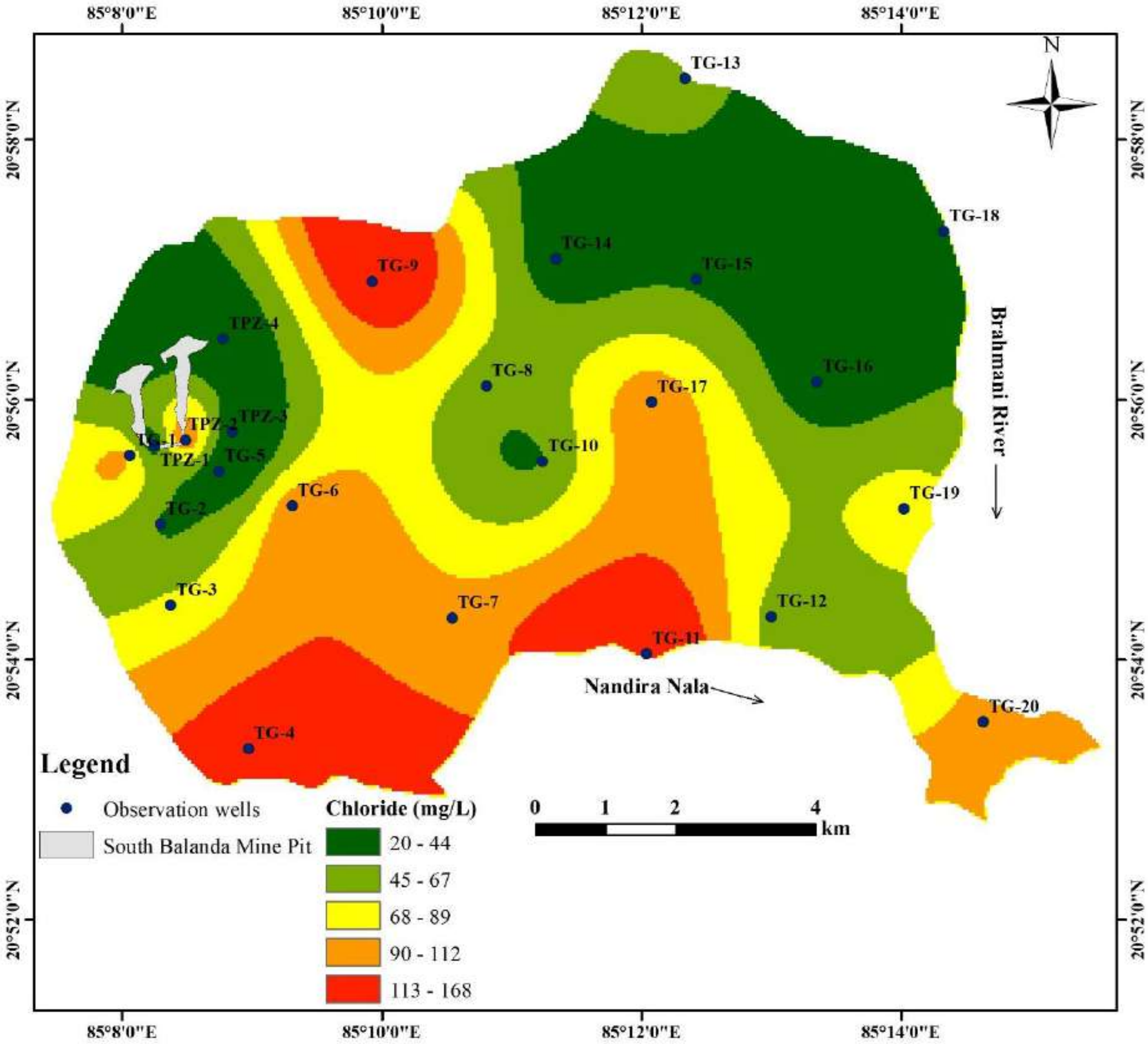


Figure 4.30 (f): Chloride concentration in groundwater of the study area in October 2019

Table 4.3 (a): Physico-chemical results of collected groundwater samples and surface water samples (April 2018)

Sr. No	Sample code	pH	EC	TDS (mg/l)	Turbidity	Total Hardness as $CaCO_3$	Calcium as Ca^{2+}	Magnesium Mg^{2+}	Sodium	Potassium	Total alkalinity as $CaCO_3$	Phosphate as PO_4^{-2}	Fluoride as F^-	Nitrate NO_3^-	sulphate	chloride
Units	**-**	**-**	**µS/cm**	**mg/L**	**NTU**	**mg/L**										
BIS 10500:2012 (Acceptable/ Permissible limit)		**6.5/8.5**	**-**	**500/ 2000**	**1/5**	**200/ 600**	**75/200**	**30/100**	**-**	**-**	**200/600**	**-**	**1.0/1.5**	**45**	**200/400**	**250/ 1000**
1	TG-1	6.3	287	172	**17**	116	37	6	10	4	105	0.2	0.2	0	25	20
2	TG-2	7.7	549	329	0.9	**276**	83	16	10	1	**210**	0.4	0.6	1	51	44
3	TG-3	7.8	1121	**673**	0.6	**416**	99	40	87	5	**325**	0.3	0.9	18	95	100
4	TG-4	7.5	855	**513**	**1.1**	**300**	54	39	80	1	**400**	0.2	1.0	1	45	52
5	TG-5	6.9	363	218	**6.6**	**204**	46	21	7	2	125	0.2	0.2	0	48	20
6	TG-6	7.4	1205	**723**	0.4	**368**	85	37	102	2	**450**	0.3	0.9	13	92	110
7	TG-7	7.4	1282	**769**	0.5	**412**	72	56	132	1	**475**	0.9	**1.7**	20	96	100
8	TG-8	6.3	332	199	**18**	120	37	7	14	7	50	0.9	0.2	10	23	50
9	TG-9	6.7	723	434	**10**	**240**	56	24	40	31	100	0.9	0.2	28	61	84
10	TG-10	7.6	626	376	0.9	**280**	58	33	20	1	150	0.8	0.4	5	55	48
11	TG-11	7.1	1928	**1157**	0.9	**660**	173	55	84	1	**400**	0.9	0.4	6	**210**	**290**
12	TG-12	7.7	927	**556**	**1.6**	184	42	19	136	2	**325**	0.9	0.5	1	30	74
13	TG-13	7.3	968	**581**	**2.9**	**448**	69	66	36	20	**475**	0.9	1.0	1	28	46
14	TG-14	6.3	151	90	**5.5**	144	24	20	4	6	75	1.0	0.2	2	20	24
15	TG-15	7.7	338	203	0.8	100	29	7	29	16	75	0.9	0.2	7	25	46
16	TG-16	6.8	207	124	0.8	116	30	10	6	2	60	1.2	0.2	2	9	26
17	TG-17	7.2	905	**543**	1.0	**332**	75	35	60	6	**310**	0.9	0.7	19	66	44
18	TG-18	6.7	225	130	**11**	**292**	24	18	4	5	120	0.9	0.4	0	12	12
19	TG-19	7.4	981	**589**	0.6	200	69	7	114	1	**355**	0.9	**1.6**	2	21	90
20	TG-20	7.5	813	488	**22**	180	45	16	133	2	**285**	0.9	**3.1**	0	27	110
21	TPZ-1-T	7.9	446	268	**5.6**	**236**	67	16	10	11	150	0.9	0.5	4	39	30
22	TPZ-1-B	7.3	460	276	**4.7**	**256**	48	8	14	11	150	0.2	0.4	2	42	30
23	TPZ-2-T	7.2	998	**599**	**2.6**	**464**	163	13	59	1	**300**	0.1	0.3	1	132	68
24	TPZ-3-T	7.2	149	89	**21**	112	35	2	5	5	65	0.5	0.2	0	10	14
25	TPZ-3-B	7.1	140	84	**28**	96	35	2	5	5	60	0.3	0.1	0	12	14
26	TPZ-4-T	6.9	821	493	**1.6**	**360**	104	24	38	4	**250**	0.1	0.4	14	179	12

Sr. No	Sample code	pH	EC	TDS (mg/l)	Turbidity	Total Hardness as $CaCO_3$	Calcium as Ca^{2+}	Magnesium Mg^{2+}	Sodium	Potassium	Total alkalinity as $CaCO_3$	Phosphate as PO_4^{-2}	Fluoride as F^-	Nitrate NO_3^-	sulphate	chloride
Units	-	-	µS/cm	mg/L	NTU	mg/L										
BIS 10500:2012 (Acceptable/ Permissible limit)		**6.5/8.5**	**-**	**500/ 2000**	**1/5**	**200/ 600**	**75/200**	**30/100**	**-**	**-**	**200/600**	**-**	**1.0/1.5**	**45**	**200/400**	**250/ 1000**
27	TPZ-5-T	6.8	845	**507**	**4.0**	**384**	**117**	22	45	5	95	0.1	0.4	1	**327**	28
28	TS-1	8.4	499	299	0.9	152	38	13	37	13	110	0.3	**2.1**	8	75	52
29	TS-2	7.9	109	65	**1.3**	56	18	3	6	1	55	0.3	0.2	0.6	3	10
30	TS-3	7.8	109	65	**1.2**	64	19	4	5	1	50	0.2	0.2	0.7	5	8
31	TS-4	8.0	500	300	0.8	188	48	16	35	9	150	0.2	**2.5**	3	92	40

Table 4.4 (b): Physico-chemical results of collected groundwater samples (June 2018)

Sr. No	Sample Code	pH	EC	TDS (mg/l)	Turbidity	Total Hardness as	Calcium as Ca2+	Magnesium Mg2+	Sodium	Potassium	Total alkalinity as CaCO3	Phosphate as PO4-2	Fluoride as F-	Nitrate NO3-	sulphate	chloride
Units	-	-	µS/cm	mg/L	NTU	mg/L										
BIS 10500:2012 (Acceptable/ Permissible limit)		6.5/8.5	-	500/ 2000	1/5	200/ 600	75/200	30/100	-	-	200/600	-	1.0/1.5	45	200/400	250/ 1000
1	TG-1	5.6	290	174	600	112	26	12	22	7	112	0.03	0.04	0	30	20
2	TG-2	6.7	648	389	33	284	35	47	40	2	208	0.05	0.3	0	68	44
3	TG-3	6.9	1176	706	4.7	272	24	51	114	25	332	0.02	0.5	33	106	102
4	TG-4	6.9	855	513	5.9	316	18	65	91	1	328	0.08	0.6	0	73	60
5	TG-5	6.8	420	252	450	200	40	24	24	5	132	0.03	0.6	0	84	22
6	TG-6	7.2	1134	680	6.1	204	16	39	104	4	312	0.10	0.6	18	66	98
7	TG-7	6.9	1561	937	19	128	64	77	134	4	392	0.05	0.6	23	141	166
8	TG-8	5.9	262	157	500	72	16	8	36	8	80	0.02	0.6	0	27	46
9	TG-9	6.4	787	472	95	148	50	30	70	32	132	0.05	0.6	28	83	84
10	TG-10	6.9	502	301	7.5	192	48	17	36	8	136	0.05	0.6	0	96	50
11	TG-11	6.8	1967	1180	45	300	147	98	99	5	392	0.05	0.6	40	239	288
12	TG-12	7.4	857	514	2.1	116	8	23	141	2	404	0.04	0.6	0	11	50
13	TG-13	6.6	948	569	60	248	8	55	60	22	420	0.02	0.6	0	10	42
14	TG-14	5.4	138	83	650	60	10	9	30	8	68	0.09	0.6	0	18	20
15	TG-15	6.3	256	154	130	48	10	6	47	18	80	0.05	0.6	0	6	42
16	TG-16	5.9	179	107	16	60	21	2	14	4	68	0.02	0.6	0	10	24
17	TG-17	7.1	944	566	7.7	200	21	36	90	7	336	0.03	0.6	10.1	11	100
18	TG-18	6.7	264	158	500	128	18	20	8	6	148	0.01	0.6	0	2	20
19	TG-19	7.2	962	577	21	100	27	16	113	10	332	0.0	0.6	0	8	100
20	TG-20	7.2	861	517	60	124	18	19	138	4	272	0.02	0.6	0	4	130
21	TPZ-1	6.2	338	203	60	160	46	11	18	11	124	0.04	0.3	0	45	14
22	TPZ-2	6.6	725	435	40	200	43	22	39	7	232	0.01	0.3	0	88	26
23	TPZ-3	6.2	1034	620	150	376	88	37	18	7	108	0.02	0.08	15	300	66
24	TPZ-4	6.0	669	401	120	460	59	75	27	12	172	0.04	0.07	0	224	24
25	TPZ-5	5.9	1050	630	550	280	26	60	60	22	120	0.02	0.09	0	413	22

Table 4.5 (c): Physico-chemical results of collected groundwater samples (November 2018)

Sr. No	Sample Code	pH	EC	TDS (mg/l)	Turbidity	Total Hardness as CaCO3	Calcium as Ca2+	Magnesium Mg2+	Sodium	Potassium	Total alkalinity as CaCO3	Phosphate as PO4-2	Fluoride as F-	Nitrate NO3-	sulphate	chloride
Units	-	-	µS/cm	mg/L	NTU	mg/L										
BIS 10500:2012 (Acceptable/ Permissible limit)		6.5/8.5	-	500/ 2000	1/5	200/ 600	75/200	30/100	-	-	200/600	-	1.0/1.5	45	200/400	250/ 1000
1	TG-1	7.6	566	340	300	104	24	2	85	13	148	0.08	0.72	2	12	40
2	TG-2	7.4	1709	1025	12	200	35	45	38	2	256	0.37	0.96	8	83	70
3	TG-3	6.5	214	128	7.3	300	30	54	75	24	272	0.25	1.1	37	97	56
4	TG-4	7.5	583	350	6.3	192	42	21	95	6	360	0.14	1.3	1	62	56
5	TG-5	6.9	460	276	200	128	34	11	17	10	128	0.07	0.34	6	57	20
6	TG-6	6.5	294	176	50	268	35	43	97	5	348	0.23	1.1	35	96	82
7	TG-7	7.2	767	460	8.2	124	24	15	102	3	108	0.42	3.7	5	19	142
8	TG-8	7.4	273	164	320	128	35	10	24	13	92	0.10	0.22	25	58	46
9	TG-9	6.4	176	105	7.8	328	32	34	41	42	72	0.27	0.29	81	78	64
10	TG-10	6.9	687	412	2.3	220	19	41	43	6	192	0.27	0.67	2	80	36
11	TG-11	7.4	633	380	3.1	136	40	9	111	6	116	0.16	3.9	8	42	152
12	TG-12	7.4	563	338	3.0	112	18	16	152	6	380	0.24	0.66	1	25	46
13	TG-13	7.9	350	210	6.1	520	21	112	41	24	460	0.07	1.3	1	80	40

Sr. No	Sample Code	pH	EC	TDS (mg/l)	Turbidity	Total Hardness as CaCO3	Calcium as Ca2+	Magnesium Mg2+	Sodium	Potassium	Total alkalinity as CaCO3	Phosphate as PO4-2	Fluoride as F-	Nitrate NO3-	sulphate	chloride
Units	-	-	μS/cm	mg/L	NTU	mg/L										
BIS 10500:2012 (Acceptable/ Permissible limit)		6.5/8.5	-	500/ 2000	1/5	200/ 600	75/200	30/100	-	-	200/600	-	1.0/1.5	45	200/400	250/ 1000
14	TG-14	7.7	85	51	15	68	16	7	11	7	72	0.03	0.25	2	22	12
15	TG-15	7.5	174	104	7.1	160	45	12	23	15	132	0.11	0.27	3	65	16
16	TG-16	8.0	341	205	1.5	72	19	6	12	3	56	0.31	0.22	2	13	36
17	TG-17	7.0	950	570	1.2	180	118	15	68	9	316	0.19	0.90	98	135	80
18	TG-18	6.4	294	177	39	108	32	7	18	14	96	0.09	0.31	13	29	26
19	TG-19	7.2	634	380	4.1	284	35	47	296	8	364	0.20	1.2	2	268	84
20	TG-20	7.3	367	220	21	88	29	19	32	1	200	0.38	4.0	2	3	50
24	TPZ-2	5.8	524	315	2.9	176	96	11	45	7	192	0.29	0.66	2	217	36
25	TPZ-4	7.2	493	296	<u>20</u>	272	58	31	48	12	104	0.22	0.32	6	356	10
26	TPZ-5	7.0	583	350	<u>55</u>	380	101	31	13	7	84	0.26	0.23	3	220	20

Table 4.6 (d): Physico-chemical results of collected groundwater samples (February, 2019)

Sr. No	Sample Code	pH	EC	TDS (mg/l)	Turbidity	Total Hardness as $CaCO_3$	Calcium as Ca^{2+}	Magnesium Mg^{2+}	Sodium	Potassium	Total alkalinity as $CaCO_3$	Phosphate as PO_4^{-2}	Fluoride as F^-	Nitrate NO^{3-}	sulphate	chloride
Units	-	-	µS/cm	mg/L	NTU	mg/L										
BIS 10500:2012 (Acceptable/ Permissible limit)		6.5/8.5	-	500/ 2000	1/5	200/ 600	75/200	30/100	-	-	200/600	-	1.0/1.5	45	200/400	250/ 1000
1	TG-1	6.9	292	175	**187**	144	34	14	13	5	140	0.08	0.13	1	42	26
2	TG-2	7.8	619	371	**396**	270	82	16	14	1	224	0.08	0.53	2	75	50
3	TG-3	7.8	926	556	**593**	288	56	36	73	17	280	0.12	0.97	23	116	66
4	TG-4	7.8	845	507	**541**	288	21	57	63	1	348	0.17	1.1	3	71	74
5	TG-5	7.3	443	266	**284**	196	50	17	10	4	104	0.05	0.14	3	138	20
6	TG-6	7.7	1090	654	**698**	252	64	22	95	4	156	0.11	1	**46**	111	110
7	TG-7	8.2	590	354	**378**	52	14	4	93	2	56	0.05	3.3	2	4	180
8	TG-8	7.1	354	212	**227**	112	26	12	17	11	94	0.07	0.04	3	33	52
9	TG-9	7.0	780	468	**499**	200	56	14	37	38	80	0.08	0.1	**108**	80	80
10	TG-10	7.6	688	413	**440**	208	64	12	15	2	148	0.34	0.36	3	90	42
11	TG-11	7.8	774	464	**495**	140	37	12	96	1	120	0.15	2.8	8	35	170
12	TG-12	7.8	814	488	**521**	128	5	28	147	1	408	0.11	0.39	2	20	36
13	TG-14	7.2	518	311	**332**	188	45	18	17	8	116	0.08	0.12	7	123	32

Sr. No	Sample Code	pH	EC	TDS (mg/l)	Turbidity	Total Hardness as $CaCO_3$	Calcium as Ca^{2+}	Magnesium Mg^{2+}	Sodium	Potassium	Total alkalinity as $CaCO_3$	Phosphate as PO_4^{-2}	Fluoride as F^-	Nitrate NO^{3-}	sulphate	chloride
Units	**-**	**-**	**µS/cm**	**mg/L**	**NTU**	**mg/L**										
BIS 10500:2012 (Acceptable/ Permissible limit)		**6.5/8.5**	**-**	**500/ 2000**	**1/5**	**200/ 600**	**75/200**	**30/100**	**-**	**-**	**200/600**	**-**	**1.0/1.5**	**45**	**200/400**	**250/ 1000**
14	TG-15	7.3	484	290	**<u>310</u>**	184	35	23	19	15	120	0.17	0.14	10	79	24
15	TG-16	7.3	1510	906	**<u>966</u>**	60	19	3	10	2	48	0.16	0.06	4	13	24
16	TG-17	7.5	1043	626	**<u>668</u>**	360	85	36	41	4	288	0.17	0.61	24	101	100
17	TG-18	6.9	308	185	**<u>197</u>**	100	26	9	18	16	136	0.05	0.13	2	6	36
18	TG-19	7.3	876	526	**<u>561</u>**	200	72	5	84	1	292	0.14	1.4	3	36	90
19	TG-20	7.6	763	458	**<u>488</u>**	120	29	12	125	3	256	0.06	**<u>3.1</u>**	2	17	120
20	TPZ-1	6.6	407	244	**<u>260</u>**	164	34	19	130	7	144	0.1	0.2	2	61	30
21	TPZ-2	6.7	772	463	**<u>494</u>**	280	83	17	31	2	124	0.35	0.4	15	180	52
22	TPZ-3	6.7	738	443	**<u>472</u>**	312	83	25	15	9	140	0.11	0.25	24	194	10
23	TPZ-4	6.6	1347	808	**<u>862</u>**	840	141	117	22	9	80	0.06	0.21	4	262	24

Table 4.3 (e): Phyico-chemical results of collected groundwater samples (June, 2019)

Sr. No	Sample Code	pH	EC	TDS (mg/l)	Turbidity	Total Hardness	Calcium as Ca^{2+}	Magnesium Mg^{2+}	Sodium	Potassium	Total alkalinity as	Phosphate as PO_4^{-2}	Fluoride as F^-	Nitrate NO^{3-}	sulphate	chloride
Units	**-**	**-**	**µS/cm**	**mg/L**	**NTU**	**mg/L**										
BIS 10500:2012 (Acceptable/ Permissible limit)		**6.5/8.5**	**-**	**500/ 2000**	**1/5**	**200/ 600**	**75/200**	**30/100**	**-**	**-**	**200/600**	**-**	**1.0/1.5**	**45**	**200/400**	**250/ 1000**
1	TG-1	6.8	270	162	280	120	29	12	17	5	140	0.2	0.1	1	26	22
2	TG-2	7.7	601	361	0	**248**	**78**	12	25	2	**220**	0.5	0.6	1	77	52
3	TG-3	7.6	1063	**638**	1	**280**	64	29	73	7	**260**	0.3	**1.1**	**<u>55</u>**	168	78
4	TG-4	7.6	912	**547**	1	**280**	51	**36**	68	1	**356**	0.2	**1.1**	0	73	70
5	TG-5	7.7	509	305	194	**228**	56	21	13	5	96	0.1	0.1	2	180	30
6	TG-6	7.4	1169	**701**	1	**260**	72	19	89	4	**276**	0.3	1.0	**<u>115</u>**	96	80
7	TG-7	7.8	641	385	3	64	14	7	89	2	76	0.3	**<u>3.6</u>**	2	6	170
8	TG-8	6.5	288	173	4	88	24	7	40	6	60	0.9	0.1	**<u>109</u>**	6	52
9	TG-9	6.4	770	462	13	**232**	62	18	48	13	132	0.6	0.1	**<u>114</u>**	117	94
10	TG-10	7.5	535	321	0	**212**	53	19	22	1	160	0.4	0.4	1	103	40
11	TG-11	7.7	533	320	1	68	24	2	90	1	92	0.3	**<u>3.9</u>**	3	24	150
12	TG-12	7.7	651	391	99	96	32	4	138	1	**320**	0.1	0.5	2	26	54
13	TG-13	7.2	886	**532**	1	**420**	46	**73**	49	17	**448**	0.4	1.0	8	98	46

Sr. No	Sample Code	pH	EC	TDS (mg/l)	Turbidity	Total Hardness	Calcium as Ca^{2+}	Magnesium Mg^{2+}	Sodium	Potassium	Total alkalinity as	Phosphate as PO_4^{-2}	Fluoride as F^-	Nitrate NO^{3-}	sulphate	chloride
Units	**-**	**-**	**µS/cm**	**mg/L**	**NTU**	**mg/L**										
BIS 10500:2012 (Acceptable/ Permissible limit)		**6.5/8.5**	**-**	**500/ 2000**	**1/5**	**200/ 600**	**75/200**	**30/100**	**-**	**-**	**200/600**	**-**	**1.0/1.5**	**45**	**200/400**	**250/ 1000**
14	TG-14	7.3	1002	**601**	0	152	34	16	25	10	116	0.5	0.3	13	92	34
15	TG-15	7.1	406	244	1	**220**	59	17	33	13	156	0.6	0.2	**74**	93	50
16	TG-16	6.5	621	373	0	72	21	5	20	2	52	0.5	0.1	26	16	32
17	TG-17	7.2	161	97	0	184	5	41	60	3	160	1.0	0.7	30	103	74
18	TG-18	6.9	334	200	7	100	24	10	23	13	124	0.1	0.2	3	26	36
19	TG-19	7.7	890	**534**	1	200	32	29	76	1	**328**	0.6	**1.6**	0	31	72
20	TG-20	7.7	730	438	2	96	16	13	110	3	**240**	0.5	**3.4**	9	15	90
21	TPZ-1	6.7	429	257	12	152	48	8	11	5	128	0.4	0.2	1	53	30
22	TPZ-2	6.9	919	**551**	5	**204**	54	16	27	2	108	1.2	0.3	2	170	110
23	TPZ-3	6.9	685	411	2	**236**	53	25	13	5	96	0.3	0.3	31	180	20
24	TPZ-4	6.7	1287	**772**	193	**532**	**104**	**65**	14	6	124	0.2	0.2	12	**246**	52

Table 4.3 (f): Phyico-chemical results of collected groundwater samples (October, 2019)

Sr. No	Sample Code	pH	EC	TDS (mg/l)	Turbidity	Total Hardness as $CaCO_3$	Calcium as Ca^{2+}	Magnesium Mg^{2+}	Sodium	Potassium	Total alkalinity as $CaCO_3$	Phosphate as PO_4^{-2}	Fluoride as F^-	Nitrate NO^{3-}	sulphate	chloride
Units	**-**	**-**	**µS/cm**	**mg/L**	**NTU**	**mg/L**										
BIS 10500:2012 (Acceptable/ Permissible limit)		**6.5/8.5**	**-**	**500/ 2000**	**1/5**	**200/ 600**	**75/200**	**30/100**	**-**	**-**	**200/600**	**-**	**1.0/1.5**	**45**	**200/400**	**250/ 1000**
1	TG-1	8.2	809	485	**110**	154	39	13	44	8	160	0.6	0.1	4	22	88
2	TG-2	8	637	382	0	**212**	51	20	28	4	200	0.5	0.6	1	67	44
3	TG-3	7.9	1038	**623**	1	144	40	11	97	27	**220**	0.5	**1.1**	23	122	72
4	TG-4	8.1	1105	**663**	1	**280**	51	36	83	3	**320**	0.5	**1.1**	4	56	126
5	TG-5	8.2	372	223	**177**	200	48	19	14	6	88	2	0.1	6	123	24
6	TG-6	7.8	1185	**711**	1	**232**	64	17	104	5	**280**	1.7	1.0	34	88	102
7	TG-7	8.3	615	369	3	**220**	48	24	66	3	160	1.4	**3.6**	5	9	100
8	TG-8	7.8	373	224	4	144	35	13	32	12	64	6	0.1	44	8	56
9	TG-9	7.5	1126	**676**	**8**	**300**	88	19	104	49	180	2.3	0.1	39	100	140
10	TG-10	7.7	546	328	0	200	51	17	26	3	144	0.7	0.4	8	99	44
11	TG-11	7.8	926	**556**	1	152	29	19	110	3	88	1.3	**3.9**	9	21	168
12	TG-12	7.9	900	**540**	**60**	**284**	66	29	122	3	**296**	0.8	0.5	18	55	60
13	TG-13	7.6	1121	**673**	1	**244**	56	25	69	27	**320**	0.5	1.0	8	89	60

Sr. No	Sample Code	pH	EC	TDS (mg/l)	Turbidity	Total Hardness as $CaCO_3$	Calcium as Ca^{2+}	Magnesium Mg^{2+}	Sodium	Potassium	Total alkalinity as $CaCO_3$	Phosphate as PO_4^{-2}	Fluoride as F^-	Nitrate NO^{3-}	sulphate	chloride
Units	**-**	**-**	**µS/cm**	**mg/L**	**NTU**	**mg/L**										
BIS 10500:2012 (Acceptable/ Permissible limit)		**6.5/8.5**	**-**	**500/ 2000**	**1/5**	**200/ 600**	**75/200**	**30/100**	**-**	**-**	**200/600**	**-**	**1.0/1.5**	**45**	**200/400**	**250/ 1000**
14	TG-14	7.8	507	304	0	192	51	25	69	27	120	1.2	0.3	13	92	30
15	TG-15	7.7	599	359	1	160	35	15	29	10	144	1.2	0.2	74	93	40
16	TG-16	7.9	589	353	0	**324**	72	17	37	16	180	1.2	0.1	26	16	30
17	TG-17	7.5	1157	**694**	0	180	50	35	11	4	156	0.9	0.7	30	103	104
18	TG-18	7.7	344	206	5	180	32	13	64	6	120	0.9	0.2	3	26	40
19	TG-19	7.5	902	**541**	1	**204**	64	24	28	15	**320**	1.4	**1.6**	0	31	80
20	TG-20	7.9	765	459	2	**288**	88	11	86	3	**220**	0.8	**3.4**	9	15	96
21	TPZ-1	7.5	404	242	**9**	120	34	16	88	4	108	0.8	0.2	1	53	30
22	TPZ-2	7.4	646	388	3	**240**	51	9	15	7	108	0.9	0.3	2	170	30
23	TPZ-3	7.6	558	335	1	180	43	27	22	3	88	1.3	0.3	31	180	20
24	TPZ-4	7.4	883	**530**	**156**	164	48	17	13	8	120	1.2	0.2	12	**246**	20

4.3. Trace metal concentration

The samples collected from the observation well network were analysed for heavy metals concentration in the months of April 2018 (Table 4.4a), June 2018 (Table 4.4b), November 2018 (Table 4.4c), February 2019 (Table 4.4d), June 2019 (Table 4.4e), October 2019 (Table 4.4f). It is observed that parameters of health significance, namely As and Hg are not detected or with in the acceptable limit. Fe is present in many samples. However, its presence is linked to lateritic soil in the region. The presence of Al in few samples can be linked to Al bearing minerals in the study area (NEERI Report 201….)

Table 4.7 (a): Trace metal concentration in collected groundwater and surface water samples (April 2018)

Sr. No	Sample Code	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn		Hg
BIS 10500:2012 Acceptable Limit (mg/L)		**0.03**	**0.01**	**0.003**	**0.05**	**0.05**	**0.3**	**0.10**	**0.02**	**0.01**	**5.0**		**0.001**
BIS 10500:2012 Permissible Limit (mg/L)		**0.20**	**0.05**	**-**	**-**	**1.5**	**-**	**0.30**	**-**	**-**	**15**		**-**
ICP detection Limit (mg/L)		**0.002**	**0.007**	**0.0001**	**0.01**	**0.0004**	**0.0003**	**0.0001**	**0.005**	**0.009**	**0.001**		**0.000075**
	BDL-Below Detection Limit, ND-Not Detected												
1	TG-1	0.002	BDL	ND	BDL	BDL	0.11	BDL	BDL	BDL	2.3		BDL
2	TG-2	BDL	BDL	ND	BDL	BDL	0.012	0.004	ND	ND	0.1		BDL
3	TG-3	BDL	BDL	BDL	BDL	BDL	0.004	0.003	BDL	BDL	ND		BDL
4	TG-4	BDL	BDL	BDL	BDL	BDL	0.015	0.01	ND	BDL	ND		BDL
5	TG-5	BDL	BDL	BDL	BDL	BDL	0.10	0.06	ND	BDL	ND		BDL
6	TG-6	BDL	BDL	BDL	BDL	BDL	0.05	0.005	ND	BDL	BDL		BDL
7	TG-7	BDL	BDL	BDL	BDL	ND	0.004	0.001	ND	BDL	0.5		BDL
8	TG-8	BDL	BDL	BDL	BDL	BDL	0.05	0.004	ND	BDL	BDL		BDL
9	TG-9	BDL	BDL	BDL	BDL	BDL	0.001	0.007	ND	BDL	ND		BDL
10	TG-10	BDL	BDL	BDL	BDL	BDL	0.001	0.006	BDL	BDL	0.4		BDL
11	TG-11	BDL	BDL	BDL	BDL	BDL	0.04	0.001	BDL	BDL	2.6		BDL
12	TG-12	BDL	BDL	BDL	BDL	BDL	0.01	0.005	BDL	BDL	0.05		BDL
13	TG-13	BDL	BDL	BDL	BDL	BDL	0.0007	BDL	BDL	0.0001	ND		BDL
14	TG-14	BDL	BDL	ND	BDL	BDL	0.012	BDL	BDL	BDL	0.9		BDL
15	TG-15	BDL	BDL	ND	BDL	BDL	0.08	0.001	ND	ND	1.1		BDL
16	TG-16	BDL	BDL	BDL	BDL	BDL	0.04	0.005	BDL	BDL	0.6		BDL
17	TG-17	BDL	BDL	BDL	BDL	BDL	0.005	0.002	ND	BDL	0.56		BDL
18	TG-18	BDL	BDL	BDL	BDL	BDL	0.006	0.004	ND	BDL	0.1		BDL
19	TG-19	BDL	BDL	BDL	BDL	BDL	0.01	0.1	BDL	BDL	2.1		BDL

Sr. No	Sample Code	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn		Hg
BIS 10500:2012 Acceptable Limit (mg/L)		**0.03**	**0.01**	**0.003**	**0.05**	**0.05**	**0.3**	**0.10**	**0.02**	**0.01**	**5.0**		**0.001**
BIS 10500:2012 Permissible Limit (mg/L)		**0.20**	**0.05**	**-**	**-**	**1.5**	**-**	**0.30**	**-**	**-**	**15**		**-**
ICP detection Limit (mg/L)		**0.002**	**0.007**	**0.0001**	**0.01**	**0.0004**	**0.0003**	**0.0001**	**0.005**	**0.009**	**0.001**		**0.000075**
	BDL-Below Detection Limit, ND-Not Detected												
20	TG-20	BDL	BDL	BDL	BDL	ND	0.0004	0.04	BDL	BDL	3.7		BDL
21	TPZ-1-Top	BDL	BDL	BDL	BDL	BDL	0.004	0.1	ND	BDL	0.8		BDL
22	TPZ-1-Bottom	BDL	BDL	BDL	BDL	BDL	0.1	0.09	BDL	BDL	ND		BDL
23	TPZ-2-Top	BDL	BDL	BDL	BDL	ND	0.003	0.03	BDL	BDL	BDL		BDL
24	TPZ-3-Top	BDL	BDL	BDL	BDL	BDL	0.001	0.02	ND	BDL	0.04		BDL
25	TPZ-3-Bottom	BDL	BDL	BDL	BDL	BDL	0.005	0.05	ND	BDL	0.005		BDL
26	TPZ-4-Top	BDL	BDL	BDL	BDL	ND	0.07	BDL	BDL	BDL	1.4		BDL
27	TPZ-5-Top	BDL	BDL	BDL	BDL	ND	0.04	BDL	BDL	BDL	2.1		BDL
28	TS-1	BDL	BDL	BDL	BDL	BDL	0.2	0.02	BDL	BDL	2.5		BDL
29	TS-2	BDL	BDL	BDL	BDL	ND	0.04	0.0003	BDL	BDL	0.6		BDL
30	TS-3	BDL	BDL	BDL	BDL	0.1	0.04	0.001	ND	BDL	0.8		BDL
31	TS-4	BDL	BDL	BDL	BDL	0.005	0.01	0.04	BDL	BDL	2.2		BDL

Table 4.8 (b): Trace metal concentration in collected groundwater and surface water samples (June 2018)

Sr.No	Sample code	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Hg
	BIS Limit (ppm)	**0.01-0.05**	**0.003**	**0.05**	**0.05-1.5**	**0.3-1.0**	**0.10-0.30**	**0.02**	**0.01**	**5.0-15**	**0.001**
	ICP detection Limit (ppm)	**0.007**	**0.0001**	**0.01**	**0.0004**	**0.0003**	**0.0001**	**0.005**	**0.009**	**0.001**	**0.000075**
1	TG-1	ND	ND	BDL	BDL	0.005	0.1	BDL	BDL	BDL	0.00001
2	TG-2	ND	ND	BDL	0.001	0.01	0.1	BDL	BDL	0.7	BDL
3	TG-3	ND	ND	BDL	0.001	0.01	0.01	BDL	BDL	0.8	ND
4	TG-4	ND	ND	BDL	0.04	0.001	0.02	BDL	BDL	0.1	ND
5	TG-5	ND	ND	BDL	0.001	0.004	0.03	BDL	BDL	BDL	0.0002
6	TG-6	ND	ND	BDL	BDL	0.06	0.08	BDL	BDL	BDL	0.00004
7	TG-7	ND	ND	BDL	BDL	0.005	0.01	BDL	BDL	BDL	ND
8	TG-8	ND	ND	BDL	ND	0.004	0.1	BDL	BDL	5.4	ND
9	TG-9	ND	ND	BDL	ND	0.07	0.05	BDL	BDL	3.3	ND
10	TG-10	0.02	0.001	BDL	0.01	0.06	0.1	BDL	BDL	0.1	ND
11	TG-11	0.008	ND	BDL	0.002	0.001	0.2	BDL	BDL	0.1	ND
12	TG-12	ND	ND	BDL	ND	0.006	BDL	BDL	BDL	BDL	ND
13	TG-13	ND	ND	BDL	BDL	0.1	0.2	BDL	BDL	BDL	ND
14	TG-14	ND	ND	BDL	ND	0.07	0.1	BDL	BDL	2.5	ND
15	TG-15	ND	0.001	BDL	0.001	0.1	0.7	BDL	BDL	0.1	ND
16	TG-16	ND	ND	BDL	BDL	0.1	0.06	BDL	BDL	1.9	ND
17	TG-17	ND	ND	BDL	BDL	0.04	0.01	BDL	BDL	BDL	ND
18	TG-18	ND	ND	BDL	BDL	0.01	0.04	BDL	BDL	0.1	ND
19	TG-19	ND	ND	BDL	ND	0.04	0.1	BDL	BDL	0.3	ND
20	TG-20	ND	ND	BDL	BDL	0.01	0.05	BDL	BDL	BDL	ND
21	TPZ-1	ND	ND	BDL	ND	0.005	0.1	BDL	BDL	5.4	ND
22	TPZ-2	ND	ND	BDL	ND	0.004	0.04	BDL	BDL	3.3	ND
23	TPZ-3	ND	ND	BDL	BDL	0.07	0.01	BDL	BDL	BDL	ND
24	TPZ-4	ND	ND	BDL	ND	0.06	0.05	BDL	BDL	5.4	ND
25	TPZ-5	ND	ND	0.02	ND	0.01	0.02	BDL	BDL	3.3	ND

Table 4.9 (c): Trace metal concentration in collected groundwater and surface water samples (November 2018)

Sr.No	Sample code	Al	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Hg
	BIS Limit (ppm)	0.03-0.2	0.003	0.05	0.05-1.5	0.3-1.0	0.10-0.30	0.02	0.01	5.0-15	0.001
	ICP detection Limit (ppm)	0.00001	0.0001	0.01	0.0004	0.0003	0.0001	0.005	0.009	0.001	0.000075
1	TG-1	2.894	ND	0.036	ND	63.53	0.3839	ND	0.0032	0.0468	ND
2	TG-2	0.098	ND	ND	0.0053	0.8668	0.0286	ND	0.0003	0.3639	ND
3	TG-3	7.228	BDL	ND	0.0015	0.8323	0.0174	0.0002	0.0011	0.315	BDL
4	TG-4	6.338	ND	ND	0.06857	1.929	0.058	ND	0.0003	0.152	ND
5	TG-5	0.053	ND	0.016	ND	33.63	0.1817	ND	0.0009	2.341	ND
6	TG-6	0.065	ND	ND	0.0127	0.379	0.135	0.0014	ND	0.5967	0.00004
7	TG-7	0.057	0.0001	0.007	ND	20.03	0.721	0.0135	0.0016	8.474	BDL
8	TG-8	ND	ND	ND	0.0359	2.77	0.04612	0.0132	0.0003	1.038	BDL
9	TG-9	0.063	ND	ND	0.0055	4.50	0.1307	0.00017	ND	0.0969	BDL
10	TG-10	6.90	ND	ND	ND	0.775	0.024	0.00017	ND	0.505	0.00005
11	TG-11	0.059	ND	ND	0.0007	0.769	0.0366	0.00014	0.0009	0.4033	0.00001
12	TG-12	0.229	ND	0.0054	ND	17.81	0.094	ND	ND	4.716	BDL
13	TG-13	3.76	ND	0.021	ND	43.04	0.4137	0.0051	0.0009	3.826	BDL
14	TG-14	1.40	ND	0.0002	ND	9.01	0.1384	0.0002	ND	0.078	ND
15	TG-15	6.712	ND	ND	ND	0.31	0.116	0.0014	0.0015	0.014	0.00004
16	TG-16	13.92	ND	ND	0.0021	1.17	0.119	0.0006	ND	0.0931	0.00005
17	TG-17	0.906	ND	0.0062	ND	12.93	0.118	0.0021	0.0009	0.6598	BDL
18	TG-18	4.561	ND	ND	ND	0.300	0.024	0.0006	0.0006	1.300	BDL
19	TG-19	0.573	0.0009	ND	ND	2.05	0.0837	ND	0.0003	0.229	BDL
20	TG-20	5.465	0.0009	ND	ND	0.088	0.619	0.0751	0.0005	0.0954	0.00002
21	TPZ-1	0.241	ND	ND	ND	14.78	3.36	0.014	0.0008	0.4494	ND
22	TPZ-2	6.306	ND	0.0035	ND	14.77	3.36	0.014	0.0008	0.4494	BDL
23	TPZ-4	0.1589	ND	0.0185	ND	36.47	1.692	0.0092	0.001909	0.5043	0.0007

24	TPZ-5	0.0342	ND	ND	0.00133	0.3303	0.0747	0.0010	0.00115	0.03986	BDL

Table 4.10 (d): Trace metal concentration in collected groundwater and surface water samples (June 2019)

Sr.No	Sample code	Al	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Hg
	BIS Limit (ppm)	**0.03-0.2**	**0.003**	**0.05**	**0.05-1.5**	**0.3-1.0**	**0.10-0.30**	**0.02**	**0.01**	**5.0-15**	**0.001**
	ICP detection Limit (ppm)	**0.00001**	**0.0001**	**0.01**	**0.0004**	**0.0003**	**0.0001**	**0.005**	**0.009**	**0.001**	**0.000075**
1	TG-1	**1.894**	ND	0.011	ND	**8.530**	**0.483**	ND	0.003	0.016	0.0001
2	TG-2	0.098	ND	ND	0.005	0.676	0.029	ND	0.0003	0.139	0.0004
3	TG-3	**4.228**	BDL	ND	0.001	0.632	0.017	0.0002	0.001	0.115	BDL
4	TG-4	**1.338**	ND	0.003	0.065	**2.19**	0.068	ND	0.0003	0.152	ND
5	TG-5	0.053	ND	0.016	ND	**13.62**	0.182	ND	0.0009	1.341	ND
6	TG-6	0.065	ND	ND	0.012	0.379	0.135	0.003	ND	0.567	0.00004
7	TG-7	0.057	0.0001	0.005	ND	**10.10**	**0.721**	0.011	0.001	6.474	BDL
8	TG-8	ND	ND	ND	0.035	1.47	0.026	0.012	0.0003	1.038	BDL
9	TG-9	0.063	ND	0.003	0.005	1.50	0.130	0.0001	ND	0.096	BDL
10	TG-10	**2.90**	ND	ND	ND	0.875	0.014	0.0001	ND	0.505	0.00005
11	TG-11	0.059	ND	ND	0.0007	0.569	0.026	0.0001	0.001	0.403	0.00001
12	TG-12	0.129	ND	0.004	ND	**10.81**	0.064	ND	ND	2.716	BDL
13	TG-13	**1.76**	ND	0.021	ND	**20.04**	**0.432**	0.0051	0.001	2.826	BDL
14	TG-14	**0.40**	ND	0.002	ND	**9.010**	0.103	0.0002	ND	0.078	ND
15	TG-15	**3.71**	ND	ND	ND	**0.329**	0.156	0.001	0.0015	0.014	0.00004
16	TG-16	**8.62**	ND	ND	0.002	**1.171**	0.169	0.0003	ND	0.093	0.00005
17	TG-17	**0.906**	ND	0.006	ND	**6.93**	0.118	0.001	0.001	0.658	BDL
18	TG-18	**1.561**	ND	ND	ND	0.300	0.024	0.0006	0.0006	1.300	BDL
19	TG-19	0.273	0.0009	0.001	ND	1.030	0.043	ND	0.0003	0.229	BDL
20	TG-20	**0.720**	0.0009	0.003	ND	0.088	**0.419**	0.051	0.0005	0.095	0.00006
21	TPZ-1	0.241	ND	ND	ND	**10.06**	**2.360**	0.011	0.0008	0.419	ND
22	TPZ-2	**3.060**	ND	0.003	ND	**14.77**	**3.136**	0.014	0.0008	0.409	BDL
23	TPZ-3	0.190	ND	0.018	ND	**12.30**	**0.692**	0.009	0.001	0.504	0.0007

24	TPZ-4	0.032	ND	ND	0.001	0.330	0.074	0.001	0.001	0.039	BDL

Table 4.11 (e): Trace metal concentration in collected groundwater and surface water samples (October 2019)

Sr.No	Sample code	Al	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
	BIS Limit (ppm)	**0.03-0.2**	**0.003**	**0.05**	**0.05-1.5**	**0.3-1.0**	**0.10-0.30**	**0.02**	**0.01**	**5.0-15**
	ICP detection Limit (ppm)	**0.00001**	**0.0001**	**0.01**	**0.0004**	**0.0003**	**0.0001**	**0.005**	**0.009**	**0.001**
1	TG-1	**0.4**	ND	BDL	0.004	0.02	**0.4**	0.006	BDL	0.02
2	TG-2	**0.3**	0.003	0.01	0.04	**7.3**	0.2	0.01	BDL	0.6
3	TG-3	**0.4**	ND	BDL	0.03	**4**	**0.3**	BDL	BDL	0.8
4	TG-4	**1**	0.0002	BDL	0.009	**1**	0.03	BDL	BDL	0.2
5	TG-5	0.1	0.0002	BDL	0.007	**6**	0.1	BDL	BDL	0.2
6	TG-6	0.1	ND	0.02	0.004	**25**	**0.6**	BDL	0.009	1
7	TG-7	0.09	ND	BDL	0.02	**1**	**0.4**	BDL	BDL	0.3
8	TG-8	**2.6**	ND	BDL	0.03	**5.6**	0.08	BDL	BDL	1
9	TG-9	**0.8**	ND	0.02	0.02	**20**	0.6	**0.02**	BDL	1.4
10	TG-10	**0.7**	0.0002	BDL	0.009	**1.6**	0.06	**0.02**	0.009	0.07
11	TG-11	**0.3**	0.0009	BDL	0.008	**1.7**	0.3	BDL	**0.01**	0.2
12	TG-12	**1**	0.0001	BDL	0.006	**1.4**	0.08	BDL	BDL	0.7
13	TG-13	0.03	ND	BDL	0.002	**0.01**	**0.05**	BDL	BDL	1.4
14	TG-14	**0.7**	0.0002	BDL	0.006	**0.4**	0.02	BDL	BDL	0.1
15	TG-15	**0.8**	ND	BDL	0.009	**7**	0.1	BDL	BDL	0.2
16	TG-16	**0.7**	ND	BDL	0.007	**1.5**	0.2	BDL	BDL	0.06
17	TG-17	**2.9**	ND	BDL	0.01	**2.9**	0.1	BDL	BDL	0.1
18	TG-18	**3**	ND	0.01	0.02	**14.5**	0.09	BDL	0.009	0.4
19	TG-19	**1**	ND	BDL	0.009	**1.4**	0.02	BDL	BDL	0.8
20	TG-20	**1.2**	ND	0.01	0.02	**10.9**	0.1	BDL	BDL	4.9
21	TPZ-1	**4.7**	0.0003	0.03	0.008	**39**	0.2	0.008	**0.09**	10
22	TPZ-2	**3.8**	ND	BDL	0.009	**3**	**0.5**	BDL	BDL	4

23	TPZ-3	**3.7**	0.0002	0.02	0.007	ND	**0.6**	0.02	BDL	1.6
24	TPZ-4	**3.2**	0.0009	0.05	0.03	**70**	ND	**0.04**	BDL	14

4.4. Ash characterization

The collected Ash Sample was analyzed for its leaching behaviour of trace elements by TCLP method and the concentration of mercury was also analysed by using ICP-MS.

4.4.1. Concentration of Mercury in Fly Ash

The fly ash sample was analyzed for the mercury concentration by acid digestion method of EPA 3050B using ICP-MS and it was found to be 0.0444 ppb.

4.4.2. Results of TCLP test

The TCLP test was conducted as per US EPA SW-846, method-1311. TCLP is an important study to examine the leaching behaviour of trace elements of concern. TCLP was carried out for the sample collected from the ash generation unit. The concentration of all the metals was found within regulatory level of **USEPA-RCRA-D List (Table 4.12 (a), 4.5 (b) and 4.5 (c)).**

The TCLP results shows that the ash sample was non-hazardous in nature as per RCRA guidelines (U.S. EPA, 1986). TCLP carried out in the previous studies (NEERI report 2014 and 2016) also and the leaching behaviour of toxic metals was under the regulatory level as per the USEPA-RCRA-D list.

Table 4.12: TCLP trace metal concentrations (June 2018)

Trace Elements	Concentration in Fly Ash (mg/L)	ICP Detection Limit (ppm)	Regulatory level by USEPA-RCRA-D List (mg/L)
Al	0.9480	0.002	-
As	0.0210	-	5
B	0.1240	-	100
Ba	0.0650	0.0001	-
Cd	0.0010	0.0001	1
Co	0.0043	0.0004	-
Cr	0.0421	0.01	5
Cu	1.0800	0.0004	-
Fe	0.4060	0.0003	-
Mn	0.1580	0.0001	-
Ni	0.0432	0.005	-
Pb	0.0010	0.009	5
Zn	0.0605	0.001	-
Se	0.0329	-	-

Hg	0.0001	-	-

4.4.3. Chemical constituents of Fly ash

The chemical constituents of fly ash were analyzed by using XRF instrument and the results were given in **Table 4.6. It is observed that SiO_2, Al_2O_3 and Fe_2O_3 are the major constituents.**

4.5. Planning for future work

- The monitoring in February 2019 has been completed and the results are being analysed.
- The next phase of sampling is planned in May/June 2020.

Table 4.6 : Chemical characterization of the fly ash samples

Sample Name	SiO_2	Al_2O_3	Fe_2O_3	K_2O	TiO_2	CaO	MgO	Na_2O	P_2O_5	SO_3	Cr_2O_3	MnO_2	CuO	Rb_2O	SrO	Y_2O_3	ZrO_2	Nb_2O_5	BaO	Cl	NiO	LOI
Neeri/J-18/NTPC	62.99	27.02	3.57	0.95	1.76	0.92	0.38	0.10	0.54	0.08	0.02	0.03	0.01	0.006	0.01	0.006	0.04	0.005	0.02	0.01	0.01	1.34
Neeri/F-19/NTPC	62.64	27.06	4.18	0.92	2.18	0.80	0.33	0.08	0.38	0.07	0.03	0.04	0.01	-	0.01		0.05		0.03	0.005	0.01	0.87
Neeri/J-19/NTPC	63.65	26.48	4.14	1.62	1.87	0.74	0.49	0.09	0.37	0.07	0.03	0.04	0.01	0.01	0.01		0.05		0.03	-	0.01	-

Report

on

RADIOTRACER STUDY

of

Fly-ash disposal into fly ash pond

for

M/s. TTPS (NTPC, Talcher)

By

Isotope Application Services
Board of Radiation & Isotope Technology
Department of Atomic Energy
Government of India

February 2019

CONTENTS

1. INTRODUCTION

1.1 Introduction to BRIT

Board of Radiation and Isotope Technology (BRIT) was carved out of Bhabha Atomic Research Centre, Department of Atomic Energy, Government of India to undertake commercial activities of radioisotope and radiation applications. In other words it is a commercial wing of Department of Atomic Energy. Few of the industrial applications of radioisotopes like Gamma column scanning, blockage, void, corrosion detection in pipelines, identification of location of leakage in underground pipelines, residence time distribution analysis in reactor vessels of any kind, flow rate estimation and flow-meter calibration, effluent dispersion studies in surface waters and sediment transport studies on river/sea bed, bore-well interconnection studies for groundwater, studies for the enhanced recovery of oil from the oil wells, reservoir development, interconnection between oil wells, monitoring secondary recovery of oil and its effectiveness, etc. are undertaken by BRIT.

BRIT also supplies industrial irradiators for the irradiation of surgical items for sterilization, food grains for removal of pests and enhancement of their shelf life, etc. Gamma chambers of various capacities are supplied for research purpose. Indigenous radiography cameras (Industrial gamma radiography exposure device) are supplied for industrial radiography and the radioisotopes are provided for the imported radiography camera. For diagnosis and therapy, radioisotopes are produced and supplied to the hospitals in India and abroad. BRIT has laboratories for radiopharmaceutical distribution at various locations throughout India.

Out of the above activities undertaken by BRIT/BARC, radiotracer studies for dilution and dispersion of pollutants in surface waters is helping various agencies to decide upon the outfall design and its efficacy.

1.2 Theory of Radiotracer Study

The basic principle of tracer investigation is to label a substance, an object or a phase and then to follow it through a system or to carry out a quantitative assay of the tracer after it has left the system. The requirements of tracer are that: it should behave in the same way as the material under investigation, it should be easily detectable at low concentrations, detection should be unambiguous, injection, detection and/or sampling should be performed without disturbing the system, the residual concentration in the system after the study period should be minimal. All these criteria can be met using radioisotopes as tracer and by careful selection of the most appropriate tracer for a particular application. Factors which are important in the selection of radiotracer are: *Half-life* – should be long enough to allow time to transfer the tracer from the nuclear reactor to the work site, prepare the tracer for use and complete the measurements. In order to reduce the level of residual tracer in the system short or optimum half-life tracer is desirable. *Type and energy of radiation* – should be detectable at lower concentrations either by sampling or in-situ detection, will have direct bearing on the total amount of activity which can be accommodated safely within given system. After injection, self-absorption by water present in the system may reduce the level of radiation to the levels which should be within the legal limits. *Physico-chemical form* – should be compatible with the material being traced both in physical form and chemical form and preferably behave same as the material being traced in the system. The ideal tracer in these circumstances is undoubtedly the irradiated material itself i.e. irradiated fly ash.

The final choice of radiotracer for an investigation is made after consideration of all of the above factors, many of which may be mutually exclusive.

Preferably, highly sensitive detectors which are pre-calibrated are used to track the progress and strength of the radiotracer. In the current scenario, in order to understand and establish the transport of heavy metals and other trace elements from the fly-ash to the surrounding environment, irradiated fly ash itself (target element: Zn-65, half-life: 244 days) was selected as a radiotracer.

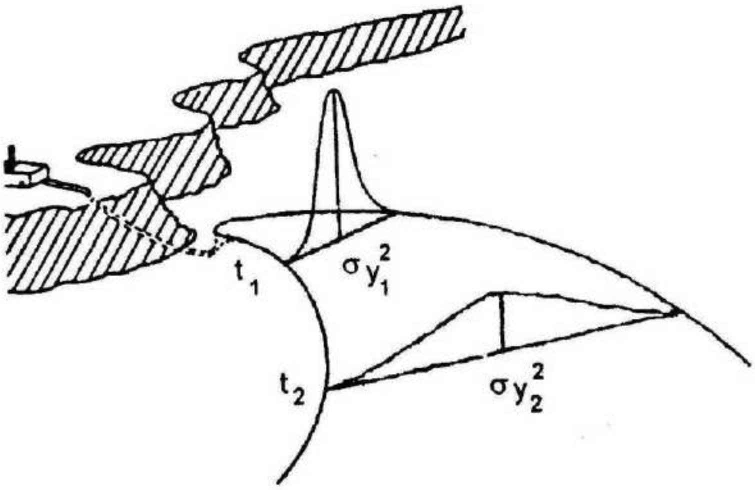
Radioactive methods can help in investigating suspended sediment dynamics, providing important parameters for better designing, maintaining and optimizing disposal of suspended load in to the surface water bodies. Radioisotopes as tracers and sealed sources have been useful and often irreplaceable tools for such studies.

There are three main transport mechanisms active in the transport of suspended particles:

1. Advection(currents)
2. Dispersion(turbulences)
3. Decantation (specific weight and volume of particles)

1.2.1 Dispersion Coefficient

Dispersion coefficient can be calculated by the method of moments:



Assuming the obtained steady state cross plume concentration profiles follows normal distribution (Gaussian), then lateral dispersion coefficient between two section, Dy is defined as:

$$Dy = \frac{\sigma y_2^2 - \sigma y_1^2}{2(t_2 - t_1)} m^2/s$$

Where σy_2^2 and σy_1^2 are the variance of cross plume concentration profiles at the sections 1 & 2 and t_1 & t_2 are time elapsed from the discharge point to the corresponding section.

Similarly, longitudinal dispersion coefficient can also be estimated using method of moments.

1.2.2 Decantation rate

The quantity of suspended matter at any moment can be obtained from

$$M(t) = M_0 . e^{\frac{-w(t-t_0)}{H.\varphi}}$$

Where: t=time

t0= time of injection

w= sinking speed of suspension particles

H=water depth

M0=total mass of suspension tracer

Φ= dimensionless function in Rouse’s theory

$$\Phi = \int_{\frac{a}{H}}^{1} [\frac{\frac{a}{H}}{\left(1-\frac{a}{H}\right)} . \frac{(1-z''')}{z'''}^{\frac{w}{k.u}} dz$$

z̀=z/H reduced height above bed

a= height of detector above bed

k= van Karman coefficient

u= shear stress velocity

Variation of M with respect to time gives decantation rate:

$$\theta = \frac{1}{M}\left|\frac{dM}{dt}\right| \text{ gm/sec-ton suspension}$$

Case studies show that flocs are formed during slack water. When currents induced due to wind are active, flocs disintegrate and tend to become homogenous.

1.2.3 Transport Velocity

From the iso-count contours, a plot between cumulative of product of count rate© and length of lateral spread (Y) (i.e. $C1 = \sum C.y$) for different locations(x) along the axis of movements is plotted against x, so that contour map is reduced to one dimension. The count distribution diagram so generated are called as ‘transport diagrams. For each diagram, the location of the weighted center of gravity along the axis movements is found out using

$$X = \frac{\int C1.x.dx}{\int C1.dx}$$

Successive tracking in time make it possible to establish many centers of gravity and the mean velocity of movement (Vm) is calculated from the shifts in the center of gravity between two successive tracking.

Radioactive tracers are the only unequivocal method of direct real time assessment of distribution of suspended matter in the surface water as well as ground water. Radiotracers are more sensitive and provide more accurate parameters than conventional tracers. In recent decades, many radiotracer studies for the investigation of suspended sediment transport in natural systems have been conducted worldwide, and various techniques for tracing and monitoring the suspended sediment have been developed by Isotope Application Services of BRIT. In addition to radiotracers, sealed source techniques can provide information on the density of suspended sediments in a channel of navigation as well as on the concentration of sediments circulating in suspension.

The environmental, economic and social benefits from the application of radiotracer and sealed source techniques can be enormous.

1.3 Advantages and Disadvantages of using radiotracer technique

Radiotracer technique is carried out without disturbing the system i.e. online. The radiotracer as the name suggests is used in trace quantity in comparison with the material in the system as it can be detected at very low concentrations using the highly sensitive radiation detectors. The detection does not depend upon physical or chemical changes during the study period as the nuclear properties of the radiotracer do not change during the course of the study. Since the properly selected radiotracer either in the same form of the material being traced or labeled on the traced material follows intended flow paths and undergoes same changes as the material being traced, ideally it follows the same flow dynamics of the mother material including leaching, sorption, desorption, flocculation, de-flocculation, floatation and settling. The conventional tracers like dyes, salts, fluorescents, etc. often are interfered by other physical or chemical parameters but radiotracers have no such adverse effect of the suppressing parameters.

Disadvantage of using radiotracers is, it requires trained manpower, additional training for handling of radioisotopes and knowledge of radiation safety. Contamination due to the use of radiotracers in powder as well as liquid form requires huge efforts to deal with.

1.4 Safety Issues

The irradiated fly ash from reactor was sealed in an aluminum can which was brought to the site by road in a lead container (weighing about 800 kg) with proper regulatory approvals of transportation and usage. The vehicle transporting the container was properly labeled with necessary safety signs.

After it arrives at the site it was kept secured in a locked room. Cutting of the aluminum can was carried out by specially designed remotely operated automatic can cutter device. After its cutting, aluminum can was handled by 1 m long cee vee tongs and irradiated fly ash was injected into the fly ash slurry tank. After successful injection, irradiated fly ash was mixed with the fly ash slurry and pumped to the mine void through pipe line. The contaminated tools and radiation waste were collected in a polythene bag and transported to the BRIT for further storage and decontamination.

In general principle of ALARA (as low as reasonably achievable) was strictly followed while performing the entire operation. Similarly, the operations of handling the radiotracers was carried out in minimum possible time, keeping the safe distance between radiotracer and personnel and using maximum possible shielding wherever required. All the personnel involved in the handling radiotracer used TLD badge and electronic pocket dosimeters to record the absorbed dose.

2. SCOPE OF THE WORK

2.1 Description about the Site

M/s. NTPC, Talcher (TTPS) is located at approx. 20 km from Angul town under the jurisdiction of Dhenkanal district and about 140 km from Bhubaneshwar in Odisha. (Figure 1).

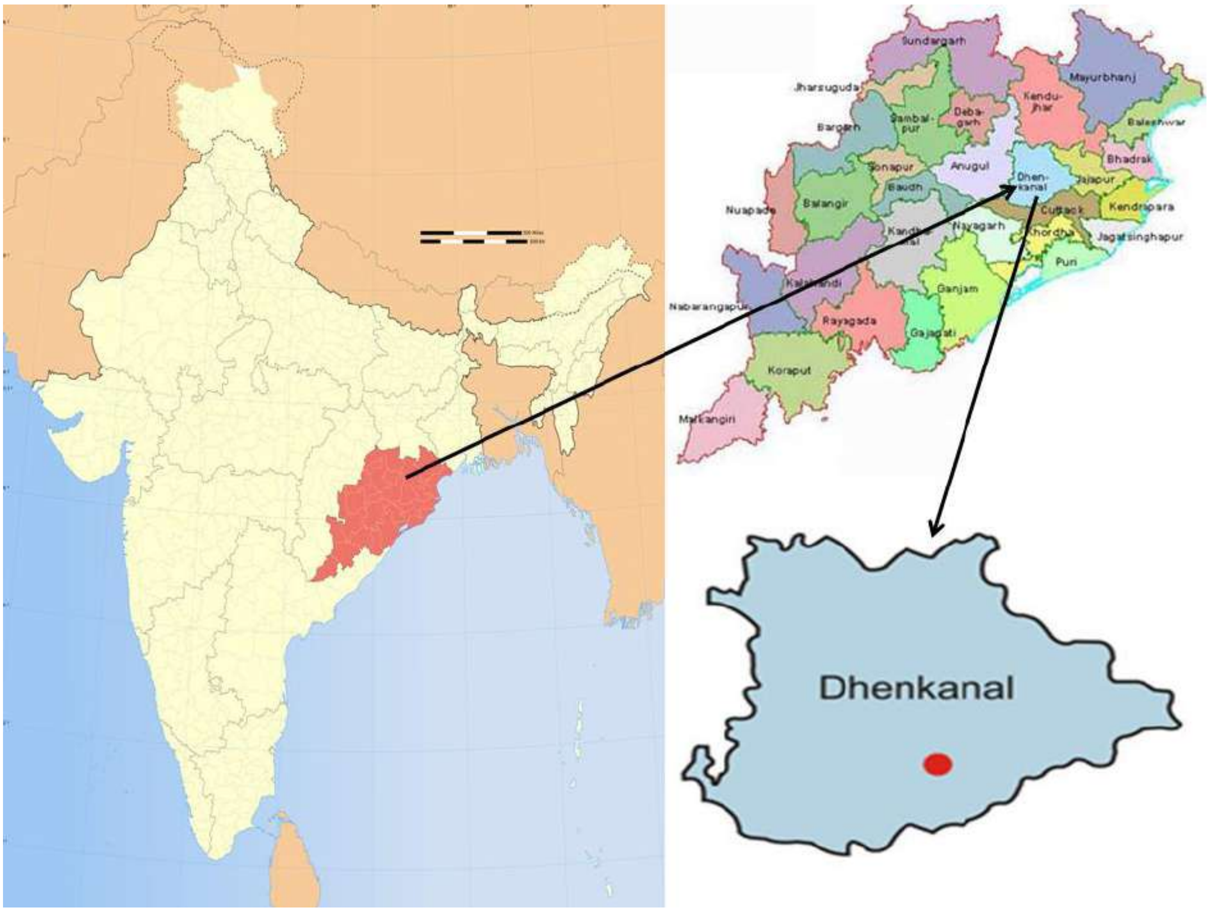


Figure 1: Location map of study area

M/s. NTPC, Talcher (TTPS) is generating 460 MW of electricity by coal combustion. It generates huge amount of fly-ash which is proposed to be disposed off in ash pond about 25 kms away from the plant. The area of study experiences tropical climate with mild winter and hot summer with an average rainfall of 1250mm during June-Sept (monsoon). It is characterized by uneven topography, some scattered hillocks, forest blocks and rocky outcrops.

2.2 Narrative of the problem

Safe disposal of fly ash is a major issue as it contains several toxic chemical constituents which may pollute the environment. Although, utilizing fly-ash for manufacturing bricks and cement could take care of this issue partially, the cost of transporting fly-ash to concerned factories limits its utility.

Ministry of Environment and Forest (MoEF) has accorded permission for disposal of fly ash from the TTPS at the disused mine void of Jagannath opencast mines of Mahanadi Coalfields limited (MCL). The fly-ash generated in the TTPS is transported to the quarry through pipeline in slurry form. In order to assess the environmental impact of the fly-ash disposal in the vicinity of the mine void and to comply with condition No.-3 (Incorporation of Radioactive tracer studies for heavy metal) of Environmental Clearance, TTPS approached Board of Radiation and Isotope Technology(BRIT) to carry out the Radiotracer study to understand the leaching of heavy metals from fly ash in to the surface water and surrounding ground water.

2.4 Targeting the task

A preliminary site visit was carried out by BRIT scientists to understand the problem and to observe the study area as well as surroundings. There was a mine void filled with fly ash slurry surrounded by thick vegetation.

The pipelines are led from the plant up to ash pond to directly deliver fly ash slurry in the pond. Depending upon the volume of the slurry being disposed, the location of disposal in to the pond is changed so as to distribute the slurry evenly all around.

On the upstream side there is decantation zone wherein excess water from the slurry is sucked through the pump and returned to the power plant as a recycled water to conserve the quantity of water.

Since the fly ash is disposed off in to the ash pond along with water, the fly ash may leach in to the void water. The leachates may contain heavy metals which could get percolated in to the ground water contaminating the ground water in the surrounding bore wells. To study the extent of leached heavy metals with respect to time, radiotracer was disposed in the same way as bulk fly ash while disposing it in to the ash pond and to study its spatial and temporal distribution in the water of the pond and its subsequent progress in to the surrounding bore wells.

Figure 2: fly ash disposal in ash pond

Major portion of the quarry was solidified. Slurry disposed into mine void was not spreading over the entire surface of the quarry. Quarry was about to reach its disposal limit.

Figure 3: decantation zone from where water is recycled to the plant

Figure 4: fly ash slurry tank inside the plant

3. EXPERIMENTAL

3.1 Selection of Radiotracer

Ideally, irradiated fly ash should be the best tracer for the proposed study. For this fly ash was irradiated in nuclear reactor to generate various radioisotopes and disposing this irradiated fly ash in to the water of mine void to study dynamics of leachates both in surface and ground water. Irradiation of the fly ash generated radioisotopes of various heavy metals present in the fly-ash and Zn-65 was isotope of interest because of its long half-life (244 days). Please see the following figure no. 4 for the nuclear properties of Zn-65.

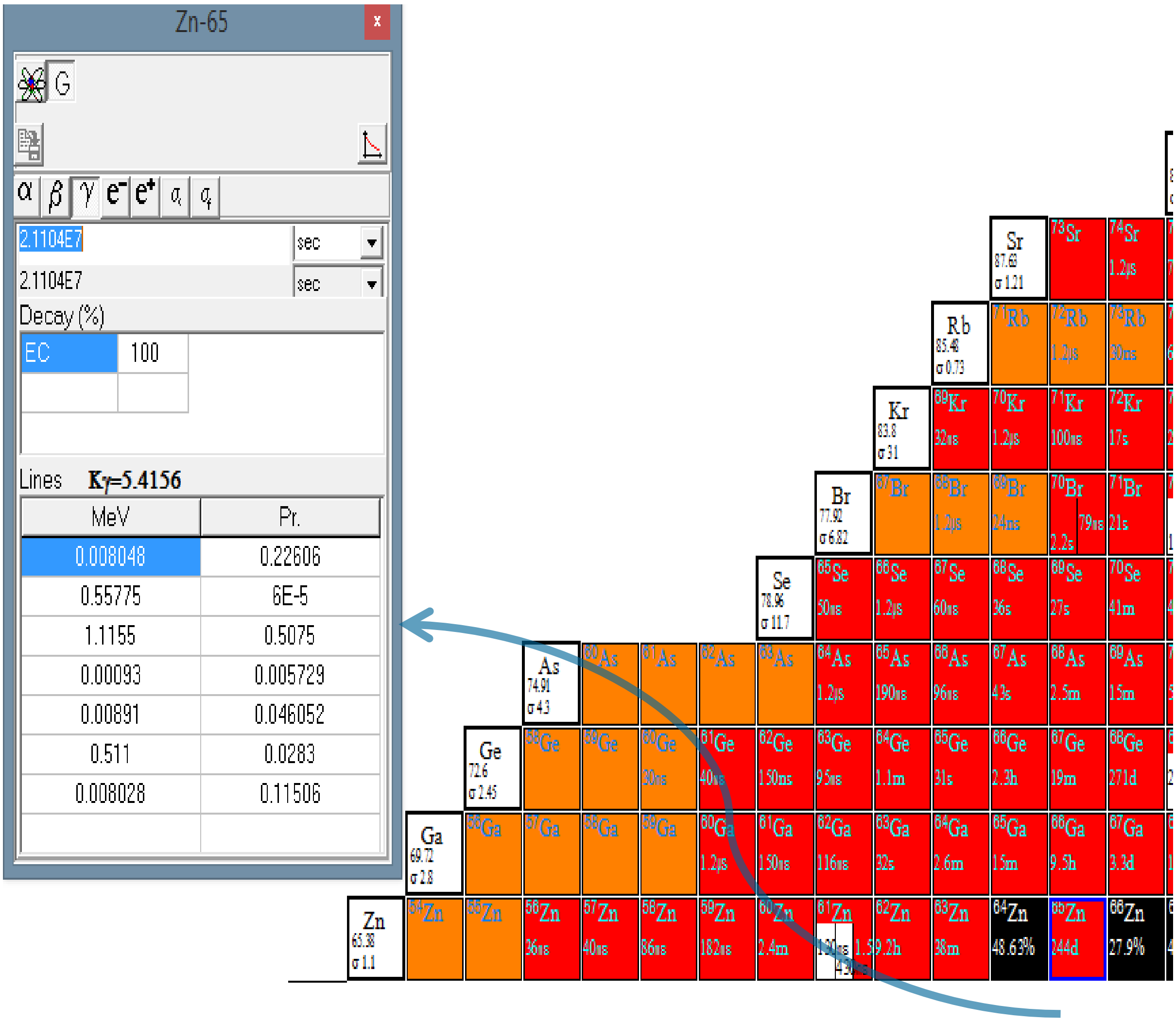


Figure 5 Nuclear properties of Zn-65 radioisotope

3.2 Laboratory studies

Since the water body of mine void is huge and the irradiated fly ash being disposed should truly represent the bulk fly ash, the quantity and activity of radiotracer was to be decided theoretically. For this purpose, 10 mg of fly ash sample was collected and sealed in quartz ampule. The sample was given for irradiation in self-serve facility of DHRUVA reactor, BARC and it was irradiated 1 hr. and activation analysis of this sample was carried out. Based on the activation analysis report of irradiated fly ash sample, it was calculated that for

5 Ci of Zn-65 present in the fly ash, 280 gms of fly ash should be irradiated and injected into the mine void.

3.3 Neutron Irradiation

The optimum quantity of radioactivity of Zn-65 was estimated to be 5 Ci which would be sufficient to be detected after the leaching and dilution in both water in the mine void and ground water. The Weight of fly ash powder was calculated to get the required activity (5 Ci of Zn-65 at the time of injection) after irradiation for one week and pile factor of 12 in Dhruva research reactor at BARC.

$$W = \frac{A.\,M_c\, e^{-\lambda t_d}.\,100}{\sigma \emptyset N_a N_e I_n (1 - e^{-\lambda t_s})}$$

Where, A= required activity

Mc= molecular weight

λ= decay constant

td= duration of irradiation

σ=neutron absorption cross section

∅=neutron flux

Na=Avogadro no.

Ne= enrichment factor

I_n= no. of atoms in one molecule

280 grams of fly ash powder was irradiated for one week to obtain approximately 5 Ci of activity.

3.4 Activities carried out at the site

Inside the TTPS plant the regular practice was to collect slurry in a tank, homogenize it and pump it through the pipeline towards the ash pond. Hence it was decided to cut open the can, empty the contents in to the slurry tank while the churning is continued. Accordingly, on 18/12/2018 using long handled tongs the cans were removed from transport container directly from the truck and was placed in an automatic can cutter with Perspex cover. Electromechanically, the can was cut open and 21 such cans were emptied out in the tank. After mixing and holding the slurry for about 2 hours, the pump was started and the radiotracer was disposed off in to the ash pond.

While disposing the slurry constant water flushing was done. Water flushing was continued till the radioactivity level in the tank was brought down to the background level.

A temporary shed was formed at the platforms above the fly ash slurry tank to carry out the radiotracer handling activities.

Figure 6: Temporary laboratory for radiotracer preparation

All the material required to carry out these activities were arranged and necessary safety precautions were taken. Before starting the preparations, all the personnel present and was to be involved in the operations were given thorough briefing of the total activity planned. Wherever the radioactivity was in use, the polythene sheets were spread and covered with absorbent sheets. From beginning to the end of the entire operation, radiation monitoring was continuously carried out. After the radioactive handling job was finished all the personnel and area under use was specifically monitored. The area was thoroughly flushed with copious amount of water so that there are no traces of radioactivity.

Dummy trials were conducted before actual handling was done. Aluminum can (filled with irradiated fly ash) were handled with the help of 1 m cee vee tongs. Cans were transferred from lead cask to lead die of automatic can cutter device. The lid of aluminum can was cut by remotely operating the automatic can cutter. Irradiated fly ash was then poured to fly ash slurry tank with the help of tongs.

Figure 7: transferring the can in the lead die of can cutter

Figure 8: Injecting the fly ash in the slurry tank through funnel

After successful injection, irradiated fly ash was mixed for few hours in the slurry tank and transported to the disposal quarry through pipeline. Since the radiotracer was disposed off on 18/12/2018 in the void, the monitoring of its spread in ash pond was carried out on 19/12/2018. 1” diameter x1” height sodium iodide scintillation detector connected by about 100 meters long cable to a scaler-ratemeter was used for monitoring the spread of the radiotracer in the pond.

Figure 9: Setup of underwater radiation detection system at fly ash disposal site

Figure 10: radiation detector placed above the slurry disposing pipeline

Figure 11: Monitoring the spread of the radiotracer near by the disposal area

Figure 12: Radiotracer tracking over the decantation zone

4. RESULTS

Counts recorded as on 19/12/2018

Location	Max. Counts per min.
Over the ash slurry in service pipeline	1250, 1500, 1750(near outlet)
Towards outflow of fly ash from disposal point	8500
Left side of offline pipeline	13500
Right side of offline pipeline	22500
On the corners of road	7500
20 m away from offline pipeline	7500
30 m away from offline pipeline	7500
40 m away from offline pipeline	2500

On the corners of the decantation zone the avg. count rate obtained was around 750 cpm which was equal to the background count rate in air. Background count rate in clear water was 100 cpm.

Counts recorded as on 29/05/2019

The disposal pipeline was not visible. All the fly ash over the pond was dried. Avg. background count rate in air was around 1500 cpm and over the pond body it was around 1900-2250 cpm.

Near the decantation zone(check dam), the avg, background count rate in air was 1500 cpm and in side the water of the dam, it was in the range of 800-1200.

5. CONCLUSION

The radiotracer could be monitored in trace quantity at the extreme boundaries of the ash pond within one month of the injection. It was below the detection limits in the subsequent monitoring.

The radiotracer could not be monitored in surrounding bore well water samples even in trace quantity after continuous dumping of the slurry.

Therefore, it appears that the fly ash leachates are not contributing to the ground water in the surrounding area of the ash pond.

IInd Year Report

On

Bioaccumulation and bio-magnification study on flora and fauna of surrounding the ash filled South Balanda Mine Void" NTPC, Talcher, Odisha

(2019)

Submitted to

Talcher Thermal Power Station

Angul district, Odisha

Submitted by

CSIR-NATIONAL BOTANICAL RESEARCH INSTITUTE

LUCKNOW, UTTAR PRADESH, INDIA

Content

Annexure-I

Programme/Project details and information

(i) PI (Name , Address, Contact No):	**Dr. Vivek Pandey** Senior Principal Scientist Plant Ecology and Climate Change Science Division CSIR-National Botanical Research Institute, Rana Pratap Marg, Lucknow-226 001 (UP), India. Email: v.pandey@nbri.res.in Mobile 09450657233 Tel: 0522-2297929
(ii) Co-PIs Name and address	**1. Dr. L.B. Choudhary** Senior Principal Scientist Plant Biodiversity Division **2. Dr. S.K. Behera** Senior Scientist Plant Ecology & Climate Change Science Div. **3. Dr. Sanjay Dwivedi** Sr. Technical Officer Plant Ecology & Climate Change Science Div. CSIR-National Botanical Research Institute, Rana Pratap Marg, Lucknow-226 001 (UP), India.
(iii) Project Title:	Bioaccumulation and bio-magnification study on flora and fauna of surrounding the ash filled South Balanda Mine Void
(iv). Project duration a. Date of start of the project b. Date of Completion	4 years 20 Jan, 2018 19 Jan, 2022
(v) Total cost of Project	**Rs. 1,09,24875/-**

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Project details and information

1. Introduction

Talcher Thermal Power Station (TTPS) is located in Angul district of Odisha. This power plant is operated by NTPC and its installed capacity is 460 MW. All units of this power station are coal fired. TTPS is filling its fly ash in to quarries situated at a distance of about 12 kms from power station. Fly ash is brought to the quarry through pipes in the form of ash slurry.

The analysis of trace and toxic elements in fly ash, soil and water in 500 m zone around the fly ash filling quarries has been done at **CSIR-National Botanical Research Institute** (CSIR- NBRI) Lucknow, Uttar Pradesh. Moreover, the biomonitoring, bioaccumulation and biomagnifications studies in flora and fauna have been also done at CSIR-NBRI to find out the time dependent metal accumulation in plants and soil samples with the seasonal variation. As, Ba, Cd, Co, Cr, Cu, F, Fe, Hg, Mn, Ni, Pb, Zn have been estimated in the samples.

2. Scope of work

The studies shall be based on primary survey (sample collection and laboratory analysis) undertaken at representative sites for flora (tree leaves, fruits, vegetation, fodder, crop yields etc.) and fauna (meat, scat and urine) for bio-accumulation and bio-magnification of trace elements during pre and post-monsoon seasons.

Number of sampling locations proposed and the parameters to be analysed are as follows:

Zone :

500 m Zone around Quarries 2, 3A and 3B and/ or nearest habitations from the mine voids.

No. of Sampling Locations:

Core Zone: 01 nos.

Buffer Zone: 05 nos. in surrounding areas up-to 500 m and/ or nearest habitations from the mine voids in all directions

Parameters to be analysed at each location :

• Analysis of trace elements in mine void supernatant, piezeometers and surface water samples. Trace elements shall include As, Ba, Cd, Co, Cr, Cu, F, Fe, Hg, Mn, Ni, Pb, Zn.

• Analysis of trace elements in Flora (in leaves, fruits, fodder, agricultural produce etc.), Fauna (Meat, Scat, Urine) and the invertebrates

• Analysis of trace elements in aquatic fauna from the mine void filled with fly ash.

The data generated above shall be analysed to establish the evidence of bio-accumulation or biomagnifications of the elements.

3. Study area and location

Talcher Thermal Power Station (TTPS) is located in Talcher sub-division of Angul district in the state of Odisha (Fig. 1). The power plant is one of the coal-based plants of NTPC. The coal for the power plant is sourced from Jagannath Mines of Mahanadi Coalfields Limited. Source of water for the plant is from Brahmani River. The nearest commercial airport is at Bhubaneshwar at an aerial distance of 90 km approx. and about 150 km by road.

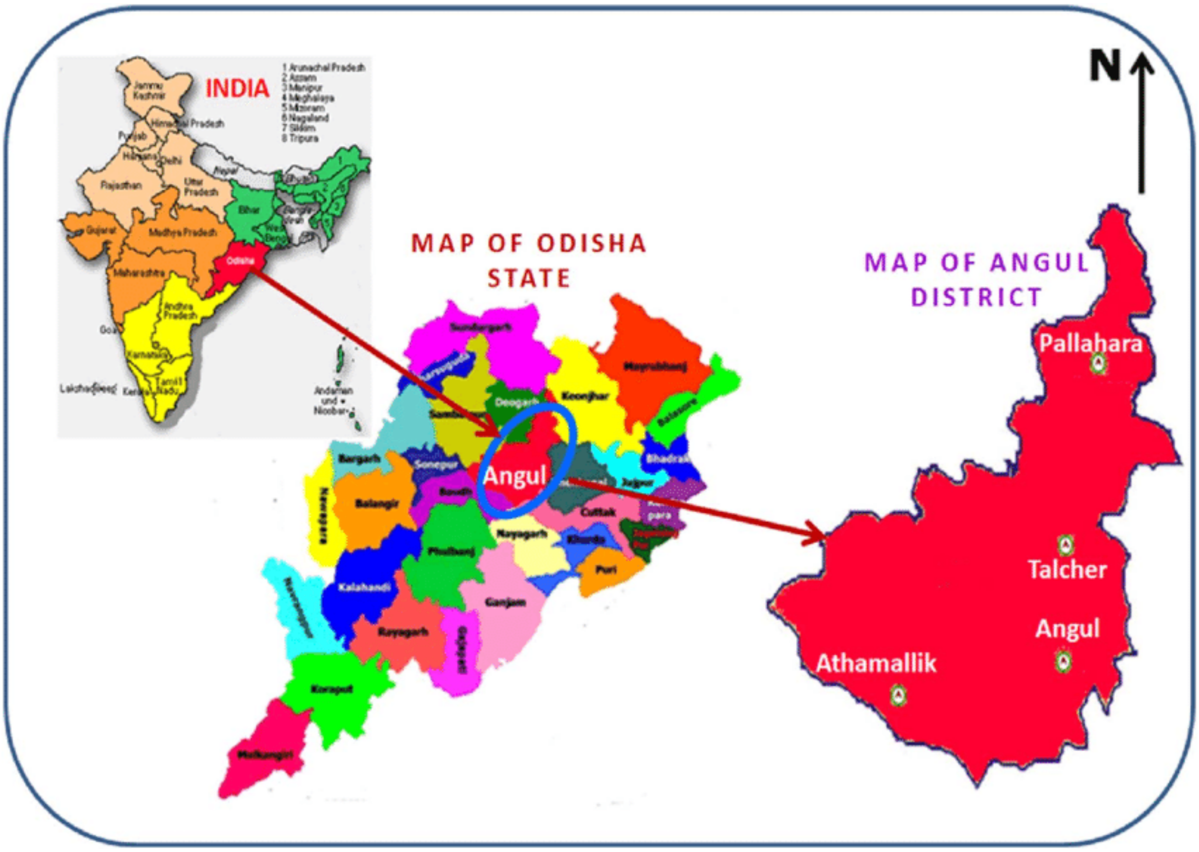

Fig. 1: Location map of study area.

Fig. 2: Sampling locations (→★Sites, S-I = Check Dam Mine Void 2; S-II = L- Shape Dam Ist Position; S-III = L-Shape Dam IInd Position; S-IV = Core Pond On The Fly Ash Dykes; S-V = Check Dam 3B; S-VI = Reservoir Pond).

3.1 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.

3.2 Description of the study area

Talcher Thermal Power plant (TPP) is situated in Talcher sub-division of Angul district in the Indian state of Odisha. The coal for the power plant is sourced from Jagannath Mines of Mahanadi Coalfields Limited. Source of water for the TPP is from Brahmani River. The TPP is owned and operated by Odisha state government and total generating capacity of Talcher TPP is 460 MW. There is a proposal for expansion of Talcher TPP by two units of 660 MW, each fired by coal and the combined capacity of plant after the expansion is to be

1780 MW. Brahmani river water is used for making steam and also as a coolant for vital machinery. The discharge from the TPP may also contaminate the river water by leaching of heavy metals from fly ash. Fly ash, water (surface and ground) and plant species (terrestrial and hydrophyte plants) were taken in the range of ten km from the TPP. Samples were collected from six selected sites (Fig. 2) namely:

i Check dam mine void 2

ii L shape dam Ist position

iii L shape dam IInd position

iv Core pond on the fly-ash dykes

v Check dam 3B

vi Reservoir pond

4. Methodology

The Scientific team of CSIR-National Botanical Research Institute (NBRI) have visited nearby areas of Talcher thermal power station district, Angul Odisha. The water and plant samples were collected from the identified sites (sites I-VI) during post monsoon (2018), pre and post monsoon (2019). The details methodology used for the metal analysis and diversity study is given in the respective subheadings.

4.1 Surface and ground water sampling

Groundwater samples and surface water samples have been collected from the identified sources. The samples were collected in clean 100 ml polyethylene bottles. The heavy metal analysis was done by using ICP-MS (Model: 7500X Make: Agilent). The detection limit for As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn is 0.001 ppm.

4.2 Plant collection and identification

To study the bioaccumulation of different metals in locally grown vegetation, the different plants samples were also collected from identified sites**.** Different sites were visited during post monsoon (November, 2018), pre and post monsoon seasons (April and September, 2019) to collect the plant samples. From each location we tried to collect as much as plant species which were commonly growing in that area. The plants were collected in good quantity and kept in zipped polythene bags and later on they were properly dried and prepared for chemical analysis. Some of the plants were also preserved for preparing voucher/herbarium specimens for future record. The plants retained for herbarium preparation were collected either in flowering or fruiting or in both conditions for their correct identification along with the data on their habits and habitats and placed them in blotting papers for drying. The standard herbarium procedures out lined by Jain & Rao (1976) were followed for preparing voucher herbarium specimens. The identification of species was carried out with the help of Floras, existing regional monographs/ revisions and other authentic specimens deposited at NBRI, Lucknow herbarium, LWG.

4.3 Estimation of heavy metals in plant samples

Plant samples were washed thoroughly tap water and de-ionized water for removing the sticking fly ash/soil particles. After washing plant samples were oven dried at 80 ºC for 72 hours and divided into root and leaves. The dried samples of the plants [root and leaves (300mg)] were taken for the acid digestion with (HNO_3+$H_2O_{2;}$ 3:1 v/v) for the heavy metal analysis in the samples. All the samples of fly ash water and plants were digested through the hot plate. The digested samples were further diluted in Milli-Q water and subjected to the Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (Fig 3).

Fig. 3. ICP-MS instrument installed at Central Instrument Facility, used for analysis of various metals.

5. Plant species found at different sites

Table 1: Major plant diversity at site I.

S. No.	Locality	Distance from site (in metre)	Botanical name	Common name	Family
SITE -I	**Chek dam mine void -2**	50 m	*Syzygium cumini*	Java plum, Jamun	Myrtaceae
		100 m	*Syzygium cumini*	Java plum, Jamun	Myrtaceae
		50 m	*Albizia lebbeck*	Persian silk tree	Fabaceae
		250 m	*Albizia lebbeck*	Persian silk tree	Fabaceae
		500 m	*Azadirachta indica*	Neem	Meliaceae
		100m	*Eucalyptus tereticornis*	Forest red gum, Blue gum	Myrtaceae
		100 m	*Chromolaena odorata*	Bitter Bush, Tonka Bean	Asteraceae
		10 m	*Mimosa pudica*	Lajwanti, Chui-mui	Fabaceae
		10 m	*Solanum nigrum*	Black nightshade	Solanaceae
		10 m	*Calotropis procera*	Aak, Madaar	Apocynaceae
		50 m	*Ziziphus nummularia*	Jhar Beri	Rhamnaceae
		10 m	*Croton bonplandianum*	Rushfoil	Euphorbiaceae

Table 2: Major plant diversity at site II.

S. No.	Locality	Distance from site (in metre)	Botanical name	Common name	Family
SITE – II	**L shape dam - Ist position**	50 m	*Dendrocalamus strictus*	Bamboo	Poaceae
		50 m	*Dalbergia sissoo*	Sisau, Sheesham	Fabaceae
		50 m	*Eucalyptus tereticornis*	Forest red gum, Blue gum	Myrtaceae
		50 m	*Cassia fistula*	Golden rain tree	Fabaceae
		50 m	*Prosopis juliflora*	Vilayati babool	Fabaceae
		50 m	*Chromolaena odorata*	Bitter Bush, Tonka Bean	Asteraceae
		20 m	*Hyptis suaveolens*	Vilaiti tulsi	Lamiaceae
		20 m	*Indigofera tinctoria.*	True Indigo	Fabaceae
		20 m	*Senna siamea*	Coffee Senna	Fabaceae
		20 m	*Cynodon dactylon*	Dhoob	Poaceae
		20 m	*Euphorbia hirta*	Bara dudhi, Asthma Weed	Euphorbiaceae
		20 m	*Evolvulus nummularius*	Visnukrantha	Convolvulaceae

Table 3: Major plant diversity at site III.

S. No.	Locality	Distance from site (in metre)	Botanical name	Common name	Family
SITE-III	**L shape dam - IInd position**	50 m	*Dalbergia sissoo*	Sisau, Sheesham	Fabaceae
		50 m	*Eucalyptus tereticornis*	Forest red gum, Blue gum	Myrtaceae
		50 m	*Saccharum spontanium*	Kans grass	Poaceae
		50 m	*Leucaena leucocephala*	White leadtree	Fabaceae

Table 4: Major plant diversity at site IV.

S. No.	Locality	Distance from site (in metre)	Botanical name	Common name	Family
SITE-IV	**Core pond on the fly ash dykes**	50 m	*Azadirachta indica*	Neem	Meliaceae
		50 m	*Delonix regia*	Flame of the forest	Fabaceae
		50 m	*Saccharum spontanium*	Kans grass	Poaceae
		50 m	*Hyptis suaveolens*	Vilaiti tulsi	Lamiaceae
		50 m	*Chromolaena odorata*	Bitter Bush, Tonka Bean	Asteraceae
		50 m	*Leucaena leucocephala*	White leadtree	Fabaceae
		50 m	*Mallotus philippensis*	Kumkum tree	Euphorbiaceae
		50 m	*Prosopis juliflora*	Vilayati babool	Fabaceae
		50 m	*Dalbergia sissoo*	Sisau, Sheesham	Fabaceae

		50 m	*Dendrocalamus*	Bamboo	Poaceae
		50 m	*Mangifera indica*	Mango	Anacardiaceae
		50 m	*Artocarpus heterophyllus*	Jackfruit	Moraceae

Table 5: Major plant diversity at site V.

S. No.	Locality	Distance from site (in metre)	Botanical name	Common name	Family
SITE-V	**Check dam 3B**	100 m	*Albizia lebbeck*	Persian silk tree	Fabaceae
		100 m	*Azadirachta indica*	Neem	Meliaceae
		100 m	*Tectona grandis*	Indian-Oak, Teak	Lamiaceae
		100 m	*Eucalyptus tereticornis*	Forest red gum, Blue gum	Myrtaceae
		20 m	*Casuarina equisetifolia*	Whistling Pine	Casuarinaceae
		20 m	*Dalbergia sissoo*	Sisau, Sheesham	Fabaceae
		20 m	*Cassia fistula*	Golden rain tree	Fabaceae
		20 m	*Hyptis suaveolens*	Vilaiti tulsi	Lamiaceae
		20 m	*Chromolaena odorata*	Bitter Bush, Tonka Bean	Asteraceae
		20 m	*Centella asiatica*	Brahmi	Apiaceae

Table 6: Major plant diversity at site VI.

S. No.	Locality	Distance from site (in metre)	Botanical name	Common name	Family
SITE-VI	**Reservoir pond**	50 m	*Lagerstroemia parviflora*	Common Crape Myrtle	Lythraceae
		50m	*Ficus hispida*	Hairy Fig	Moraceae
		50m	*Calotropis procera*	Aak, Madaar	Apocynaceae
		50 m	*Dendrocalamus strictus*	Bamboo	Poaceae
		50 m	*Leucaena leucocephala*	White leadtree	Fabaceae
		50 m	*Ficus benghalensis*	Banyan tree	Moraceae
		10m	*Lantana camara*	Raimuniya	Verbenaceae
		10 m	*Ziziphus jujuba*	Ber	Rhamnaceae
		10 m	*Ficus hispida*	Hairy Fig	Moraceae
		10 m	*Nelumbo nucifera*	Lotus	Nelumbonace ae
		10 m	*Hydrilla verticillata*	Hydrilla	Hydrocharitac eae
		10 m	*Pteris vittata*	Ladder brake	Pteridiaceae
		10 m	*Marsilea sp.*	Water clover	Marsileaceae
		10 m	*Typha latifolia*	Patera	Typhaceae
		10 m	*Leucaena leucocephala*	White leadtree	Fabaceae
		10 m	*Vachellia nilotica*	Babul	Fabaceae

Post Monsoon 2018

6. Results of the study

6.1 Concentration of different trace and toxic metals in water samples

Water samples (Piezometer and surface) were collected from identified sites (sites I-VI). All collected samples were acid digested and then analysed by ICP-MS (Table 7). The concentrations of all heavy metals such as Cd, Co, Cr, Cu, F, Fe, Mn, Ni and Zn were within the permissible limit as per BIS standard. **It needs to be mentioned that Hg was not detected in any of the samples.**

Table 7: Level of heavy metals in water samples.

Sites	Concentration of metals (µg l^{-1})											
	Cr	**Mn**	**Fe**	**Ba**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**
Site I (Piezometer)	0.00	91.14± 5.23	209.9± 7.45	22.2± 1.25	1.9± 0.02	9.94± 1.25	0.9± 0.02	8.07± 1.20	11.4± 0.03	BDL	1.01± 0.01	0.86± 0.03
Site I (Surface)	0.00	49± 2.02	192.0± 3.64	20.3± 2.21	ND	0.84± 0.25	0.4± 0.01	2.32± 0.25	0.26± 0.02	BDL	0.30± 0	0.48± 0.02
Site I (Surface)	0.64	42.84± 2.0	472.8± 16.73	14.3± 0.35	ND	1.34± 0.03	0.5± 0.01	42.7± 5.02	0.21± 0.1	BDL	0.31± 0	0.58± 0.01
Site II (Surface)	0.00	2.16± 0.03	1162.6± 8.99	15.2± 0.25	ND	12.35± 0.03	1.4± 0.03	3.20± 0.03	4.96± 0.02	BDL	0.34± 0.03	0.23± 0.01
Site III (Surface)	0.67± 0.02	70.72± 3.05	418.4± 15.11	12.2± 1.23	ND	0.61± 0.1	1.0± 0.01	2.76± 0.03	0.14± 0.01	BDL	0.33± 0.02	1.55± 0.02
Site V (Piezometer)	0.00	196.1± 10.20	740.3± 4.38	18.3± 0.21	0.1± 0	1.64± 0.01	0.9± 0.01	112.± 10.25	ND	BDL	0.31± 0.01	1.18± 0.02
Site V (Surface)	0.00	14.55± 1.02	418.1± 10.55	25.3± 0.02	ND	0.61± 0.01	0.7± 0.01	9.00± 1.25	ND	BDL	0.30± 0	0.61± 0.02
Site VI (Surface)	0.00	87.74± 3.25	380.0± 10.73	16.2± 0.24	ND	0.69± 0.02	0.6± 0.01	1.92± 0.02	0.27± 0.01	BDL	0.34± 0.01	0.74± 0.02

Note: BDL- Below detection limit
ND- Not detected

6.2 Bioaccumulation of different trace and toxic metals in Plant vegetation

Plants vegetation growing around the identified sites were thoroughly surveyed and samples of different plant species were collected. Stem and leaves of the collected samples were acid digested and then analysed by ICP-MS (Table 8-13) respectively. Plants species specific bio-accumulation of different metals were observed among the terrestrial and aquatic plants.

Chromium (Cr)

The concentration of chromium varied between 0.18-4.42 mg kg^{-1}. The accumulation of Cr was maximum in the root of *Pennisetum glaucum* (4.42 and 3.71 mg kg^{-1}) at site V and IV (Table 12 and 11) respectively. The accumulation of Cr was beyond the permissible limit (WHO-1.30 mg kg^{-1}) in most of the plants.

Manganese (Mn)

Manganese is an important plant micronutrient and is required by plant. The accumulation level of Mn ranged from 2.63-1105 mg kg^{-1}). Maximum accumulation was found in leaves of *Peltophorum pterocarpum* (1105 mg kg^{-1}) at site IV (Table 11).

Iron (Fe)

Iron is a nutrient that all plants need to function. Many of the vital functions of the plant, like enzyme and chlorophyll production, nitrogen fixing and metabolism all are dependent on Iron. The level of Iron was varied from 41.49-5249 mg kg^{-1}. Highest accumulation of Iron was found in the root of *Typha latifolia* (5249 and 5016 mg kg^{-1}) at site V and I (Table 12 and 8) respectively.

Cobalt (Co)

Cobalt is a trace element in plants. Maximum concentration of cobalt was found in the leaf of *Chromolena odorata* and *Dalbergia sissoo* (5.55 and 5.24 mg kg^{-1}) at site IV (Table 11) respectively.

Nickel (Ni)

The accumulation level of nickel was found 0.15-17.45 mg kg^{-1}. Maximum bioaccumulation of Ni was found in leaves of *Chromolena odorata* (17.45 mg kg^{-1}) at site IV (Table 11) followed by root of *Crotolaria pallida* (16.48 mg kg^{-1}) at site II (Table 9). It is an essential element needed for plants growth and development, Ni accumulation in most of the plant species was within the permissible limit (WHO-10 mg kg^{-1}).

Zinc (Zn)

Zinc is an essential micronutrient only needed by plants in small quantities. The Zinc concentration ranged between (2.18-150 mg kg^{-1}). Maximum Zn concentration was found in the leaves of *Azadirachta indica* (150 mg kg^{-1}) at site IV (Table 11). It was found below the permissible limit.

Arsenic (As)

The accumulation level of Arsenic was 0.01-22.44 mg kg^{-1}. The highest accumulation of Arsenic was found in the leaves of *Pteris vittata* (22.44 mg kg^{-1}) at site I (Table 8). *Pteris vittata* is a hyper accumulator of Arsenic however, the concentration of As was mostly found to be within the permissible limits.

Mercury (Hg)

It is to be noted that Hg was below detection limit in all plant samples.

Cadmium (Cd)

Cadmium is a toxic element for plant. The concentration of cadmium ranged from 0.00- 0.45 mg kg^{-1} dry weight. Maximum concentration of cadmium was found in the root of *Alternanthera sessiles* (0.45 mg kg^{-1}) at site II (Table 9).

Lead (Pb)

The accumulation level of Pb in stem and leaves in most of the plant species were found within the permissible limit. The concentration of lead ranged from 0.06-9.87 mg kg^{-1}. The maximum accumulation of Pb was found in the leaves of *Lantana camara* (9.87 mg kg^{-1}) at site II followed by the leaves of *Peltophorum pterocarpum* (9.08 mg kg^{-1}) at site IV (Table 9 and 11) respectively.

Fluoride (F)

Industrial activities may cause Fluoride (F) pollution. The level of fluoride concentration was found from 0.13-4.1 mg kg^{-1}. Maximum concentration was found in the stem and leaves of *Dendrocalamus sp.* (4.1 and 3.25 mg kg^{-1}) respectively at site IV (Table 11).

Barium (Ba)

Barium concentration raged between 1.5-20.0 mg kg^{-1}. Maximum concentration was found in the stem of *Azadirachta indica* (20.32 mg kg^{-1}) at site IV (Table 11).

Table 8: Bioaccumulation of different trace and toxic metals in plant vegetation at site - I.

A.		**Site - I Check Dam Mine Void - 02**													
S. No.	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**												
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Atylosia scarabaeoides***	**Root**	1.76±0.04	8.08±0.06	266.22±2	0.3±0	1.46±0.05	6.45±0.04	14.14±0.13	0.22±0.02	BDL	0.09±0.01	2.21±0.2	0.85±0.02	15.2±0.05
		Stem	0.72±0.02	17.33±0.33	220.84±5.24	0.19±0	2.45±0.04	4.96±0.11	16.34±0.56	0.12±0	BDL	0.1±0	0.24±0	0.55±0.01	12.23±0.06
		Leaf	1.32±0.07	19.41±1.01	348.42±17.92	0.25±0.01	1.34±0.07	3.72±0.17	13.27±0.8	0.27±0.01	BDL	0.05±0	0.58±0.02	0.4±0.01	8.25±0.06
		Pod	0.56±0	12.9±0.09	235.04±1.02	0.07±0	1.66±0.01	3.83±0	12.02±0.02	0.13±0.01	BDL	0.06±0	1.15±0.04	0.15±0.03	6.65±0.02
2	***Pennisetum glaucum***	**Root**	2.6±0.03	52.73±0.26	820.53±2.49	2.08±0.01	4.82±0.04	4.14±0.02	21.65±0.23	1.68±0.01	BDL	0.1±0	0.35±0.01	0.32±0.02	10.2±0.07
		Leaf	1.02±0.02	33.71±0.32	156.93±1.15	0.23±0	0.77±0.01	2.2±0.02	10.44±0.17	0.99±0.02	BDL	0.1±0	0.89±0.01	0.35±0.01	7.12±0.05
3	***Alternanthera sessiles***	**Root**	0.74±0	8.58±0.06	244.46±1.65	0.52±0	1.22±0	5.12±0.02	29.88±0.06	2.75±0.01	BDL	0.09±0	0.27±0	0.45±0	8.56±0.02
		Stem	0.59±0.01	6.53±0.1	585.84±5.9	0.18±0	0.68±0.01	1.57±0.02	21.15±0.43	0.37±0	BDL	0.06±0	0.27±0	0.3±0.01	6.23±0.01
		Leaf	0.73±0.03	9.7±0.05	134.33±1.04	0.06±0	0.1±0	0.37±0	2.3±0.01	0.62±0.01	BDL	0.09±0	0.86±0.01	0.2±0.0.2	5.65±0.03
		Flower	0.74±0.01	31.99±0.09	234.05±1.1	0.56±0	2.9±0	3.39±0	26.77±0.08	0.93±0.01	BDL	0.18±0	0.86±0	0.15±0.01	2.25±0.01
4	***Scoparia dulcis***	**Root**	0.4±0.01	7.9±0.01	213.01±0.54	0.2±0	0.57±0	5.66±0.02	7.13±0.43	0.09±0	BDL	0.08±0	0.22±0.01	0.65±0.03	10.3±0.09
		Stem	0.31±0.01	10.99±0.13	153.31±1.52	0.14±0	0.4±0	1.78±0.05	6.12±0.1	0.1±0	BDL	0.1±0	0.24±0	0.49±0.02	8.56±0.02
		Leaf	0.51±0.05	4.28±0.03	63.69±1.44	0.06±0	0.24±0.01	0.39±0.01	2.18±0.13	0.18±0	BDL	0.05±0	0.31±0	0.3±0.01	6.65±0.01
5	***Andrographis paniculata***	**Root**	1.32±0	12.37±0.05	330.14±0.2	0.18±0	0.84±0	8.23±0.02	14.77±0.13	0.32±0	BDL	0.04±0	0.49±0.01	1.2±0.01	12.5±0.06
		Stem	0.53±	12.21±	155.4±	0.18±	0.67±	4.21±	17.81±	0.16±	BDL	0.08±	0.85±	0.8±	7.98±

			0.01	0.18	3.29	0	0.01	0.08	0.5	0		0	0	0.01	0.02
		Leaf	0.92± 0.01	6.11± 0.06	187.3± 5.77	0.17± 0	0.55± 0	1.17± 0.02	26.73± 0.58	0.44± 0.01	BDL	0.03± 0	0.3± 0.01	0.4± 0.01	5.35± 0.02
6	***Mimosa pudica***	**Root**	0.74± 0.01	20.12± 0.06	558.48± 6.54	1.44± 0	4.72± 0.02	6.45± 0.03	35.41± 0.18	1.16± 0.01	BDL	0.21± 0	0.64± 0.01	1.1± 0.03	8.45± 0.04
		Stem	0.36± 0.02	19.13± 0.98	105.74± 4.74	0.24± 0.01	1.78± 0.08	5.02± 0.24	17.31± 0.76	0.42± 0.03	BDL	0.18± 0.01	1.8± 0.07	1.15± 0.01	6.2± 0.06
		Leaf	0.51± 0.01	29.28± 0.78	156.99± 4.11	0.21± 0.01	1.05± 0.02	3.04± 0.08	13.01± 0.29	0.41± 0.01	BDL	0.04± 0	0.26± 0	1.85± 0.03	3.21± 0.01
7	***Parthenium hysterophorus***	**Root**	1.04± 0.01	4.37± 0.07	257.73± 2.49	0.12± 0	0.29± 0.01	1.89± 0.02	10.54± 0.26	0.11± 0	BDL	0.03± 0	0.51± 0	1.55± 0.02	10.35± 0.12
		Stem	0.66± 0.01	7.13± 0.07	229.53± 14.11	0.09± 0	0.34± 0.02	4.54± 0.01	12.51± 0.05	0.56± 0.44	BDL	0.02± 0	0.62± 0	1.25± 0.01	7.68± 0.01
		Leaf	1.74± 0.1	53.92± 3.04	621.12± 32.55	0.4± 0.03	1.22± 0.08	5.63± 0.34	39.04± 2.12	0.44± 0.03	BDL	0.07± 0	0.43± 0.02	1.15± 0.03	5.68± 0.02
8	***Typha latifolia***	**Root**	2.06± 0.06	261.41± 6.8	5016.15± 126.71	10.18± 0.23	4.86± 0.15	2.77± 0.08	53.41± 1.21	3.59± 0.08	BDL	0.07± 0	0.61± 0.02	2.1± 0.21	13.6± 0.21
		Leaf	0.56± 0.02	671.36± 10.18	124.02± 6.5	1.32± 0.02	1.02± 0.02	0.91± 0.03	13.74± 0.26	0.11± 0.02	BDL	0.02± 0	0.78± 0.02	1.5± 0.02	11.2± 0.03
9	***Ocimum basilicum***	**Root**	0.76± 0.02	10.56± 0.39	202.75± 9.1	0.2± 0.01	0.5± 0.03	14.88± 0.63	21.27± 0.59	0.14± 0.01	BDL	0.03± 0	0.87± 0.03	0.84± 0.03	15.3± 0.21
		Stem	0.45± 0.02	4.27± 0.18	67.79± 1.48	0.08± 0.01	1.15± 0.07	8.06± 0.33	31.51± 0.98	0.06± 0	BDL	0.02± 0	0.9± 0.03	0.72± 0.02	10.32± 0.21
		Leaf	1.58± 0.03	22.73± 0.45	434.39± 7.87	0.37± 0.01	0.83± 0.02	3.93± 0.08	27.61± 0.52	0.34± 0.01	BDL	0.04± 0	0.32± 0.01	0.5± 0	8.56± 0.03
		Inflorescence	0.53± 0.01	11.09± 0.34	186.6± 7.22	0.26± 0.01	0.45± 0.02	3.85± 0.14	23.69± 0.72	0.09± 0.01	BDL	0.01± 0	0.21± 0.01	0.18± 0	7.65± 0.01
10	***Tridax procumbens***	**Root**	1.44± 0.02	8.31± 0.09	330.59± 1.73	0.15± 0	0.24± 0	4.13± 0.05	8.76± 0.09	0.21± 0	BDL	0.01± 0	0.19± 0	1.12± 0.01	12.3± 0.25
		Stem	0.69± 0.01	19.58± 0.19	166± 1.7	0.14± 0	0.37± 0.01	3.49± 0.13	23.91± 0.24	0.09± 0	BDL	0.03± 0	0.36± 0.01	0.65± 0.02	8.32± 0.01
		Leaf	0.82± 0.01	16.36± 0.18	190.69± 2.16	0.23± 0	0.42± 0.01	3.44± 0.06	21.62± 0.21	0.2± 0	BDL	0.02± 0	0.42± 0.01	0.48± 0.01	6.54± 0.03
		Flower	0.99±	9.2±	209.05±	0.29±	0.76±	5.74±	14.44±	0.19±	BDL	0.1±	2.66±	0.09±	3.2±

			0.05	0.42	9.03	0.02	0.05	0.26	0.85	0.01		0	0.79	0	0.01
11	***Pteris vittata***	**Root**	0.78± 0.03	182.03± 7.3	49.36± 1.3	7.67± 0.42	2.33± 0.11	0.24± 0.02	0.5± 0.02	0.03± 0	BDL	ND	0.05± 0	1.1± 0.01	10.21± 0.15
		Leaf	0.85± 0.03	63.45± 25.23	253.71± 6.39	2.78± 1.66	1.74± 0.6	4.89± 0.07	10.85± 0.86	22.44± 0.13	BDL	0.05± 0	0.88± 0.08	0.75± 0.01	7.4± 0.03
12	***Urena lobata***	**Stem**	0.25± 0.01	16.29± 0.34	58.22± 3.58	0.16± 0.03	0.15± 0.03	6.47± 0.14	11.88± 1.48	0.08± 0.03	BDL	0.04± 0	0.91± 0.19	0.32± 0.02	7.32± 0.04
		Leaf	0.75± 0.01	43.17± 0.58	156.79± 2.18	0.3± 0	0.47± 0	2.32± 0.02	15.4± 0.3	0.13± 0	BDL	0.01± 0	0.78± 0	0.3± 0	4.2± 0.01
13	***Woodfordia fruticosa***	**Root**	0.37± 0.03	12.36± 0.87	134.19± 8.71	0.09± 0.01	3.9± 0.26	4.19± 0.27	6.06± 0.4	0.04± 0.01	BDL	0.34± 0.02	0.32± 0.02	0.21± 0	6.23± 0.02
		Leaf	0.6± 0.01	40.13± 0.58	156.61± 1.37	0.74± 0.01	3.4± 0.06	1.6± 0.02	20.08± 0.36	0.18± 0	BDL	0.04± 0	0.14± 0.01	0.18± 0	4.3± 0.03
		Flower	0.19± 0.01	9.94± 0.47	64.57± 3.6	0.1± 0.01	1.12± 0.06	1.95± 0.09	8.66± 0.4	0.01± 0.01	BDL	0.02± 0	0.73± 0.04	0.15± 0	2.01± 0.01
14	***Ziziphus nummularia***	**Stem**	0.27± 0.01	3.7± 0.12	51.09± 1.31	0.02± 0	ND	1.14± 0.04	5.23± 0.17	0.02± 0	BDL	0.01± 0	0.62± 0.02	1.42± 0.01	10.2± 0.16
		Leaf	0.49± 0.01	30.99± 0.24	151.6± 0.26	0.12± 0	0.94± 0.01	1.57± 0.01	9.38± 0.14	0.07± 0	BDL	0.01± 0	0.09± 0.01	1.12± 0.01	7.45± 0.08
15	***Holarrhena antidysenterica***	**Root**	1.43± 0.02	71.16± 0.77	482.61± 6.18	0.91± 0.01	0.93± 0.02	8.63± 0.1	11.63± 0.19	0.15± 0	BDL	0.01± 0	0.43± 0.01	2.1± 0.02	15.2± 1.45
		Stem	0.55± 0.01	58.31± 1.6	142.92± 3.45	0.62± 0.02	0.87± 0.03	5.84± 0.14	10.07± 0.32	0.05± 0.01	BDL	0.01± 0	0.45± 0.02	1.5± 0.01	12.3± 1.65
		Leaf	1.25± 0.09	203.78± 12.48	307.16± 24.29	0.82± 0.06	1.97± 0.16	8.23± 0.61	16.33± 0.9	0.55± 0.29	BDL	0.03± 0	0.17± 0.02	1.1± 0.01	11.21± 1.98
		Inflorescence	1± 0.07	269.05± 17.95	279.26± 17.36	1.04± 0.06	6.31± 0.39	11.11± 0.68	29.84± 1.59	0.2± 0.02	BDL	0.11± 0	0.86± 0.05	0.2± 0	3.21± 0.03
16	***Hyptis suaveolens***	**Stem**	0.48± 0.04	10.71± 0.6	77.45± 3.27	0.2± 0.01	0.39± 0.02	9.78± 0.65	9.2± 0.42	0.24± 0	BDL	0.05± 0	0.58± 0.04	0.22± 0	16.21± 1.65
		Leaf	1.63± 0.08	21.27± 1.14	306.77± 17.26	0.22± 0.01	0.75± 0.05	2.88± 0.19	16.66± 0.52	0.34± 0.02	BDL	0.02± 0	0.16± 0.02	0.17± 0.01	8.2± 0.02
		Inflorescence	1.06± 0.05	14.64± 0.89	568.57± 33.22	0.16± 0.01	0.7± 0.05	3.33± 0.13	14.81± 1.02	0.22± 0.01	BDL	0.04± 0	0.49± 0.03	0.08± 0.01	2.64± 0.01
17	***Senna siamea***	**Stem**	0.64±	28.1±	111.01±	0.1±	0.78±	7.29±	9.43±	0.13±	BDL	0.08±	0.57±	1.13±	15.2±

			0.01	0.34	0.69	0	0.01	0.07	0.11	0		0	0.02	0.08	1.12
		Leaf	0.83± 0.01	58.47± 0.83	255.48± 5.25	0.24± 0	0.7± 0.02	2.54± 0.04	8± 0.2	0.29± 0.01	BDL	0.03± 0	0.15± 0	0.97± 0.03	9.1± 1.42
		Flower	0.61± 0.02	18.29± 0.65	124.21± 4.4	0.04± 0	1.07± 0.14	1.7± 0.08	7.65± 0.38	0.11± 0	BDL	0.04± 0	0.47± 0.02	0.22± 0.1	1.5±0
18	***Syzygium cumini***	**Stem**	0.4± 0	16.39± 0.37	83.5± 0.56	0.25± 0	3.21± 0.05	9.06± 0.14	11.26± 0.28	0.14± 0	BDL	0.07± 0	1.53± 0.03	2.1± 0.04	13.2± 0.02
		Leaf	0.51± 0.03	55.64± 2.7	122.3± 5.95	0.13± 0.01	3.28± 0.19	2.27± 0.11	5.09± 0.37	0.14± 0	BDL	0.04± 0	0.3± 0.02	1.11± 0.02	8.5± 0.01
19	***Azadirachta indica***	**Stem**	0.31± 0.03	3.81± 0.37	60.13± 10.06	0.03± 0.01	0.21± 0.05	2.95± 0.32	5.52± 0.97	0.1± 0.01	BDL	0.03± 0	0.31± 0.03	1.42± 0.01	13.21± 1.74
		Leaf	0.93± 0.02	37.57± 0.68	252.39± 2.49	0.14± 0	0.76± 0.02	0.68± 0.02	19.51± 0.38	0.29± 0	BDL	0.04± 0	0.47± 0.02	1.12± 0.01	9.45± 1.65
20	***Acacia auriculiformis***	**Stem**	0.42± 0.01	12.55± 0.13	87.24± 3.47	0.14± 0	1.37± 0.01	4.25± 0.07	6.77± 0.19	0.11± 0	BDL	0.05± 0.01	1.07± 0.06	0.98± 0.02	18.2± 1.52
		Leaf	1.02± 0.03	114.32± 3.25	339.55± 10.47	0.28± 0.01	5.71± 0.19	3.81± 0.11	18.38± 0.7	0.26± 0.01	BDL	0.06± 0	0.2± 0	0.25± 0.01	11.02± 1.32

Note: BDL- Below detection limit

ND- Not detected

Table 9: Bioaccumulation of different trace and toxic metals in plant vegetation at site - II.

B.		**Site - II - L - Shape Dam (Frist Position)**													
S.N	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**												
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Pennisetum glaucum***	**Root**	3.5± 0.1	39.89± 1.35	631.03± 20.82	1.27± 0.05	2.2± 0.09	6.11± 0.23	19.08± 0.66	3.42± 0.13	BDL	0.04± 0	0.87± 0.04	0.28± 0.01	10.3± 1.2
		Shoot	1.48± 0.07	21.87± 1.16	200.85± 10.16	0.15± 0.01	0.32± 0.04	1.86± 0.18	8.75± 0.23	0.44± 0.06	BDL	0.04± 0	0.85± 0.04	0.22± 0.01	7.3± 0.02
		Inflorescence	2.49± 0.14	64.66± 2.92	412.56± 22.82	0.51± 0.02	1.77± 0.08	5.37± 0.27	23.85± 1.87	0.75± 0.04	BDL	0.06± 0	1.23± 0.03	0.13± 0.02	1.53± 0.01
2	***Alternanthera sessiles***	**Root**	2.25± 0.09	81.19± 4.23	548± 26.7	1.28± 0.06	5.2± 0.23	20.85± 0.85	44.69± 1.78	2.98± 0.14	BDL	0.45± 0.02	0.53± 0.03	0.35± 0.01	10.32± 0.04
		Stem	1.23± 0.03	36.42± 0.5	453.8± 6.35	0.5± 0.01	1.63± 0.03	2.49± 0.03	22.19± 0.26	1.49± 0.02	BDL	0.11± 0	0.35± 0.02	0.27± 0.02	8.65± 0.2
		Leaf	2.49± 0.19	112.86± 11.42	374.9± 24.15	1.07± 0.08	2.45± 0.37	2.71± 1.72	35.92± 1.46	2.56± 0.15	BDL	0.25± 0.02	0.38± 0.02	0.2± 0.02	5.2± 0.1
		Inflorescence	0.2± 0	0.59± 0.02	3.61± 0.19	ND	ND	ND	3.2± 0.69	0.07± 0	BDL	0.03± 0	0.64± 0.11	0.08± 0	2.1± 0.1
3	***Hyptis suaveolens***	**Root**	3.54± 0.01	26.05± 0.29	452.41± 4.73	1.1± 0.01	1.12± 0.02	21.96± 0.18	28.96± 0.49	0.99± 0.01	BDL	0.16± 0	0.36± 0.01	1.8± 0.05	15.35± 1.35
		Stem	1.2± 0.02	27.5± 0.36	133.03± 1.84	0.81± 0.01	0.42± 0.01	12.31± 0.16	23.44± 0.68	0.48± 0	BDL	0.05± 0	0.22± 0.01	1.46± 0.04	10.2± 1.21
		Leaf	2.42± 0.09	46.1± 1.85	447.67± 13.55	0.87± 0.03	1.47± 0.05	5.15± 0.19	36.53± 1.65	2.01± 0.07	BDL	0.09± 0	0.68± 0.03	1.25± 0.03	7.65± 0.1
		Inflorescence	1.32± 0.06	31.69± 1.63	294.88± 19.63	1.21± 0.07	2.7± 0.18	7.74± 0.47	33.86± 1.95	0.8± 0.04	BDL	0.05± 0	2.52± 0.14	0.26± 0.02	1.3± 0.01
4	***Atylosia scarabaeoides***	**Root**	2.58± 0.14	12.84± 0.66	658.96± 39.04	0.47± 0.03	3.47± 0.14	14.54± 0.71	17.26± 0.98	0.43± 0.03	BDL	0.1± 0.01	0.48± 0.03	0.7± 0.02	8.3± 0.35
		Stem	0.89± 0.04	36.44± 1.5	278.44± 14.49	0.56± 0.03	9.16± 0.43	18.58± 0.88	23.12± 1.09	0.16± 0	BDL	0.26± 0.01	0.71± 0.03	0.52± 0.02	6.32± 0.23
		Leaf	1.33± 0.1	32.65± 2.23	324.33± 22.55	0.27± 0.02	3.31± 0.24	3.59± 0.27	14.61± 1.03	0.28± 0.03	BDL	0.07± 0	1.4± 0.09	0.32± 0.01	5.54± 0.03
5	***Calotropis***	**Stem**	0.28±	20.75±	63.44±	0.16±	0.51±	0.74±	11.06±	0.09±	BDL	0.02±	0.74±	0.65±	12.2±

	procera		0.02	1.65	4.9	0.02	0.04	0.09	0.8	0.01		0	0.05	0.01	2.3
		Leaf	1.66± 0.11	133.21± 8.65	181.66± 11.5	0.87± 0.06	3.47± 0.23	2.94± 0.2	21.13± 1.24	0.35± 0.07	BDL	0.03± 0	0.86± 0.05	0.43± 0.02	7.65± 1.1
6	***Psidium guajava***	**Stem**	0.45± 0.02	85.6± 2.6	158.23± 5.14	0.57± 0.04	1.06± 0.03	6.54± 0.19	14.04± 0.25	0.04± 0	BDL	0.04± 0	1.1± 0.07	0.21± 0.01	11.2± 0.56
		Leaf	0.86± 0.06	72.17± 4.62	274.33± 19.18	0.69± 0.05	1.68± 0.09	3.41± 0.17	17.81± 0.42	0.15± 0.01	BDL	0.04± 0.01	1.64± 0.1	0.18± 0.01	8.56± 0.87
		Fruit	0.47± 0.02	12.71± 0.65	67.55± 3.24	0.53± 0.03	1.45± 0.08	8.19± 0.45	18.6± 0.98	0.02± 0	BDL	0.01± 0	0.83± 0.03	0.07± 0	2.1± 0.01
7	***Saccharum spontanium***	**Root**	0.68± 0.05	14.34± 1.25	109.4± 10.22	0.34± 0.03	1.41± 0.12	12.54± 1.05	11.69± 1.1	0.79± 0.07	BDL	0.07± 0.01	3.74± 0.29	0.58± 0.03	12.1± 0.99
		Stem	0.61± 0.03	35.21± 1.85	246.16± 11.66	1.05± 0.06	1.17± 0.07	35.55± 1.9	40.46± 2.45	0.28± 0.02	BDL	0.14± 0.01	0.77± 0.03	0.44± 0.06	7.5± 0.84
		Leaf	0.76± 0.05	29.81± 1.67	137.03± 7.58	0.19± 0.01	0.6± 0.05	1.42± 0.11	5.16± 0.34	0.32± 0.02	BDL	0.05± 0	1.47± 0.07	0.22± 0.02	4.3± 0.05
8	***Azadirachta indica***	**Stem**	0.48± 0.03	9.75± 0.47	75.13± 4.92	0.15± 0.01	2.11± 0.11	24.99± 1.18	32.83± 2.14	0.09± 0.01	BDL	0.02± 0	0.73± 0.03	1.1± 0.06	11.2± 0.21
		Leaf	1.02± 0.02	102.9± 2.77	511.59± 13.26	0.25± 0.01	2.24± 0.06	2.72± 0.06	19.89± 0.73	0.33± 0	BDL	0.08± 0	2.37± 0.1	0.7± 0.01	9.12± 0.12
9	***Lygodium flexuosum***	**Root**	2.22± 0.08	52.46± 2.33	62.96± 1.38	1.78± 0.11	6.84± 0.3	3± 0.12	15.73± 1.76	0.13± 0	BDL	0.05± 0.01	0.63± 0.01	0.21± 0.01	6.24± 0.01
		Stem	2.28± 0.06	125.94± 2.43	536.07± 13.23	1.06± 0.07	5.66± 0.29	4.78± 0.36	52.41± 5.52	0.27± 0.02	BDL	0.33± 0.03	2.67± 0.57	0.18± 0.02	3.2± 0.2
		Leaf	2.43± 0.08	326.74± 11.69	771.65± 30.79	1.05± 0.04	7.36± 0.28	5.37± 0.21	31.68± 0.75	0.49± 0.03	BDL	0.06± 0	0.87± 0.05	0.07± 0	2.45± 0.23
10	***Ziziphus nummularia***	**Stem**	0.6± 0.03	39.47± 2.57	135.57± 5.77	0.17± 0.01	0.56± 0.03	9.7± 0.57	11.62± 0.7	0.45± 0.03	BDL	0.02± 0	0.4± 0.02	1.12± 0.05	13.2± 0.32
		Leaf	1.19± 0.03	67.14± 1.88	689.48± 18.81	0.29± 0.01	1.28± 0.04	2.39± 0.08	8.19± 0.32	0.63± 0.01	BDL	0.02± 0	0.96± 0.05	0.82± 0.02	6.3± 0.21
		Fruit	0.28± 0.03	21.06± 1.99	80.25± 41.36	0.07± 0.01	1.16± 0.13	2.08± 0.19	6.24± 0.83	0.29± 0.03	BDL	0.03± 0	3.08± 0.27	0.12± 0.01	1.56± 0.02
11	***Cryptolepis buchananii***	**Stem**	0.63± 0.07	111.78± 12.93	178.82± 19.39	0.26± 0.04	0.84± 0.1	9.26± 0.93	14.93± 1.13	0.31± 0.05	BDL	0.07± 0.01	1.03± 0.11	0.26± 0.02	8.65± 0.3
		Leaf	0.88±	313.11±	385.64±	0.22±	1.59±	2.89±	13.39±	0.45±	BDL	0.02±	0.33±	0.17±	6.53±

			0.06	20.69	25.71	0.02	0.1	0.18	0.84	0.03		0	0.02	0.01	0.25
12	***Cassia fistula***	**Stem**	0.35± 0.02	14.51± 1.27	668.63± 53.18	0.03± 0.01	0.72± 0.06	1.39± 0.12	3.05± 0.2	0.07± 0.01	BDL	0.01± 0	0.22± 0.01	0.32± 0.01	12± 1.56
		Leaf	1.34± 0.08	102.68± 5.61	536.43± 28.99	0.41± 0.02	1.26± 0.07	2.11± 0.1	8.63± 0.69	0.52± 0.04	BDL	0.1± 0	4.08± 0.17	0.26± 0.1	8.64± 0.26
		Flower	1.22± 0.06	60.32± 3.25	258.47± 13.36	0.3± 0.02	1.69± 0.1	1.33± 0.09	12.1± 0.49	0.25± 0.02	BDL	0.03± 0	0.76± 0.04	0.06± 0.1	2.12± 0.01
13	***Leucaena leucocephala***	**Stem**	0.49± 0.03	21.15± 1.55	113.73± 12.56	0.11± 0.01	0.66± 0.04	7± 0.51	10.44± 0.94	0.04± 0	BDL	0.05± 0	7.77± 0.58	0.62± 0.01	7.3± 0.35
		Leaf	1.36± 0.05	78.81± 3.15	624.68± 30.05	0.86± 0.04	1.06± 0.05	2.21± 0.1	16.87± 0.99	0.38± 0.01	BDL	0.11± 0	4.83± 0.24	0.38± 0.03	5.21± 0.26
14	***Phyllanthus amarus***	**Stem**	0.54± 0.07	15.54± 2.1	159.03± 15.58	0.14± 0.02	0.94± 0.13	13.11± 1.79	15.53± 0.98	0.07± 0.01	BDL	0.1± 0.01	4.95± 0.78	0.32± 0.02	8.2± 0.24
		Leaf	0.8± 0.05	26.4± 1.75	177.32± 12.27	0.79± 0.06	0.77± 0.04	1.08± 0.06	10.51± 0.7	0.21± 0.01	BDL	0.02± 0	0.91± 0.08	0.22± 0.01	6.3± 0.21
15	***Prosopis juliflora***	**Stem**	0.5± 0.03	11.76± 0.41	86.65± 3.11	0.36± 0.02	3.6± 0.15	6.37± 0.26	14.13± 0.49	0.02± 0	BDL	0.01± 0	0.44± 0.01	0.45± 0.02	12.3± 1.65
		Leaf	1.28± 0.02	228.8± 2.68	330.09± 4.73	0.89± 0.01	6.21± 0.07	29.18± 0.43	39.28± 0.83	0.17± 0	BDL	0.02± 0	0.48± 0.01	0.37± 0.02	8.54± 0.23
16	***Chromolena odorata***	**Stem**	0.72± 0.02	39.11± 0.98	138.76± 2.7	0.2± 0.01	4.74± 0.12	8.5± 0.2	16.77± 0.33	0.05± 0	BDL	0.02± 0	0.96± 0.02	1.25± 0.32	18.23± 1.65
		Leaf	1.86± 0.04	126.38± 2.62	405.77± 6.5	1.53± 0.03	6.07± 0.09	15.73± 0.23	25.17± 0.21	0.17± 0	BDL	0.07± 0	2.16± 0.04	0.85± 0.12	12.3± 2.65
17	***Cassia siamea***	**Stem**	0.86± 0.04	37.04± 1.81	145.5± 7.71	0.88± 0.04	11.38± 0.55	14.62± 0.72	44.87± 2.39	0.02± 0	BDL	0.12± 0	4.87± 0.22	0.72± 0.02	11.23± 1.1
		Leaf	0.78± 0.02	38.58± 0.81	206.41± 4.48	0.37± 0.01	1.9± 0.03	6.76± 0.11	14.31± 0.42	0.12± 0	BDL	0.01± 0	1.29± 0.05	0.32± 0.01	7.65± 0.08
18	***Vachellia nilotica***	**Stem**	0.38± 0.02	11.41± 0.53	48.45± 2.08	0.02± 0	0.35± 0.02	4.44± 0.22	14.7± 1.09	0.02± 0	BDL	0.01± 0	0.29± 0.02	0.52± 0.05	9.65± 0.65
		Leaf	1.27± 0.07	246.35± 6.08	400.73± 7.46	0.34± 0.01	2.65± 0.07	9.63± 0.15	40.85± 1.02	0.36± 0.4	BDL	0.05± 0.01	2.37± 1.54	0.41± 0.05	6.32± 0.03
19	***Scoparia dulcis***	**Stem**	0.5± 0.02	7.02± 0.25	87.32± 2.1	0.36± 0.01	0.69± 0.01	2.33± 0.06	9.45± 0.18	0.04± 0	BDL	0.14± 0.01	3.78± 0.12	0.21± 0.02	8.56± 0.65
		Leaf	1.37±	29.25±	671.34±	0.5±	2.59±	2.71±	11.24±	0.18±	BDL	0.13±	3.66±	0.17±	6.21±

			0.14	2.77	65.16	0.05	0.26	0.27	0.98	0.01		0.01	0.3	0	0.35
		Fruit	0.59± 0.03	6.37± 0.28	192.28± 12.29	0.09± 0.01	3.77± 0.23	1.54± 0.11	9.54± 0.59	0.08± 0.02	BDL	0.16± 0.01	1.77± 0.12	0.04± 0	2.5± 0.01
20	***Mimosa pudica***	**Stem**	0.67± 0.01	83.9± 1.26	131.4± 2	0.3± 0.01	5.97± 0.07	4.22± 0.04	39.38± 0.46	0.07± 0	BDL	0.11± 0	7.63± 0.17	0.85± 0.03	10.2± 0.2
		Leaf	0.94± 0.06	147.61± 10.25	289.4± 19.21	0.42± 0.03	7.13± 0.46	5.96± 0.35	27.67± 1.62	0.1± 0.01	BDL	0.04± 0	1.69± 0.09	1.13± 0.2	5.3± 0.23
21	***Crotalaria pallida***	**Root**	0.78± 0.02	10.92± 0.37	279.34± 5.6	0.76± 0.02	16.48± 0.27	14.26± 0.24	29.25± 0.88	0.08± 0	BDL	0.05± 0	1.46± 0.05	0.65± 0.02	8.54± 0.52
		Stem	0.18± 0.01	11.23± 0.71	41.49± 2.21	0.14± 0.01	5.2± 0.29	2.67± 0.14	19.72± 1.14	BDL	BDL	0.01± 0	0.65± 0.04	0.51± 0.02	5.62± 0.21
		Leaf	2.11± 0.1	87.16± 4.57	505.56± 25.42	0.84± 0.05	9.99± 0.49	3.37± 0.16	13± 0.12	0.16± 0.01	BDL	0.08± 0.01	3.3± 0.16	0.32± 0.02	3.6± 0.02
		Flower	1.61± 0.04	48.61± 1.35	272.36± 6.45	0.43± 0.02	11.81± 0.29	2.36± 0.05	18.44± 1.31	0.05± 0.01	BDL	0.02± 0	3.91± 0.09	0.08± 0	0.9± 0.01
22	***Lantana camara***	**Stem**	0.2± 0.01	30.01± 1.91	18.4± 1.33	0.05± 0.01	0.13± 0.01	2.87± 0.16	3.11± 0.26	0.07± 0.08	BDL	0.01± 0	0.9± 0.06	0.62± 0.01	12.3± 2.61
		Leaf	1.34± 0.05	297.46± 8.89	337.46± 10.72	0.49± 0.02	3.23± 0.11	12.12± 0.38	20.62± 1.06	0.89± 0.05	BDL	0.08± 0	9.87± 0.33	0.33± 0.1	8.65± 0.36

Note: BDL- Below detection limit

ND- Not detected

Table 10: Bioaccumulation of different trace and toxic metals in plant vegetation at site - III.

C.		Site - III - L - Shape Dam (Second Position)													
S.N	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**												
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Andrographis paniculata***	**Root**	1± 0.05	43.16± 2.02	357.13± 17.95	0.79± 0.04	1.07± 0.05	6.18± 0.26	18.46± 0.92	0.11± 0.01	BDL	0.03± 0	1.16± 0.06	0.95± 0.03	11.2± 0.62
		Stem	0.52± 0.01	31.48± 0.43	85.17± 0.77	0.09± 0	2.03± 0.12	5.44± 0.08	20.61± 0.22	0.04± 0	BDL	ND	0.58± 0.13	0.75± 0.05	8.3± 0.21
		Leaf	0.94± 0.02	72.84± 1.67	440.21± 14.54	0.91± 0.02	2.13± 0.07	2.61± 0.06	39.12± 0.94	0.14± 0.01	BDL	0.34± 0.01	8.75± 0.33	0.85± 0.02	7.6± 0.1
		Pod	0.79± 0.02	9.42± 0.24	294.85± 6.84	0.21± 0.01	2.09± 0.04	3.23± 0.05	12.94± 0.35	0.02± 0	BDL	0.04± 0.01	2.5± 0.05	0.08± 0	1.5± 0.01
2	***Ficus hispida***	**Stem**	0.41± 0.01	9.83± 0.27	58.81± 2.07	1.07± 0.02	2.05± 0.04	5.14± 0.14	13.22± 0.31	ND	BDL	0.07± 0	1.56± 0.06	1.12± 0.12	13.65± 0.25
		Leaf	1.04± 0.01	132.3± 2.04	163.79± 1.7	2.27± 0.03	6.07± 0.05	1.1± 0.02	18.54± 0.23	0.11± 0	BDL	0.03± 0	2.29± 0.01	1.25± 0.15	10.3± 0.36
3	***Celosia spicata***	**Root**	1.68± 0.04	12.99± 0.28	250.7± 4.99	0.68± 0.01	0.78± 0.01	8.28± 0.17	11.97± 0.96	0.3± 0.04	BDL	0.04± 0	1.72± 0.14	1.3± 0.03	8.62± 0.02
		Stem	0.8± 0.01	13.62± 0.13	301.5± 3.34	0.33± 0	0.59± 0.02	5.01± 0.04	12.7± 0.38	0.23± 0.01	BDL	0.04± 0	1.19± 0.03	0.95± 0.06	6.54± 0.01
		Leaf	2.96± 0.19	24.39± 1.64	566.13± 32.53	0.64± 0.04	1± 0.08	3± 0.11	12.01± 0.53	0.72± 0.04	BDL	0.01± 0	0.47± 0.02	0.75± 0.02	4.32± 0.32
		Inflorescence	1.62± 0.07	49.23± 1.76	270.3± 10.16	0.83± 0.03	1.29± 0.05	1.88± 0.07	32.94± 1.25	0.22± 0.01	BDL	0.05± 0	2.34± 0.11	0.09± 0	1.54± 0.02
4	***Cajanus cajan***	**Root**	0.99± 0.03	8.67± 0.39	180.43± 7.06	0.23± 0.01	3.14± 0.15	16.37± 0.74	15.16± 0.53	0.04± 0	BDL	0.03± 0	3± 0.17	2.1± 0.35	15.3± 1.52
		Stem	0.85± 0.02	18.25± 0.3	101.76± 8.6	0.3± 0.01	7.48± 0.17	11.27± 0.28	17.23± 0.49	0.06± 0.02	BDL	0.08± 0	4.39± 0.06	1.6± 0.32	12.3± 1.36
		Leaf	2.43± 0.09	84.21± 2.98	523.86± 18.77	0.71± 0.03	3.36± 0.13	8.68± 0.32	18.6± 0.65	0.37± 0.02	BDL	0.02± 0	1.43± 0.02	1.32± 0.31	10.25± 0.23
		Pod	0.96± 0.01	37.36± 0.73	134.7± 2.98	0.14± 0	9.22± 0.24	9.97± 0.18	27.97± 0.85	0.07± 0	BDL	0.02± 0	0.88± 0.01	0.2± 0	18.25± 2.14
5	***Syzygium***	**Stem**	0.51±	34.55±	78.36±	1.02±	10.27±	13.04±	16.84±	0.02±	BDL	0.01±	1.48±	2.1±	13.2±

	cumini		0.02	1.15	2.14	0.04	0.33	0.39	0.34	0		0	0.07	0.25	1.12
		Leaf	0.63± 0.02	178.71± 6.68	131.54± 3.4	1.2± 0.05	5.38± 0.2	4.97± 0.1	15.32± 0.29	0.11± 0.01	BDL	0.04± 0	1.6± 0.03	1.85± 0.12	9.26± 0.65
6	***Solanum nigrum***	**Stem**	0.32± 0.01	35.55± 0.77	120.98± 4.87	1.42± 0.04	1.04± 0.03	1.9± 0.07	63.52± 1.26	0.02± 0.01	BDL	0.01± 0	0.67± 0.02	1.11± 0.11	7.54± 0.15
		Fruit	0.41± 0.03	25.29± 1.55	83± 5.07	0.32± 0.02	1.97± 0.13	3.37± 0.19	9.43± 0.45	0.01± 0	BDL	0.04± 0	1.15± 0.07	0.7± 0	2.31± 0.12
7	***Mangifera indica***	**Leaf**	1.1± 0	280± 23.77	183.62± 1.93	0.97± 0.01	3.3± 0.05	5.69± 0.09	17.89± 0.07	0.14± 0	BDL	0.03± 0	2.48± 0.04	1.47± 0.03	11.2± 0.11
8	***Ficus benghalensis***	**Stem**	0.6± 0	130.26± 2.88	230.46± 3.56	2.2± 0.04	2.5± 0.04	8.65± 0.08	33.79± 0.63	0.03± 0.01	BDL	0.44± 0	1.6± 0.06	1.87± 0.04	16.2± 0.45
		Leaf	1.37± 0.07	71.13± 3.53	198.68± 8.94	0.3± 0.02	0.64± 0.03	1.3± 0.08	17.6± 0.68	0.22± 0.01	BDL	0.01± 0	1.4± 0.07	1.12± 0.12	9.6± 0.31
9	***Dalbergia sissoo***	**Stem**	0.2± 0	7.74± 0.23	50.04± 0.23	0.07± 0	1.21± 0.03	2± 0.07	10.04± 0.11	ND	BDL	0.02± 0	0.6± 0.02	1.8± 0.02	18.3± 3.5
		Leaf	1.22± 0.1	154.14± 13.17	174.45± 11.29	1.34± 0.12	1.86± 0.16	3.84± 0.31	57.93± 4.79	0.61± 0.05	BDL	0.03± 0	0.39± 0.02	1.6± 0.03	9.6± 0.36
10	***Leucaena leucocephala***	**Stem**	0.54± 0.02	11.37± 0.6	56.96± 2.97	0.27± 0.02	0.6± 0.04	5.18± 0.34	7.57± 0.18	ND	BDL	0.1± 0.01	6.07± 0.4	2.15± 0.29	12.65± 1.64
		Leaf	2.18± 0.03	116.24± 1.5	137.42± 9.35	1.32± 0.01	3.37± 0.06	9.54± 0.2	18.74± 1.95	0.3± 0.03	BDL	0.02± 0	2± 0.12	1.92± 0.13	10.25± 1.11
		Pod	0.96± 0.01	34.01± 0.18	152.76± 0.86	0.32± 0	1.14± 0.01	2± 0.02	6.85± 0.04	0.06± 0	BDL	0.06± 0	3.58± 0.04	0.08± 0.01	1.56± 0.01
11	***Smithia sensitiva***	**Root**	1.03± 0.08	84.44± 9.06	324.72± 15.77	1.33± 0.08	5.6± 0.3	12.65± 1.19	35.29± 3.08	0.35± 0.06	BDL	0.12± 0.03	5.11± 1.65	1.1± 0.05	8.6± 0.06
		Stem	1.14± 0.08	194.29± 14.74	189.81± 12.99	1.14± 0.09	5.19± 0.39	3.57± 0.27	66.86± 4.59	0.1± 0.01	BDL	0.14± 0.01	3.61± 0.24	0.83± 0.07	6.3± 0.03
		Leaf	0.75± 0.02	441.08± 10.36	142.99± 4.09	2.33± 0.05	6.11± 0.15	4.17± 0.16	57.47± 1.29	0.09± 0	BDL	0.09± 0	1.83± 0.07	0.62± 0.02	5.35± 0.64

Note: BDL- Below detection limit

ND- Not detected

Table 11: Bioaccumulation of different trace and toxic metals in plant vegetation at site - IV.

D.		**Site - IV Core Pond**													
S.N	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**												
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Mallotus nudiflorus***	**Stem**	0.24± 0.01	30.98± 0.42	79.06± 0.39	1± 0.02	2.19± 0.03	7.27± 0.09	76.29± 1.23	ND	BDL	ND	0.49± 0	1.65± 0.21	8.64± 1.25
		Leaf	1.27± 0.03	169.78± 2.66	967.43± 9.89	1.07± 0.02	8.89± 0.13	1.94± 0.04	119.51± 1.86	ND	BDL	ND	0.64± 0.01	1.32± 0.11	5.65± 0.36
2	***Terminalia bellirica***	**Stem**	0.7± 0	225.79± 0.69	24.61± 4.7	1.7± 0.01	6.85± 0.02	6± 0.05	114.3± 0.75	ND	BDL	ND	0.39± 0.01	2.5± 0.18	18.65± 2.41
		Leaf	0.79± 0.06	537.16± 38.87	65.7± 5.94	8.67± 0.59	6.68± 0.46	2.01± 0.1	69.76± 4.7	ND	BDL	0.09± 0.02	3.04± 0.31	2.2± 0.16	13.65± 1.36
		Fruit	0.6± 0.01	96± 2.03	26.36± 5.33	1.7± 0.05	5.82± 0.14	4.57± 0.05	23.33± 0.66	ND	BDL	ND	2.45± 0.06	0.25± 0.01	3.56± 0.25
3	***Vachellia nilotica***	**Stem**	0.48± 0.01	17.98± 0.31	56.12± 1.48	ND	3.66± 0.06	7.9± 0.16	21.06± 0.47	ND	BDL	ND	2.72± 0.04	1.13± 0.03	10.25± 1.5
		Leaf	0.5± 0.02	287.63± 7.3	136.67± 2.76	0.14± 0.01	7.59± 0.15	4.95± 0.12	104.04± 2	ND	BDL	ND	0.41± 0.01	0.86± 0.02	6.35± 0.02
4	***Senna siamea***	**Stem**	0.55± 0.02	164.15± 6.88	70.2± 6.25	2.07± 0.09	2.89± 0.07	4.34± 0.15	114.58± 1.22	ND	BDL	0.03± 0.04	3.58± 0.07	1.78± 0.13	12.35± 2.36
		Leaf	1.26± 0.05	86.46± 3.37	130.78± 44.39	1.3± 0.05	2.8± 0.07	4.56± 0.16	100.77± 4.34	0.07± 0.01	BDL	0.05± 0.01	2.08± 0.1	1.36± 0.12	8.98± 0.13
5	***Azadirachta indica***	**Stem**	0.36± 0.03	39.63± 2.47	59.91± 1.79	0.96± 0.03	2.65± 0.13	3.86± 0.1	45± 1.09	ND	BDL	0.02± 0.01	6.8± 0.17	2.62± 0.35	20.32± 3.1
		Leaf	0.83± 0.02	258.4± 4.84	81.83± 4.15	1.15± 0.03	8.83± 0.18	2.35± 0.04	150.75± 3.27	0.07± 0	BDL	ND	2.37± 0.05	1.85± 0.15	12.25± 1.25
6	***Dalbergia sissoo***	**Stem**	0.67± 0.13	48.53± 7.51	177.33± 25.15	1.11± 0.19	4.39± 0.67	10.77± 1.63	72.45± 10.84	ND	BDL	ND	0.97± 0.12	2.42± 0.16	15.3± 1.64
		Leaf	0.48± 0.01	407.28± 8.17	95.34± 3.78	5.24± 0.12	9.96± 0.26	10.16± 0.19	227.01± 5.21	ND	BDL	0.07± 0	0.72± 0.03	1.97± 0.31	11.2± 1.1
7	***Chromolena odorata***	**Stem**	0.59± 0.03	55.13± 2.04	172.82± 3.64	0.46± 0.04	16.24± 1.07	3.92± 0.3	47.59± 0.59	ND	BDL	ND	3.79± 0.16	3.2± 0.56	13.26± 1.24
		Leaf	1.64± 0	220.13± 0.63	588.44± 3.57	5.55± 0.05	17.45± 0.11	18.32± 0.15	111.01± 1.12	0.14± 0.01	BDL	ND	1.78± 0.03	2.5± 0.42	10.25± 1.2
		Flower	0.72± 0.04	67.86± 57.98	206.19± 1.42	1.14± 0.01	12.26± 0.15	7.36± 0.06	21.84± 0.42	ND	BDL	ND	2.73± 0.01	0.35± 0.31	2.24± 0.01

8	***Dendrocalamus sp.***	**Stem**	0.62± 0.09	31.81± 5.37	24.39± 1.3	0.05± 0.02	1.17± 0.12	16.02± 1.97	39.42± 6.77	ND	BDL	ND	3.58± 0.46	4.1± 0.26	12.3± 1.11
		Leaf	1.26± 0.07	42.04± 5.32	67.22± 2.58	0.62± 0.05	1.55± 0.07	2.63± 0.11	14.93± 0.84	0.07± 0.06	BDL	ND	1.41± 0.08	3.25± 0.12	6.35± 0.01
9	***Pennisetum glaucum***	**Root**	1.37± 0.06	129.1± 5.12	468.4± 20.67	2.17± 0.1	4.12± 0.18	3.3± 0.14	149.8± 6.26	ND	BDL	ND	1.17± 0.05	0.65± 0.02	10.45± 0.56
		Shoot	0.36± 0.02	154.94± 6.91	85.36± 4.51	0.36± 0.03	0.27± 0.02	0.81± 0.06	48.96± 3.14	ND	BDL	ND	1.74± 0.12	0.38± 0.03	8.54± 0.12
		Inflorescence	0.84± 0.06	120.11± 8	143.49± 8.69	0.21± 0.03	1.83± 0.14	4.43± 0.3	21.19± 1.73	ND	BDL	ND	3.66± 0.22	0.07± 0	1.64± 0.01
10	***Peltophorum pterocarpum***	**Stem**	0.49± 0.03	271.42± 11.02	175.82± 7.5	2.2± 0.09	6.18± 0.23	3.55± 0.15	88.36± 3.3	ND	BDL	ND	0.88± 0.04	0.26± 0.02	9.87± 0.41
		Leaf	1.31± 0.03	1105.12± 27.21	307.36± 7.39	1.91± 0.04	5± 0.12	2.94± 0.12	177.29± 3.56	0.05± 0.01	BDL	0.23± 0.01	9.08± 0.21	0.24± 0.01	6.47± 0.21
11	***Pennisetum glaucum***	**Root**	3.71± 0.28	30.89± 2.58	143.84± 11.86	1.13± 0.1	6.69± 0.56	4.43± 0.35	14.69± 1.33	0.28± 0.03	BDL	0.15± 0.02	6.52± 0.49	0.97± 0.03	13.65± 1.24
		Shoot	1.21± 0.07	39.53± 2.29	338.62± 80.94	0.02± 0.01	0.66± 0.04	2.07± 0.13	32.93± 1.82	0.05± 0.01	BDL	ND	0.71± 0.03	0.56± 0.02	7.56± 0.02
		Inflorescence	1.18± 0.02	169.57± 2.15	340.53± 2.55	0.26± 0.01	3.49± 0.04	5.11± 0.07	39.61± 0.27	0.31± 0.01	BDL	0.08± 0	7.02± 0.22	0.21± 0.02	2.41± 0.01
12	***Syzygium cumini***	**Stem**	2.04± 0.08	71.94± 3.05	35.8± 2.5	1.08± 0.05	4.19± 0.19	8.96± 0.41	30.96± 0.51	0.07± 0.01	BDL	ND	1.29± 0.05	2.21± 0.16	16.3± 1.64
		Leaf	0.83± 0.02	450.55± 12.41	143.79± 4.25	2.22± 0.08	8.82± 0.25	2.55± 0.06	29.21± 1.18	0.01± 0.01	BDL	ND	5.38± 0.09	2.02± 0.23	10.45± 0.85
13	***Holarrhena antidysenterica***	**Stem**	0.36± 0.01	38.05± 0.99	51± 0.37	ND	1.41± 0.04	4.78± 0.12	16.82± 0.16	ND	BDL	0.16± 0.01	3.25± 0.24	3.1± 0.32	18.54± 2.1
		Leaf	0.88± 0.03	370.19± 13.96	80.77± 8.32	0.97± 0.04	4.22± 0.17	5.18± 0.19	17.79± 1.17	0.11± 0.01	BDL	ND	1.65± 0.06	1.92± 0.12	11.35± 1.2
14	***Leucaena leucocephala***	**Stem**	0.33± 0.01	15.46± 0.1	307.88± 4.41	0.07± 0.01	2.09± 0.06	4.9± 0.07	51.12± 0.71	ND	BDL	0.09± 0	7.83± 0.31	3.1± 0.36	16.45± 1.1
		Leaf	1.29± 0.05	86.2± 3.71	283.29± 11.84	1.06± 0.05	2.9± 0.13	2.04± 0.09	18.9± 1.23	0.19± 0.01	BDL	ND	3.6± 0.18	2.42± 0.11	12.3± 0.85
		Pod	0.37± 0.04	40.35± 3.05	168.4± 12.82	0.93± 0.08	18.97± 1.45	3.94± 0.3	24.2± 2.38	ND	BDL	ND	0.86± 0.05	0.25± 0.01	3.2± 1.06

Note: BDL- Below detection limit
ND- Not detected

Table 12: Bioaccumulation of different trace and toxic metals in plant vegetation at site - V.

E.		**Site - V Check Dam - 3B**													
S.N	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**												
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Tectona grandis***	**Stem**	0.35±0.02	7.59±0.29	55.46±2.38	ND	0.22±0.02	7.22±0.22	11.22±0.43	ND	BDL	ND	0.87±0.05	2.1±0.35	17.5±1.64
		Leaf	0.9±0.03	29.54±0.94	169.36±5.98	0.08±0.01	2.07±0.07	4.34±0.13	21.74±0.97	0.09±0	BDL	ND	2.33±0.03	1.65±0.12	8.6±0.65
2	***Leucaena leucocephala***	**Stem**	0.37±0.01	2.63±0.01	66.53±1.1	ND	0.39±0	7.11±0.07	11.53±0.36	ND	BDL	ND	2.07±0.04	2.5±0.21	15.65±1.3
		Leaf	0.97±0.15	13.33±3	133.2±13.85	0.15±0.02	1.91±0.25	2.76±1.13	19.1±12.78	0.11±0.03	BDL	ND	1.93±0.31	1.85±0.33	10.35±1.1
		Pod	1.16±0.09	13.25±0.97	394.31±30.49	0.39±0.04	15.71±0.81	9.26±0.67	33.02±2.16	ND	BDL	ND	3.39±0.84	0.36±0.01	1.56±0.01
3	***Dalbergia sissoo***	**Stem**	0.31±0.01	5.15±0.16	46.69±1.4	0.02±0	2.1±0.07	7.38±0.22	12.66±0.22	0±0	BDL	ND	4.13±0.1	2.13±0.26	11.2±0.34
		Leaf	0.83±0.05	62.63±3.11	303.14±13.96	0.28±0.02	1.29±0.05	4.13±0.2	31.58±0.96	0.29±0.02	BDL	0.18±0.02	6.09±0.25	1.95±0.34	7.54±0.05
4	***Senna siamea***	**Stem**	0.49±0.02	10.44±0.56	83.69±4.08	0.03±0.01	1.25±0.06	7.62±0.38	16.65±0.65	ND	BDL	ND	3.94±0.2	1.29±0.02	14.56±1.28
		Leaf	0.73±0.03	21.04±0.63	164.24±4.2	0.07±0.01	0.76±0.03	3.34±0.11	13.73±0.6	0.1±0.01	BDL	ND	0.97±0.03	1.11±0.02	8.55±0.52
5	***Casuarina equisetifolia***	**Stem**	0.42±0.03	30.67±2.06	202.81±13.59	0.03±0.01	1.02±0.08	6.53±0.36	26.16±1.54	ND	BDL	ND	2.26±0.15	2.56±0.46	12.54±0.3
		Leaf	1.16±0.07	63.38±3.45	320.05±16.99	0.44±0.03	4.62±0.24	2.5±0.13	15.89±1.3	0.11±0.01	BDL	ND	1.77±0.07	2.1±0.42	6.54±0.31
6	***Ziziphus jujuba***	**Stem**	0.54±0.02	9.36±0.33	87.53±3.96	0.08±0.01	0.48±0.03	6.57±0.15	24.3±1.12	ND	BDL	0.34±0.02	6.88±0.7	1.12±0.03	10.26±0.16
		Leaf	0.53±0.02	13.23±0.37	106.44±4.28	0.01±0	1.09±0.05	3.54±0.11	8.28±0.55	ND	BDL	ND	3.5±0.12	0.98±0.02	7.65±0.28
		Fruit	0.63±0.01	4.22±0.06	46.77±1.4	ND	0.83±0.01	7.58±0.11	18.09±0.53	ND	BDL	0±0	2.66±0.03	0.21±0.01	2.12±0.03
7	***Azadirachta***	**Stem**	1.42±0.11	6.22±0.72	72.2±8.34	0.07±0.01	0.96±0.1	4.62±0.54	15.92±1.35	0.06±0.01	BDL	0.02±0	0.87±0.15	1.32±0.02	12.65±1.54

	indica	**Leaf**	1.02± 0.08	21.05± 5.29	101.51± 6.9	0.11± 0.01	0.61± 0.06	1.71± 0.13	9.75± 0.64	0.1± 0.01	BDL	0.01± 0	0.18± 0.01	1.12± 0.03	8.65± 0.24
8	***Chromolena odorata***	**Stem**	1.19± 0.06	11.51± 0.28	144.4± 2.45	0.1± 0	1.52± 0.1	3.87± 0.08	12.34± 0.19	0.05± 0	BDL	0.01± 0	0.26± 0.01	3.1± 0.32	17.65± 2.65
		Leaf	1.77± 0.1	52.48± 0.47	70.78± 2.93	0.6± 0.01	3.74± 0.01	15.15± 0.31	23.26± 0.41	0.21± 0.01	BDL	0.03± 0	0.33± 0.01	2.12± 0.2	11.2± 1.35
9	***Calotropis procera***	**Stem**	1.13± 0.19	24.95± 4.08	60.24± 10.41	0.37± 0.06	1.66± 0.27	8.34± 1.16	17.23± 1.97	0.07± 0.01	BDL	0.01± 0.01	0.14± 0.02	0.95± 0.02	9.65± 0.68
		Leaf	1.52± 0.12	123.6± 10.36	247.96± 19.83	0.52± 0.04	2.44± 0.18	3.99± 0.25	29.64± 1.56	0.13± 0.01	BDL	0.01± 0	0.07± 0	0.87± 0.25	6.32± 0.31
10	***Atylosia scarabaeoides***	**Stem**	2.82± 0.11	11.16± 0.3	218.37± 8.49	0.18± 0.01	2.77± 0.14	4.37± 0.08	40.55± 0.64	0.17± 0.02	BDL	0.06± 0.01	0.36± 0.02	0.86± 0.26	9.65± 0.86
		Leaf	2.79± 0.3	40.16± 4.38	396.37± 42.94	0.35± 0.03	2.25± 0.25	5.51± 0.53	22.41± 1.94	0.28± 0.03	BDL	0.02± 0	0.12± 0.01	0.56± 0.01	6.54± 0.23
11	***Pennisetum glaucum***	**Root**	4.42± 0.27	28.19± 1.78	1362.21± 96.65	0.58± 0.04	1.3± 0.09	4.3± 0.26	11.32± 0.56	0.53± 0.03	BDL	0.03± 0	0.19± 0.02	0.85± 0.04	10.32± 0.58
		Shoot	1.21± 0.1	57.81± 5.26	151.38± 13.46	1.93± 0.17	0.76± 0.07	2.18± 0.18	58.21± 4.02	0.08± 0.01	BDL	0.05± 0	2.05± 0.23	0.72± 0.02	9.65± 0.84
12	***Alternanthera sessilis***	**Root**	1.63± 0.3	22.8± 4.31	205.21± 37.16	0.31± 0.06	0.99± 0.19	4.02± 0.68	9.18± 1.34	0.14± 0.02	BDL	0.02± 0	0.37± 0.05	0.65± 0.02	11.65± 0.95
		Stem	1.82± 0.04	9.22± 0.06	149.98± 0.37	0.15± 0	0.43± 0	5.01± 0.08	8.68± 0.2	0.12± 0.01	BDL	0.03± 0	0.15±0	0.42± 0.01	8.65± 0.26
		Leaf	1.91± 0.03	97.69± 8.03	358.51± 5.74	0.75± 0.05	1.6± 0.02	1.77± 0.07	21.81± 0.7	0.26± 0.04	BDL	0.02± 0	0.15± 0.01	0.5± 0.01	6.32± 0.32
13	***Typha latifolia***	**Root**	2.18± 0.3	469.16± 66.21	5249.28± 678.04	0.88± 0.12	0.17± 0.04	0.88± 0.1	2.05± 0.25	5.02± 0.62	BDL	0.02± 0	0.07± 0.01	2.1± 0.32	16.3± 2.65
		Leaf	0.87± 0.11	211.93± 26.75	80.59± 8.93	0.12± 0.01	0.74± 0.09	1.09± 0.11	50.14± 4.21	0.07± 0	BDL	0.04± 0	0.17± 0.01	1.86± 0.36	10.36± 1.65
14	***Scoparia dulcis***	**Root**	0.7± 0.04	23.95± 1.58	120.95± 8.08	0.56± 0.03	1.17± 0.08	9.69± 0.6	19.11± 0.91	0.17± 0.01	BDL	0.03± 0	0.16± 0.01	0.95± 0.02	9.32± 0.98
		Stem	1.18± 0.12	107.92± 10.36	242.31± 21.49	1± 0.07	1.73± 0.13	4.83± 0.35	29.4± 1.33	0.13± 0.01	BDL	0.06± 0	2.32± 0.03	0.83± 0.02	7.65± 0.32
		Leaf	1.32± 0.11	83.72± 7.33	74.01± 6.79	1.56± 0.14	2.45± 0.2	4.18± 0.29	31.89± 2.27	0.11± 0.01	BDL	0.05± 0	0.57± 0.03	0.56± 0.01	5.64± 0.5

Note: BDL- Below detection limit; ND- Not detected

Table 13: Bioaccumulation of different trace and toxic metals in plant vegetation at site - VI.

F.		**Site - VI Reservoir Pond**													
S.N	***Plants***	**Parts**	**Metal concentration (mg kg^{-1} dw)**												
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Andrographis paniculata***	**Stem**	0.71± 0.05	37.74± 3	68.07± 4.8	0.22± 0.02	1.16± 0.08	11.9± 0.78	51.31± 3.92	0.04± 0	BDL	0.02± 0.01	0.07± 0.01	0.44± 0.03	6.36± 0.85
		Leaf	1.85± 0.26	61.96± 9.14	133.31± 19.67	0.47± 0.06	4.55± 0.59	10.62± 1.31	53.21± 6.8	0.16± 0.02	BDL	0.01± 0	0.19± 0.02	0.4± 0.02	4.21± 0.25
2	***Ficus benghalensis***	**Stem**	1.03± 0.05	56.13± 2.88	63.13± 2.81	0.53± 0.03	3.04± 0.14	7± 0.34	11.99± 0.47	0.04± 0	BDL	0.04± 0	0.2± 0.01	2.12± 0.32	16.54± 2.4
		Leaf	1.17± 0.07	47.29± 3.05	122.26± 7.84	0.13± 0.01	1.79± 0.11	3.32± 0.18	9.24± 0.52	0.11± 0.01	BDL	0.02± 0	0.16± 0.07	1.87± 0.18	10.26± 1.2
3	***Lantana camara***	**Stem**	1.15± 0.06	86.73± 4.64	368.82± 21.46	0.25± 0.01	0.94± 0.05	9.46± 0.46	25.99± 1.12	0.05± 0	BDL	0.11± 0	0.9± 0.02	1.65± 0.03	17.32± 2.65
		Leaf	2.06± 0.18	192.59± 16.21	349.53± 30.09	0.52± 0.05	4.51± 0.39	17.27± 1.41	27.59± 2.49	0.17± 0.02	BDL	0.03± 0	0.22± 0.02	1.36± 0.04	12.3± 2.32
4	***Leucaena leucocephala***	**Stem**	1.18± 0.12	12.02± 1.2	101.39± 10.04	0.12± 0.01	1.43± 0.14	9.21± 0.88	15.66± 1.51	0.04± 0	BDL	0.02± 0	1± 0.09	2.11± 0.26	12.65± 1.36
		Leaf	2.11± 0.19	79.22± 6.8	60.23± 5.38	0.78± 0.06	2.22± 0.18	6.8± 0.5	14.69± 0.81	0.22± 0.02	BDL	0.03± 0.01	0.26± 0.01	1.54± 0.12	8.54± 0.26

Note: BDL- Below detection limit

ND- Not detected

Plate 1: A-C: Different views showing collection of plant samples at selected sites.

Plate 2: A-B: Different views showing collection of water samples at different sites.

C: A View showing collection of plant samples at site-II of L-shape dam.

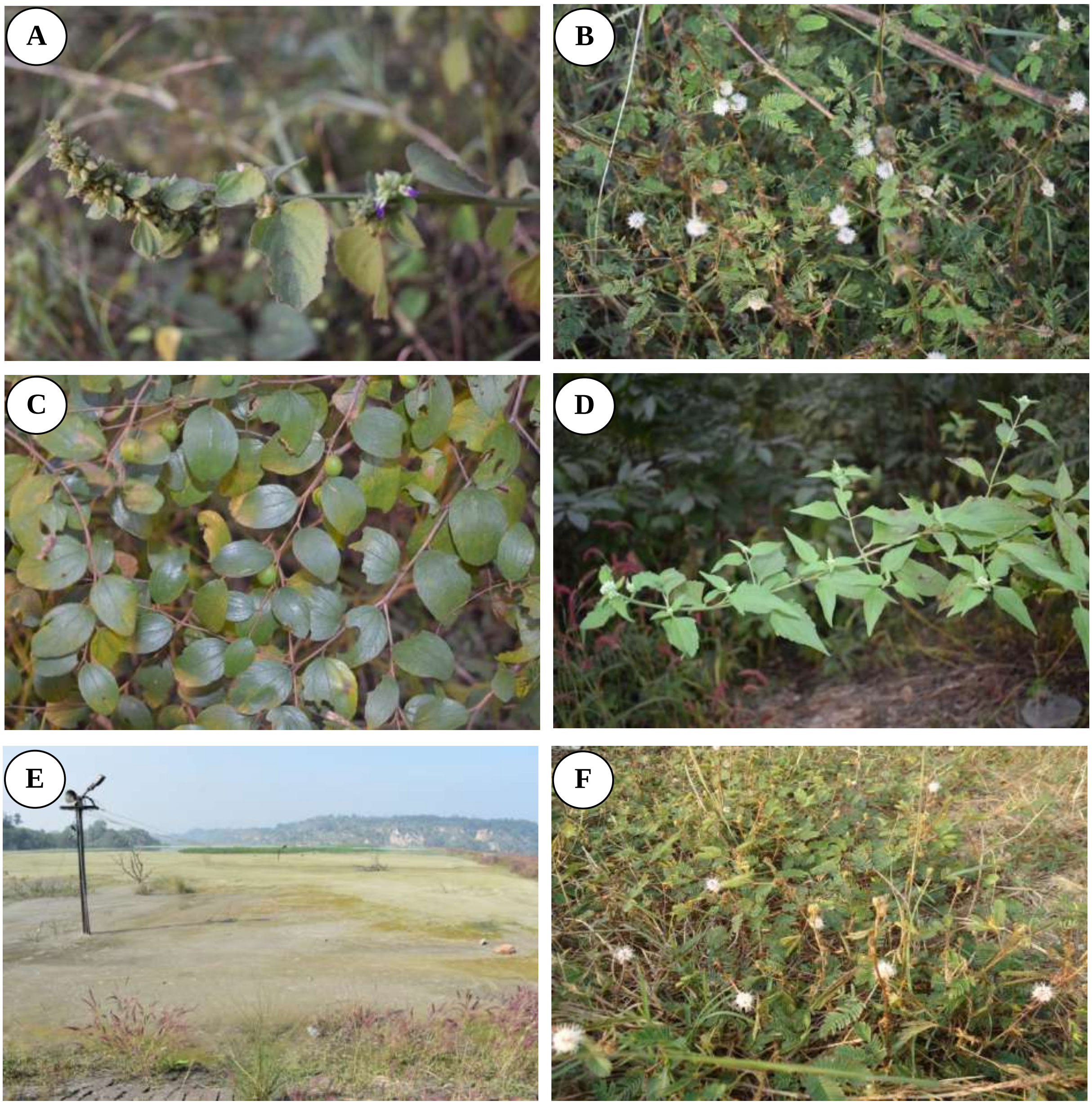

Plate 3: *Hyptis suaveolens* **(A),** *Mimosa pudica* **(B)** *Ziziphus nummularia* **(C)** *Eupatorium adenophorum* **(D)** *Mimosa pudica* **(F);** A view of site location of L- shape dam at Talcher, district Angul, Odisha **(E).**

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6.3. Concentration of different trace and toxic metals in the water samples

The concentrations of all heavy metals such as Cd, Co, Cr, Cu, F, Fe, Mn, Ni and Zn were within the permissible limit as per BIS standard. **It needs to be mentioned that Hg was not detected in any of the samples.**

Table 14: Level of heavy metals in water samples.

Sites	Concentration of metals (μg l^{-1})										
	Cr	**Mn**	**Fe**	**Ba**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**
Site I surface	4.10± 0.02	76.22± 2.42	240.31± 9.25	23.2± 1.22	0.51± 0.02	5.22± 0.02	2.95± 0.03	17.44± 2.02	1.55± 0.01	BDL	Nd	0.25± 0.01
Site I Piezometer	1.58± 0.02	70.44± 3.13	272.11± 12.23	25.11± 2.26	0.93± 0.03	7.03± 0.02	6.40± 0.02	18.34± 3.15	0.92± 0.01	BDL	0.01± 0	0.08± 0
Site I surface	1.85± 0.04	98.43± 2.35	495.22± 20.21	19.31± 2.22	0.87± 0.02	1.84± 0.02	3.15± 0.02	23.15± 1.23	1.95± 0.02	BDL	0.01± 0	0.06± 0.01
Site II surface	3.21± 0.21	94.73± 2.11	1550.56± 4.12	16.52± 1.44	0.28± 0.01	6.56± 0.01	9.25± 0.03	65.29± 4.43	2.36± 0.01	BDL	Nd	0.09± 0.02
Site III surface	2.78± 0.02	21.27± 1.42	462.73± 13.15	14.51± 1.17	0.15± 0	2.66± 0.03	8.08± 0.02	29.14± 0.52	1.23± 0.02	BDL	0.04± 0	1.09± 0.02
Site IV surface	1.93± 0.01	78.50± 4.32	1160.31± 6.44	14.14± 1.26	0.22± 0.01	6.30± 0.02	3.80± 0.01	14.25± 0.03	2.12± 0.01	BDL	0.01± 0	0.08± 0.02
Site V Piezometer	1.76± 0.01	270.21± 5.35	756.55± 6.18	22.12± 1.52	1.57± 0.02	3.96± 0.01	4.72± 0.02	125.15± 12.25	1.38± 0.23	BDL	0.01± 0	0.35± 0.04
Site V surface	2.26± 0.02	39.66± 0.26	491.65± 13.16	25.21± 4.11	0. 95± 0.01	4.52± 0.02	3.12± 0.01	14.12± 0.03	1.94± 0.05	BDL	Nd	0.24± 0.01
Site V surface	1.28± 0.01	18.50± 2.24	465.71± 6.51	20.71± 1.77	0.45± 0.1	3.33± 0.02	6.39± 0.04	28.41± 4.22	0.85± 0.02	BDL	0.02± 0	0.22± 0
Site VI surface	1.85± 0.25	105.41± 4.35	490.28± 8.62	21.14± 2.72	0.01± 0	0.92± 0.01	0.16± 0	1.45± 0	0.02± 0	BDL	Nd	0.08± 0

Note: BDL- Below detection limit

ND- Not detected

6.4 Bioaccumulation of different trace and toxic metals in plant vegetation

In continuation of the second tour, a third tour visited with scientist of NBRI, Tech Officer and research scholars at Talcher thermal power plant on April, 2019. Plants vegetation growing around the identified sites (site I-site VI) and samples were collected. Stem and leaves of the collected plant samples were acid digested and then analysed by inductively coupled plasma mass spectrometry (ICP-MS) Table 15 and 20.

Chromium (Cr)

The concentration of chromium ranged between 0.14 - 2.88 mg kg^{-1}. The maximum accumulation of Cr was found in the root of *Typha latifolia* (2.88 mg kg^{-1}) at site I (Table 15). Permissible limit of Cr by (WHO-1.30 mg kg^{-1}) for the plant.

Manganese (Mn)

The accumulation level of Mn ranged between 3.12-2429 mg kg^{-1}). Maximum accumulation was found in shoot of *Typha latifolia* (2429 mg kg^{-1}) at site I (Table 15).

Iron (Fe)

Plants only need a tiny amount of Iron to be healthy, but that small amount is crucial. The level of Fe was found from 16.54-5573 mg kg-^{1}, highest accumulation of Fe was found in the root of *Typha latifolia* (5573 mg kg^{-1}) at site I (Table 15).

Cobalt (Co)

Cobalt is a trace element in plants. Maximum concentration of cobalt was found in flower of *Holarrhena antidysenterica* (12.99 mg kg^{-1}) at site I (Table 15).

Nickel (Ni)

It is an essential micro-element essential for plant. The accumulation level of nickel was found between 0.11- 12.59 mg kg-1. The maximum bioaccumulation of Ni was found in the root of *Typha latifolia* (12.59 mg kg^{-1}) followed by leaves of *Hyptis suaveolens* (9.99 mg kg^{-1}) at site VI and III (Table 20 and 17) respectively. Ni accumulation in most of the plant species was within the permissible limit of WHO- 10 mg kg-^{1}.

Zinc (Zn)

Zinc is an essential micronutrient required by plants in small quantities. The Zinc concentration ranged between (0.45-103 mg kg^{-1}). Maximum Zn concentration was found in the leaves of *Hyptis suaveolens* (103 mg kg^{-1}) at site III (Table 17). It was found below the permissible limit according to WHO.

Arsenic (As)

The accumulation level of Arsenic was 0.01-22.63 mg kg^{-1}. *Pteris vittata* is a hyper accumulator of Arsenic. Highest accumulation of Arsenic was found in the leaves and root of *Pteris vittata* (22.63 and 14.66 mg kg^{-1}) at site I (Table 15) respectively.

Mercury (Hg)

It is to be noted that Hg was below detection limit in all plant samples.

Cadmium (Cd)

Cadmium is a toxic element for plant. The concentration of cadmium ranged from 0.00 - 0.20 mg kg^{-1} dry weight. Maximum concentration of cadmium was found in the flower of *Holarrhena antidysenterica* (0.20 mg kg^{-1}) at site I (Table 15).

Lead (Pb)

The accumulation level of Pb in the stem and leaves in most of the plant species were found within the permissible limit. The concentration of lead ranged between 0.00-9.38 mg kg^{-1}. Maximum accumulation of Pb was found in flower of *Holarrhena antidysenterica* (Kurchi) (9.38 mg kg^{-1}) at site I (Table 15).

Fluoride (F)

The level of fluoride concentration was found from 0.12-3.1 mg kg-^{1}. Maximum concentration was found in the stem of *Lantana camara* and root of *Hyptis suaveolens* (3.1 mg kg^{-1}) at site II (Table 16).

Barium (Ba)

Barium concentration ranged was found between 1.21 - 18.63 mg kg^{-1}. Maximum concentration was found in the stem of *Syzygium cumini* (18.63 mg kg^{-1}) at site IV (Table 18).

Table 15: Bioaccumulation of different trace and toxic metals in plant vegetation at site – I.

A		Site - I Check Dam Mine Void - 02												
S. No.	Plants	Plant parts	Metal concentration (mg kg^{-1} dw)											
			Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Hg	Cd	Pb	F	Ba
1	*Ziziphus nummularia*	Stem	1.02± 0.14	30.76± 4.52	50.69± 7.1	0.16± 0.02	1.82± 0.31	3.13± 0.3	7.64± 1.16	0.03± 0.01	BDL	0.02± 0	0.14± 0.03	1.52± 0.08	16.23± 2.32
		Leaf	0.76± 0.09	130.66± 14.48	105.74± 3.08	0.28± 0.03	2.54± 0.72	2.2± 0.23	25.54± 2.85	0.06± 0.01	BDL	0.01± 0	0.07± 0.01	1.12± 0.12	10.23± 1.25
2	*Albizia lebbeck*	Stem	1.27± 0.1	25.14± 2.13	106.73± 9.4	0.19± 0.01	1.92± 0.02	4.66± 0.46	42.37± 4.31	0.07± 0.01	BDL	0.01± 0	0.21± 0.01	0.48± 0.03	12.12± 1.23
		Leaf	0.7± 0.07	20.9± 2.11	78.71± 7.6	0.08± 0.01	0.62± 0.06	1.54± 0.14	33.83± 3.07	0.06± 0.01	BDL	0.01± 0	0.1± 0.01	0.25± 0.01	8.6± 1.36
3	*Holarrhena antidysenterica*	Stem	0.65± 0.08	6.18± 0.67	70.46± 8.82	0.04± 0	0.75± 0.09	2.4± 0.3	5.09± 0.55	0.06± 0.01	BDL	0.01± 0.01	0.06± 0.01	2.12± 0.35	13.65± 0.36
		Leaf	1.3± 0.07	147.89± 7.74	114± 5.68	0.23± 0.01	2.12± 0.1	3.73± 0.16	12.12± 0.52	0.13± 0	BDL	0.01± 0	0.11± 0	1.42± 0.08	8.36± 0.45
		Flower	1.22± 0.02	398.68± 17.1	92.35± 3.42	12.99± 0.38	5.51± 0.2	3.92± 0.15	27.53± 1.58	0.05± 0	BDL	0.2± 0.03	9.38± 1.58	0.56± 0.02	1.53± 0.02
4	*Syzygium cumini*	Stem	0.77± 0.08	11.94± 1.13	236.65± 27.31	0.09± 0	2.19± 0.14	4.96± 0.51	6.59± 0.36	0.04± 0	BDL	0.01± 0	1.26± 0.11	2.11± 0.65	17.32± 1.25
		Leaf	0.89± 0.05	62.6± 3.26	88.8± 5.09	0.08± 0.01	1.96± 0.11	1.82± 0.09	5.37± 0.48	0.05± 0	BDL	0.02± 0	0.16± 0.03	1.84± 0.07	11.23± 0.06
5	*Semecarpus anacardium*	Stem	0.94± 0.05	186.83± 11.03	170.61± 9.32	0.27± 0.02	0.99± 0.07	9.21± 0.54	19.97± 1.23	0.06± 0	BDL	0.02± 0	0.39± 0.03	0.86± 0.23	8.54± 0.03
		Leaf	1.33± 0.11	1522.09± 117.76	104.42± 7.95	0.53± 0.04	4.94± 0.34	2.83± 0.19	47.48± 3.75	0.16± 0.01	BDL	0.04± 0	0.19± 0.02	0.74± 0.21	6.32± 0.02
6	*Chromolena odorata*	Stem	1.35± 0.01	9.08± 0.18	76.25± 0.29	0.09± 0	0.78± 0	4.19± 0.02	21.51± 0.2	0.13± 0	BDL	0.01± 0	0.14± 0.01	2.8± 0.02	15.56± 1.65
		Leaf	1.66± 0.16	45.73± 4.54	266.16± 26.48	0.41± 0.04	1.87± 0.18	6.15± 0.61	18.96± 1.76	0.38± 0.04	BDL	0.01± 0	0.29± 0.02	1.82± 0.02	8.75± 0.03
7	*Typha latifolia*	Root	2.88± 0.24	125.57± 11.73	5573.49± 430.45	0.35± 0.03	0.11± 0.02	2.55± 0.19	10.06± 0.77	1.54± 0.14	BDL	0.01± 0	0.08± 0.01	1.2± 0.03	9.54± 0.03
		Shoot	0.89± 0.04	2429.93± 144.69	140.32± 5.9	1.22± 0.05	1.09± 0.06	2.66± 0.12	11.68± 1.17	0.08± 0	BDL	0.01± 0.01	0.04± 0.01	0.88± 0.06	7.65± 0.05

8	***Pteris vittata***	**Root**	2.59± 0.2	26.8± 1.4	356.23± 22.3	1.22± 0.05	0.81± 0.07	5.63± 0.13	8.07± 0.29	14.66± 0.31	BDL	0.01± 0	0.07± 0.05	0.76± 0.04	10.23± 0.12
		Stem	1.78± 0.15	24.88± 3.88	299.47± 10.61	9.64± 0.3	0.82± 0.06	4.86± 0.56	20.2± 1.98	4.64± 0.36	BDL	0.04± 0	3.96± 0.36	0.25± 0.03	8.65± 0.36
		Leaf	1.09± 0.07	51.18± 1.68	92.5± 1.74	0.46± 0	1.06± 0.3	3.95± 0.12	11.53± 0.66	22.63± 0.56	BDL	0.02± 0	0.19± 0	0.56± 0.02	6.25± 0.25
9	***Alternanthera paronychioides***	**Stem**	1.25± 0.23	20.05± 3.79	183.78± 34.48	0.31± 0.05	1.23± 0.19	1.59± 0.27	20.43± 3.47	1.1± 0.2	BDL	0.02± 0	0.11± 0.01	1.26± 0.06	9.67± 0.56
		Leaf	1.65± 0.17	129.33± 14.54	343.57± 35.88	0.77± 0.08	2.43± 0.22	3.3± 0.3	25.04± 2.12	1.31± 0.12	BDL	0.18± 0.01	0.87± 0.03	0.76± 0.04	7.54± 0.54
		Flower	1.01± 0.08	59.67± 4.9	70.63± 5.51	0.64± 0.05	2.8± 0.23	2.97± 0.22	27.61± 2	0.99± 0.07	BDL	0.05± 0.01	0.19± 0.02	0.12± 0.02	2.3± 0.02
10	***Ageratum houstonianum***	**Stem**	1.04± 0.06	37.44± 2.48	121.54± 7.23	0.14± 0.01	1.14± 0.08	10.79± 0.54	18.08± 1.02	0.08± 0.01	BDL	0.04± 0.01	0.11± 0.01	0.96± 0.2	8.79± 0.23
		Leaf	2.55± 0.26	96.15± 10.6	62.33± 6.9	0.65± 0.06	2.38± 0.23	8.31± 0.77	24.1± 2.32	0.13± 0.01	BDL	0.14± 0.01	0.07± 0	0.66± 0.32	6.56± 0.21
		Flower	1.4± 0.02	87.22± 1.86	16.54± 0.57	0.64± 0.01	2.13± 0.03	8.34± 0.32	29.76± 0.53	0.2± 0	BDL	0.07± 0	0.05± 0	0.23± 0.18	2.21± 0.25
11	***Mimosa pudica***	**Root**	0.85± 0.08	10.15± 0.91	256.24± 22.88	0.14± 0.01	0.62± 0.06	6.68± 0.71	17.2± 1.44	0.12± 0.01	BDL	0.02± 0	0.15± 0.03	1.3± 0.03	12.34± 1.23
		Stem	0.85± 0.06	24.38± 1.54	110.11± 6.77	0.29± 0.01	1.69± 0.11	4.28± 0.28	21.42± 1.25	0.1± 0	BDL	0.01± 0	0.37± 0.02	1.1± 0.12	10.26± 1.21
		Leaf	0.91± 0.02	52.38± 0.72	219.63± 3.39	0.3± 0	3.3± 0.05	6.15± 0.09	24.11± 0.37	0.22± 0	BDL	0.01± 0	0.16± 0	0.72± 0.1	8.46± 0.21
12	***Tridax procumbens***	**Stem**	1.05± 0.07	61.04± 3.95	177.26± 11.25	0.12± 0.01	2.75± 0.14	3.78± 0.18	15.58± 0.8	0.12± 0.01	BDL	0.02± 0	0.08± 0.01	1.2± 0.02	12.3± 1.24
		Leaf	1.87± 0.17	132.15± 12.67	107.85± 9.97	0.38± 0.03	3.42± 0.3	6.08± 0.51	29.26± 2.38	0.28± 0.02	BDL	0.06± 0	0.08± 0	0.88± 0.45	7.85± 0.45
		Flower	2.26± 0.27	67.91± 8.34	164.44± 19.37	0.25± 0.03	7.42± 0.8	9.62± 1.1	24.88± 2.66	0.49± 0.06	BDL	0.01± 0	0.27± 0.02	0.24± 0.05	2.56± 0.54
13	***Vachellia nilotica***	**Stem**	0.87± 0.04	8.88± 0.45	53.99± 3.37	0.1± 0	1.04± 0.05	6.6± 0.3	7.44± 0.28	0.03± 0	BDL	0.04± 0	4.14± 0.11	1.18± 0.02	15.65± 1.24
		Leaf	0.83± 0.04	89.09± 4.4	83.94± 4.34	0.08± 0	1.37± 0.08	3.9± 0.19	9.03± 0.45	0.07± 0	BDL	0.02± 0	0.22± 0.02	0.73± 0.03	11.23± 1.69

Note: BDL- Below detection limit
ND- Not detected

Table 16: Bioaccumulation of different trace and toxic metals in plant vegetation at site – II.

B		Site - II - L - Shape Dam (Frist Position)													
S.N	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**												
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Hyptis suaveolens***	**Root**	0.38± 0.02	16.52± 0.57	68.22± 2.08	1.37± 0.04	1± 0.03	9.5± 0.19	11.55± 0.79	1± 0.04	BDL	0.01± 0	0.06± 0	3.1± 1.2	18.65± 2.32
		Stem	0.04± 0.01	5.33± 0.95	37.99± 4.61	0.22± 0.03	0.55± 0.09	6.54± 0.78	9.45± 1.54	0.22± 0.04	BDL	ND	0.26± 0.02	1.61± 0.52	10.23± 1.65
		Leaf	2.25± 0.02	9.75± 1.4	189.92± 34.17	0.36± 0.05	0.58± 0.07	3.67± 0.47	5.06± 0.79	0.29± 0.05	BDL	ND	0.04± 0	1.23± 0.32	12.35± 1.32
		Inflorescence	0.45± 0.04	8.19± 0.45	62.87± 3.23	0.46± 0.02	0.8± 0.04	6.16± 0.35	14.51± 0.74	0.35± 0.02	BDL	ND	0.02± 0	0.22± 0.03	1.5± 0.01
2	***Leucaena leucocephala***	**Stem**	0.21± 0.04	10.42± 0.7	145.51± 6.88	0.14± 0.01	0.51± 0.03	5.1± 0.14	9.48± 0.31	0.1± 0.01	BDL	ND	0.1± 0.01	1.15± 0.05	12.45± 1.78
		Leaf	0.93± 0.16	29.17± 3.43	54.9± 2.82	1.02± 0.09	1.65± 0.14	2.67± 0.26	5.19± 0.28	0.75± 0.12	BDL	0.01± 0	0.02± 0	0.64± 0.06	8.54± 0.23
3	***Chromolena odorata***	**Stem**	0.44± 0.03	16.63± 0.74	34.86± 0.98	0.41± 0.01	1.69± 0.05	1.51± 0.07	5.17± 0.26	0.48± 0.02	BDL	0.02± 0	0.01± 0	2.53± 0.32	16.35± 0.3
		Leaf	1.58± 0.14	27.28± 2.36	332.75± 8.41	0.66± 0.03	1.49± 0.08	2.1± 0.1	5.16± 0.31	1.04± 0.07	BDL	0.01± 0	0.01± 0.01	1.74± 0.45	8.65± 0.36
4	***Prosopis juliflora***	**Stem**	0.35± 0.07	7.29± 0.64	58.08± 4.29	0.07± 0.01	0.49± 0.05	5.38± 0.38	6.37± 0.57	0.07± 0.01	BDL	ND	0.04± 0.02	0.96± 0.03	9.65± 0.54
		Leaf	0.9± 0.12	67.62± 6.67	153.24± 16.16	0.28± 0.03	1.54± 0.15	4.39± 0.42	10.17± 0.95	0.39± 0.04	BDL	ND	0.03± 0	0.66± 0.02	5.45± 0.36
5	***Phyllanthus amarus***	**Stem**	0.31± 0.03	18.53± 1.6	67.16± 5.5	0.3± 0.03	0.31± 0.03	7.59± 0.45	22.81± 1.11	0.21± 0.03	BDL	ND	0.02± 0	0.44± 0.02	6.32± 0.21
		Leaf	1.17± 0.1	235.1± 10.6	132.79± 6.94	0.72± 0.03	2.12± 0.09	3.1± 0.12	15.98± 0.61	0.64± 0.04	BDL	ND	0.03± 0	0.33± 0.01	4.23± 0.02
		Fruit	0.59± 0.07	64.32± 3.39	39.8± 3.43	0.36± 0.02	4.83± 0.18	7.45± 0.41	13.62± 0.63	0.3± 0.03	BDL	0.01± 0	0.04± 0	0.12± 0.01	1.25± 0.01
6	***Ziziphus nummularia***	**Stem**	0.4± 0.06	12.2± 0.37	76.67± 5.85	0.15± 0.01	0.5± 0.03	5.43± 0.06	15.38± 1	0.17± 0.01	BDL	ND	0.03± 0.01	1.6± 0.01	16.26± 1.36
		Leaf	1.58± 0.04	16.83± 1.1	213.47± 42.83	0.18± 0.03	0.79± 0.14	2.6± 0.45	6.87± 1	0.16± 0.03	BDL	ND	0.03± 0	0.98± 0.02	9.35± 0.02

7	***Syzygium cumini***	**Stem**	0.46± 0.08	13.09± 1.05	33.82± 4.85	0.29± 0.03	4.7± 0.39	5.75± 0.21	5.96± 0.35	0.23± 0.02	BDL	0.01± 0	0.1± 0.01	2.12± 0.15	20.21± 0.05
		Leaf	1± 0.06	222.78± 26.16	229.65± 32.82	0.73± 0.06	1.54± 0.06	2.86± 0.05	13.92± 0.14	0.67± 0.01	BDL	ND	0.02± 0	1.72± 0.16	11.54± 0.05
8	***Azadirachta indica***	**Stem**	0.42± 0.05	14.71± 0.54	62.59± 4.05	0.31± 0.02	3.26± 0.11	3.36± 0.14	10.54± 0.57	0.56± 0.03	BDL	0.01± 0	0.01± 0.01	1.8± 0.65	14.56± 1.87
		Leaf	1.42± 0.16	27.19± 1.87	241.65± 15.31	0.73± 0.05	1.46± 0.09	7.24± 0.17	16.85± 0.84	0.58± 0.04	BDL	ND	0.06± 0.01	1.2± 0.26	7.54± 1.78
9	***Lantana camara***	**Stem**	0.29± 0.03	17.44± 0.84	60.51± 2.32	0.29± 0.01	0.74± 0.04	7.72± 0.27	9.45± 0.43	0.22± 0.01	BDL	0.01± 0.01	0.25± 0.03	3.1± 0.21	12.25± 1.65
		Leaf	1.95± 0.15	112.68± 6.34	344.76± 16.88	0.4± 0.02	1.76± 0.1	6.51± 0.36	8.77± 0.45	0.7± 0.04	BDL	ND	0.04± 0.01	2.6± 0.32	7.23± 0.02
		Fruit	0.7± 0.02	103.39± 4.22	118.29± 3.89	0.65± 0.03	6.24± 0.25	8.84± 0.41	17.55± 0.64	0.72± 0.02	BDL	0.01± 0	0.04± 0.01	0.23± 0.02	2.12± 0.01
10	***Vachellia nilotica***	**Stem**	0.6± 0.03	11.43± 0.24	76.67± 2.09	0.15± 0	1.6± 0.03	6.81± 0.17	18.59± 0.72	0.22± 0.02	BDL	0.01± 0	0.05± 0.01	0.66± 0.03	13.65± 1.31
		Leaf	2.37± 0.09	120.76± 5.64	408.27± 18.35	0.42± 0.03	2.51± 0.11	8.46± 0.39	24.15± 0.74	0.5± 0.03	BDL	0.01± 0	0.05± 0.01	0.4± 0.01	8.74± 1.31
		Fruit	1.03± 0.06	17.47± 0.78	100.79± 4.48	0.17± 0.01	3.81± 0.06	3.49± 0.1	5.25± 0.11	0.15± 0.01	BDL	ND	0.04± 0	0.14± 0.01	1.23± 0.01
11	***Mimosa pudica***	**Stem**	0.71± 0.07	9± 0.82	132.59± 6.12	0.39± 0.02	0.63± 0.03	1.9± 0.11	16.42± 0.77	0.39± 0.03	BDL	ND	0.07± 0	1.23± 0.06	11.1± 1.25
		Leaf	0.87± 0.07	27.08± 1.55	130.35± 5.17	0.26± 0.01	1.49± 0.04	2.8± 0.13	11.29± 0.43	0.3± 0.01	BDL	ND	0.03± 0.01	0.88± 0.05	7.56± 0.32
12	***Cassia fistula***	**Stem**	1.77± 0.29	33.28± 2.75	35.6± 4.68	0.23± 0.02	1.04± 0.1	6.47± 0.24	13.02± 1.39	0.39± 0.05	BDL	0.01±0	0.03± 0.01	1.32± 0.04	13.26± 1.56
		Leaf	0.71± 0.09	86.43± 6.55	74.78± 7.49	2.33± 0.2	1.97± 0.18	1.72± 0.2	5.86± 0.56	1.76± 0.14	BDL	ND	0.06± 0.01	0.76± 0.02	9.65± 0.36
		Fruit	0.99± 0.08	66.36± 3.87	182.52± 10.5	2.15± 0.1	4.45± 0.11	4.39± 0.15	15.93± 0.29	1.89± 0.05	BDL	0.03± 0	0.43± 0.01	0.2± 0.02	3.15± 1.23
13	***Calotropis procera***	**Stem**	1.4± 0.06	32.19± 4.52	70.65± 3.94	0.61± 0.11	2.9± 0.12	7.45± 0.41	9.22± 0.56	0.42± 0.09	BDL	ND	0.03± 0	0.55± 0.12	8.64± 0.65
		Leaf	1.52± 0.09	86.05± 2.61	179.86± 8.29	0.75± 0.03	1.72± 0.07	2.54± 0.1	7.35± 0.22	0.54± 0.03	BDL	ND	0.03± 0	0.45± 0.12	6.36± 0.12

		Fruit	1.1± 0.11	34.92± 3.36	159.97± 15.41	0.15± 0.01	0.61± 0.06	3.64± 0.22	1.97± 0.13	0.12± 0.01	BDL	ND	0.02± 0	0.18± 0.01	2.54± 0.02
14	***Tridax procumbens***	**Stem**	1.39± 0.12	3.83± 0.18	131.68± 1.22	0.14± 0	0.92± 0.02	3.41± 0.14	8.2± 0.45	0.12± 0.01	BDL	ND	0.04± 0	1.7± 0.18	10.25± 0.21
		Leaf	2.63± 0.38	9.82± 1.39	489± 61.69	0.1± 0.01	0.21± 0.03	4.07± 0.52	5.21± 0.47	0.16± 0.03	BDL	ND	0.02± 0	1.11± 0.05	6.52± 0.25
		Fruit	2.21± 0.12	12.41± 0.32	251.47± 6.91	0.35± 0.01	4.53± 0.1	7.56± 0.19	16.76± 0.5	0.29± 0.01	BDL	ND	0.11± 0	0.23± 0.01	1.32± 0.01
15	***Euphorbia prostrata***	**Root**	1.04± 0.03	13.85± 0.6	176.16± 3.32	0.35± 0.01	2.25± 0.07	3.3± 0.15	15.23± 0.62	0.36± 0.02	BDL	0.04± 0	0.07± 0.05	1.6± 0.25	6.41± 0.02
		Stem	2.32± 0.23	39.53± 7.04	431.87± 71.52	0.64± 0.09	4.84± 0.75	3.73± 0.68	26.46± 0.17	0.55± 0.08	BDL	0.01± 0	0.06± 0.01	1.12± 0.36	4.36± 0.01
		Leaf	1.36± 0.11	23.01± 0.88	254.49± 10.55	0.48± 0.02	4.3± 0.26	1.65± 0.07	18.89± 0.48	0.51± 0.03	BDL	0.01± 0	0.14± 0.01	0.75± 0.02	3.14± 0.03
16	***Solanum nigrum***	**Stem**	1.71± 0.08	31.16± 2.41	491.49± 40.1	1.01± 0.06	1.84± 0.19	4.35± 0.29	47.14± 3	0.87± 0.06	BDL	0.01± 0	0.02± 0	0.76± 0.01	9.69± 0.25
		Leaf	0.97± 0.15	10.18± 1.16	3.68± 2.69	0.28± 0.03	1.7± 0.1	3.1± 0.37	2.91± 2.39	0.39± 0.04	BDL	ND	0.07± 0.1	0.44± 0.05	7.32± 0.12
		Fruit	1.4± 0.5	22.45± 4.05	293.65± 59.99	0.41± 0.09	3.75± 0.48	11.49± 3.09	29.37± 7.16	0.68± 0.16	BDL	0.05± 0.01	1.24± 0.26	0.16± 0.06	2.1± 0.01

Note: BDL- Below detection limit

ND- Not detected

Table 17: Bioaccumulation of different trace and toxic metals in plant vegetation at site – III.

C		Site - III - L - Shape Dam (Second Position)													
S.N	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**												
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Azadirachta indica***	**Stem**	0.62± 0	7.48± 1.43	220.16± 20.81	0.28± 0.03	3.13± 0.03	12.76± 0.05	12.71± 0.04	0.27± 0.03	BDL	ND	0.06± 0.05	2.13± 0.32	18.3± 1.56
		Leaf	0.84± 0.03	38.63± 0.7	213.47± 9.75	0.29± 0.01	2.57± 0.06	5.39± 0.08	12.87± 0.3	0.9± 0.02	BDL	0.01± 0	0.04± 0.05	1.54± 0.12	12.21± 1.26
2	***Vachellia nilotica***	**Stem**	1.25± 0.15	13.18± 1.69	84.67± 6.93	0.15± 0.01	2.06± 0.17	8.82± 0.55	18.92± 0.89	0.67± 0.04	BDL	0.05± 0.01	1.36± 0.09	0.95± 0.23	12.36± 1.23
		Leaf	1.22± 0.17	67.52± 6.29	92.18± 8.37	0.22± 0.02	4.95± 0.34	5.74± 0.47	25.42± 2.52	0.52± 0.06	BDL	0.01± 0	0.02± 0.02	0.56± 0.06	9.64± 0.56
		Fruit	1.16± 0.08	62.87± 3.14	298.08± 4.75	0.4± 0.02	13.04± 0.45	6.35± 0.16	19.82± 0.54	0.75± 0.02	BDL	0.03± 0	0.55± 0.02	0.22± 0.05	1.32± 0.01
3	***Hyptis suaveolens***	**Root**	0.89± 0.03	195.36± 1.98	162.78± 4.98	5.48± 0.09	3.26± 0.07	24.16± 0.41	22.57± 0.22	6.2± 0.13	BDL	0.07± 0	0.42± 0.01	2.76± 0.02	16.46± 1.54
		Stem	1.08± 0.06	385.56± 18.98	57.04± 1.6	5.55± 0.21	2.04± 0.06	10.08± 0.42	30.52± 1.36	6.24± 0.24	BDL	0.05± 0	0.26± 0.02	1.74± 0.06	10.36± 1.26
		Leaf	2.62± 0.04	210.72± 11.72	236.92± 18.71	4.88± 0.3	9.99± 0.53	8.86± 0.56	103.98± 4.65	6.25± 0.31	BDL	0.04± 0	0.06± 0.01	1.11± 0.04	8.63± 0.05
		Inflorescence	0.26± 0.07	26.57± 5.91	29.37± 6.54	0.93± 0.22	1.37± 0.3	1.85± 0.43	20.1± 3.47	1± 0.11	BDL	0.01± 0	0.01± 0	0.17± 0.01	2.3± 0.01
4	***Ficus benghalensis***	**Leaf**	1.52± 0.35.10	55.20± 1.78	210± 0.49	0.30± 0.01	0.70± 0.04	1.53± 0.03	25.10± 0.06	0.25± 0.04	BDL	0.01± 0	1.52± 0.23	1.23± 0.01	9.78± 0.09
5	***Acacia auriculiformis***	**Stem**	1.01± 0.04	8.09± 2.45	58.87± 27.88	0.18± 0.01	4.99± 2.35	8.25± 3.52	14.22± 5.14	1.17± 0.06	BDL	0.03± 0.02	0.84± 0.04	1.86± 0.12	12.34± 1.25
		Leaf	0.75± 0.08	18.45± 15.77	63.47± 54.27	0.25± 0.23	3.44± 2.96	2.25± 2	4.18± 3.59	0.82± 0.06	BDL	0.02± 0.03	0.13± 0.14	1.21± 0.25	8.67± 0.98
6	***Artocarpus heterophyllus***	**Stem**	1.05± 0.05	47.57± 2.77	62.75± 3.3	5.55± 0.1	3.32± 0.07	5.99± 0.15	21.1± 0.56	5.69± 0.15	BDL	0.04± 0	0.13± 0.01	0.44± 0.32	10.34± 0.98
		Leaf	0.96± 0.32	386.12± 139.69	78.5± 27.41	4.25± 1.52	9.64± 3.37	2.16± 0.58	15.12± 4.45	4.53± 1.07	BDL	0.06± 0.02	0.59± 0.16	0.33± 0.01	8.88± 0.12
7	***Mangifera indica***	**Stem**	0.63± 0	11.18± 0	11.39± 0	0.2± 0	0.12± 0	0.48± 0	1.78± 0	2.47± 0	BDL	0.02± 0	0.07± 0	0.44± 0.05	6.56± 0.06

		Leaf	1.58± 0.17	316.04± 20.55	138.31± 8.85	0.84± 0.04	2.6±0.21	5.36± 0.8	9.24± 0.27	0.9± 0.81	BDL	0.05± 0	0.63± 0.04	0.21± 0.01	4.64± 0.08
8	***Leucaena leucocephala***	**Stem**	1±0	129.92± 0	98.94± 0	0.96± 0	2.97± 0	13.04± 0	28.53± 0	0.75± 0	BDL	0.26± 0	1.78± 0	1.65± 0.16	12.36± 1.56
		Leaf	1.62± 0.09	65.87± 43.51	51.89± 31.39	1.12± 0.75	2.34± 1.64	3.63± 2.6	5.64± 3.87	2.62± 0.17	BDL	0.01± 0.01	0.08± 0.09	1.12± 0.18	11.36± 1.87
		Pod	0±0	26.91± 7.62	84.49± 26.67	0.17± 0.01	0.45± 0.14	3.13± 2.07	1.05± 0.14	ND	BDL	ND	0.01± 0.01	ND	3.1± 0.02
9	***Mimosa pudica***	**Stem**	1.6± 0.09	64.37± 7.87	133.69± 9.27	0.5± 0.05	3.8± 0.1	3.78± 0.08	11.66± 0.31	1.38± 0.05	BDL	0.11± 0.03	0.34± 0.45	1.24± 0.18	14.36± 1.26
		Leaf	1.69± 0.18	93.51± 47.09	166.62± 84.84	0.61± 0.31	5.03± 2.58	4.13± 2.14	9.38± 4.93	2.41± 0.19	BDL	0.02± 0.01	0.47± 0.24	0.96± 0.05	7.68± 0.21
		Fruit	2.26± 0	1.91± 0	4.67± 0	0.00	0.06± 0	0.06± 0	0.27± 0	1.49± 0	BDL	ND	0.04± 0	0.14± 0.01	2.15± 0.23
10	***Lantana camara***	**Stem**	0.5± 0.04	44.79± 3.97	132.61± 8.91	0.77± 0.05	0.64± 0.06	5.22± 0.57	6.79± 0.65	0.46± 0.11	BDL	0.02± 0	0.31± 0.04	2.46± 0.78	17.86± 1.65
		Leaf	0.44± 0.05	32.36± 9.63	115.87± 5.85	0.68± 0.1	0.47± 0.1	4.54± 0.55	7.92± 1.76	0.48± 0.04	BDL	0.02± 0	0.22± 0.06	1.44± 0.08	12.56± 1.26
		Fruit	0.00	214.9± 29.79	29.38± 2.71	1.04± 0.18	1.87± 0.29	4.46± 0.81	3.66± 0.13	0.84± 0.16	BDL	0.04± 0.01	0.01± 0	0.22± 0.03	2.36± 0.02
11	***Lycopersicon esculentum***	**Root**	0.41± 0.11	26.54± 15.51	25.4± 11.55	0.81± 0.31	1.94± 0.81	5.55± 0.52	7.02± 6.07	0.89± 0.22	BDL	0.01± 0.01	0.08± 0.06	0.46± 0.04	5.65± 0.06
		Stem	0.09± 0.02	10.43± 0.11	24.62± 20.09	0.61± 0.09	1.12± 0.15	4.93± 0.13	13.92± 1.19	0.38± 0.08	BDL	0.01± 0	0.00	0.32± 0.02	4.36± 0.04
		Leaf	0.14± 0.08	11.04± 0.49	43.64± 5.39	0.66± 0.08	0.73± 0.11	6.6± 0.56	16.07± 0.4	0.47± 0.01	BDL	0.06± 0.01	0.41± 0.03	0.15± 0.01	3.26± 0.01
		Fruit	0.00	27.7± 0.03	0.22± 0	0.68± 0	1.21± 0	2.87± 0	0.45± 0	1.11± 0	BDL	0.02± 0	ND	ND	1.21± 0.01

Note: BDL- Below detection limit
ND- Not detected

Table 18: Bioaccumulation of different trace and toxic metals in plant vegetation at site – IV.

D		Site - IV Core Pond													
S.N	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**												
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Azadirachta indica***	**Stem**	0.78± 0.07	7.97± 0.05	62.88± 0.24	0.19± 0.01	2.72± 0.1	3.55± 0.04	8.35± 0.05	0.13± 0	BDL	0.01± 0	0.16± 0	2.76± 0.62	16.32± 1.65
		Leaf	0.94± 0.05	26.91± 0.07	141.08± 0.47	0.21± 0	2.14± 0.05	4.17± 0.05	14.17± 0.12	0.1± 0	BDL	0.01± 0	0.14± 0	1.65± 0.15	10.23± 1.65
2	***Dalbergia sissoo***	**Stem**	0.71± 0.01	10.68± 0.08	26.54± 0.15	0.05± 0	1.3± 0.07	2.89± 0.03	9.22± 0.11	0.05± 0	BDL	0.02± 0	0.18± 0	1.11± 0.18	14.36± 1.45
		Leaf	1.1± 0.01	31.79± 0.15	102.31± 3.87	0.14± 0.02	2.36± 0.08	2.42± 0.09	15.81± 0.05	0.22± 0	BDL	0.01± 0	0.06± 0	0.86± 0.23	12.3± 2.36
3	***Syzygium cumini***	**Stem**	0.87± 0.04	19.61± 0.17	57.8± 0.08	0.84± 0.02	2.44± 0.09	1.81± 0.05	6.14± 0.11	0.68± 0.08	BDL	ND	0.08± 0	2.46± 0.65	18.63± 2.54
		Leaf	1.05± 0.01	46.12± 3.46	122.51± 5.43	0.31± 0.02	0.92± 0.06	2.07± 0.05	5.91± 0.02	0.24± 0.01	BDL	ND	0.05± 0	1.85± 0.12	12.54± 1.65
4	***Holarrhena antidysenterica***	**Stem**	0.43± 0.01	102.28± 3.4	38.26± 0.04	2.52± 0.03	4.96± 0.06	7.64± 0.05	22.86± 0.26	1.88± 0.04	BDL	0.01± 0	ND	2.65± 0.32	11.23± 1.36
		Leaf	1.11± 0	241.82± 0	78.47±2.	2.01± 0	3.72± 0	7.78± 0	51.14± 0	1.54± 0	BDL	0.02± 0	0.04± 0	1.83± 0.2	9.36± 0.06
5	***Terminalia bellirica***	**Stem**	0.76± 0.03	64.47± 0.4	28.9± 0.73	0.68± 0.04	4.78± 0.01	3.6± 0.07	35.42± 1.11	0.54± 0	BDL	0.01± 0	0.09± 0	1.18± 0.12	9.65± 0.05
		Leaf	0.27± 0.05	110.42± 4.21	78.45± 0.04	6.23± 0.13	11.3± 0.28	1.22± 0.05	5.34± 0.08	4.65± 0.11	BDL	0± 0.01	ND	0.76± 0.21	5.34± 0.05
6	***Ageratina adenophora***	**Stem**	0.66± 0.04	23.71± 0.53	24.75± 0.3	0.27± 0.02	6.4± 0.11	2.67± 0.04	12.48± 0.03	0.21± 0.02	BDL	0.02± 0	0.06± 0	0.96± 0.23	8.65± 0.04
		Leaf	1.14± 0.1	70.67± 3.62	148.54± 8.29	1.46± 0.04	2.12± 0.07	5.09± 0.12	13.56± 0.05	1.18± 0.03	BDL	0.01± 0	0.06± 0	0.55± 0.31	6.23± 0.3
7	***Cassia fistula***	**Stem**	0.92± 0.06	26.15± 0.27	51.07± 0.6	0.43± 0.01	3.23± 0.07	5.39± 0.02	25.06± 0.51	0.3± 0	BDL	ND	0.04± 0	1.26± 0.03	12.56± 1.45
		Leaf	1.07± 0.02	113.58± 1.72	144.91± 8.34	0.42± 0.06	4.5± 0.04	3.24± 0.13	16.65± 0.22	0.34± 0	BDL	ND	0.08± 0	0.97± 0.01	8.56± 0.86
8	***Lantana camara***	**Stem**	0.8± 0.04	22.51± 0.32	80.9± 0.25	0.4± 0.05	1.43± 0.04	3.78± 0.07	9.06± 0.06	0.26± 0	BDL	ND	0.05± 0	2.15± 0.16	13.54± 0.87

		Leaf	1.3± 0.04	44.86± 0.18	120± 0.02	0.27± 0	3.53± 0.02	1.71± 0.02	0.21± 0	0.25± 0	BDL	ND	ND	1.33± 0.18	7.85± 0.45
9	***Dendrocalamus strictus***	**Stem**	0.54± 0.01	19.79± 0.08	29.73± 0.04	0.11± 0	0.73± 0	7.41± 0.03	10.06± 0.17	0.09± 0	BDL	0.02± 0	0.71± 0.04	0.99± 0.06	9.64± 0.65
		Leaf	1.45± 0.07	49.9± 0.14	173.42± 3.29	0.48± 0	1.33± 0	1.33± 0.02	5.19± 0.09	0.41± 0	BDL	ND	0.15± 0	0.56± 0.04	6.54± 0.36

Note: BDL- Below detection limit

ND- Not detected

Table 19: Bioaccumulation of different trace and toxic metals in plant vegetation at site – V.

E		**Site - V Check Dam - 3B**													
S.N	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**												
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Azadirachta indica***	**Stem**	0.44± 0	5.79± 0.09	36.49± 0.16	0.08± 0	0.51± 0	2.95± 0.13	4.33± 0.21	0.13± 0	BDL	0.01± 0	0.1± 0	2.41± 0.25	12.32± 1.89
		Leaf	0.91± 0	18.99± 0	100.99± 0	0.14± 0	0.86± 0	4.86± 0	12.47± 0	0.29± 0	BDL	0.01± 0	0.03± 0	1.65± 0.12	8.69± 1.54
2	***Acacia auriculiformis***	**Stem**	0.6± 0	6.81± 0.02	46.51± 0.14	0.06± 0	0.59± 0	2.6± 0.04	2.89± 0.04	0.52± 0.01	BDL	0.02± 0	0.05± 0	1.25± 0.33	12.56± 1.25
		Leaf	1.11± 0.05	29.72± 0.13	95.37± 0.92	0.09± 0	1.67± 0	1.63± 0.01	4.26± 0.09	0.14± 0	BDL	ND	0.09± 0	0.78± 0.02	8.78± 1.36
3	***Tectona grandis***	**Stem**	0.93± 0	3.12± 0	69.87± 0	0.04± 0	0.46± 0	4.14± 0	2.77± 0	0.01± 0	BDL	ND	0.04± 0	1.17± 0.05	9.87± 1.45
		Leaf	0.97± 0.01	12.02± 0.16	103.45± 0.6	0.08± 0.02	0.71± 0.04	1.56± 0.1	4.19± 0.09	0.15± 0	BDL	ND	0.12± 0	0.88± 0.06	6.32± 0.23
4	***Andrographis paniculata***	**Root**	0.15± 0	13.48± 0.17	6.25± 0.21	0.07± 0	0.41± 0	1.77± 0.04	7.15± 0.12	0.3± 0	BDL	ND	ND	0.96± 0.04	13.45± 1.87
		Stem	0.79± 0.08	2.86± 0.05	70.21± 0.37	0.05± 0	0.27± 0.01	3.23± 0.08	16.28± 0.14	0.04± 0	BDL	ND	0.04± 0	0.78± 0.02	8.65± 0.98
		Leaf	0.82± 0.03	113.55± 0.02	40.78± 0.07	0.14± 0	1.29± 0.02	1.26± 0.06	9.2± 0.07	0.21± 0	BDL	ND	0.07± 0	0.45± 0.02	9.64± 0.78
5	***Lantana camara***	**Stem**	0.67± 0	12.45± 0	72.81± 0	0.12± 0	0.46± 0	8.38± 0	7.02± 0	0.07± 0	BDL	ND	0.13± 0	2.18± 1.2	17.56± 1.47
		Leaf	1.4± 0.05	23.49± 0.02	51.49± 0.06	0.13± 0	0.8± 0.04	1.92± 0.13	5.36± 0.08	0.19± 0	BDL	ND	0.02± 0	1.68± 0.25	8.36± 0.26
		Fruit	0.93± 0.03	5.9± 0.1	113.84± 0.94	0.09± 0	2.38± 0.06	7.27± 0.04	8.18± 0.13	0.05± 0	BDL	ND	0.11± 0	0.3± 0.01	2.15± 0.02
6	***Ziziphus nummularia***	**Stem**	0.75± 0.01	3.24± 0.1	40.75± 0.23	0.13± 0	1.17± 0.04	4.46± 0.05	4.32± 0.06	0.08± 0	BDL	ND	0.15± 0	1.1± 0.02	15.26± 1.24
		Leaf	1.14± 0.06	6.29± 0.04	132.4± 4.66	0.24± 0	1.18± 0.05	2.9± 0.02	5.1± 0.02	0.18± 0	BDL	ND	0.04± 0	0.86± 0.03	8.63± 1.23
7	***Leucaena leucocephala***	**Stem**	0.87± 0.03	4.4± 0.1	132.57± 2.44	0.05± 0	1.09± 0.01	3.38± 0.02	3.33± 0.01	0.03± 0	BDL	ND	0.15± 0	1.12± 0.24	12.56± 1.87

		Leaf	1.22± 0.04	12.79± 0.08	238.48± 6.06	0.18± 0	2.14± 0.04	6.11± 0.04	8.88± 0.08	0.14± 0	BDL	ND	0.05± 0	0.77± 0.24	8.54± 1.87
8	***Typha latifolia***	**Root**	1.73± 0.1	146.71± 0.5	280.64± 0.11	0.65± 0.03	1.26± 0.03	0.57± 0.01	0.04± 0	0.63± 0.04	BDL	ND	ND	1.2± 0.32	12.87± 1.56
		Leaf	0.66± 0.08	269.33± 12.08	335.99± 0.12	0.13± 0.01	0.33± 0	1.11± 0.03	7.03± 0.13	0.2± 0	BDL	ND	0.08± 0	0.88± 0.04	8.45± 0.36
9	***Pteris vittata***	**Root**	0.34± 0.04	47.79± 4.03	0.87± 0.06	0.49± 0.03	0.68± 0.02	0.33± 0.01	0.09± 0.01	0.35± 0.01	BDL	ND	ND	1.78± 0.06	9.68± 0.25
		Stem	0.7± 0.03	21.09± 0.29	86.53± 1.68	0.1± 0.01	0.48± 0.01	6.46± 0.02	3.95± 0.13	0.52± 0	BDL	ND	0.1± 0	0.66± 0.12	6.54± 0.14
		Leaf	1.16± 0.03	39.81± 0.57	226.27± 0.7	0.22± 0.01	0.54± 0.01	1.68± 0.03	4.08± 0.09	1.25± 0.06	BDL	ND	0.05± 0	0.78± 0.21	5.32± .12
10	***Mimosa pudica***	**Stem**	0.79± 0.04	11.77± 0.07	74.05± 2.04	0.14± 0.01	2.39± 0.06	4.24± 0.1	13.58± 0.07	0.16± 0.01	BDL	0.01± 0	0.05± 0	1.26± 0.12	12.56± 1.21
		Leaf	1.14± 0.07	24.98± 0.96	29.63± 0.48	0.35± 0.01	5.44± 0.19	1.36± 0.04	9.72± 0.09	0.55± 0	BDL	ND	0.02± 0	0.65± 0.02	10.32± 1.23
11	***Casuarina equisetifolia***	**Stem**	0.9± 0.04	5.2± 0.05	52.99± 0.29	0.07± 0	0.62± 0.05	2.57± 0.03	2.24± 0.05	0.04± 0	BDL	ND	0.06± 0	1.78± 0.12	10.29± 1.54
		Leaf	1.21± 0.04	19.96± 0.67	152.26± 2.05	0.31± 0.01	2.15± 0.05	0.94± 0.08	4.44± 0.08	0.43± 0.01	BDL	ND	0.08± 0	0.78± 0.02	6.54± 0.32

Note: BDL- Below detection limit

ND- Not detected

Table 20: Bioaccumulation of different trace and toxic metals in plant vegetation at site – VI.

F		**Site - VI**	**Reservoir Pond**												
S.N	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**												
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Azadirachta indica***	**Stem**	1.32± 0.02	11.15± 0.09	75.94± 0.27	0.08± 0	0.88± 0.05	5.25± 0.12	9.24± 0.07	0.05± 0	BDL	0.01± 0	0.08± 0	1.55± 0.12	15.96± 2.3
		Leaf	0.71± 0.03	18.08± 0.05	159± 0.05	0.11± 0	1.06± 0.02	3.07± 0.05	11.36± 0.08	0.68± 0.08	BDL	0.01± 0	0.01± 0	0.86± 0.12	11.24± 1.23
2	***Syzygium cumini***	**Stem**	0.82± 0.01	11.28± 0.07	85.79± 0.08	0.09± 0	2.86± 0.05	5.99± 0.05	18.1± 0.2	0.2± 0	BDL	0.01± 0	0.01± 0	1.21± 0.13	13.74± 1.36
		Leaf	0.52± 0.02	6.83± 0.09	194± 0.02	0.06± 0	1.8± 0.05	2.56± 0.07	11.78± 0.08	0.21± 0	BDL	ND	ND	0.88± 0.05	9.64± 1.21
3	***Leucaena leucocephala***	**Stem**	1.48± 0.1	4.49± 0.09	442.62± 0.31	0.14± 0.01	1.83± 0.09	6.5± 0.08	11.36± 0.06	0.21± 0	BDL	0.02± 0	0.12± 0	1.28± 0.16	12.56± 1.87
		Leaf	2.75± 0.04	9.01± 0.07	650± 0.07	0.15± 0.02	1.72± 0.06	1.63± 0.07	1.45± 0.09	0.54± 0.04	BDL	ND	ND	0.83± 0.14	8.76± 1.32
4	***Ageratina adenophora***	**Stem**	1.45± 0.03	19.76± 0.06	122.65± 0.29	0.17± 0	2.53± 0.08	4.41± 0.12	18.73± 0.17	0.28± 0.01	BDL	0.03± 0	0.04± 0	0.44± 0.02	9.78± 1.56
		Leaf	1.67± 0	40.1± 0	177± 0	0.69± 0	1.38± 0	1.42± 0	0.31± 0	0.76± 0	BDL	ND	ND	0.23± 0.01	7.86± 0.36
5	***Lantana camara***	**Stem**	1.35± 0.04	14.35± 0.07	118.24± 0.09	0.12± 0.01	0.52± 0.01	3.05± 0.08	6.2± 0.09	0.08± 0.01	BDL	0.01± 0	ND	2.54± 0.23	12.65± 2.35
		Leaf	2.61± 0.02	25.24± 0.15	330.87± 12.5	0.17± 0	1.32± 0.01	0.79± 0.21	20.7± 3.34	0.93± 0.25	BDL	0.01± 0	ND	1.66± 0.26	7.89± 0.54
6	***Parthenium hysterophorus***	**Root**	1.18± 0	22.26± 0.37	129.12± 12.02	0.8± 0.04	2.63± 0.02	4.06± 0.07	22.96± 2.06	0.81± 0.06	BDL	0.01± 0	ND	1.78± 0.12	10.36± 1.59
		Stem	1.14± 0.01	7.75± 0.23	172.5± 8.56	0.12± 0.01	0.74± 0.05	1.8± 0.03	15.49± 2.09	0.14± 0	BDL	ND	ND	1.11± 0.05	5.64± 0.06
		Leaf	0.51± 0	59.97± 4.65	272.5± 15.56	1.23± 0.07	1.36± 0.07	0.73± 0.03	22.84± 4.08	1.94± 0.09	BDL	ND	ND	0.85± 0.02	4.85± 0.02
7	***Pteris vittata***	**Root**	0.49± 0.06	5.87± 0.09	135.20± 6.11	0.12± 0.01	0.49± 0	1.71± 0.08	12.2± 3.09	0.13± 0.01	BDL	ND	ND	1.11± 0.03	9.68± 0.08
		Stem	1.2± 0.09	4.76± 0.08	77.41± 4.05	0.07± 0.01	0.48± 0.01	2.96± 0.11	9.98± 0.08	0.08± 0	BDL	0.01± 0	0.05± 0	0.44± 0.01	7.12± 0.87

		Leaf	0.88± 0	15.06± 0.62	146.32± 0.05	0.25± 0	0.9± 0.05	0.58± 0	5.6± 0.14	0.5± 0	BDL	ND	ND	0.72± 0.02	6.97± 0.78
8	***Typha latifolia***	**Root**	2.98± 0.90	497.86± 3.55	537± 0.04	1.96± 0.09	12.59± 0.46	0.12± 0.01	2.63± 0.08	1.93± 0.08	BDL	0.01± 0	ND	0.86± 0.04	12.36± 1.28
		Leaf	1.48± 0	226.12± 27.68	131.38± 0	0.08± 0	1.32± 0	1.99± 0	6.46± 0	0.08± 0	BDL	ND	0.07± 0	0.44± 0.01	6.39± 0.02

Note: BDL- Below detection limit

ND- Not detected

Plate 4: A-C: Different views showing collection of plant samples at selected sites.

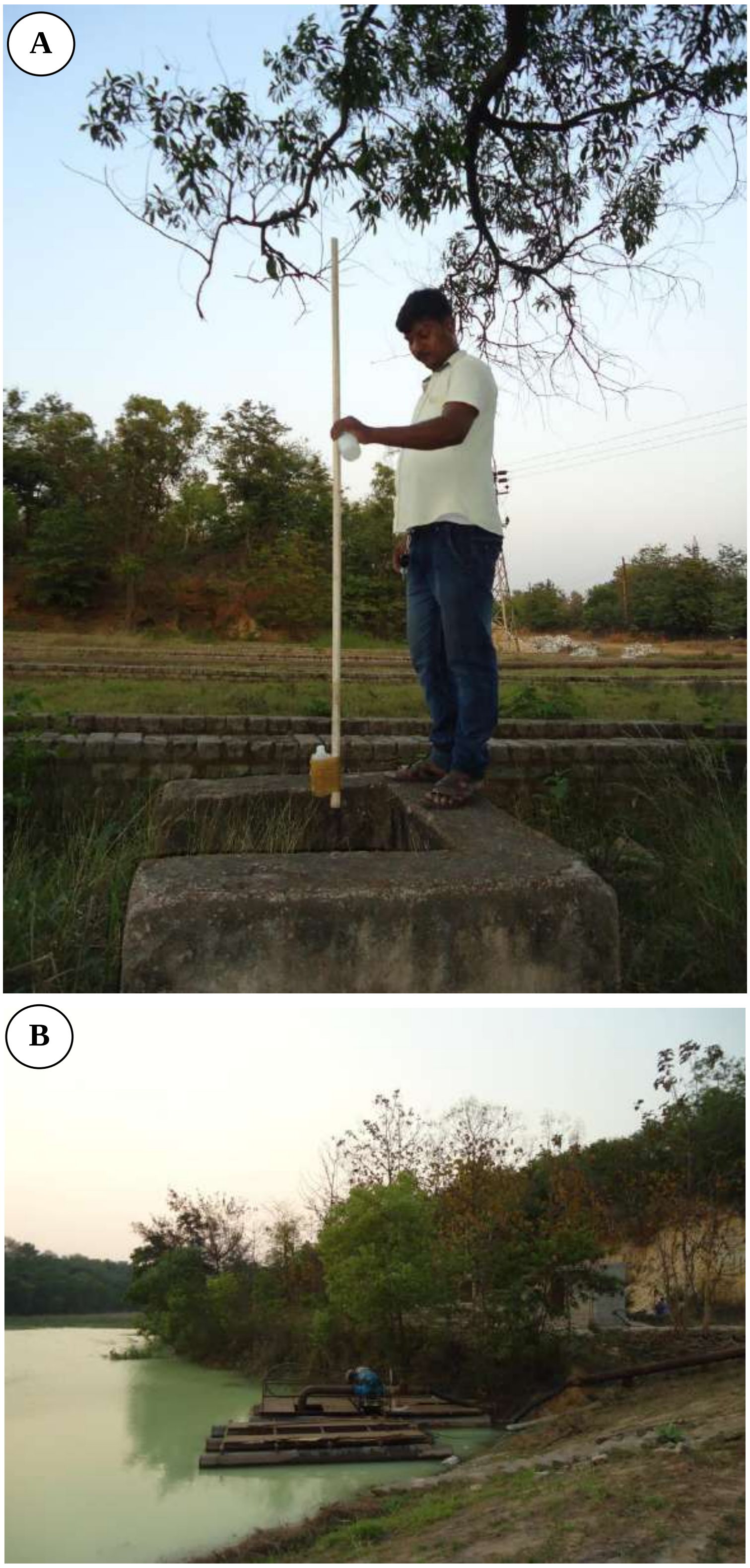


Plate 5: A: view showing collection of water sample at site; **B:** A view showing site location (Check dam 3B) Talcher, district Angul, Odisha.

6.5 Concentration of different trace and toxic metals in water samples

The concentrations of all heavy metals such as Cd, Co, Cr, Cu, F, Fe, Mn, Ni and Zn were within the permissible limit as per BIS standard. **It needs to be mentioned that Hg was not detected in any of the samples.**

Table 21: Level of heavy metals in water samples.

Sites	Concentration of metals (μg l^{-1})											
	Cr	**Mn**	**Fe**	**Ba**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**
Site I surface	2.00± 0.02	64.12± 2.32	110.41± 7.25	21.2± 2.12	0.41± 0.02	3.26± 0.02	1.95± 0.03	15.84± 1.02	0.45± 0.01	BDL	Nd	0.12± 0.01
Site I Piezometer	1.28± 0.02	67.84± 3.23	242.11± 10.23	23.1± 1.26	0.83± 0.03	5.06± 0.03	5.04± 0.02	16.24± 2.25	0.84± 0.01	BDL	0.01± 0	0.06± 0
Site I surface	1.65± 0.03	96.43± 2.25	483.42± 14.25	18.3± 2.12	0.87± 0.02	0.84± 0.02	3.70± 0.02	21.60± 1.13	0.95± 0.02	BDL	0.01± 0	0.04± 0.01
Site II surface	2.21± 0.31	84.73± 3.21	1250.76± 5.32	16.2± 1.54	0.18± 0.01	3.56± 0.01	6.64± 0.03	61.19± 5.23	0.36± 0.01	BDL	Nd	0.06± 0.01
Site III surface	1.78± 0.02	18.26± 1.32	416.83± 12.25	11.5± 1.87	0.05± 0	0.66± 0.03	4.07± 0.02	27.44± 0.05	0.13± 0.01	BDL	0.04± 0	0.09± 0.02
Site IV surface	1.63± 0.01	73.59± 2.32	1041.41± 7.54	13.84± 1.36	0.11± 0.01	1.30± 0.02	2.08± 0.01	10.15± 0.02	0.22± 0.01	BDL	0.01± 0	0.06± 0.01
Site V Piezometer	1.36± 0.01	213.41± 2.25	726.65± 7.78	20.8± 2.58	1.17± 0.02	2.96± 0.01	2.52± 0.03	119.97± 10.02	1.18± 0.23	BDL	0.01± 0	0.15± 0.01
Site V surface	1.86± 0.01	37.46± 0.36	463.62± 3.56	23.2± 3.21	0.89± 0.01	3.92± 0.02	1.22± 0.01	12.82± 0.02	0.94± 0.03	BDL	Nd	0.14± 0.01
Site V surface	1.28± 0.01	15.70± 1.24	440.47± 4.54	19.7± 1.87	0.30± 0.1	2.13± 0.02	5.29± 0.05	26.11± 2.24	0.41± 0.02	BDL	0.02± 0	0.12± 0
Site VI surface	1.65± 0.21	97.41± 5.25	411.18± 5.68	18.2± 1.78	0.01± 0	0.82± 0.01	0.06± 0	1.14± 0	0.01± 0	BDL	Nd	0.05± 0

Note: BDL- Below detection limit

ND- Not detected

6.6 Bioaccumulation of different trace and toxic metals in plant vegetation

Similarly, the next tour visited with team of NBRI scientist, Tech Officer and research scholars at Talcher thermal power station during September, 2019. Plant samples were collected from identified sites, collected samples were acid digested and then analysed by ICP-MS Table 22-27.

Chromium (Cr)

The concentration of chromium ranged between 0.19-4.05 mg kg^{-1}. The maximum accumulation of Cr was found in the root of *Mimosa pudica* (4.05 mg kg^{-1}) at site V (Table 26). Permissible limit of Cr set by WHO 1.30 mg kg^{-1} for the plant.

Manganese (Mn)

The accumulation level of Mn ranged between 3-666 mg kg^{-1}). Maximum accumulation was found in leaves of *Typha latifolia* (666 mg kg^{-1}) at site V (Table 26).

Iron (Fe)

The level of Fe was varied from 8.00-4921 mg $kg\text{-}^{1}$, highest accumulation of Fe was found in the root of *Typha latifolia* (4921 mg kg^{-1}), followed by the stem of *Holarrhena antidysenterica* (466 mg $kg\text{-}^{1}$) at site V (Table 26) respectively.

Cobalt (Co)

Cobalt is a trace element in plants. Maximum concentration of cobalt was found in leaf of *Syzygium cumini* (6.04 mg kg^{-1}) at site II (Table 23).

Nickel (Ni)

The bio-accumulation level of nickel was found from 0.12-13.02 mg kg^{-1}. The maximum bioaccumulation of Ni was found in stem of *Chromolena odorata* (13.02 mg kg^{-1}) at site II (Table 23). Ni accumulation in most of the plant species was within the permissible limit of WHO-10 mg kg^{-1}.

Zinc (Zn)

The Zinc concentration ranged between (2.63-63 mg $kg\text{-}^{1}$). Maximum Zn concentration was found in stem of *Holarrhena antidysenterica* (63 mg kg^{-1}) at site IV (Table25).

Arsenic (As)

The accumulation level of Arsenic was 0.01-7.85 mg kg^{-1}. The highest accumulation of Arsenic was found in the leaves of *Syzygium cumini* (7.85 mg kg^{-1}) at site II (Table 23).

Mercury (Hg)

It is to be noted that Hg was below detection limit in all plant samples.

Cadmium (Cd)

The concentration of cadmium ranged from 0.00 - 0.28 mg kg^{-1} dry weight. Maximum concentration of cadmium was found in the stem of *Holarrhena antidysenterica* (0.28 mg kg^{-1}) at site IV (Table 25).

Lead (Pb)

The bio-accumulation level of Pb in the stem and leaves in most of the plant species were found within the permissible limit. The concentration of lead ranged from 0.00-5.7 mg kg^{-1}. The maximum accumulation of Pb was found in the leaves of *Chromolena odorata* (5.7 mg kg^{-1}) at site II (Table 23).

Fluoride (F)

The concentration was found from 0.25-3.21 mg kg^{-1}. Maximum concentration was found in the root of *Saccharum spontaneum* (3.21 mg kg^{-1}) at site I (Table 22).

Barium (Ba)

Barium concentration raged was found 2.1 - 21.3 mg kg^{-1}. Maximum concentration was found in the stem of *Acacia auriculiformis* (21.3 mg $kg^{-}1$) at site IV (Table 25).

Table 22: Bioaccumulation of different trace and toxic metals in plant vegetation at site-I.

A.		**Site - I Check Dam Mine Void - 02**													
S.No	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**												
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Azadirachta indica***	**Stem**	1.23± 0.05	16.41± 0.28	66.6± 6.01	0.05± 0	1.52± 0.05	0.52± 0.04	4.31± 0.04	0.39± 0	BDL	ND	0.03± 0	1.5± 0.02	14.45± 1.25
		Leaf	1.55± 0.09	17.93± 0.24	230.41± 10.20	0.58± 0.02	2.09± 0.03	2.26± 0.08	37.9± 0.32	0.6± 0.03	BDL	0.03± 0	0.13± 0.01	1.11± 0.05	9.85± 0.25
2	***Semecarpus anacardium***	**Stem**	0.91± 0	102.33± 0	44.72± 0	0.37± 0	2.01± 0.03	1.52± 0.05	22.97± 0	0.75± 0	BDL	0.02± 0	0.23± 0	0.95± 0.02	8.65± 0.36
		Leaf	1.38± 0.05	10.66± 0.26	50.55± 0	0.08± 0.01	1.93± 0.04	2.49± 0.1	5.56± 0.08	0.15± 0	BDL	0.01± 0	0.16± 0.01	0.5± 0.01	6.54± 0.21
3	***Syzygium cumini***	**Stem**	2.27± 0.08	35.03± 0.36	43.27± 0.3	0.09± 0	4.39± 0.07	2.4± 0.08	6.05± 0.08	0.25± 0.04	BDL	ND	0.05± 0	2.23± 0.21	15.56± 2.5
		Leaf	1.53± 0.14	11.81± 1.03	48.95± 0.08	0.04± 0	2.16± 0.05	5.42± 0.08	7.93± 0.1	0.34± 0.01	BDL	0.02± 0	0.73± 0	1.65± 0.04	9.36± 0.24
4	***Holarrhena antidysenterica***	**Stem**	1.99± 0.09	21.92± 0.02	33.42± 0.08	0.08± 0	1.87± 0.09	2.9± 0.16	8.29± 0.16	0.22± 0.01	BDL	ND	0.19± 0	2.26± 0.12	16.15± 0.36
		Leaf	1.01± 0.08	11.54± 0.23	58.68± 0.34	0.06± 0	1.48± 0.08	3.56± 0.06	7.64± 0.12	0.22± 0	BDL	0.03± 0	0.18± 0	1.42± 0.31	11.36± 0.95
5	***Grewia hirsuta***	**Stem**	0.58± 0.05	7.45± 0.11	36.47± 2.01	0.65± 0	1.45± 0.08	0.79± 0.01	0.08± 0	0.8± 0.04	BDL	ND	ND	0.38± 0.02	9.78± 0.32
		Leaf	1.26± 0.09	7.13± 0.47	40.02± 2.41	0.07± 0.01	1.57± 0.09	3.04± 0.1	10.26± 0.31	0.12± 0.01	BDL	0.01± 0	0.13± 0.01	0.31± 0.02	6.38± 0.54
6	***Ageratina adenophora***	**Stem**	1.57± 0.08	21.13± 0.57	86.65± 4.07	0.16± 0.04	1.23± 0.08	3.9± 0.2	17.27± 0.41	0.2± 0	BDL	0.01± 0	0.01± 0	0.76± 0.02	11.36± 1.26
		Leaf	2.02± 0.08	9.25± 0.14	25.62± 0.7	0.04± 0.01	0.91± 0.1	2.76± 0.15	7.64± 0.46	0.04± 0.01	BDL	ND	0.11± 0	0.52± 0.03	8.45± 0.85
7	***Senna siamea***	**Stem**	1.24± 0.13	41.98± 1.2	134.31± 8.26	0.91± 0.02	11.25± 0.27	14.46± 0.29	44.39± 1.61	0.02± 0	BDL	0.11± 0	4.74± 0.22	1.13± 0.03	14.21± 2.5
		Leaf	2.3± 0.06	37.6± 0.42	208.77± 5.57	0.43± 0.1	1.87± 0.03	6.66± 0.14	13.95± 0.19	0.12± 0.01	BDL	0.01± 0	1.7± 0.08	0.87± 0.01	9.12± 1.25
8	***Ziziphus nummularia***	**Stem**	1.34± 0.07	21.53± 0.7	23.69± 1.66	0.06± 0	0.83± 0.11	1.78± 0.09	7.93± 0.29	0.37± 0.03	BDL	ND	0.28± 0.05	1.52± 0.21	11.3± 1.23

		Leaf	2.44±0.09	9±0.25	111.03±8.19	0.32±0.05	0.95±0.05	7.17±0.3	8.06±0.28	0.35±0.09	BDL	0.01±0	0.03±0	1.11±0.12	7.52±1.25
9	***Tephrosia purpurea***	**Root**	1.51±0.11	12.81±0.37	47.42±1.91	0.06±0.02	0.49±0.06	4.45±0.11	12±0.12	0.12±0.01	BDL	0.01±0	0.15±0.02	1.45±0.21	10.23±0.35
		Stem	0.94±0.08	19.21±0.99	44.5±1.6	0.15±0.01	0.43±0.01	1.61±0.08	18.46±0.33	0.36±0.02	BDL	ND	0.08±0.01	1.12±0.32	8.56±0.25
		Leaf	2.13±0.09	19.62±1.25	31.62±0.83	0.11±0.03	0.23±0.01	0.14±0.01	0.17±0	0.05±0	BDL	ND	ND	0.86±0.02	6.54±0.36
10	***Andrographis paniculata***	**Root**	1.24±0.15	3.02±0.28	120.43±4.39	0.1±0.01	0.43±0.02	1.06±0.12	0.39±0.04	0.09±0.01	BDL	ND	0.51±0.07	1.42±0.21	13.54±2.25
		Stem	1.83±0.12	17.86±0.83	260.9±11.38	0.11±0.02	0.60±0.06	1.37±0.12	19.96±0.53	1.65±0.04	BDL	0.01±0	0.02±0	1.13±0.04	8.62±0.45
		Leaf	0.66±0.08	36.79±1.13	80±4.25	0.26±0.05	0.35±0.03	0.54±0.08	0.32±0.03	0.23±0.01	BDL	ND	ND	0.82±0.02	6.32±0.65
11	***Typha latifolia***	**Root**	1.58±0.12	28.19±0.06	3550.62±85.46	0.48±0.02	0.48±0.02	1.18±0.09	10.98±0.59	0.54±0.02	BDL	0.01±0	0.67±0.09	2.23±0.25	14.2±0.21
		Leaf	2.06±0.07	93.81±6.58	102.84±7.45	0.16±0.03	0.52±0.04	2.29±0.07	4.49±0.14	0.14±0.01	BDL	ND	0.28±0.03	1.65±0.6	10.34±1.52
12	***Crotalaria pallida***	**Root**	0.72±0.09	8.63±0.55	19.67±0.99	0.08±0	0.44±0.01	5.21±0.27	9.57±0.33	0.22±0.02	BDL	0.01±0	0.22±0.01	0.86±0.04	9.35±0.25
		Stem	1.44±0.14	14±0.97	49.45±0.44	0.07±0	0.48±0.01	2.4±0.08	9.39±0.18	0.13±0.02	BDL	0.06±0.01	0.11±0.02	0.58±0.02	6.34±0.23
		Leaf	2.46±0.12	17.08±0.82	36.49±1.68	0.16±0.02	0.41±0.05	3.69±0.21	8.99±0.2	0.26±0.01	BDL	0.1±0.01	1.12±0.07	0.35±0.01	3.12±0.21
13	***Saccharum spontaneum***	**Root**	0.72±0.03	15.1±0.95	116.07±5.04	0.36±0.02	1.49±0.07	13.2±0.69	12.44±0.15	0.84±0.05	BDL	0.07±0	3.88±0.34	3.21±0.25	9.65±0.36
		Leaf	0.73±0.07	28.44±2.35	130.71±10.66	0.18±0.02	0.57±0.07	1.36±0.15	4.87±0.44	0.31±0.03	BDL	0.05±0	1.41±0.1	2.5±0.35	6.38±0.21
14	***Mimosa pudica***	**Stem**	0.29±0.01	15.24±0.82	84.11±3.82	0.19±0.01	1.41±0.06	3.99±0.21	13.79±0.55	0.33±0.02	BDL	0.14±0	1.42±0.08	1.21±0.02	9.86±0.56
		Leaf	0.51±0.01	29.05±0.99	155.8±5.17	0.21±0.01	1.04±0.03	3.02±0.1	12.9±0.36	0.41±0.02	BDL	0.04±0	0.26±0	1.54±0.03	7.48±0.54
15	***Vachellia nilotica***	**Stem**	0.42±0.01	12.4±0.16	87.19±3.77	0.14±0	1.35±0	4.23±0.01	6.74±0.19	0.11±0	BDL	0.05±0.01	1.07±0.07	0.92±0.01	21.35±3.25

		Leaf	1.05± 0.01	117.56± 1.48	349.72± 3.69	0.28± 0.01	5.89± 0.06	3.92± 0.05	19.02± 0.01	0.27± 0	BDL	0.07± 0	0.2± 0	0.35± 0.02	12.36± 1.26
16	***Phyllanthus niruri***	**Stem**	0.72± 0.03	75.79± 7.1	65.6± 11.09	0.1± 0.01	0.89± 0.03	4.1± 0.18	9.56± 0.29	0.13± 0.02	BDL	0.02± 0.01	0.28± 0.02	0.82± 0.02	9.34± 0.25
		Leaf	1± 0.12	27.13± 2.76	16.53± 0.75	0.13± 0	1.32± 0.16	2.88± 0.06	16.51± 4.33	0.44± 0.04	BDL	0.05± 0	0.15± 0.02	0.42± 0.05	6.65± 0.21
17	***Tridax procumbens***	**Stem**	0.38± 0.1	17.01± 0.78	41.79± 3.06	0.18± 0.01	1.42± 0.1	2.69± 0.15	0.22± 0.05	1.28± 0.08	BDL	ND	ND	1.65± 0.21	14.2± 1.25
		Leaf	0.84± 0.1	19.18± 0.55	38.82± 0.49	0.13± 0	5.03± 0.08	7.45± 0.45	19.31± 0.11	0.29± 0.04	BDL	0.01± 0	0.28± 0.05	1.25± 0.12	11.23± 1.26
		Flower	1.5± 0.03	13.57± 0.6	65.31± 2.19	0.21± 0.01	1.05± 0.13	9.46± 0.12	15.65± 0.7	0.27± 0.05	BDL	ND	0.03± 0.01	0.42± 0.02	5.25± 0.12
18	***Calotropis procera***	**Stem**	0.58± 0.1	20.96± 0.98	120.54± 5.12	0.2± 0.02	2.1± 0.08	3.28± 0.11	4.17± 0.16	0.72± 0.09	BDL	ND	ND	1.53± 0.12	12.36± 2.5
		Leaf	0.66± 0.11	4.66± 0.23	78.51± 3.72	0.03± 0.01	0.22± 0.02	3.75± 0.22	2.4± 0.11	0.13± 0.02	BDL	ND	0.01± 0	0.84± 0.02	8.54± 0.26

Note: BDL- Below detection limit

ND- Not detected

Table 23: Bioaccumulation of different trace and toxic metals in plant vegetation at site-II.

B.		**Site - II - L - Shape Dam (Frist Position)**													
S.N.	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**												
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Syzygium cumini***	**Stem**	0.76± 0.13	22.73± 0.97	71.38± 3.41	0.07± 0.02	5± 0.15	0.35± 0.03	38.67± 2.32	5.78± 0.11	BDL	0.01± 0	ND	2.52± 0.24	16.25± 1.56
		Leaf	1.7± 0.09	241.5± 6.25	252.7± 8.15	6.04± 0.1	12.59± 0.1	1.06± 0.1	22.94± 1.38	7.85± 0.31	BDL	0.12± 0.01	0.07± 0	1.62± 0.02	8.45± 0.36
2	***Leucaena leucocephala***	**Stem**	0.94± 0.11	8.35± 0.13	413.92± 1.79	0.09± 0	1.24± 0.19	1.58± 0.12	5.04± 0.27	1.21± 0.12	BDL	0.01± 0	0.5± 0	1.8± 0.12	11.36± 1.24
		Leaf	1.39± 0.16	78.05± 2.66	333.31± 12.33	0.54± 0.03	1.85± 0.1	0.89± 0.13	10.97± 0.19	3.51± 0.18	BDL	0.03± 0	0.09± 0	0.86± 0.25	7.85± 0.54
3	***Lantana camara***	**Stem**	1.78± 0.16	31.53± 0.43	10.25± 0.26	0.28± 0.04	1.1± 0.09	0.62± 0.03	7.43± 0.22	3.37± 0.23	BDL	0.04± 0	0.06± 0	1.46± 0.12	18.56± 2.5
		Leaf	2.13± 0.12	114.66± 5.07	282.99± 7.23	0.07± 0	1.32± 0.12	1.21± 0.13	7.24± 0.11	0.5± 0.08	BDL	0.02± 0	0.84± 0.06	0.97± 0.15	12.87± 1.54
4	***Chromolena odorata***	**Stem**	1.45± 0.11	137.16± 9.39	115.44± 2.06	4.37± 0.07	13.02± 0.31	1.25± 0.16	24.47± 1.31	6.58± 0.19	BDL	0.16± 0	0.13± 0	1.66± 0.23	20.12± 3.5
		Leaf	1.99± 0.12	119.12± 0.1	268.04± 8.71	0.04± 0	2.06± 0.07	1.06± 0.09	24.48± 0.5	4.49± 0.09	BDL	0.07± 0	5.7± 0.04	1.12± 0.21	12.3± 0.85

Note: BDL- Below detection limit

ND- Not detected

Table 24: Bioaccumulation of different trace and toxic metals in plant vegetation at site-III.

C.		**Site - III - L - Shape Dam (Second Position)**												
S.N	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**											
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Leucaena leucocephala***	**Stem**	2.06± 0.13	20.11± 0.09	25.23± 1.06	0.06± 0.01	2.32± 0.06	0.47± 0.05	5.19± 0.09	2.58± 0.11	BDL	0.01± 0	0.2± 0.01	2.46± 0.16	13.56± 1.45
		Leaf	1.66± 0.08	96.16± 2.31	132.99± 3.41	0.15± 0.01	2.55± 0.16	2.52± 0.1	16.71± 0.08	0.19± 0	BDL	0.01± 0	0.19± 0	1.28± 0.02	8.54± 0.26
2	***Mangifera indica***	**Leaf**	1.66± 0.13	244.65± 0.24	104.94± 0.53	0.2± 0	1.06± 0.1	0.95± 0.06	8.99± 0.38	0.35± 0.03	BDL	0.01± 0	0.16± 0	2.68± 0.82	18.78± 2.12
		Stem	1.43± 0.14	11.02± 0.29	44.05± 1.01	0.11± 0	1.32± 0.12	4.6± 0.08	9.76± 0.15	0.14± 0	BDL	0.01± 0	0.28± 0.04	1.32± 0.12	11.87± 1.26
3	***Ficus benghalensis***	**Leaf**	1.22± 0.13	72.43± 0.35	186.28± 5.59	0.33± 0.02	1.69± 0.09	7.25± 0.06	11.08± 0.13	0.36± 0.01	BDL	0.01± 0	0.1± 0.01	1.71± 0.21	17.58± 2.54
		Stem	1.42± 0.06	61.74± 0.65	156.15± 3.27	0.16± 0.01	1.78± 0.07	5.66± 0.13	32.7± 1.2	0.21± 0.01	BDL	0.02± 0	0.14± 0.01	0.95± 0.04	8.65± 0.25
4	***Artocarpus heterophyllus***	**Stem**	2.12± 0.11	102.64± 3.62	120.06± 3.64	0.23± 0.02	3.42± 0.12	2.6± 0.11	17.39± 0.13	0.5± 0.03	BDL	ND	0.05± 0	1.28± 0.12	11.23± 1.36
		Leaf	1.65± 0.08	350.21± 12.05	63.94± 1.56	0.03± 0	5.88± 1.07	2.62± 0.13	10.39± 0.28	0.07± 0	BDL	ND	0.03± 0	0.85± 0.02	8.54± 0.25
5	***Azadirachta indica***	**Stem**	2.35± 0.12	4.11± 0.3	198.23± 5.18	0.16± 0	0.95± 0.07	3.3± 0.1	7.5± 0.37	0.2± 0.01	BDL	ND	0.05± 0	2.1± 0.15	19.84± 1.98
		Leaf	1.81± 0.12	27.92± 1.91	133.86± 3.17	0.13± 0.01	1.74± 0.12	4.56± 0.11	12.26± 0.26	0.2±0	BDL	0.01± 0	0.56± 0.04	1.65± 0.18	12.36± 1.65

Note: BDL- Below detection limit

ND- Not detected

Table 25: Bioaccumulation of different trace and toxic metals in plant vegetation at site-IV.

	D.	**Site - IV**	**Core Pond**											
S.N	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**											
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Syzygium cumini***	**Stem**	1.73± 0.12	24.68± 0.09	89.14± 2.38	0.51± 0.05	1.27± 0.08	5.35± 0.12	14.01± 0.17	0.55± 0	BDL	ND	0.07± 0	2.41± 0.25	18.54± 1.26
		Leaf	1.32± 0.1	91.43± 3.92	144.61± 5.19	1.45± 0.08	4.91± 0.09	2.46± 0.09	36.19± 0.12	1.99± 0.16	BDL	0.03± 0	0.13± 0.01	1.26± 0.32	12.3± 1.24
2	***Holarrhena antidysenterica***	**Stem**	1.31± 0.11	171.6± 10.02	39.89± 0.69	4.25± 0.26	2.7± 0.15	4.73± 0.13	63.91± 3.45	4.79± 0.27	BDL	0.28± 0.01	0.11± 0.01	0.95± 0.02	12.65± 2.12
		Leaf	1.97± 0.15	217.37± 12.21	123.89± 0.6	0.76± 0.08	1.59± 0.1	4.57± 0.13	20.12± 0.98	0.77± 0.09	BDL	0.02± 0	0.06± 0.01	0.54± 0.03	7.48± 0.54
3	***Azadirachta indica***	**Stem**	2.46± 0.1	19.03± 0.9	52.43± 0.92	0.42± 0.03	1.94± 0.1	4.19± 0.29	16.76± 0.16	0.48± 0.01	BDL	0.01± 0	0.04± 0	3.1± 0.24	18.15± 2.12
		Leaf	1.57± 0.11	19.27± 0.18	132.85± 2.31	1.68± 0.07	1.36± 0.11	1.68± 0.09	25.24± 0.31	1.67± 0.08	BDL	0.01± 0	0.08± 0.01	2.2± 0.45	10.2± 0.54
4	***Acacia auriculiformis***	**Stem**	2.44± 0.13	113.24± 1.33	172.2± 8.78	1.51± 0.09	2.15± 0.08	2.07± 0.12	46.99± 0.46	1.53± 0.09	BDL	0.01± 0	0.05± 0	2.42± 0.35	21.3± 2.56
		Leaf	2.14± 0.13	28.58± 0.71	41.55± 1.43	0.09± 0.01	2.12± 0.12	4.37± 0.09	12.43± 0.5	0.16± 0.01	BDL	0.01± 0	0.19± 0.01	1.26± 0.25	13.65± 1.25
5	***Dendrocalamus strictus***	**Stem**	2.16± 0.13	10.02± 0.54	87.98± 3.54	0.06± 0	1.72± 0.08	2.77± 0.09	14.38± 0.31	0.14± 0.01	BDL	ND	0.07± 0	1.82± 0.14	12.54± 1.21
		Leaf	2.27± 0.06	40.04± 0.46	153.6± 5.15	2.02± 0.23	3.47± 0.14	1.85± 0.12	11.21± 0.65	1.88± 0.08	BDL	0.02± 0	0.06± 0	1.11± 0.06	8.52± 0.12

Note: BDL- Below detection limit

ND- Not detected

Table 26: Bioaccumulation of different trace and toxic metals in plant vegetation at site-V.

E.		Site - V	Check Dam - 3B												
S.N	Plants	Parts	Metal concentration (mg kg^{-1} dw)												
			Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Hg	Cd	Pb	F	Ba
1	*Tectona grandis*	Stem	0.53± 0.07	10.93± 0.61	27.3± 1.5	0.11± 0	0.98± 0.13	5.04± 0.08	10.99± 0.29	0.15± 0	BDL	0.01± 0	0.05± 0	2.46± 0.21	14.25± 1.26
		Leaf	0.95± 0.1	15.54± 1.38	76.89± 6.23	0.05± 0	1.17± 0.09	4.46± 0.84	8.55± 1.9	0.13± 0.05	BDL	0.01± 0	0.16± 0.16	1.52± 0.12	9.65± 0.25
2	*Senna siamea*	Stem	0.82± 0.12	26.05± 0.89	63.27± 3.82	0.13± 0	0.61± 0.08	3.21± 0.06	10.25± 0.26	0.72± 0.1	BDL	0.01± 0	0.07± 0	1.56± 0.08	12.36± 1.24
		Leaf	1.45± 0.17	25.41± 2.19	164.9± 4.2	0.07± 0	0.84± 0.1	3.67± 0.09	6.78± 0.22	0.11± 0	BDL	0.01± 0	0.74± 0.05	0.85± 0.02	8.54± 0.65
3	*Leucaena leucocephala*	Stem	0.94± 0.07	2.45± 0.06	123.82± 3.95	0.04± 0.01	0.16± 0.01	0.62± 0.13	2.14± 0.1	0.11± 0.01	BDL	ND	0.65± 0.08	2.58± 0.35	18.3± 1.52
		Leaf	2.15± 0.05	14.43± 2.5	259.8± 15.86	1.31± 0.02	3.33± 0.1	9.44± 0.32	19.05± 2.45	0.3± 0.04	BDL	0.02± 0.01	2.01± 0.15	1.65± 0.02	12.36± 1.54
4	*Ziziphus nummularia*	Stem	0.81± 0.13	3.35± 0.32	39.08± 1.04	0.12± 0	1.17± 0.13	4.18± 0.09	4± 0.13	0.07± 0	BDL	ND	0.14± 0	1.25± 0.04	15.54± 1.35
		Leaf	1.15± 0.13	6.26± 0.24	112.19± 3.08	0.22± 0.02	1.14± 0.05	2.88± 0.07	4.89± 0.12	0.17± 0	BDL	ND	0.04± 0	0.92± 0.01	8.58± 1.12
5	*Dalbergia sissoo*	Stem	0.44± 0.04	7.89± 0.53	17.73± 0.29	0.07± 0	1.2± 0.02	1.9± 0.06	9.66± 0.03	ND	BDL	0.02± 0	0.57± 0.01	2.15± 0.25	18.1± 2.12
		Leaf	1.39± 0.12	45.55± 8.45	166.58± 7.37	1.4± 0.11	1.76± 0.1	3.64± 0.2	54.96± 3.79	0.58± 0.02	BDL	0.03± 0	0.38± 0.01	1.85± 0.56	11.36± 1.35
		Pod	0.19± 0.02	2.79± 0.2	8.49± 0.41	0.05± 0	0.66± 0.09	1.13± 0.08	4.25± 0.2	ND	BDL	0.01± 0	0.13± 0.02	0.15± 0.01	3.21± 0.02
6	*Calotropis procera*	Stem	0.28± 0.01	21.34± 1.56	65.04± 5	0.16± 0.02	0.53± 0.04	0.77± 0.09	11.34± 0.75	0.09± 0	BDL	0.02± 0	0.75± 0.06	3.1± 0.45	12.25± 0.65
		Leaf	1.67± 0.09	134.87± 4.07	183.75± 5.54	0.89± 0.03	3.51± 0.11	2.96± 0.18	21.22± 1.11	0.34± 0.09	BDL	0.03± 0	0.86± 0.05	2.56± 0.35	7.78± 0.03
		Flower	0.2± 0	6.71± 0.07	43.48± 2.71	0.19± 0.02	0.57± 0	0.79± 0.08	6.52± 0.2	0.09± 0	BDL	0.01± 0	0.51± 0	0.25± 0.02	2.1± 0.04
7	*Lantana camara*	Stem	0.19± 0.01	28.83± 1.53	17.68± 1.31	0.04± 0.01	0.12± 0.01	2.76± 0.09	2.97± 0.23	0.03± 0.01	BDL	0.01± 0	0.86± 0.01	2.42± 0.36	12.35± 1.25

		Leaf	1.31± 0.06	290.04± 11.06	329.25± 14.03	0.48± 0.02	3.15± 0.15	11.82± 0.5	20.06± 1.42	0.86± 0.07	BDL	0.07± 0	9.63± 0.44	1.85± 0.12	7.42± 0.54
8	***Holarrhena antidysenterica***	**Stem**	1.38± 0.02	68.86± 0.9	466.64± 7.98	0.88± 0.01	0.92± 0.02	8.35± 0.11	11.32± 0.07	0.15± 0	BDL	0.01± 0	0.42± 0	1.75± 0.21	16.56± 1.58
		Leaf	0.55± 0	58.06± 0.51	142.04± 1.17	0.62± 0	0.87± 0	5.81± 0.03	10.04± 0.13	0.06± 0.01	BDL	0.01± 0	0.45± 0	0.85± 0.02	11.25± 1.25
9	***Saccharum spontaneum***	**Root**	0.72± 0.03	15.06± 0.95	115.73± 5.03	0.35± 0.02	1.48± 0.07	13.16± 0.69	12.41± 0.14	0.84± 0.05	BDL	0.07± 0	3.87± 0.34	2.1± 0.18	15.62± 1.21
		Leaf	0.71± 0.06	27.7± 2.28	127.29± 10.38	0.17± 0.02	0.56± 0.06	1.32± 0.14	4.74± 0.43	0.3± 0.03	BDL	0.05± 0	1.37± 0.1	1.82± 0.15	9.85± 0.98
10	***Typha latifolia***	**Root**	2.02± 0.04	256.2± 4.44	4921.41± 94.92	10± 0.17	4.76± 0.11	2.71± 0.05	52.37± 0.46	3.52± 0.04	BDL	0.07± 0	0.62± 0	2.1± 0.18	9.21± 1.11
		Leaf	0.56± 0.01	666.4± 12.32	124.83± 7.21	1.31± 0.03	1.02± 0.03	0.91± 0.02	13.68± 0.27	0.11± 0.01	BDL	0.02± 0	0.78± 0.02	1.25± 0.02	6.21± 0.88
11	***Acacia auriculiformis***	**Stem**	0.39± 0.02	11.6± 0.36	49.23± 1.19	0.03± 0	0.35± 0.01	4.53± 0.12	15.09± 0.91	0.02± 0	BDL	0.01± 0	0.3± 0.01	2.13± 0.25	17.25± 1.71
		Leaf	1.2± 0.03	242.68± 5.75	393.75± 7.06	0.34± 0.01	2.61± 0.06	9.42± 0.18	40.11± 1.23	0.13± 0.01	BDL	0.04± 0	1.45± 0.01	1.68± 0.26	8.62± 0.85
12	***Hyptis suaveolens***	**Root**	0.87± 0.04	191.46± 2.44	160.51± 7.04	5.36± 0.11	3.21± 0.1	23.63± 0.51	22.17± 0.33	6.05± 0.15	BDL	0.07± 0	0.42± 0	1.89± 0.12	14.2± 1.26
		Stem	2.92± 0.21	3.16± 0.12	114.7± 2.51	4.96± 0.07	4.05± 0.08	4.58± 0.11	4.75± 0.2	6.33± 0.15	BDL	0.24± 0.22	1.3± 0.09	1.23± 0.16	18.23± 2.13
		Leaf	3.99± 0.16	2.31± 0.07	44.17± 1.21	5.37± 0.13	3.81± 0.07	5.35± 0.12	6.35± 0.29	3.72± 0.1	BDL	0.16± 0.18	1.41± 0.12	1.45± 0.25	12.3± 1.24
13	***Mimosa pudica***	**Root**	4.05± 0.32	19.17± 0.26	30.07± 0.22	1.33± 0.08	3.16± 0.2	6.46± 0.13	7.2± 0.21	1.92± 0.24	BDL	0.01± 0	0.12± 0	1.85± 0.02	9.52± 0.36
		Stem	2.36± 0.11	2.71± 0.11	16.03± 0.42	3.09± 0.2	3.45± 0.05	4.51± 0.15	3.08± 0.21	1.12± 0.09	BDL	0.02± 0	0.15± 0	1.25± 0.03	7.45± 0.25
		Leaf	1.56± 0.1	19.49± 1.29	15.14± 0.36	0.4± 0.14	0.96± 0.12	1.21± 0.07	3.55± 0.15	0.25± 0.16	BDL	0.01± 0	0.02± 0	1.53± 0.04	5.25± 0.24
14	***Crotalaria pallida***	**Stem**	2.27± 0.12	3.84± 0.16	36.13± 0.64	0.13± 0	0.67± 0.09	2.16± 0.06	5.47± 0.14	0.16± 0	BDL	0.01± 0	0.08± 0	1.25± 0.05	9.56± 0.98
		Leaf	0.6± 0.04	1.16± 0.08	24.23± 0.42	ND	0.25± 0.01	0.13± 0	0.21± 0	0.01± 0	BDL	ND	ND	0.95± 0.04	6.35± 0.63

15	***Andrographis paniculata***	**Root**	3.64± 0.11	31.29± 0.43	323.58± 12.05	0.88± 0.05	1.86± 0.11	4.24± 0.14	27.45± 1.26	2.68± 0.1	BDL	0.03± 0	ND	1.85± 0.65	8.26± 0.88
		Stem	1.46± 0.02	15.15± 1.21	216.37± 10.09	0.04± 0	0.64± 0.05	3.48± 0.07	17.24± 0.32	0.7± 0.03	BDL	ND	0.03± 0	1.42± 0.25	7.32± 0.45
		Leaf	2.14± 0.07	13.92± 0.09	319.56± 8.89	0.08± 0	0.26± 0.01	0.32± 0.01	28.27± 1.25	0.67± 0.02	BDL	ND	0.01± 0	1.26± 0.021	6.52± 0.2

Note: BDL- Below detection limit

ND- Not detected

Table 27: Bioaccumulation of different trace and toxic metals in plant vegetation at site-VI.

F.		**Site - VI Reservoir Pond**													
S.N.	**Plants**	**Parts**	**Metal concentration (mg kg^{-1} dw)**												
			Cr	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Hg**	**Cd**	**Pb**	**F**	**Ba**
1	***Azadirachta indica***	**Stem**	1.22± 0.02	10.25± 0.08	65.23± 2.15	0.07± 0	0.75± 0.06	4.28± 0.15	8.45± 0.78	0.58± 0.07	BDL	0.01± 0	1.18± 0.03	1.52± 0.05	9.56± 0.85
		Leaf	0.62± 0.02	15.21± 0.12	185.12± 5.65	0.10± 0	1.15± 0.03	3.54± 0.12	12.56± 0.11	0.65± 0.05	BDL	0.01± 0	1.24± 0.02	1.11± 0.08	7.45± 0.25
2	***Syzygium cumini***	**Stem**	0.56± 0.13	20.73± 0.97	58.38± 3.41	0.06± 0.02	2.13± 0.15	3.35± 0.03	15.67± 2.32	2.12± 0.11	BDL	0.01± 0	ND	1.52± 0.24	11.25± 1.56
		Leaf	1.32± 0.09	211.5± 6.25	152.7± 8.15	0.04± 0.1	1.75± 0.1	1.06± 0.1	22.94± 1.38	1.98± 0.31	BDL	0.01± 0.01	0.17± 0	0.97± 0.02	7.45± 0.36
3	***Leucaena leucocephala***	**Stem**	0.84± 0.11	15.35± 0.13	250.92± 1.79	0.09± 0	1.24± 0.19	2.58± 0.12	10.04± 0.27	0.20± 0.12	BDL	0.01± 0	0.15± 0	1.8± 0.12	10.36± 1.24
		Leaf	1.19± 0.16	68.05± 2.66	211.31± 12.33	0.44± 0.03	1.85± 0.1	1.89± 0.13	8.97± 0.19	0.44± 0.18	BDL	0.01± 0	0.19± 0	0.86± 0.25	6.85± 0.54
4	***Lantana camara***	**Stem**	1.48± 0.16	28.53± 0.43	115.25± 0.26	0.11± 0.04	1.41± 0.09	3.62± 0.03	7.43± 0.22	0.82± 0.23	BDL	0.00± 0	0.06± 0	1.16± 0.12	13.56± 2.5
		Leaf	1.53± 0.12	88.66± 5.07	290.99± 7.23	0.15± 0	1.22± 0.12	2.21± 0.13	18.24± 0.11	0.52± 0.08	BDL	ND	0.82± 0.06	0.88± 0.15	8.87± 1.54

Note: BDL- Below detection limit

ND- Not detected

Plate 6: A-B: Different views showing collection of water samples at different sites.

C: A View showing site location Talcher, district Angul, Odisha.

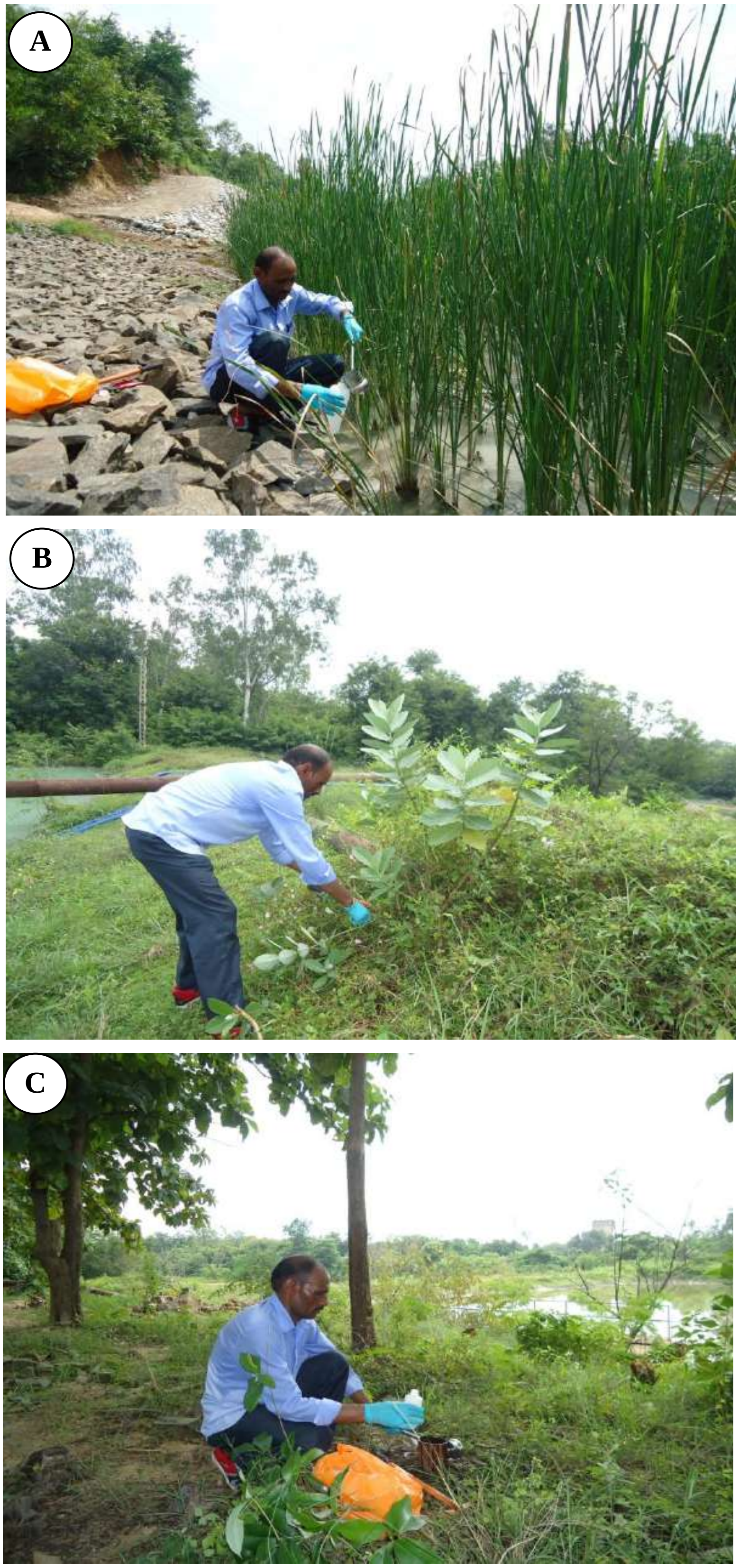


Plate 7: A-B: Different views showing collection of plant samples at various sites;

C: A View showing collection of water sample at site..

7. Faunal diversity and analysis of heavy metals

Different groups of faunal samples including Insecta, Arachnids, butterflies and bovinae were collected from study sites. The collected species mostly consist of Insecta followed by butterflies. In general, Site-IV had maximum ranges of species availability as compared to other sites. Apart from the live-animal collections, various animal-parts like goat-milk, infected goats pellets, palm civet scat and cow-dung, were also collected from the study sites.

Identification of faunal samples

The faunal samples were further identified by means of enumerating various morphological attributes (Plate 8 and 9). Abnormalities of any morphological features were also recorded.

Processing of the samples

The dried samples were acid digested with HNO_3:$HCLO_4$ (3:1 v/v) for the heavy metal analysis. The digested samples were analysed with Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (Table 28-33).

Brachythemis contaminata (F)

Normal goats pellets

Danaus chrysippus

Acraea terpsicore

Toxomerus geminates

Catopsilia pomona (F)

Alphitobius diaperinus

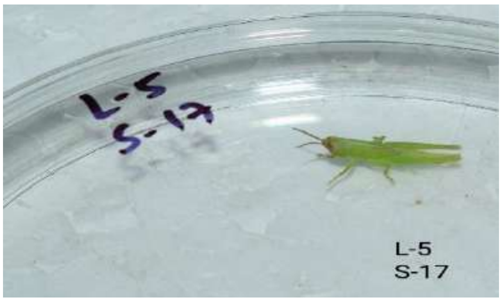
Euphlyctis cyanophlyctis (F)

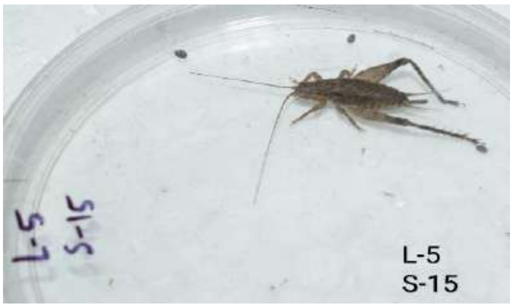
Plate 8: View of selected faunal samples collected from different sites.

Tenebrio obscures *Apis mellifera*

Hierodula patellifera *Gryllodes sigillatus*

Neurothemis tullia *Amata huebneri*





Latana megastridula *Xenogryllus transversus*

Plate 9: View of selected faunal samples collected from different sites.

Metal content in faunal samples

Chromium (Cr)

The concentration of chromium ranged between 0.24-21 mg kg^{-1}. The maximum concentration of Cr was found in Argiope anasuja (21 mg kg^{-1}) at site IV followed by in Atteva aurea and Phlaeoba infumata at site V (Table 31 and 32) respectively.

Manganese (Mn)

Maximum concentration of manganese was found in Camponotus compressus (209 mg kg^{-1}) at site II (Table 29).

Iron (Fe)

The level of Fe was varied from 61-1752 mg kg-^{1}, highest concentration of Fe was found in Hypercompe scibonia (1752 mg kg-^{1}) at site V (Table 32).

Cobalt (Co)

Maximum cobalt content was found in Hypercompe scibonia (3.3 mg kg^{-1}) at site V followed by in Scolopendra calcarata (1.66 mg kg-^{1}) at site IV (Table 32 and 31) respectively.

Nickel (Ni)

Maximum content of nickel was found in Blattella asahinai (22.51 mg kg-^{1}) at site II (Table 29).

Zinc (Zn)

The concentration of zinc was maximum observed in Oxyopes salticus and Hogna conalinensis (382 mg kg-^{1}) at site II and site V (Table 29 and 32) respectively.

Arsenic (As)

Maximum concentration of arsenic was found in Camponotus compressus (4 mg kg-^{1}) followed by in Blattella asahinai (3.7 mg kg-^{1}) at site II (Table 29).

Cadmium (Cd)

The concentration of cadmium was maximum found in Drosophila simulans (8.22 mg kg-^{1}) at site II (Table 29)

Lead (Pb)

The concentration of lead ranged between 0.00-47 mg kg^{-1}. The maximum concentration of Pb was found in Pterostichus melanarius (47 mg kg^{-1}) at site II followed by in Crocothemis servilia (44 mg kg^{-1}) at site III (Table 29 and 30) respectively.

Barium (Ba)

Maximum Barium concentration was found in Pterostichus melanarius (1.35 mg kg^{-1}) at site II (Table 29).

Fluoride and mercury were found to be below detection limit in all the samples.

Table 28: Concentration of different trace and toxic metals in faunal samples at site-I.

A	**Site - I Check Dam Mine Void - 02**											
		Metal concentration (mg kg^{-1} dw)										
S.N.	**Samples**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**	**Ba**
1	*Brachythemis contaminata*	1.41± 0.03	9.57± 0.26	200.78± 3.57	ND	1.34± 0.03	50.3± 0.92	89.75± 1.88	0.76± 0.03	0.13± 0.01	3.07± 0.05	0.75± 0.12
2	*Brachythemis contaminata (F)*	1.03± 0.02	7.03± 0.09	206.48± 2.19	1.1± 0.02	1.29± 0.05	46.23± 0.61	85.79± 1	1.13± 0.02	0.07± 0	1.84± 0.04	0.68± 0.02
3	*Chlaenius tetragonoderus*	1.31± 0.02	12.23± 0.11	220.04± 1.69	0.73± 0.01	1.12± 0.02	6.32± 0.06	67.31± 0.07	0.1± 0	ND	11.5± 0.19	0.52± 0.02
4	*Cormocephalus aurantiipes*	0.54± 0.01	15.34± 0.1	139.88± 0.58	0.06± 0	1.27± 0.01	22.76± 0.06	258.29± 2.6	0.45± 0.01	0.06± 0	0.97± 0.01	0.64± 0.03
5	*Crematogaster subnuda*	6.21± 0.03	79.56± 0.4	318.34± 0.87	ND	9.2± 0.71	24.08± 0.55	428.05± 10.16	ND	ND	1.92± 0.13	0.56± 0.03
6	Goats milk	0.32± 0.01	2.03± 0.03	117.86± 0.33	ND	0.28± 0	1.45± 0.02	28.67± 0.19	0.08± 0	ND	0.54± 0.01	0.00
7	Infected goats pellets	0.36± 0	0.96± 0	30.5± 0.13	ND	0.29± 0	2.69± 0.02	24.29± 0.04	0.04± 0	ND	1.64± 0.01	0.00
8	*Isodermus sp.*	1.37± 0.01	44.38± 0.17	552.75± 1.45	0.45± 0.01	1.63± 0	66.09± 0.26	690.73± 10.4	0.53± 0	0.5± 0	4.1± 0.05	0.55± 0.02
9	*Macrosiagon dimidiata*	1± 0.02	28.44± 0.34	269.8± 2.51	0.56± 0.01	2.46± 0.03	34.76± 0.61	393.35± 4.89	0.35± 0	2.02± 0.02	22.62± 2.29	0.58± 0.03
10	Normal goats pellets	4.05± 0.03	166.44± 0.35	596.8± 5.92	1.55± 0	5.94± 0.01	11.31± 0.02	42.29± 0.06	0.36± 0	ND	0.22± 0	0.68± 0.01

ND- Not detected

Table 29: Concentration of different trace and toxic metals in faunal samples at site-II.

B	Site - II - L - Shape Dam (Frist Position)										
		Metal concentration (mg kg^{-1} dw)									
S.N.	**Samples**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**	**Ba**
1	*Acraea terpsicore*	1.83± 0.19	14.13± 0.52	274.33± 9.55	0.12± 0.01	1.16± 0.12	20.57± 0.4	98.72± 5.87	0.33± 0.04	0.11± 0.01	13.12± 0.87	0.47± 0.02
2	*Acrida conica*	2.11± 0.16	17.53± 0.66	314.58± 10.04	0.42± 0.03	9.1± 0.83	73.92± 5.94	150.12± 7.67	0.16± 0.02	ND	5.53± 0.28	0.35± 0.12
3	*Alphitobius diaperinus*	3.48± 0.1	41.58± 0.94	525.59± 11.69	0.3± 0.01	2.41± 0.08	12.11± 0.15	298.55± 7.65	1.92± 0.05	0.26± 0	40.32± 0.07	0.87± 0.15
4	*Blattella asahinai*	6.16± 0.69	41.32± 0.96	161.48± 1.27	ND	22.51± 0.83	51.34± 1.29	121.36± 15.77	3.74± 0.04	ND	ND	0.00
5	*Butterflies larva*	2.54± 0.06	31.01± 0.89	1594.7± 25.76	0.32± 0.01	1.68± 0.04	6.42± 0.12	83.62± 1.1	0.25± 0.01	ND	6.08± 0.17	0.00
6	*Camponotus compressus*	7.49± 0.08	209.89± 2.55	529.04± 2.62	1.56± 0.03	5.99± 0.1	17.59± 0.27	179.56± 3.01	4.06± 0.07	1.9± 0.03	30.95± 2.43	0.25± 0.02
7	*Catantops pinguis*	3.16± 0.05	52.74± 0	307.55± 0.27	0.47± 0	4.32± 0.04	52± 0.39	229.18± 12.35	0.13± 0	0.18± 0	32.87± 0.52	0.72± 0.12
8	*Catopsilia pomona (F)*	0.85± 0	30.56± 0.01	155.31± 0.37	0.08± 0	0.48± 0	15.62± 0.01	105.99± 0.02	0.15± 0	0.02± 0	3.39± 0	0.21± 0.03
9	Cow dung	4.96± 0.04	396.78± 28.74	544.28± 25.16	1.77± 0.05	4.4± 0.07	11.05± 0.42	27.27± 8.1	0.22± 0.03	0.15± 0.02	1.83± 0.21	1.25± 0.13
10	*Danaus chrysippus*	4.22± 0.34	14.71± 0.66	538.3± 37.49	0.21± 0.01	2.82± 0.66	8.42± 0.67	32.05± 1.65	0.84± 0.12	ND	25.84± 1.97	0.85± 0.14
11	*Diplacodes trivialis*	0.24± 0.04	3.19± 0.11	61.45± 2.97	ND	0.2± 0.02	3.12± 0.14	12.17± 0.45	ND	ND	0.74± 0.06	0.15± 0.02
12	*Diplacodes trivialis*	2.51± 0.51	12.64± 2.4	366.02± 61.28	ND	1.85± 0.41	20.67± 3.76	62.32± 12.15	0.17± 0.05	0.28± 0.07	11.73± 1.99	0.35± 0.03
13	*Drosophila simulans*	16.32± 2.98	54.97± 7.88	1386.26± 98.03	1.45± 0.05	7.08± 1.15	42.34± 2.04	252.46± 57.22	ND	8.22± 3.26	39.08± 2.16	0.78± 0.03
14	*Euploea core*	2.46± 0.02	62.99± 0.18	340.42± 2.48	0.44± 0	1.26± 0.01	16.71± 0.06	117.91± 0.65	0.12± 0	0.2± 0	12.54± 0.14	0.65± 0.02
15	*Jamides celeno*	8.68±	26.64±	267.82±	ND	5.59±	24.88±	170.85±	0.09±	0.18±	41.13±	1.32±

		0.05	0.03	3.15		0.02	0.15	0.98	0.01	0.01	0.54	0.15
16	*Oxyopes salticus*	6.38± 0.01	117.79± 1.37	409.24± 4.49	ND	5.05± 0.09	145.68± 1.75	382.5± 7.36	0.02± 0.01	1.58± 0.01	38.85± 3.24	0.86± 0.02
17	*Pantala flavescens*	1.62± 0.09	26.08± 0.94	1409.26± 109.55	0.16± 0.02	1.55± 0.24	19.91± 0.22	73± 1.01	0.2± 0.02	0.29± 0.02	26.55± 1.17	0.38± 0.03
18	*Pterostichus melanarius*	0.98± 0.03	22.37± 0.95	240.98± 8.87	0.64± 0.03	0.64± 0.03	10.45± 0.45	59.53± 2.71	0.38± 0.02	1.03± 0.05	47.38± 1.59	1.35± 0.14
19	*Pyrrharctia isabella*	7± 0.78	91.65± 7.5	1270.7± 68.94	1.36± 0.18	4.45± 0.78	27.77± 1.36	277.81± 24.67	1.26± 0.06	1± 0.07	38.18± 6.05	0.45± 0.02
20	*Pyrrhocoris apterus*	2.29± 0.02	196.02± 1.38	470.48± 6.38	0.14± 0	1.67± 0.01	32.08± 0.42	174.34± 2.54	0.29± 0.01	0.4± 0.01	4.28± 0.03	0.26± 0.02
21	*Tineola bisselliella*	16.54± 0.03	29.48± 0.02	210.67± 3.58	ND	13.6± 0.13	21.89± 0.43	336.07± 10.28	3.29± 0.08	ND	1.36± 0.92	0.15± 0.02
22	*Xylocopa violacea*	0.41± 0.02	6.59± 0.28	231.94± 9.76	0.14± 0.01	0.47± 0.02	11.65± 0.48	90.44± 3.64	0.31± 0.02	0.07± 0	9.32± 0.37	0.31± 0.02

ND- Not detected

Table 30: Concentration of different trace and toxic metals in faunal samples at site-III.

C	Site - III - L - Shape Dam (Second Position)											
		Metal concentration (mg kg^{-1} dw)										
S.N.	**Samples**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**	**Ba**
1	*Crocothemis servilia*	5.51± 0.02	15.39± 0.12	341.12± 3.41	0.65± 0	2.34± 0	11.97± 0.12	147.8± 0.92	0.8± 0.02	0.43± 0.01	44.7± 2.1	0.82± 0.03
2	*Delta pyriforme*	2.31± 0.03	63.66± 0.09	197.32± 0.04	0.08± 0	0.77± 0	28.26± 0.14	91.29± 0.44	0.51± 0	0.02± 0	1.59± 0.02	0.24± 0.01
3	*Diplacodes trivialis*	2.34± 0.03	18.29± 0.06	418.29± 1.64	0.07± 0	1.91± 0	22.36± 0.05	97.48± 0.1	1.76± 0.01	0.1± 0	4.65± 0.01	0.35± 0.02
4	*Euphlyctis cyanophlyctis (F)*	1.24± 0	32.71± 0.24	704.28± 18.96	0.46± 0.01	1.14± 0.02	4.77± 0	49.68± 0.2	0.16± 0	0.01± 0	0.51± 0.02	0.00
5	*Euphlyctis cyanophlyctis (M)*	1.4± 0.02	19.35± 0.11	821.29± 12.49	0.47± 0	0.96± 0	4.09± 0.03	58.69± 0.43	0.43± 0	0.06± 0	0.38± 0	0.00
6	*Hydaticus continentalis*	4.66± 0.01	23.37± 0.04	281.78± 0.38	0.19± 0	2.74± 0.02	27.79± 0.13	91.3± 0.31	0.66± 0.03	0.17± 0.01	4.01± 0.02	0.15± 0.02
7	*Orthetrum luzonicum*	2.09± 0	15.61± 0.38	418.49± 10.4	0.27± 0	1.24± 0.01	34.67± 0.35	81.9± 0.86	0.44± 0.01	0.27± 0	3.92± 0	0.40± 0.03
8	*Pardosa milvina*	8.52± 0.19	53.98± 0.35	666.69± 12.78	0.5± 0.01	4.43± 0.09	72.81± 1.09	302.25± 4.54	0.56± 0.01	3.22± 0.03	2.41± 0.08	0.32± 0.04

ND- Not detected

Table 31: Concentration of different trace and toxic metals in faunal samples at site-IV.

D	Site - IV Core Pond										
		Metal concentration (mg kg^{-1} dw)									
S.N.	**Samples**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**	**Ba**
1	*Argiope anasuja*	21.21± 1.26	92.3± 5.56	780.35± 49.32	1.35± 0.14	12.83± 0.49	127.04± 3.93	397.8± 24.01	ND	1.51± 0.19	10.57± 1.53	0.35± 0.02
2	*Diplacodes trivialis*	4.49± 0.25	13.69± 0.03	262.62± 10.27	0.18± 0	1.63± 0	18.12± 0.02	85.19± 0.48	0.38± 0	0.14± 0	6.25± 0.04	0.38± 0.01
3	*Earias biplaga*	11.84± 1.06	28.74± 0.13	398.86± 12.35	0.37± 0	5.07± 0.07	30.61± 0.14	223.76± 8.72	ND	0.64± 0.01	21± 0.15	0.42± 0.01
4	*Pheretima praepinguis*	0.95± 0.01	19.15± 0.02	598.07± 22.11	0.42± 0	0.73± 0.01	2.52± 0.01	69.36± 0.65	1.37± 0.01	0.06± 0	0.69± 0	0.00
5	*Plexippus paykulli*	5.67± 0.08	18.52± 0.19	235.3± 2.34	ND	2.61± 0.02	102.61± 5.65	344.62± 0.47	1.08± 0.03	3.83± 0.05	9.13± 0.21	0.15± 0.02
6	*Scolopendra calcarata*	4.29± 0.07	30.99± 0.51	558.89± 16.76	1.66± 0.01	3.43± 0.06	23.58± 0.35	315.63± 1.69	0.92± 0	0.3± 0.01	8.08± 0.04	0.32± 0.03
7	*Sybra aequabilis*	1.46± 0.01	52.88± 0.14	209.3± 3.54	0.32± 0	2.05± 0.02	15.74± 0.14	72.45± 0.38	2.22± 0.04	0.45± 0	3.13± 0	0.25± 0.02

ND- Not detected

Table 32: Concentration of different trace and toxic metals in faunal samples at site-V.

E	**Site - V Check Dam - 3B**											
		Metal concentration (mg kg^{-1} dw)										
S.N.	**Samples**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**	**Ba**
1	*Acraea terpsicore*	3.63± 0.09	36.58± 0.96	517.83± 13.15	0.56± 0.01	5.11± 0.16	12.29± 0.38	90.94± 1.78	ND	0.26± 0	9.27± 0.1	0.28± 0.12
2	*Atteva aurea*	18.5± 0.03	117.5± 1.39	800.2± 11.6	ND	21.56± 0.06	40.26± 0.54	441± 28.57	ND	ND	20.7± 0.03	0.38± 0.15
3	*Brachythemis contaminata*	2.67± 0.08	32.4± 0.95	633.7± 23.22	0.94± 0.03	3.01± 0.16	27.4± 0.61	93.94± 1.94	0.63± 0.04	0.32± 0.01	6.89± 0.19	0.42± 0.03
4	*Caleta decidia*	9.78± 1.41	34.15± 2.2	365.32± 26.72	ND	4.97± 0.48	10.75± 1.36	257.32± 13.03	ND	0.45± 0.01	10.56± 1.84	0.36± 0.05
5	*Cobras scale*	0.89± 0.05	4.89± 0.26	124.08± 4.44	0.12± 0	0.51± 0.04	2.59± 0.12	40.46± 2.04	0.16± 0.01	0.06± 0	2.67± 0.12	0.28± 0.03
6	*Dichromorpha viridis*	2.02± 0.02	6.23± 0.04	133.56± 1.26	0.13± 0	1.05± 0	44.9± 0.01	172.86± 5.55	ND	0.12± 0	2.72± 0.04	0.21± 0.02
7	*Euphlyctis cyanophlyctis*	1.24± 0	16.19± 0.07	430.22± 7.7	0.48± 0	0.92± 0.02	2.54± 0.02	67.86± 0.83	0.09± 0	0.08± 0	2.48± 0.01	0.22± 0.01
8	*Gomphocerippus rufus*	4.91± 0.01	47.08± 0.35	332.9± 2.56	0.64± 0	4.63± 0.02	44.58± 0.41	186.04± 5.88	ND	0.85± 0.01	37.9± 0.27	0.65± 0.25
9	*Hogna conalinensis*	12.35± 0.01	41.81± 0.44	487.8± 3.3	1.12± 0	6.58± 0.14	23.22± 0.31	382.87± 19.9	2.47± 0.01	0.57± 0.02	6.92± 0.17	0.45± 0.15
10	*Hypercompe scibonia*	8.85± 0.07	177.83± 1.72	1752.53± 24.48	3.3± 0.01	9.29± 0.07	11.71± 0.1	178.59± 1.51	1.39± 0.01	0.34± 0.01	7.01± 0.21	0.24± 0.02
11	*Jamides celeno*	14.86± 0.12	66.31± 1.09	484.71± 9.33	ND	8.54± 0.15	22.62± 0.06	192.09± 15.39	ND	ND	24.55± 0.48	0.35± 0.01
12	*Latana megastridula*	8.82± 0.06	36.59± 0.46	654.28± 1.34	1.51± 0	5.82± 0	39.61± 0	227.93± 15.44	ND	0.49± 0.01	9.97± 0.03	0.25± 0.05
13	*Missulena walckenaer*	5.93± 0.04	42.84± 0.05	605.87± 2.62	0.51± 0	3.25± 0.02	64.82± 0.43	261.05± 0.31	ND	1.03± 0	29.03± 2.26	0.55± 0.03
14	*Neurothemis tullia*	2.7± 0.04	10.95± 0.07	166.52± 3.37	0.25± 0	1.84± 0.05	13.84± 0.23	77.97± 0.3	0.56± 0.01	0.63± 0	2.48± 0	0.15± 0.01
15	Palm civet scat	1.1±	42.22±	134.17±	0.24±	3.22±	12.22±	31.74±	0.07±	0.03±	0.28±	0.00

		0.02	0.5	1.57	0	0.05	0.18	0.43	0	0	0	
16	*Phlaeoba infumata*	18.98± 1.07	58.68± 5.8	361.72± 17.48	0.5± 0.03	6.61± 0.53	40.42± 1.39	199.18± 8.89	ND	0.38± 0	24.6± 0.76	0.58± 0.02
17	*Physa fontinalis*	0.43± 0.08	85.02± 14.25	917.01± 44.09	1.07± 0.15	3.83± 0.34	5.16± 0.83	9.4± 1.95	0.85± 0.15	0.53± 0.11	0.4± 0.08	0.35± 0.05
18	*Sceliphron caementarium*	9.16± 0	20.75± 0.05	349.49± 2.94	ND	4.99± 0.05	18.85± 0.03	88.62± 0.27	ND	0.31± 0.01	25.99± 0.24	0.52± 0.05
19	*Trechus obtusus*	6.3± 0.07	20.3± 0.01	213.05± 0.11	0.35± 0	2.9± 0.03	15.04± 0.02	91.82± 0.02	ND	0.17± 0	29.76± 0.08	0.50± 0.03
20	*Xenogryllus transversus*	1.87± 0.04	59.73± 0.27	251.4± 2.73	0.31± 0	1.57± 0.02	33.49± 0.27	155.2± 0.66	ND	0.08± 0	3.54± 0	0.12± 0

ND- Not detected

Table 33: Concentration of different trace and toxic metals in faunal samples at site-VI.

F	**Site - VI Reservoir Pond**											
		Metal concentration (mg kg^{-1} dw)										
S.N.	**Samples**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**	**Ba**
1	*Amata huebneri*	3.02± 0.44	25.41± 5.78	309.3± 63.31	0.47± 0.32	1.76± 0.38	20.14± 4.36	93.63± 42.94	0.36± 0.06	0.18± 0.17	2.79± 0.21	0.12± 0.02
2	*Anacridium aegyptium*	0.87± 0.08	39.03± 46.65	177.63± 15.78	0.27± 0.27	1.19± 0.94	26.79± 29.63	88.81± 66.18	0.11± 0.04	0.11± 0.02	0.83± 0.23	0.25± 0.01
3	*Brachythemis contaminata*	2.91± 0.01	21.06± 17.78	160.41± 28.98	0.23± 0.33	1.89± 0.44	23.53± 21.06	68.21± 18.26	0.38± 0.53	0.15± 0.22	1.75± 0.08	0.12± 0.01
4	*Ceriagrion coromandelianum*	5.36± 0.2	15.88± 0.44	182.79± 2.41	ND	2.83± 0.18	15.94± 0.49	101.26± 4.04	ND	ND	3.18± 0.31	0.32± 0.03
5	*Euphlyctis cyanophlyctis (M)*	0.33± 0.01	5.89± 0.2	81.81± 1.31	0.19± 0.01	0.37± 0.02	0.4± 0.01	10.84± 0.62	0.15± 0.01	ND	ND	0.00
6	*Hanuman langurs scat*	4.08± 0.24	235.15± 18.95	785.77± 42.99	1.36± 0.18	12.37± 0.41	13.39± 1.45	61.47± 4.08	0.23± 0.01	0.03± 0.01	ND	0.00
7	*Neurothemis tullia*	3.83± 0.46	40.86± 0.17	397.99± 82.31	0.72± 0.2	2.58± 0.11	37.58± 12.36	88.18± 14.39	0.65± 0.37	0.22± 0.22	2.65± 0.82	0.21± 0.02
8	*Oechophylla smaragdina*	6.87± 0.11	171.75± 10.96	1194.15± 11.93	0.29± 0.01	3.26± 0.07	9.27± 0.15	172.91± 1.43	ND	0.37± 0	10.31± 0.01	0.48± 0.25
9	*Oxya hyla*	2.25± 0.01	26.5± 0.44	274.28± 4.77	0.42± 0.01	3.4± 0.03	33.8± 0.54	171.94± 2.88	ND	0.11± 0.01	5.41± 0.06	0.36± 0.15
10	*Xylocopa latipes*	0.47± 0.01	7.4± 0.03	82.38± 5.78	0.18± 0	0.45± 0.01	2.15± 0.04	22.33± 0.04	0.1± 0	0.02± 0	0.51± 0.01	0.00

ND- Not detected

Table 34: Guidelines for Metals in foods, Vegetables and plants.

Metals (mg kg^{-1})	WHO/FAO	EC/CODEX	Normal range in plants
As	1.0	-	-
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

Final Report

Downstream Impacts of Water Withdrawal by TTPS from Brahmani River

Submitted to:

NTPC LIMITED
TALCHER THERMAL POWER STATION
ANGUL, ODISHA

NATIONAL INSTITUTE OF HYDROLOGY
(An ISO 9001:2015 Institute under DoWR, RD & GR, Ministry of Jal Shakti, GoI)
ROORKEE – 247 667 (UTTARAKHAND)

July 2019

CONTRIBUTIONS

Project Director	**Dr. Sharad K. Jain** **Director** **National Institute of Hydrology** **Roorkee – 247 667**
Principal Investigator	**Dr. Pradeep Kumar** **Scientist 'C'** **Environmental Hydrology Division** **National Institute of Hydrology** **Roorkee – 247 667**
Co-Investigators	**Dr. C. K. Jain, Sc. 'G' & Head, EHD** **Dr. M. K. Sharma, Sc. 'D'** **Dr. S. S. Rawat, Sc. 'D'**
Scientific/Technical Staff	**Smt. Babita Sharma, RA** **Smt. Beena Prasad, RA** **Sh. Rakesh Goyal, Tech. Gr. I**

PREFACE

NTPC is operating Talcher Thermal Power Station (TTPS) at Talcher, Distt. Angul, Odisha with total installed capacity of 460 MW [{4x60 MW (Stage-I)} + {2x110 MW (Stage-II)}]. The project was implemented by erstwhile Orissa State Electricity Board (OSEB) and was subsequently taken over by NTPC on 03.06.1995 and is under commercial operation.

TTPS is filling its fly ash into Quarry Nos. 2, 3A & 3B of South Balanda Open Cast Mines of MCL since in Sep.-2005. These quarries are at distance of about 12 km from TTPS Stage – I & II. MoEF&CC has accorded the permission to TTPS to continue the disposal of fly ash for the maximum quantity of 1.2 MTPA on temporary basis for a further period of five years with effect from 10.04.2017 with certain conditions. One of the conditions is that "Only decanted water from mine, make up water from treated effluents such as cooling tower blow down and treated sewage water shall be used for making ash slurry. Raw water withdrawal from Brahmani River for purpose of making ash slurry shall be minimised. Downstream impacts of water withdrawal from Brahmani River shall be studied and report submitted to the Ministry."

In view of the power generation capacity requirements and future capacity addition plans, NTPC is proposing to enhance the capacity of Talcher Thermal Power Station (TTPS) by adding 2 nos. units of 660 MW each, as Talcher Thermal Power Project (TTPP) Stage-III (2x660 MW). The TTPP Stage-III is envisaged as an inter-regional base load station for meeting the power demand of Eastern Region Beneficiaries and the home state - Odisha. TTPS has submitted the EIA report for TTPP Stage – III (2 x 660 MW) to the MoEF&CC, Govt. of India. The project is expected to start yielding benefits in 2022. TTPP Stage III will be using about 3800 cubic meters per hour water from the upstream of Samal Barrage on the River Brahmani for operating the new units.

Accordingly, TTPS intended to carry out the study of "Downstream impacts of water withdrawal from Brahmani River" due to operation of the ongoing TTPS Stage I (4x60 MW) & Stage II (2x110 MW) and the TTPP Stage III (2x660 MW).

In this regard, the NTPC Limited, Talcher Thermal Power Station, Angul, Odisha has awarded this work to National Institute of Hydrology, Roorkee to study "Downstream impacts of water withdrawal by TTPS from Brahmani River". NIH scientists have carried out the study as per the agreed plan.

This report has been prepared by a team of NIH scientists, led by Dr. Pradeep Kumar, Sc. 'C', Environmental Hydrology Division, National Institute of Hydrology, Roorkee, based on the field investigations and analysis carried out during the project period.

(Sharad K. Jain)
DIRECTOR

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1.0 INTRODUCTION

1.1 Background

NTPC is operating Talcher Thermal Power Station (TTPS) at Talcher, Distt. Angul, Orissa with total installed capacity of 460 MW [{4x60 MW (Stage-I)} + {2x110 MW (Stage-II)}]. The project was implemented by erstwhile Orissa State Electricity Board (OSEB) and was subsequently taken over by NTPC on 03.06.1995 and is under commercial operation. The project is located near Talcher town in Angul district of Orissa having Latitude and Longitude as 20°55' N and 85°25' E respectively. The site is approachable from Banarpal–Talcher section of National Highway No. 23 at a distance of about 1 km from Anand Bazar. Nearest railway station is at Talcher on Talcher-Cuttack section of North Eastern Railway at about 4 Kms. The nearest commercial airport is Bhubaneswar at about 90 km.

TTPS is filling its fly ash into Quarry Nos. 2, 3A & 3B of South Balanda Open Cast Mines of MCL since in Sep.-2005. These quarries are at distance of about 12 km from TTPS Stage – I & II. MoEF&CC has accorded the permission to TTPS to continue the disposal of fly ash for the maximum quantity of 1.2 MTPA on temporary basis for a further period of five years with effect from 10.04.2017 with certain conditions. One of the conditions is that "Only decanted water from mine, make up water from treated effluents such as cooling tower blow down and treated sewage water shall be used for making ash slurry. Raw water withdrawal from Brahmani River for purpose of making ash slurry shall be minimised. Downstream impacts of water withdrawal from Brahmani River shall be studied and report submitted to the Ministry."

In view of the power generation capacity requirements and future capacity addition plans, NTPC is proposing to enhance the capacity of Talcher Thermal Power Station (TTPS) by adding 2 nos. units of 660 MW each, as Talcher Thermal Power Project (TTPP) Stage-III (2x660 MW). The TTPP Stage-III is envisaged as an inter-regional base load station for meeting the power demand of Eastern Region Beneficiaries and the home state - Odisha. TTPS has submitted the EIA report for TTPP Stage – III (2 x 660 MW) to the MoEF&CC, Govt. of India. The project is expected to start yielding benefits in 2022. TTPP Stage III will be using about 3800 cubic meters per hour water from the upstream of Samal Barrage on the River Brahmani for operating the new units.

Accordingly, TTPS intends to carry out the study of "Downstream impacts of water withdrawal from Brahmani River" due to operation of the ongoing TTPS Stage I (4x60 MW) & Stage II (2x110 MW) and the TTPP Stage III (2x660 MW).

Keeping in view the above, NTPC issued a NIT No. 40081902 dated 25.10.2017 for study of "Downstream impacts of water withdrawal from the upstream of Samal Barrage Discharge on River Brahmani" with last date as 03.11.2017. The National Institute of

Hydrology (NIH), Roorkee participated in the tender process and the consultancy was successfully awarded to NIH.

1.2 Objectives

The broad objectives for the studies proposed to be undertaken are as follows:

i) To analyse the quantity of raw water required to be withdrawn for TTPS (Stage I & II) and TTPP Stage III from river Brahmani before and after the closure of TTPS Stage I&II,

ii) To collect and compile various water withdrawals from Brahmani river in the vicinity of the points of diversion of flows for TTPS,

iii) To assess the impacts of water withdrawal from Brahmani river for TTPS on the downstream water requirements,

iv) To assess the impacts of water withdrawal from Brahmani river for TTPS on the deposition of sediment and reduction in sediment supply to downstream reaches.

1.3 Scope of Work

As per the tender documents, the scope of work is divided into two parts:

a) Study of "Downstream impacts of water withdrawal from Brahmani River" due to operation of 460MW [{4x60 MW (Stage-I)} + {2x110 MW (Stage-II)}] :

(i). Estimation of quantity of water requirement for making ash slurry on an average.

(ii). Estimation of quantity of recyclable water available for ash slurry making like mine decanted water, cooling tower blow down and treated sewage water.

(iii). Estimation of quantity of raw water from river Brahmani required if any for ash slurry making.

(iv). Study on any deposition of sediment and a reduction in sediment supply to downstream reaches due to water intake point.

(v). Stress on the downstream flows of river Brahmani due to this water intake to be studied.

(vi). Various uses of water and their implications in the downstream flows of Brahmani river up to 500 m from the intake point of NTPC/TTPS Stage – I & II may be studied.

Long Term Hydro-meteorological Data like Water Availability, Gauge and Discharges, etc. already available with Government Agencies like Water Resources Department, etc. may be used for the purpose of water availability and impact of drawal on downstream users.

b) Study of "Downstream impacts of water withdrawal from the upstream of Samal Barrage Discharge on the River Brahmani" due to operation of Stage – III (2 x 660 MW).

(i). Study on any deposition of sediment and a reduction in sediment supply to downstream reaches due to drawal of water.

(ii). Stress on the downstream flows of river Brahmani due to this drawal of water to be studied.

(iii). Various uses of water and their implications in the downstream flows of Brahmani river up to 500 m from the drawal point of NTPC/TTPS Stage - III may be studied.

Long Term Hydro-meteorological Data like Water Availability, Gauge and Discharges, etc. already available with Government Agencies like Water Resources Department, etc. may be used for the purpose of water availability and impact of drawal on downstream users.

After assessment of individual projects (TTPS Stage I&II and TTPP Stage III), the analysis has also been carried out for both the scenarios, before and after the closure of TTPS Stage I & Stage II.

2.0 STUDY AREA

The study area covers presently operational Talcher Thermal Power Station (Stage I & II), proposed Talcher Thermal Power Station (Stage III), Brahmani river reach of 500m downstream of the water withdrawal points for operational and proposed TTPS. The TTPS is located near Talcher town, District Angul, Odisha State. The vicinity map of Angul district and is shown in Fig. 2.1.

Fig. 2.1 Vicinity map of Angul district

However, the Brahmani river from Rengali reservoir to 10 km downstream of intake point of TTPS (Stage I&II) is also required to be mapped with respect to the analysis undertaken. As per the basin classification of Central Water Commission (CWC), Brahmani river is part of Brahmani-Baitarni Basin (Fig. 2.2). Brahmani sub-basin is shown in Fig. 2.3.

2.1 Angul District

The District of Angul situated at the heart of Odisha was a part of Undivided Dhenkanal District till early March 1993, but for the administrative convenience, Dhenkanal District was divided into two parts i.e. Dhenkanal and Angul vide State Government Notification No. DRC-44/93/14218/R. dated 27 March 1993. Angul District came into existence as a separate District on April 1, 1993. The District is surrounded by Cuttack & Dhenkanal on the east, Sambalpur & Deogarh on the west, Sundargarh & Keonjhar on the north and Phulbani on the south. Covering an area of 6232 sq.km, Angul District is located at Latitude 20.50 North to 85.00 East Longitude.The altitude of this place is 564 to 1187 m.

Angul District is densely populated as per the 2011 census.The District has 1930 villages with 1273821 population comprising of 655718 male and 618103 female. District‘s rural population is more compared to its urban population, as is the case in almost all other Districts of the state. Total rural population of the District is 1067275 while total urban population is 206546 as per 2011 census. The District has 239552 SC and 179603 ST population.

The Administrative headquarters of the Angul District is located at Angul city. In the present scenario of the administrative set up, there are 4 sub division, 8 tahsils and 8 blocks in the District. There are total number of 225 Gram Panchayats, 2 Municipalities, 1 Notified Area Council (NAC), and 23 Police stations functioning in the District of Angul.

The climatic condition of Angul District is much varied.The average annual rainfall of the District is 1421 mm. However there is a great variation of rainfall from year to year. The rainfall in the District during the last 10 years varied between 896 mm & 1744 mm. The best time to visit this District is during winter.

Agriculture occupies a vital place in the economy of Angul District, as it provides direct and indirect employment to around 70 % of its total work force, as per the 2001 census. The total cultivable area of this District is 2, 16,403 hectares, covering 32.7 % of its total geographical area. The major crops of the Kharif season are paddy, maize, ragi, oilseeds, pulses, small millets and vegetables etc. Paddy, wheat, maize, field pea, sunflower, garlic, ginger, potato, onion, tobacco, sugarcane and coriander etc are the major Rabi crops.

The last decade has witnessed a tremendous improvement in the industrial scenario of Angul District.Many public sector undertakings have setup up plants and offices here, like National Aluminium Company Limited (NALCO), Mahanadi Coal Fields Limited (MCL), National Thermal Power Corporation (NTPC) and Talcher Thermal Power Station (TTPS). One of the major coalfields is the Talcher coalfield, which contains huge reserves of power grade non-coking coal. Engineering Units, Rice Mills, Hotels, Fly Ash Brick units, Stone Crushers, Service Units, Bleaching units, Bread and Bakery units, Tyre Retreading units, Flour Mills and Spices Grinding units etc. are some of the small scale industries functioning here.

Dhokra casting works, Terracotta works, Wood carvings, Art textiles and Soft toys etc are some examples of the crafts that have been generating revenues for this District. The District Industries Center functioning in the District promotes its various industrial activities.

The Angul District is having 4,09.260 male literates and 2,62,173 female literates. As per educational institutes are concerned Angul District has many Government and Private Institutes. Government College (Angul), Angul Women's College (Angul) and Talcher College (Talcher) are the important educational institutions of the District. There are other training institutes of the District, like Police Training College (PTC) Angul, Forest Rangers College Angul and a number of industrial training institutes providing quality technical education to a vast number of students of the District. Different educational programmes like Sarva Sikhya Aviyan, Total Literacy Campaign, Post Literacy Campaign, Continuing Education Programme and National Child Labour Project have been initiated by the Government with an objective of reaching education to all, including those unprivileged ones for whom education is still out of bounds and reach.

2.2 Brahmani-Baitarni River Basin

Brahmani and Baitarni basin is comprised of two sub-basins; Brahmani sub basin and Baitarni sub basin draining total area of 51822 Sq.km. Brahmani alone occupies 72.35% geographical area of the basin. The two sub basins are further divided into 79 watersheds. Brahmani and Baitarni basin has a tropical climate and receives most of the rainfall from the South-west monsoon during the period from June to October. The major part of basin is covered with agricultural land accounting to 52.04% of the total area and 20.95% of the basin is covered by water bodies. The basin has a cultivable area of about 3.2 M. ha which is 1.6% of the total cultivable area of the country.

As far as water resources are concerned, the utilizable surface water of the basin has been estimated to be about 18.3 BCM. Average water resource potential of the basin is 28.48 BCM. The basin has total live storage capacity of 5523.69 MCM. Apart from Tanks, ponds and lakes, the basin also has few major water reservoirs like Rengali and Salandi.

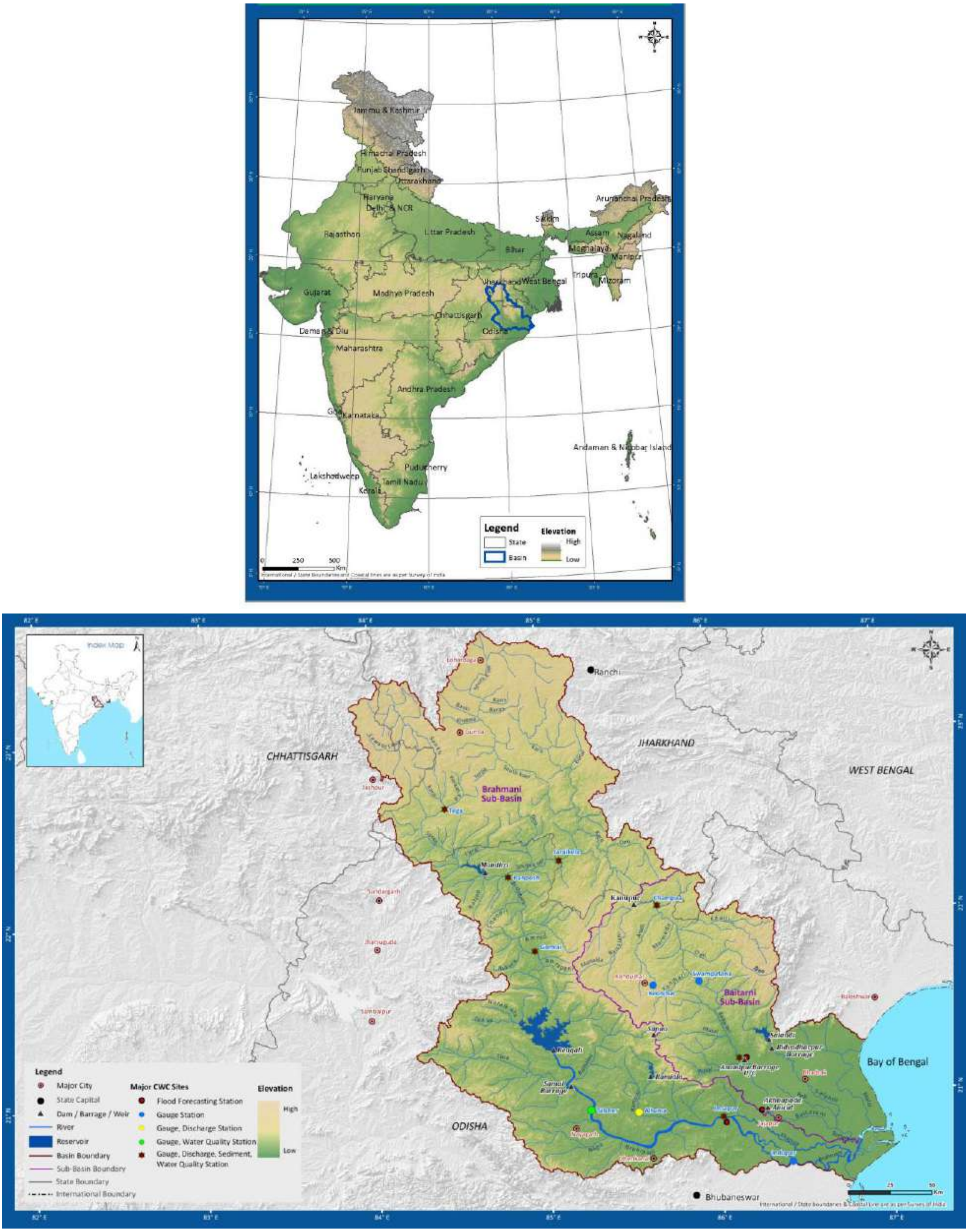

Fig. 2.2: Brahmani and Baitarni Basin (Source: MOWR, 2014)

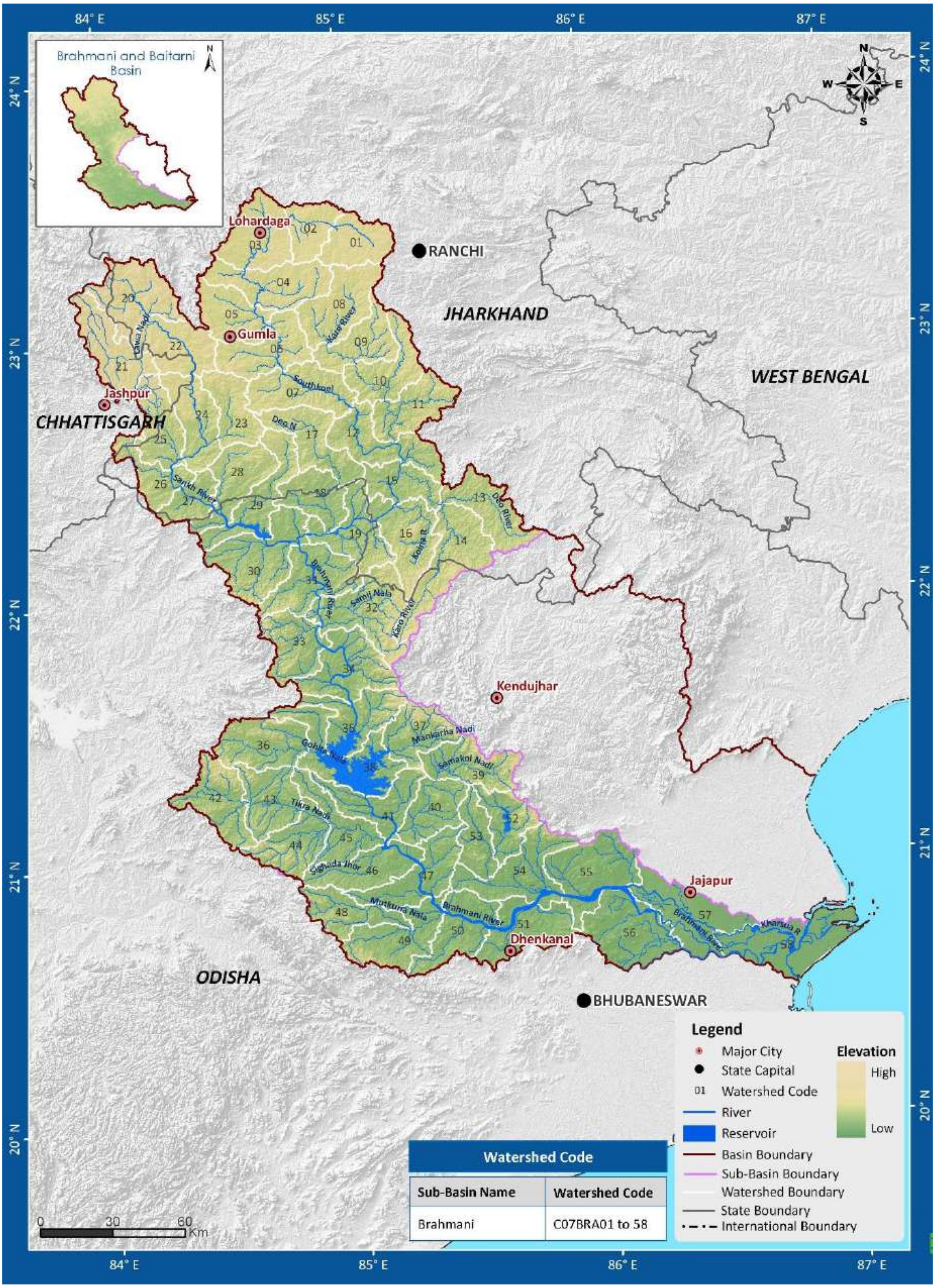

Fig. 2.3 Brahmani River Basin (Source: WRIS Website)

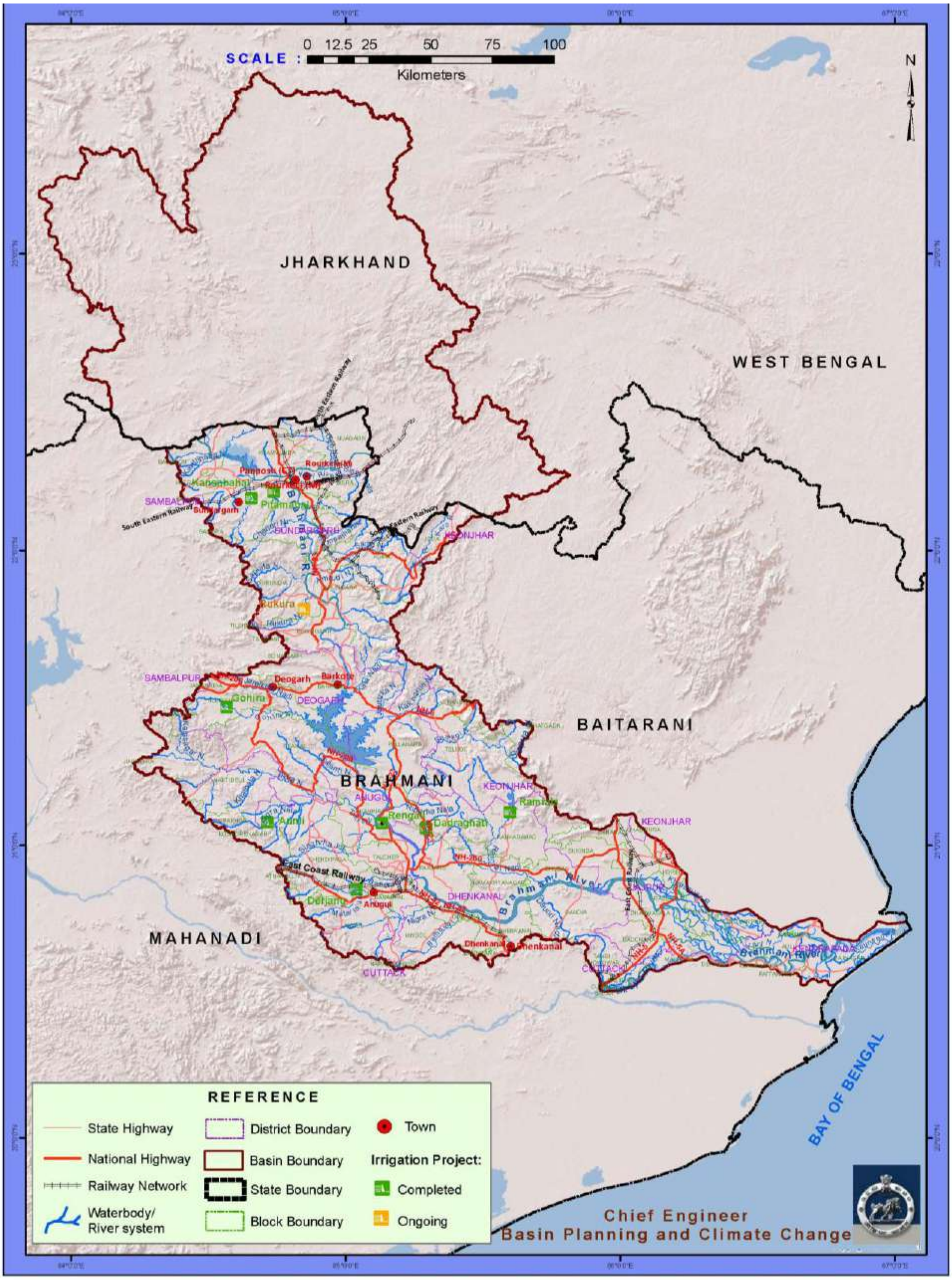

Fig. 2.4 Water Resources Projects in Brahmani River Basin (Source: WRD, Odisha)

2.3 Talcher Town

Talcher also named as Coal City of Odisha is one of the fastest growing industrial and coal hubs in the state. Because of its huge coal reserves, the city has been ranked among the highest in terms of GDP in Odisha. It is also one of the 4 sub-divisions of Angul district in the Indian state of Odisha. Situated on the right bank of the river Brahmani, it is one of the fastest growing industrial and mining complexes of the country. The city is surrounded by the coalfields under MCL (Mahanadi Coalfields Limited) and has two Mega Power plants like NTPC, TTPS.

As of 2011 India census, Talcher had a population of 40,841 males constitute 55% of the population and females 45%. Talcher has an average literacy rate of 75%, higher than the national average of 59.5%: male literacy is 80%, and female literacy is 62%. In Talcher, 12% of the population is under 6 years of age.

Talcher is known for its coal reserves. It has numbers of underground and open-cast mines. Dera colliery is the oldest mine here. The coalfields are managed by Mahanadi Coalfields Limited (MCL), a subsidiary of Coal India Limited (CIL). The establishment of Talcher Thermal Power Station (TTPS) and Talcher Super Thermal Power Station (TSTPS) both owned by National Thermal Power Corporation, Fertilizer Corporation of India (FCI), Heavy Water Plant and the Collieries of Mahanadi Coalfields Limited (MCL) have enhanced the importance of the place.

NTPC: The National Themal Power Corporation, India's leader in power generation has 2 numbers of thermal power plant in Angul district. One, NTPC/TTPS located 7 km from Talcher on the way to Bhubaneswar is of 460MW and the other one, the bigger one NTPC/TSTPS also known as NTPC Kaniha is of 3000 MW super thermal power station located at Kaniha, in Talcher subdivision. NTPC is also proposing to enhance the capacity of Talcher Thermal Power Station (TTPS) by adding 2 nos. units of 660 MW each, as Talcher Thermal Power Project (TTPP) Stage-III (2x660 MW).

MCL: Mahanadi Coal Field Limited is located in Talcher, a well known mining centre of coal. A unit of Coal India Limited, MCL was previously under SECL (South Eastern Coal Field Ltd.). The major mines under MCL in Talcher are the Bhubaneswari OCP (Capacity-25 MT), Ananta OCP, Bharatpur OCP, Lingaraj OCP, Kaniha OCP, Jagannath OCP, Hingula OCP, Balram OCP, Nandira colliery(UG) Dera colliery(UG). Some new projects will also come up in future which are under progress of exploration by CMPDI Ltd.

FCI: The Fertilizer Corporation of India has its unit in Talcher. One of the oldest industries of this area, FCI Talcher has faced problems in its viable operation. Hence, the plant has faced a closure since 1998. The township & plants do exist, waiting for much needed revival. As per a recent report RCF (Rashtriya Chemicals and Fertilizers) plans to revive the FCI plant in Talcher with a capital outlay of about Rs. 3000 crores.

HWP: The Heavy Water Plant is located in Talcher is a Govt. of India organisation under the aegis of Ministry of Atomic Power & Energy. This plant is involved in production of Organic Solvents like TBP, D2EFHA, TAPO & TOPO etc. and other allied chemicals required as a part of the Nuclear Power Programme of the country.

2.3 Talcher Thermal Power Station (TTPS)

Talcher Thermal Power Station (TTPS) is situated near Talcher town in Angul district of Odisha having existing capacity of 460 MW [Stage-I (4x60 MW) + Stage-II (2x110 MW)]. The project was implemented by erstwhile Orissa State Electricity Board (OSEB) and was subsequently taken over by NTPC on 03.06.1995 and is under commercial operation.

In view of the power generation capacity requirements and future capacity addition plans, NTPC is proposing to enhance the capacity of Talcher Thermal Power Station (TTPS) by adding 2 nos. units of 660 MW each, as Talcher Thermal Power Project (TTPP) Stage-III (2x660 MW). The TTPP Stage-III is envisaged as an inter-regional base load station for meeting the power demand of Eastern Region Beneficiaries and the home state - Odisha. TTPS has submitted the EIA report for TTPP Stage – III (2 x 660 MW) to the MoEF&CC, Govt. of India and the project is expected to start yielding benefits in 2022. Coal for the power generation is sourced from the Talcher Coalfield and water for the thermal power is proposed to be taken from Samal Barrage.

The proposed site is located at a Latitude of 20° 54' 02" North to 20° 55' 05" North and Longitude of 85° 12' 10" East to 85° 13' 00" East near Talcher Town, Angul district of Odisha. The site is about 4 km from Talcher Town and about 25 km from district headquarters Angul. The nearby gram panchayats are Santaparha, Jagannathpur, Bantol, and Gurujanguli. Nearest railway station named 'Talcher' is on Talcher-Cuttack section of North Eastern Railway (renamed East Coast Railway) at about 2 Kms. However, a small railway station named 'Talcher Thermal' is located near project boundary. The area is accessible by NH-23 (renamed NH-149) at about 1 km. The nearest commercial airport is at Bhubaneshwar at an aerial distance of 90 km approx. and about 150 km by road.

No additional land acquisition is envisaged for proposed TTPS Stage-III (2x660 MW). The plant facilities for this expansion stage would be accommodated within the land available in the existing power station and township of Talcher TPS, Stage-I & II. However, about 2.337 acres of government forest land near upstream of Samal Barrage on Brahmani River, is proposed to be acquired from state government. Make-up Water Pipelines (about 30 km) are proposed to be laid along the Right Bank Canal of Samal Barrage up to TTPP.

About 223 acres of land would be required for Right of Use (ROU) for about 30 meter wide corridor and about 30 km long pipeline (NTPC, 2018).

3.0 METHODOLOGY

3.1 Assessment of Quantity of Raw Water to be Withdrawn from Brahmani River for TTPS (Stage I & II)

Water is one of the key input requirements for thermal power generation. Water is required for process cooling in the condenser, ash disposal, removal of heat generated in plant auxiliaries, and various other plant consumptive uses. For power plants located on main land, the raw water is generally drawn from fresh water source such as river, lake, canal, reservoir, barrage. Plant consumptive water requirement is governed by a number of factors such as quality of raw water, type of condenser cooling system, quality of coal, ash utilization, type of ash disposal system, waste water management aspects etc.

Based on the reports on total ash generation from TTPS (Stage I & II), average annual quanity of ash generation has been assessed and the water required for making ash slurry and disposal has been estimated. Information on quantity of recyclable water available for ash slurry making for currently operational TTPS (Stage I & II) has been collected from NTPC, Talcher and used for estimating the quantity of raw water required to be withdrawn from Brahmani river.

3.2 Water Withdrawals from Brahmani River in the Downstream of the Withdrawal Points for TTPS (Stage I&II and Stage III)

The water of Brahmani river is the major source for various water demands in the region. In the study area, water withdrawals from Brahmani river for various purposes (particularly domestic and industrial) are being allocated by the Irrigation Division, Angul of Water Resources Department, Govt. of Odisha. The information on water withdrawal from Brahmani river downstream of the withdrawal points has been collected from the Irrigation Division, Angul District (Annexure I). Thus obtained information is presented in Table 3.1. The location of withdrawal points have been verified during the field investigations. The intake points for various diversions downstream of TTPS (Stage I&II and III) alongwith the diversions for TTPS are illustrated in Figs. 3.1a and 3.1b. It is emphasized here that the intake point of TTPS Stage I&II is downstream of Samal Barrage while for TTPP Stage III, intake point is upstream of Samal Barrage.

Table 3.1 Various water withdrawals from Brahmani river d/s of TTPS withdrawals

SN	Name of Industries	Allocated Quantity (cusec)	Allocated Quantity (cumec)	Intake Point	Remarks
1.	Proposed TTPP (Stage III), NTPC, Talcher	39	1.105	Just U/S of Samal Barrage along the RBC	
2.	M/S Bindal Sponge Ltd., Talcher	0.81	0.023	Ekagharia, Talcher (D/S of Samal Barrage)	Company closed since 14.12.2014
3.	IWSS, MCL, Talcher	12.111	0.343	Talcher Town (D/S of Samal Barrage)	Drawing Water
4.	TTPS (Stage I&II), NTPC, Talcher	16.49	0.467	Mandapal, Talcher (D/S of Samal Barrage)	Drawing Water
5.	P.H. Division, Angul (Water Supply to Talcher town)	3.7	0.105	Mandapal, Talcher (D/S of Samal Barrage)	Drawing Water
6.	NALCO, Angul	47.696	1.352	Santhapada, Talcher (D/S of Samal Barrage)	Drawing Water
7.	NSL Nagapatnam Power & Infratech Limited	35.81	1.015	Santhapada, Talcher (D/S of Samal Barrage)	Allocated, but not drawing water

Fig. 3.1a Intake from Brahmani river for TTPS (Stage I, II & III) and other uses (marked on Google Earth)

For identifying the locations of various diversions from Brahmani river in the concerned river reach, a field visit by the NIH team was carried out during 24-27 July. During the field visit, we carried out reconnaissance survey of the study area along the Brahmani river from 1 km d/s of intake point of NTPC Talcher upto Rengali Dam (approx. 75 km) covering all the intake points for various purposes (viz. industries, public water supply and irrigation). The photographs of the major diversions, Samal Barrage and Rengali dam are illustrated in Fig. 3.2 to Fig. 3.8.

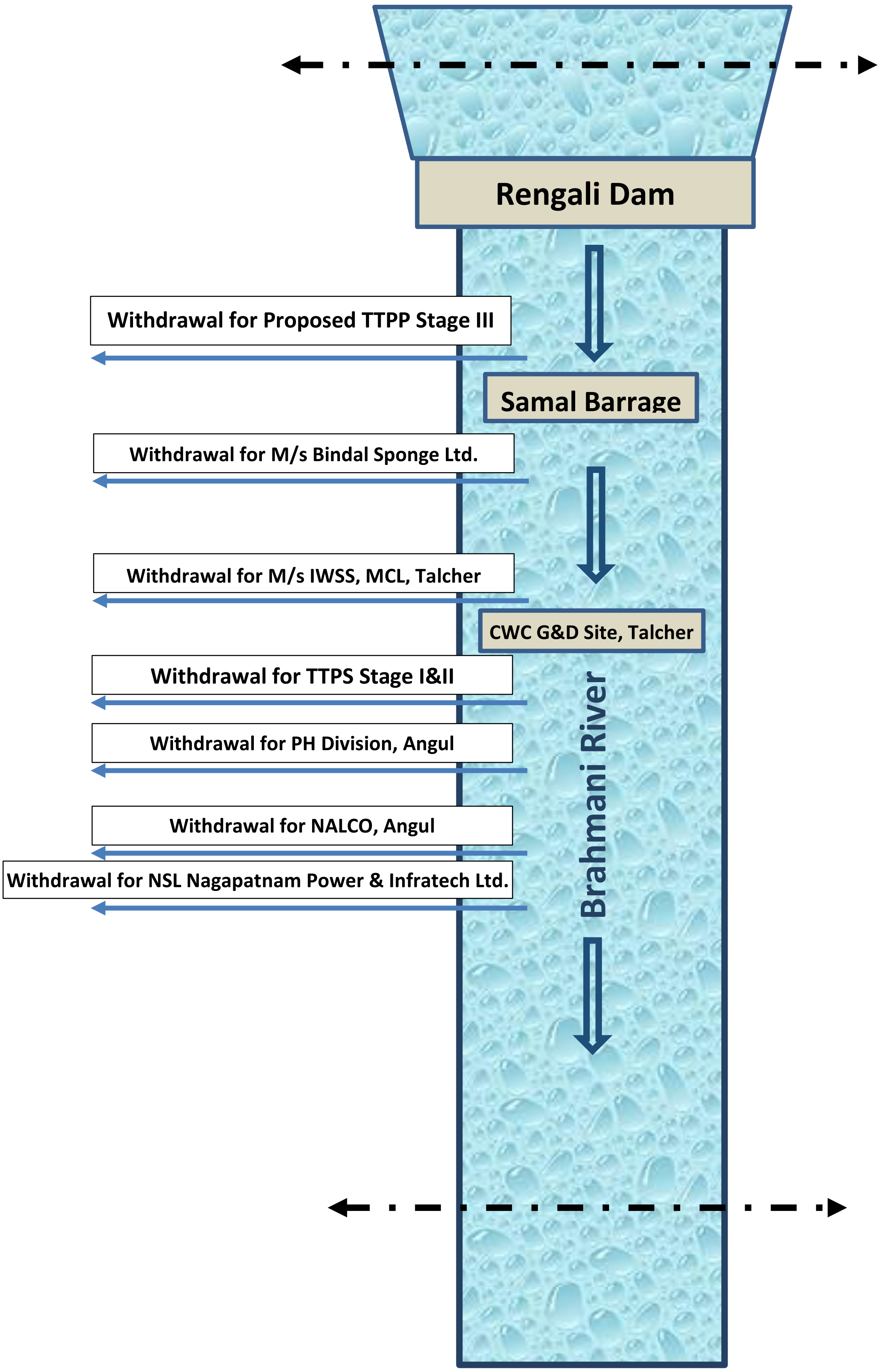

Fig. 3.1b Line diagram showing various withdrawals from Brahmani river for TTPS (Stage I, II & III) and other uses

Fig. 3.2 NALCO Intake Pump House

Fig. 3.3 Intake of P.H. Division, Angul (Water Supply to Talcher town)

Fig. 3.4 TTPS Stage (I&II) Intake

Fig. 3.5 Intake Pump House of MCL, Talcher

Fig. 3.6 Samal Barrage

Fig. 3.7 Right Bank Canal from Samal Barrage (TTPS Stage III intake is proposed along this canal)

Fig. 3.8 Upstream and Downstream view of Brahmani river from Rengali Dam

3.3 Assessment of Impacts of Water Withdrawal from Brahmani River for TTPS on the Downstream Water Requirements

To assess the impacts of water withdrawal, water availability in the Brahmani river at the points of concern i.e. (i) Intake point of TTPS Stage I & II and (ii) Proposed Intake Point of TTPS Stage III is required to be assessed in relation to the downstream water requirements. For carrying out water availability analysis, availability of flow data of Brahmani river has been assessed and summarized in Table 3.2.

Table 3.2 Availability of flow data of Brahmani river

SN	Site	Period	Latitude (DMS)	Longitude (DMS)	Altitude (m)	Tehsil/ Taluk	District	State	Catchment Area (sq. km)
WRIS Website									
1	Gomlai	1978-2016	21°47'40" N	84°58'15" E	135.00	Bonei	Sundergarh	Odisha	21950
2	Indupur	2003-2016	20°37'37" N	86°24'41" E	9.00	Kendrapada	Kendrapada	Odisha	36840
3	Jenapur	1979-2016	20°53'05" N	86°00'59" E	13.00	Darpani	Jajpur	Odisha	33955
4	Panposh	1972-2016	22°16'44" N	84°51'07" E	170.50	Panposh	Sundergarh	Odisha	19448
5	Talcher	1985-2016	20°57'03" N	85°14'33" E	51.00	Talcher	Angul	Odisha	29750
		WRD, Odisha							
6	Rengali Dam	1988-2018	21°16'35" N	85°02'07" E	76.00	Talcher	Angul	Odisha	25250
7	Samal Barrage	2010-2018	21°04'21" N	85°07'57" E	60.98	Talcher	Angul	Odisha	30030

As the inflows to Rengali dam are the natural flows and the flows downstream of Rengali dam are controlled by the operation of dam, the dependability analysis has been carried out using the inflows to Rengali dam through the construction of Flow Duration Curve (FDC).

The Flow Duration Curve (FDC) is one of the most descriptive methods of exhibiting the complete range of river discharges from low flow to high flow (flood) events. It is a relationship between any given discharge value and the percentage of time that this discharge is equaled or exceeded, or we can say in other words that are the relationship between magnitude and frequency of stream flows discharges. FDC may be constructed using different time resolutions of stream flow data: annual, monthly, m-day or daily. In the present study, daily inflows have been aggregated to estimate annual flow series. Annual flow series has been used for the derivation of FDC. Further, FDC is constructed by arranging the annual flow series values in decreasing order of magnitude.

m = order of event,   N = total number of events

Probability, P (IN %) = m/ (N+1)x100

From the FDC, the driest year (corresponding to the highest probability) has been identified for further analysis.

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3.3.1 Impacts of water withdrawal for TTPS (Stage I&II) on the downstream water requirements

The intake point of TTPS (Stage I & Stage II) is just downstream of CWC G&D site at Talcher as shown in Fig. 3.9. Various other water withdrawals from Brahmani river d/s of TTPS Stage (I & II) have been listed in Table 3.3. The daily flows at Talcher is available for the period 1985-2016. For the driest year obtained from the frequency analysis of inflows to Rengali dam, average 10-daily flows at CWC G&D site, Talcher have been estimated and checked whether these flows are sufficient to meet the downstream water requirement after water withdrawal for TTPS (Stage I & Stage II).

Fig. 3.9 Intake points for various uses d/s of TTPS (Stage I& II) intake from Brahmani river

Table 3.3 Various water withdrawals from Brahmani river d/s of TTPS (Stage I&II) withdrawals

SN	Name of Industries	Allocated Quantity (cusec)	Allocated Quantity (cumec)	Distance from TTPS (Stage I&II) intake (km)
1.	TTPS (Stage I&II), NTPC, Talcher	16.49	0.467	0.0
2.	P.H. Division, Angul (Water Supply to Talcher town)	3.7	0.105	0.1
3.	NALCO, Angul	47.696	1.352	6.5
4.	NSL Nagapatnam Power & Infratech Limited	35.81	1.015	6.5

3.3.2 Impacts of water withdrawal for TTPS (Stage III) on the downstream water requirements

The intake point of TTPS (Stage III) is just upstream of Samal Barrage as shown in Fig. 3.10. Various other water withdrawals from Brahmani river d/s of TTPS Stage (I & II) have been listed in Table 3.4. The average daily outflows at Samal Barrage are available for the period 2010-2018. For the driest year obtained from the frequency analysis of inflows to Rengali dam, average 10-daily flows at Samal Barrage have been estimated and checked whether these flows are sufficient to meet the downstream water requirement after water withdrawal for TTPS (Stage III).

Table 3.4 Various water withdrawals from Brahmani river d/s of TTPS (Stage III) withdrawals

SN	Name of Industries	Allocated Quantity (cusec)	Allocated Quantity (cumec)	Intake Point	Distance from TTPS (Stage III) intake (km)
1	Proposed TTPS (Stage III), NTPC, Talcher	39	1.105	Just U/S of Samal Barrage along the RBC	0.0
2	M/S Bindal Sponge Ltd., Talcher	0.81	0.023	Ekagharia, Talcher (D/S of Samal Barrage)	5.5
3	IWSS, MCL, Talcher	12.111	0.343	Talcher Town (D/S of Samal Barrage)	20.0

Fig. 3.10 Intake points for various uses d/s of TTPS (Stage III) intake from Brahmani river

3.4 Assessment of Impacts of water withdrawal from Brahmani river for TTPS on the deposition of sediment and reduction in sediment supply to downstream reaches

Soil erosion, its transportation and subsequent deposition in a river channal is a universal phenomenon and continuously take place in space and time. The changes in flow regime and sediment load have a dramatic effect on the channel morphology, since these are two of the controlling factors. A river compensates for the imposed changes due to withdrawal or storage of water by adjusting to a new quasi-stable form. The closure of a withdrawal or storage has an immediate impact on the downstream river channel by changing the natural water discharge and sediment load. The magnitude of this impact depends on various factors. The primary impacts of withdrawl of water from a river are the attenuation of flood peaks and the withdrawal of sediments from river, leading to changes in channel cross-section, bed particle size, channel pattern and roughness. If significant water withdrawal with the condition that water remain in main River in that condition sediment deposition occurred nearby withdrawal point and also reduce the sediment supply in the downstream reaches. Water withdrawal from any river, not only are sediments removed, but the transport capacity in the downstream channel also decreases due to the attenuated flood peaks.

The effect of sediment withdrawal could be understood from Fig. 3.11 where longitudinal profile adjust itself to transport the new sediment regime after withdrawal start. Sediment is withdrawn continuously from the river at a certain location (A). This produces punctuated local erosion without immediate effects on the water levels along the river (B). This erosion advances downstream as a rarefaction wave. In a later stage, after sufficient erosion, the water levels decrease above the area of erosion and further upstream. The corresponding higher flow velocities cause erosion upstream of the intervention. Eventually, in the long run, the river reaches a new morphological equilibrium without further trends of erosion or sedimentation (C). All bed levels and water levels have become lower than at the start of the intervention. If sediment is withdrawn during a limited period, only the initial response occurs. Eventually the river then restores its original profile.

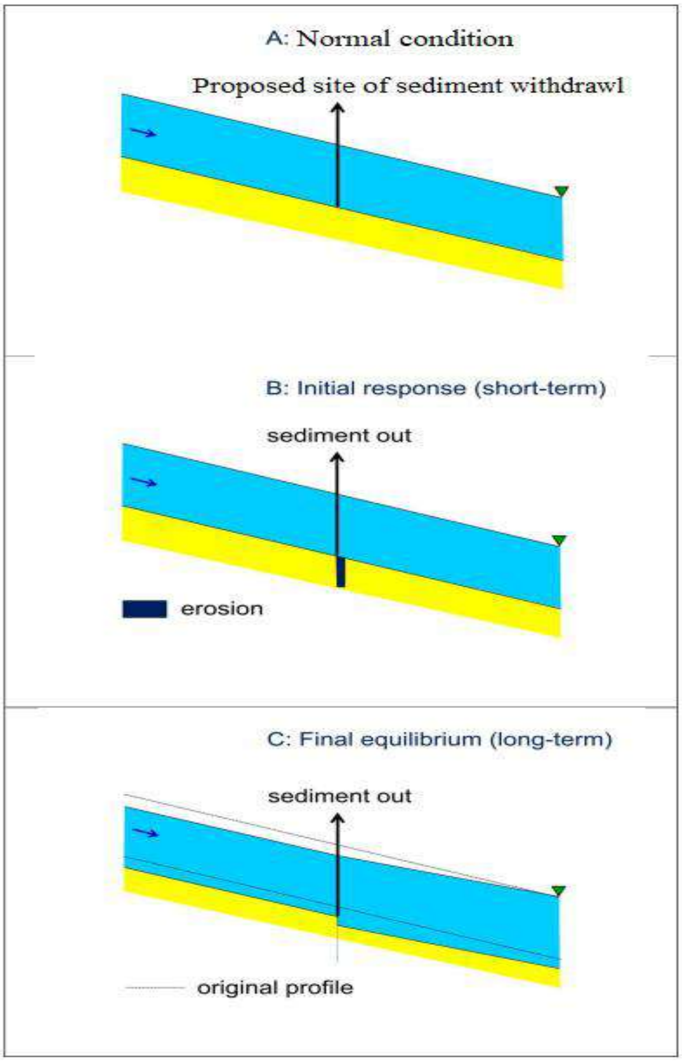

Fig 3.11 Effect of sediment withdrawal on longitudinal profile of a river

Not only longitudinal profiles change even channel width, bed sediment composition or vegetation also affected by the withdrawal. However it is depending upon the local pressures or measures and their effects far upstream and downstream.

In the present study, the sediment data of the Rengali reservoir is used to estimate the sediment yield in the Brahmani River catchment at different sites. As the Rengali dam management authorities have informed that they are not carrying out regular sediment monitoring, the required data have been taken from the report on “Capacity survey for sedimentation studies of Rengali reservoir” prepared by Central Water Commission (Watershed and Reservoir Sedimentation Directorate). The effect of water withdrawal on sediment regime has been assessed at two sites: (i) at upstream of Samal barrage (water intake for Stage III of TTPS); and (ii) at downstream of Samal Barrage (water intake for Stage I & Stage II for TTPS).

The sediment outflow from Rengali dam and the sediment contributed by the intermediate catchment between Rangali dam and Samal barrage, the sediment yield at Samal barrage (35 km downstream of Rengali) was estimated. Future sediment yield at Samal barrage was estimated based on varying trapping efficiency of Renagali dam by year 2106 by assuming stationary inflow sediment rate at Rengali dam.

4.0 RESULTS AND DISCUSSIONS

4.1 Assessment of Quantity of Raw Water to be Withdrawn from Brahmani River for TTPS (Stage I & II)

TTPS (Stage I&II) has been allocated 16.49 cusec (0.467 cumec) of water to be withdrawn from Brahmani river near Talcher town. The actual water balance of the plant shows that the plant is withdrawing 1805 cubic meter / hour during ash handling period (13 hours) and 1505 cubic meter / hour without ash handling period (11 hours). Hence, plant consumes only 4002 cubic meter / day (0.0463 cumec) of raw water from Brahmani river.

Based on the reports on total ash generation from TTPS (Stage I & II), annual ash generation for the last five years is summarized in Table 4.1. Average annual quanity of ash generation has been assessed as 1207303 cubic meter out of which 1169756 cubic meter is being used for mine backfilling. The data on average Information on various components of water balance for currently operational TTPS (Stage I & II) has been collected from NTPC, Talcher and used for estimating the quantity of raw water required to be withdrawn from Brahmani river. The water required for making ash slurry and disposal has been given in Table 4.2. The estimates show that if ash slurry is made in ash to water ratio of 1:6, no raw water will be required for (TTPS Stage I&II).

Table 4.1: Annual ash generation (in metric tonne/ m^3) of TTPS (Stage I&II)

Activity	2013-14	2014-15	2015-16	2016-17	2017-18	Average
Ash Generation	**1217254**	**1207580**	**1207477**	**1174978**	**1229224**	**1207303**
Ash Bricks (NTPC)	6755	5014	3303	6670	410	4430
Ash Bricks (Industries)	33160	14319	10433.2	19687.2	17435.5	19007
Asbestos/Cement	2545	-	-	-	-	2545
Ash Dyke raising	-	66001	7800	8813	10000	23154
Road Embankment	-	2000	-	-	-	2000
Mines Back Filling	**1174794**	**1120246**	**1193742**	**1148621**	**1211378**	**1169756**
% Utilisation	**100**	**100.41**	**100.65**	**100.75**	**100.81**	**101**

Table 4.2 Quantity of raw water (MCM) required for ash slury making on annual basis

		Ash to water ratio		
		1:6	1:7	1:8
Water required for ash disposal		7018537	8188293	9358050
Recyclable Water	Mine decanted water (AWRS)	3679200	3679200	3679200
	Waste Water Pit Plant	273750	273750	273750
	Cooling Tower Blow Down	2628000	2628000	2628000
	treated sewearge water	832200	832200	832200
Quantity of raw water required for ash disposal		Nil	775143	1944900
Quantity of raw water required for ash disposal (in cubic meter / hr)		Nil	88.49	222.02

4.2 Assessment of Impacts of Water Withdrawal from Brahmani River for TTPS on the Downstream Water Requirements

The inflow series at Rengali dam has been shown in Fig. 4.1. The inflows to Rengali dam have been selected for the frequency analysis. The results of frequency analysis are summarized in Table 4.3 and Table 4.4. These tables suggest that the driest year corresponding to 97% dependability was year 2010-11. Further, the flow data corresponding to the year 2010-11 at Samal Barrage and at Talcher G&D site of CWC were used to assess the impacts of water withdrawal.

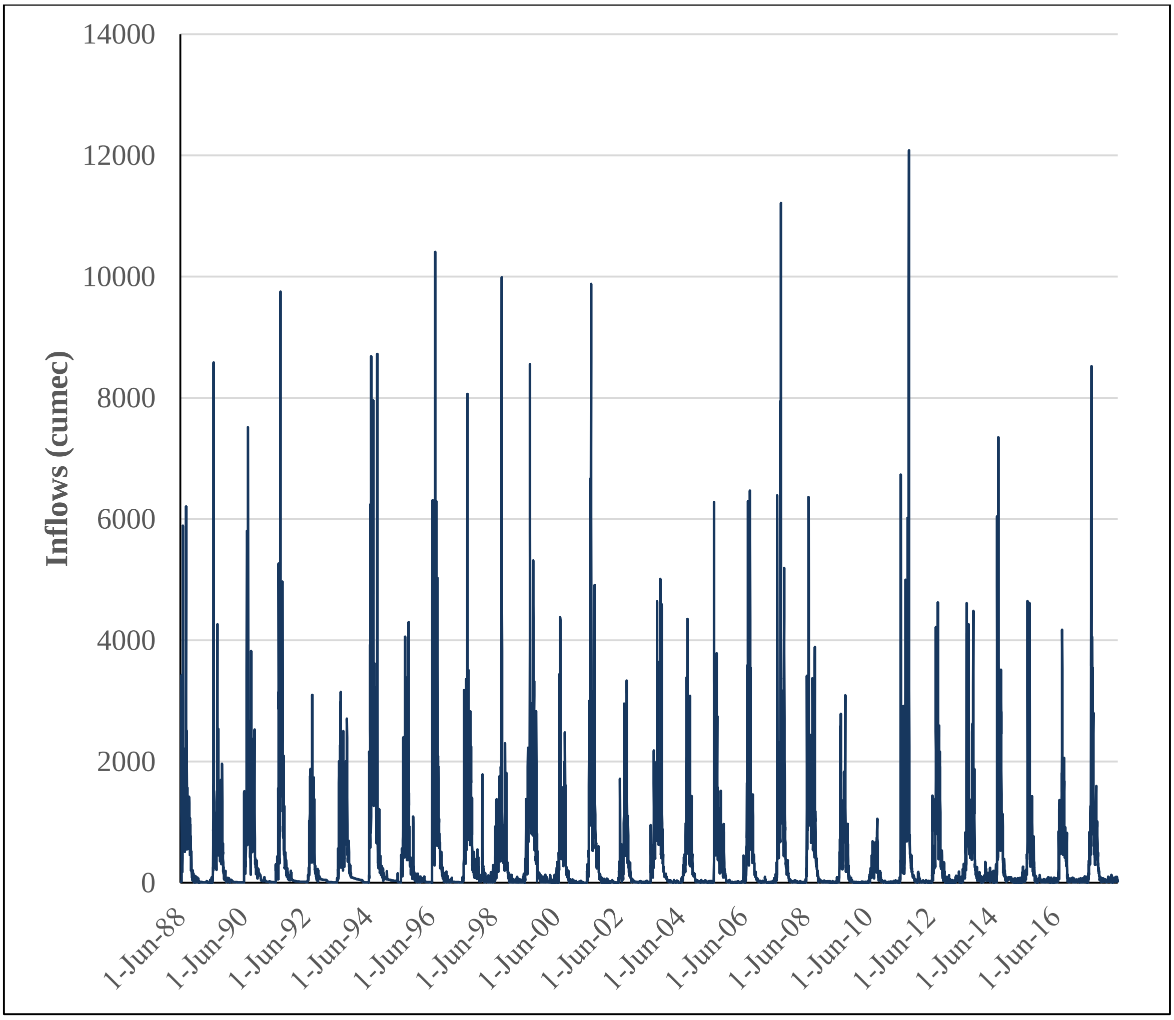

Fig. 4.1 Inflow series at Rengali dam

Table 4.3 Frequency analysis of inflows at Rengali dam

Year	Annual Flow (MCM)	Rank	Probaility (%)
1994-95	26565.97	1	3.23
2001-02	19274.62	2	6.45
2011-12	18457.11	3	9.68
1999-2000	17452.00	4	12.90
1997-98	16301.96	5	16.13
2007-08	16270.80	6	19.35
1991-92	15091.42	7	22.58
1996-97	14727.78	8	25.81
1990-91	14500.92	9	29.03
2008-09	14103.11	10	32.26
2003-04	13498.74	11	35.48
2013-14	12995.34	12	38.71
1988-89	12691.23	13	41.94
2017-18	12554.42	14	45.16
2012-13	11922.01	15	48.39
2006-07	11903.48	16	51.61
1998-99	11741.38	17	54.84
1993-94	11709.83	18	58.06
1995-96	11096.44	19	61.29
2014-15	10849.34	20	64.52
1989-90	10233.69	21	67.74
2005-06	9576.80	22	70.97
2004-05	9082.39	23	74.19
2016-17	8956.60	24	77.42
2000-01	8185.32	25	80.65
2002-03	8054.95	26	83.87
2015-16	7773.13	27	87.10
2009-10	7347.99	28	90.32
1992-93	6966.54	29	93.55
2010-11	3532.51	30	96.77

Table 4.4 Summary of frequency analysis of inflows at Rengali dam

Dependability (%)	Corresponding Year	Annual Inflow (MCM) to Rengali Dam
75%	2004-05	9082.39
90%	2009-10	7347.99
97%	2010-11	3532.51

4.2.1 Impacts of water withdrawal for TTPS (Stage I&II) on the downstream water requirements

The intake point of TTPS (Stage I&II) is just downstream of CWC G&D site at Talcher as shown in Fig. 3.1. The flow data of Talcher is available for the period 1985-2016. Average 10-daily flows at CWC G&D site, Talcher for the driest year (i.e. 2010-11) have been estimated and checked whether these flows are sufficient to meet the downstream water requirement after water withdrawal for TTPS (Stage I&II). Table 4.5 presents the summary of water withdrawals and water availability at different points d/s of intake of TTPS (Stage I&II). The table suggests that the percentage withdrawals for TTPS Stage (I&II) varies from 0.84 % to 0.85 % of the flows available at CWC G&D site, Talcher for the driest year. This percentage will be lower than this for other years. Even after fulfilling all the allocated requirements d/s of TTPS (Stage I&II), water left in Brahmani river varies from 94.652 % to 94.716 % of the flows available at CWC G&D site, Talcher for the driest year. As the requirements for the industries and domestic water supply are of very small amount in comparison to the quantum of flows available in Brahmani river, the results indicate that Brahmani river d/s of TTPS (Stage I&II) still carrying sufficient flows to meet other such requirements in future.

Table 4.5 Summary of water withdrawals and water availability at different points d/s of intake of TTPS (Stage I&II)

	Av. 10-daily flows at CWC G&D Site, Talcher	Flows diverted to TTPS Stage I&II		Flows diverted to PHD Supply	Flows diverted to NALCO	Flows diverted to NSL Nagapatnam Power & Infratech Limited	Flows left in Brahmani river meeting requirements d/s TTPS (Stage I&II)	
Units	cumec	cumec	%	cumec	cumec	cumec	cumec	%
Jun-I	55.466	0.467	0.57	0.105	1.352	1.015	52.527	99.24
Jun-II	54.954	0.467	1.63	0.105	1.352	1.015	52.015	97.82
Jun-III	55.002	0.467	1.48	0.105	1.352	1.015	52.063	98.03
Jul-I	55.100	0.467	1.14	0.105	1.352	1.015	52.161	98.48
Jul-II	55.184	0.467	0.99	0.105	1.352	1.015	52.245	98.69
Jul-III	55.427	0.467	0.63	0.105	1.352	1.015	52.488	99.17
Aug-I	55.616	0.467	0.42	0.105	1.352	1.015	52.677	99.45
Aug-II	55.190	0.467	1.23	0.105	1.352	1.015	52.251	98.37
Aug-III	55.062	0.467	1.57	0.105	1.352	1.015	52.123	97.91
Sep-I	55.228	0.467	0.75	0.105	1.352	1.015	52.289	99.00
Sep-II	55.222	0.467	1.25	0.105	1.352	1.015	52.283	98.34
Sep-III	55.146	0.467	1.62	0.105	1.352	1.015	52.207	97.84
Oct-I	55.088	0.467	3.07	0.105	1.352	1.015	52.149	95.92
Oct-II	55.102	0.467	4.43	0.105	1.352	1.015	52.163	94.11
Oct-III	55.093	0.467	5.25	0.105	1.352	1.015	52.154	93.01
Nov-I	55.108	0.467	5.31	0.105	1.352	1.015	52.169	92.93
Nov-II	55.160	0.467	4.57	0.105	1.352	1.015	52.221	93.92
Nov-III	55.152	0.467	3.97	0.105	1.352	1.015	52.213	94.72
Dec-I	55.180	0.467	3.62	0.105	1.352	1.015	52.241	95.18
Dec-II	55.198	0.467	3.59	0.105	1.352	1.015	52.259	95.23
Dec-III	55.133	0.467	4.25	0.105	1.352	1.015	52.194	94.34
Jan-I	55.156	0.467	3.77	0.105	1.352	1.015	52.217	94.99
Jan-II	55.154	0.467	3.29	0.105	1.352	1.015	52.215	95.63
Jan-III	55.147	0.467	1.97	0.105	1.352	1.015	52.208	97.38
Feb-I	55.148	0.467	2.21	0.105	1.352	1.015	52.209	97.06
Feb-II	55.088	0.467	3.53	0.105	1.352	1.015	52.149	95.30
Feb-III	55.085	0.467	1.56	0.105	1.352	1.015	52.146	97.92
Mar-I	55.074	0.467	2.83	0.105	1.352	1.015	52.135	96.23
Mar-II	55.108	0.467	2.38	0.105	1.352	1.015	52.169	96.83
Mar-III	55.080	0.467	1.71	0.105	1.352	1.015	52.141	97.73
Apr-I	55.070	0.467	1.93	0.105	1.352	1.015	52.131	97.43
Apr-II	55.106	0.467	1.55	0.105	1.352	1.015	52.167	97.94
Apr-III	55.214	0.467	0.98	0.105	1.352	1.015	52.275	98.70
May-I	55.496	0.467	0.48	0.105	1.352	1.015	52.557	99.36
May-II	55.526	0.467	0.57	0.105	1.352	1.015	52.587	99.24
May-III	55.111	0.467	2.57	0.105	1.352	1.015	52.172	96.58

4.2.2 Impacts of water withdrawal for TTPS Stage III on the downstream water requirements: Scenario 1 (before closure of TTPS Stage I&II)

The proposed intake point of TTPS (Stage III) is just upstream of Samal Barrage as shown in Fig. 3.1. As the Samal Barrage also diverts water for major irrigation project, the outflows from Samal Barrage have been considered for this analysis. The outflow data of Samal Barrage is available for the period 2010-2018. Average 10-daily flows at Samal Barrage for the driest year (i.e. 2010-11) have been estimated and checked whether these flows are sufficient to meet the downstream water requirement after water withdrawal for TTPS (Stage III). Table 4.6 presents the summary of water withdrawals and water availability in Brahmani river d/s of intake of TTPS (Stage I&II and Stage III). The table suggests that the percentage withdrawals for TTPS (Stage III) varies from 0.416 % to 5.313 % of the flows available at Samal Barrage for the driest year. This percentage will be lower than this for other years. Even after fulfilling all the allocated requirements d/s of TTPS (Stage III) and TTPS Stage I&II, water left in Brahmani river varies from 78.798 % to 98.338 % of the flows available at Samal Barrage for the driest year. As the requirements for the industries and domestic water supply are of very small amount in comparison to the quantum of flows available in Brahmani river at Samal Barrage, the results indicate that Brahmani river d/s of TTPS (Stage I&II and Stage III) still carrying sufficient flows to meet other such requirements in future.

4.2.3 Impacts of water withdrawal for TTPS Stage III on the downstream water requirements: Scenario 2 (after closure of TTPS Stage I&II)

The assessment of impacts of water withdrawal for TTPS (Stage III) after the closure of TTPS Stage I&II has been made in the similar pattern as detailed in Section 4.2.2, the only difference being that the water diverted for TTPS Stage I&II has not been considered. Table 4.7 presents the summary of water withdrawals and water availability in Brahmani river d/s of intake of TTPS Stage III. The table suggests that the percentage withdrawals for TTPS (Stage III) varies from 0.416 % to 5.313 % of the flows available at Samal Barrage for the driest year. This percentage will be lower than this for other years. Even, after fulfilling all the allocated requirements d/s of TTPS (Stage III) and TTPS Stage I&II, water left in Brahmani river varies from 81.043 % to 98.514 % of the flows available at Samal Barrage for the driest year. As the requirements for the industries and domestic water supply are of very small amount in comparison to the quantum of flows available in Brahmani river at Samal Barrage, the results indicate that Brahmani river d/s of TTPS Stage III still carrying sufficient flows to meet other such requirements in future.

Table 4.6 Summary of water withdrawals and water availability d/s of intakes of TTPS (Stage I&II and Stage III): Scenario 1 (before closure of TTPS Stage I&II)

	Av. 10-daily flows at Samal Barrage	Flows diverted to Proposed TTPS Stage III		Flows diverted to M/S Bindal Sponge Ltd.	Flows diverted to MCL, Talcher	Flows diverted to TTPS Stage I&II	Flows diverted to PHD Supply	Flows diverted to NALCO	Flows diverted to NSL Nagapatnam Power & Infratech Limited	Flows left in Brahmani river meeting requirements d/s TTPS (Stage I&II)	
Units	cumec	cumec	%	cumec	cumec	cumec	cumec	cumec	cumec	cumec	%
Jun-I	192.4	1.105	0.574	0.023	0.343	0.467	0.105	1.352	1.015	187.99	97.708
Jun-II	67.6	1.105	1.635	0.023	0.343	0.467	0.105	1.352	1.015	63.19	93.476
Jun-III	74.75	1.105	1.478	0.023	0.343	0.467	0.105	1.352	1.015	70.34	94.100
Jul-I	96.85	1.105	1.141	0.023	0.343	0.467	0.105	1.352	1.015	92.44	95.447
Jul-II	112.15	1.105	0.985	0.023	0.343	0.467	0.105	1.352	1.015	107.74	96.068
Jul-III	176.7	1.105	0.625	0.023	0.343	0.467	0.105	1.352	1.015	172.29	97.504
Aug-I	265.4	1.105	0.416	0.023	0.343	0.467	0.105	1.352	1.015	260.99	98.338
Aug-II	90.1	1.105	1.226	0.023	0.343	0.467	0.105	1.352	1.015	85.69	95.105
Aug-III	70.318	1.105	1.571	0.023	0.343	0.467	0.105	1.352	1.015	65.908	93.728
Sep-I	147.7	1.105	0.748	0.023	0.343	0.467	0.105	1.352	1.015	143.29	97.014
Sep-II	88.4	1.105	1.25	0.023	0.343	0.467	0.105	1.352	1.015	83.99	95.011
Sep-III	68.25	1.105	1.619	0.023	0.343	0.467	0.105	1.352	1.015	63.84	93.538
Oct-I	36.01	1.105	3.069	0.023	0.343	0.467	0.105	1.352	1.015	31.6	87.753
Oct-II	24.96	1.105	4.427	0.023	0.343	0.467	0.105	1.352	1.015	20.55	82.332
Oct-III	21.036	1.105	5.253	0.023	0.343	0.467	0.105	1.352	1.015	16.626	79.036
Nov-I	20.8	1.105	5.313	0.023	0.343	0.467	0.105	1.352	1.015	16.39	78.798
Nov-II	24.18	1.105	4.57	0.023	0.343	0.467	0.105	1.352	1.015	19.77	81.762
Nov-III	27.84	1.105	3.969	0.023	0.343	0.467	0.105	1.352	1.015	23.43	84.159
Dec-I	30.55	1.105	3.617	0.023	0.343	0.467	0.105	1.352	1.015	26.14	85.565
Dec-II	30.81	1.105	3.586	0.023	0.343	0.467	0.105	1.352	1.015	26.4	85.686
Dec-III	26	1.105	4.25	0.023	0.343	0.467	0.105	1.352	1.015	21.59	83.038
Jan-I	29.34	1.105	3.766	0.023	0.343	0.467	0.105	1.352	1.015	24.93	84.969
Jan-II	33.63	1.105	3.286	0.023	0.343	0.467	0.105	1.352	1.015	29.22	86.887
Jan-III	56.136	1.105	1.968	0.023	0.343	0.467	0.105	1.352	1.015	51.726	92.144
Feb-I	50.05	1.105	2.208	0.023	0.343	0.467	0.105	1.352	1.015	45.64	91.189
Feb-II	31.33	1.105	3.527	0.023	0.343	0.467	0.105	1.352	1.015	26.92	85.924
Feb-III	70.688	1.105	1.563	0.023	0.343	0.467	0.105	1.352	1.015	66.278	93.761
Mar-I	39	1.105	2.833	0.023	0.343	0.467	0.105	1.352	1.015	34.59	88.692
Mar-II	46.41	1.105	2.381	0.023	0.343	0.467	0.105	1.352	1.015	42	90.498
Mar-III	64.764	1.105	1.706	0.023	0.343	0.467	0.105	1.352	1.015	60.354	93.191
Apr-I	57.33	1.105	1.927	0.023	0.343	0.467	0.105	1.352	1.015	52.92	92.308
Apr-II	71.25	1.105	1.551	0.023	0.343	0.467	0.105	1.352	1.015	66.84	93.811
Apr-III	113.1	1.105	0.977	0.023	0.343	0.467	0.105	1.352	1.015	108.69	96.101
May-I	228.85	1.105	0.483	0.023	0.343	0.467	0.105	1.352	1.015	224.44	98.073
May-II	193.05	1.105	0.572	0.023	0.343	0.467	0.105	1.352	1.015	188.64	97.716
May-III	43.018	1.105	2.569	0.023	0.343	0.467	0.105	1.352	1.015	38.608	89.748

Table 4.7 Summary of water withdrawals and water availability d/s of intakes of TTPS (Stage I&II and Stage III): Scenario 2 (after closure of TTPS Stage I&II)

	Av. 10-daily flows at Samal Barrage	Flows diverted to Proposed TTPS Stage III		Flows diverted to M/S Bindal Sponge Ltd.	Flows diverted to MCL, Talcher	Flows diverted to TTPS Stage I&II	Flows diverted to PHD Supply	Flows diverted to NALCO	Flows diverted to NSL Nagapatnam Power & Infratech Limited	Flows left in Brahmani river meeting requirements d/s TTPS (Stage I&II)	
Units	cumec	cumec	%	cumec	cumec	cumec	cumec	cumec	cumec	cumec	%
Jun-I	192.4	1.105	0.574	0.023	0.343	0	0.105	1.352	1.015	188.457	97.951
Jun-II	67.6	1.105	1.635	0.023	0.343	0	0.105	1.352	1.015	63.657	94.167
Jun-III	74.75	1.105	1.478	0.023	0.343	0	0.105	1.352	1.015	70.807	94.725
Jul-I	96.85	1.105	1.141	0.023	0.343	0	0.105	1.352	1.015	92.907	95.929
Jul-II	112.15	1.105	0.985	0.023	0.343	0	0.105	1.352	1.015	108.207	96.484
Jul-III	176.7	1.105	0.625	0.023	0.343	0	0.105	1.352	1.015	172.757	97.769
Aug-I	265.4	1.105	0.416	0.023	0.343	0	0.105	1.352	1.015	261.457	98.514
Aug-II	90.1	1.105	1.226	0.023	0.343	0	0.105	1.352	1.015	86.157	95.624
Aug-III	70.318	1.105	1.571	0.023	0.343	0	0.105	1.352	1.015	66.375	94.393
Sep-I	147.7	1.105	0.748	0.023	0.343	0	0.105	1.352	1.015	143.757	97.330
Sep-II	88.4	1.105	1.25	0.023	0.343	0	0.105	1.352	1.015	84.457	95.540
Sep-III	68.25	1.105	1.619	0.023	0.343	0	0.105	1.352	1.015	64.307	94.223
Oct-I	36.01	1.105	3.069	0.023	0.343	0	0.105	1.352	1.015	32.067	89.050
Oct-II	24.96	1.105	4.427	0.023	0.343	0	0.105	1.352	1.015	21.017	84.203
Oct-III	21.036	1.105	5.253	0.023	0.343	0	0.105	1.352	1.015	17.093	81.256
Nov-I	20.8	1.105	5.313	0.023	0.343	0	0.105	1.352	1.015	16.857	81.043
Nov-II	24.18	1.105	4.57	0.023	0.343	0	0.105	1.352	1.015	20.237	83.693
Nov-III	27.84	1.105	3.969	0.023	0.343	0	0.105	1.352	1.015	23.897	85.837
Dec-I	30.55	1.105	3.617	0.023	0.343	0	0.105	1.352	1.015	26.607	87.093
Dec-II	30.81	1.105	3.586	0.023	0.343	0	0.105	1.352	1.015	26.867	87.202
Dec-III	26	1.105	4.25	0.023	0.343	0	0.105	1.352	1.015	22.057	84.835
Jan-I	29.34	1.105	3.766	0.023	0.343	0	0.105	1.352	1.015	25.397	86.561
Jan-II	33.63	1.105	3.286	0.023	0.343	0	0.105	1.352	1.015	29.687	88.275
Jan-III	56.136	1.105	1.968	0.023	0.343	0	0.105	1.352	1.015	52.193	92.976
Feb-I	50.05	1.105	2.208	0.023	0.343	0	0.105	1.352	1.015	46.107	92.122
Feb-II	31.33	1.105	3.527	0.023	0.343	0	0.105	1.352	1.015	27.387	87.415
Feb-III	70.688	1.105	1.563	0.023	0.343	0	0.105	1.352	1.015	66.745	94.422
Mar-I	39	1.105	2.833	0.023	0.343	0	0.105	1.352	1.015	35.057	89.890
Mar-II	46.41	1.105	2.381	0.023	0.343	0	0.105	1.352	1.015	42.467	91.504
Mar-III	64.764	1.105	1.706	0.023	0.343	0	0.105	1.352	1.015	60.821	93.912
Apr-I	57.33	1.105	1.927	0.023	0.343	0	0.105	1.352	1.015	53.387	93.122
Apr-II	71.25	1.105	1.551	0.023	0.343	0	0.105	1.352	1.015	67.307	94.466
Apr-III	113.1	1.105	0.977	0.023	0.343	0	0.105	1.352	1.015	109.157	96.514
May-I	228.85	1.105	0.483	0.023	0.343	0	0.105	1.352	1.015	224.907	98.277
May-II	193.05	1.105	0.572	0.023	0.343	0	0.105	1.352	1.015	189.107	97.958
May-III	43.018	1.105	2.569	0.023	0.343	0	0.105	1.352	1.015	39.075	90.834

4.3 Assessment of Impacts of water withdrawal from Brahmani river for TTPS on the deposition of sediment and reduction in sediment supply to downstream reaches

Rengali reservoir is a multipurpose major dam project for flood control, irrigation and generation of electricity and located on Brahmani River in Angul district. The project covers about 108 lakh populations of various villages of Odisha, Jharkhand and Chhattisgarh. Th Rengali dam is constructed across Brahamani River, intercepting catchment area of about 25250 sq. km resulting in gross storage of about 4464.24 MCM and for providing irrigation to 423000 ha. The Rengali reservoir was impounded in 1982-83 with live and dead storage provided for the reservoir at planning stage were 3465.92 MCM and 998.92 MCM, respectively with Gross storage of 4464.24 MCM at FRL and Gross storage at MWL as 5216.77 MCM. Centre Water Commission (CWC) conducted capacity survey of reservoir at regular interval on the recommendation of the reservoir sedimentation committee constituted by the Ministry of Irrigation (now Ministry of Water Resources, River Development & Ganga Rejuvenation), Govt of India in 1978 in its report in 1985. First capacity survey was conducted in year 2006 (after 27 years of impound) and detail of sediment survey has been depicted in Table 4.8.

Table 4.8 Details of sediment data of Rengali reservoir

SN	Year	Period (Years)	Reservoir Capacity (MCM)			Loss of capacity (MCM)		Observed rate of sedimentation since last survey (mm/yr)
			Gross	Live	Dead	Since last Survey	Cumulative (%)	
1	1982		4494.77	3505.9	988.87			
2	2006	24	3749.75	3130.5	619.24	745.02	16.58	1.229

(Source: Compendium on silting of reservoir in India, 2015)

The observed rate of sedimentation was found 1.229 mm/yr which is quite higher than the values adopted for at planning stage of dam as 0.395 mm/yr. Considering the sediment outflow from Rengali dam and the sediment contributed by the intermediate catchment between Rangali and Samal (4780 sq. km), the sediment values at Samal barrage (35 km downstream of Rengali) was estimated. Future sediment yield at Samal barrage was estimated based on varying trapping efficiency of Renagali dam by year 2106 by assuming inflow sediment rate stationery at Rengali dam and depicted in Table 4.8. Sediment yield at Samal barrage was estimated in the range of 984828 tonne/yr to 1180332 tonne/yr. Impounding of Rengali dam was started 36 years before, so Brahamani river channels may already be adjusted its channel morphology to carry this sediment load and flow regime. The sediment withdrawal at upstream (due to withdrawal point for Stage III) and downstream (due to withdrawal point of Stage I & Stage II) of Samal barrage were estimated as 22612 to 27100 tonne/ year and 8332 to 9986 tonne/ year, respectively (Table 4.9).

Table 4.9: Estimation of future sediment load regime after withdrawal of water at two sites of Brahamani River based by considering the variable trapping efficiency of Rangali dam

Year	Sediment Inflow Rate at Rengali dam	Trapping efficiency	Sediment outflow from Rengali (tonne/yr)	Sediment contribution by the catchment area between Rengali and Samal (tonne/yr)	Total sediment at Samal	Sediment withdrawal by TTPS at site upstream of Samal (for Stage III)		Sediment withdrawal by TTPS at site downstream of Samal (for Stage I & II)	
Units	mm/yr		tonne/yr	tonne/yr	tonne/yr	tonne/yr	%	(tonne/yr)	%
2017	1.229	0.965	152058	832770	984828	22612	2.296	8332	0.846
2037	1.229	0.955	195503	832770	1028274	23610	2.296	8699	0.846
2057	1.229	0.945	238948	832770	1071719	24607	2.296	9067	0.846
2077	1.229	0.935	282393	832770	1115164	25604	2.296	9434	0.846
2097	1.229	0.92	347561	832770	1180332	27100	2.296	9986	0.846

The withdrawal of the sediment load is only 2.296% and 0.846% of the present sediment carrying at the withdrawal site for TTPS (Stage III) and TTPS (Stage I & Stage II), respectively. These values are very small as compare to the present existing sediment load of channel. The channel has already been adjusted itself due to change in flow regime as impounding has been occurred since last 36 years.

The magnitude of the withdrawal is very less as compare to the existing flow in the river so the transport capacity especially for high flows (generally responsible for carrying sediment load) will not be affected and possibilities of sediment deposition may not be encountered. On the other hand the water released from the reservoir mostly comprises fine sediment as coarser sediment trapped in the Rengali reservoir. Worth notable that deposition of coarse sediment in the channel bed can reduce the slope of channel and hence reduce the transport capacity of the channel, which could not be happening here due to coarser sediment trapped in the Rengali dam.

In the nutshell, the magnitudes of withdrawals at both of the sites are not significant so that the remaining flows are unable to transport the existing sediment load in the main River channel. Therefore withdrawal of water at both sites does not seem any effect on sediment erosion /deposition in the downstream of the water intake points at main River channel.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the availability of data, the analysis was divided into three parts:

(i). Estimation of quantity of raw water from river Brahmani required if any for ash slurry making.

(ii). Impact of withdrawal of water for TTPS (Stage I, II & III) on the various uses of water and their implications in the downstream flows of Brahmani river

(iii). Study on any deposition of sediment and a reduction in sediment supply to downstream reaches due to water intake.

TTPS (Stage I&II) has been allocated 16.49 cusec (0.467 cumec) of water to be withdrawn from Brahmani river near Talcher town. The actual water balance of the plant shows that the plant is withdrawing 1805 cubic meter / hour during ash handling period (13 hours) and 1505 cubic meter / hour without ash handling period (11 hours). Hence, plant consumes only 4002 cubic meter / day (0.0463 cumec) of raw water from Brahmani river.

Average annual quanity of ash generation has been assessed as 1207303 cubic meter out of which 1169756 cubic meter is being used for mine backfilling. As the ash slurry is usually being made in ash to water ratio of 1:6, no raw water will be required for making ash slurry and disposal for TTPS Stage I&II.

The inflows to Rengali dam have been selected for the frequency analysis. The analysis shows that the driest year corresponding to 97% dependability was year 2010-11. Further, the flow data corresponding to the year 2010-11 at Samal Barrage and at Talcher G&D site of CWC were used to assess the impacts of water withdrawal.

The proposed intake point of TTPS (Stage I&II) is just downstream of CWC G&D site, Talcher. The flows at this site have been considered for the analysis of impact of TTPS (Stage I&II) on downstream uses and availability of flows in Brahmani river. The percentage withdrawals for TTPS Stage (I&II) varies from 0.84% to 0.85% of the flows available at CWC G&D site, Talcher for the driest year. This percentage will be lower than this for other years. Even after fulfilling all the allocated requirements d/s of TTPS (Stage I&II), water left in Brahmani river varies from 94.652 % to 94.716 % of the flows available at CWC G&D site, Talcher for the driest year. As the requirements for the industries and domestic water supply are of very small amount in comparison to the quantum of flows available in Brahmani river, the results indicate that Brahmani river d/s of TTPS (Stage I&II) still carrying sufficient flows to meet other such requirements in future.

The proposed intake point of TTPS (Stage III) is just upstream of Samal Barrage. As the Samal Barrage also diverts water for major irrigation project, the outflows from Samal Barrage have been considered for this analysis. The outflow data of Samal Barrage have been used to estimate average 10-daily flows at Samal Barrage for the driest year (i.e. 2010-11) and checked whether these flows are sufficient to meet the downstream water requirement. The results indicate that the percentage withdrawals for TTPS (Stage III) varies from 0.416 % to 5.313 % of the flows available at Samal Barrage for the driest year. This percentage will be lower than this for other years. Even after fulfilling all the allocated requirements d/s of TTPS (Stage III), water left in Brahmani river varies from 78.798 % to 98.338 % (in case of Scenario 1 i.e. before closure of TTPS Stage I&II) and 81.043 % to 98.514 % (in case of Scenario 2 i.e. after closure of TTPS Stage I&II) of the flows available at Samal Barrage for the driest year. As the requirements for the industries and domestic water supply are of very small amount in comparison to the quantum of flows available in Brahmani river at Samal Barrage, the results indicate that Brahmani river d/s of TTPS (Stage III) still carrying sufficient flows to meet other such requirements in future.

Rengali reservoir is a multipurpose major dam project for flood control, irrigation and generation of electricity and located on Brahmani River in Angul district. The project covers about 108 lakh populations of various villages of Odisha, Jharkhand and Chhattisgarh. Th Rengali dam is constructed across Brahamani River, intercepting catchment area of about 25250 sq. km resulting in gross storage of about 4464.24 MCM and for providing irrigation to 423000 ha. The Rengali reservoir was impounded in 1982-83 with live and dead storage provided for the reservoir at planning stage were 3465.92 MCM and 998.92 MCM, respectively with Gross storage of 4464.24 MCM at FRL and Gross storage at MWL as 5216.77 MCM. Centre Water Commission (CWC) conducted capacity survey of reservoir at regular interval on the recommendation of the reservoir sedimentation committee constituted by the Ministry of Irrigation (now Ministry of Water Resources, River Development & Ganga Rejuvenation), Govt of India in 1978 in its report in 1985. First capacity survey was conducted in year 2006 (after 27 years of impound).

The observed rate of sedimentation was found 1.229 mm/yr which is quite higher than the values adopted for at planning stage of dam as 0.395 mm/yr. Considering the sediment outflow from Rengali dam and the sediment contributed by the intermediate catchment between Rangali and Samal, the sediment values at Samal barrage (35 km downstream of Rengali) was estimated. Future sediment yield at Samal barrage was estimated based on varying trapping efficiency of Renagali dam by year 2106 by assuming inflow sediment rate stationery at Rengali dam. Sediment yield at Samal barrage was estimated in the range of 984828 tonne/yr to 1180332 tonne/yr. Impounding of Rengali dam was started 36 years before, so Brahamani river channels may already be adjusted its channel morphology to carry this sediment load and flow regime. The sediment withdrawal at upstream (due to withdrawal point for Stage III) and downstream (due to withdrawal point of Stage I & Stage II) of Samal barrage were estimated as 22612 to 27100 tonne/ year and 8332 to 9986 tonne/ year, respectively.

The withdrawal of the sediment load is only 2.296% and 0.846% of the present sediment carrying at the withdrawal site for TTPS (Stage III) and TTPS (Stage I & Stage II), respectively. These values are very small as compare to the present existing sediment load of channel. The channel has already been adjusted itself due to change in flow regime as impounding has been occurred since last 36 years. The magnitude of the withdrawal is very less as compared to the existing flows in the river so the transport capacity especially for high flows (generally responsible for carrying sediment load) will not be affected and possibilities of sediment deposition may not be encountered. On the other hand, the water released from the reservoir mostly comprises fine sediment as coarser sediment trapped in the Rengali reservoir. Worth notable that deposition of coarse sediment in the channel bed can reduce the slope of channel and hence reduce the transport capacity of the channel, which could not be happening here due to coarser sediment trapped in the Rengali dam. The magnitudes of withdrawals at both of the sites are not significant so that the remaining flows are unable to transport the existing sediment load in the main River channel. Therefore, withdrawal of water at both sites does not seem any effect on sediment erosion /deposition in the downstream of the water intake points at main River channel.

The following conclusions may be drawn from the study:

- The percentage withdrawals for TTPS Stage (I&II) varies from 0.84% to 0.85% of the flows available at CWC G&D site, Talcher for the driest year. This percentage will be lower than this for other years. Even after fulfilling all the allocated requirements d/s of TTPS (Stage I&II), water left in Brahmani river varies from 94.652 % to 94.716 % of the flows available at CWC G&D site, Talcher for the driest year.
- The percentage withdrawals for TTPS (Stage III) varies from 0.416 % to 5.313 % of the flows available at Samal Barrage for the driest year. This percentage will be lower than this for other years. Even after fulfilling all the allocated requirements d/s of TTPS (Stage III), water left in Brahmani river varies from 78.798 % to 98.338 % (in case of Scenario 1 i.e. before closure of TTPS Stage I&II) and 81.043 % to 98.514 % (in case of Scenario 2 i.e. after closure of TTPS Stage I&II) of the flows available at Samal Barrage for the driest year.
- As the requirements for the industries and domestic water supply are of very small amount in comparison to the quantum of flows available in Brahmani river at Samal Barrage, the results indicate that Brahmani river d/s of TTPS (Stage III) still carrying sufficient flows to meet other such requirements in future.
- The withdrawal of the sediment load is only 2.296% and 0.846% of the present sediment carrying at the withdrawal site for TTPS (Stage III) and TTPS (Stage I & Stage II), respectively. These values are very small as compared to the present existing sediment load of channel. The channel has already been adjusted itself due to change in flow regime as impounding has been occurred since last 36 years.
- The magnitude of the withdrawal is very less as compared to the existing flow in the river so the transport capacity especially for high flows (generally responsible for carrying sediment load) will not be affected and possibilities of sediment deposition may not be encountered.

6.0 REFERENCES

MOWR (2014), Brahmani and Baitarni Basin, Version 2.0, report prepared by Central Water Commission and National Remote Sensing Centre under India-WRIS Project, Ministry of Water Resources, Government of India, p. 82.

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NTPC (2018), Final Environmental Impact Assessment Report for Talcher Thermal Power Project Stage-III (2x660 MW), prepared by EQMS India Pvt. Ltd., New Delhi and submitted to NTPC Ltd., p. 318.

CWC (2006), Capacity Survey for Sedimentation Studies of Rengali Reservoir" prepared by Central Water Commission (Watershed and Reservoir Sedimentation Directorate) (Report No.: R-051/2006).

CWC (2015), Compendium on Silting of Reservoir in India, prepared by Central Water Commission (Watershed and Reservoir Sedimentation Directorate), p.194.

7.0 ACKNOWLEDGEMENT

We are thankful to NTPC for sponsoring the consultancy project on Study on "Downstream Impacts of Water Withdrawal by TTPS from Brahmani River" to National Institute of Hydrology, Roorkee. Special thanks are also due to Er. R. C. Kukreti, AGM and all other officials of NTPC, Talcher for extending all the help and support during field investigations and in completion of this report.

We are also thankful to Er. Saroj Panda, Chief Engineer and Basin Manager, Brahmani basin and his team for their cooperation in providing all the data/information about the study area.

We are also thankful to Director, National Institute of Hydrology, Roorkee for providing all administrative and financial suoport for the successful completion of the project.

Annexure – I

Office of the Executive Engineer
Head Works Division, Samal
At/Po-Samal Barrage Township, Dist.-Angul
e-mail.id.: (ee.hwd.samal@gmail.com)

ANNEXURE-VIII (B)

Lr. No. : HWD.Estr./2018 3314 /WB /Dt. 24/5/18

To,

The A.G.M (TS)
M/s National Thermal Power Corporation,
Talcher Thermal

→ Sr Mgr (ME)

Sub : Request to provide water requirements of the present and proposed power plants and availability of water in the Brahmani River considering the potential users in the upstream and downstream.

Ref : Your Lr. No. 045/TS/TTPS/ dated 17.05.2018.

Sir,

With reference to your letter under reference, it is to enclose herewith the data's you have asked for in a pro-forma regarding water requirement of the existing and proposed power plants vis-a-vis availability of water in the River Brahmani considering the potential users in the upstream and downstream data's can't be provided as this office jurisdiction is in between Renagali Dam to Samal Barrage Reservoir vide Gazette No. 1614 dated 16.08.2008.

Further, it is to intimate that, as per WAPCOS report Provision for drawal of water from U/s of Samal Barrage is 9.909 Cu. m/Sec. and currently there are no proposed /upcoming Power Plants pertaining to this office.

This is for your information and necessary action.

Encl: As above.

Yours faithfully,

24/5/18
Executive Engineer,
Head Works Division, Samal

Memo No. 3315 Dated: 24/5/18

Copy submitted to the Chief Engineer & Basin Manager, Brahmani Basin, Samal for favour of kind information and necessary action.

Executive Engineer

ANNEXURE-VIII (A)

//9//

Memo No. 15234 /WR. Dtd. 4/6/18 /

Copy forwarded to Department of Energy/ CMD, IPICOL/ CMD, IDCO for information and necessary action.

EIC-Cum-Special Secretary to Government

Memo No. 15235 /WR. Dtd. 4/6/18 /

Copy forwarded to the Collector & District Magistrate, Angul for information and necessary action.

EIC-Cum-Special Secretary to Government

Memo No. 15236 /WR. Dtd. 4/6/18 /

Copy forwarded to EIC, WR/ Chief Engineer, Water Services/ Chief Engineer & Basin Manager, Basin Planning & Climate Change/ Chief Engineer & Basin Manger, Brahmani Left Basin, Samal/ EE, Head Works Division, Samal for information and necessary action.

EIC-Cum-Special Secretary to Government

ANNEXURE-VIII (B)

List of Existing Power Plants presently drawing water from U/s of Samal Barrage

Sl. No.	Name of the Industry	Qty. of water allocated in Cusecs	Qty. of water allocated in Cu. m/Sec	Qty. of water reserved against the industry in Cusecs	Allocated Vide Lr. No. & Date of DoWR	Point of Intake	Remarks
1	M/s National Thermal Power Corporation	105	2.973	105	Lr. No. 14771 dtd. 22.05.2013 Lr. No. 8395 dtd. 06.04.2016 Lr. No. 15385 dtd. 30.06.2016	U/s	Drawing
2	M/s Jindal India Thermal Power Ltd.	25	0.7079	25	Lr. No. 1122 dtd. 15.01.2016 of DoWR	U/s	Drawing
3	M/s Jindal Steel & Power Ltd.	45.69	1.873	66.16	Lr. No. 16692/WR dtd.14.07.2017 of DoWR	U/s	Drawing
4	Monnet Power Company Ltd.	37	1.048	37	DoWR Lr. No. 3947 dtd. 17.02.2014 Lr. No. 4718 dtd. 22.02.2014	U/s	has Not been commissioned yet
	Total		6.6019				
Availability = 1.808 Cu.m/Sec.							

N.B : There are no proposed power plants till date pertaining to this office.

Provision for drawal of water from U/s of Samal Barrage as per WAPCOS report : 9.909 Cu. m/Sec.

24/5/18

Executive Engineer
Head Works Division, Samal

ANNEXURE-VIII (C)

OFFICE OF THE EXECUTIVE ENGINEER,
ANGUL IRRIGATION DIVISION, ANGUL.
At/PO:- Hakimpada, Dist- Angul, Odisha
FAX:-06764 236252 Email: eeangulirrigation@gmail.com

No. 4163 Date. 29.5.18

To

The Additional General Manager (TS)
Talcher Thermal Power Station (NTPC) ,
AT/ PO:- Talcher Thermal
Dist :- Angul, Odisha.

Sub: - Water Requirement of the present and proposed power plant and availability of water in the River Brahmani considering the potential users in the upstream and downstream.

Ref:- Your Lr. No. 473 Dated 25.05.2018

Sir,

In inviting a reference to the subject cited above, it is to inform that; this Division is collecting water rate from different Industries and commercial establishments drawing water from river Brahmani within Angul District from downstream of Samal Barrage.

The following existing Power plants/ Industries / Commercial Establishment are drawing water from River Brahmani (D/S of Samal Barrage) within jurisdiction of this Division as detailed below.

Sl. No.	Name of Industries	Allocated Quantity/ drawl Quantity	Intake Point	Remarks
01	M/s Bindal Sponge Ltd Talcher	0.81 Cusec	Ekagharia, Talcher (D/S of Samal Barrage)	Company closed since 14.12.2014.
02	IWSS, MCL, Talcher	12.111 Cusec	Talcher Town (D/S of Samal Barrage)	Drawing Water
03	TTPS, (NTPC) Talcher	16.49 Cusec	Mandapal, Talcher (D/S of Samal Barrage)	-do-
04	P.H. Division, Angul, (**Water Supply to Talcher town**)	3.70 Cusec	Mandapal, Talcher (D/S of Samal Barrage)	-do-
05	NALCO, Angul	47.696 Cusec	Santhapada, Talcher (D/S of Samal Barrage)	-do-

Further Department of Water Resources, Government of Odisha has allocated water against the following upcoming Power Plant.

Sl. No.	Name of Industries	Allocated Quantity/ drawl Quantity	Intake Point	Remarks
01	NSL Nagapatnam Power & Infratech Limited	35.81 Cusec	(D/S of Samal Barrage)	Allocated. But not drawing Water

ANNEXURE-VIII (C)

This office has no further information on proposed /upcoming power plants along with their proposed quantity of drawl of water and intake point.

In this context it is to inform that: Rengali Dam Division, Rengali and Head works Division, Samal are controlling the discharge of river Brahmani at Rengali Dam and Samal Barrage respectively. Head works Division, Samal is collecting water rate from different industries drawing water from River Brahmani within downstream of Rengali Dam and Samal Barrage. Hence the Head Works Division Samal may be contacted to get information related to availability of water in the River Brahmani both on upstream & downstream of Samal Barrage.

Yours faithfully,

29/3/16

Executive Engineer,
Angul Irrigation Division,
Angul.

Third party evaluation / Environment Audit for reviewing the compliance conditions stipulated in the Environmental clearance vide letter no. J-11015 / 276 /2011-IA.II (M) dated 19.04.2017

S.No	EC Stipulation in EC letter dated 19.04.2017	Status of Compliance
10	The matter was placed before the Re-constituted Expert Appraisal Committee (Thermal Power) in its 4th Meeting held on 16.03.2017. In acceptance of the recommendation of the Re-constituted Expert Appraisal Committee (Thermal Power) and in view of the information / clarification furnished by you, with respect to the above project, the Ministry hereby accords the permission to continue the disposal of fly ash for the maximum quantity of 1.2 MTPA on temporary basis for a further period of five years w.e.f. from 10.04.2017 subject to following conditions.	
i.	A pilot project shall be explored for implementation for Cenosphere extraction from flyash and manufacturing of by-products in consultation with organizations like CSIR, ISM (IIT) Dhanbad.	Awarded to M/s NEERI, Nagpur. A Prototype unit of 10 Kg ash capacity has been fabricated by M/s NEERI.
ii.	As recommended by NEERI, Ash characterisation, hydro-geological studies, leachability of trace metals, monitoring of trace elements in the supernatant, pH of the water and the piezometers on a quarterly basis and reports shall be submitted to the Ministry and its regional office annually.	Awarded to M/s NEERI, Nagpur. The work is in progress as per schedule.
iii.	Radio tracer studies shall be continued once in six months and the findings of the study shall be submitted to the Ministry and its Regional office annually.	Awarded to BRIT, Mumbai. Final report submitted by M/s BRIT. The report concluded that "it appears that the fly ash leachates are not contributing to the ground water in the surrounding area of the ash pond."
iv.	Bioaccumulation and bio-magnification tests shall be	Awarded to NBRI, Lucknow. The work is in progress as per schedule.

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S.No	EC Stipulation in EC letter dated 19.04.2017	Status of Compliance
	conducted on surrounding flora and fauna (tree leaves, vegetation, crop yields and cattle population etc) during pre-monsoon and post monsoon to find out any trace metals escaped through groundwater or runoff and the reports shall be submitted to the Ministry annually.	
v.	Surface runoff and supernatant water, in any case shall not be let into surroundings. It shall be collected by providing adequate drains around the mine. As proposed the supernatant water along with surface runoff shall be treated and re-used for ash mixing and plant operations. Surface and ground water quality along with existing piezometric wells shall be monitored quarterly and the reports shall be submitted to the Ministry annually.	It is found that, the supernatant water along with surface runoff are being treated and re-used for ash mixing and plant operations. Surface runoff and supernatant water are not being discharged outside. Surface and ground water quality along with existing piezometric wells are being monitored by M/s NEERI
vi.	After the mine void reaches its full capacity, 30 cm sweet soil lining and proper compacting be provided on the top to avoid any wash off during rainy season. Reclamation activities along with greenbelt development shall be carried out in consultation with M / s MCL in accordance with approved Mine Closure Plan. An action plan in this regard shall be submitted to the Ministry and its Regional Office.	M/s NTPC had a plan to provide earth cover followed by green cover above the surface of ash upon exhaustion of mine voids.

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S.No	EC Stipulation in EC letter dated 19.04.2017	Status of Compliance
vii	Only decanted water from mine, make up water from treated effluents such as cooling tower blow down and treated sewage water shall be used from making ash slurry. Raw water withdrawal from Brahmani river for purpose of making ash slurry shall be minimized. Downstream impacts of water withdrawal from Brahmani River shall be studied and report submitted to the Ministry.	Decanted water from mine, make up water from treated effluents are being used for making ash slurry. Downstream impacts of water withdrawal from Brahmani River studied by M/s NIH, Roorkee and the following conclusions drawn from the study: ➢ The percentage withdrawals for TTPS Stage (I&II) varies from 0.84% to 0.85% of the flows available at CWC G&D site, Talcher for the driest year. This percentage will be lower than this for other years. Even after fulfilling all the allocated requirements d/s of TTPS (Stage I&II), water left in Brahmani river varies from 94.652 % to 94.716 % of the flows available at CWC G&D site, Talcher for the driest year. ➢ The percentage withdrawals for TTPS (Stage III) varies from 0.416 % to 5.313 % of the flows available at Samal Barrage for the driest year. This percentage will be lower than this for other years. Even after fulfilling all the allocated requirements d/s of TTPS (Stage III), water left in Brahmani river varies from 78.798 % to 98.338 % (in case of Scenario 1 i.e. before closure of TTPS Stage I&II) and 81.043 % to 98.514 % (in case of Scenario 2 i.e. after closure of TTPS Stage I&II) of the flows available at Samal Barrage for the driest year. ➢ As the requirements for the industries and domestic water supply are of very small amount in comparison to the

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S.No	EC Stipulation in EC letter dated 19.04.2017	Status of Compliance
		quantum of flows available in Brahmani river at Samal Barrage, the results indicate that Brahmani river d/s of TTPS (Stage III) still carrying sufficient flows to meet other such requirements in future. ➢ The withdrawal of the sediment load is only 2.296% and 0.846% of the present sediment carrying at the withdrawal site for TTPS (Stage III) and TTPS (Stage I & Stage II), respectively. These values are very small as compared to the present existing sediment load of channel. The channel has already been adjusted itself due to change in flow regime as impounding has been occurred since last 36 years. ➢ The magnitude of the withdrawal is very less as compared to the existing flow in the river so the transport capacity especially for high flows (generally responsible for carrying sediment load) will not be affected and possibilities of sediment deposition may not be encountered.
viii.	Mercury in fly ash shall be periodically monitored by Inductively Coupled Plasma Mass Spectrometry (ICP-MS)	Awarded to M/s NEERI, Nagpur. The work is in progress as per schedule.
ix.	Details of month-wise quantity of fly ash disposed and water consumption along with nature of water shall be submitted to Ministry.	NTPC is submitting annual report of Ash utilization to MOEF&CC. Annual Environmental Statement containing ash utilization and Water consumption for various purposes is also being submitted to SPCB, Odisha.

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S.No	EC Stipulation in EC letter dated 19.04.2017	Status of Compliance
x.	Half-yearly Compliance report for all the stipulated condition in this permission shall be submitted to the Ministry and its Regional Office	NTPC is submitting Half-yearly Compliance report to the Ministry and its Regional Office
xi.	The fly ash utilization shall be in compliance with Fly ash Notification and its amendments issued from time to time by the Ministry.	Around 1% of flyash is being used in manufacturing of ash based industries. Balance ash is being utilized in filling of abandoned South Balanda Mine Voids of MCL. Both these ash utilisation activities are in compliance with Fly ash Notification
xii.	Third party evaluation / Environment Audit shall be conducted annually for reviewing the compliance conditions stipulated in the clearances along with the baseline data / studies to be carried out during the period of temporary permission.	Awarded M/s SV Enviro Labs.
xiii.	Compliance of EC / amendment conditions, Environment (Protection) Act. 1986, Rules and MoEF&CC Notifications issued time to time shall be done by an Environment Officer to be nominated by the Project Head of the Company who shall be responsible from implementation and necessary compliance timely.	A senior officer in the rank of Additional General Manger (Env. Management Group/Ash Utilization) is made responsible by NTPC management for implementation & necessary compliance timely.
11.	All other studies & conditions prescribed in the earlier permissions dated 05.09.2013, 02.03.2015 and 11.04.2016 shall also be complied with by NTPC and other concerned, as applicable.	All other studies & conditions prescribed in the earlier permissions dated 05.09.2013, 02.03.2015 and 11.04.2016 are being complied by NTPC

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