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Environmental Health Impact Assessments and Eco-modernity of Sukinda Chromite Ultramafic Belt, India

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The Precambrian geological chromite formation in the Sukinda Ultramafic chromite Belt (SUCB) at Jajpur, Odisha, has added to India's economy but simultaneously deteriorated the environment, habitat health, and societal values in India's largest chrome mine. The Environmental Impact Assessment (EIA) and Health Impact Assessment (HIA) are diversified independent studies blended into the Environmental Health Impact Assessment (EHIA), which is conducted as an emerging tool to discuss the environment and human health in mining areas in one basket. The study involved a rigorous literature review, field survey, and use of geoinformatics (arc GIS, Remote Sensing software) to generate aspect, stream order and other maps. Information was gathered from dispensaries to community health centres in Sukinda Valley for all individual players, i.e., water, air,

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noise, soil, and health concerns and their impacts on comprehending the environment and people's health. Key findings are decadal environmental degradation and people's health with mining-related diseases mainly due to open-cast mining, waste mismanagement, environmental regulations disobedience and improper monitoring of quality water, air, noise, tailings and soil of the mining pitch, mainly due to surged mining activity. Tuberculosis, cancer, Skin diseases and Malaria are the leading health issues, naming it the "Valley of Despair". The immediate and long-remedial measures warranted to satiate the burning problems and oblige the SDGs 1,3,6,7,13 and 15.
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Keywords: Chromite; EIA; EHIA; sustainability; geology; pollution; Sukinda.

1. INTRODUCTION

Global mining activities date back to the prehistoric ages, during the Stone Age and the Holocene era, before modern humans' appearance. Proxies in the cavern remnants reveal that mining started when the Homosapiens tamed fire, i.e. 40000 YBP to 20000 YBP (Years before the present). Harappan and Mohenjo-Daro civilisations in the Indian subcontinent used copper, bronze, tin, and silver minerals from 5300YBP to 3300YBP (Soni 2020, Bhardwaj). Chromite ore was discovered in Maryland-Pennsylvania in 1827 and Odisha in 1942 (Shroder 2014, Mishra et al. 2022). It is the most rigid, non-rusting metal, reflecting ≈70% of visible light, and used to make stainless steel; https://monroeengineering.com/blog/5-fun-facts-about-chromium. In 2020, about 332MMT (2% of global deposits), with "Reserves" as 79MMT in Sukinda Ultramafic Chromite Belt (SUCB), Odisha https://www.pureearth.org/project/sukinda-valley/#, GOI, Ministry of Mines 2021. In 1949, Tata Steel launched the first Ferro Alloys industry at Joda, Odisha, in 1958. About 96% of India's chromite (FeOCr2O3) is stored in Sukinda Valley, Odisha (Table 1) (Government of India, Government of Odisha 2014-15).

The Sukinda Valley in Dhenkanal, Jajpur, and Keonjhar districts has about 7010 chromite mine workers engaged in 15 mines Fig. 2. The state ranks 1st in chrome-ore extraction, and mineral royalty goes to the State's fund (70% of this state's revenue in the last 4 years, (Government of India, Government of Odisha 2014-15, Mishra 2024).

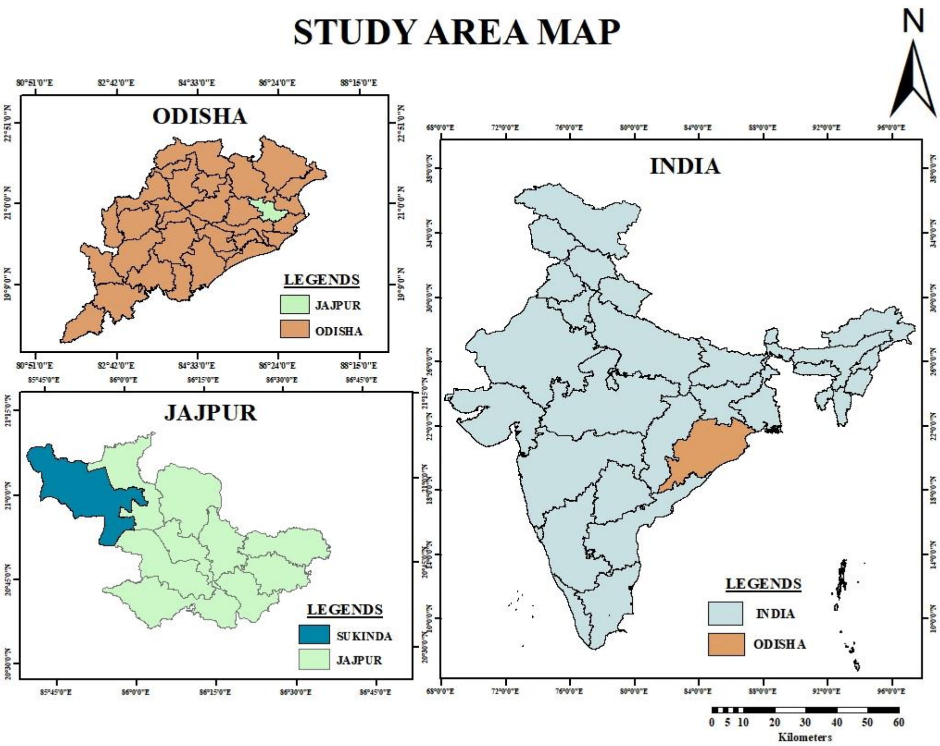
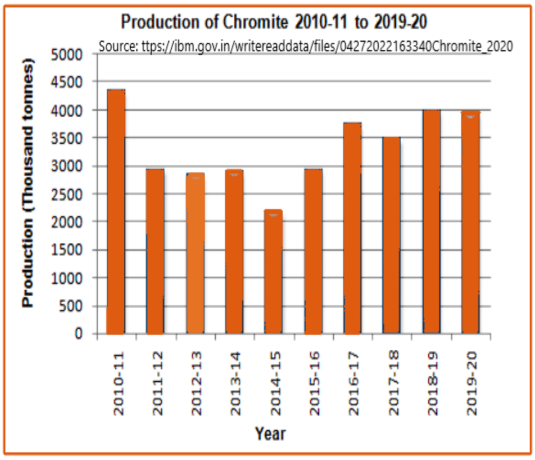


Fig. 1. The index map of the Sukinda Ultramphic Chromite Valley, Jajpur district, Odisha

Table 1. The stock of mineral resources: Share of Odisha India (2022 – 2023)

Mineral Resources	Prod^{n} in MT	Prod^{n} in MT	CAGR (2014-15 to 22-23)	Rank in India Prod^{n}	In Ind. Prod^{n}	Major Districts
Major	2014-15	2022-23	(%)	(%)	Rank	
Coal	122.8	216.1	7.3	25%	1st	Angul, Jharsuguda, Sundergarh, Sambalpur
Iron ore	53.3	155.3	14.3	55	1st	Kendujhar, Mayurbhanj, Sundergarh
Bauxite	9.2	17.5	9.1	73	1st	Koraput, Sundergarh
Chromite	2.2	3.7	8.4	100	1st	Dhenkanal, Jajpur, Kendujhar
Manganese	0.3	0.6	6.7	25%	3rd	Bolangir, Rayagada, Kendujhar, Sundergarh

Source: Indian Bureau of Mines, Government of India; Department of Steel & Mines, Government of Odisha: CAGR: Compound annual growth rate



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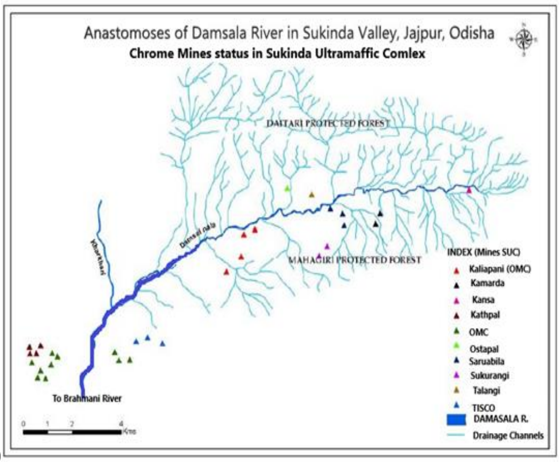


(b)

Fig. 2(a-b). The Chromite extraction from mines in India, 2010-11 to 2021(b) the Damsala river that receives the liquid waste from the mines in the *Valley of Despair*

1.1 Chromite Mining Study and Importance

The Sukinda Valley has an expanse of 200 Km^2) in the Jajpur district of Odisha. Odisha possesses 98.6% of chromite resources in India, and the Sukinda ultramafic complex contributes about 95% of the national reserve (Panda et al. 2020). The Sukinda Valley covers ≈34.20 Km^2 sq. km. chromite mines accommodating 7010 mining workers. The Valley is the chromite hub (183 MMT deposits) and contributes a lion's share towards India's economic growth. Simultaneously deteriorated the ecosystem and people's health in the Valley, the fourth most polluted place in the world (Blacksmith) and "The Valley of Despair". Modern technologies and procedures use solid waste as concrete additives (Das et al. 2019). The state ranks 1st in the country in terms of minerals and royalty in Odisha's revenue, about 70% of Odisha's in the last four years, according to the (Das et al. 2019). So, it is essential for a study.

The chromite mines possess 13 open casts (OC) and two underground (OG) mines in Sukinda Valley. The mines produce millions of tonnes of tailings, wastes and overburdens, contaminating the local air, noise, soil and water bodies and environment of communities around the Sukinda Valley of Jajpur district (Mallick et al. 2020).

1.2 Study Area

Sukinda Valley’s underneath is by banded iron formation (BIF), which is Precambrian chromite-bearing ultramafic rocks stratified between Lat. (21°0'-21°5'N: and Long85°43'-86°0'E), included in SOI Topo Sheet 73G/12 and 16 [Fig. 3]. The chromite minerals are housed in the east-west (E-W), trending within the Daitari range of hills in the north and the Mahagiri range of Hills in the south. The village at the easterly fringe is Kansa, and Maruabali is at the westerly end. The chromite reserve is about 232 MMT. The chromite of Sukinda Valley is intruded into the Iron-Ore Supergroup (2950-3200 million years) in the eastern margin of the Precambrian Shield of India. The chromite is sporadically deposited as stratified or in pockets laterally and vertically, either massive, banded, spotted, laminated, and friable folded or with intermittent strike (bands and seams). These bands house in a 25 km stretch and 2-5km across. The chromite grain size varies from 0.25 to 4 mm (Krasaesen et al. 2024).

The Valley is doubly plunging syncline, cross-folded, striking the ENE-WSW axis of the Eastern Ghats Orogenic belt parallel to the prominent fold, Fig. 3; (Chakraborty et al. 1984). Rainfall on average is winter, pre-monsoon, monsoon, and post-monsoon 28.8, 198.7, 1241.1, and 187.1mm, and a total of 1468.6mm, mausam.imd.gov.in/bhubaneswar/mcdata/rfnorm al.

1.3 The Environmental Statistics

Primary Drainage system: The rivers, drains (Nallah) and water bodies in the Valley are Damsala Nallah-2.2 km, Damsala Canal -4.5 km, SW, Nadibarana Nalah -5.0 km, Puagaghua

Nalah-5.3 km, Ragda Reservior-5.7 km, Sasubhuashuri Nalah-6.1 km, Patharkanchia Nalah-8.3 km, Near Natisahi vill. Canal-9.7 km, Petapeti Nalah-9.8 km, Khari Nalah-10.8 km, Porvajhara Nala-10.9 km, Barangi Nalah-11.8 km, Gahira Nala-13.6 km, Damsala nallah drains finally debouching to the Brahmani R (Barik et al. 2024).

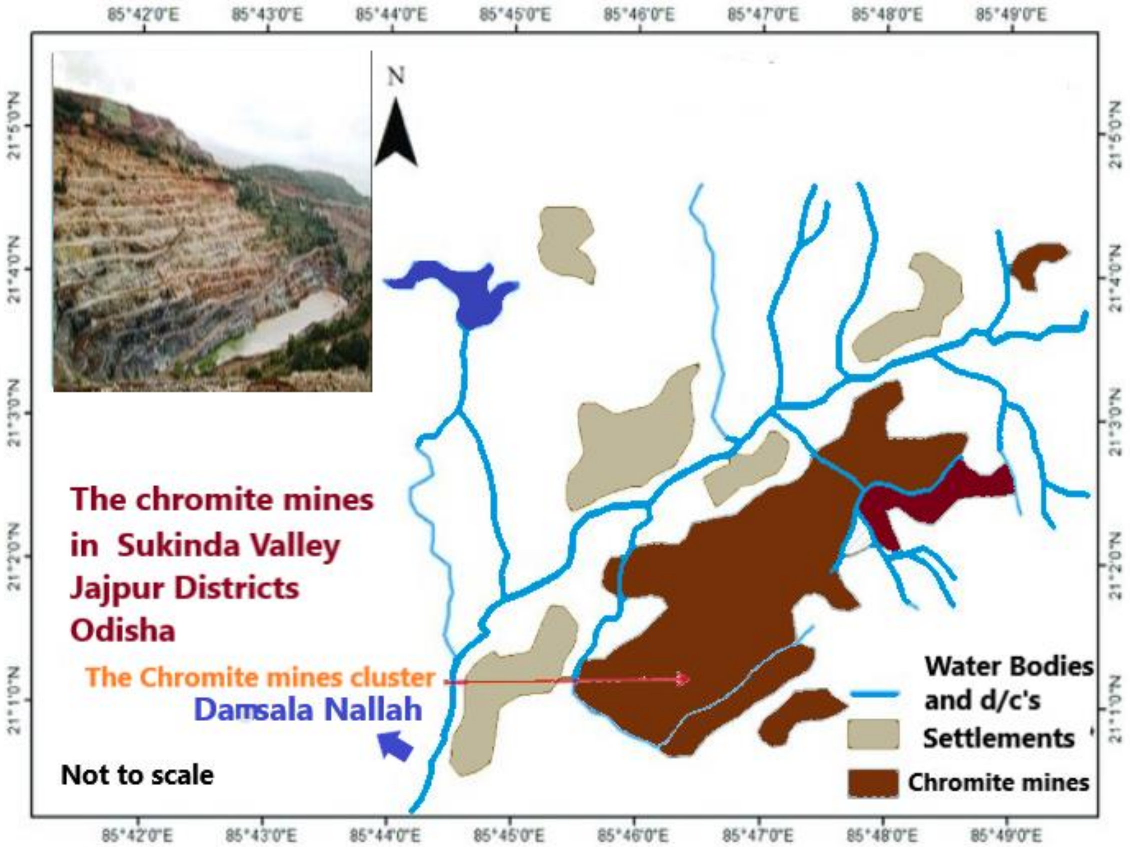


Fig. 3. The Sukinda Chromite Ultramafic Valley, the location map at Jajpur

Fig. 4. The satellite map of Sukinda Valley
(source: HTTPs://ejatlas.org/?translate=es)

The Reserve (RF)/ protected (PF): Forests in the Valley are Daitari PF-3.7 km, Ranjaga RF-5.3 km, Dhalapathara RF-5.8 km, Birasal RF-6.5 km, Tipilei RF-10.9 km, Barabati PF-10.9 km, Bhuban RF-11.4 km, Pubal PF-12.7 km, etc.

The active mines: The active mines in operation are 12-14. Those in operation are Odisha Sukinda Chromite Mine TISCO, Mining Corporation (OMC) (South Kaliapani), Indian Metals & ferroalloys (IMFA), IDCOL, Mishrilal Mining Pvt Ltd, B.C. Mohanty and Sons, Mahagiri Chromite Mines (IMFA), Balasore Alloys Ltd (Kaliapani), and Ferro Alloys Corporation FACOR (Ostapal Mines), (Pre-feasibility report 2015).

Villages affected by the polluted water of Damsala Nallah are Tungeisuni, Kansa, Balipura, Pentha Sahi, Tulang, Kamarada, Gurujanga, Patna, Ostia, Ostapal, Dhabahali, Kulipasi, Kaliapani, Chiringia, Chingudia Pal, Rangamatia, Badabena, Godisahi, Maruabili, Bena Gadia, Saruabilo, Kharakhari, Bhagiasahi, Kochila baana, Kussumo Gotha, Bhima Tangar, Kalarangira, Kothapalla, Bhalutangar, Bandhania, Daratota, Koriapal, Sitalbasa, Mahidharpur, Mochibahal, Bherubania, Kohlinia, Kanheipal, Baragaji, Badakathia, Baranali, Orisa, Bhimatanar, Barua, Kaisiri, Ramkrushnapur, Balijhati, Samal, Dangradiha, Marthapur sasan, Dangabahali, Malpura, Nuagaon, Dayanabila, Ragadipada, Tipilei, Anjei Tipei, Gabagoda, Mugakasipur, Srirampur, Alipur, Jiral, Mathakaragola, Kundigoda, Dankardia, Surupratapur, Kauri. (75 villages or settlements), (Lanmbodar 2019).

Perineal Brooks: Polluted by mining activity: Listed 32 perennial brooks (Jhars) locally named Mankadchua, Kankada, Kundapani, Anjani, Ashok, Tikarpada, Khandadadhua, Kansachanda, Purunapani, Kendu, Dhalangi, Kaliapani, Usha, Patana, Kankada, Jhuna, Bunimayuri, Mahukhunta, Kaina, Sandhatangara, Panasia, Amba, Bhimtangar, Nachiakholo, Champa, Kakudia, Kamarada, Mahagiri, Malharsahi, Chuanali, Puria, and Dehurisahi etc. (listed 32 perennial streams)

1.4 Objective of the Study

Chrome mineral is the main constituent of ferrochrome. In the 21st century, steel is the most wanted metal, whereas Chrome is an exceptional amalgamated mineral. Most mines in SUCB are open cast (13 numbers), generating enormous mining solid wastes by leaching, containing carcinogenic hexavalent Chromium (Cr VI) (permissible limit of 0.05mg/l) occur even in the shallow depth unconfined aquifers (Chakraborty et al. 1984, Barik et al. 2024). The ambient parameters need sustenance for the miners and the local human health, risks/safety, and sustainability. The Socio-economic stigmas, quality of life, water, air, noise, soil, biodiversity, natural resources, economic damage, and the area's aesthetic (Das 2014, Mohsin et al. 2021). So, the research demands.

1. To detect mining-affected aboriginals, residents, and their quality of life.
2. To identify health-related issues for the residents of the Sukinda Valley.
3. Prioritized the Environmental Impact Study and the Health Impact Study.
4. To formulate strategies for improving the quality of life of affected people.

2. REVIEW OF LITERATURE

The Environmental impact assessment (EIA) for the last 25 years and the health impact assessment (HIA) are blended. The amalgamation has evolved as an Environmental Health Impact Assessment (EHIA), which warrants exploring and emerging instruments during the Anthropocene. The outcrop has ended with an amended health card level, albeit that complied with all the critical gaps, shortfalls and challenges of EIA and EHA with sharing involvement (Giuliano et al. 2022, Dardier et al. 2023, Mutambo et al. 2024).

The Human health hazards due to environmental pollution have affected over 50,000, primarily agriculturalists profoundly dependent on the Brahmani River and Damsala tributary. They suffer health issues mainly from the negative impacts of dissolved Hexavalent Chromium (Cr-VI) and polluted air, soil and water, which cause respiratory diseases, skin irritation, and carcinoma. The mining activities surge suspended particulate matter (SPM) (Tripathy 2023).

Appropriate bioremediation activities like *Acidophilium* and *Acidithiobacillus caldus* (Bioleaching), *Pseudomonas, Micrococcus and Bacillu*s (Bioreduction), *Aereo bacterium* and *Saccharomyces* (Biosorption), cellular adsorptions can ameliorate the negative impacts of hex -Chromium in the dust, soil and water in the Valley (Sarathchandra et al. 2023). Cr(VI) is toxic, fibrogenic, explosive, and carcinogenic, and causes diseases like Asthma, lung cancer, cardiovascular diseases, and premature deaths in humans if not within safe limits of 55 - 90 µg/m3 (WHO guidelines) (Momoh et al. 2013, Nayak et al. 2020, Tumolo et al. 2020, Wang et al. 2022, Xu et al. 2023, Sazakli 2024).

The blast loads from mining operations cause significant damage to structures (causing cracks in buildings and glassware). Open-cast mining generates noise and dust due to the operation of heavy machinery like dumpers, loaders, and drills, which affects environmental sustainability (Pantelic et al. 2023, Zajac et al. 2024). There is a need for an EIA, HIA, and EHIA of the pre-independence Chromite Valley in Sukinda, (Mishra et al. 2022). The various literature searches reveal a concise result about the EIA of Sukinda Valley. The environmental issue of Sukinda Valley, EIA–Salem, has been less discussed. The research gap found that a combined Environmental Health Impact Assessment (EHIA) does not correlate.

3. METHODOLOGY

Chromite ($FeOCr_2O_3$ or $FeCr_2O_4$) is the only source of Chromium. Globally, ≈ 94.5% of chromite produced has application in metallurgy, 3.5% in the refractories and foundries, and the rest in the chemical industry (Panda et al. 2020). The extraction of Chrome from chromite ore is a herculean task. The process requires vast amounts of water and is highly deterrent to humans.

The EHIA method efficiently identifies and appraises the budding life cycle and environmental health possessions of its habitats in the mine's biome. The life cycle decision-making process in mining extant needs judicious plans, programs under legislative regulations for human health, and conducive geo-bio-hydro environments. The EIA studies should solve the challenges that can ameliorate the physio-chemical, biotic, socio-economic, societal, land use, and land cover related to the environment (Ayer 2024).

The line departments include the health centres within Sukinda and the headquarters in Jajpur Directorate of Mines, Mining companies, Sukinda, Block office, and governing SPCBs offices at Jajpur, Bhubaneswar provided the data. The Field surveyed nine Sukinda Valley villages from February 1 2024, to February 10 2024. Various GIS maps are prepared and given in Fig. 5.

Connectivity: The Sukinda Valley is connected to Jajpur by NH-215 (100km from Bhubaneswar) and the connective districts Bhadrak, Keonjhar and Mayurbhanj by State Highway by SH 53. Sukinda Road, Jajpur - Keonjhar Road, and Jakhapura are the nearest railway stations. The nearest airport is the Biju Patnaik International Airport, Bhubaneswar is at a distance of 134km.

3.1 Issues in the SUCB

Air, soil, noise pollution and water poisoning in the Sukinda region result in many health hazards.

Child deaths @ 86.42% of the industrial domain is due to chromite-related diseases.

The waste/tailings from the mines heaped on the roadside. At the onset of the monsoons, the trash and the chromite particles flow with runoff into the Damsala Nalla. Finally, hexavalent Chromium makes Damsala River's water turn toxic. People around 76 villages are affected. The soil turns infertile, and crops produce less yield (Sahoo 2017).

The Odisha Voluntary Health Association (OVHA) has reported that 84.75% of deaths in the mining areas and 86.42% of deaths in the adjoining villages are due to chromite-related diseases.

SUCB is the world's largest open-cast mining hub and also the world's 4th most polluted place.

Demographic and Geological Status: Nine villages were considered for the sample, living in 2608 houses with a population of 13377 in 13.56Ha (Census, 2011).

GIS Studies: People in the Sukinda Valley are tribal and ignorant about tackling chromite and other pollution. The stakeholders must receive adequate education and awareness about pollution control methods. The Sukinda Valley's people warrant a unique opportunity to address pressing health hazards and environmental issues associated with mining activities.

The (a) Stream Order Map (b) Hill shade map (c) Aspect Map of Jajpur (d) Hydrology map of the Sukinda Valley using GIS has been prepared along with the Damsala river system in the Sukinda Valley Fig. 2 and Fig. 3. All the chromite mines are clustered around the Damsala River in a valley within the Daitari Hills range Fig. 6.

3.2 Sample Design

The present research focuses on plummeting the negative impact of mining activities on its habitat's health, ecosystem, and the environment. A sample size of 150 (1.12% of the total population) was considered, where the total population - was 13377 people, and the total households were 2608. The air, noise, soil, and water quality were collected with health data (through surveys and health records) Table 2.

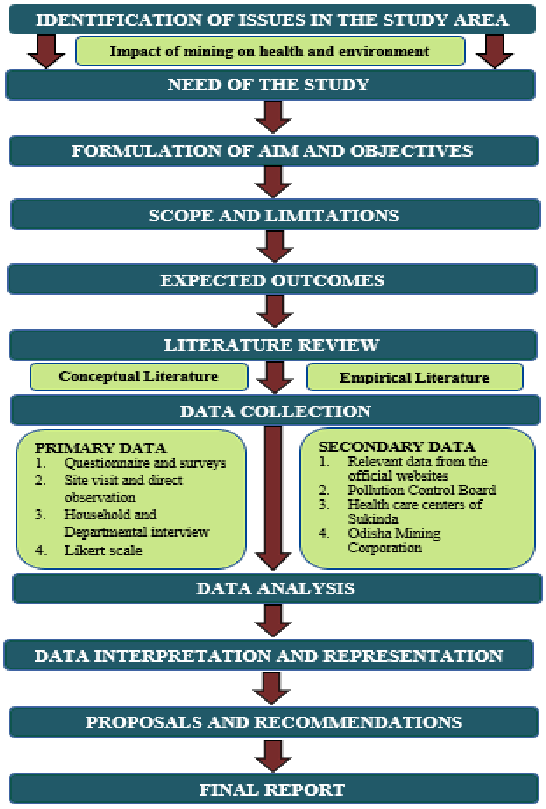


Fig. 5. The flow diagram of the research activities for the study in the Valley of Despair

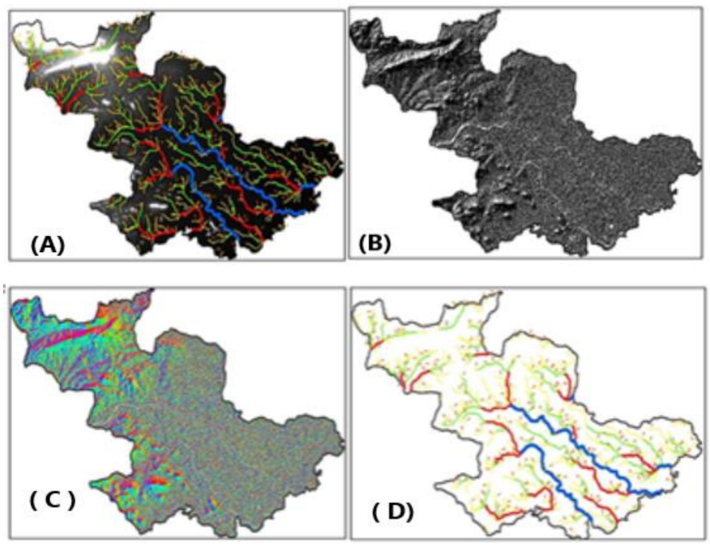


Fig. 6. The GIS studies of SUCB: (a) Stream Order Map (b) Hill shade map (c) Aspect Map of Jajpur (d) Hydrology map of the Sukinda valley

Table 2. The demographic and geographic profile details of sukinda valley

Demographic Profile	Data	Geographic Profile	Data
No. of villages (No)	9	Area of villages (km^2.)	13.56Ha
No. of households	2608	Mining area (sq.km.)	34.197
Population (2011 census)	13,377	Longitude	85°45'14.70"E – 85°54'35.21"E
Projected population (in 2023)	17,862	Latitude	21° 3'29.81"N – 20°57'38.54"N
Male	7200	Annual avg. rainfall	1468mm
Female	6177	Climate	Savanna AW Hot and Humid
Children rate (0-6 years)	1029	Average temperature	45 degrees in summer & 7 - 8 degrees in winter
Literacy rate	7758	Humidity	60% - 70%
Scheduled Caste (SC)	5986	Elevation	650.69m - 710.42m
Scheduled Tribe (ST)	4046	Wind speed	Max 55 - 75 km/hr
Working population	9350	Nearest River	Damsala river (<5km), Brahmani River (15Km)
Non-working population	4027		
Mine Workers	5980		

Source – Census India 2011; Wikipedia, Site survey, Dist. report Jajpur.

Data collection is completed before the analysis of the sample design. The sample size of 150 was analysed, with a confidence level of 92%, a margin of error of 7%, and all the collected household data.

3.3 Sample Villages

The statistics of the sample villages demographic status of people of the area are (Table 3):

Site Survey reveals that the first six villages are closer to the mining areas, within 5 km beyond the mining activity area, and are worst affected in various aspects Fig. 7.

3.4 Mining Area Status

SUCB region has been a hub of mining activity for decades, which has substantial implications for the local environment, including its forest cover losses. Chromite mining is economically vital for metallurgy. The economy of the state and nation is at the cost of ecology. The secondary data covered the Sukinda Valley of Jajpur district in 2010 and 2021 Tale 4.

3.5 Current Status of Mining and Forest Covers in The Lease Area

Literature sources reveal that, from the total Mining Lease area of 34.1979 km^2, current mining areas cover 20.2702 km^2. Forests and other landforms cover about 13.9277 km^2. Chromite deposits are in forest areas. Mining causes loss of forest cover and decreases plants and habitats. Companies like IMFA, Talangi, and IDCOL have paused their work since 2016 (Table 4). Underground (UG) mines require less surface disruption and have less forest destruction (Kathapal mine). TISCO mine frequently does mining activities and sometimes violates regulations and stipulations (CPCB and SPCB) after the emergence of new mines. The deforested area needs compensation of ten times the afforestation stipulated by the State Forest Department Odisha Minor Mineral Concession Rules**.** As per the Forest (Conservation) Act 1980, the mining lease should have the forest cover double the size of the mining activate area in the South Kaliapani; OMC. There is underreporting of afforestation area, i.e. 60% reported, but the actual is 40%.

3.6 EIA Studies

3.6.1 Socio economic status

Socio-economic data is crucial for planning and decision-making in regions affected by mining activities. The socio-economic regime includes assessing communities' demographic and economic conditions, vulnerability, habitat health risks, and environmental resilience. Practical training and educational campaigns raise the socioeconomic landscape and help to plan and adopt environmental conservation while maintaining societal values and the economy. The results of the study are in Fig. 8:

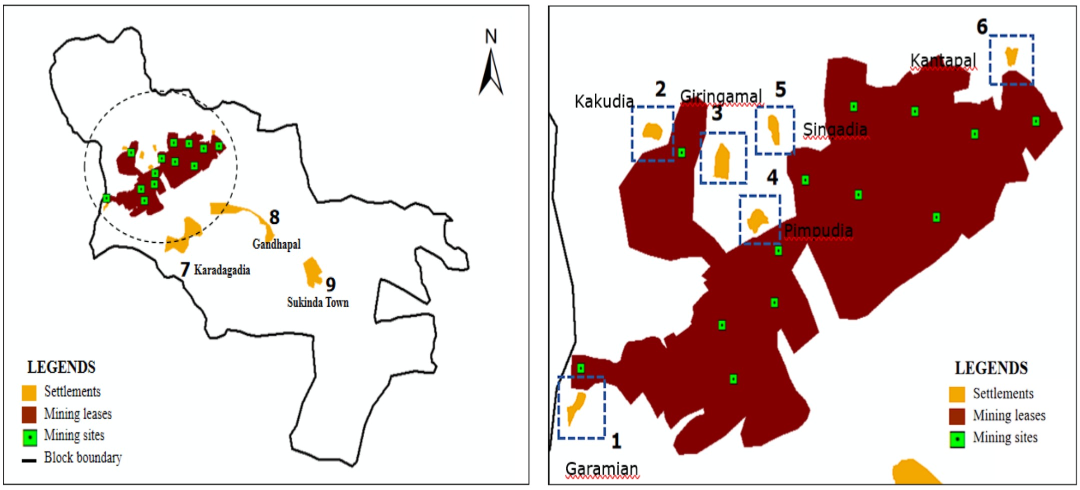
(i) Category of workers: The household survey inferred that 80% of people in the Sukinda Valley are mining dependent (85% for males and 15% for females) working in mines. (ii)**Workers' Income:** The monthly wages of the mining workers are>Rs 25000/-, which is less. The substantial number of workers who receive monthly wages between 10000 and 15000 is large and the lower-income group. However, Miners have higher incomes than agriculture workers and others.(iii) **Literacy rate:** The literacy rate of the people of the Chromite Valley is 58%, whereas Odisha's is 72.9% (2011 Census). (iv) **Working Time:** Most mining workers work in Shift A, from 7.00 am - 3.00 pm. (v) **Worker's Physical/Mental Health:** The workers are primarily illiterate and involved in menial mining activities like blasting, drilling, etc. They are ill-paid and under physical strain, fatigue, and risk of accidents. It can also affect their mental health and work-life balance Fig. 9.

3.6.2 Polluting agents

The aim was to identify and document the extent and intensity of pollution that has health impacts on the targeted mining people. They intervene in addressing environmental degradation and health outcomes. The political communities, the local governing body, and the policymakers advocate for discussions with mining companies to adopt more sustainable mining practices. Educational and awareness campaigns have highlighted specific environmental issues in Sukinda Valley to increase community involvement in environmental health issues and lead to grassroots initiatives to mitigate pollution (Arzoo and Satapathy 2016).

Table 3. Nearby affected villages around the Sukinda Valley (Census of India)

##	Village	Population (2011 Census)	No. Of Households
1	Garamian	1,873	333
2	Kakudia	643	135
3	Giringamal	2,404	440
4	Pimpudia	2,461	508
5	Singadia	746	165
6	Kantapal	308	61
7	Karadagadia	1,167	214
8	Gandhapal	1,207	224
9	Sukinda	2,568	528
	Total	13,377	2608



(A) **(B)**

Fig. 7. Sample sites and villages around Sukinda Valley due to mining by Arc GIS

Table 4. Area covered by Chromite mines in Sukinda Valley; Source – Dept. of Mines, Jajpur

#	Mine's Name	Area leased	2010		2021		Status
			Mining Area	Forest	Mining area	Forest	
		Km^2	Km^2	Km^2	Km^2	Km^2	
1	Kathapal; FACOR	1.133	0	1.133	0	1.133	Active
2	Kaliapani;JINDL	0.89	0.6475	0.2424	0.6965	0.193	Active
3	Sukinda (TISCO)	4.06	3.6230	0.4369	2.9256	1.1343	Active
4	Sukinda (IMFA)	1.1676	1.1676	0	0.2311	0.9365	Dead
5	Kaliapani (Balasore Alloys)	0.6446	0.6446	0	0.5332	0.1113	Active
6	Chingudipal;IMFA	0.2662	0	0.2662	0.0867	0.1795	Active
7	Kaliapani (OMC)	9.7124	2.2125	7.4999	5.3526	4.359	Active
8	Kaliapani (S);OMC	5.5245	1.3595	4.1649	2.3590	3.1654	Active
9	Sukrangi (OMC)	3.8270	2.0494	1.7776	1.8133	2.0137	Active
10	Ostapal (FACOR)	0.8284	0.1441	0.6842	0.1078	0.7206	Active
11	Talangi (IDCOL)	0.6568	0.4480	0.2088	0.0197	0.6372	dead
12	Saruabil;MLMines	2.4685	0.2222	2.2463	1.4036	1.5720	Active
13	Kamarda (B.C.Mohanty & Sons)	1.0956	0.0906	1.0049	0.5219	0.5736	Active
	Total	34.197	13.747	20.45	14.928 (44%)	19.269 (56%)	

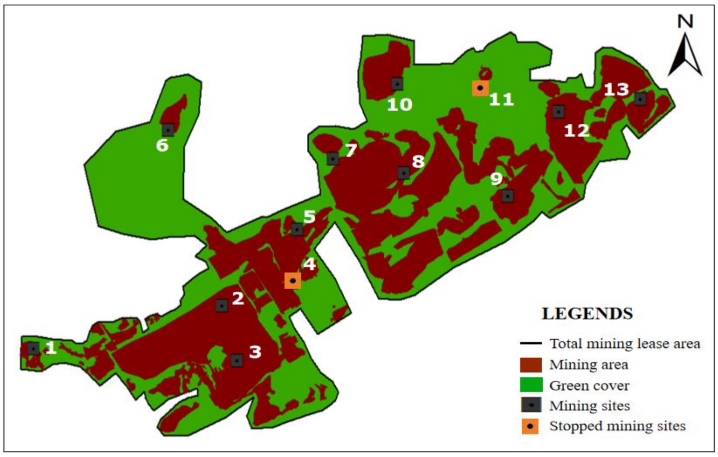


Fig. 8. Land cover and forest cover in mining sites
Source: Google Earth, Arc GIS

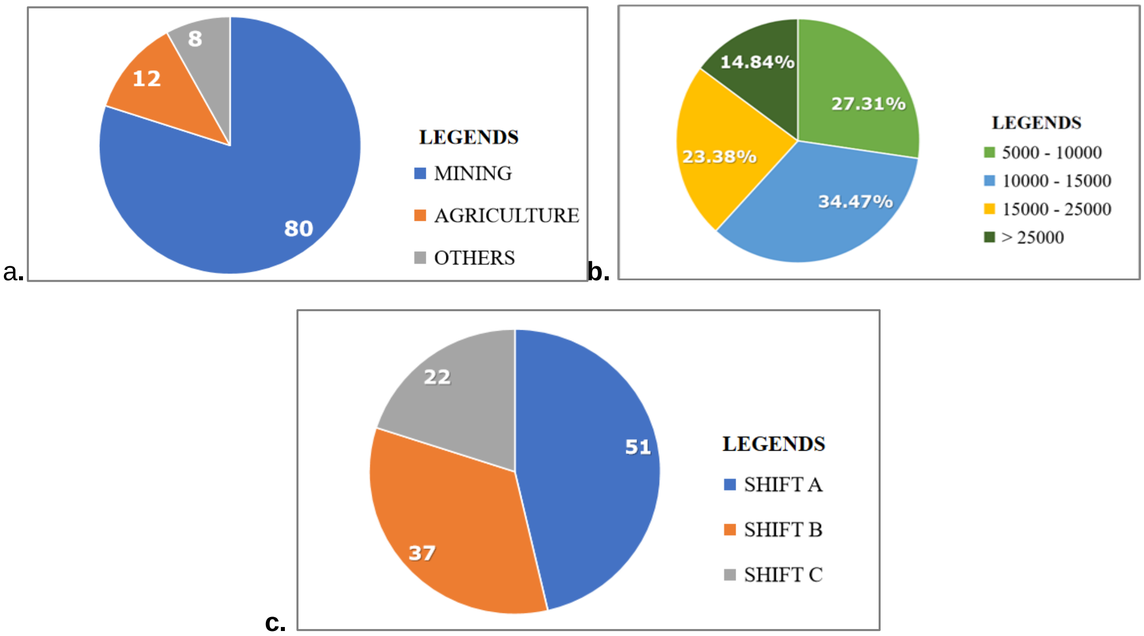


Fig. 9(a-c). (a) % of Occupation of local communities (b) The average income of mining workers (results of Household Survey) (c) Working Hours of Mine Workers

3.6.3 Water as a pollutant

Most villagers collect potable water from tube wells or water from the Damsala nallah system, which gets contaminated for daily use. The contamination is highest during the rains Table 5, Fig. 10 (a)and Fig. 10 (b).

The drinking water pH standard in India, as per IS 12500, is 6.6 - 8.5. During 2010-11, the value ranged from 7.4 to 7.8, whereas during 2021-22, the upper limit increased from 7.8 to 8.4, converted to more alkaline. The taste turned bitter, while this higher pH poses no severe health risks. It can cause the skin to dry, itchy, and irritated Fig. 10 (a) and Fig. 10 (b).

Water Quality Index (WQI): The water Quality Index (WQI) is dependent on parameters like temperature (^{0}C), conductivity, DO (dissolved oxygen), Total Suspended Sediment (TSS), and BOD (Biological Oxygen Demand) (Mishra et al. 2021). The WQI is a number ranging from 1 to 100. The higher number indicates better water quality and vice versa, i.e., .65 - 79 is Fair, and 80 – 90, the water quality is good Fig. 11 (a to d).

Table 5. Dependence on water sources of the communities

SL NO	Sources	Present Status	Dependence of People (%)
1	Bore well	5	39.4
2	Tube well	11	59
3	Dug well	3	31
4	Supply water	9	38.7
5	Pond	4	34.5
6	River	1	11.6

Source - Household survey

pH value of water:

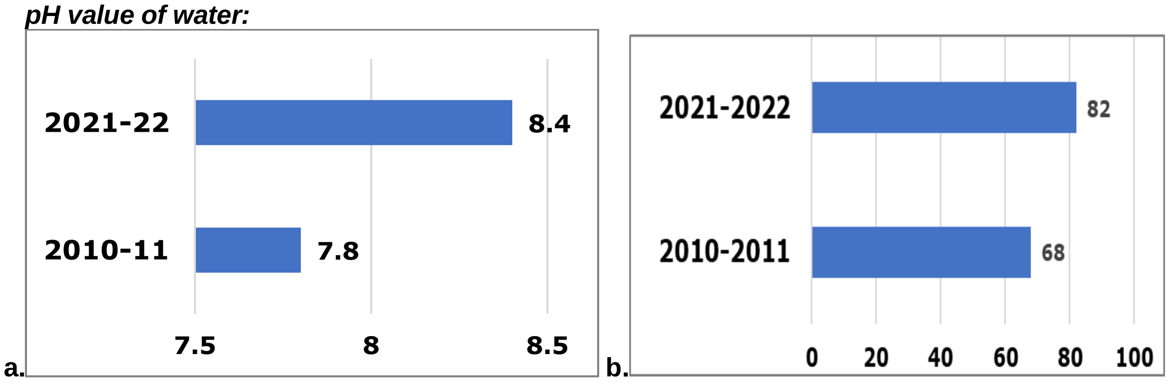


Fig. 10 (a-b). PH and WQI in SUCB, Source - Report of WQ/WQI Assessment, Jajpur

Fig. 11 (a-d). The water pollution in Damsala Nallah (streams) in SUCB

The WQI of Damsala Nallah is 82 (Fair). The surface water has turned more alkaline and has a foul smell and bitter taste. In the extraction process of Chromium from chromite, the carcinogenic chromium ion and acidic runoff slip into water, soil, and air. Cr+3 or +6 and sulphide ions contaminate water, air, and soil, creating health issues. Discharge of mining waste, chemical leaching from the mining operations, and the release of heavy metals into the water harm the local ecosystem and the user's Health (Mishra et al. 2023).

Nowadays, the mining sites release treated water into the Damsala River. The Chromium tailings, the detritus of plant materials, and the sewerage of residents were later used for drinking in the hating (Slums), causing toxic reactions in their bodies Fig. 11 (a-d). The agriculture of the area is in jeopardy as it is becoming acidic. The soil pH of 2023-24 was compared with the same values in 2010-2011 (Fig. 12). The standard pH value of soil is 5.5 - 7.5, and for agricultural purposes is 5 - 6. According to the Department of Agriculture's norms, the region falls under DRY LAND. It has become drier, and agrarian yield has decreased in the last decade.

3.7 Physicochemical Properties of Soil

The rainfed agriculture areas adjacent to the mining patches are polluted with chromium particles. No canal passes through the area. The nearby streams, rivers, and groundwater have been polluted. Poor contaminated soil and water affect yield and the aboriginals, Fig. 12 (a-b) and (Table 6).

The soil analysis shows that the soil in the areas having a 5 - 10 km distance from the mining sites is better than the core zone for agricultural activities. There is a little primitive and underdeveloped agrarian land within the core zone. The soil quality analysis reveals that the pH of the soil in nearby villages around Sukinda Valley varies due to:

Chromite Oxidation: The open-cast Chromite mining operations in SUCB are exposed to air, water, and soil. The oxidation of chromite minerals can release chromium ions and other compounds into the soil, altering pH.

Sedimentation: The Nallahs are continuously sedimented, and mining slopes are under erosion in the hills.

Disruption of Soil Structure: Heavy machinery like excavators, dump trucks, bulldozers, drilling rigs, crushers, screens, etc., are used in mining operations and can compact/loose the soil and disrupt its structure strata. The impact of altering soil quality can lead to soil erosion, Health impact, contamination of food and water, etc. Fig. 13.

Air Quality Status: The graph of the Air Quality Index in 2010-11 and 2021-22 of the area are Fig. 14(a-b)

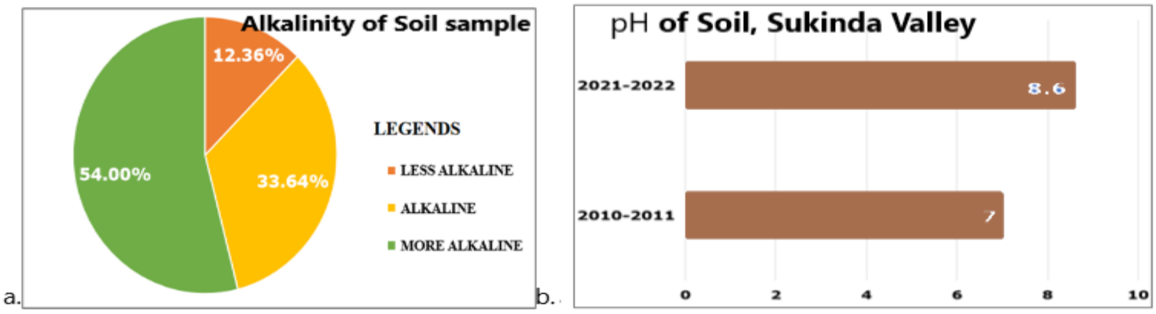


Fig. 12 (a-b). The water potable's alkalinity and soil pH value in the Chromite Valley Sukinda. Source - Report on environmental issues of chromite mining in Sukinda Valley (2021)

Table 6. Characteristics of the soil of the SUCB

#	Parameters			
1	**Colour**	**Red, brown, yellow**	**Reddish brown**	**Blackish brown**
2	PH	5.5 - 7.5	8.2	8.6
3	Moisture content (%)	0.2 - 0.6	6.7	22.1
4	Water holding capacity (%)	---	35.6	35.0
5	Organic carbon (%)	0.5 - 3	2.33	2.78

(Source - Soil Investigation Bureau, Jajpur)

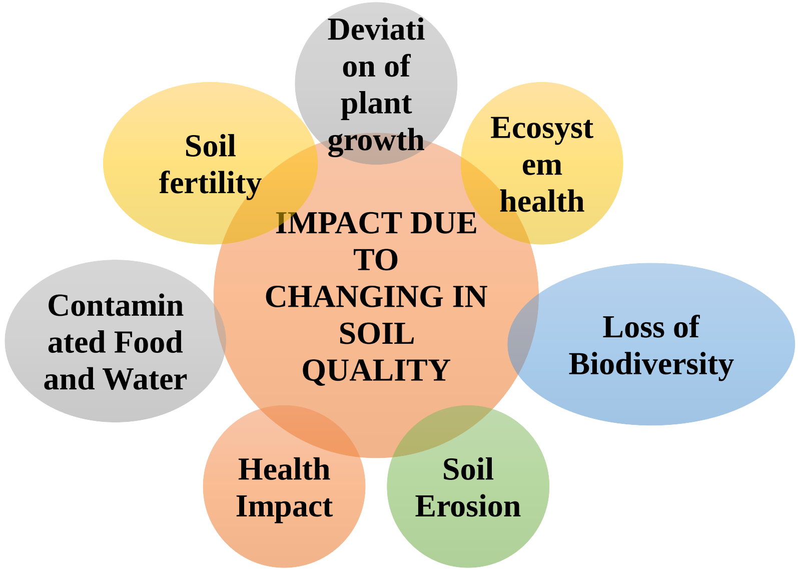


Fig. 13. Impact due to changes in soil quality (Inference from field survey)

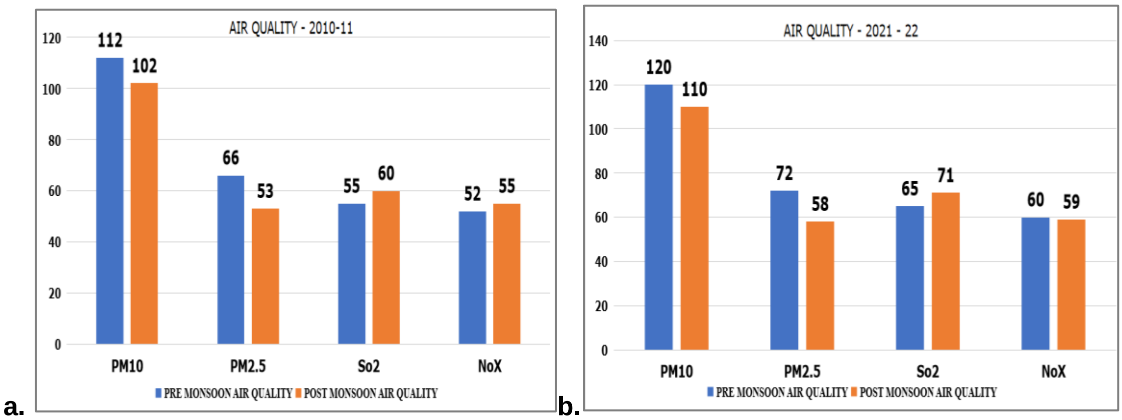


Fig. 14 (a). Air quality status in 2010 – 11(b) (b) Air quality status in 2021 – 22
Source - Report on environmental issues of chromite mining in Sukinda Valley (2021)

The air quality (AQ) of the region is deteriorating because of crossing the standard air quality index limit in certain areas, particularly in the vicinity of active mining areas. The various contributing factors are (Fig. 14 (a and (b):

Dust Emissions from mining procedures like excavation, drilling, blasting, and transportation of chromite ore and waste/tailings dumping generate dust (PM10 and PM2.5) and contribute to air pollution in dry and windy conditions (Mishra et al. 2023).

Vehicle Emissions from heavy machinery, trucks, tippers, dumpers, and other vehicles emit greenhouse gases (GHG) pollutants such as oxides of carbon (CO_2), nitrogen oxides (NOx), sulphur dioxide (SO2), carbon monoxide (CO), and particulate matter (PM), which degrade air quality, active mining areas with high vehicular traffic or inadequate emission controls.

Basting Operations: Blasting activities release dust, gases, and particulates into the air, contributing to localised air pollution.

Open Pit Mining: Responsible for increasing dust and releasing natural pollutants, such as radon gas, from the ground.

Deforestation and vegetation practices in the SUCB are of deficient standards due to soil infertility, disrupting natural air purification processes and increasing the vulnerability to air pollution.

Meteorological factors such as heat islands, wind speed, temperature inversions, and atmospheric instability also influence the dispersion and concentration of pollutants in the air in the study area. Average air quality variation in SUCB is seen as % in pre-monsoon, 11.05%, and post-monsoon, 9.68 %. Due to the increased SPM values in the air, people in SUCB are facing Health impacts, like COPD, reduced lung function, mortality risks associated with Social and economic impacts - Increasing medical costs, and high healthcare expenditures.

Noise Quality Status: The noise level analysis study reveals that noise pollution increased in SUCB in 2010 -11 and reduced in 2021-22. The standard noise level in the daytime is 70db, and at night, it is 65-70db. The noise level during the day is higher than at night due to the operational activities that generate noise during daylight hours. At night, these activities are typically reduced or paused. Contributing factors to noise pollution in SUCB are the operation of heavy machinery, blasting operation, vehicle traffic, construction, maintenance, etc. The noise level during the day is higher than at night, and the mining area is higher than residential areas. These activities are typically reduced or paused at night, leading to lower noise levels. Three noise monitors are regularly used to report noise levels at Ostapal (by FACOR), Kaliapani (by JINDAL), and Sukinda (TISCO). It is observed that the issues surge due to less Inadequate implementation of control measures like physical barriers and sound walls, establishing buffer zones, implementing noise schedules, etc. Fig. 15.

3.8 Health Impact Analysis

Mining significantly impacts local communities' health, primarily due to environmental contamination. The SUCB ranks fourth most polluted mining area in India (Blacksmith) primarily due to the hexavalent chromium leaching, directly debouching into drains and unconfined aquifers from the chromite mines. This toxic water contamination affects drinking water supplies, causing gastrointestinal disorders, kidney damage, and increased risks of cancers. The list of Health Care Centers in SUCB is in (Table 7) and Table 8. The air pollution (dust and SPM) released into the air can lead to respiratory disorders, including Asthma and other lung diseases.

The contaminated soil and vegetation have poor yields, mainly affecting food security. People are at risk of exposure to toxic metals throughout the food chain. Acute and chronic diseases heighten with increased pollutants, as shown in Fig. 15.

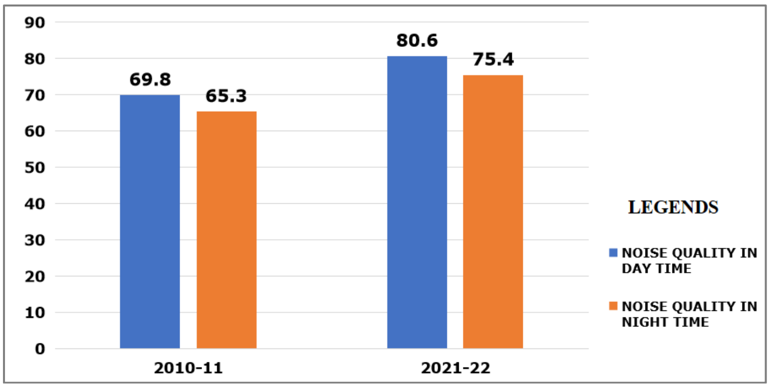


Fig. 15. Noise level status in 2010-11 and 2021 – 22
(Source - Report on environmental issues of chromite mining in Sukinda Valley, 2022)

Table 7. Status of health care centres in the SUCB and their quality of facilities

Health Care Centers	Present Status	Quality of Facilities
CHC Sukinda	3	Fair
PHC	2	Fair
Mobile medical units	1	Fair
Medical sub-centers	7	Good
Private Clinics	2	Good

Source - Household survey & site visit)

Table 8. Villages with health-related issues in the mines area and disease manifestations

#	Major Polluting Mines	Polluting Air in Villages Due to Nearby Mines	Diseases Caused
1	Kaliapani (JINDAL)	Pimpudia	Skin allergy, TB, Asthma
2	Sukinda (TISCO)	Karadagadia, Sukinda	Lung cancer, TB, Malaria, C holera, Hearing loss
3	Kaliapani (B-sore Alloys)	Pimpudia	Skin allergy, Asthma, TB
4	Chingudipal (IMFA)	Kakudia, Giringamal	Malaria, Skin allergy
5	Kaliapani (OMC)	Pimpudia, Singadia	Skin allergy, Cholera, TB
6	Saruabil Mine	Kantapal, Gandhapal, Sukinda	Cholera, Malaria, Typhoid
7	Kamarda Mines	Kantapal,Gandhapal	Cholera, Malaria, Typhoid

Source - OMC Report, Jajpur

The analysis shows that SUCB people predominantly suffer from respiratory diseases like Asthma, Tuberculosis, Malaria, skin diseases, Chronic Obstructive Pulmonary Disease (COPD), Upper Respiratory Tract Infection (URTI), etc. The death rate in the study area is around 86.63% due to mining-associated health Fig. 16.

3.9 Mining-Associated Health

The data collected from the local Public Health Centers (PHCs), Community health Centers (CHC) at Sukinda, local health units, and health workers ascertained that Tuberculosis, asthma, Malaria, and other dominating mining-related diseases are gathered and analyzed (Fig. 17).

A maximum of people (77.8) suffer from Tuberculosis and asthma-like respiratory diseases (69.8%) Figs. 17 and 18.

Data regarding diseases of various age groups was also collected. The analysis indicates that children are mainly suffering from skin diseases and Malaria, and the above 15-60 age group suffers predominantly from respiratory diseases like asthma and tuberculosis Fig. 17. Age group ≥60 years, people suffer primarily from lung cancer and COPD diseases Fig. 18 (Tripathy and Mishra 2023).

4. RESULTS AND DISCUSSION

The blue-white chromium metal is hard and brittle, which is highly corrosion-resistant. It is used to make stainless steel, glass, catalysts, and high-speed metal-cutting tools for hardening steel and refractories in the modern world. The Chromium's impact on health is due to air, water, soil, and noise pollution felt within the chromite mines. The dumping of mining waste has increased the wasteland, encroaching forests, green agricultural land, and vegetation in the Sukinda Valley. The study needs an integrated approach to the resource governance community response to health stewardship and policy analysis through judicious planning to ensure sustainable extraction while curtailing environmental squalor (Harichandan 2022).

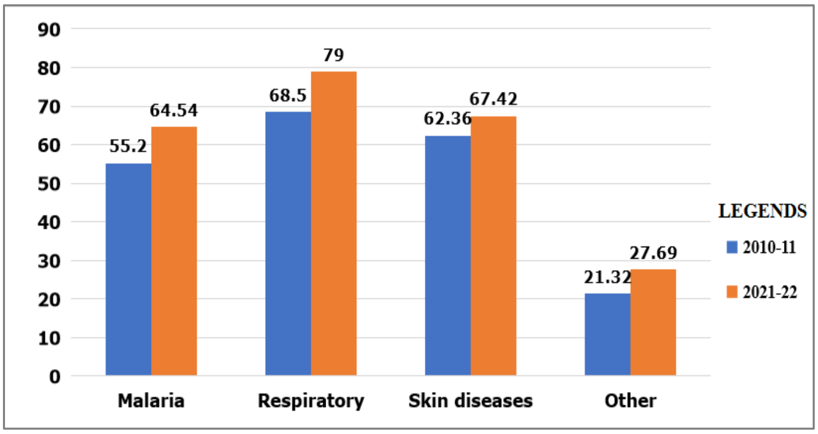


Fig. 16. Percentage of diseases caused in 2010-11 and 2021-22 in the study area
Source - (Community Health Centre, Sukinda)

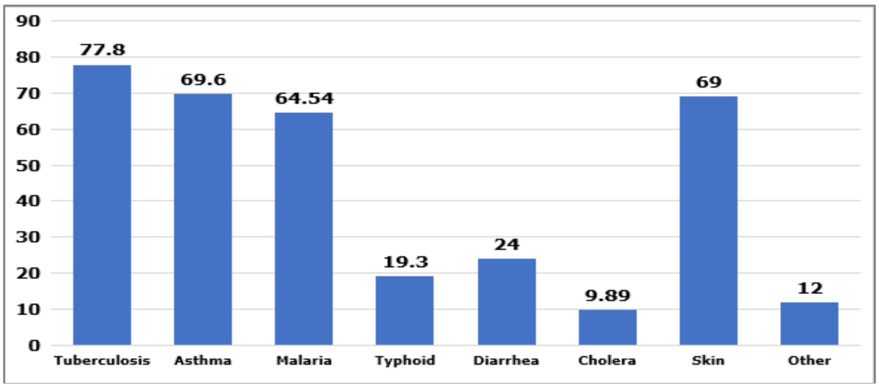


Fig. 17. People affected by mining-related diseases
Source - CHC, Sukinda etc.

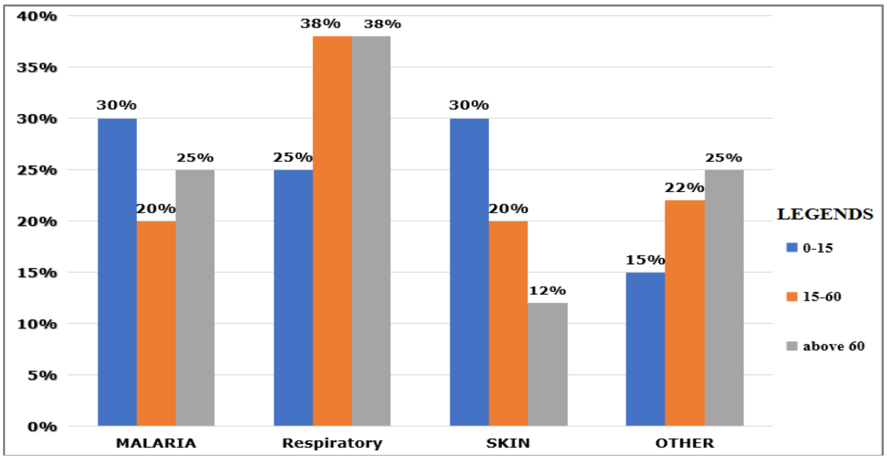


Fig. 18. Diseases for different age group people
Source - CHC, Sukinda)

It also prioritises the negative issues of the affected land patrons, environmental degradation, unsafe mining, and failed healthcare amenities. The strategic plan and judicious implementation shall promote sustainable development by analysing existing policies. The proposed mitigation strategies are to minimise negative impacts. Supportive community engagement requirements with improved local community quality of life are optimised through resource utilisation, environmental impact mitigation, and promoting responsible mining practices (Mishra et al. 2022). Presently, research about the direct impacts of mining on the environment and fiscal and societal impacts are present in the Sukinda Valley and all mining areas globally. The various studies are:

4.1 Environmental Health Impact Analysis (EHIA)

Socio-Economic Impacts: Mines are in remote, inaccessible areas and forests without urbanisation and modern amenities availed by the local communities, tribes, and aboriginals. They live on natural resources for their livelihood. The start and closure of mines negatively impact society. The continuous mining operations cause migrations, job-hopping, and relocation, leaving aside their traditional livelihood.

4.2 Environmental Impact

Vegetation: Mining negates the natural environment and communities. Derisory landscape and improper wastes, tailings, and overburden mismanagement directly impact the vegetation, habitats, ethnobotany, and forests, distressing the community's livelihoods. Removing vegetation and resetting the outsees significantly impact land use; if not correctly managed, they are detrimental.

Soil Erosion: Mining activities cause loss of topsoil (overburden), creation of waste dumps, deforestation, etc., badly affecting the agricultural yield and traditional livelihoods and enhancing soil erosion (Mishra and Mishra 2018).

Natural Resources: The destruction of stakeholders' livelihoods, technical education, natural resources, and land use compels the landholders to opt for mining menial Jobs of low wages. The adverse impacts on the bumpkins are protuberant living within mines, close to the dumping yard, and are a significant source of health problems.

Air and Noise Pollution: The blasting, drilling, and transportation processes in mining areas lead to a high air quality index affecting the locals and wild habitats. The high noise and vibrations damage people's property and the health of the people. The related human sufferings are Asthma, hearing impairment, Nasal track irritation, COPD, ulceration, and lung cancer (Katariya et al. 2024).

Water Pollution: A sizable quantity of water required for mining activities affects water availability, and waste discharge in the rivers and drains pollutes it and creates major health issues. Chromium pollution is common in SUCB.

Conflicts in mining areas include land use, water-related environmental damage, people from diversified cast, colours, and creeds, and discriminations within the migrated or deployed workers and the host communities that initiate conflicts. Strikes are caused by unfulfilled promises, compensation, and miscoordination between mines and communities, creating conflicts in SUCB.

Judiciary Stepping: The Various acts and laws in force in India for EHIA are (1) The Mines and Mineral Development and Regulation Act 1957 (MMDRA); The Forest Conservation Act 1980; The Water Prevention and Control of Pollution Act 1974; The Air, 1984; Environmental (Protection) Act, 1986 (6) *Odisha Minor Mineral Concession Rules 1990 (amended up to 1994; The EIA Notification of 1994 and 2006 (necessary amendments). Like the EIA notification prescribed for environmental protection, there is an urgent need for the Health Impact Assessment Act/law* to emphasizes the health dimensions (Dua and Acharya 2014).

It should be mandatory to follow EHIA guidelines prescribed by WHO, such as screening, scoping, appraisal, reporting, decision-making and recommendations, monitoring, risk assessment, cost-benefit analysis, and follow-up with strategic environmental assessment (SEA) (Mishra and Mishra 2018). https://www.who.int/tools/health-impact-assessments

4.3 Hazard and Risk Emergency Plans

Land Slide: Landslides are a common disaster in dump yards and hillslopes. The natural angle in dumps and hill slopes in open-cast mines must be maintained to prevent slope failure. Regular slope measurement and protection steps are needed with priority. To prevent waterlogging, peripheral catch water drains must be excavated and maintained to divert rainwater. Under risk, the area is declared unsafe; evacuation to a safe zone needs prioritisation.

B**reaching of Slime Dam:** The Chrome Ore Beneficiation (COB) plant and the slime dam need regular inspection and report. Leakages, seepages, and failure must be attended to by ceasing inflow immediately to avoid spilling, and repair is prioritised.

Fire/ Explosion: Lightening arresters, avoiding flammable materials, storing explosives in magazines, and evading naked fire are essential for fire prevention. A safe UG diesel tank. Flame/lightning arresters and fire extinguishers must be provided in crucial areas. The machines/ vehicles are operated by skilled personnel at steep slopes. Earthling systems of COB plant HT & LT installations are regularly tested to avoid hazards (Mishra et al. 2024).

Accidents to Man & Machine: All the safety practices and use of PPE kits are inculcated to save both man and machine from the potential risk and lessen idle period.

4.4 The Health Impact Analysis in SUCB

a) The social well-being is health. The children in SUCB are suffering from malaria and skin diseases. The middle-aged group and above are suffering from respiratory diseases due to a combination of environmental, socio-economic, and healthcare access factors (physical and mental).
b) Mosquito breeding increased because of environmental and climate change. Deforestation, waterlogging, and altered land use patterns create breeding grounds for mosquitoes and other vectors that create dengue, but rarely Filaria.

c) Poor housing and shanty township conditions include overcrowding, water, sanitation, and hygiene (WASH) nonavailability, and scarce access to clean water, aggravating the spread of Malaria, skin, and other diseases Fig. 19 (a-d).
d) Access to Healthcare – The people of the Valley have limited access to healthcare facilities and resources, including diagnosis, treatment, and preventive measures for different diseases.
e) It is seen that Children living in mining areas are exposed to occupational hazards on involvement in mining-related activities such as scavenging for ore or working in informal mining operations; exposure to hazardous substances and unsafe working conditions that spread the risk of injuries and infections among children.

4.5 Environment Health Impact Management

Reducing Air Pollution: Significant pollutants in the SUCB are PM_{10} and $PM_{2.5}$

Adopt a wet drilling method for ore operation and a water sprinkling method to reduce the dust particles on the road during heavy vehicular transport. Use well-covered leakproof sheets (PVC tarpaulins) during ore transportation. Provide chutes (sloping channels) at ore discharge, stockpile, and loading points to minimise the discharge height and spread of airborne dust. Fixing the time for blasting and adjusting to local activities. Avoid blasting when there is solid and gusty wind and lightning. Afforestation and keeping the area green all along mine roads and fallow lands. Air filter facilities like HEPA-High Efficiency Particulate Air must be provided in every heavy vehicle and wheel wash facilities to minimise mud and dust particles from unpaved approach roads to public roads. It is mandatory to use N95 masks that protect against dust particles and respiratory diseases.

4.6 Recommendations to Reduce Air Pollution by The Mines

The water Sprinkling method is proposed to be implemented in 4 major polluting mines -Kalia-pani (Balasore Alloys), Chingudipal (IMFA), Saruabil (ML Mines), Kamarda B.C. Mohanty & Sons. The wet Drilling Method is proposed to be implemented in 3 major dust-generating mines - Kaliapani (JINDAL), Saruabil (ML Mines), and Sukinda (TISCO) Fig. 20 (a-d).

Fig. 19 (a-d). Diseases of workers /children from mining-related Health

Fig. 20 (a-d). Water sprinkling method on the road(b) Wet drilling method (c) Wheel wash technique (d)- HEPA Filter in heavy vehicles

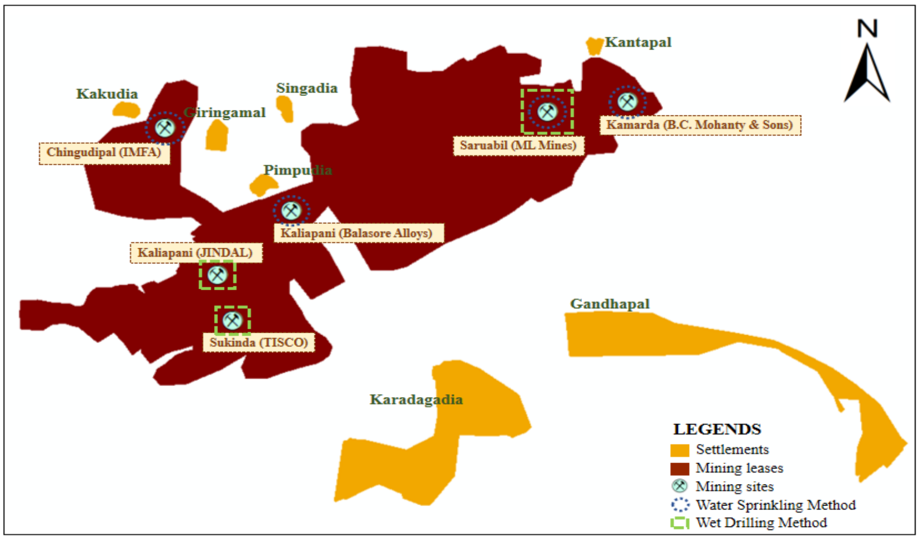


Fig. 21. Map showing the mining sites that will adopt water sprinkling and wet drilling methods and nearer villages that can benefit

4.7 Recommendations Against Noise Pollution

At Day Time: The average noise level in the day is 70db, whereas the observed value in the study area in the day is 80.6. So, it is recommended to use ear protectors to protect from noise pollution and dense vegetation, and blasting should not be done near residential areas.

At Night Time: The standard noise level value during nighttime is 65 - 70db, and the observed value in the daytime is 75.4.

Selection of Equipment: A suitable selection of equipment with an inbuilt effective silencer and sound-insulated enclosure padding should be adopted, particularly at night, along with a proper monitoring system to reduce shock waves. The ear protector can be earmuffs, earplugs, or semi-insert earplugs and Sound-insulated enclosures (SIE) that comply with health and safety regulations and improve worker productivity and morale.

Reducing Soil Pollution: The soil remediation techniques can be adopted by huge afforestation, planting pollution-resistive/absorbent vegetation., soil erosion and washing, soil protective structures, and catchment treatment plans. Soil erosion is maximum in the dump yard of the mines area. It is necessary to cover the dumped dry wastes with tarpaulins or any plastics where the mine wastes are dumped.

Revegetation using the hydro-seeding technique in villages. Stabilization, erosion control of soil, and dust suppression help attenuate noise in the surrounding area. Slope stabilization is achieved by establishing vegetation with deep root systems that anchor the soil and reduce the likelihood of erosion and mass movement. Adding compost into the soil and more lined drains to increase plant growth.

4.8 Proposals for Reducing Water Pollution

Adoption of rooftop rainwater harvesting projects can help to get clean water. Adopt re-use and re-cycle methodologies in all households and mining companies. The water quality should be regularly monitored and reported for analysis. The Sewage treatment plants (STPs), if unavailable for wastewater, need to be installed. Training the people about health issues regarding water pollution will be taught through community participation.

Sukinda town (28numbers), Garamian (5 numbers), Pimpudia (12 numbers), and Keredagadia (3 numbers) have rooftop harvesting structures installed, including schools and other official buildings to reduce water scarcity by conserving water.

Proposals For Mitigating Health Impact: A periodic medical examination is to be adopted for every worker. Community awareness, such as regular meetings, podcasts, or distribution of pamphlets, should be done. Permanent mobile medical facilities with doctors and para-medical staff are to be deployed for emergencies. Ambulance facilities need allocation during emergencies. Establish more healthcare units and various specialities in the hospital. Controlling the speed limit of vehicles to avoid accidents should be mandatory.

Recommendations for Establishing Framework: Develop setting policies and strategies for addressing pollution-specific measures and technical guidance to achieve pollution prevention. Improve planning tools for pollution control, especially for closure planning requirements. Create compelling and adequate financial assurance mechanisms. Strengthen mechanisms for public participation. Create economic and other incentives for developing the community women and teach them pollution prevention technology through community meetings, regular mobile messages, or pamphlets.

Fig. 22. Rooftop rainwater harvesting in the Sukinda Block office

Safe Construction Practice: Safe construction/ mining practices for workers in mining areas are essential to prevent accidents, injuries, and fatalities in a hazardous working environment. The safety practices of hazard identification, risk assessment, and safety training should be mandatory. Based on the requirement for the appropriate use of personal protective equipment (PPE), an emergency response plan, first aid, and risqué management training should be compulsory. There must be a siren and flag signals for clear communication between workers, supervisors, and management to address safety concerns promptly.

EHIA and SDGs: The Sustainable Development Goals (SDGs) can be fulfilled by achieving the norms fixed by the Govt of India's Ministry of Environment and Forests (MOEF &CC), Ministry of Mines, and Ministry of Health and Family Welfare Department, the potential environmental and health impacts are Goal 1(No Poverty, i.e., identifying vulnerability to poverty), Goal 3: Good Health and Well-being (assessing the health impacts like air pollution), Goal 6: Clean Water and Sanitation (identifying role of environmental on potable water quality), Goal 7: Affordable and Clean Energy, Goal 13 (Climate action) and Goal 15: (life on land).

5. CONCLUSION

The positive impacts of mining growth augment national income and employment generation where, in contrast, the negative impacts are environmental pollution, the surge in Health issues, and resource depletion with change in the livelihood of the people of the land and predominantly ab-originals. It is essential to have unplanned industrial growth, modernisation of outdated technology, provision of quality water, adequate afforestation, strict implementation of policies/ stipulations, efficient waste disposal, and adoption of nationwide pollution tax to add to the longevity, sustainable mining life cycle and satisfying the SDGs 1, 3, 6, 7, 13 and 15.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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