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Chromite Mining: Disbalancing the Aquatic Environment of Sukinda Valley

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Abstract

The Sukinda Valley of Odisha is renowned for its widespread chromite ore deposits. Different water bodies of this area are relentlessly receiving the effluents of mining activities as well as run-off and leachate. Different physicochemical parameters of ground water, surface water and mine drainage water along with bottom sediment of Damsal Nala were analysed seasonally during the year 2010 - '11. Comparative and seasonal analysis of physicochemical parameters of its uncontaminated upstream and contaminated downstream regions was recorded in this study. Statistical interpretations were also carried out to access the level of contamination. Concentrations of heavy metals in the ground water (Cr^{+6}: 0.00 - 0.06 mg/l; $Cr^{+3,+6}$: 0.01 - 0.11 mg/l; Fe: 1.03 - 1.50 mg/l), surface water (Cr^{+6}: 0.000 - 0.066 mg/l; $Cr^{+3,+6}$: 0.01 - 0.21 mg/l; Fe:0.72 - 9.72 mg/l) and mine drainage water (Cr^{+6}: 0.98 - 1.42 mg/l; $Cr^{+3,+6}$: 49.32 - 55. 24 mg/l; Fe: 0.75 - 3.56 mg/l) were found to cross the standard value in many sites which caused severe menace to the inhabitants and aquatic organisms of this region. The bottom sediment of Damsal Nala was also found to contain high level of heavy metals like total chromium (0.29 - 31.03 g/kg) and total iron (0.63 - 89 g/kg) which may transfer to the entire food chain including human being.

Keywords: Chromite mining, damsal nala, enrichment factor, heavy Metal, Sukinda Valley, water pollution.

Introduction

Sukinda Valley is famous for production of chromite ore through opencast as well as underground mining processes since last six decades in India. Due to mining, in one hand, environment is deteriorating day by day[1] as well as the indigenous people are losing their original habitat, source of food, drinking water and shelter[2]. Ground water and surface water sources of Sukinda Valley may contaminate through leaching and over flow of overburden dumps especially during rainy season. Direct discharge of untreated or improperly treated mining effluents contain various poisonous elements including heavy metals which pour into the Damsal Nala water (the only surface water source of Sukinda Valley) and can be harmful for the aquatic inhabitants including fish[3,4] and also may create serious health hazards to its consumers[5]. Few authors have tried to measure the degree of metallic constituents of different aquatic bodies including bottom sediment of Damsal Nala of Sukinda Valley[6,7]. Very petite and meagre study was reported on the physicochemical analysis of ground water, Damsal Nala water and mine drainage water as well as bottom sediment of Damsal Nala. The present work aimed to study concentration levels of various physicochemical parameters (together with a number of toxic metallic elements) of contaminated and uncontaminated sites of Sukinda Valley regions on a comparative basis.

Material and Methods

Description of the study area: Sukinda Valley is embraced with Daitari and Mahagiri hill ranges on two sides. For comparison and convenience of the study this area is divided into two regions – upstream (relatively less polluted) and downstream (heavily polluted) of Damsal Nala. All the study sites are located in the Jajpur district of Odisha. The entire area is localised in the south-western quadrant of topo-sheet no. 73G/12 and 73G/16 and is lying between latitude $21^0 0'$ to 21^0 3'N and longitude 85^0 43' to 85^0 52'E.

Collection, storage and analysis: Water (surface water i.e., water of Damsal Nala, ground water and mine drainage water) and bottom sediment of Damsal Nala were evaluated to determine the impact of chromite mining in Sukinda valley region of Odisha, India. Water samples were collected seasonally (winter, summer and monsoon) during the year 2010 - '11. Collection, preservation, storage and measurement of aqueous samples were done following an assortment of benchmark processes[8]. Parameters like pH, conductivity, salinity and dissolved oxygen were analysed in the field. Collection, preservation, storage, digestion (for heavy metal extraction) and analysis of bottom sediments were carried out following different standard methods[9-14]. Enrichment Factor (EF) was reckoned following the standard method[15,16]. Statistical analysis including Pearson correlation matrix was calculated with the help of statistical software SPSS 16.0 for windows.

Results and Discussion

Limnological parameters: The physicochemical characteristics of different water samples collected from Damsal Nala (upstream and downstream), groundwater (upstream and downstream), and mine drainage water have been recorded in table-1, table-2 and table-3 respectively.

Table-1
Analysis of physicochemical parameters of Damsal Nala water

Parameter	Upstream Region		Downstream Region	
	Mean ± SD ± SE	Range	Mean ± SD ± SE	Range
pH	7.54 ± 0.575 ± 0.332	7.15 - 8.20	7.61 ± 0.450 ± 0.260	7.21 - 8.10
EC	170.66 ± 79.002 ± 45.613	92.00 - 250.00	160.33 ± 53.107 ± 30.662	100.00 - 200.00
DO	7.12 ± 0.170 ± 0.098	6.96 - 7.30	6.91 ± 0.200 ± 0.115	6.72 - 7.12
Salinity	82.33 ± 35.303 ± 20.383	50.00 - 120.00	70.73 ± 16.273 ± 9.395	56.00 - 88.20
TDS	124.33 ± 48.398 ± 27.943	84.00 - 178.00	102.00 ± 23.580 ± 13.614	82.00 - 128.00
TSS	19.66 ± 10.786 ± 6.227	12 - 32	15.66 ± 4.726 ± 2.729	12 - 21
TA	111.33 ± 24.007 ± 13.861	96.00 - 139.00	101.66 ± 46.694 ± 26.960	48.00 - 133.00
COD	5.33 ± 2.309 ± 1.333	4 - 8	33.33 ± 2.309 ± 1.333	32 - 36
TH	108.66 ± 16.442 ± 9.493	90.00 - 121.00	103.00 ± 13.892 ± 8.021	87.00 - 112.00
F^-	0.126 ± 0.032 ± 0.018	0.09 - 0.15	0.116 ± 0.021 ± 0.012	0.10 - 0.14
Fe	5.24 ± 4.374 ± 2.525	0.98 - 9.72	5.03 ± 4.014 ± 2.317	0.72 - 8.66
Cr^{+6}	0.010 ± 0.010 ± 0.006	0.000 - 0.020	0.044 ± 0.019 ± 0.011	0.032 - 0.066
$Cr^{+3,+6}$	0.026 ± 0.015 ± 0.009	0.010 - 0.040	0.193 ± 0.015 ± 0.009	0.180 - 0.210
Pb	32.53 ± 17.580 ± 10.150	21.40 - 52.80	39.43 ± 32.707 ± 18.884	2.70 - 65.40
Cd	2.13 ± 3.695 ± 2.133	0.00 - 6.40	2.63 ± 2.409 ± 1.391	1.00 - 5.40

All values are expressed in mg/l except pH, EC (µs/cm/sec), lead (µg/l) and cadmium (µg/l)

Table-2
Analysis of physicochemical parameters of ground water

Parameter	Uncontaminated Region		Contaminated Region	
	Mean ± SD ± SE	Range	Mean ± SD ± SE	Range
pH	6.65 ± 0.176± 0.102	6.45 - 6.78	6.27 ± 0.461 ± 0.266	5.93 - 6.80
EC	86.33 ± 11.015 ± 6.360	79.00 - 99.00	178.66 ± 64.345 ± 37.151	125.00 - 250.00
DO	3.44 ± 0.426 ± 0.246	2.96 - 3.75	2.43 ± 0.600 ± 0.346	2.03 - 3.12
Salinity	48.43 ± 12.615 ± 7.283	41.10 - 63.00	83.43 ± 30.375 ± 17.537	61.00 - 118.00
TDS	60.66 ± 10.693 ± 6.174	54.00 - 73.00	110.66 ± 27.791 ± 16.046	89 - 142.00
TSS	8.66 ± 1.527 ± 0.882	7 - 10	16.33 ± 4.509 ± 2.603	12 - 21
TA	48.66 ± 14.742 ± 8.511	32.00 - 60.00	37.66 ± 10.786 ± 6.227	30.00 - 50.00
COD	9.00 ± 1.732 ± 1.000	7 - 10	64.00 ± 4.000 ± 2.309	60 - 68
TH	46.00 ± 7.000 ± 4.042	41.00 - 54.00	38.66 ± 10.693 ± 6.174	32.00 - 51.00
F^-	0.243 ± 0.076 ± 0.044	0.19 - 0.33	0.390 ± 0.207 ± 0.119	0.16 - 0.56
Fe	1.06 ± 0.047 ± 0.027	1.03 - 1.12	1.27 ± 0.207 ± 0.119	1.09 - 1.50
Cr^{+6}	BDL	BDL	0.046 ± 0.015 ± 0.009	0.030 - 0.060
$Cr^{+3,+6}$	0.023 ± 0.011 ± 0.006	0.010 - 0.030	0.086 ± 0.025 ± 0.014	0.060 - 0.110
Pb	22.63 ± 4.382 ± 2.530	19.00 - 27.50	33.63 ± 29.150 ± 16.830	0.00 - 51.60
Cd	BDL	BDL	0.46 ± 0.808 ± 0.466	0.00 - 1.40

All values are expressed in mg/l except pH, EC (µs/cm/sec), lead (µg/l) and cadmium (µg/l)

Table-3
Analysis of physicochemical parameters of mine drainage water

Parameter	Mean ± SD ± SE	Range
pH	7.14 ± 0.256 ± 0.148	6.90 - 7.41
EC	368.00 ± 114.595 ± 66.163	270.00 - 494.00
DO	4.15 ± 0.165 ± 0.095	3.99 - 4.32
Salinity	172.33 ± 58.227 ± 33.618	127.00 - 238.00
TDS	231.66 ± 104.290 ± 60.214	158.00 - 351.00
TSS	20.00 ± 7.211 ± 4.163	14 - 28
TA	113.66 ± 35.275 ± 20.367	73.00 - 136.00
COD	105.33 ± 19.731 ± 11.392	92 - 128
TH	66.33 ± 5.508 ± 3.180	60.00 - 70.00
F^-	0.260 ± 0.087 ± 0.050	0.21 - 0.36
Fe	2.09 ± 1.409 ± 0.813	0.75 - 3.56
Cr^{+6}	1.173 ± 0.225 ± 0.130	0.980 - 1.420
$Cr^{+3,+6}$	52.233 ± 2.961 ± 1.710	49.320 - 55.240
Pb	32.73 ± 3.402 ± 1.964	30.20 - 36.60
Cd	3.86 ± 3.946 ± 2.278	1.20 - 8.40

All values are expressed in mg/l except pH, EC (µs/cm/sec), lead (µg/l) and cadmium (µg/l)

pH is an important limnological factor in measuring the water quality, other aspect of water, such as acid and base neutralization, water softening, precipitation, coagulation and acid disinfections, because they are pH dependent. pH of Damsal Nala water ranged from 7.15 to 8.20 and 7.21 to 8.10 in the upstream and downstream regions respectively which were very much within the permissible limit[17]. The values of pH of ground water varied from 6.45 to 6.78 and 5.93 to 6.80 in the uncontaminated and contaminated regions respectively and were found acidic in nature. Most of the values were crossed the specified permissible limit[17]. The values of pH of mine drainage water samples varied from 6.90 to 7.41 and were very much within the permissible limit[17]. Similar findings were evidenced by different workers[3-7].

The values of conductivity (EC) of Damsal Nala water varied from 92.00 to 250.00 µS/cm/sec and 100.00 to 200.00 µS/cm/sec in the upstream and downstream regions respectively. The values of conductivity of ground water ranged from 79.00 to 99.00 µS/cm/sec and 125.00 to 250.00 µS/cm/sec in the uncontaminated and contaminated regions respectively. The results showed a sharp seasonal fluctuation. The conductivity of mine drainage water varied from 270.00 to 494.00 µS/cm/sec. The high conductivity in mine drainage water may be due to the discharge of heavy metals and many other ionized elements along with mining effluents. The results found similarities with the work of other researchers[3-7].

Dissolved oxygen (DO) is the fundamental fuel of life in water comes partly of being dissolved from the atmosphere at the air-water interface. The DO content of any aqua system largely determines the effects of waste discharges in water bodies. The DO content of Damsal Nala water varied from 6.96 to 7.30 mg/l and 6.72 to 7.12 mg/l in the upstream and downstream regions respectively. Seasonal fluctuations were recorded. Low DO content in summer may be due to increased temperature of Damsal Nala water. The DO content of ground water ranged from 2.96 to 3.75 mg/l and 2.03 to 3.12 mg/l in the uncontaminated and contaminated regions respectively. The DO content of mine drainage water varied from 3.99 to 4.32 mg/l. Ground water and mine drainage water samples were found to contain low to very low amount of DO throughout the entire period of study which was in conformity with water pollution. Similar results were also observed by others[3-7].

Salinity is an important water quality parameter representing the dissolved inorganic materials and salts in water. Salinity plays a major role in maintaining the hydrodynamics. It enters into the water body either due to natural processes such as atmospheric deposition of oceanic aerosols found in coastal areas or by anthropogenic sources like domestic discharge, agricultural release *etc*. It maintains the osmotic pressure, water balance and acid-base balance in aquatic organisms. Salinity of Damsal Nala water varied from 50.00 to 120.00 mg/l and 56.00 to 88.20 mg/l in the upstream and downstream regions respectively. Seasonal fluctuations were also very distinct. The average values of salinity of Damsal Nala water showed similar trends in both (upstream and downstream) regions. The salinity of ground water ranged from 41.10 to 63.00 mg/l and 61.00 to 118.00 mg/l in the uncontaminated and contaminated regions respectively depicting comparatively higher values in the downstream region. Salinity of mine drainage water samples fluctuated between 127.00 and 238.00 mg/l showing seasonal variations.

Total dissolved solids (TDS) values of Damsal Nala water ranged from 84.00 to 178.00 mg/l and 82.00 to 128.00 mg/l in the upstream and downstream regions respectively. TDS values of ground water were fluctuated between 54.00 to 73.00 mg/l and 89.00 to 142.00 mg/l in the uncontaminated and contaminated regions respectively. TDS values of mine drainage water samples varied from 158.00 to 351.00 mg/l. This moderate amount of TDS was due to livestock waste, landfills, hazardous waste and dissolved minerals like iron, chromium, lead *etc*. All the values were within the specified limit[17,18]. Similar findings were also evidenced by other workers[3-7].

Total suspended solids (TSS) refer to the organic and inorganic matter suspended in water relates to its physical influence on light and bottom sediments and which can adversely affect the quality of water. TSS increases the turbidity and decreases the transparency of water which affects the aquatic organisms. TSS values of Damsal Nala water varied from 12 to 32 mg/l and 12 to 21 mg/l in the upstream and downstream regions respectively. TSS values of ground water were fluctuated between 7 and 10 mg/l and 12 and 21 mg/l in the uncontaminated and contaminated regions respectively. TSS values of mine drainage water samples ranged from 14 to 28 mg/l. The average values of TSS of Damsal Nala water and mine drainage water crossed the specified limit[18]. The average values of TSS of ground water of downstream region were also found to cross the specified limit[18]. Large quantities of materials are washed into running waters and carried to the downstream. Other researchers[3-7] were also made similar observations and interpreted accordingly. Aquatic animals, particularly fishes were affected largely as it clogs their gills and filtering apparatus.

Total Alkalinity (TA) in streams and rivers fluctuates in a wide range and mainly depends on influx of effluents, evaporation and precipitation. Here, total Alkalinity of Damsal Nala water varied from 96 to 139 mg/l and 48 to 133 mg/l in the upstream and downstream regions respectively. Total Alkalinity of ground water samples were fluctuated between 32 and 60 mg/l and 30 and 50 mg/l in the uncontaminated and contaminated regions respectively. Total Alkalinity of mine drainage water samples ranged from 73 to 136 mg/l. The results depicted seasonal variations. The average values of ground water sources were well below the specified limit[17]. The values of Damsal Nala water and mine drainage water samples were also within the limit[18] specified for inland surface water. Similar observations were also noticed by others[3-7]. There were only seasonal changes due to rainfall and evaporation.

Chemical oxygen demand (COD) values of Damsal Nala water ranged from 4 to 8 mg/l and 32 to 36 mg/l in the upstream and downstream regions respectively. COD values of ground water were fluctuated between 7 and 10 mg/l and 60 and 68 mg/l in the uncontaminated and contaminated regions respectively. COD values of mine drainage water samples varied from 92 to 128 mg/l. COD values of Damsal Nala water and ground water of downstream regions were found to contain comparatively much higher concentration than the upstream regions indicating high level of pollution load. The high level of COD in ground water of downstream regions was a matter of great concern and it may be due to long history of leaching of heavy metals (chromium, lead, iron *etc.*,) through different soil horizons. The results showed that the water of Damsal Nala and ground water of contaminated regions were not fit for drinking purpose as far as the safe limit[19] for COD is concerned. However, in no case, the COD crossed the maximum permissible limit[17] for inland surface water. Similar results were also observed by other workers[3-7].

Total hardness (TH) includes the sulphates and chlorides of calcium and magnecium. Normally, the water hardness reflects the geology of the catchment area. Total hardness of Damsal Nala water fluctuated between 90 and 121 mg/l and 87 and 112 mg/l in the upstream and downstream regions respectively. Total hardness of ground water varied from 41 to 54 mg/l and 32 to 51 mg/l in the uncontaminated and contaminated regions respectively. Total hardness of mine drainage water samples ranged from 60 to 70 mg/l. All the values were well below the desirable specified limit[18] and with the similar findings as noticed by others[3-7]. Seasonal fluctuations resulted from the addition and precipitation as well as through rainfall and evaporation.

Fluoride (F^-) has some definite role in maintaining the populations of aquatic organisms including fish. Fluoride of Damsal Nala water fluctuated between 0.09 and 0.15 mg/l and 0.10 and 0.14 mg/l in the upstream and downstream regions respectively. Fluoride of ground water varied from 0.19 to 0.33 mg/l and 0.16 to 0.56 mg/l in the uncontaminated and contaminated regions respectively. Fluoride of mine drainage water samples ranged from 0.21 to 0.36 mg/l. The ground water and surface water was not fit for drinking purpose because of very low content of fluoride as compared with the specified desirable limit[18] and it was comparable with the similar findings as evidenced by other researchers[6,7].

Iron is the most copious metal in nature because of its availability in earth's crust. It plays an important part in the metabolic processes of many organisms. But it can also create health hazards to its consumers if excessively high concentration of iron is present in drinking water. Total Iron (Fe) of Damsal Nala water varied from 0.98 to 9.72 mg/l and 0.72 to 8.66 mg/l in the upstream and downstream regions respectively. Total Iron of ground water samples were fluctuated between 1.03 and 1.12 mg/l and 1.09 and 1.50 mg/l in the uncontaminated and contaminated regions respectively. Total Iron of mine drainage water samples ranged from 0.75 to 3.56 mg/l. Seasonal fluctuations were evidenced. The water of Damsal Nala and ground water was not considered fit for drinking purpose because in all the cases it crossed the desirable limit[18] of iron for drinking water. Similar observations were also noticed by different workers[3-7].

The higher oxidation state hexavalent chromium (Cr^{+6}), however, rarely found in nature, is more mobile, more soluble in water, and several times more toxic than trivalent chromium (Cr^{+3}). It is mainly produced due to anthropogenic activities. Hexavalent chromium of Damsal Nala water fluctuated between zero to 0.020 mg/l and 0.032 and 0.066 mg/l in the upstream and downstream regions respectively. Hexavalent chromium of ground water samples of upstream regions were found below the detection limit (BDL) in all the seasons whereas, it varied from 0.030 to 0.060 mg/l in the contaminated regions. Hexavalent chromium of mine drainage water samples ranged from 0.980 to 1.420 mg/l. In the upstream regions, all the values of Damsal Nala water and ground water samples were well below the desirable specified limit[17]. Whereas, in the downstream region the hexavalent chromium content of Damsal Nala water and ground water samples were found high to cross the desirable limit[17] in many cases. It is presumed that chromite mining is the main source of hexavalent chromium in the study area. Mine drainage water containing hexavalent chromium contaminates surface as well as ground water of the study area. All the mine drainage water was found to contain high level of hexavalent chromium and was found to cross the effluent discharge limit[20] specified for inland surface water during the period of experimentation in most of the seasonal values. The results found similarities with the work of other researchers[3-7].

Trivalent chromium is less soluble in water and thus less toxic than hexavalent chromium and is involved in metabolism of glucose and lipid. Total chromium ($Cr^{+3,+6}$) of Damsal Nala water varied from 0.01 to 0.04 mg/l and 0.18 to 0.21 mg/l in the upstream and downstream regions respectively. Total chromium of ground water samples were fluctuated between 0.01 and 0.03 mg/l and 0.06 and 0.11 mg/l in the uncontaminated and contaminated regions respectively. Total chromium of mine drainage water samples ranged from 49.32 to 55.24 mg/l. All the values of Damsal Nala water and ground water samples were found well below the desirable specified limit[17] in the upstream region. But the total chromium content of Damsal Nala water and ground water samples of downstream regions were found high to cross the desirable limit[17] in all the cases and reflected the similar findings obtained by others[3-7]. The weathered as well as semi-weathered underlying ultramafic parent rocks (dunite, peridotite and pyroxenite), mainly associated with chromite ore deposits, may be the natural source of chromium present in the different water bodies of the study area of both downstream as well as of upstream regions. All the mine drainage water was found to contain extremely high level of total chromium and crossed the specified limit[20].

Lead (Pb) is an extremely persistent and noxious element. Lead of Damsal Nala water fluctuated between 21.40 and 52.80 µg/l and 2.70 and 65.40 µg/l in the upstream and downstream regions respectively. Lead of ground water varied from 19.00 to 27.50 µg/l and zero to 51.60 µg/l in the uncontaminated and contaminated regions respectively. Lead of mine drainage water samples ranged from 32.20 to 36.60 µg/l. The study revealed that the Damsal Nala water, ground water and mine drainage water samples of upstream as well as downstream regions were well below the desirable limit[17] throughout the entire period of study and thus poses no threat of lead related health hazards. Similar observations were also evidenced by different workers[3,4,6].

Cadmium (Cd) is the extremely poisonous component. Cadmium of Damsal Nala water varied from zero and 6.40 µg/l and 1.00 and 5.40 µg/l in the upstream and downstream regions respectively. Cadmium of ground water samples of uncontaminated regions was found below the detection limit throughout the entire period of study. Cadmium of ground water samples were fluctuated between zero and 1.40 µg/l in the contaminated regions. Cadmium of mine drainage water samples ranged from 1.20 to 8.40 µg/l. All the values were well below the specified limit[17]. Similar findings were also noticed by other researchers[3,4,6].

The physicochemical analysis of water samples disclosed that the chromite mining has generated no end of damage to the surface water as well as ground water of the study area especially in the effluent-rich downstream region. The degree of heavy metal accumulation was found in the order of Fe > Pb > Cr > Cd and Fe > Cr > Pb > Cd in the upstream and downstream region of Damsal Nala respectively. The degree of heavy metal accumulation of ground water was found in the order of Fe > Cr ≥ Pb > Cd and Fe> Cr > Pb > Cd in the uncontaminated and contaminated regions respectively. Whereas, the degree of heavy metal accumulation was found in the order of Cr >> Fe > Pb > Cd in the mine drainage water samples. Damsal Nala as well as ground water samples were found to contain excess of COD, TDS, TSS *etc.*, including heavy metals like hexavalent chromium, total chromium and total iron particularly in the contaminated region and thus should be treated properly before consumption.

Bottom sediment: The physicochemical characteristics of bottom sediments (collected from upstream and downstream regions of Damsal Nala) have been recorded in table-4.

pH of bottom sediment determines its acidity or alkalinity and also influences the solubility as well as availability of nutrients to the primary producers of any aquatic ecosystem. It affects the presence of microorganisms which are responsible for breaking down of organic matter and other chemicals. The pH of bottom sediment of Damsal Nala ranged from 5.83 to 6.24 and 6.21 to 6.66 in the upstream and downstream regions respectively. The results showed seasonal variations. Rain water may have some role in lowering the pH during rainy season. pH of bottom sediment of Damsal Nala was found acidic in nature and was with the line of other worker[7].

Table-4
Analysis of physicochemical parameters of bottom sediment of Damsal Nala

Parameter	Upstream Region		Downstream Region	
	Mean ± SD ± SE	Range	Mean ± SD ± SE	Range
pH	5.97 ± 0.23 ± 0.13	5.83 - 6.24	6.40 ± 0.23 ± 0.13	6.21 - 6.66
EC (µs/cm/sec)	48.00 ± 10.82± 6.24	39 - 60	76.33 ± 14.57 ± 8.41	66 - 93
OM (%)	1.75 ± 0.26 ± 0.15	1.59 - 2.05	1.32 ± 0.46 ± 0.27	0.99 - 1.85
NO_3^{-2} (kg/ha)	22.39 ± 3.08 ± 1.78	20.12 - 25.90	15.63 ± 7.63 ± 4.41	11.03 - 24.45
PO_4^{-3} (kg/ha)	94.79 ± 15.30 ± 8.83	83.15 - 112.12	78.54 ± 42.38 ± 24.47	51.12 - 127.36
K^+ (kg/ha)	414.31 ± 23.06 ± 13.31	393.66 - 439.19	260.94 ± 150.05 ± 86.63	127.32 - 423.27
Fe (g/kg)	0.71 ± 0.09 ± 0.05	0.63 - 0.81	0.77 ± 0.11 ± 0.06	0.69 - 0.89
Cr^{+6} (g/kg)	BDL	BDL	0.006 ± 0.005 ± 0.0003	0.002 - 0.012
$Cr^{+3,+6}$ (mg/kg)	415.36 ± 108.54 ± 62.67	291.20 - 492.20	*27.26 ± 3.70 ± 2.14	23.63 - 31.03
Pb (mg/kg)	72.73 ± 9.77 ± 5.64	61.50 - 79.30	137.63 ± 4.63 ± 2.67	132.40 - 141.20
Cd (mg/kg)	3.44 ± 0.40 ± 0.23	2.99 - 3.75	7.61 ± 1.16 ± 0.67	6.33 - 8.60

[* Values are expressed in g/kg]

The ecological condition of an aquasystem is exceedingly influenced by the conductivity (EC) of the sediment of that water body. It controls the availability of nutrients to the aquatic plants. The conductivity of bottom sediment of Damsal Nala varied from 39 to 60 µS/cm/sec and 66 to 93 µS/cm/sec in the upstream and downstream regions respectively. Wide range of seasonal fluctuations was also noticed. The average values of conductivity of bottom sediment of Damsal Nala in the downstream regions were found higher than that in the upstream regions. This may be due to the presence of heavy metals and many other ionized elements which were produced from mining activities[7].

Organic matter (OM) content of the bottom sediment of any water body is mainly composed of dead materials of living organisms. It can be increased due to the ascription of organic pollutant. It is a measure of humic acid and bacterial activity. Organic matter content of bottom sediment of Damsal Nala fluctuated between 1.59 and 2.05% and 0.99 and 1.85% in the upstream and downstream regions respectively showing wide range of seasonal variations. The occurrence of organic matter in the bottom sediment possibly owing to putrefaction of leaf, algae, fish and other aquatic organisms[7].

Availability of nitrogen is of prime importance to autotrophs for energy and photosynthesis and the bottom sediment is the main source of nitrogen in an aquatic ecosystem. It also determines the productivity of any water body. Available nitrogen (NO_3^{-2}) content of bottom sediment of Damsal Nala ranged from 20.12 to 25.90 kg/ha and 11.03 to 24.45 kg/ha in the upstream and downstream regions respectively. The results showed a small range of seasonal fluctuations. Similar findings were also noticed by other researcher[7].

Phosphorous as phosphate plays a decisive role in maintaining the primary productivity of an aquatic environment. The exchange of phosphorous from sediment to water occurs through sediment-water interface. Available phosphate (PO_4^{-3}) content of bottom sediment of Damsal Nala varied from 83.15 to 112.12 kg/ha and 51.12 to 127.36 kg/ha in the upstream and downstream regions respectively and the results showed seasonal variations. Available phosphate ranging from 22.50 to 56.00 kg/ha in soil is considered as medium[12]. The available phosphate values of bottom sediment of Damsal Nala were found very high in the upstream region whereas, it ranged from medium to very high in the downstream regions. Seasonal fluctuations were more prominent in the downstream regions.

Productivity of an aquatic ecosystem is greatly induced by the potassium content of the bottom sediment in addition to nitrogen and phosphorous. Available potassium (K^+) content of bottom sediment of Damsal Nala fluctuated between 393.66 and 439.19 kg/ha and 127.32 and 423.27 kg/ha in the upstream and downstream regions respectively. The average concentrations of available potassium of bottom sediment of Damsal Nala in the upstream region were found much higher than that in the downstream regions. The results also varied seasonally. Similar results were also recorded by other worker[7].

Iron is the most abundant as well as wide spread element in earth's crust. It is a very essential metal for all living organisms. Total iron (Fe) content of bottom sediment of Damsal Nala ranged from 0.63 to 0.81 g/kg and 0.69 to 0.89 g/kg in the upstream and downstream regions respectively. Seasonal fluctuations were recorded. The results were supported by other researcher[7].

Hexavalent chromium (Cr^{+6}), a lethal ingredient, is produced due to anthropogenic activities. It is carcinogenic in nature. Hexavalent chromium content of bottom sediment of Damsal Nala were found below the detection limit (BDL) in the upstream region throughout the entire period of study. Although it varied from 0.002 to 0.012 g/kg in the downstream region and seasonal fluctuations were also recorded. Chromite mining may be the source of this hexavalent chromium which was present in the bottom sediment of Damsal Nala in the downstream region. Mine drainage water containing hexavalent chromium contaminates Damsal Nala in the downstream region and thereby also contaminating the bottom sediment there through leaching. Similar findings were reported by others[7].

Chromium is found in nature mainly in the form of Cr^{+6} and/or Cr^{+3} states. Trivalent chromium is an essential element involved in glucose and fat metabolism unlike hexavalent chromium. During the reduction of Cr^{+6} to Cr^{+3} several other oxidative states transiently occur, namely Cr^{+4} and Cr^{+5}, but these are very unstable in nature.

Total chromium ($Cr^{+3,+6}$) content of bottom sediment of Damsal Nala fluctuated between 291.20 and 492.20 mg/kg and 23.63 to 31.03 g/kg in the upstream and downstream regions respectively. The total chromium content of bottom sediment of Damsal Nala varied seasonally. Bottom sediment of Damsal Nala contained extremely high level of total chromium in the downstream region than the upstream region. The weathering as well as semi-weathering of underlying ultramafic parent rocks (dunite, peridotite and pyroxenite) mainly associated with chromite ore deposits may be the natural source of chromium present in the bottom sediment of Damsal Nala of both the downstream as well as of upstream regions. Analogous results were recorded by other researchers[7].

Lead is very toxic and biopersistent and can cause neurological discrepancy. Lead content of bottom sediment of Damsal Nala ranged from 61.50 to 79.30 mg/kg and 132.40 to 141.20 mg/kg in the upstream and downstream regions respectively. Seasonal fluctuations were noticed in case of lead content in the bottom sediment of Damsal Nala. High lead content was also reported in the bottom sediment of Damsal Nala by other workers[7].

Cadmium is also highly biopersistent as well as hyperaccumulative in nature and can hamper the various metabolic activities of aquatic organisms. Cadmium content of bottom sediment of Damsal Nala varied from 2.99 to 3.75 mg/kg and 6.33 to 8.60 mg/kg in the upstream and downstream regions respectively. The average values of cadmium of bottom sediment of Damsal Nala were recorded higher in the downstream regions than in the upstream regions. The results also showed seasonal variations.

Bottom sediments of Damsal Nala, mainly the contaminated downstream regions, were found to contain enormous quantity of total chromium and total iron which may possibly affect the human beings through water of Damsal Nala *via* food web. The degree of heavy metal accumulation in the bottom sediment of Damsal Nala was found in the order of total iron > total chromium > lead > cadmium and total chromium >> total iron > lead > cadmium in the upstream and downstream regions respectively.

Statistical Analysis: Correlation Coefficient: A cross correlation analysis was formulated to access possible similar sources and to establish the association amid an assortment of parameters. From this correlation analysis it was found that there was no strong correlation between some parameters, but strong in some other parameters. Some parameters were positively correlated whereas negative correlation between some parameters was also observed. A cross correlation analysis (data in Table-5 to Table-11) was mentioned to determine the relation between various parameters.

The correlation analysis of Damsal Nala water in the upstream region (table-5) showed very strong and positive correlation between conductivity and other parameters like salinity (99%) and TDS (97%). Again strong and positive correlation was observed between salinity and TDS (99%). Hence, it can be deduced that conductivity and salinity depends on the dissolved salts of different inorganic constituents. COD showed strong and positive correlation with iron (89%), total chromium (80%) and lead (99%); it can be said that COD values depends on the presence of different heavy metals like iron, total chromium and lead. Whereas, iron showed strong and positive correlation with total chromium (99%) and lead (86%); this may be indicated the same or similar source inputs of iron, total chromium and lead. DO showed very strong and negative correlation with COD (84%), iron (99%), total chromium (99%) and lead (81%); this was indicative of the fact that increase or decrease of DO greatly controlled by the parameters like COD, iron, total chromium and lead.

The correlation analysis of Damsal Nala water in the downstream region (table-6) showed very strong and positive correlation between conductivity and heavy metals like cadmium (89%) and lead (99%). It may be said that conductivity depends on the presence of heavy metals like cadmium and lead. A strong and positive correlation was observed between salinity and TDS (99%) and salinity and cadmium (93%); it can be alleged that salinity was caused due to dissolved salts of inorganic elements like cadmium. Iron showed strong and positive correlation with hexavalent chromium (84%) and total chromium (94%). Whereas, total chromium showed strong and positive correlation with hexavalent chromium (97%). Hence, it can be said that these heavy metals were generated from similar or same source inputs like chromite mining apart from natural sources. DO showed very strong and negative correlation with hardness (92%), COD (84%), iron (99%), hexavalent chromium (89%) and total chromium (97%); it may be assumed that increase or decrease of DO is influenced by the parameters like COD, iron, hexavalent chromium, hardness and total chromium. Again, lead and cadmium showed very strong and positive (86%) correlation which indicated their similar source inputs.

Table-5
Cross Correlation Matrix of Damsal Nala water of upstream region

	pH	**EC**	**DO**	**Sal.**	**TDS**	**TSS**	**TA**	**COD**	**TH**	**F^-**	**Fe**	**$Cr^{+3,+6}$**	**Pb**
pH	1												
EC	0.09	1											
DO	-0.78	0.53	1										
Sal.	-0.03	**0.99**	0.64	1									
TDS	-0.13	**0.97**	0.71	**0.99**	1								
TSS	-0.27	**0.92**	0.80	**0.97**	**0.99**	1							
TA	**0.99**	0.05	-0.81	-0.07	-0.18	0.32	1						
COD	**0.99**	-0.01	-0.84	-0.13	-0.24	-0.38	**0.99**	1					
TH	0.23	**-0.94**	-0.78	**-0.98**	**-0.99**	**0.99**	0.27	0.33	1				
F^-	0.71	0.77	-0.12	0.69	0.60	0.48	0.68	0.63	-0.52	1			
Fe	0.83	-0.47	**-0.99**	-0.58	-0.66	0.76	0.85	0.89	0.73	0.20	1		
$Cr^{+3,+6}$	0.74	-0.60	**-0.99**	-0.70	-0.77	0.85	0.76	0.80	0.83	0.04	**0.99**	1	
Pb	**0.99**	0.05	-0.81	-0.07	-0.18	0.32	**0.99**	**0.99**	0.28	0.67	0.86	0.77	1

Significant level = 1% i.e., P = 0.01 and Sal. = Salinity

Table-6
Cross Correlation Matrix of Damsal Nala water of downstream region

	pH	**EC**	**DO**	**Sal.**	**TDS**	**TSS**	**TA**	**COD**	**TH**	**F^-**	**Fe**	**Cr^{+6}**	**$Cr^{+3,+6}$**	**Pb**	**Cd**
pH	1														
EC	0.88	1													
DO	-0.58	-0.12	1												
Sal.	0.23	0.66	0.66	1											
TDS	0.15	0.60	0.72	**0.99**	1										
TSS	0.06	0.53	0.78	**0.99**	**0.99**	1									
TA	0.84	0.99	-0.04	0.72	0.66	0.60	1								
COD	**0.93**	0.65	-0.84	-0.14	-0.22	-0.31	0.58	1							
TH	0.22	-0.27	**-0.92**	**-0.90**	**-0.93**	-0.96	-0.35	0.56	1						
F^-	**-0.90**	**-0.99**	0.18	-0.61	-0.55	-0.47	**-0.99**	-0.69	0.20	1					
Fe	0.50	0.03	**-0.99**	-0.73	-0.78	-0.83	-0.05	0.78	**0.95**	0.09	1				
Cr^{+6}	0.89	0.56	-0.89	-0.25	-0.32	-0.41	0.49	**0.99**	0.64	-0.61	0.84	1			
$Cr^{+3,+6}$	0.76	0.36	**-0.97**	-0.46	-0.53	-0.60	0.28	**0.94**	0.80	0.42	**0.94**	**0.97**	1		
Pb	**0.90**	**0.99**	-0.18	0.62	0.56	0.48	**0.99**	0.69	-0.21	**0.99**	0.09	0.61	0.41	1	
Cd	0.57	0.89	0.35	**0.93**	**0.90**	0.86	**0.92**	0.22	-0.68	0.86	-0.43	0.12	-0.11	0.86	1

Significant level = 1% i.e., P = 0.01 and Sal. = Salinity

Table-7
Cross Correlation Matrix of ground water of upstream region

	pH	**EC**	**DO**	**Sal.**	**TDS**	**TSS**	**TA**	**COD**	**TH**	**F^-**	**Fe**	**$Cr^{+3,+6}$**	**Pb**
pH	1												
EC	0.57	1											
DO	-0.47	0.46	1										
Sal.	0.64	**0.99**	0.38	1									
TDS	0.68	**0.99**	0.33	**0.99**	1								
TSS	0.87	0.01	-0.84	0.18	0.23	1							
TA	**0.99**	0.59	-0.44	0.66	0.70	0.86	1						
COD	-0.35	0.58	**0.99**	0.50	0.46	-0.76	-0.31	1					
TH	0.74	**0.97**	0.24	**0.99**	**0.99**	0.33	0.76	0.37	1				
F^-	**-0.99**	-0.53	0.51	-0.61	-0.65	-0.89	**-0.99**	0.38	-0.72	1			
Fe	0.54	-0.39	**-0.99**	-0.31	-0.26	0.88	0.51	**-0.98**	-0.17	0.57	1		
$Cr^{+3,+6}$	**0.98**	0.42	-0.62	0.49	0.54	**0.94**	**0.98**	-0.50	0.62	**0.99**	0.67	1	
Pb	0.83	**0.93**	0.10	**0.96**	**0.97**	0.45	0.84	0.24	**0.99**	0.80	-0.03	0.72	1

Significant level = 1% i.e., P = 0.01 and Sal. = Salinity

Table-8
Cross Correlation Matrix of ground water of downstream region

	pH	**EC**	**DO**	**Sal.**	**TDS**	**TSS**	**TA**	**COD**	**TH**	**F^-**	**Fe**	**Cr^{+6}**	**$Cr^{+3,+6}$**
pH	1												
EC	0.89	1											
DO	-0.72	-0.33	1										
Sal.	**0.94**	**0.99**	-0.43	1									
TDS	**0.92**	**0.99**	-0.39	**0.99**	1								
TSS	0.80	**0.98**	-0.15	**0.96**	**0.97**	1							
TA	-0.54	-0.10	**0.97**	-0.21	-0.17	0.07	1						
COD	**0.94**	0.69	**-0.91**	0.77	0.74	0.55	-0.79	1					
TH	-0.29	-0.69	-0.46	-0.60	-0.64	-0.80	-0.65	0.05	1				
F^-	0.57	0.88	0.16	0.82	0.85	**0.95**	0.38	0.27	**-0.95**	1			
Fe	0.85	**0.99**	-0.24	**0.98**	**0.98**	**0.99**	-0.01	0.63	-0.75	**0.92**	1		
Cr^{+6}	0.37	-0.09	**-0.91**	0.02	-0.03	-0.27	**-0.98**	0.65	0.79	0.55	0.18	1	
$Cr^{+3,+6}$	0.30	-0.17	-0.88	-0.05	-0.10	-0.34	**-0.96**	0.60	0.83	0.61	0.25	**0.99**	1

Significant level = 1% i.e., P = 0.01 and Sal. = Salinity

The correlation analysis of ground water in the upstream region (table-7) showed very strong and positive correlation between conductivity and other parameters like TDS (99%), lead (93%) and salinity (99%); again salinity showed strong and positive correlation with TDS (99%) and lead (96%); hence it may be concluded that dissolved salts of various inorganic elements like lead might be the cause of increasing salinity as well as conductivity of ground water. Fluoride showed high and positive correlation with total chromium (99%) and lead (80%); it was indicative of the fact that fluoride, total chromium and lead were generated from same or similar source inputs like natural processes. DO showed strong and negative correlation with iron (99%); it was presumed that DO level of ground water decreased due to oxidation of iron.

The correlation analysis of ground water in the downstream region (table-8) showed very strong and positive correlation between conductivity and other parameters like salinity (99%), TDS (99%), fluoride (88%) and iron (99%); it may be said that conductivity is depended on these parameters. Salinity showed strong and positive correlation with TDS (99%), fluoride (82%) and iron (98%); again, TDS showed very strong and positive correlation with fluoride (85%) and iron (98%); hence, it may be presumed that dissolved salts of different inorganic elements like iron and fluoride might be the cause of increasing salinity of ground water. Fluoride showed very strong and positive correlation with iron (92%); it was indicative of the fact that fluoride and iron were generated from the same or similar source inputs like chromite mining other than natural sources like weathering *etc*., whereas, DO showed strong and negative correlation with hexavalent chromium (91%); it could be said that DO level of ground water decreased during the oxidation process of chromium. Again, hexavalent chromium showed very strong and positive correlation with total chromium (99%); hence, it can be concluded fact that increasing presence of hexavalent chromium in the ground water of downstream region was surely may be due to chromite mining.

The correlation analysis of mine drainage water (table-9) showed strong and positive correlation between conductivity and other parameters like lead (88%), salinity (99%) and TDS (98%); it was indicated that conductivity depended on the dissolved salts of lead. Salinity showed strong and positive correlation with TDS (99%) and lead (92%); it indicated that dissolved salts of lead were responsible for increasing salinity. COD showed strong and positive correlation with iron (85%), hexavalent chromium (98%), total chromium (92%) and cadmium (100%). It can be inferred that high COD value is due to presence of some inorganic form of heavy metals. Iron showed strong and positive correlation with hexavalent chromium (72%) and cadmium (85%). It might be due to same or similar source inputs like natural as well as anthropogenic sources. Again, hexavalent chromium showed strong and positive correlation with total chromium (98%) and cadmium (98%); this might be due to the same or similar kind of source inputs like chromite mining. Whereas, pH showed strong and negative correlation with iron (98%) and cadmium (75%); it was indicative of the fact that low pH increased the availability of heavy metals like iron and cadmium. Strong and negative correlation was observed between DO and other parameters like COD (80%), iron (99%) and cadmium (80%); this was clearly indicated that DO level decreased during the transformation of iron and cadmium from lower oxidative states to the higher. Total chromium showed strong and positive correlation with cadmium (92%). It might be due to same or similar source inputs.

Table-9
Cross Correlation Matrix of mine drainage water

	pH	**EC**	**DO**	**Sal.**	**TDS**	**TSS**	**TA**	**COD**	**TH**	**F^-**	**Fe**	**Cr^{+6}**	**$Cr^{+3,+6}$**	**Pb**	**Cd**
pH	1														
EC	-0.40	1													
DO	**0.99**	-0.32	1												
Sal.	-0.31	**0.99**	-0.23	1											
TDS	-0.23	**0.98**	-0.15	**0.99**	1										
TSS	-0.37	**0.99**	-0.29	**0.99**	**0.99**	1									
TA	0.78	0.27	0.83	0.36	0.43	0.29	1								
COD	-0.75	-0.31	-0.80	-0.40	-0.47	-0.34	**-0.99**	1							
TH	0.86	0.12	**0.90**	0.21	0.29	0.15	**0.99**	**-0.98**	1						
F^-	-0.81	-0.21	-0.86	-0.30	-0.38	-0.24	**-0.99**	**0.99**	**-0.99**	1					
Fe	**-0.98**	0.24	**-0.99**	0.14	0.06	0.21	-0.87	0.85	**-0.94**	**0.90**	1				
Cr^{+6}	-0.58	-0.51	-0.65	-0.58	-0.65	-0.53	**-0.97**	**0.98**	**-0.92**	**0.95**	0.72	1			
$Cr^{+3,+6}$	-0.43	-0.65	-0.51	-0.72	-0.77	-0.67	**-0.90**	**0.92**	-0.83	0.88	0.58	**0.98**	1		
Pb	0.08	0.88	0.16	**0.92**	**0.95**	**0.90**	0.69	-0.72	0.57	-0.64	-0.25	-0.85	**-0.93**	1	
Cd	-0.75	-0.31	-0.80	-0.40	-0.47	-0.34	**-0.99**	**1**	**-0.98**	**0.99**	0.85	**0.98**	**0.92**	-0.72	1

Significant level = 1% i.e., P = 0.01 and Sal. = Salinity

The correlation analysis of bottom sediment of Damsal Nala in the upstream region (table-10) showed very strong and positive correlation between organic matter and other nutrients like available nitrogen (99%), available phosphate (97%) and available potassium (91%); it is indicated that the amount of organic matter was depended on available nitrogen, available phosphate and available potassium. Available nitrogen showed strong and positive correlation with available phosphate (93%) and available potassium (86%); it revealed that those were generated from same or similar source inputs like agricultural run offs, decomposition of dead aquatic organisms *etc*. Again, total iron showed strong and positive correlation with lead (99%) which indicated that both of these heavy metals might be originated from same ultramafic parent rocks. Whereas, pH showed very strong and negative correlation with total iron (86%) and lead (86%); it disclosed that low pH enhanced the availability of iron and lead in the bottom sediment. Whereas, conductivity showed very strong and positive correlation between organic matter (94%), available nitrogen (90%), available phosphate (99%), available potassium (99%), iron (93%) and lead (93%); it indicated that presence of these ionic elements increased the conductivity of bottom sediment.

The correlation analysis of bottom sediment of Damsal Nala in the downstream region (table-11) showed very strong and positive correlation between conductivity and other heavy metals like total iron (93%), total chromium (93%) and cadmium (86%); it was indicative of the fact that conductivity depended on the presence of these heavy metals. Organic matter showed very strong and positive correlation with other nutrients like available nitrogen (99%), available phosphate (99%) and available potassium (98%); it indicated that the amount of organic matter was depended on available nutrients. Available nitrogen showed strong and positive correlation with available phosphate (99%) and available potassium (95%) and indicated that those were generated from same or similar source inputs like agricultural run offs, decomposition of dead aquatic organisms *etc*. Again, total iron showed strong and positive correlation with total chromium (99%) and cadmium (98%); this might be due to the fact that all these metals were generated from same or similar source inputs like chromite mining apart from natural sources. Whereas, pH showed very strong and negative correlation with total iron (86%), total chromium (86%) and cadmium (75%); it expressed that low pH enhanced the availability of these heavy metals in the bottom sediment of Damsal Nala in the downstream region.

Table-10
Cross Correlation Matrix of bottom sediment of Damsal Nala of upstream region

	pH	**EC**	**OM**	**NO_3^{-2}**	**PO_4^{-3}**	**K^+**	**Fe**	**$Cr^{+3,+6}$**	**Pb**	**Cd**
pH	1									
EC	-0.18	1								
OM	-0.49	**0.94**	1							
NO_3^{-2}	-0.59	**0.90**	**0.99**	1						
PO_4^{-3}	-0.26	**0.99**	**0.97**	**0.93**	1					
K^+	-0.09	**0.99**	**0.91**	0.86	**0.99**	1				
Fe	-0.86	**0.93**	-0.67	0.04	-0.32	-0.47	1			
$Cr^{+3,+6}$	0.41	-0.25	0.65	0.53	0.19	0.02	0.12	1		
Pb	-0.86	**0.93**	-0.68	0.56	0.23	0.06	**0.99**	0.11	1	
Cd	**0.94**	-0.87	**0.99**	0.48	0.14	-0.03	-0.64	0.69	0.64	1

Significant level = 1% i.e., P = 0.01

Table-11
Cross Correlation Matrix of bottom sediment of Damsal Nala of downstream region

	pH	**EC**	**OM**	**NO_3^{-2}**	**PO_4^{-3}**	**K^+**	**Fe**	**Cr^{+6}**	**$Cr^{+3,+6}$**	**Pb**	**Cd**
pH	1										
EC	-0.80	1									
OM	-0.11	-0.51	1								
NO_3^{-2}	-0.23	-0.40	**0.99**	1							
PO_4^{-3}	-0.19	-0.44	**0.99**	**0.99**	1						
K^+	0.09	-0.68	**0.98**	**0.95**	**0.96**	1					
Fe	-0.86	**0.93**	-0.67	-0.35	-0.39	-0.64	1				
Cr^{+6}	0.41	-0.25	0.65	**0.94**	**0.93**	0.79	0.12	1			
$Cr^{+3,+6}$	-0.86	**0.93**	-0.68	-0.06	-0.10	-0.38	**0.99**	0.11	1		
Pb	**0.94**	-0.87	**0.99**	**-0.98**	**-0.99**	**-0.99**	-0.64	0.69	-0.64	1	
Cd	-0.75	0.86	-0.54	0.19	0.15	-0.14	**0.98**	0.29	**0.98**	0.49	1

Significant level = 1% i.e., $P = 0.01$

Table-12
Seasonal analysis of Enrichment Factor (EF) of Damsal Nala water, ground water and bottom sediment of Damsal Nala

Sample	Heavy metal	Winter	Summer	Monsoon	Mean
Damsal Nala water	Iron	0.735	0.891	1.135	0.920
	Total Chromium	18.000	5.250	6.786	10.012
	Lead	2.145	1.239	0.126	1.170
Ground water	Iron	1.204	1.339	1.038	1.194
	Total Chromium	6.000	3.000	3.667	4.222
	Lead	2.595	-	1.876	2.235
Bottom sediment of Damsal Nala	Iron	1.095	1.043	1.099	1.079
	Total Chromium	81.147	58.613	63.044	67.601
	Lead	2.265	1.711	1.781	1.919
	Cadmium	2.117	2.194	2.293	2.201

Enrichment Factor: Enrichment factor (EF) can be implemented to make a distinction among metals generating from natural and man-made sources and to evaluate the extent of human intervention. EF value increases with the increasing contributions of the anthropogenic origins. Similarly, EF value decreases with the decreasing rate of anthropogenic contributions. The results of the estimation of enrichment factor of heavy metals for Damsal Nala water, ground water and bottom sediment of Damsal Nala were shown in table-12. The EF values of Damsal Nala water showed that the level of enrichment remained within minimal or no enrichment level (0.735 to 1.135) for total iron throughout the entire period of study and it was indicative of the fact that those were free from anthropogenic influences and the variations were probably may be due to the temporal as well as special difference. Whereas, the EF values of Damsal Nala water calculated for total chromium showed significant enrichment level (5.250 to 18.000) throughout the whole period of study indicated high level of pollution and that may be surely due to anthropogenic activities like chromite mining. The EF values of Damsal Nala water calculated for lead illustrated that the level of enrichment ranged from minimal or no enrichment (0.126) to moderate enrichment (2.145) and revealed that those were not originated from anthropogenic activities and the minimal pollution was may be due to natural processes like weathering *etc*.

The EF values of ground water showed that the level of enrichment remained within minimal or no enrichment level

(1.038 to 1.339) for total iron throughout the entire period of study and it was indicative of the fact that those were free from anthropogenic persuades and the differences were perhaps may be caused by the temporal as well as special difference. Whereas, the EF values of ground water calculated for total chromium ranged from moderate (3.000) to significant (6.000) level of enrichment which indicated high level of pollution and that may be surely due to anthropogenic intervention apart from the natural processes. Whereas, the EF values of ground water varied from minimal or no enrichment (1.876) to moderate enrichment (2.595) for lead and divulged that those were not instigated from human activities and the minimal pollution was may be owing to natural processes like weathering *etc*. The EF values of the heavy metals in Damsal Nala water as well as that of the ground water were found in the order of total chromium > lead > iron.

The EF values of bottom sediment of Damsal Nala showed that the level of enrichment remained within minimal or no enrichment level (1.043 to 1.099) for total iron throughout the entire period of study clearly indicated no anthropogenic influence and the deviations were probably may be as a result of the sequential plus special discrepancy. But the EF values of bottom sediment of Damsal Nala showed extremely high level of enrichment (58.613 to 81.147) for total chromium throughout the entire period of study visibly demonstrating extremely high level of contamination and that may be surely due to soaring anthropogenic intervention like chromite mining. The EF values of bottom sediment of Damsal Nala showed that the level of enrichment fluctuated between minimal or no enrichment level (1.711) and moderate enrichment (2.265) level for lead and it was indicative of the fact that those were free from human influences and the minimal pollution was possibly caused by natural processes like weathering *etc*. The moderate (2.117 to 2.293) level of EF values of bottom sediment of Damsal Nala calculated for cadmium revealed that it was not originated from anthropogenic activities and the minimum level pollution was may be due to natural processes like weathering *etc*. The EF values of the heavy metals in the bottom sediment of Damsal Nala were found in the order of total chromium > cadmium > lead > iron.

Conclusion

The present work revealed that several mining operations of Sukinda Valley region of Odisha, generating certain environmental problems, like other mining areas. The downstream region is encompassed with the bulk of the chromite mining activity. The contaminated Damsal Nala water and ground water with heavy metals, in particular, enter into the food chain up to a level of secondary, tertiary consumers, would be a serious threat to the health of the entire flora and fauna. The important and urgent task is to study the uptake of various heavy metals by the plants and animals and finally into the human food chain in the region. The present study is able to furnish detailed information for the group of workers to take proper mitigation measures and make aware of the situation of contamination. The major study on physicochemical analysis of Damsal Nala water including its bottom sediment, ground water, mine drainage water, and statistical interpretations provides all-embracing grades on the impact of chromite contamination in aquatic environment of Sukinda Valley region of Odisha, India.

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