CHAPTER 4

RESULTS & DISCUSSION

4.1 Introduction

Opencast mines are extensively in practice for excavation of coal. It is necessary to study the quantity of waste material and the quality of water in and around the mine. Over time and during the abundant phase, water quality is deteriorating due to mining. In this research, it was observed that laboratory quality water testing of abandoned mine treated with overburden and flyash caused a change in water quality. However, their impact on water quality and the environment needs to be studied extensively. To assess the potential of overburden, as well as fly ash for abandoned and active dumping in abandoned mines and its effect: Several samples of overburden, flyash and water were collected from the Singrauli coalfield. Their effect was studied by studying geochemical and water quality analysis. Keeping all the above requirements in mind, a detailed investigation has been carried out both in the field and in the laboratory. The detail investigation under following headings have been conducted:

1) Geochemical analysis of overburden, flyash and overburden + 30% flyash
2) Heavy metals and trace elements concentration in overburden, and overburden+30% flyash
3) Mineralogical analysis
4) XRF analysis of overburden, fly ash, and overburden + 30% fly ash
5) Microscopic analysis of size
6) Physico-chemical characteristics of water quality

7) Application of work in field

8) Design and fabrication of experimental setup for rock - water interaction study

9) Statistical analysis of water sample data

10) Graphical representation of water quality data

4.2 Geochemical analysis

4.2.1 Geochemical analysis of overburden, flyash and overburden + 30% flyash

The geochemical analysis of overburden, flyash and overburden + 30% flyash are summarized in **Table 4.1, 4.2 & 4.3**. From the tables shows that oxides of Ca, Mg, K and Na along with silica, iron and Al in the rock. It may be observed that the average calcium oxide (CaO) percentage which is 5.43% and varying between from 4.04-7.79%. Also similar fluctuation have been observed in potassium oxide (K_2O). The percentage of magnesium oxide (MgO) is relatively higher and ranging between 6.31-9.37% with an average value of 7.75%. On the other hand the least reactive oxides (Al_2O_3, SiO_2, FeO, and MnO) percentage are significant and corresponds to more than 60% in the rock. The **Tables** gives a hint about the geo-chemical characteristics of associated rocks.

Table 4.1: Geochemical composition (%) of overburden of various mines of NCL

Mines Name	Sample Code	CaO	MgO	K_2O	Na_2O	MnO	FeO	SiO_2	Al_2O_3
Gorbi	G001	3.62	6.31	6.72	4.17	1.84	2.63	55.8	11.8
Amlohri	AML001	3.18	7.14	6.64	3.86	1.38	2.74	56.4	9.2
	AML002	3.07	7.23	7.31	3.81	1.82	2.39	53.2	11.2
	AML003	3.42	7.82	7.64	3.72	2.91	2.84	55.7	10.7
Bina	BN001	3.94	9.37	7.61	3.14	2.81	2.81	56.9	10.6
	BN001	2.97	8.42	7.09	4.17	1.96	2.66	54.2	10.4
	JHN001	3.64	6.74	7.13	4.22	1.94	2.54	56.5	11.6
Jhingurdha	JHN002	3.13	6.92	6.97	3.91	1.98	2.58	57.3	11.9
	JHN003	3.74	6.77	6.82	3.98	1.34	2.39	50.3	13.4
Dudhichua	DD001	3.92	6.82	6.74	3.73	1.67	2.82	56.4	13.6
	DD002	3.66	7.99	6.30	3.46	1.72	2.83	54.2	11.3
Jayant	JY001	3.27	7.87	7.82	3.41	1.88	2.76	53.8	10.9
	JY002	3.92	6.90	7.74	4.08	1.74	2.49	58.4	11.2
	JY003	3.80	7.81	7.82	4.18	1.62	2.95	57.3	14.0
	JY004	3.83	8.01	8.31	4.12	1.84	2.61	57.0	14.2
Kakri	KAK001	3.17	8.34	7.92	4.36	1.73	3.08	56.8	13.8
	KAK002	3.26	8.24	7.84	4.12	1.92	2.09	55.2	12.07
	KAK003	3.99	8.64	8.32	4.19	1.48	2.73	53.0	14.2
Khadia	KHA001	3.57	8.34	8.17	4.27	1.62	2.48	54.8	11.8
	KHA002	3.68	8.14	9.24	4.15	1.81	2.66	53.0	11.2
	KHA003	3.77	8.80	8.37	3.81	1.82	2.73	55.8	11.3
Krishnashila	KSL001	3.24	7.94	8.42	2.92	1.83	2.48	56.4	12.2
	KSL002	3.97	8.34	8.91	3.81	1.84	2.66	53.1	10.9
	KSL003	3.66	8.12	8.44	3.18	1.88	2.92	50.7	10.9
Nigahi	NGH001	2.98	6.94	7.92	3.16	1.34	2.19	51.3	11.6
	NGH002	2.89	7.62	5.93	2.86	2.47	3.12	56.91	12.05

Table 4.2: Geochemical composition (%) of overburden + 30% flyash of various mine of NCL

Mines Name	Sample Code	CaO	MgO	K_2O	Na_2O	MnO	FeO	SiO_2	Al_2O_3
Gorbi	G001	7.48	14.36	8.36	4.03	1.24	1.84	50.53	8.34
Amlohri	AML001	7.62	13.24	8.14	2.81	1.32	2.62	53.58	7.81
	AML002	4.89	10.07	6.24	2.01	1.87	2.39	54.43	9.76
	AML003	5.88	11.21	7.66	3.22	1.34	2.44	51.39	12.82
Bina	BN001	6.37	10.62	7.38	2.92	1.28	2.76	53.46	10.34
	BN001	4.23	9.18	5.22	1.84	1.44	2.78	63.99	7.38
Jhingurdha	JHN001	6.34	12.43	4.57	2.85	2.03	1.43	54.74	10.19
	JHN002	5.77	11.04	6.94	3.00	1.37	1.94	53.74	12.34
	JHN003	6.03	10.62	5.62	4.28	1.44	2.30	48.91	10.41
Dudhichua	DD001	5.01	8.62	6.38	2.82	1.87	2.34	58.86	9.88
	DD002	6.82	14.07	7.08	1.08	1.82	2.81	49.35	13.27
Jayant	JY001	8.41	9.72	5.84	2.96	1.09	2.96	54.14	10.38
	JY002	3.18	8.31	4.22	0.89	1.70	2.64	63.08	12.94
	JY003	6.22	11.00	8.04	3.41	1.84	2.69	54.60	7.82
	JY004	5.31	12.32	7.32	2.27	1.92	2.27	58.36	5.94
Kakri	KAK001	2.81	6.04	3.64	2.81	1.09	2.34	69.34	8.29
	KAK002	2.10	5.21	4.07	1.74	1.34	2.81	71.41	8.43
	KAK003	2.34	5.32	3.82	2.92	1.88	2.33	71.49	6.81
Khadia	KHA001	2.82	6.04	3.41	3.42	1.24	2.42	68.49	8.74
	KHA002	7.92	16.33	8.07	3.48	2.07	3.01	46.46	7.94
	KHA003	6.21	10.87	7.18	3.00	1.64	1.84	56.06	8.38
Krishnashila	KSL001	7.66	15.32	8.09	3.27	1.87	2.18	48.31	8.61
	KSL002	3.14	7.48	4.72	2.84	1.92	2.37	67.17	6.28
	KSL003	6.60	11.37	5.89	3.84	1.31	2.81	55.49	8.94
	KSL004	3.28	7.62	4.54	2.90	1.10	2.53	65.40	8.69
Nigahi	NGH001	4.22	9.28	5.34	3.11	1.23	2.73	61.16	9.71
	NGH002	3.09	7.04	6.04	2.97	1.88	2.39	67.21	8.44
Gorbi Block B	GBB001	3.12	8.01	6.84	3.14	1.82	2.34	59.6	11.2
	GBB002	3.74	6.82	6.39	4.22	1.72	2.62	53.2	12.7

Table 4.3: XRF results of flyash

Thermal Power Station	Samples Code	SiO_2	Al_2O_3	CaO	FeO	MgO	MnO	Na_2O	K_2O
Anpara	ATPP01	47.53	21.10	5.04	9.32	1.36	0.50	1.19	0.67
	ATPP02	51.01	21.56	4.30	10.01	1.97	0.32	0.52	0.33
	ATPP03	59.79	26.06	5.78	8.54	2.09	0.18	0.81	0.20
	ATPP04	47.31	26.84	5.24	10.83	2.74	0.20	0.44	0.74
	ATPP05	58.72	20.76	4.04	5.27	0.91	0.36	0.59	0.92
Renusagar	RTPP01	45.85	27.73	7.40	3.19	2.90	1.04	0.64	0.71
	RTPP02	40.54	23.04	6.08	8.09	2.99	0.91	1.38	0.66
	RTPP03	57.73	26.27	5.61	8.30	1.72	2.12	1.25	0.42
	RTPP04	44.02	20.67	4.89	8.39	0.81	1.45	1.20	0.21
	RTPP05	56.56	25.51	5.57	7.56	2.20	1.12	1.27	0.65
Shaktinagar	STPP01	59.71	21.07	5.48	9.87	2.13	0.42	0.83	0.48
	STPP02	52.88	26.60	5.32	4.98	0.94	1.29	0.81	0.27
	STPP03	40.76	21.10	4.96	13.08	2.25	0.70	0.46	0.35
	STPP04	59.15	26.06	5.01	4.02	0.78	0.10	1.29	0.32
	STPP05	55.23	25.57	4.46	10.94	2.23	1.50	1.47	0.47
Vindhyachal	VTPP01	51.15	29.67	7.79	10.57	2.32	0.72	1.41	1.18
	VTPP02	47.33	27.10	5.28	9.55	0.74	1.81	0.67	0.20
	VTPP03	47.91	27.56	6.72	7.97	2.07	0.53	0.67	0.22
	VTPP04	45.98	26.95	5.67	6.86	1.66	0.11	0.64	0.71
	VTPP05	40.69	24.37	4.06	9.02	0.78	0.52	0.70	0.85

4.3 Heavy metals and trace elements concentration in overburden, and overburden+30% flyash

Potentially toxic metals and elements concentration of overburden, and overburden + 30% flyash and their statically analysis are presented **(Table 4.4 and 4.5)**. In case of overburden, the average concentration of Al, B, Ca, Cd, Cu. Fe, K, Mg, Ni, and Zn are 3137.81 mg/kg, 47.50 mg/kg, 489.20 mg/kg, 5.23 mg/kg, 28.87 mg/kg, 3134.53 mg/kg, 1541.92 mg/kg, 1089.35 mg/kg, 14.07 mg/kg, and 34.97 mg/kg. The decreasing order of heavy metals for overburden are found to be Al>Fe>K>Mg>Ca>B>Zn>Cu>Ni>Cd. For OB+30% flyash, the average concentration of Al, B, Ca, Cd, Cu, Fe, K, Mg, Ni, and Zn are 3450.56 mg/kg, 22.20 mg/kg, 763.32 mg/kg, 5.20 mg/kg, 27.47 mg/kg 1535.90 mg/kg 1025.87 mg/kg, 1050.01 mg/kg, 10.48 mg/kg and 46.36 mg/kg. The decreasing order of heavy metals for overburden are found to be Al>Fe>Mg>K>Ca>Zn>Cu>B>Ni>Cd. The trace and heavy elements concentration analysed and which is found to be well within the standards and standard are given in **Tables 4.6 to 4.7**.

Table 4.4: Heavy metals and trace elements concentration analysis results in overburden mine sample

Parameters	Unit	Gorbi	Bina	DD	AML	JHN	JAY	KAK	KHA	KKR
pH		6.63	6.12	6.58	6.42	5.98	5.19	6.09	5.98	6.18
Al	**mg/kg**	2972.70	2995.53	2259.56	3488.96	3722.70	3323.91	3653.80	2489.90	3333.24
B		22.50	BDL	BDL	72.50	BDL	BDL	BDL	BDL	BDL
Ca		645.59	563.11	580.97	316.05	455.08	288.35	665.84	410.33	477.45
Cd		3.67	6.23	4.99	5.66	5.22	5.38	5.98	5.29	4.64
Cu		35.14	37.48	38.35	24.55	19.98	32.18	12.36	26.72	33.07
Fe		3816.35	2326.72	2478.90	1997.65	1938.72	3255.40	4369.88	4120.50	3906.63
K		1855.85	1667.94	1486.30	1585.64	1489.07	1880.43	983.03	1640.16	1288.87
Mg		1372.54	776.26	1328.25	944.91	936.67	1111.75	1158.77	885.02	1290.01
Ni		13.62	12.62	13.46	12.08	10.78	19.03	11.09	21.06	12.94
Zn		25.89	31.39	25.60	40.44	41.29	30.91	34.00	44.89	40.31

BDL – Below Detection Limit

Table 4.5: Heavy metals and trace elements concentration analysis results in overburden + 30% flyash sample

Parameters	Unit	Gorbi	Bina	DD	AML	JHN	JAY	KAK	KHA	KKR
pH		8.63	7.12	8.58	6.42	5.98	8.19	8.09	8.98	8.18
Al	**mg/kg**	3450.56	3708.2	2622.18	3981.97	3573.69	3909.5	3564.24	2954.47	3023.18
B		12.3	BDL	BDL	32.1	BDL	BDL	BDL	BDL	BDL
Ca		980.7	627.21	813	780.68	811.4	675.53	681.46	695.08	804.84
Cd		4.71	6.69	8.82	7.6	5.12	5.89	7.36	7.81	5.2
Cu		17.25	17.9	17.83	24.75	27.86	21.89	29.8	26.93	27.47
Fe		1649.61	1272.28	1754.51	1643.37	1603.94	1619.24	1603.26	1323.05	1353.83
K		1213.4	904.29	902.55	1032.36	944.27	1091.73	1075.89	928.35	1140.02
Mg		1020.21	1247.06	1165.4	912.84	1029.86	964.41	1096.87	1060.18	953.24
Ni		7.2	8	10.64	8.41	11.46	8.8	14.66	11.49	13.65
Zn		68.84	25.9	24.25	57.98	51.87	49.16	38.33	55.57	45.31

BDL – Below Detection Limit

Table 4.6: Indian safety limit for soil

Elements	Co	Cr	Cu	Mn	Ni	Pb	Zn
Standard (mg/kg or ppm)	60-100	NA	135-270	NA	75 - 150	250 - 500	300 – 600

Table 4.7: Regulatory limits on heavy metals as per as US EPA (1993)

Elements	Cd	Cr	Cu	Ni	Pb	Zn
Max. concentration in sludge (mg/kg or ppm)	85	3000	4300	75 - 150	420	7500

4.4 Mineralogical analysis

In this thesis, the overburden, flyash, and overburden + 30% flyash metals were subjected to XRD, XRF and SEM analysis for identification of mineral phases, examination of morphology and measurement of elemental concentration and distribution.

4.4.1 XRD results of overburden, flyash, and overburden + 30% flyash

The mineral phase XRD pattern, resulting peaks **(Fig. 4.1 & 4.2)** are compared to the standards JCPDS number. The major minerals phases in overburden and overburden +30% flyash samples are found to be quartz, SiO_2, CaO and Fe_2O_3 minerals are observed. The X-ray plot of diffraction angle (2θ) versus intensity of radiation which reveals the interplanar spacing and in turn, the type of mineral. The crystalline phases present in fly ash consist of quartz (SiO_2), Mullite (Al_6SiO_2), hematite (Fe_2O_3) and Calcium oxide (CaO).

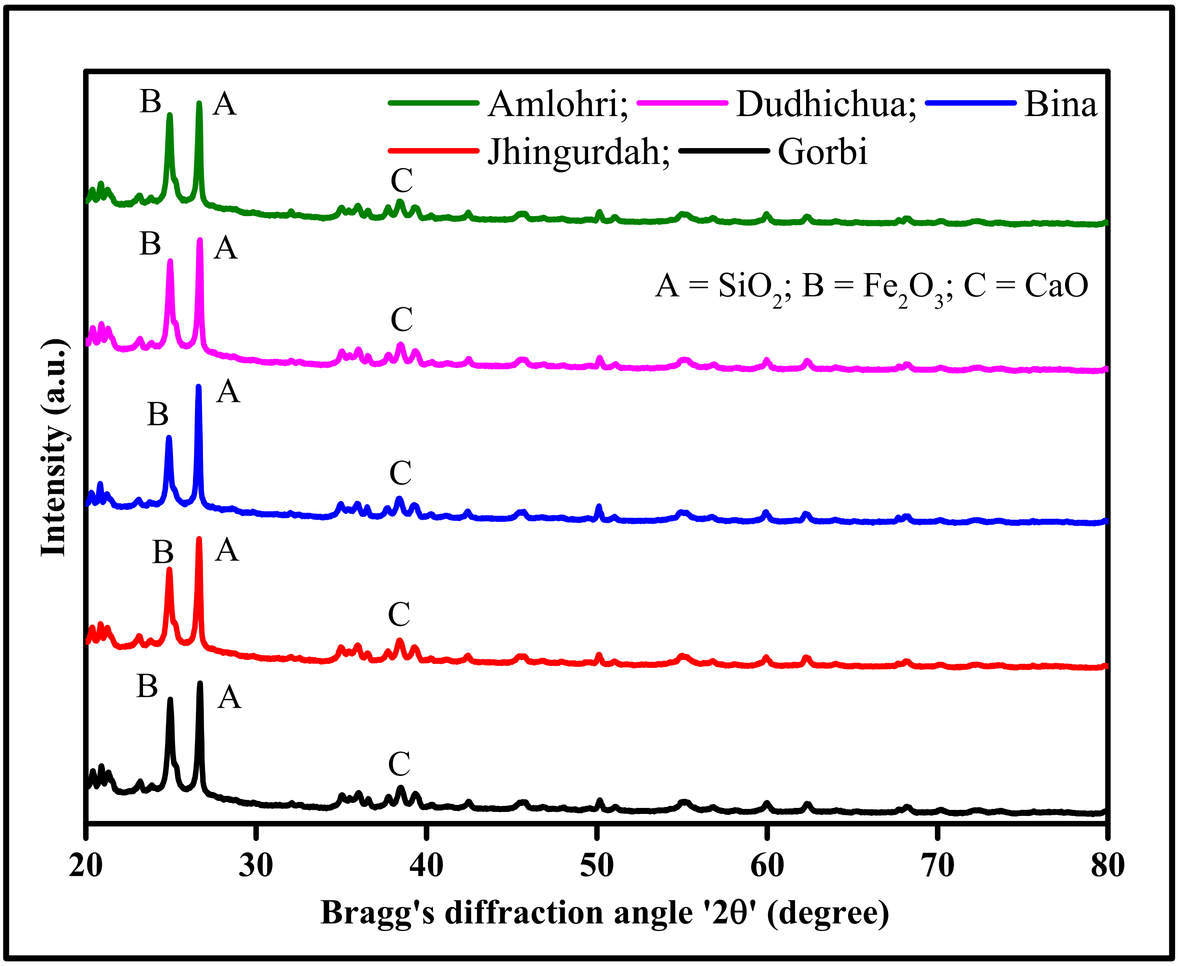

Fig 4.1: XRD analysis of various type of overburden NCL mines

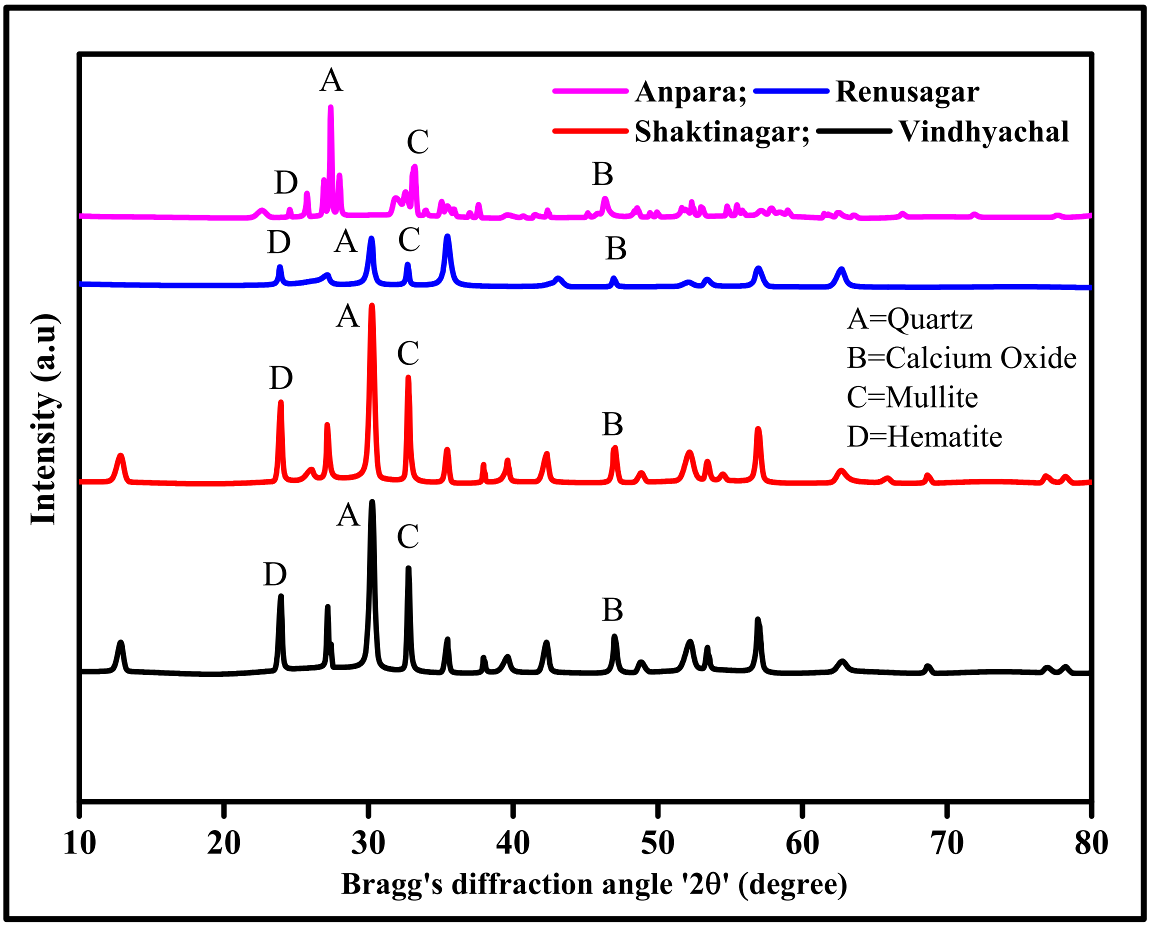

Fig 4.2: XRD analysis of flyash different type of Thermal Power Plants Singrauli Coalfield

4.4.2 XRF analysis of overburden, flyash, and overburden + 30% flyash

The data of analyzed overburden samples shows that Alumina (Al_2O_3) content of the OB varies from 15.60% - 26.79 % with an average of 20.84%. The lower alumina content may be attributed to their low content of clay. Magnesium Oxide (MgO) varies from 0.52% to 4.50% with an average value of 1.98%. The Silica (SiO_2) content of the OB varies from 39.98% to 49.53% with an average value of 45.01%. High silica content shows that the soil is coarse sand in texture. The concentration of Calcium Oxide (CaO) varies from 4.89% - 5.99% with an average value of 10.57%. This mineral increases the cohesiveness of the soil as well as water holding capacity.it may also reduce the impact of the pyrites present in the material. The concentration of Iron Oxides Fe_2O_3 varies from 6.29% to 14.12% with an average value of 8.66%. High iron oxides increase the bulk density as well as specific gravity of the overburden. Potassium Oxide (K_2O) varies from 0.93% to 6.22% with an average value of 2.58% which is much higher than prescribed safe limit of 2.39%. The cumulative graph XRF analysis of overburden, flyash, and overburden + 30 % flyash **(Table 4.8 and Fig. 4.3)**.

Table 4.8: Characterization of XRF analysis of overburden, flyash, and overburden + 30% flyash

Parameters	**Overburden**		**Flyash**		**70% Overburden + 30% Flyash**	
	Range	**Average**	**Range**	**Average**	**Range**	**Average**
CaO	4.89-5.99	10.51±0.35	6.14-7.79	5.43±0.99	2.10-8.41	5.12±1.88
MgO	0.52-4.50	1.98±0.75	0.74-2.99	1.77±0.74	5.21-16.33	9.98±2.98
K_2O	0.93-5.24	6.62±0.81	0.20-1.18	0.52±0.28	3.41-8.36	6.11±1.52
Na_2O	0.186-1.236	0.398±0.44	0.44-1.47	0.91±0.35	0.89-4.28	2.89±0.80
MnO	1.34-2.91	1.85±0.37	0.10-2.12	0.79±0.59	1.09-2.07	1.57±0.31
FeO	6.29-14.12	8.66±0.24	3.19-13.08	8.31±2.48	1.43-3.01	2.44±0.36
SiO_2	39.98-49.53	45.01±2.17	40.54-59.79	50.49±6.65	46.46-71.49	58.06±7.37
Al_2O_3	15.60-26.79	20.84±1.29	20.67-29.67	24.77±2.82	5.94-13.27	9.40±2.0

± = *Standard Deviation*

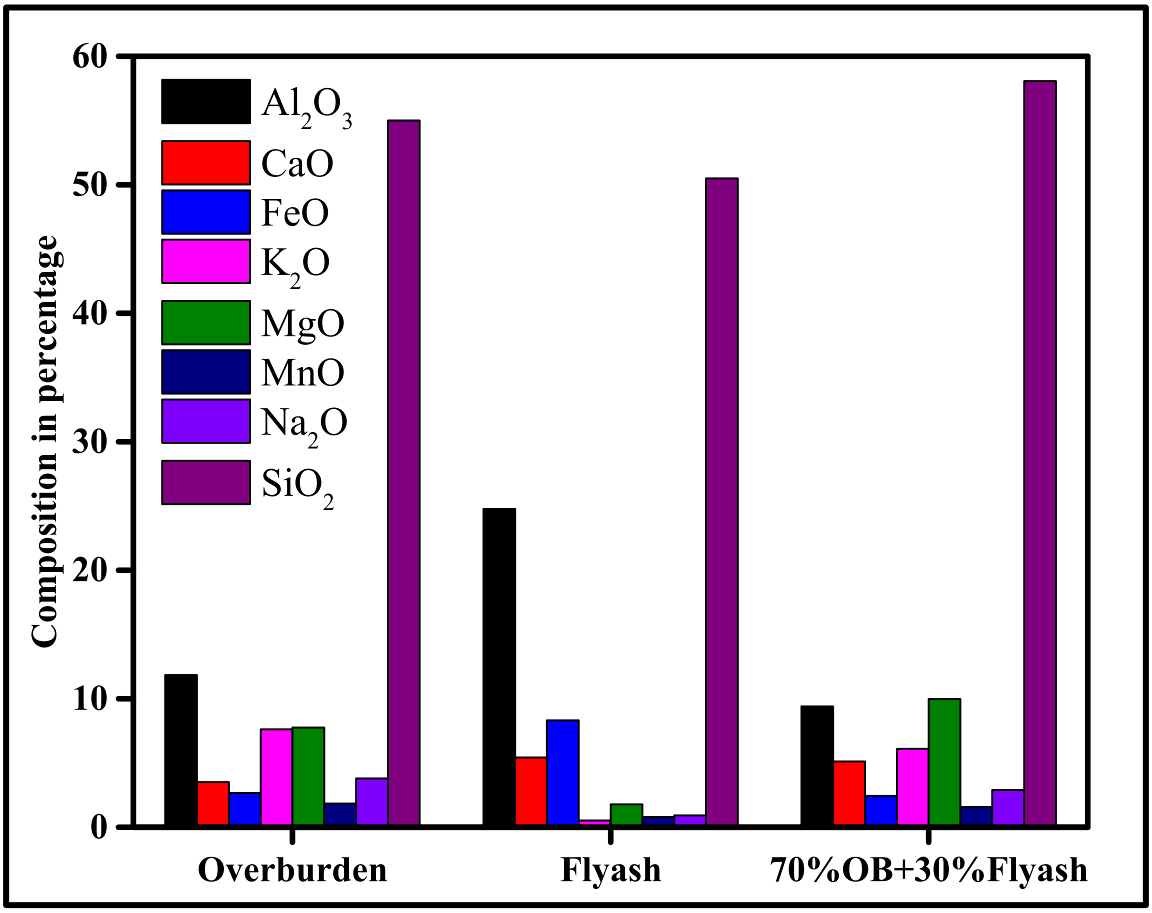

Fig. 4.3: Cumulative XRF analysis of overburden, flyash, and overburden + 30% flyash

4.5 Microscopic analysis of size

4.5.1. SEM analysis of overburden, flyash, and overburden + 30% flyash

The SEM images show the sand size (0.0625 to 2mm), silt size and aggregated clay size overburden and overburden +30% flyash particles. Few samples are having micro crack and pores **(Fig. 4.8, 4.20 & 4.18)** Reasonable pozzolanic activity of flyash with overburden has been confirmed in some of the SEM images as glassy fibrous particles are observed **(Fig. 4.4 to 4.21)** though peaks for calcium silicates hydrate and calcium aluminium hydrates is observed due to the pozzolanic activity of flyash particles. Big agglomerated particles are seen in the overburden + 30% flyash mixture samples. Several spherical particles together with irregularly shaped particles are observed **(Fig. 4.21 to 4.11)**. The rounded particles are mostly glassy. The angular particles are typically made of crystalline solids such as quartz, Mullite, magnetite, hematite etc. SEM photography showing shape and size of mineral present in overburden, flyash, and overburden + 30% flyash.

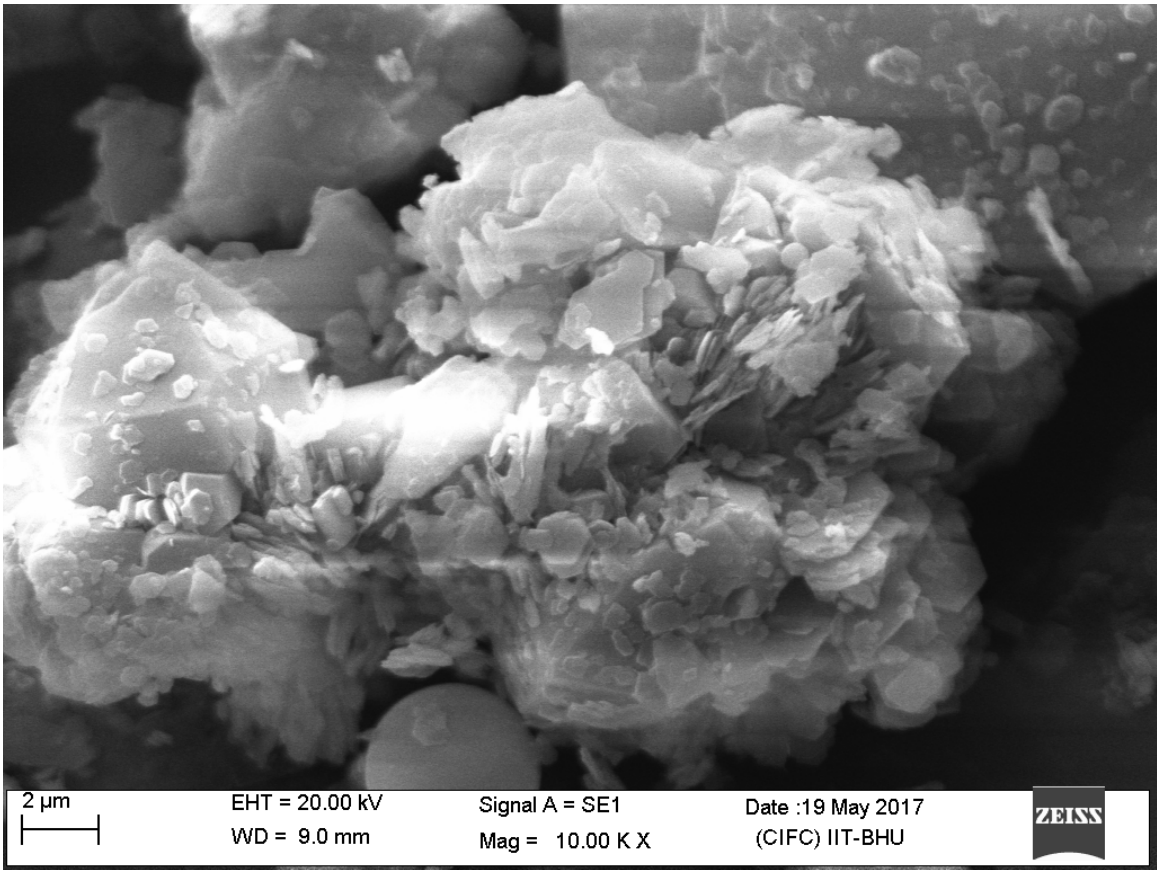

Fig 4.4: SEM image (2µm) of flyash of Anpara TPP

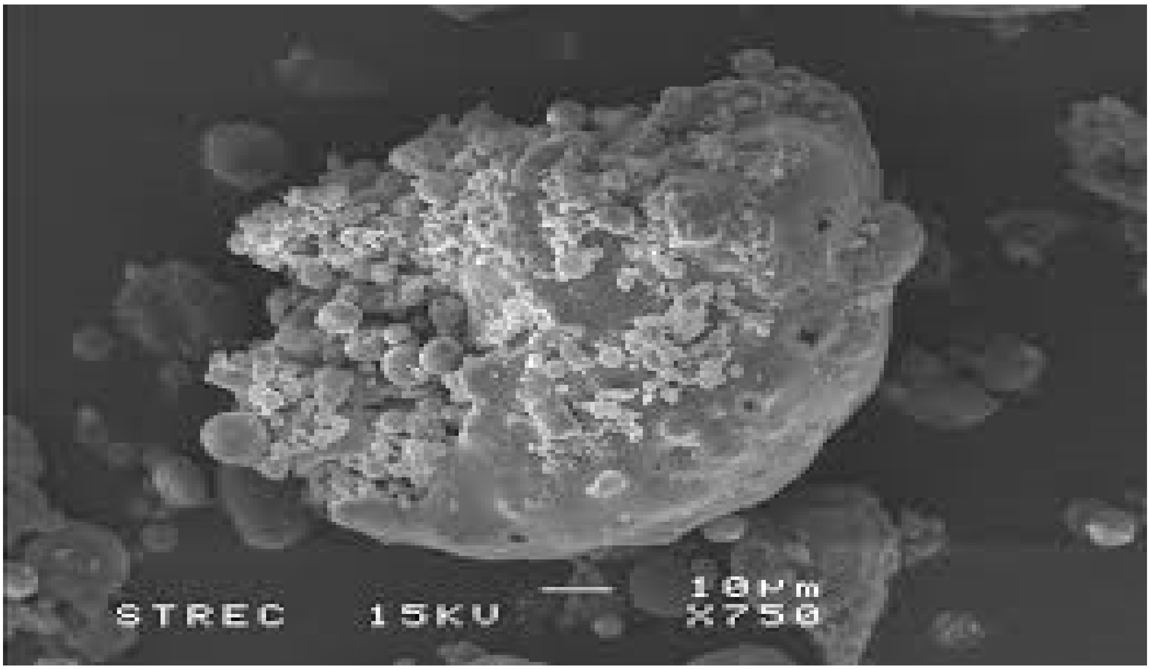

Fig 4.5: SEM image (2µm) of flyash of Shaktinagar TPP

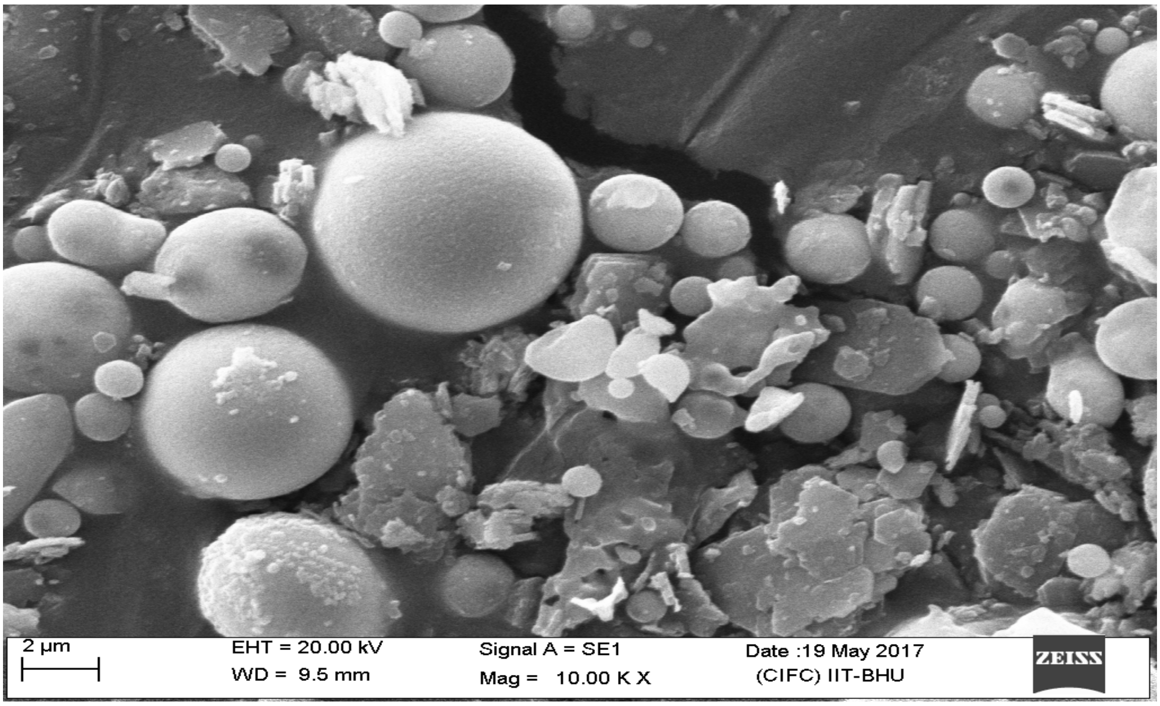

Fig 4.6: SEM image (2µm) of flyash of Shaktinagar TPP

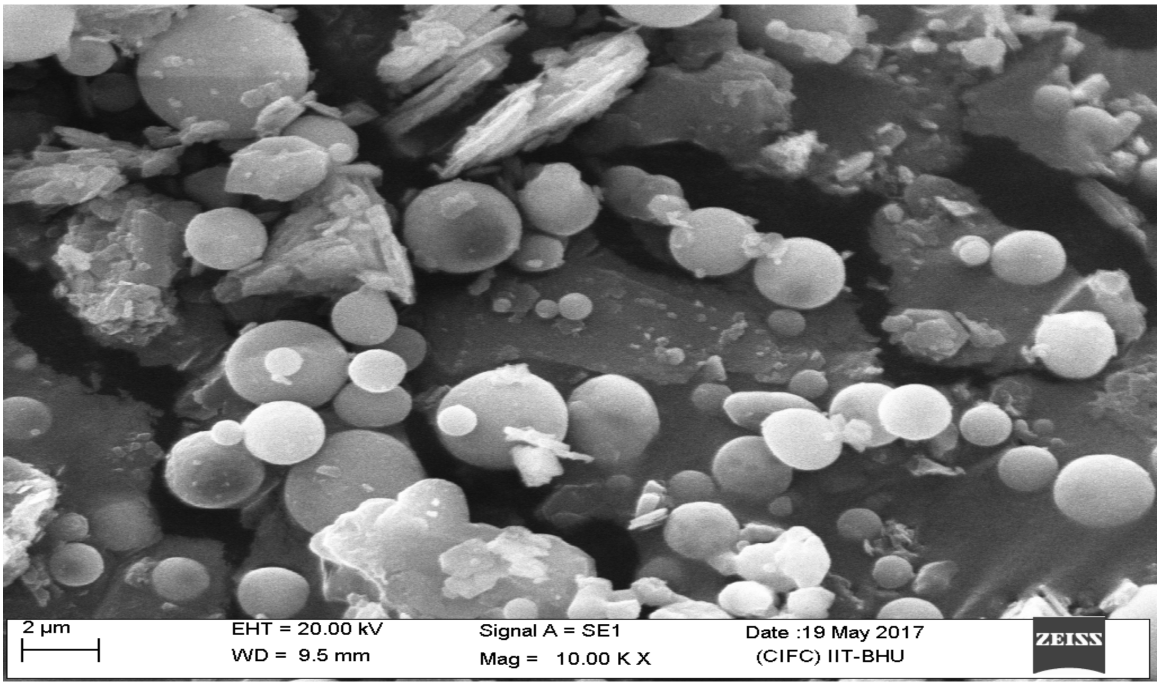

Fig 4.7: SEM image (2µm) of flyash of Renusagar TPP

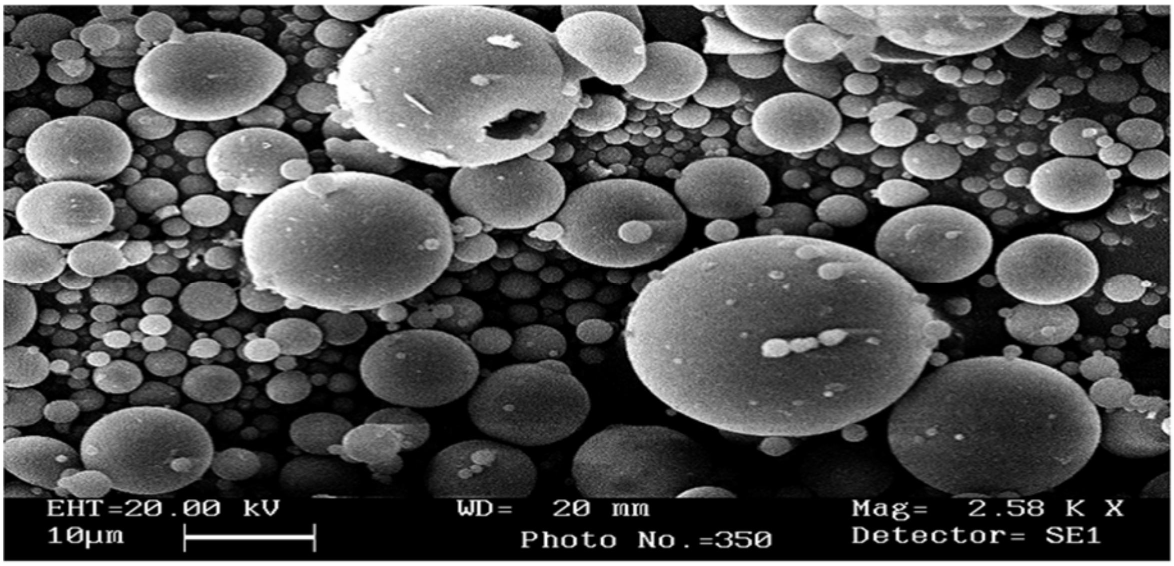

Fig 4.8: SEM image (10µm) of flyash of Renusager TPP

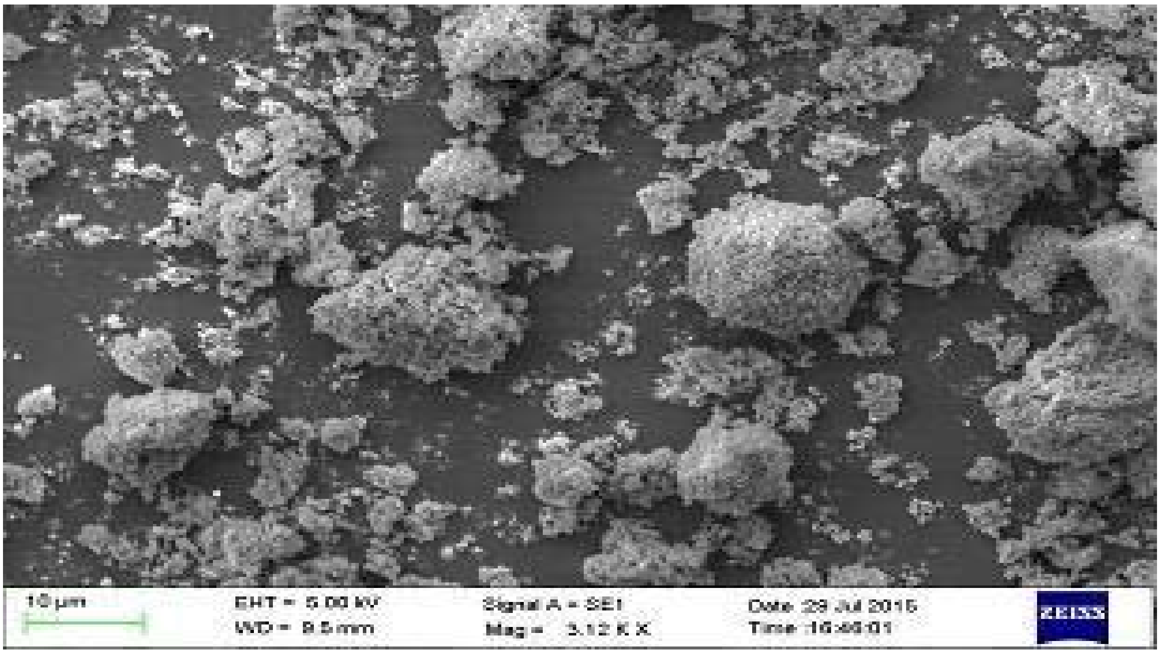

Fig 4.9: SEM image (10µm) of flyash of Anpara TPP

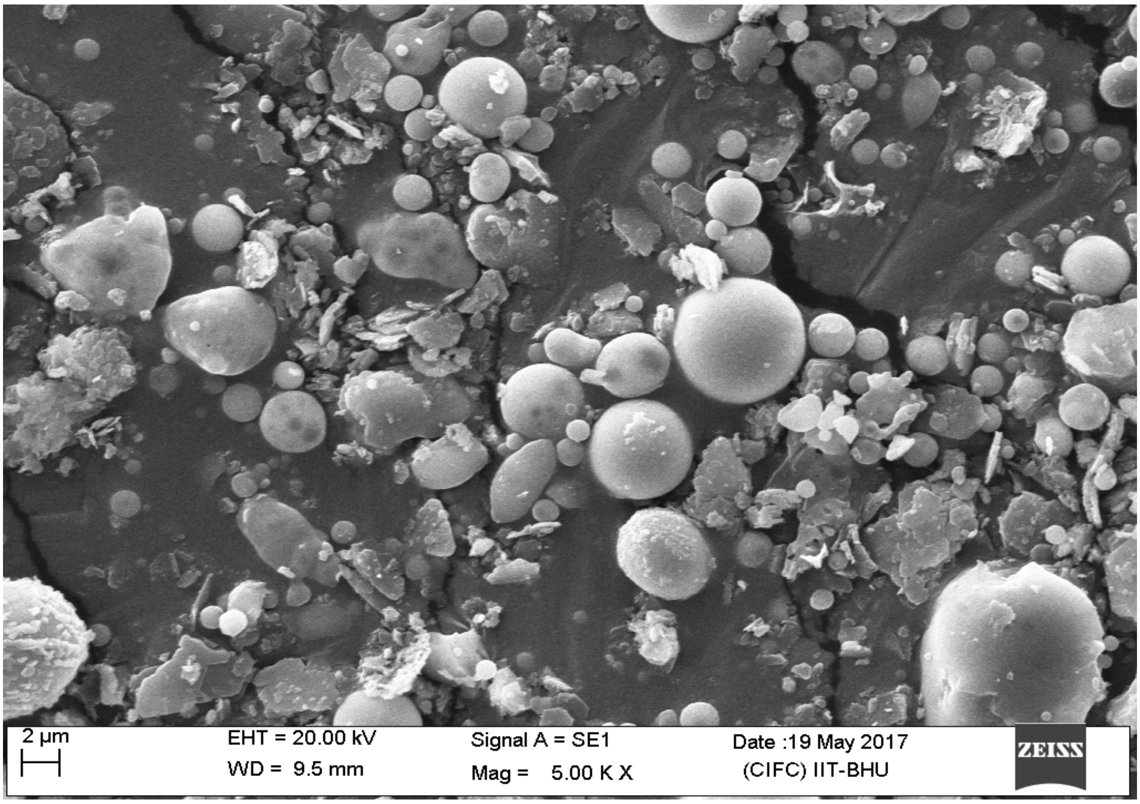

Fig 4.10: SEM image (2µm) of overburden of Gorbi mine

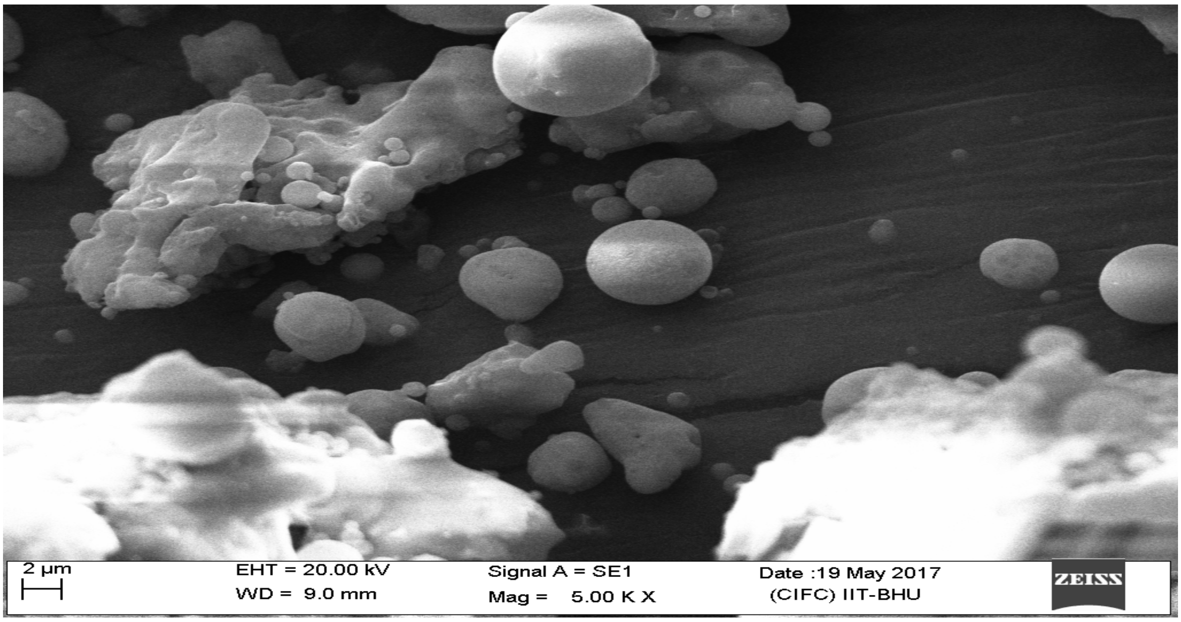

Fig 4.11: SEM image (2µm) of overburden of Nighai mine

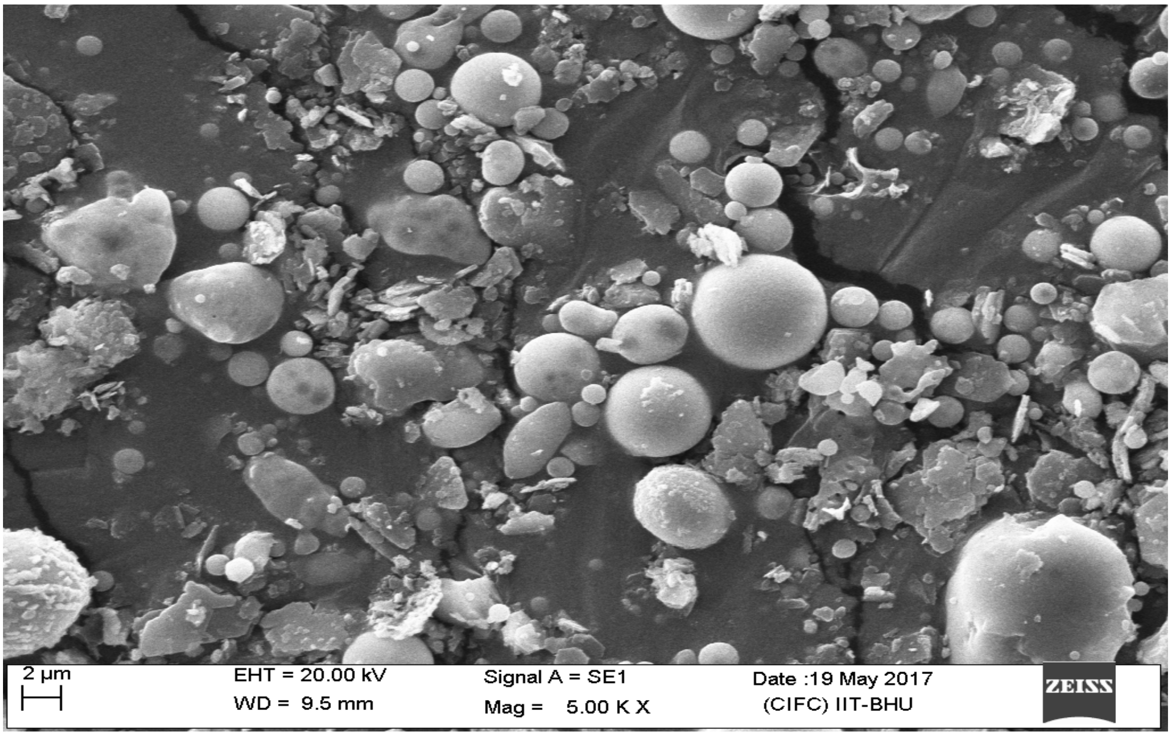

Fig 4.12: SEM image (2µm) of overburden of Gorbi Block 'B'

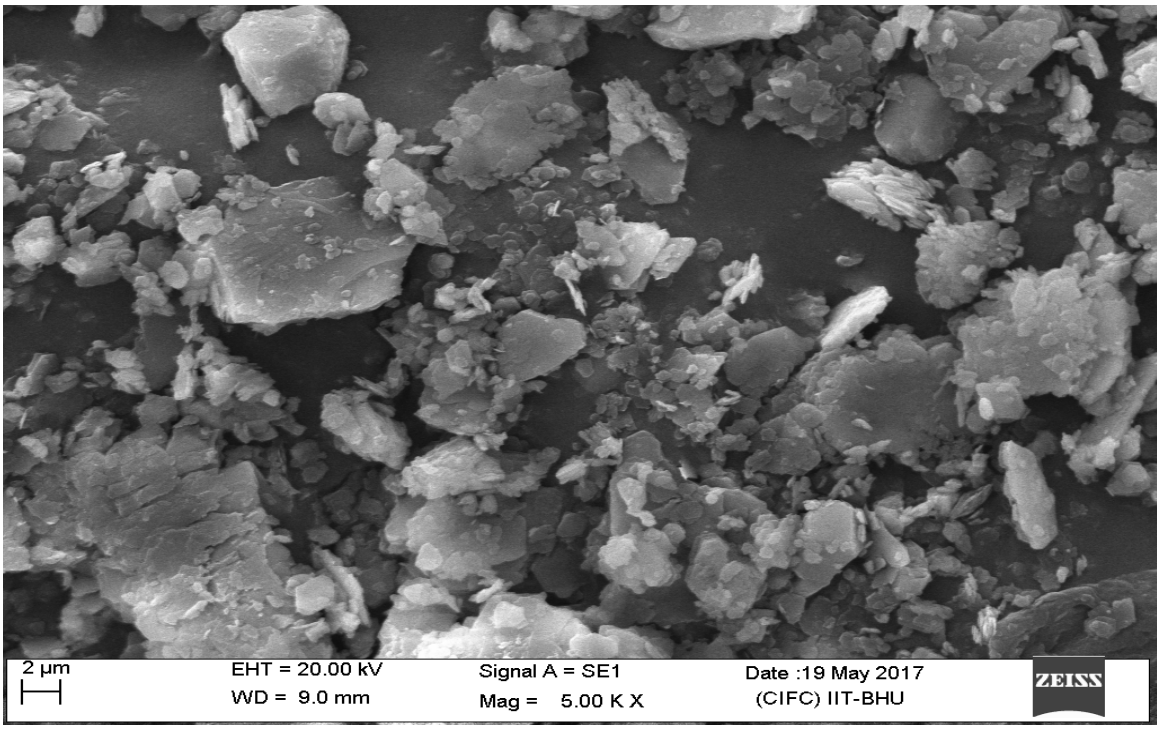

Fig 4.13: SEM image (2µm) of overburden of Bina mine

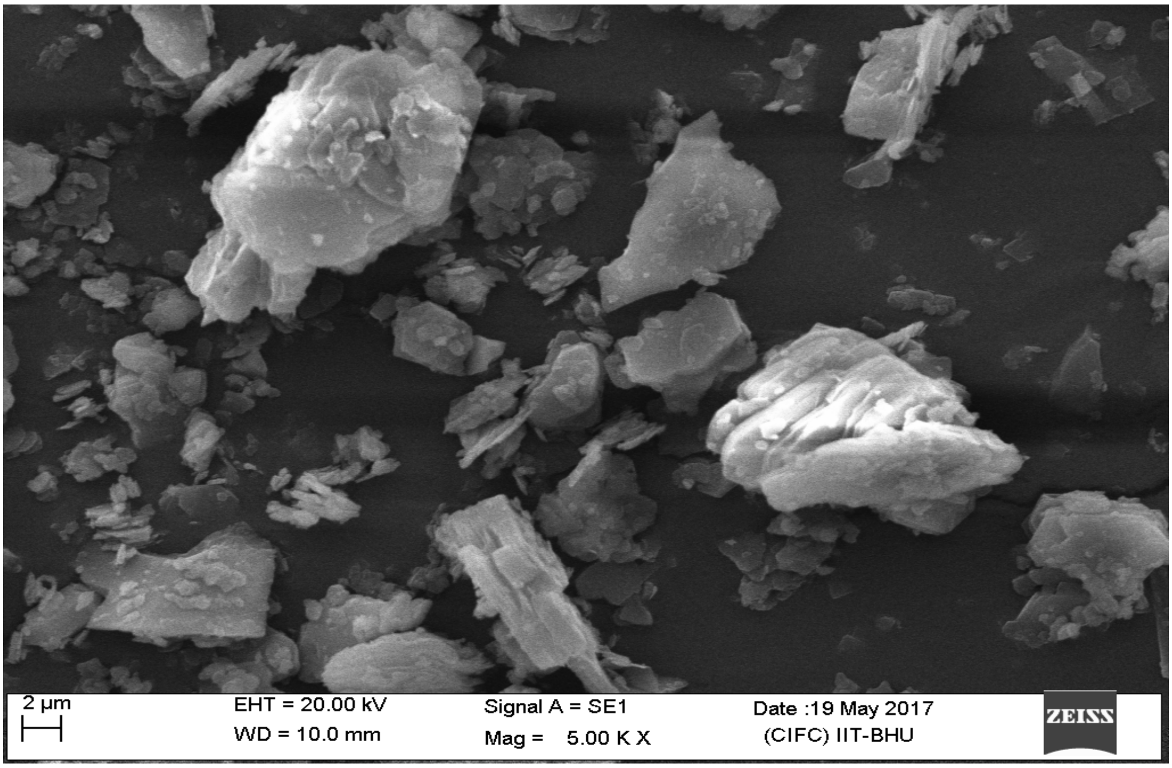

Fig 4.14: SEM image (2µm) of overburden of Dudhichua mine

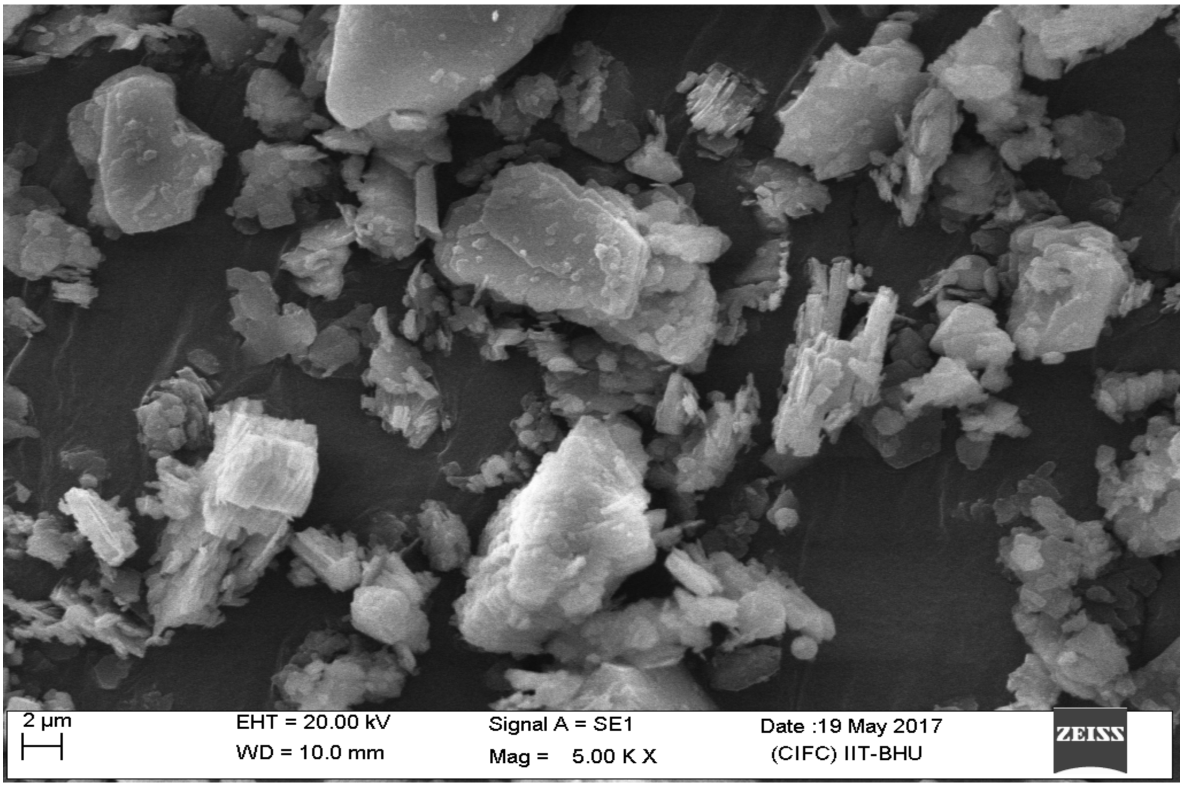

Fig 4.15: SEM image (2µm) of overburden of Khadia

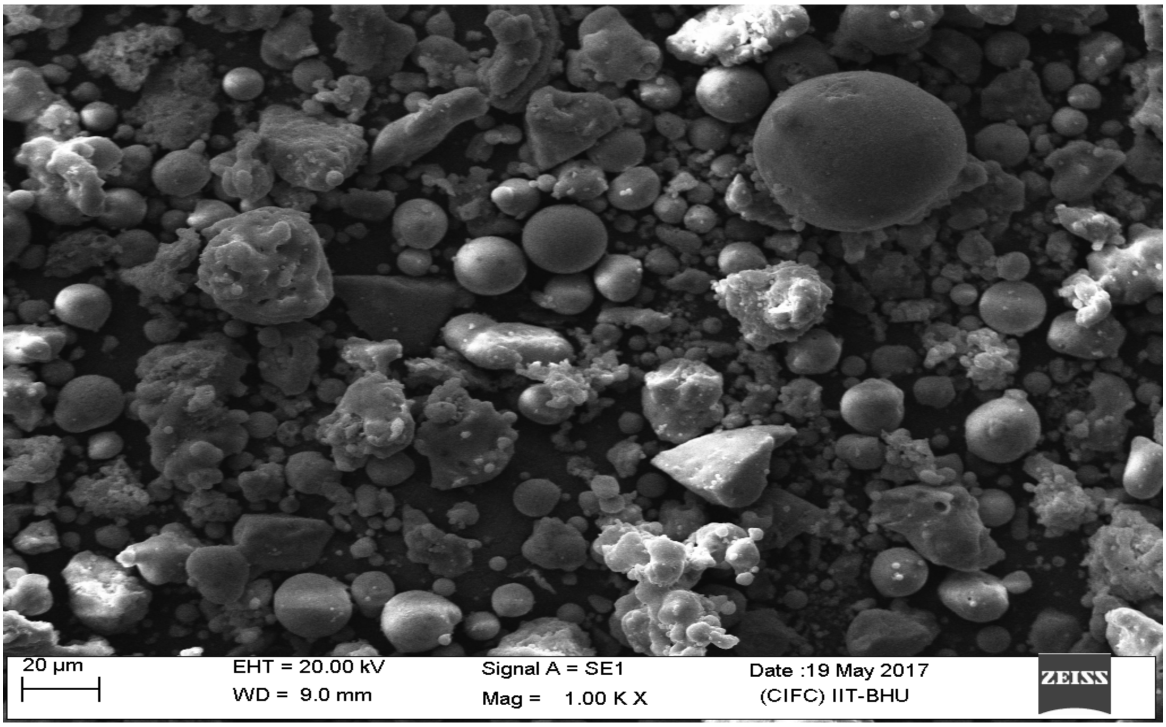

Fig 4.16: SEM image (20μm) of overburden of Amlohri mine

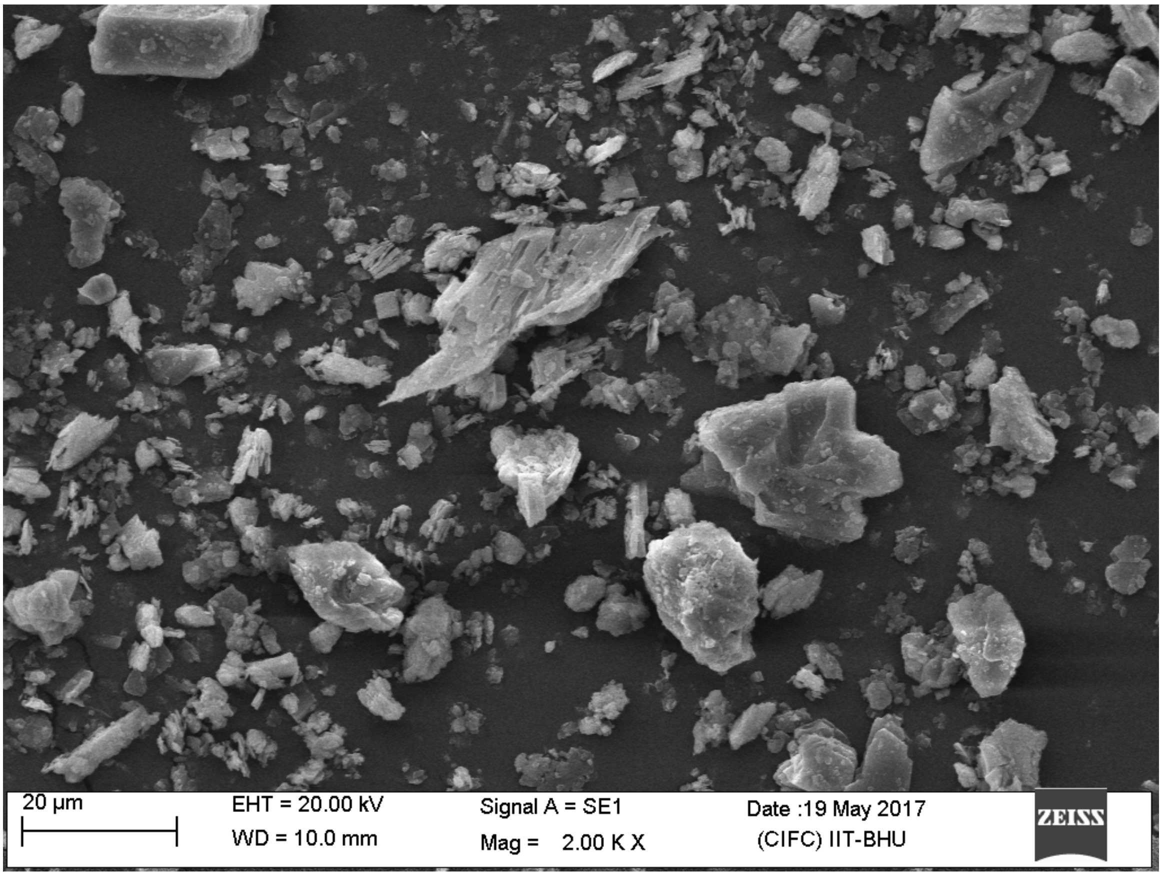

Fig 4.17: SEM image (20μm) of overburden of Jhingurdah mine

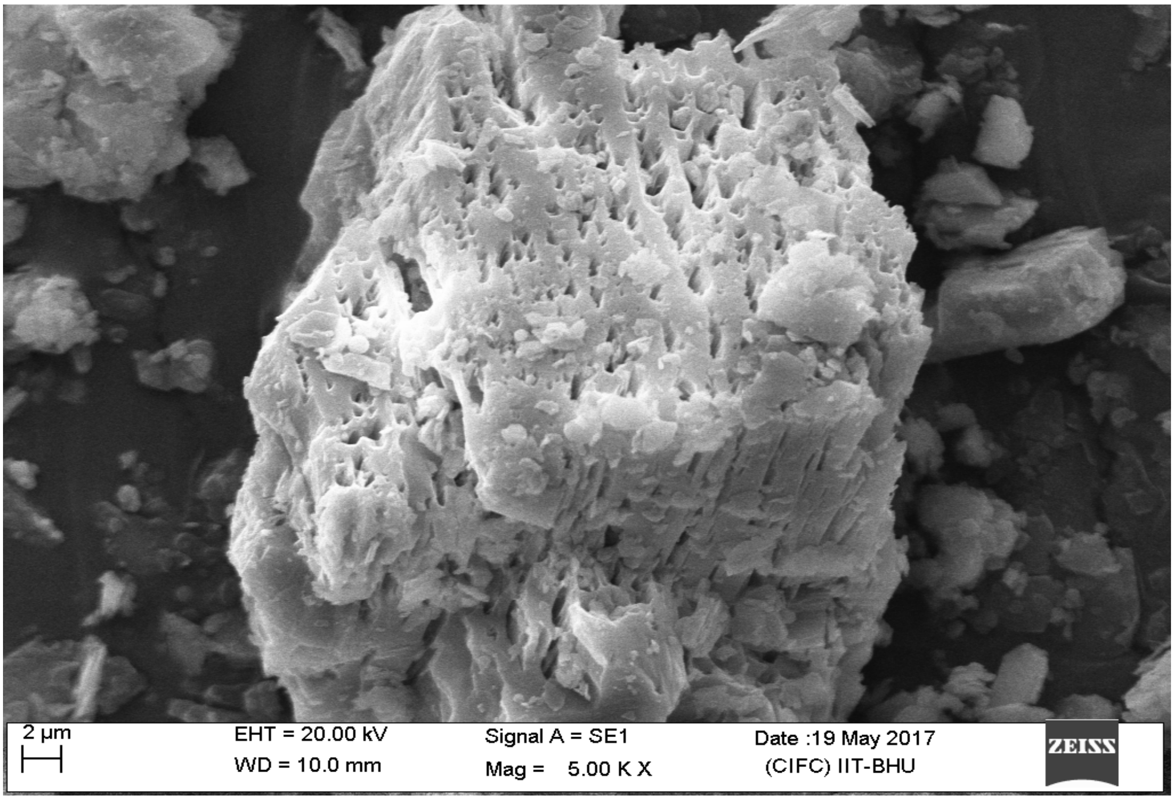

Fig 4.18: SEM image (2µm) of overburden + 30% flyash of Vindhyachal TPP

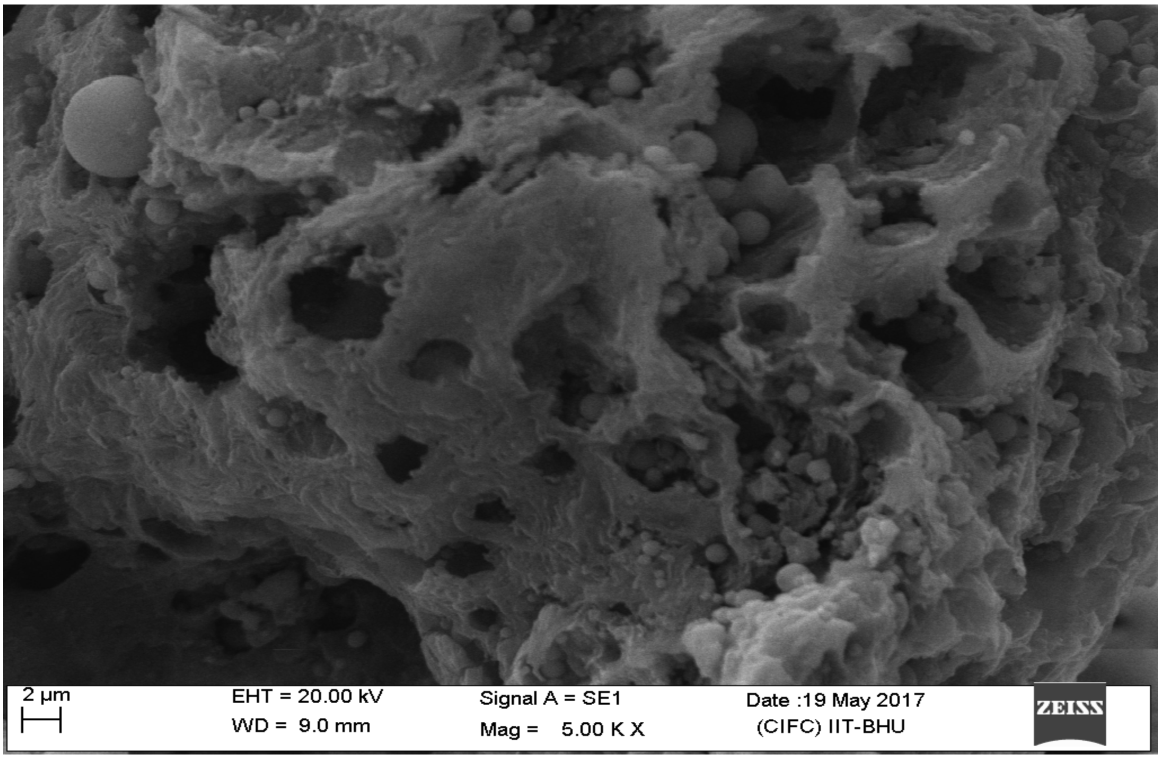

Fig 4.19: SEM image (2µm) of overburden + 30% flyash of Amlohri mine

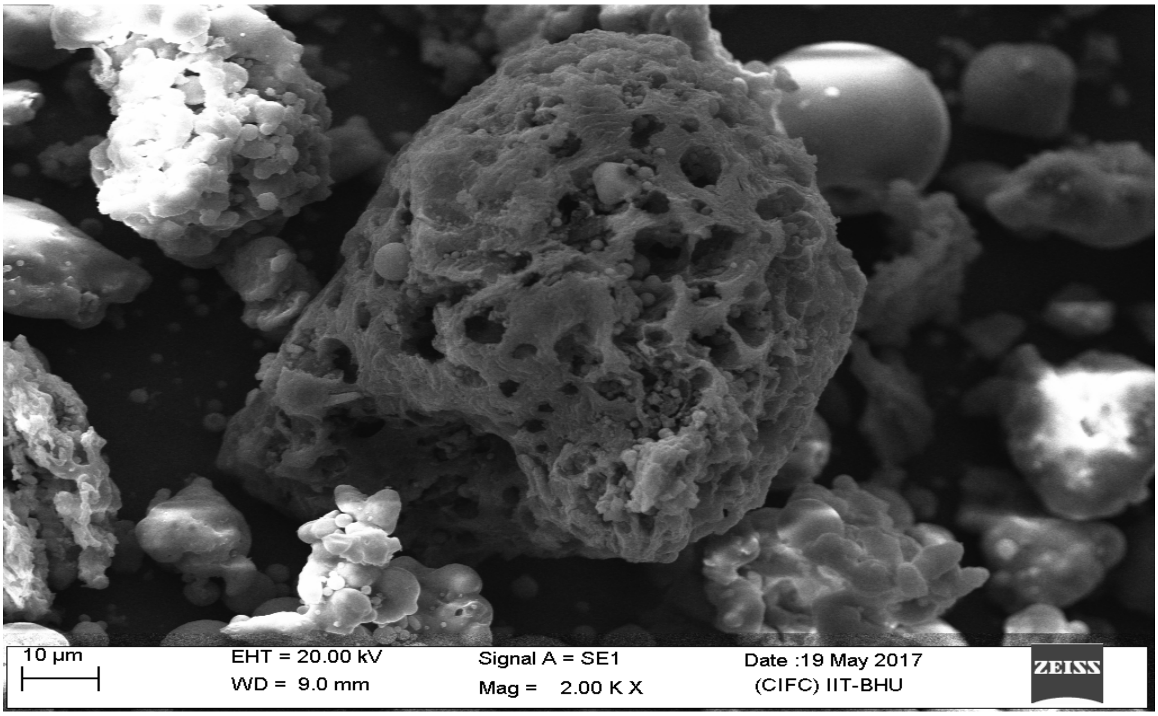

Fig 4.20: SEM image (10µm) of overburden + 30% flyash of Bina mine

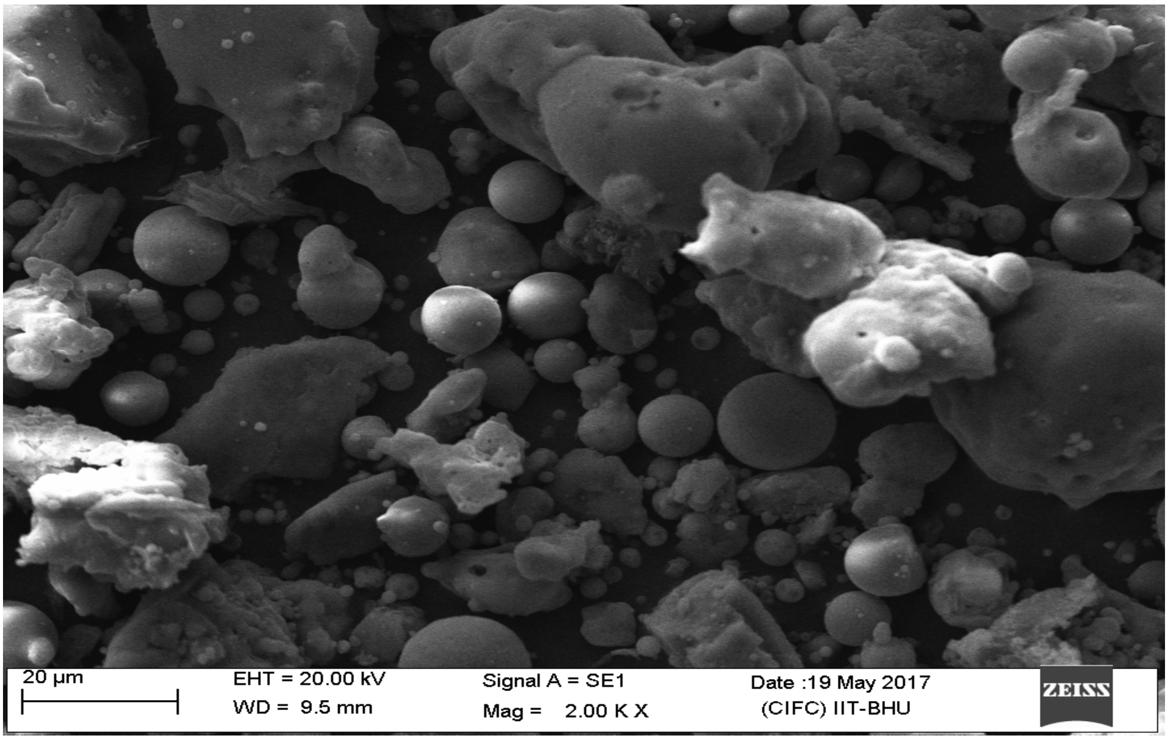

Fig 4.21: SEM image (20µm) of overburden + 30% flyash of Jhingurdah mine

4.6 Physico-chemical characteristics of water quality

The purpose of this analysis is conduct to find out the quality of water in the study area and to analyze the physico-chemical parameter of water samples. These samples were collected from mine sumps, inlet, and outlet of effluent treatment plants and ground water of NCL coal field. The sample preparations were done as per the prescribed specification **(Table 4.9 to 4.22)**.

Table 4.9: Water characteristics in Amlohri opencast project

Sl. No.	Parameters	Sump water	Workshop effluent
		Average	
1	Colour, Hazen Unit.	Black	Black
2	Temp(°C)	34.4	33.4
3	pH	5.12	5.32
4	Calcium	50.000	65.000
5	Sulphate	57.000	43.000
6	Nitrate	278.000	196.000
7	Chloride	12.900	45.000
8	Iron	156.000	166.000
9	Copper	0.131	0.300
10	Manganese	0.073	0.028
11	Arsenic	0.098	BDL
12	Lead	BDL	BDL
13	Zinc	0.340	0.550

All values are expressed in mg/lit, Except color & pH value

Table 4.10: Water Characteristics in Amlohri opencast project (As per IS-10500/2012 for drinking water standard)

Sl. No.	Parameters	Hand Pump	Tap Water-Guest House	Tolerance Limit	
				Acceptable Limit	Permissible Limit
1	Colour, Hazen Unit.			5	15
2	pH Value	6.64	7.41	6.5 – 8.5	No relaxation
3	Iron	0.168	0.052	0.3	No relaxation
4	Chlorides	146	200	250	1000
5	Calcium	13	12	75	200
6	Sulphate	4	32	200	400
7	Nitrate	3.3	3.4	45	No relaxation
8	Fluoride	0.2	0.1	1.0	1.5
9	Copper	0.025	0.03	0.05	1.5
10	Manganese	0.102	BDL	0.1	0.3
11	Arsenic	BDL	BDL	0.01	0.05
12	Selenium	BDL	BDL	0.01	No relaxation
13	Lead	BDL	BDL	0.01	No relaxation
14	Zinc	0.7204	0.0907	5	15
15	Mercury	BDL	BDL	0.001	No relaxation

All values are expressed in mg/lit, Except color & pH value

Table 4.11: Water characteristics in Dudhichua opencast project

Sl. No.	Parameters	Sump water	Workshop effluent
		Average	
1	Colour, Hazen Unit.	Black	Black
2	Temp(0c)	35	34
3	pH	6.29	7.08
4	Calcium	31.000	20.000
5	Sulphate	160.000	200.000
6	Nitrate	45.000	12.000
7	Fluoride	0.730	0.400
8	Copper	2.320	1.240
9	Manganese	675.000	273.000
10	Arsenic	0.710	0.210
11	Lead	BDL	BDL
12	Zinc	38.000	18.000

All values are expressed in mg/lit, Except color & pH value

Table 4.12: Water Characteristics in Dudhichua opencast project (As per IS-10500/2012 for drinking water standard)

Sl. No.	Parameters	Tap water of guest house	Tolerance Limit	
			Acceptable Limit	Permissible Limit
1	Colour, Hazen Unit.	Colorless	5	15
2	pH Value	7.53	6.5 – 8.5	No relaxation
3	Iron	0.188	0.3	No relaxation
4	Chlorides	90	250	1000
5	Calcium	13	75	200
6	Sulphate	23	200	400
7	Nitrate	4.2	45	No relaxation
8	Flouride	0.2	1	1.5
9	Copper	BDL	0.05	1.5
10	Manganese	BDL	0.1	0.3
11	Arsenic	BDL	0.01	0.05
12	Selenium	BDL	0.01	No relaxation
13	Lead	BDL	0.01	No relaxation
14	Zinc	0.0678	5	15
15	Mercury	BDL	0.001	No relaxation

All values are expressed in mg/lit, Except color & pH value

Table 4.13: Water Characteristics in Jayant opencast project

Sl. No.	Parameters	Sump water	Effluent from coal handling plant
		Average	
1	Colour, Hazen Unit.	Black	Black
2	Temp(0c)	34.4	33.4
3	pH	6.85	6.58
4	Calcium	38.000	29.000
5	Sulphate	387.000	346.000
6	Nitrate	17.000	19.000
7	Chloride	12.000	15.000
8	Iron	0.1.34	1.630
9	Copper	3.500	4.700
10	Manganese	105.000	131.000
11	Arsenic	0.580	0.630
12	Lead	0.050	0.120
13	Zinc	17.200	23.100

All values are expressed in mg/lit, Except color & pH value

Table 4.14: Water Characteristics in Jayant opencast project (As per IS-10500/2012 for drinking water standard)

Sl. No.	Parameters	Tape water	Tolerance Limit	
			Acceptable Limit	Permissible Limit
1	pH Value	7.89	6.5 – 8.5	No relaxation
2	Iron	0.21	0.3	No relaxation
3	Chlorides	236	250	1000
4	Calcium	4	75	200
5	Sulphate	20	200	400
6	Nitrate	4.6	45	No relaxation
7	Fluoride	0.3	1.0	1.5
8	Copper	BDL	0.05	1.5
9	Manganese	BDL	0.1	0.3
10	Arsenic	BDL	0.01	0.05
11	Selenium	BDL	0.01	No relaxation
12	Lead	BDL	0.01	No relaxation
13	Zinc	0.0515	5	15
14	Mercury	BDL	0.001	No relaxation

All values are expressed in mg/lit, Except color & pH value

Table 4.15: Water Characteristics in Kakri opencast project

Sl. No.	Parameters	Sump water (Average)	
		Old	New
1	Colour, Hazen Unit.	Black	Black
2	Temp(^{0}c)	33.1	32.4
3	pH	6.71	6.52
4	Calcium	33.000	36.000
5	Sulphate	321.000	409.000
6	Nitrate	4.770	2.590
7	Chloride	56.000	68.000
8	Iron	0.780	0.150
10	Copper	3.150	2.160
11	Manganese	264.000	178.000
12	Arsenic	0.720	0.510
13	Lead	0.070	0.100
14	Zinc	18.100	20.300

All values are expressed in mg/lit, Except color & pH value

Table 4.16: Water Characteristics in Kakri opencast project (As per IS-10500/2012 for drinking water standard)

Sl. No.	Parameters	Tap water – Guest house	Hand Pump	Tolerance Limit	
				Acceptable Limit	Permissible Limit
1	Colour, Hazen Unit.	Colorless	Colorless	5	15
2	Odour	Unobjectionable	Unobjectionable	Agreeable	Agreeable
3	pH Value	8.4	7.54	6.5 – 8.5	No relaxation
4	Iron	0.29	0.11	0.3	No relaxation
5	Chlorides	156	166	250	1000
6	Calcium	6	32	75	200
7	Sulphate	12	42	200	400
8	Nitrate	4.2	7.9	45	No relaxation
9	Fluoride	0.2	0.3	1.0	1.5
10	Copper	0.023	0.024	0.05	1.5
11	Manganese	BDL	BDL	0.1	0.3
12	Arsenic	BDL	BDL	0.01	0.05
13	Selenium	BDL	BDL	0.01	No relaxation
14	Lead	BDL	BDL	0.01	No relaxation
15	Zinc	0.0634	0.0864	5	15
16	Mercury	BDL	BDL	0.001	No relaxation

All values are expressed in mg/lit, Except color & pH value

Table 4.17: Water characteristics in Khadia opencast project

Sl. No.	Parameters	Sump water (Average)	
		Old	New
1	Colour, Hazen Unit.	Black	Black
2	Temp(^{0}c)	33.9	32.9
3	pH	7.41	7.52
4	Calcium	30.000	16.000
5	Sulphate	321.000	409.000
6	Nitrate	4.500	5.500
7	Chloride	56.000	68.000
8	Iron	1.300	0.400
10	Copper	2.050	1.160
11	Manganese	204.000	198.000
12	Arsenic	0.580	0.510
13	Lead	0.060	0.090
14	Zinc	38.100	20.500

All values are expressed in mg/lit, Except color & pH value

Table 4.18: Water Characteristics in Khadia opencast project (As per IS-10500/2012 for drinking water standard)

Sl. No.	Parameters	Tap water	Tolerance Limit	
			Acceptable Limit	Permissible Limit
1	Colour, Hazen Unit.	Colorless	5	15
2	Odour	Unobjectionable	Agreeable	Agreeable
3	pH Value	7.84	6.5 – 8.5	5.5 – 8.5
4	Iron	0.131	0.3	No relaxation
5	Chlorides	120	250	1000
6	Calcium	6	75	200
7	Sulphate	20	200	400
8	Nitrate	2.2	45	No relaxation
9	Fluoride	0.1	1.0	1.5
10	Copper	0.025	0.05	1.5
11	Manganese	BDL	0.1	0.3
12	Arsenic	BDL	0.01	0.05
13	Selenium	BDL	0.01	No relaxation
14	Lead	BDL	0.01	No relaxation
15	Zinc	0.052	5	15
16	Mercury	BDL	0.001	No relaxation

All values are expressed in mg/lit, Except color & pH value

Table 4.19: Water characteristics in Krishnashila opencast project

Sl. No.	Parameters	Sump water (Average)	
		Old	New
1	Colour, Hazen Unit.	Black	Black
2	Temp(^{0}c)	34.5	34.4
3	pH	6.50	6.80
4	Calcium	57	36
5	Sulphate	392	278
6	Nitrate	1.57	1.69
7	Chloride	51	35
8	Iron	2.84	2.91
9	Copper	2.13	2.19
10	Manganese	134.0	148
11	Arsenic	0.33	0.41
12	Lead	0.02	0.07
13	Zinc	49.9	46.6

All values are expressed in mg/lit, Except color & pH value

Table 4.20: Water characteristics in Krishnashila opencast project (As per IS-10500/2012 for drinking water standard)

Sl. No.	Parameters	Tap Water	Hand Pump	Tolerance Limit	
				Acceptable Limit	Permissible Limit
1	pH Value	7.59	7.29	6.5 – 8.5	No relaxation
2	Calcium	14	30	75	200
3	Sulphate	38	32	200	400
4	Nitrate	4	4.5	45	No relaxation
5	Fluoride	0.1	0.4	1.0	1.5
6	Nitrate	4	4.5	45	No relaxation
7	Fluoride	0.1	0.4	1.0	1.5
8	Copper	0.024	0.033	0.05	1.5
9	Manganese	BDL	0.109	0.1	0.3
10	Arsenic	BDL	BDL	0.01	0.05
11	Selenium	BDL	BDL	0.01	No relaxation
12	Lead	BDL	BDL	0.01	No relaxation
13	Zinc	0.060	0.302	5	15
14	Mercury	BDL	BDL	0.001	No relaxation

All values are expressed in mg/lit, Except color & pH value

Table 4.21: Water characteristics in Jhingurdah opencast project

Sl. No.	Parameters	Sump water (Average)	
		Old	**New**
1	Colour, Hazen Unit.	Black	Black
2	Temp(^{0}c)	33.1	32.4
3	pH	5.31	5.42
4	Calcium	58	33
5	Sulphate	357	354
6	Nitrate	1.77	1.59
7	Chloride	30	37
8	Iron	1.13	0.41
10	Copper	1.25	1.16
11	Manganese	234.0	198
12	Arsenic	0.13	0.18
13	Lead	0.001	0.001
14	Zinc	28.1	20.9

All values are expressed in mg/lit, Except color & pH value

Table 4.22: Water Characteristics in Jhingurdha opencast project (As per IS-10500/2012 for drinking water standard)

Sl. No.	Parameters	Tap Water	Hand Pump	Tolerance Limit	
				Acceptable Limit	**Permissible Limit**
1	Colour, Hazen Unit.	Colorless	Colorless	5	15
2	pH Value	6.45	7.26	6.5 – 8.5	No relaxation
3	Iron	0.086	0.2	0.3	No relaxation
4	Chlorides	164	136	250	1000
5	Calcium	6	268	75	200
6	Sulphate	23	2	200	400
7	Nitrate	4.6	5	45	No relaxation
8	Fluoride	0.2	0.4	1.0	1.5
10	Copper	0.028	0.029	0.05	1.5
11	Manganese	BDL	BDL	0.1	0.3
12	Arsenic	BDL	BDL	0.01	0.05
13	Selenium	BDL	BDL	0.01	No relaxation
14	Lead	BDL	BDL	0.01	No relaxation
15	Zinc	0.0884	0.4102	5	15
16	Mercury	BDL	BDL	0.001	No relaxation

All values are expressed in mg/lit, Except color & pH value

4.7 Application of work in field: case studies

Water quality from adjacent mines can be a good indicator of expected mine drainage with certain condition. This may include mining must be on the same seam with similar stratigraphy, topography, hydrology and mining methods Rocks that could significantly change water chemistry, pollutant concentrations in surface mine discharge often peak, within 5-10 years after mining and gradually decline thereafter. In this research work, investigation of the active mine and abandoned mine site represents water quality. Keeping the above aspect in view, mines have been selected from NCL Singrauli coalfield. Conducted at Laboratory scale to see the impact of material filling in mine on water quality under the following conditions:

1. Case study 1- Rainwater quality after passing through different lithotypes of overburden with associated rock, flyash and mix flyash + overburden.

1. Case study 2- When mine is abandoned and water is very acidic.

2. Case study 3- When mine is active flyash, OB and mix flyash + overburden is being filled and mine water is slightly acidic.

3. Case study 4- When mine is active and flyash, OB and mix flyash + overburden is being filled and mine water is alkaline.

4.7.1 Basic description of experiment

The purpose of this analysis was conduct to find out the quality of water in the study area and to analyse the Physico-chemical parameter of water samples. The impact of water quality at the exploration stage, before the start of acid mine drainage, can be done by various technique with the help of a variety of data collected during field and laboratory investigations. The mine water analysis of the above mines is summarized in **Tables 4.27, 4.30, 4.31 and 4.32.** The study area location is shown in **Fig. 4.22.** The details of the water sampling source, codes and coordinates are presented in **Table 4.23**. The sampling area photographs have been presented **(Fig. 4.29 a.b).**

Table 4.23: Detailed sources of water sampling points

Sl. No.	Location	Sample Code	Type of sample	Latitude	Longitude
1.	Gorbi	GB	Pit water	N 24.15759	E 82.72292
2.	Amlohri 1	AML 1	Sump water New	N 24.15751	E 82.74289
3.	Amlohri 2	AML 2	Sump water Old	N 24.15754	E 82.74293
4.	Jhingurdah	JH 1	Sump water Old	N 24.17427	E 82.75422
5.	Jhingurdah	JH 2	Sump water new	N 24.17391	E 82.75426
6.	Dudhichua	DD1	Sump water New	N 24.17028	E 82.67058
7.	Dudhichua	DD 2	Workshop effluent	N 24.16995	E 82.67056

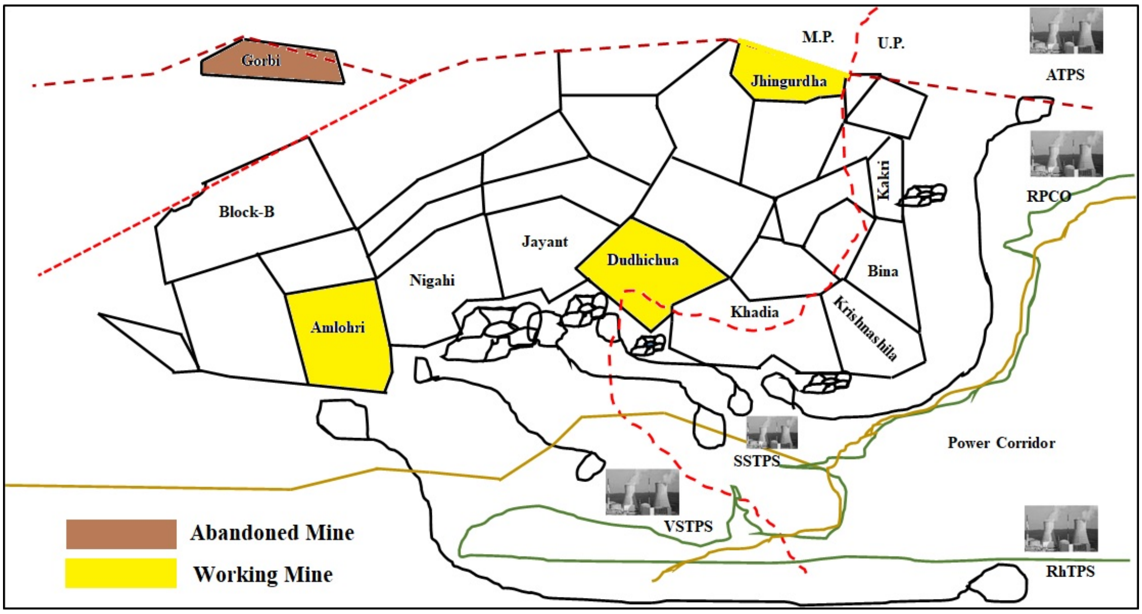

Fig. 4.22: Location map of study area (Northern Coalfield Ltd) Singrauli

4.7.1.1 Leaching experiments parameters

The leaching sample type mixed with different mine overburden and flyash are presented in **Table 4.24**.

Leaching experiment parameters	Flyash, Overburden, 70% O/B+ 30% Flyash
Particle size	Powder/size 5mm to 25mm
Leaching medium	Acidic mine water, Alkaline mine water and Rainwater

Table 4.24: Leaching sample type

Sl. No. / Name of Mines	Leachate Sample
1. Gorbi	Overburden + Acid Water Leachate
	Flyash + Acid Water Leachate
	70% Overburden + 30% Acid Water Leachate
2. Amlohri	Overburden + Acid Water Leachate
	Flyash + Acid Water Leachate
3. Jhingurdah	70% Overburden + 30% Acid Water Leachate
	Overburden + Acid Water Leachate
	Flyash + Acid Water Leachate
	70% Overburden + 30% Acid Water Leachate
4. Dudhichua	Overburden + Alkaline Water Leachate
	Flyash + Alkaline Water Leachate
	70% Overburden + 30% Alkaline Water Leachate
5. Rain water	Overburden + Rainwater Leachate
	Flyash + Rainwater Leachate
	70% Overburden + 30% Flyash Rainwater Leachate

4.7.1.2 Design and fabrication of experimental setup for rock - water interaction study

A simple box model was designed and fabricated in the laboratory. It contained four boxes **(Fig 4.23)**. The sample of different OB associated rocks was prepared in desirable sizes (5mm to 25mm) by conventional sieve techniques. The boxes were filled with overburden, flyash and mixed overburden flyash in a different experiment **(Fig 4.24, 4.25)**. The base of each box was perforated in order to allow percolation of water through material filled in succeeding upper box into the lower boxes. Each sample was subjected to acid leaching, alkaline water, and rainwater leaching. Hence, a total of three different types of leachates samples were produced from each sample. Finally, the leachate samples were collected and filtered into sampling bottles for further testing. The leachate was collected from the bottom-most box and analysis of physico-chemical parameter of water was conducted in the laboratory **(Fig 4.26)**. All the glassware were initially washed with 1:3 nitric acid followed by tap water and finally with double distilled water thoroughly.

4.7.2 Case Study 1: Rainwater analysis and observation

The experimental setup has been designed to the simulation of actual mine condition at Laboratory scale. In this experimental work has done analysis with rainwater, which passes through the different lithotype of overburden in mine. The quality of mine water depends upon the amount of rainfall, the reactivity of rocks through which the water flows, porosity and permeability of rocks, interaction duration between water and the rocks, types of mining machinery, production of the dust and fine particles of rocks, and many other factors.

In the present work, the leaching experiment has been carried out to compare the leaching type of different lithotypes in mine with natural processes like weathering. After putting off the flyash, overburden & mixed disposal of overburden in rainwater the range of pH was increased and showing in the graph **(Fig. 4.27 and Table 4.25)**.

Fig 4.23: Experimental setup for water quality analysis

Fig. 4.24: Box fill with different lithotypes of sandstones

Fig. 4.25: Fill the different type of sandstones in experimental setup

Fig. 4.26: Rain water passing through different litho- types of overburden

Table 4.25: Variation in pH in leachate collected from FA, OB and FA-OB mix for 45 days feed with rain water

Time (min)	**Flyash**	**OB+30%Flyash**	**Combined (White sandstone, yellow sandstone & red sandstone**
0 (min)	6.55	6.55	6.55
30 (min)	6.6	6.56	6.67
720 (min)	6.71	6.58	6.79
2880 (48 h)	6.75	6.64	6.91
7200 (5 days)	7.1	6.88	7.18
14400 (10 days)	7.45	7.15	7.38
21600 (15 days)	7.7	7.46	7.53
43200 (30 days)	7.8	7.64	7.76
57600 (40 days)	7.9	7.77	7.77
64800 (45 days)	8.1	7.99	7.77

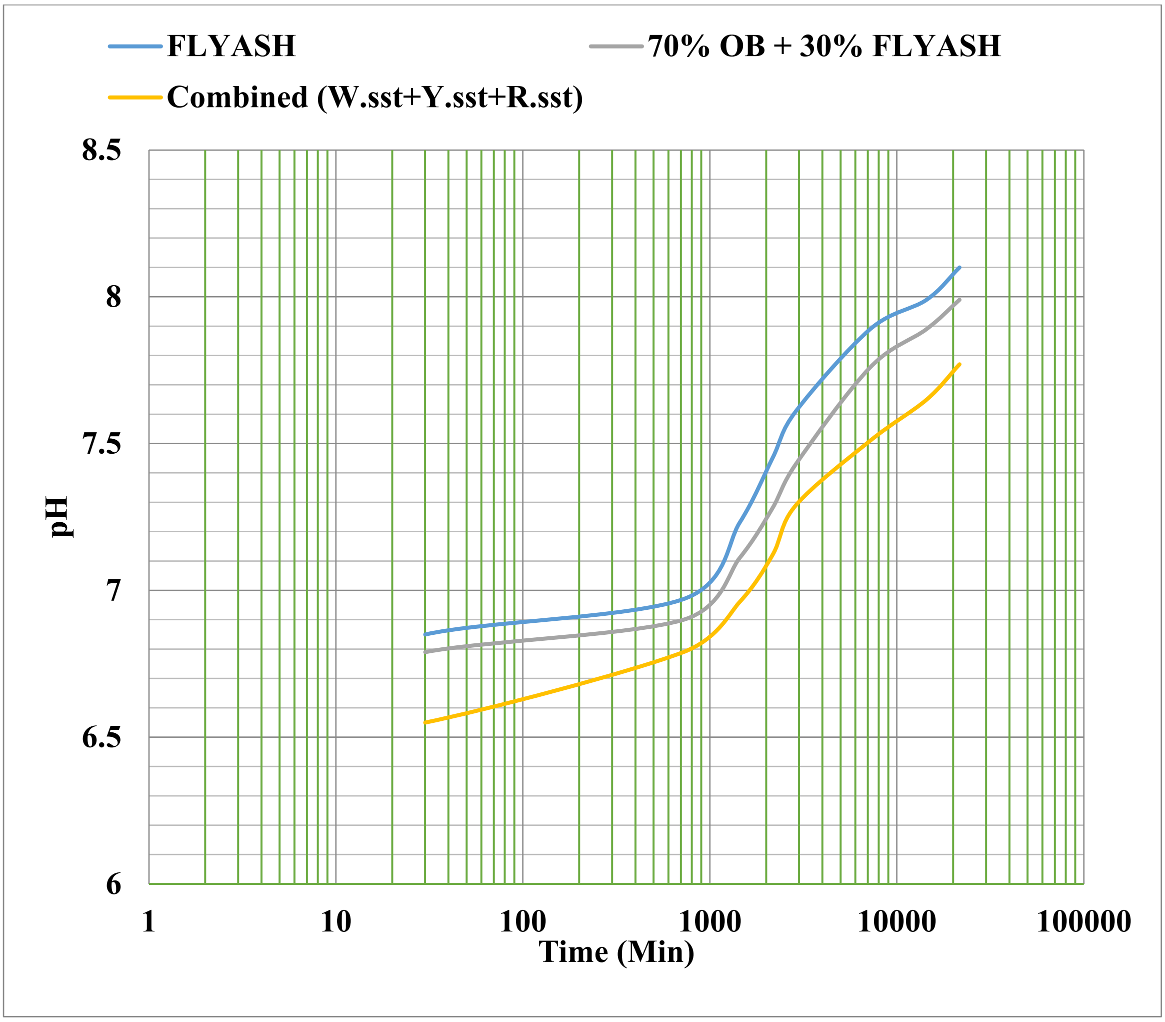

Fig. 4.27: Variation of pH of rain water leachate with time

The leachate was collected in the beakers from bottom box of experimental setup and after this, pH parameter of rain water was analysed in laboratory. After putting of the overburden (white sandstone, yellow sandstone, red sandstone) flyash & mixed disposal of overburden+30%flyash in rain water the range of pH was increased.

4.7.3 Case Study 2: Gorbi abandoned mine

4.7.3.1 When mine is abandoned and filled with highly acidic mine water:

The basis of this work, there is an abandoned coal mine having acidic water Gorbi mine Northern Coalfield, Singrauli. The Gorbi mine has three abandoned mine pits i.e. Pit I, Pit

II & Pit III **(Fig. 4.28 and Table 4.26)**. The abandoned area is partly backfilled with OB material is covered by moderately grown tall trees and bushes. The region is a sedimentary terrain with good ground water potentialities and characterized with high porosity and permeability. As a result, water is always present in all the three pits. Results of bathymetry survey reveal that the volume of water in the pit as under:

Fig. 4.28: Location of sample collection point in Gorbi abandoned mine, Singrauli coalfield (Image © 2019 CNES/Airbus, Image © 2019 Digital Globe, © 2018 Google)

Table 4.26: Detail of Pit No with area and volume of water

Sl. No.	Pit No.	Pit Area in Ha	Depth	Volume of water as on
1	Pit No. I	40.00 Ha	50 M *	20.00 Million m³
2	Pit No. II	8.00 Ha		4.00 Million m³
3	Pit No. III	26.00 Ha		13.00 Million m³
		74.00 Ha		37.00 Million m³

**Approximate considered and approximate depth*

4.7.3.2 Determination of mine water quality in Gorbi abandoned mine

Under this research work, Gorbi abandoned mine, one of the oldest projects (1974 – 75) of NCL Mines. Here, the pH value of voids water is 2.54. The concentration of Sulphate ranges from 850 mg/l whereas the concentration of total iron is also varying from 57.35

mg/l. this is the mine which is posing acid mine drainage problem in the area for the last 20 years or more.

Fig. 4.29 (a): Water body of Gorbi abandoned mine

Fig. 4.29 (b): Sample collected from water body of Gorbi abandoned mine

From **Table 4.27**, it may be observed that the water of Gorbi mine has objectionable parameters. Therefore, there is an immediate need to develop a methodology for the mitigation of these parameters. The mine water should be free from acidity. Parameters should also be brought within permissible limit by appropriate field applicable methodology.

Table 4.27: Mine pit water characteristics of Gorbi mine

Parameters	**Gorbi mine water**
Temp (^{0}C)	33.2
pH value	2.54
Colour	Brown
TDS (ppm)	2270
Chloride	58
Sulphate	822
Calcium	80
Iron	57.35
Magnesium	53
Potassium	6
Sodium	27

All values are in mg/L except temp., pH value and colour

To assess the quality of water in and around Gorbi mine, representative water sampling sites were selected. This investigation was carried out at the laboratory level to find out how to the impact on pH and TDS of mine water after treated with flyash, overburden and mixed disposal of OB+30%Flyash. **Table 4.28 and 4.29** and the values are plotted in **Fig. 4.30 and 4.31**.

Table 4.28: Variation in pH value of leachate of FA, OB and FA-OB mix for 95 days with Gorbi mine water (pH 2.54)

Time (min/Day)	Temp. (^{0}C)	pH (O/B)	pH (Flyash)	pH (30 % FLYASH + 70 % O/B)
0 (Blank)	34	2.54	2.54	2.54
10 (Min)	35	2.54	2.6	2.69
30 (Min)	32	2.55	2.64	2.77
720 (12 Hours)	32	2.59	2.72	2.93
1440 (24 H)	33	2.68	2.84	43.11
2880 (48 H)	35	2.81	2.91	3.29
7200 (5 Days)	30	2.89	3.01	3.43
14400 (10 D)	32	3.01	3.14	3.55
21600 (15 D)	35	3.09	3.25	3.68
43200 (30 D)	34	3.17	3.33	3.79
50400 (35 D)	35	3.33	3.49	3.88
57600 (40 D)	32	3.48	3.57	3.99
64800 (45D)	32	3.62	3.69	4.11
72000 (50 D)	33	3.71	3.81	4.25
79200 (55 D)	33	3.89	3.95	4.42
86400 (60 D)	35	3.98	4.13	4.57
93600 (65 D)	30	4.09	4.35	4.66
100800 (70 D)	32	4.24	4.56	4.75
108000 (75 D)	35	4.37	4.69	4.88
115200 (80 D)	34	4.45	4.77	4.98
122400 (85 D)	35	4.59	4.84	5.16
129600 (90 D)	32	4.77	4.95	5.29
136800 (95 D)	32	4.85	4.99	5.37

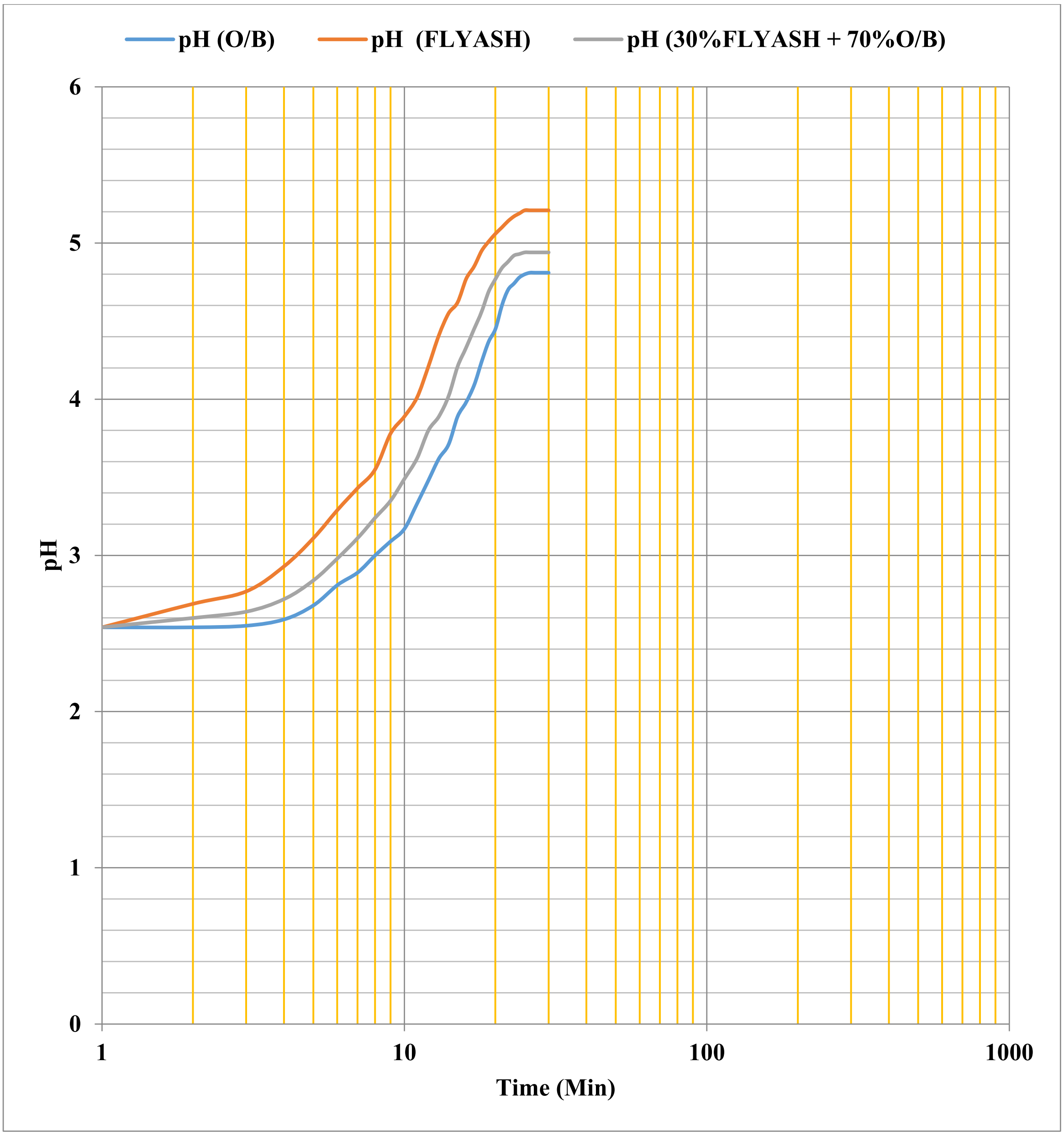

Fig. 4.30: Change in leachate pH of Gorbi mine treated with OB, FA and OB-FA mix with time

Table 4.29: Monitoring of reduction in TDS in Gorbi mine water treated with OB, FA and OB-FA mix with time

Time (min)	**TDS (ppm) (O/B)**	**TDS (ppm) (FLYASH)**	**TDS (ppm) (30% FLYASH + 70% O/B)**
0 (Blank)	1477	1421	1393
10 (Min)	1460	1349	1357
30 (Min)	1458	1320	1316
720 (12 Hours)	1395	1317	1298
1440 (24 H)	1336	1299	1189
2880 (48 H)	1301	1295	1075
7200 (5 D)	1297	1284	1054
14400 (10 D)	1255	1280	1024
21600 (15 D)	1241	1248	1012
43200 (30 D)	1150	1212	989
50400 (35 D)	1120	1060	982
57600 (40 D)	1101	1118	971
21600 (45D)	1089	1083	957
72000 (50 D)	1067	1017	913
79200 (55 D)	1037	995	901
86400 (60 D)	1012	916	874
93600 (65 D)	989	880	846
100800 (70 D)	972	847	817
108000 (75 D)	959	820	798
115200 (80 D)	923	815	781
122400 (85 D)	913	781	750
129600 (90 D)	901	715	695
136800 (95)	879	695	682

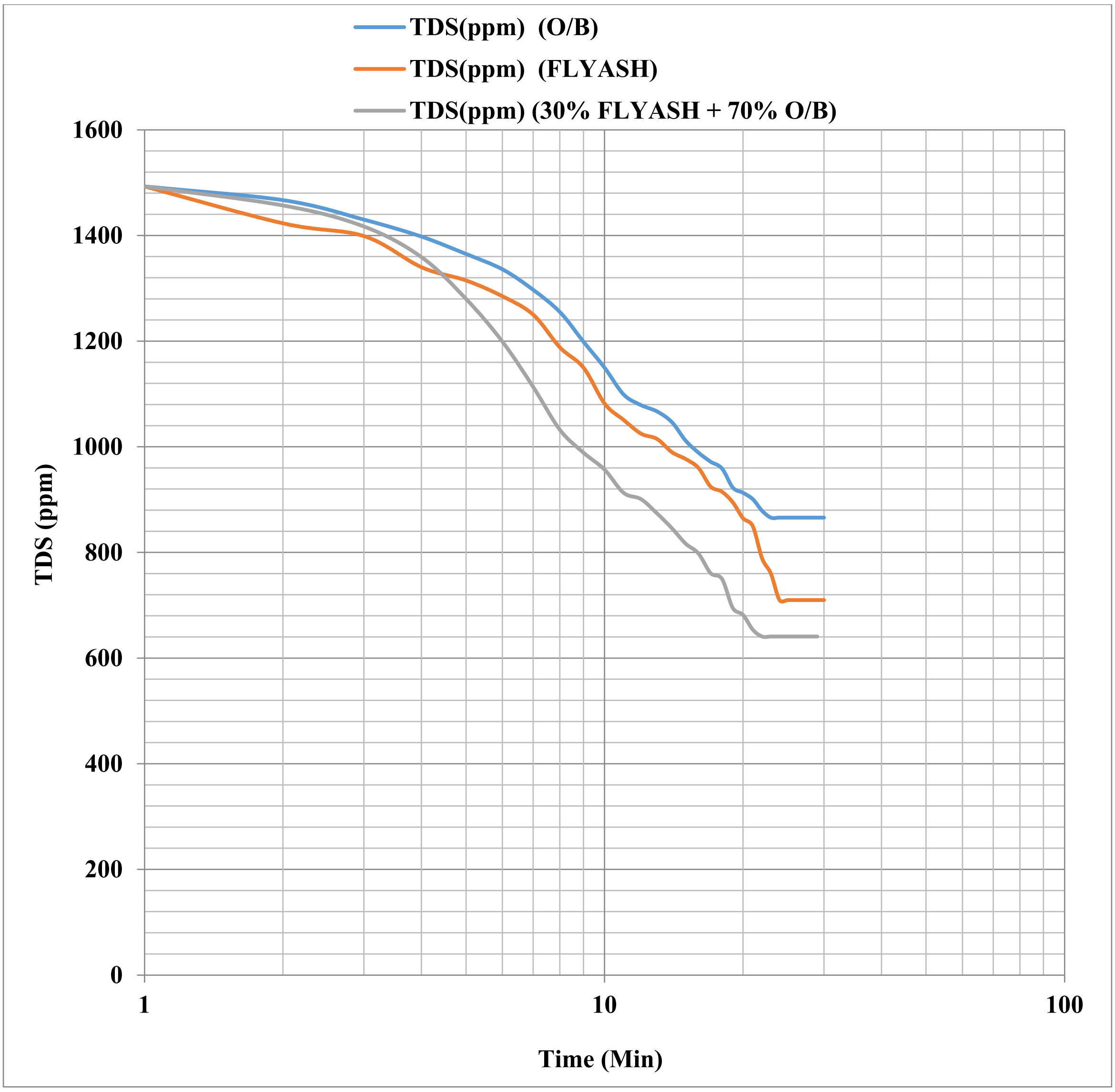

Figure 4.31: Reduction in TDS of Gorbi mine water with OB, FA and OB-FA mix with time

Fig. 4.32: Analysis of leachates

It may be observed from **Table 4.28** that there is material neutralization of acidic water with time when crushed overburden, flyash and mix material (flyash + overburden) is allowed to interact. **Fig. 4.30** also show the increase is pH value with time for all three material. Further, it may also be observed that the neutralization become more effective when mixed material (overburden and flyash) was used. **Table 4.28** reveals that after 95 days of interaction with flyash and mixed material specially the highest **pH 5.37** was with mixed material. It may be conducted concluded that flyash mixed overburden may be filled in an abandoned mine where there is no question of stability of waste dump. The pit is surrounded from almost all side. The additional advantage of filling of flyash with overburden in abandoned mine suffering with highly acidic water is faster neutralization. The leached water will be naturally treated as per the permissible standard.

4.7.4. Case study 3a - Amlohri opencast project

4.7.4.1 When water is acidic

This OCP is designed to produce 14.00 Mtpa of coal from the four working seams namely, Purewa Top, Purewa Bottom, Purewa Merge and Turra, with an average stripping ratio of 4.18 m^3/t. The gradient of the seams varies from 2° to 5°. The average grade of coal is G-7 & G-10. Total land requirement was estimated as 2175 ha, out of which 1195 ha is forestland, 898 ha is tenancy land and 82 ha is wasteland. The Project is being worked by combined mining system deploying dragline and shovel dumper combination. The ultimate working depth has been estimated as 165m. The total O.B. during the mine life has been estimated as 1314.87 Mm^3, out of which only 185 Mm^3 is proposed to dump externally and balance as backfill, internally. The overall dump slope will be kept at 28° to prevent dump slide.

Table 4.30: Water Characteristics in Amlohri opencast project

Sl. No.	Parameters	AML 1 Sump water New	AML 2 Workshop effluent
1	Colour, Hazen Unit.	Black	Black
2	Temp(°C)	34.4	33.4
3	pH	5.12	5.32
	TDS (ppm)	1516	1956
4	Calcium	50	65
5	Sulphate	43	57
6	Nitrate	196	278
7	Chloride	12.9	45
8	Iron	156	166
9	Copper	0.131	0.3
10	Manganese	0.023	0.078
11	Arsenic	BDL (<0.05)	0.098
12	Lead	BDL (<0.01)	BDL (<0.01)
13	Zinc	0.34	0.55

All values are expressed in mg/lit, Except color & pH value

4.7.5 Case study 3b - Jhingurdah opencast project

4.7.5.1 When water is acidic

This Project is designed to produce 5.00 Mtpa of coal from one working seam namely, Jhingurdah Top, with an average stripping ratio of 1.78 m^3/t. The gradient of the seams varies from 11°to 15°. The average grade of coal is E. Total land requirement was estimated as 1200 ha, out of which 748.00 ha is forestland, 206 ha is agricultural land and 246.00 ha is wasteland. The Project is being worked by shovel dumper mining system. The ultimate working depth has been estimated as 290 m. The total O.B. During the mine life has been estimated as 193.65 Mm^3, which will be dumped as External dump. The overall dump slope will be kept at 28° to prevent dump slide.

It may be observed from **Tables 4.30 & 4.31**, the pH of water discharged from various points in the mine is acidic in nature. All the pH values are below than the recommended permissible limit of industrial effluent discharge (5.5-8.5) and hence, it is of objectionable water quality parameter.

Table 4.31: Water characteristics in Jhingurdah opencast project

Sl. No.	Parameters	Sump water	
		Old	New
1	Colour, Hazen Unit.	Black	Black
2	Temp(^{0}c)	33.9	32.9
	TDS (ppm)	1130	1920
3	pH	5.31	5.42
4	Calcium	30	46
5	Sulphate	321	409
6	Nitrate	4.5	5.5
7	Chloride	56	68
8	Iron	1.3	2.4
10	Copper	2.05	2.16
11	Manganese	204.0	298
12	Arsenic	0.58	0.71
13	Lead	0.06	0.09
14	Zinc	38.1	40.5

All values are expressed in mg/lit, Except color & pH value

4.7.6 Case study 4 – Dudhichua opencast project

4.7.6.1 When water is alkaline

This opencast is designed to produce 15.50 Mtpa of coal from the three working seams namely, Purewa Top, Purewa Bottom, and Turra, with an average stripping ratio of 3.29 m3/t. The gradient of the seams varies from 2° to 3°. The average grade of coal is G-10. Total land requirement was estimated as 1752 ha, out of which 750 ha is forestland, 636 ha is tenancy land and 366 ha are wasteland. The opencast is being worked by combined mining system deploying dragline and shovel dumper combination. The ultimate working depth has been estimated as 235 m. The total overburden during the mine life has been estimated as 1133.41 Mm^3, out of which only 134.00 Mm^3 is proposed to be dumped externally and balance as backfill internally. The overall dump slope will be kept at 28° to prevent dump slide. Keeping in view, the above description.

The water discharged from various locations of mine are given in **Table 4.32.** The pH of water discharged from various points in the mine is alkaline in nature. The pH values of sump water is much higher average value is 8.71.

Table 4.32: Water Characteristics in Dudhichua opencast project

Sl. No.	Parameters	Sump water	Workshop effluent
1	Colour, Hazen Unit.	Black	Black
2	Temp(0c)	35	34
3	pH	8.71	8.89
	TDS	1812	2314
4	Calcium	31	20
5	Sulphate	160	200
6	Nitrate	45	72
7	Fluoride	0.43	0.74
8	Copper	2.32	3.24
9	Manganese	575	673
10	Arsenic	0.21	0.71
11	Lead	BDL (<0.05)	BDL (<0.05)
12	Zinc	38	18

All values are expressed in mg/lit, Except color & pH value

It may be observed from **Table 4.33** that there is material neutralization of acidic water with time when crushed overburden, flyash and mix material (flyash + overburden) is allowed to interact. The increase is pH value with time for all three material. The results are encouraging and indicating that along with pH value, some toxic metals and TDS was also decreasing **Table 4.33.** The experiment was also conducted at laboratory scale with alkaline water and overburden of Dudhichua opencast mine. The water characteristic of mine is given in **Table 4.32**. It may be concluded from the above observation that there is no need of addition/ filling of flyash with overburden in case of mine having alkaline water. The alkalinity of leached water may further increased. Not only this, the higher stripping ratio of the Dudhichua and other mines also not allow to accommodate flyash which may increase unstability of overburden but also occupy is space of feeling. Both the overburden and flyash have significant neutralization capacity for reducing the acidity of mine water and therefore this can be used with advantage in abandoned mines, having a problem of acid mine drainage. The additional advantage of filling of flyash with overburden in abandoned mine suffering with highly acidic water is faster neutralization. The leached water will be naturally treated as per the permissible standard.

Table 4.33: Leaching for 70 % overburden+30 % flyash with active mine water

Parameters	**Mixture of 70% Overburden and 30% Flyash**			
	Gorbi	**Amlohri**	**Jhingurdha**	**Dudhichua**
pH	5.37	7.62	7.58	8.01
TDS (ppm)	682	759	750	715
NO_3	3.18	3.14	4.16	2.96
SO_4	32.89	48.01	40.71	50.1
Cl	156	166	23	24
Mn	121	118	115	196
Ca	12.41	16.35	12.36	10.32
Cu	1.14	1.17	1.21	1.31
Zn	23	25	19	31

4.8 Statistical analysis of water sample data

4.8.1 Correlation analysis

The correlation analysis study involving statistical calculation was devised by **Pearson (1896)**. Based on the value of correlation coefficient 'r', the correlation between two variable parameters shows in matrix can be termed as positive or negative. The mathematical model used to estimate water quality requires two parameters to describe water situations. Correlation analysis measures the closeness of the relationship between chosen independent and dependent variables (Nair et al. 2005, 2006). If the correlation coefficient is nearer to +1 or -1, it shows the probability of linear relationship which is between the variables. The parameters are characterized as strong, moderate and weak based on correlation. Correlation analysis is a common useful statistical tool for water quality studies indicating which ions control the water chemistry (Box et al. 1978; Chapman 1996; Shrivastava and Patil 2002; Zeng et al. 2005). It is simply a measure to exhibit how well one variable predicts the other (Kurumbein and Graybill 1965).

4.8.1.1 Correlation Matrix mine water for pre-monsoon season

In this study, the correlation among various parameters has been established using Pearson r correlation coefficient **(Table 4.9 & 4.11)**. The correlation matrix indicates the negative correlation of pH with most of the variables in both the season. Strong correlation is observed between NO_3^--Cu, pH - Mn, Pb^-- As, and Cd^-- Cr in pre-monsoon.

4.8.1.2 Correlation Matrix mine water for post-monsoon season

In post- monsoon, a strong positive correlation is identified with F^-- Pb, Mg -Na, SO_4 -Cd, Fe-Mn are observed. The correlation matrix **(Fig. 4.32 and 4.33)** indicates the negative correlation of pH with most of the variables in both the seasons.

In both the pre - monsoon and post - monsoon seasons, some pairs of parameters shows moderate to strong correlation ($r > 0.6$), no correlation (r close to 0), and negative correlation (r is negative).

Table 4.34: Physiochemical characteristics of mine water of pre-monsoon season

	pH	**F^-**	**SO_4^{2-}**	**NO_3^-**	**Ca**	**Mg**	**Na^+**	**K^+**	**Fe**	**Zn**	**Cu**	**Cd**	**As**	**Pb**	**Cr**	**Mn**
AML 1	6.8	0.26	278	12	57	64.2	31.02	11.4	0.13	0.17	0.020	0.002	0.01	0.03	0.001	0.02
AML 2	7.8	0.36	196	45	43	59.3	34.67	17.5	0.30	0.21	0.047	0.006	0.01	0.05	0.002	0.05
BN 1	6.5	0.36	241	19	43	54.4	24.02	12.8	0.48	0.14	0.019	0.007	0.62	0.09	0.003	0.01
BN 2	6.8	0.27	265	26	56	33.4	25.35	14.4	0.35	0.07	0.048	0.001	0.61	0.14	0.001	0.03
DD 1	6.3	0.22	160	45	31	31.1	22.34	12.1	0.12	0.03	0.052	0.004	0.71	0.05	0.003	0.01
DD 2	7.1	0.20	200	12	20	53.7	24.87	12.9	0.50	0.06	0.017	0.007	0.21	0.05	0.003	0.04
JY 1	6.9	0.35	387	17	38	33.3	35.54	16.5	0.13	0.02	0.041	0.004	0.58	0.05	0.002	0.01
JY 2	6.6	0.21	346	19	29	25.1	36.62	11.3	1.63	0.24	0.008	0.006	0.63	0.12	0.003	0.02
KAK1	6.7	0.34	321	4.77	33	38.7	18.57	11.7	0.78	0.03	0.004	0.003	0.72	0.07	0.002	0.02
KAK 2	6.5	0.30	409	2.59	36	58.8	19.67	25.6	0.15	0.04	0.030	0.004	0.51	0.1	0.001	0.01
KHA 1	7.4	0.27	321	4.77	30	34.1	24.11	12.9	1.30	0.00	0.005	0.006	0.58	0.06	0.002	0.03
KHA 2	7.5	0.39	409	2.59	16	45.9	21.96	18.2	0.40	0.00	0.033	0.006	0.51	0.09	0.003	0.04
JHA 1	6.5	0.36	392	1.57	57	41.8	23.68	16.3	2.84	0.00	0.010	0.001	0.33	0.02	0.002	0.01
JHA 2	6.8	0.39	278	1.69	36	38.03	30.22	17.8	2.91	0.00	0.008	0.001	0.41	0.07	0.001	0.03
NGH 1	6.5	0.31	357	1.77	58	44.67	18.89	12.5	1.13	0.00	0.011	0.002	0.13	0.001	0.002	0.02
NGH 2	6.6	0.28	354	1.59	33	34.2	29.94	10.5	0.41	0.00	0.004	0.004	0.18	0.001	0.001	0.01

Table 4.35: Correlation Matrix of physiochemical characterization of mine water for pre-monsoon season

	pH	*F^-*	*SO_4^{2-}*	*NO_3^-*	*Ca*	*Mg*	*Na^+*	*K^+*	*Fe*	*Zn*	*Cu*	*Cd*	*As*	*Pb*	*Cr*	*Mn*
pH	1.00															
F^-	0.28	1.00														
SO_4^{2-}	-0.10	0.35	1.00													
NO_3^-	0.14	-0.26	-0.73	1.00												
Ca	-0.31	0.16	0.01	0.05	1.00											
Mg	0.27	0.20	-0.16	-0.01	0.21	1.00										
Na^+	0.24	-0.06	-0.11	0.34	0.00	-0.14	1.00									
K^+	0.19	0.46	0.36	-0.13	-0.07	0.35	-0.13	1.00								
Fe	-0.15	0.26	0.22	-0.41	0.15	-0.31	0.04	0.02	1.00							
Zn	0.14	-0.27	-0.37	0.54	0.12	0.28	0.57	-0.18	-0.20	1.00						
Cu	0.19	0.01	-0.35	**0.75**	0.05	0.11	0.11	0.34	-0.57	0.16	1.00					
Cd	0.43	-0.20	-0.20	0.28	-0.68	0.11	0.19	-0.04	-0.36	0.37	0.07	1.00				
As	-0.30	-0.03	0.10	0.07	-0.35	-0.59	-0.25	0.04	0.01	-0.17	0.12	0.13	1.00			
Pb	0.07	-0.06	-0.03	0.21	-0.23	-0.16	0.03	0.29	-0.09	0.34	0.30	0.19	**0.64**	1.00		
Cr	-0.09	-0.11	-0.08	0.14	-0.38	-0.11	-0.12	-0.31	-0.01	0.16	-0.05	**0.62**	0.24	-0.01	1.00	
Mn	**0.86**	0.10	-0.33	0.20	-0.27	0.25	0.15	0.10	-0.01	0.21	0.17	0.28	-0.33	0.18	-0.04	1.00

Table 4.36: Physico-chemical parameters of mine water sample in Post – Monsoon

Mine (NCL)	pH	F^-	SO_4^{2-}	NO_3^-	Ca	Mg	Na^+	K^+	Fe	Zn	Cu	Cd	As	Pb	Cr	Mn
AML 1	6.5	0.40	241	19	43	24.53	11.56	27.2	0.48	0.003	0.002	0.204	0.62	0.09	0.007	0.025
AML 2	6.8	0.30	265	26	56	25.71	15.53	24.1	0.35	0.002	0.018	0.223	0.61	0.14	0.004	0.045
BN 1	6.8	0.70	278	13	57	27.44	19.09	22.1	0.13	0.282	0.011	0.079	0.01	0.34	0.004	0.039
BN2	7.8	0.70	196	45	43	27.12	19.87	21.9	0.30	0.006	0.005	0.062	0.01	0.55	0.001	0.025
DD 1	6.3	0.60	160	45	31	35.76	47.13	21.9	0.12	0.009	0.011	0.153	0.71	0.05	0.001	0.038
DD 2	7.1	0.20	200	12	20	32.12	34.89	20.5	0.50	0.008	0.004	0.132	0.21	0.05	0.001	0.033
JY 1	6.9	0.50	387	17	38	27.76	14.01	30.5	0.13	0.055	0.009	0.005	0.58	0.05	0.005	0.045
JY 2	6.6	0.20	346	19	29	29.32	16.34	29.7	1.63	0.003	0.010	0.008	0.63	0.12	0.004	0.036
KAK1	6.7	0.40	321	15	33	20.85	28.77	18.1	0.78	0.006	0.008	0.015	0.72	0.07	0.002	0.043
KAK 2	6.5	0.50	409	13	36	25.78	21.34	14.0	0.15	0.001	0.015	0.013	0.51	0.1	0.001	0.030
KHA 1	7.4	0.30	321	15	30	15.46	11.67	45.3	1.30	0.068	0.012	0.012	0.58	0.06	0.001	0.018
KHA 2	7.5	0.30	409	11	16	15.13	11.43	38.3	0.40	0.055	0.004	0.01	0.51	0.09	0.003	0.038
JHA 1	6.6	0.20	392	15	57	27.87	18.12	37.4	1.84	0.002	0.007	0.006	0.33	0.02	0.001	0.030
JHA 2	6.8	0.20	278	16	36	25.41	18.65	37.1	1.91	0.014	0.007	0.006	0.41	0.07	0.002	0.026
NGH 1	6.5	0.10	357	17	58	20.89	17.14	21.9	1.13	0.011	0.011	0.007	0.13	0.001	0.002	0.040
NGH 2	6.6	0.30	354	15	33	20.18	12.79	19.1	0.41	0.004	0.009	0.009	0.18	0.001	0.002	0.020

Table 4.37: Correlation matrix of physiochemical characterization of mine water for post-monsoon season

	pH	***F^-***	***SO_4^{2-}***	***NO_3^-***	***Ca***	***Mg***	***Na^+***	***K^+***	***Fe***	***Zn***	***Cu***	***Cd***	***As***	***Pb***	***Cr***	***Mn***
pH	1.00															
F^-	0.18	1.00														
SO_4^{2-}	-0.09	-0.35	1.00													
NO_3^-	0.10	0.51	-0.67	1.00												
Ca	-0.29	0.10	0.01	0.12	1.00											
Mg	-0.39	0.30	-0.54	0.48	0.12	1.00										
Na^+	-0.28	0.25	-0.59	0.45	-0.22	**0.67**	1.00									
K^+	0.35	-0.36	0.25	-0.21	-0.14	-0.37	-0.44	1.00								
Fe	-0.10	-0.69	0.24	-0.27	0.09	-0.15	-0.22	0.59	1.00							
Zn	0.16	0.46	0.00	-0.23	0.25	-0.05	-0.13	0.07	-0.25	1.00						
Cu	-0.33	0.06	0.17	0.06	0.35	0.05	0.03	-0.23	-0.12	0.09	1.00					
Cd	-0.13	0.22	**0.71**	0.41	0.18	0.41	0.29	-0.27	-0.43	-0.04	0.05	1.00				
As	-0.32	-0.11	0.10	0.01	-0.35	-0.02	0.12	0.22	0.06	-0.37	0.20	0.17	1.00			
Pb	0.57	**0.68**	-0.39	0.49	0.23	0.16	-0.04	-0.19	-0.31	0.37	-0.11	0.15	-0.47	1.00		
Cr	-0.19	0.08	0.05	-0.17	0.19	-0.03	-0.46	0.06	-0.19	0.22	-0.14	0.37	0.26	0.01	1.00	
Mn	-0.24	0.09	0.07	0.03	0.19	0.27	0.26	-0.27	**0.69**	0.17	0.28	0.17	0.25	-0.05	0.29	1.00

4.9 Graphical representation of water quality data

4.9.1 Hydro-chemical Facies

Piper trilinear plot was made using Origin Pro 2016 to determine the major cations and anions of analyzed water samples (**Fig. 4.33 to 4.38**). The dominant anions were found to be sulfate and chloride because of the oxidation of sulphides and disintegration of sandstone and shale. The major cations were calcium and magnesium. These may be produced due to weathering and leaching of carbonate and silicates minerals such as crystalline, dolomitic limestone, Calcium-Magnesium Silicates and biotite. The two major hydro-geo-chemical facies were found to be Ca-HCO_3^-(groundwater type) and Ca- Mg-SO_4 (mine water type) in the study area. The two major hydro-geo-chemical facies were found to be Ca- HCO_3^- **(Fig 4.36, 4.37, & 4.38)** and Ca- Mg - SO_4 in the study area **(Fig 4.33, 4.34, & 4.35)**. The trilinear graph of Calcium - Magnesium - Bicarbonate shows that groundwater of Singrauli coalfield is under the permissible limit.

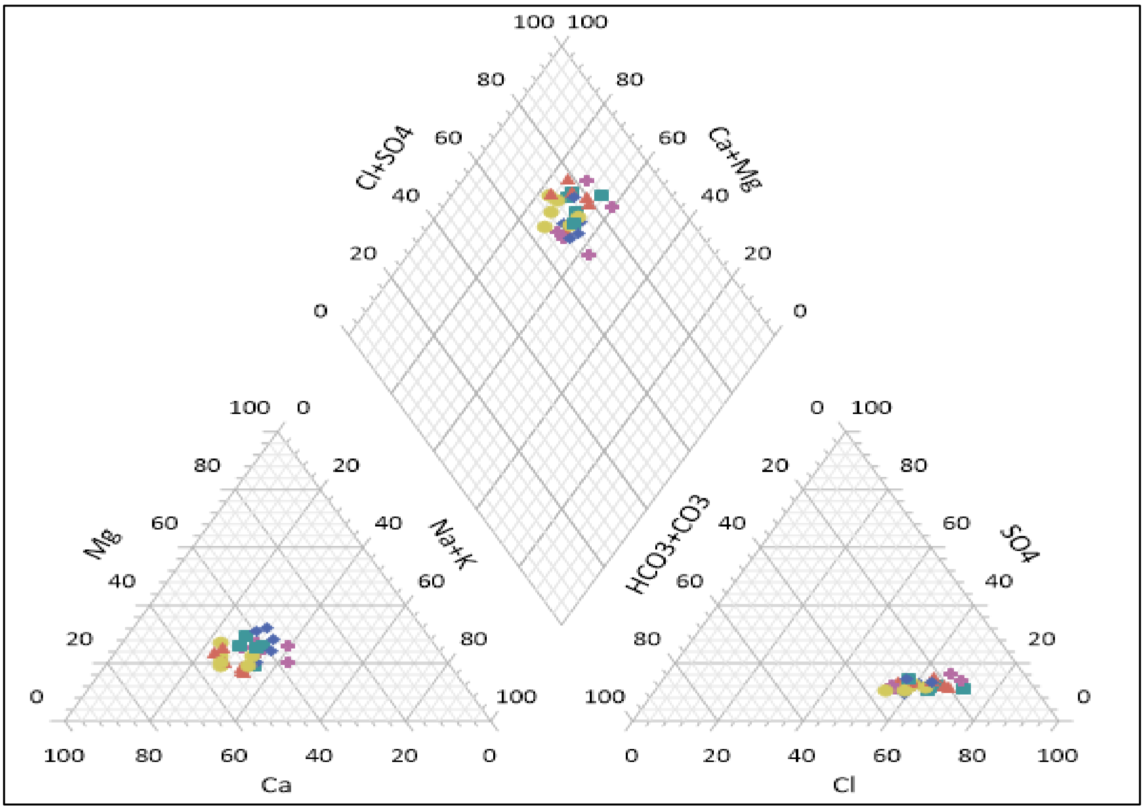

Fig. 4.33: Trilinear piper dig Amlohri of mine water

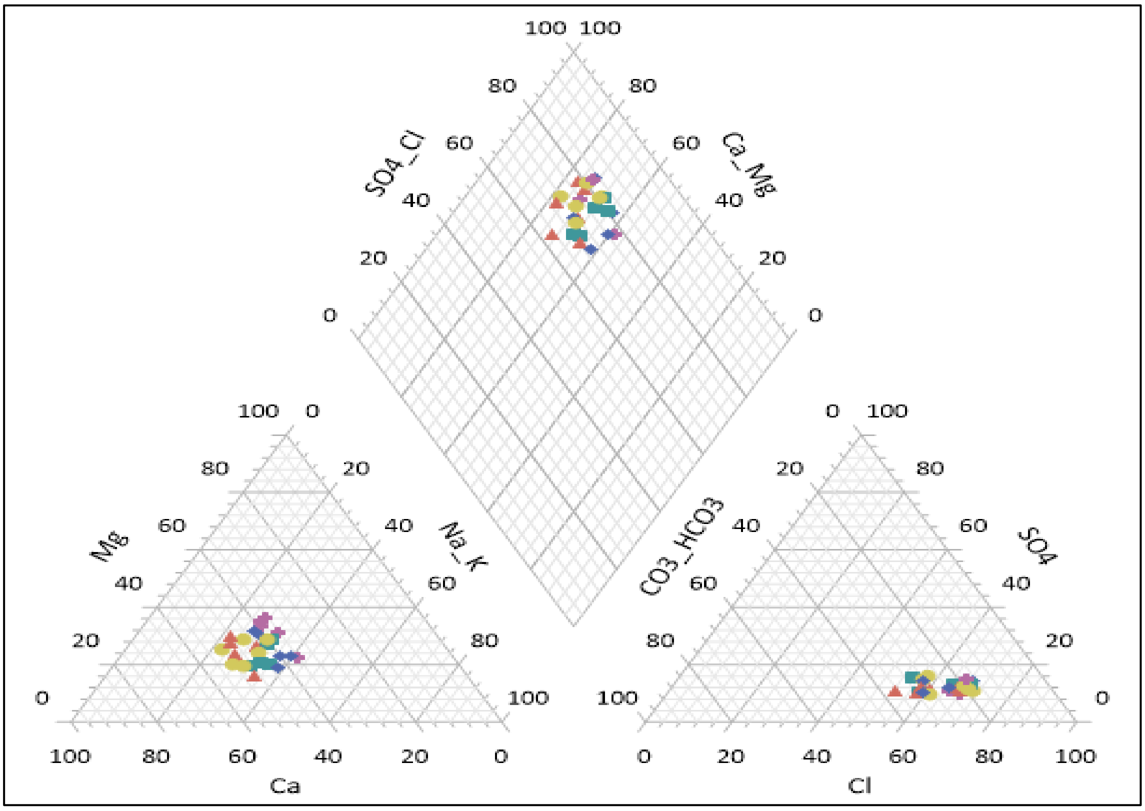

Fig. 4.34: Trilinear piper dig of Dudhichua mine water

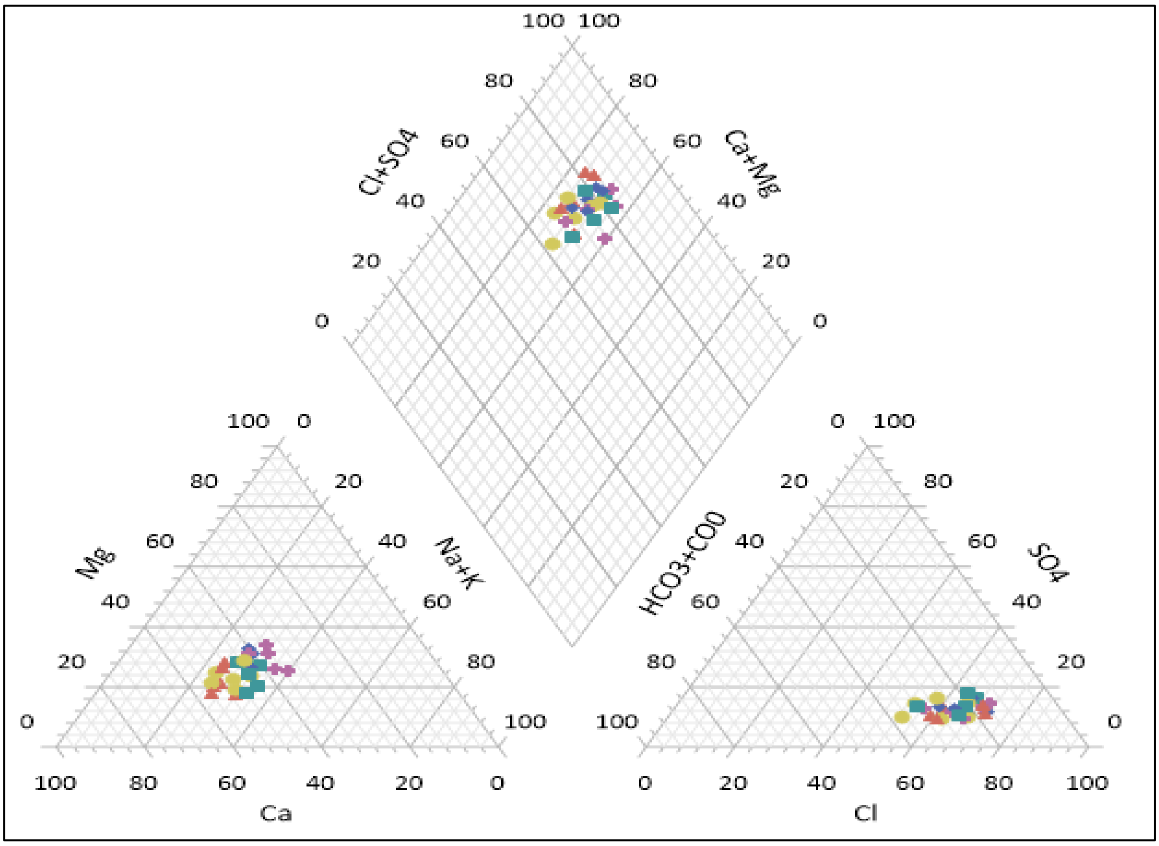

Fig. 4.35: Trilinear piper dig of Bina mine water

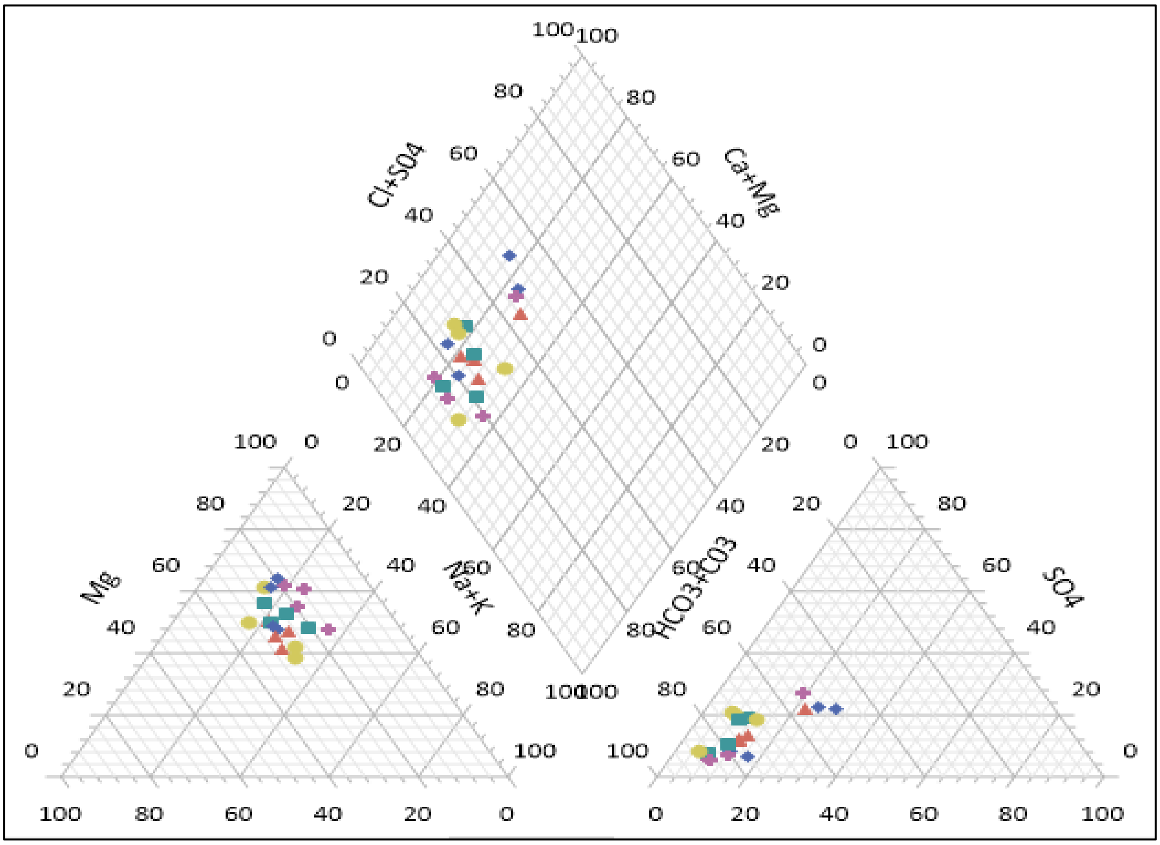

Fig. 4.36: Trilinear piper dig of Amlohri ground water

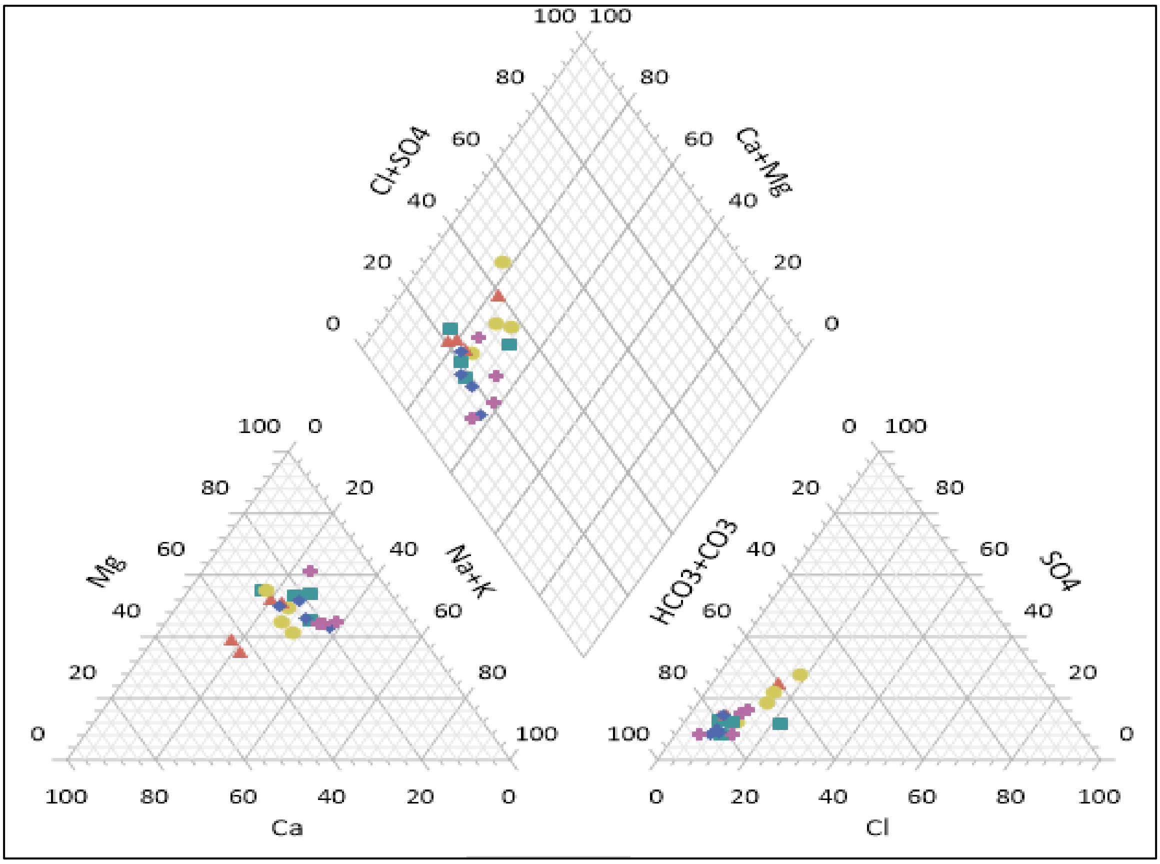

Fig. 4.37: Trilinear piper dig of Dudhichua ground water

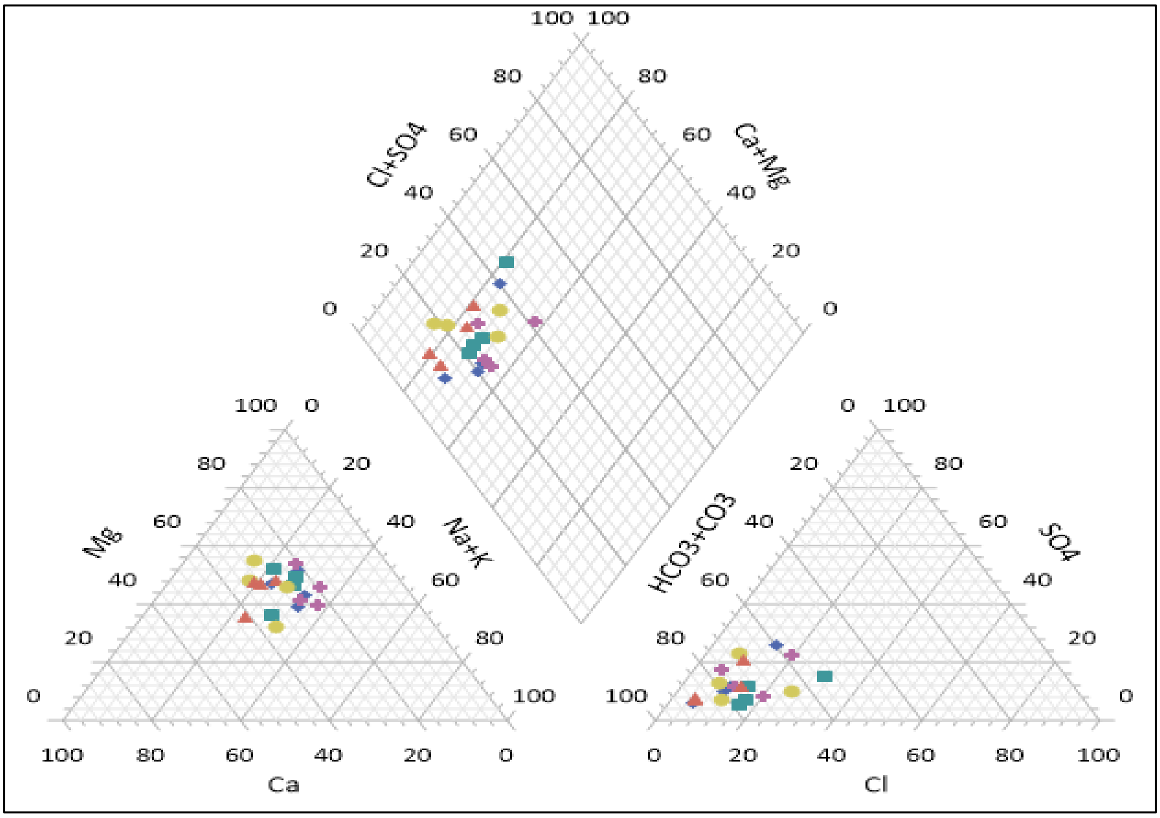

Fig. 4.38: Trilinear piper dig of Bina ground water

4.10 Contour mapping

Contour maps show the concentration of analyzed heavy metals in mine water samples in two seasons. In the water samples studied, the concentration of iron (Fe), manganese (Mn), and lead (Pb) are the most dominant metals. The concentration of heavy metals were above the desirable limit of specified in Indian drinking water standards (BIS 2012) in pre-monsoon. Concentration contours plots of Fe, Pb, Mn, Cu, Mg and Mn show, concentration in the mine water samples collected from different mines of NCL. The water that contained higher Fe and Mn concentration would require treatment before domestic and irrigation use. Contour map showing, trace metal concentration in water samples during pre-monsoon and post-monsoon **(Fig. 4.39 to 4.54)**.

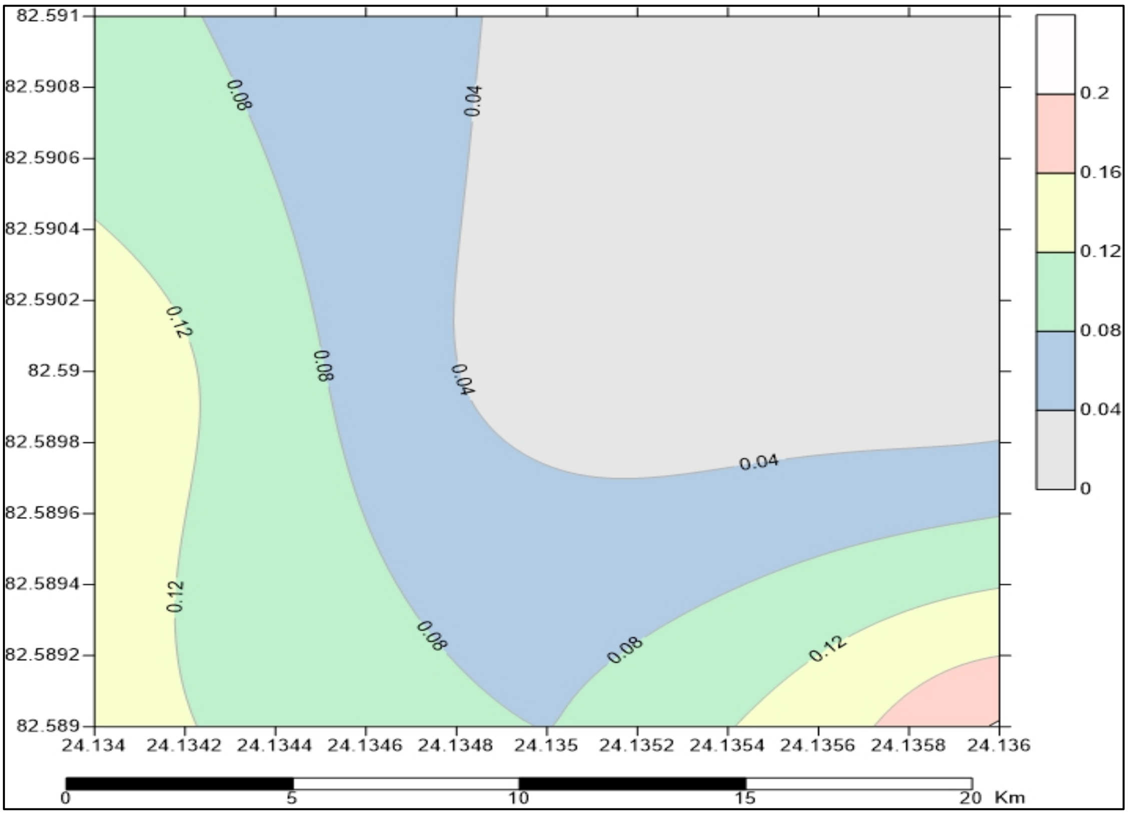

Fig. 4.39: Contour map for Cadmium concentration in water samples during pre-monsoon season

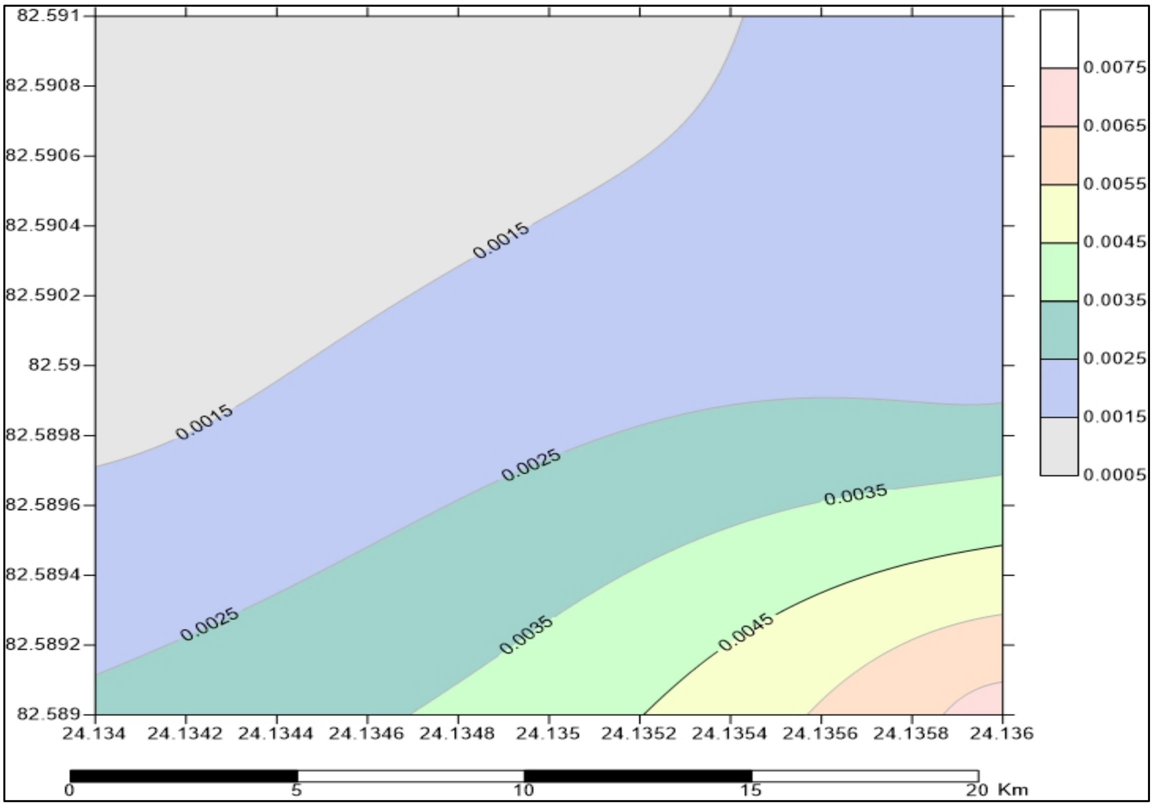

Fig. 4.40: Contour map for Chromium concentration in water samples during pre-monsoon season

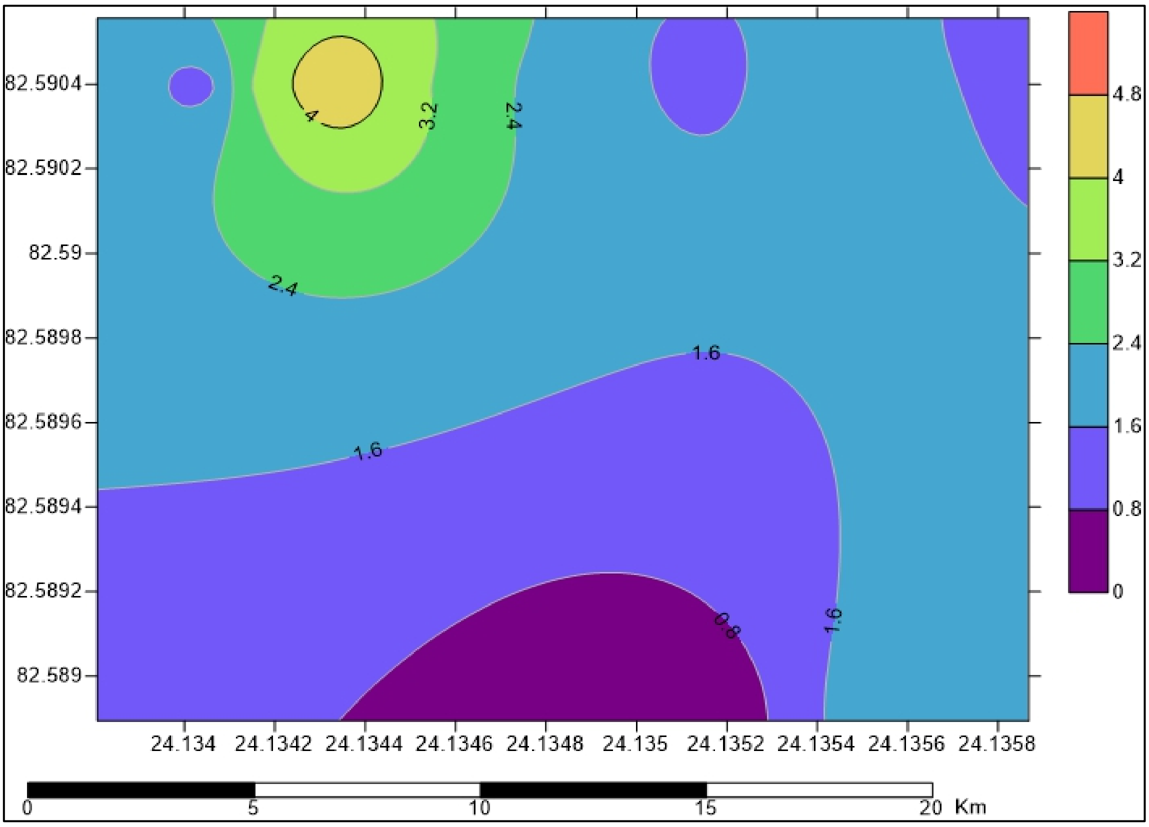

Fig. 4.41: Contour map for Copper concentration in water samples during pre-monsoon season

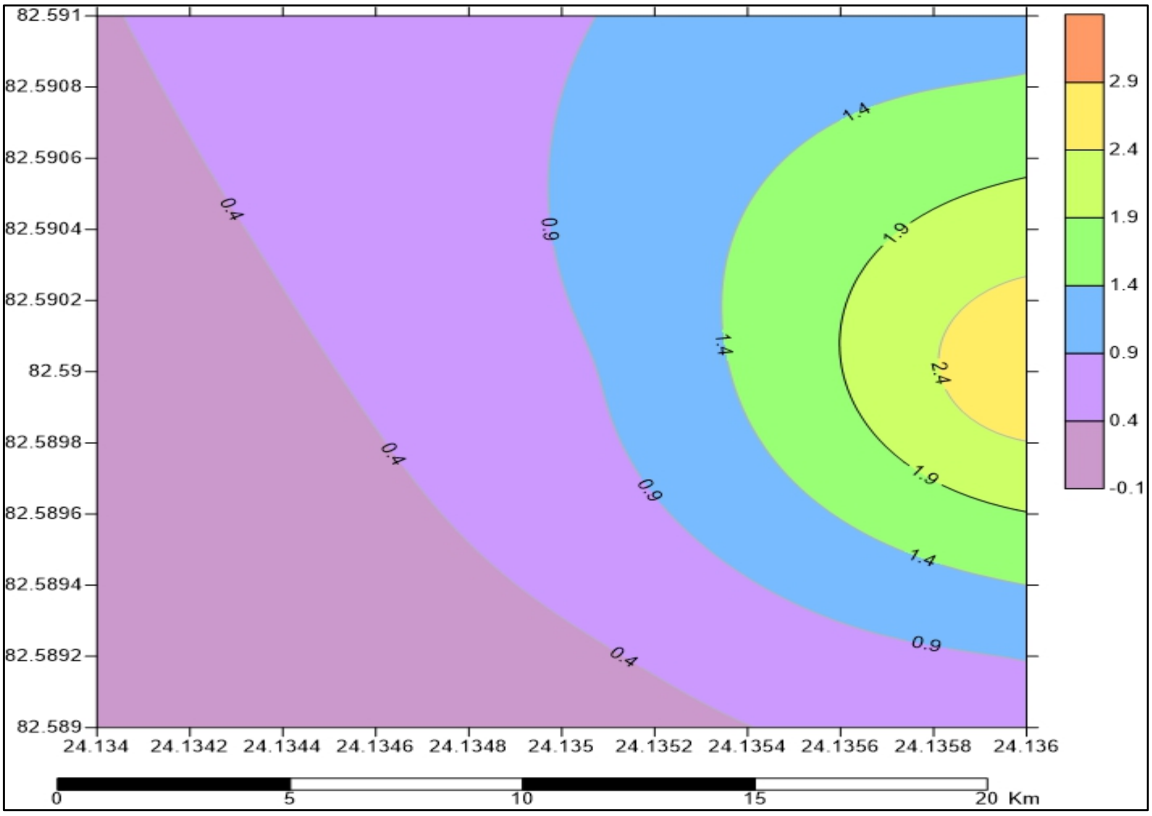

Fig. 4.42: Contour map for Iron concentration in water samples during pre-monsoon season

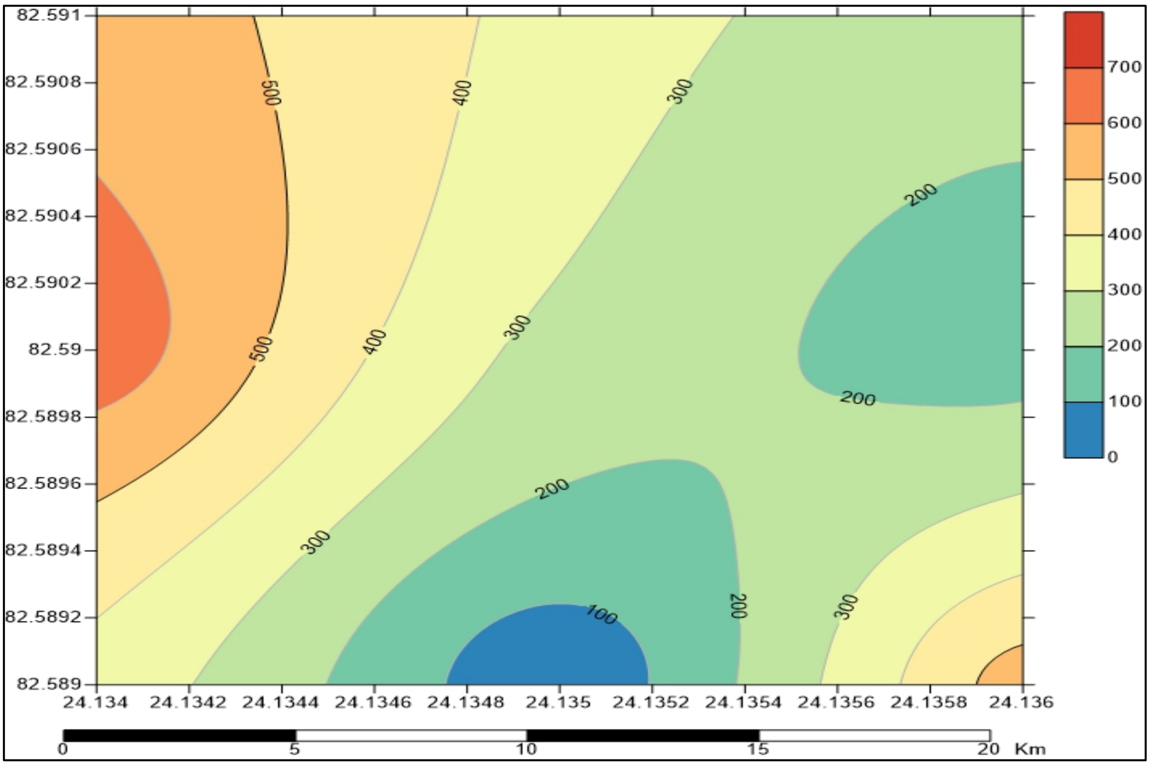

Fig. 4.43: Contour map for Manganese concentration in water samples during pre-monsoon season

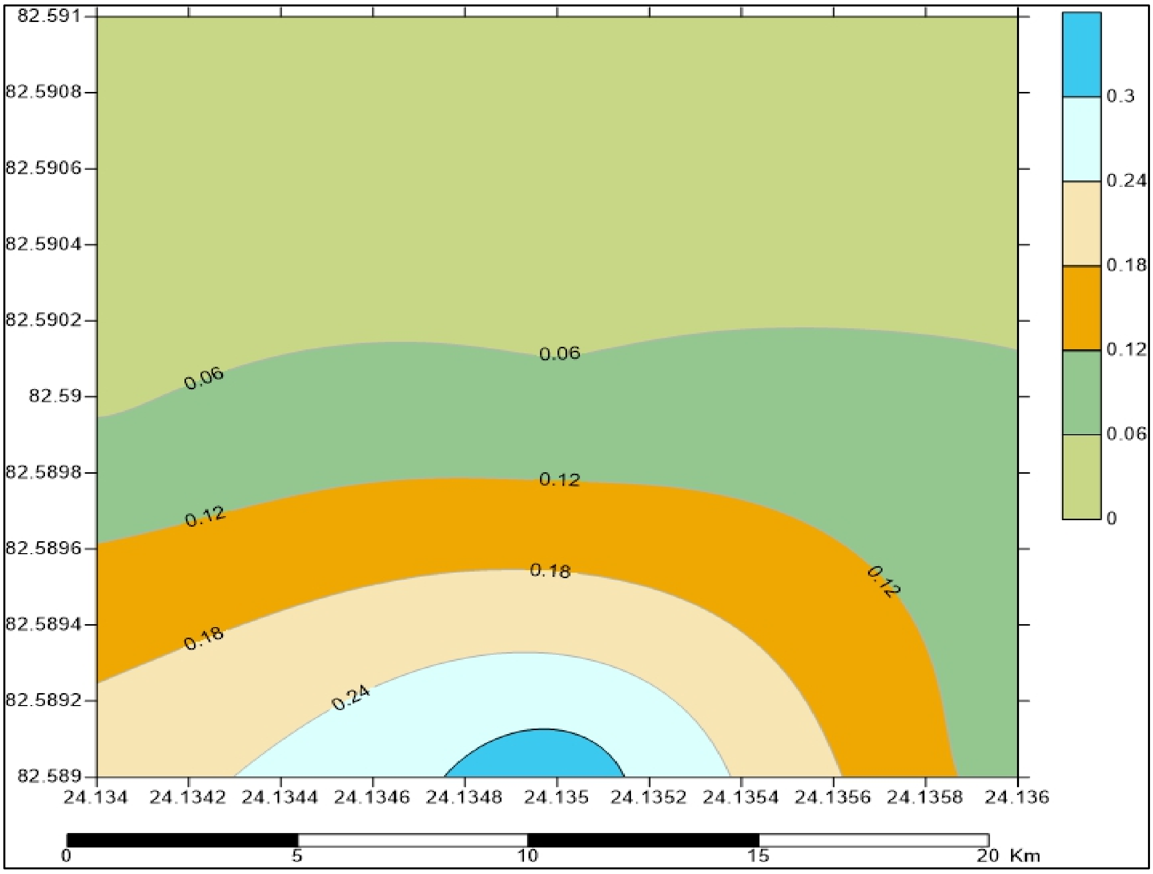

Fig. 4.44: Contour map for Lead concentration in water samples during pre-monsoon season

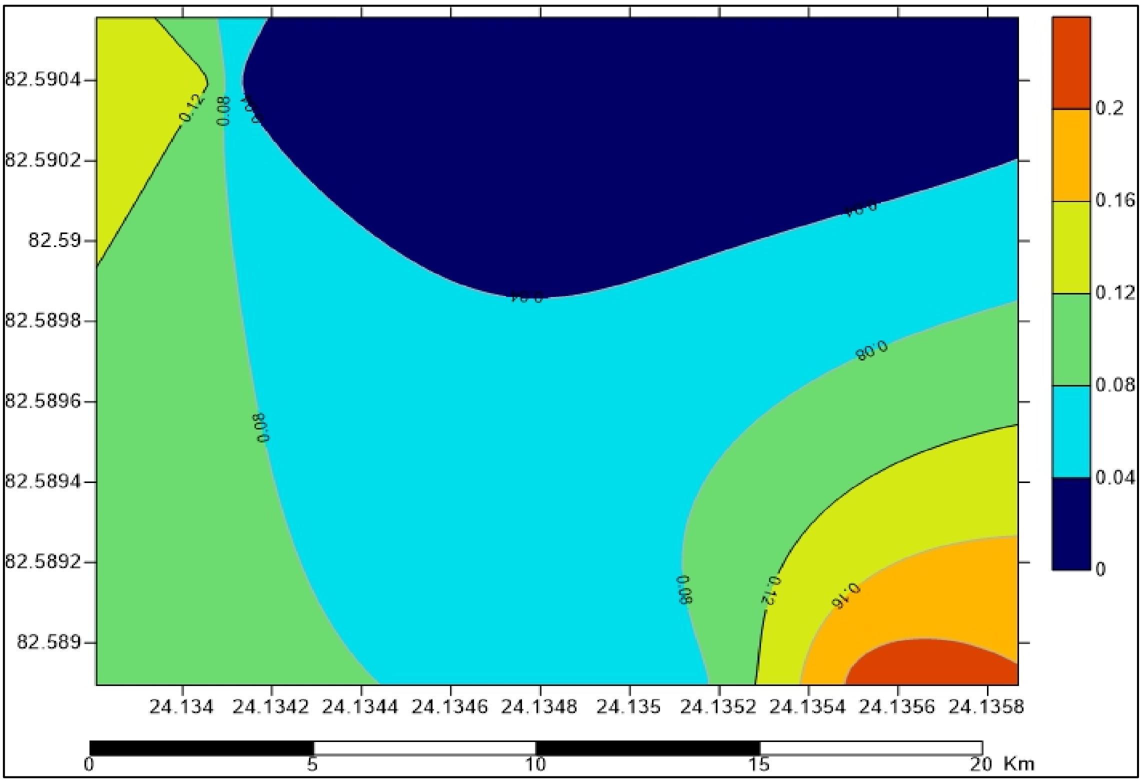

Fig. 4.45: Contour map for Cadmium concentration in water samples during post-monsoon season

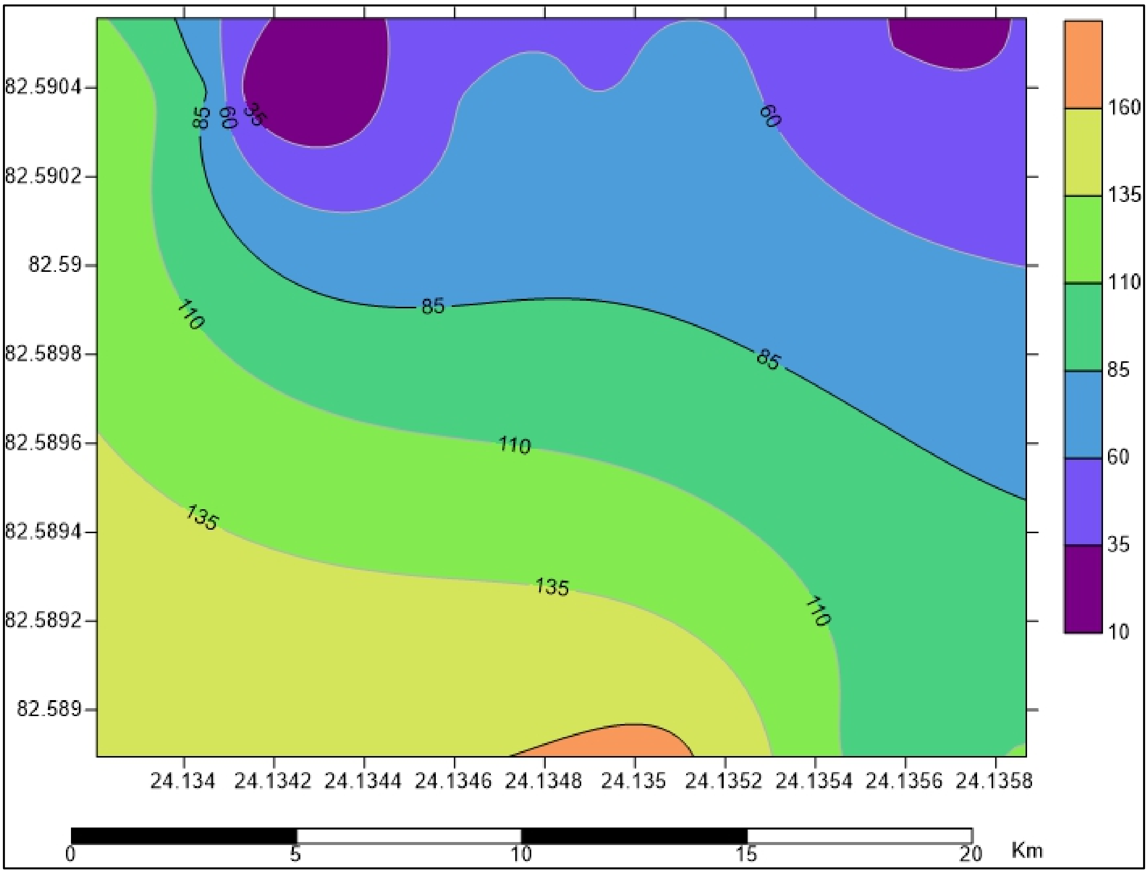

Fig. 4.46: Contour map for Chloride concentration in water samples during post-monsoon season

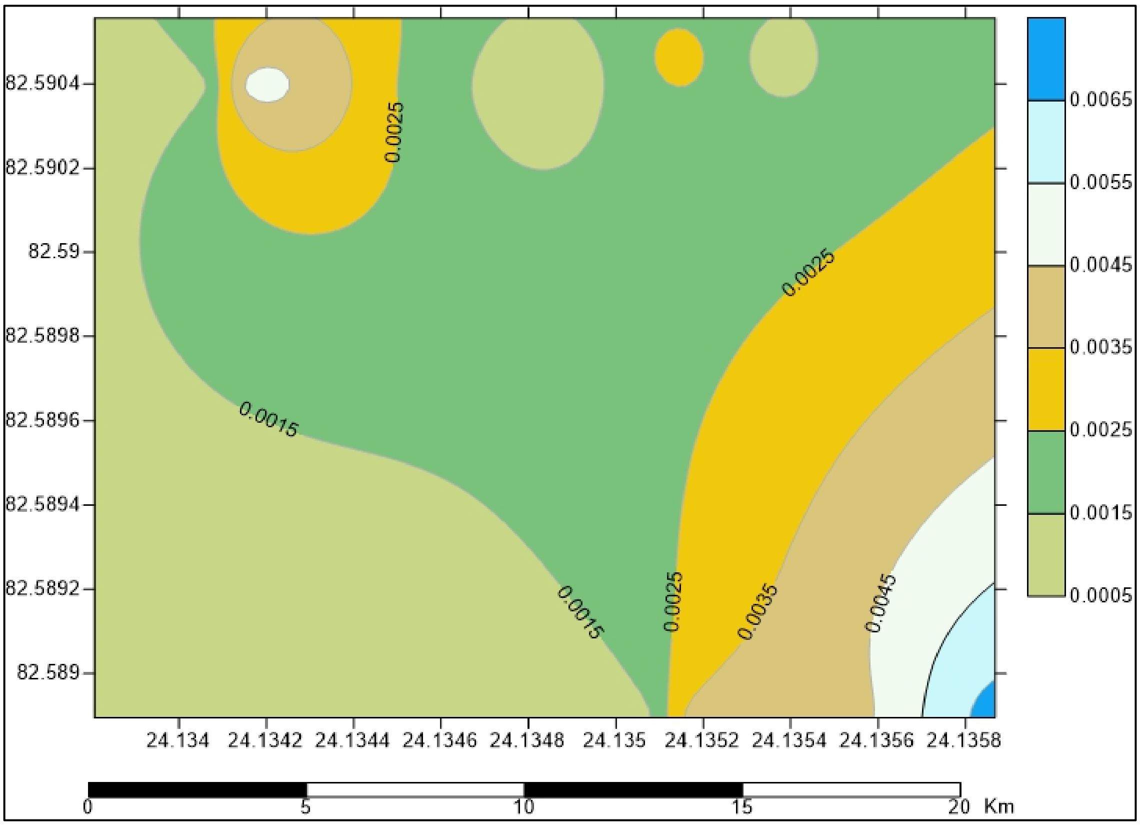

Fig. 4.47: Contour map for Chromium concentration in water samples during post-monsoon season

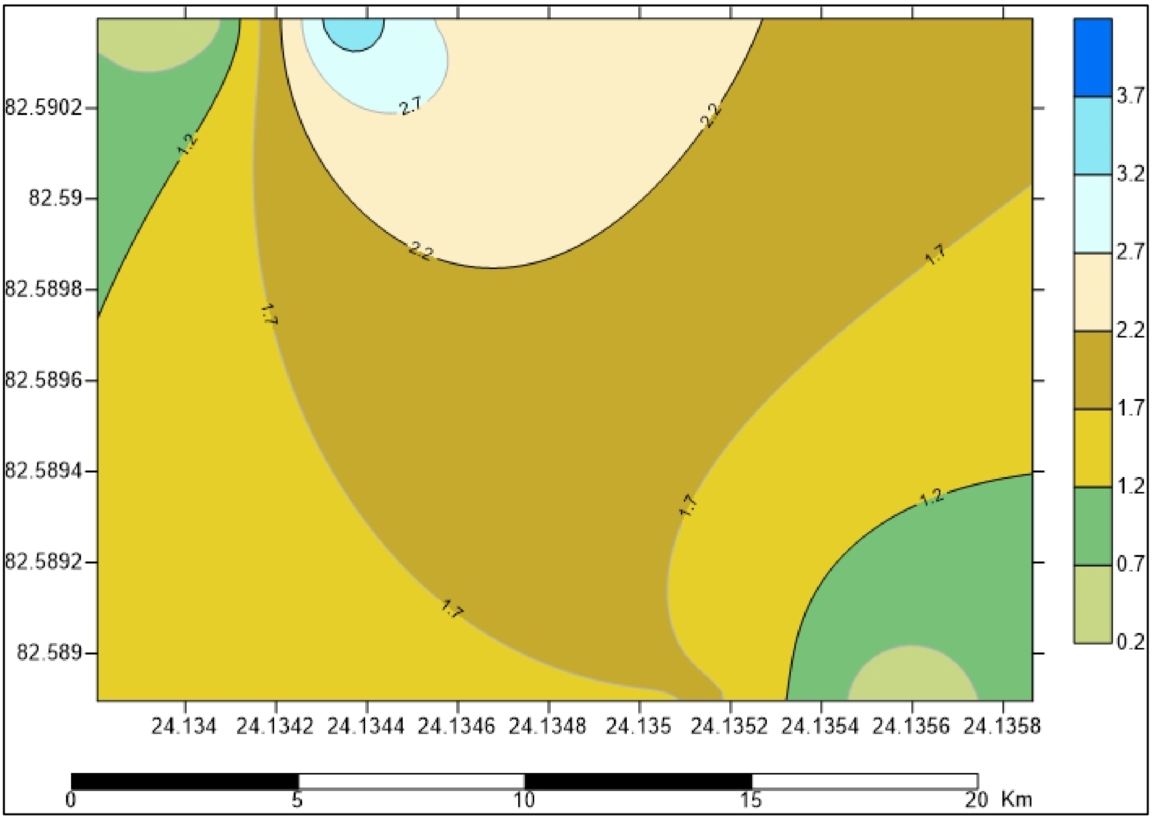

Fig. 4.48: Contour map for Copper concentration in water samples during post-monsoon season

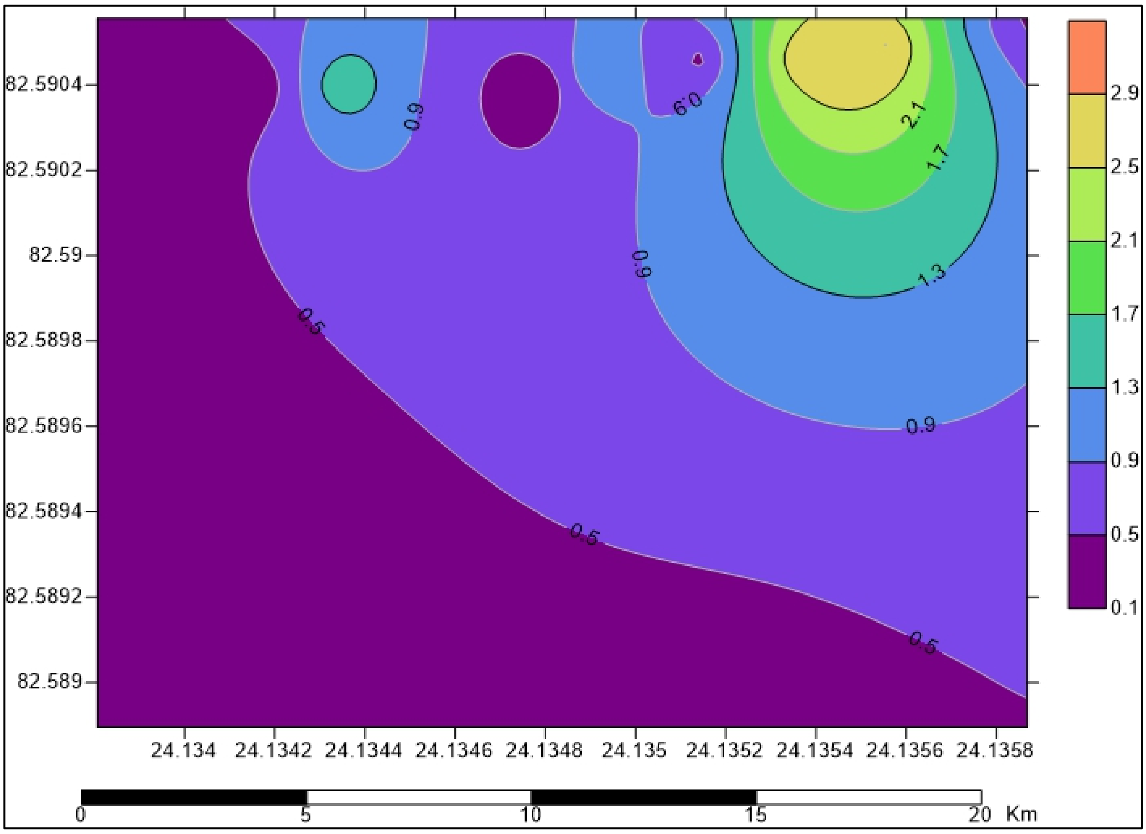

Fig. 4.49: Contour map for Iron concentration in water samples during post-monsoon season

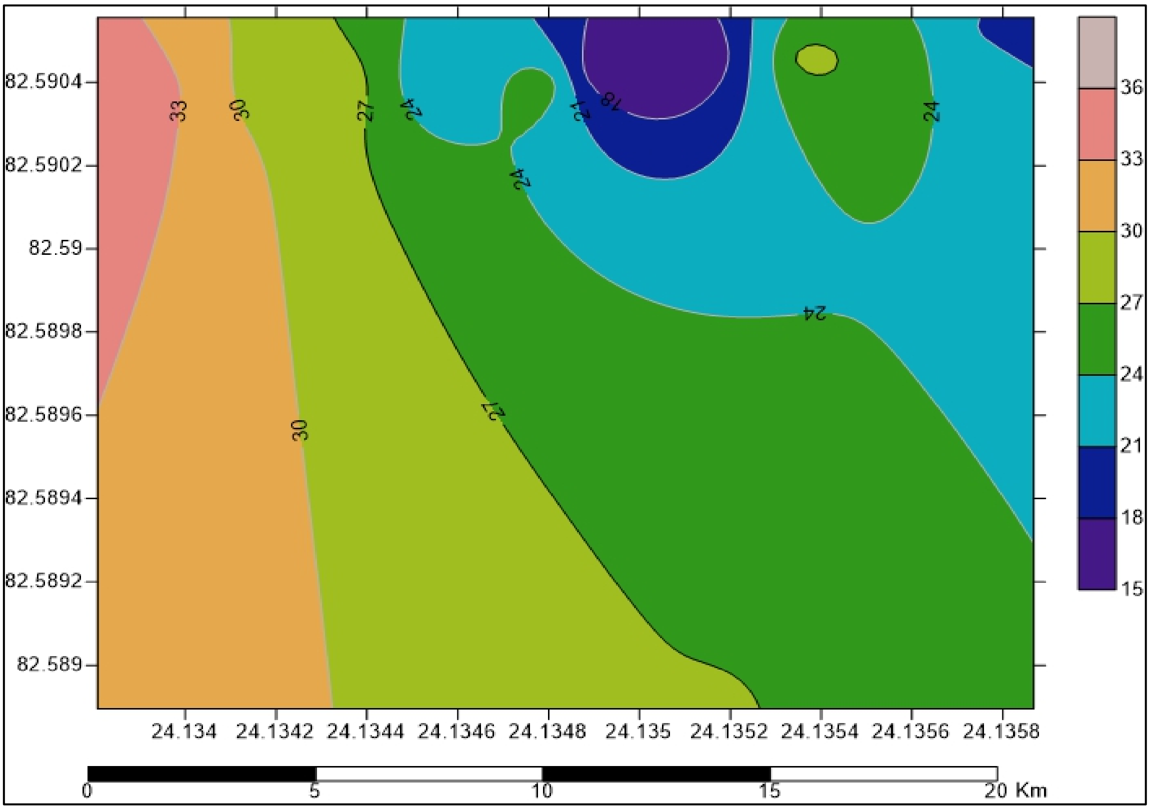

Fig. 4.50: Contour map for Magnesium concentration in water samples during post-monsoon season

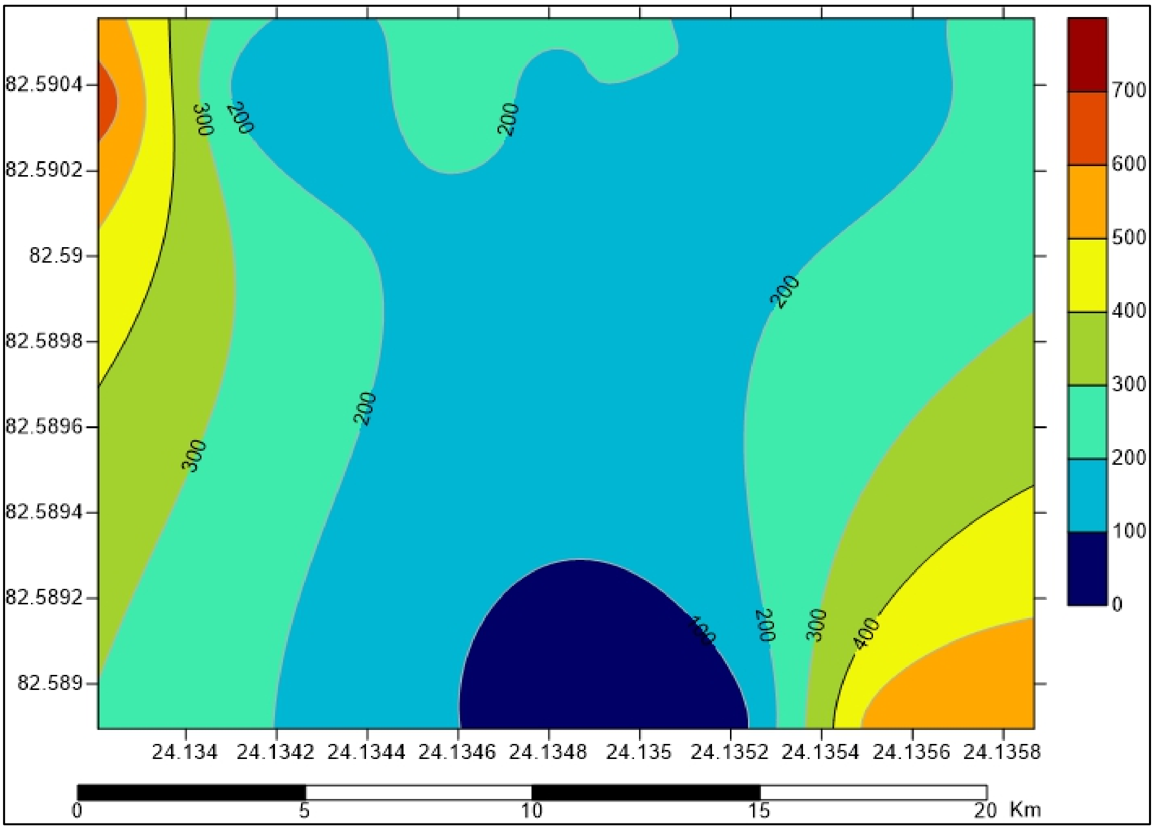

Fig. 4.51: Contour map for Manganese concentration in water samples during post-monsoon season

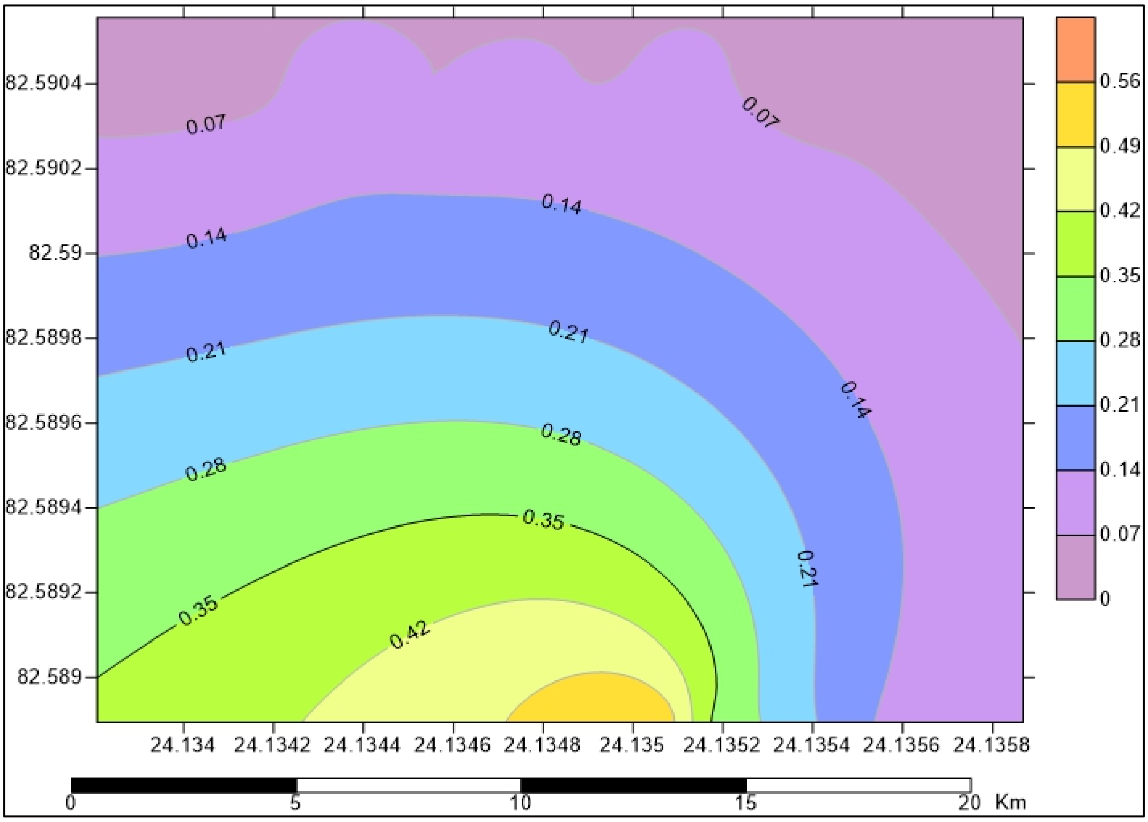

Fig. 4.52: Contour map for Lead concentration in water samples during post-monsoon season

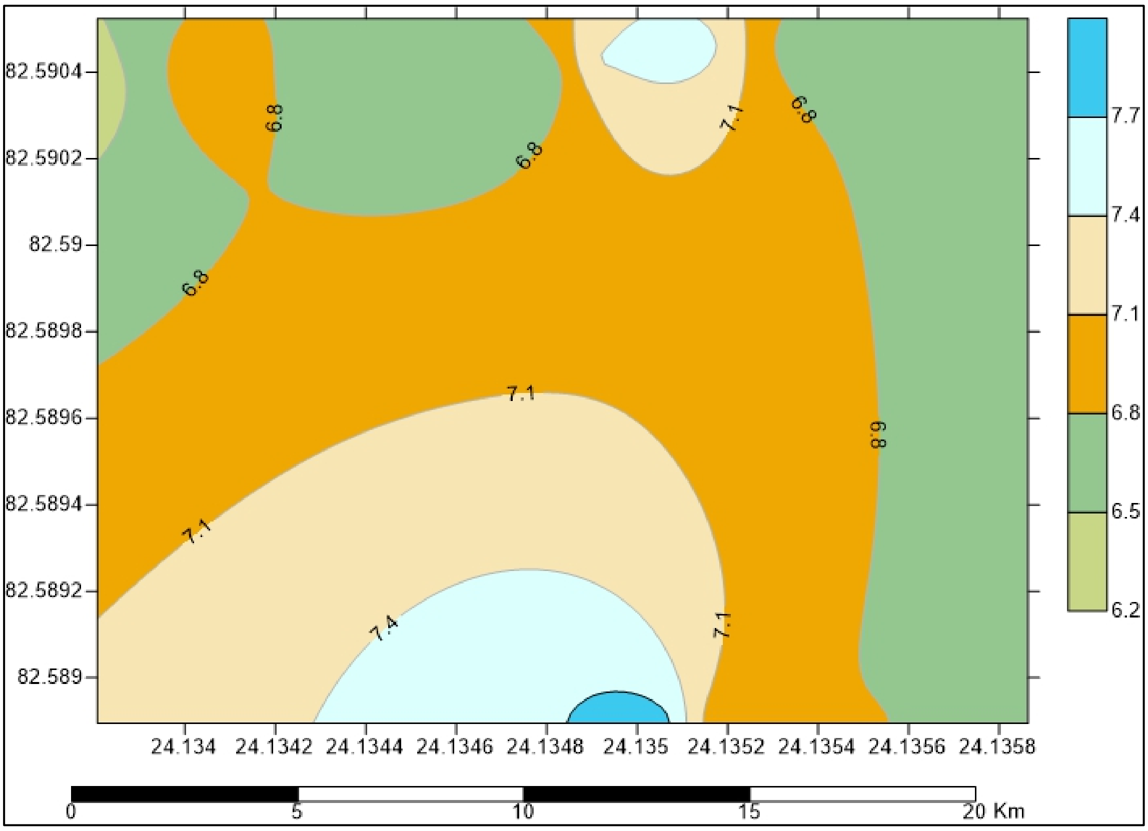

Fig. 4.53: Contour map for pH concentration in water samples during post-monsoon season

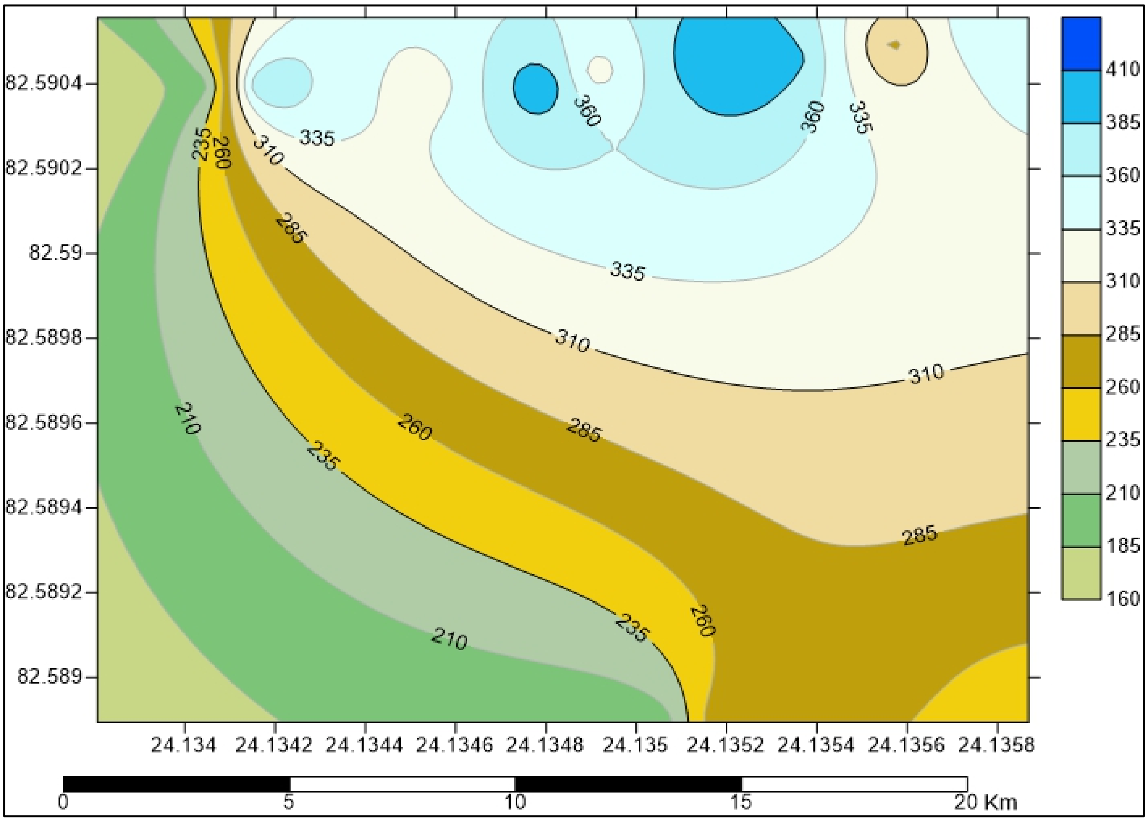

Fig. 4.54: Contour map for Sulphate concentration in water samples during post-monsoon season

This has been concluded from above studies that Flyash, Overburden and OB+30% Flyash samples were found to be mostly alkaline. The detail of mineral phases of the Flyash, OB and OB + 30% flyash mixture were confirmed by the XRF and XRD elemental mapping. The mineral peak of XRD include essential minerals SiO_2, Fe_2O_3, CaO, and Al_6SiO_2. The mineral phases of XRF include essential minerals Al_2O_3, FeO, CaO, K_2O, MgO, MnO and SiO_2. Reasonable pozzolanic activity of flyash with overburden has been confirmed in some of the SEM images as glassy fibrous particles observed. The OB+ 30% Flyash samples were observed in SEM images to have micro-cracks and pores which confirms that increasing of permeability after addition of flyash.

The result indicates that the water is acidic, neutral and slightly alkaline in nature in most part of Singrauli coalfield. However, acidic water has been observed in the voids of the Gorbi abandoned mine, Amlohri opencast mine, and the Jhingurdah opencast mine. Whereas, alkaline water has been found in Dudhichua opencast mine. The major water types are found to be calcium -magnesium - sulphate and calcium - bicarbonate in Singrauli coalfield. The ions, heavy metals, and other elements were found to be in low concentration in the monsoon season than pre-monsoon due to dilution effect caused by rain and surface runoff. In both season pre-monsoon and post-monsoon of water quality analysis of the samples reveals low pH and high concentrations of TDS, iron, lead and manganese in some samples in the Singrauli coalfield. Similarly, some heavy metal has been found in the permissible limit in samples of Singrauli coalfield in pre-monsoon and monsoon season. The Physico-chemical parameters of groundwater of Singrauli coalfield found to be under the permissible limits. After laboratory experiment, the observed values of groundwater at all the monitoring locations were found to be within permissible limits.