Impact of Acid Rain on Chromite Mines and Human Health: Environmental and Public Health Implications

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Abstract

Although chromite mining is a significant source of chromium and a significant economic activity, overburden disposal, mine drainage, ore dust, and contaminated runoff can result in significant environmental pollution. By changing the chemistry of the soil and water and possibly increasing the mobility of metals linked to mine wastes, acid rain may exacerbate these effects. The relationship between acid deposition, chromite-mining environments, chromium mobilisation, and related health risks is examined in this paper. The Sukinda chromite-mining region of Odisha, India, receives special attention because widespread chromite extraction has been linked to soil and water contamination with chromium. Acidic soils, chromium-bearing mine drainage, heavy metal contamination, and health hazards in the area have all been reported in earlier research. However, it is still unclear how directly atmospheric acid rain contributes to chromium mobilisation and human illness. Therefore, the paper makes a distinction between the potentially amplifying role of acid deposition and documented chromium exposure related to mining. Chromium transport and bioavailability may be altered by acid rain's effects on mineral weathering, soil pH, metal dissolution, runoff chemistry, and groundwater recharge. Because hexavalent chromium [Cr(VI)] is toxic, mobile, and carcinogenic, it is especially concerning. Integrated monitoring of precipitation chemistry, mine drainage, soil and groundwater pH, chromium speciation, occupational exposure, and community health is necessary for effective management. Mine-waste stabilisation, drainage treatment, dust control, vegetation-based rehabilitation, and ongoing biomonitoring are all suggested preventive measures.

Keywords: mine drainage, acid rain, chromite mining, chromium, Cr(VI), environmental contamination, human health, Sukinda, Odisha, heavy metals

1. Introduction

Although mining plays a significant role in employment and industrial growth, extraction operations have the potential to significantly impact nearby ecosystems. Because chromium is a necessary raw material for ferrochrome, stainless steel, refractories, pigments, and other industrial products, chromite mining is especially significant. However, when exposed to weathering, water, oxygen, and shifting geochemical conditions, chromite-bearing rocks and mine wastes can become sources of chromium contamination.

In many mining regions, the effects of chromite mining on the environment are well documented. One of the main regions of India that produces chromite is the Sukinda Valley in Odisha. Chromium and other metals have been found in mine, agricultural, roadside, and surrounding soils; there are significant differences between mining areas and comparatively uncontaminated areas. High concentrations of Cr(III), Cr(VI), Ni, Pb, Cd, Mn, Fe, and Zn were found in the soils surrounding the Sukinda chromite-mining region, according to one study, which also calculated significant non-cancer and cancer risks for exposed populations.[1] Another environmental stressor is acid rain. Rain, snow, fog, or dry deposition are the main ways that atmospheric sulphur and nitrogen oxides are converted into sulphuric and nitric acids, which are then deposited. Acidic precipitation can interact with contaminated soils, overburden, tailings, and exposed rock in mining environments. In addition to affecting the dissolution, adsorption, transport, and biological availability of metals, these interactions may alter pH and redox conditions.

But it's crucial to remember that acid rain isn't the only source of chromium pollution in areas where chromite is mined. Runoff, overburden, mine water, and dust containing chromium are known to originate from mining operations. Leaching from overburden and mine wastes can contribute to chromium contamination, especially during rainy seasons, according to research conducted in Sukinda.[2]

In order to differentiate this mechanism from the more general and well-established health effects of chromite mining, the purpose of this paper is to investigate how acid rain may interact with chromite-mining wastes and potentially increase environmental and health risks.

2. Chromite Mining and Chromium Pollution

Spinel minerals that contain chromium make up the majority of chromite. Large amounts of overburden and waste rock may be visible at the surface during open-cast mining. Rainfall can penetrate these materials and carry particulate and dissolved pollutants into groundwater, streams, ponds, and agricultural soils.

Mine waste and mine-water seepage have been found to be significant sources of chromium pollution in the Sukinda chromite-mining region. Evidence of Cr(VI) enrichment downstream of mining areas was discovered in a groundwater simulation study, which linked the contamination to mine discharge and leachate migration from waste-rock materials, especially during rainy conditions. [3]

Strongly acidic soil conditions were discovered in a subsequent study of soil and water close to an Odisha chromite mining site, with measured soil pH values ranging from 4.33 to 5.24 at locations about 3–5 km from the mining area. Significant water turbidity and a decline in the nutrient status of the soil were also noted in the study. These findings demonstrate that mining areas can already possess chemical conditions favorable to environmental degradation. Acid deposition may interact with this existing contamination rather than acting as an independent source of chromium. These results show that mining regions may already have chemical conditions that are conducive to environmental deterioration. Rather than serving as a separate source of chromium, acid deposition may interact with this current contamination.

3. Acid Rain and Its Interaction with Chromite Mine Wastes

3.1 Acidification of soil and surface materials

Mine wastes and surface soils can have their pH lowered by acid rain. A lower pH may cause some minerals to dissolve more readily and change how well soil particles hold onto metals. Metals that were previously connected to mineral surfaces may become more mobile as soil chemistry shifts. Because chromium can exist in several oxidation states, its response is complicated. While Cr(VI), which is frequently found as chromate or dichromate, is relatively mobile and toxic, Cr(III) is typically less mobile and less toxic. As a result, measuring total chromium alone cannot determine the environmental significance of acid rain. Monitoring needs to differentiate between various species of chromium.[4]

3.2 Increased leaching and runoff

In exposed mine wastes, acid precipitation may intensify water-rock interactions. Rainfall can carry dissolved components into drainage systems when it seeps into overburden piles and tailings. Mineralogy, soil buffering capacity, organic matter, hydrology, and the site's oxidation-reduction conditions all affect the outcome. Chromium has already been shown to move seasonally from mining areas into surface water systems in Sukinda, according to mining studies. Therefore, it is especially crucial to look into mine-waste leaching during times of heavy precipitation.

3.3 Influence on chromium mobility

Acidity and chromium mobility have a complicated relationship. pH, oxidation-reduction conditions, iron and manganese minerals, organic matter, microbial activity, and chromium's chemical form all affect how chromium behaves.

Consequently, it would be incorrect from a scientific standpoint to say that "acid rain directly converts all chromite into toxic Cr(VI)". Rather, acid deposition may change the transport and retention of chromium as well as the geochemical environment in which chromium-bearing minerals weather.

Recent studies in Sukinda highlight how intricate natural attenuation and geochemical processes regulate chromium mobility. According to a 2026 study, mine-tailing runoff had a significant impact on surface waters, but natural Cr(VI) attenuation linked to iron reduction was evident in deeper groundwater.

4. Pathways of Human Exposure

Humans can be exposed to chromium released from mining sites in a number of ways.

4.1 Inhalation

Airborne particulate matter can be produced during the mining, crushing, blasting, transportation, and handling of materials containing chromite. Residents may be exposed to contaminated dust that is transported outside the mine, and workers may breathe in dust that contains chromium. Inhalation and skin contact are significant routes of occupational Cr(VI) exposure, according to occupational research on Indian chromite miners. [5]

4.2 Drinking water

When mine drainage enters nearby water systems, contaminated groundwater or surface water may be a possible exposure route. Seasonally and geographically, chromium concentrations can differ significantly. Groundwater may be impacted by mine seepage and leachate, according to historical research in Sukinda that found Cr(VI) in surface waters impacted by mines.

4.3 Food-chain exposure

Agricultural soils may be contaminated by irrigation water and sediments that contain chromium. Metals from contaminated soils can be absorbed by plants, opening up a potential dietary route. Studies conducted in the vicinity of chromite-mining sites have documented decreased soil fertility and the transfer of metal ions into agricultural land.

4.4 Dermal exposure

Dermal exposure may occur from direct contact with contaminated mine water, soil, sludge, and dust. Workers who frequently come into contact with materials containing chromium should be especially concerned about occupational exposure.

5. Health Effects Associated with Chromium Exposure

Rather than acid rain itself, the health impact of chromite mining is mainly linked to exposure to chromium compounds, especially Cr(VI). Transport mechanisms typically utilised for sulphate and related ions can allow Cr(VI) to enter cells. Once inside cells, it may go through reduction processes that produce oxidative stress and reactive intermediates. DNA is one of the cellular components that these processes can harm. The carcinogenic potential of Cr(VI) has been highlighted by occupational studies of chromite miners, which have identified inhalation and dermal exposure as significant exposure routes. The importance of biomonitoring and enhanced occupational protection was emphasised in a recent review of human exposure to chromite-mining pollution, which found that chromium-containing environmental media can pose health risks to mining workers and surrounding populations.[6]

Significant or extended exposure to chromium may have the following negative health effects:

- effects on the respiratory system and respiratory irritation;
- dermatitis and skin irritation;
- oxidative damage to cells;
- effects on the kidneys and other systems after significant exposure;
- genotoxic consequences
- a higher risk of cancer, especially when exposed to Cr(VI) at work.

Elevated cancer and non-cancer risk estimates were linked to several heavy metals, with Cr(VI), nickel, and lead contributing to the overall risk profile, according to a soil-risk assessment conducted in the Sukinda mining region.

6. Environmental Health Effects of Acidified Chromite-Mining Areas

Beyond direct human exposure, the combination of mining and acid deposition can have an impact on the environment.

6.1 Soil degradation

Microbial communities and nutrient availability may be impacted by lower soil pH. Poor nutrient status and changed soil properties have been noted in studies conducted in Odisha's chromite-mining regions.

6.2 Water-quality deterioration

The chemistry of water can be altered by acidified runoff, which also increases the movement of particulate and dissolved pollutants. Groundwater, ponds, and streams may be impacted by mine drainage.

6.3 Agricultural impacts

Agricultural soils may become contaminated with chromium and other metals that are transported from mining regions. The availability of nutrients and metals to plants can also be affected by pH variations, which may lower crop productivity and raise the risk of food chain exposure.

6.4 Ecological effects

Changes in pH and concentrations of dissolved metals can be especially harmful to aquatic organisms. Ecological processes may be altered by chromium toxicity's effects on microorganisms, algae, plants, and aquatic animals.

7. Conceptual Relationship between Acid Rain, Chromite Mining and Health

The general route can be shown as:

Changes in pH and geochemical conditions → acid deposition → contact with mine waste or overburden → soil and water contamination → human exposure → health effects

This conceptual model should not be taken as evidence that the main cause of diseases linked to chromium in communities that mine chromite is acid rain. Instead, it pinpoints a likely environmental mechanism that necessitates site-specific measurement.[7]

The path that has been established is:

Chromite mining
↓
Waste and dust containing chromium
↓
Environmental contamination
↓
Human exposure
↓
Possible negative health consequences

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The mobility of contaminants may be altered by acid rain, a secondary environmental factor.

8. Proposed Methodology for Future Research

To ascertain the true contribution of acid rain to chromium mobilisation, a field-based investigation could be planned.

8.1 Rainwater monitoring

Rainwater should be gathered at a suitable background/control location as well as in several locations throughout the mining area. Among the parameters should be:

- **a.** pH
- **b.** electrical conductivity;
- **c.** Sulphate
- **d.** Nitrate
- **e.** chloride
- **f.** major cations;
- **g.** The total amount of chromium
- **h.** Cr (VI).

8.2 Soil analysis

Samples of soil should be taken at various distances from waste disposal sites and mines. Analysisoughttocomprise:

a. pH
b. carbon that is organic;
c. the ability to exchange cations;
d. The total amount of chromium
e. Cr (III);
f. Cr (VI);
g. Ni, Fe, Mn, Pb, and Cd;
h. The texture and moisture of the soil.

8.3 Surface-water and groundwater monitoring

Pre-monsoon, monsoon, and post-monsoon are the best times to gather samples. It is necessary toexaminethefollowingparameters:

a. pH
b. dissolved oxygen;
c. electrical conductivity;
d. The total amount of dissolved solids
e. nitrate and sulphate;
f. The total amount of chromium
g. Cr (VI);
h. Cr (III);
i. additional pertinent heavy metals.

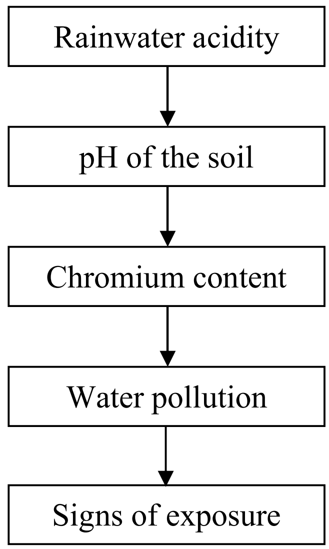
8.4 Health assessment

An appropriate control population could be compared to exposed mine workers and local residents in a cross-sectional epidemiological study. Occupational history, respiratory symptoms, dermatological symptoms, duration of exposure, and validated biomarkers of chromium exposure are examples of pertinent measurements.

Informed consent and the proper ethics approval are prerequisites for any human study.

8.5 Statistical analysis

Regression and correlation analyses could be used to look at connections between:



Because monsoon rainfall can significantly alter mine drainage and contaminant transport, seasonal analysis would be especially crucial.

9. Mitigation Measures

In areas where chromite is mined, a number of steps can lower the risks to the environment and human health.

9.1 Mine-waste management

In order to prevent uncontrolled rainfall infiltration, overburden and tailings must be appropriately contained, stabilised, and isolated. The design of waste dumps should reduce leaching and erosion.

9.2 Drainage treatment

Before being released, contaminated mine drainage needs to be gathered and cleaned. Reduction of Cr(VI) to the less mobile Cr(III) form, followed by precipitation or other appropriate treatment technologies, are examples of treatment strategies.

9.3 Vegetative stabilization

Erosion, dust production, and direct contact between rainfall and contaminated mine wastes can all be decreased by phytostabilization and vegetation. Phytostabilization is specifically identified in recent research as a possible management approach for Sukinda's chromium-contaminated mining landscapes.

9.4 Dust control

Chromium-containing dust exposure at work can be decreased by water spraying, enclosed conveyors, protective gear, road management, and better ventilation.

9.5 Water-resource protection

Regularly tested drinking water supplies should be available to communities close to mining areas. It is important to keep mine drainage from contaminating sources of drinking water.

9.6 Health surveillance

Exposure assessment, appropriate medical surveillance, and biomonitoring of workers with significant chromium exposure should all be part of long-term occupational health programs.

10. Research Gaps

Relatively few studies directly quantify the contribution of acid rain to chromium mobilisation, despite the fact that chromium contamination and health risks related to chromite mining have been extensively studied.

Thus, future studies ought to concentrate on:

- Measuring the Sukinda chromite-mining area reveals soil and water contamination and significant possible health risks related to chromium and other heavy metals. the chemical makeup and acidity of precipitation near chromite mines;
- investigating chromium release from mine waste experimentally at various pH levels;
- figuring out how pH influences Cr(III)/Cr(VI) transformations;
- examining seasonal correlations between rainfall, mine drainage, and chromium concentrations;
- separating atmospheric acid deposition from mining-related contamination; and
- combining environmental measurements with data on occupational and community health.

This distinction is crucial because the presence of acidic soil or water in a mining area does not prove that acid rain caused the acidity.

11. Conclusion

Through chromium-bearing dust, mine wastes, contaminated runoff, and leachate, chromite mining can result in serious environmental contamination and health risks to humans. Evidence from the Sukinda chromite-mining area shows that soil and water are contaminated and that chromium and other heavy metals pose serious health risks. PubMed+1 By altering the chemistry of soil and mine-waste, encouraging mineral weathering, affecting metal adsorption and desorption, and altering the movement of pollutants into surface water and groundwater, acid rain may exacerbate these effects. However, the evidence that is currently available does not support linking acid rain alone to chromium-related health effects in communities that mine chromite. Exposure to chromium and other pollutants produced or mobilised by mining operations continues to be the main and well-established concern.

Therefore, rather than treating acid deposition as the only source of chromium contamination, a thorough environmental-health strategy should address it as a potentially significant modifying factor. To determine the true relationship between acid deposition and chromium toxicity, integrated monitoring of precipitation, mine wastes, soil, surface water, groundwater, airborne dust, and human exposure is required. More efficient mine management, environmental restoration, and worker and community protection in the vicinity of chromite-mining areas can all benefit from such research.

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