From Pixels to Policy: Using Geospatial Technologies to Assess Sand Mining Regulations

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Abstract

Sand mining is the practice of removing sand from lakes, rivers, and streams using various techniques, including dry and wet pool mining, bar excavations, skimming, and scalping. Excessive and illegal mining activities can lead to severe environmental hazards, including deforestation, water pollution, soil pollution, and air pollution. Fallacious mining practices can also lead to the exhaustion of resources on open lands and riverbeds. In this study, geospatial techniques have been utilised to investigate and audit sand mining practices surrounding a city in North India, where resources are extracted for the city's development. The present study was conducted with the objective of identifying unauthorised mining activities in allotted sites and nearby areas, mapping and verifying mining operations in relation to approved mining plans and environmental clearances, and estimating the minor minerals extracted at the mining site. Satellite images from Sentinel-2 and Google Earth, along with the lease area coordinates and Environmental Impact Assessment (EIA) reports for the site, served as the data sources for the research. Violations of the rules, such as flow obstruction, mining along riverbanks, and mining outside the lease area, were observed using remote sensing imagery. Further, the present study concludes that Satellite-derived analysis can provide a time- and cost-effective means of inspecting mining areas.

1. Introduction

Sand mining involves extracting material from aquatic ecosystems using techniques such as dry and wet pool mining, bar excavations, and skimming. (Hill, 1999). Sand is the most often used building material worldwide. A survey found that roughly 50 billion tons of sand are used each year solely for construction. (Koehnken & Rintoul, 2018). Sand also serves as habitat for a variety of marine species and is crucial to maintaining the coastal ecosystem. (Kudale et al., 2014). Sand resources are under tremendous pressure due to the growing demand in the construction industry, leading to extensive legal and illegal sand mining. Mining activities beyond the replenishment limit of sand pose significant environmental threats, including deforestation, water pollution, depletion of the groundwater table, and soil pollution. (Bindhusri & Arunachalam, 2015; Sonak et al., 2006; Sreebha & Padmalal, 2011). Imprudent Sand Mining also adversely affects the water quality parameters and makes it unfit for use (Akankali et al., 2017). Numerous studies have been conducted to preserve Land Use and Land Cover (LULC) and assess the environmental impact of sand mining using various satellite data. (Adedeji et al., 2014; Atejioye & Odeyemi, 2018; Santo & Sánchez, 2002). Remote sensing and Geographic Information System (GIS) can be effectively used to map and plan sand mining lease areas.(Li et al., 2014; Reddy et al., 2020). High-resolution satellite images such as QuickBird, Cartosat, and WorldView can be used to accurately demarcate legal and illegal sand-mining zones. (Chaussard & Kerosky, 2016; Duan et al., 2019; Mitra & Singh, 2015). GIS can also help to estimate the amount of sand minerals that can be extracted from the mining zones (Atejioye & Odeyemi, 2018). The present research has been carried out with the objective of: identification of unauthorized mining activities in allotted sites and nearby areas; mapping/verifying mining operations in accordance with approved mining plans and environmental clearances; and estimating the minor minerals extracted in selected mining sites using Geo-Spatial Technologies. A mining lease around Dehradun, Uttarakhand, is selected as the Study area. For confidentiality reasons, the authors cannot disclose the exact mining site.

2. Methodology

To identify unauthorized mining activities, Sentinel-2 satellite images and Google Earth imagery were analyzed. The site coordinates were plotted in Quantum Geographic Information System (QGIS) and Google Earth Pro to create a polygon (shapefile), which was further analyzed using remote sensing tools for the different periods. The observations of the study were developed in two lines:

1) Mining occurred after it was officially closed and
2) Mining outside the permissible boundaries is created with the help of the coordinates provided.

For verification of mining operations, the comparison between the mining rules specified in the EIA/mining plan and those followed on site is conducted through remote sensing techniques and field visits. The following points are considered: - Mining occurs very near river banks, Flow obstruction, In-stream mining, Permissible mining depth, etc.

Estimation of minor mineral quantities is done using the volumetric method. In this method, the calculated area (using remote sensing tools) is multiplied by the sand's bulk density and the depth to which mining is permissible. Different scenarios of extracting minor minerals have been considered in the present study. The first scenario is the calculation of minor minerals regarding the area given in the mining plan. The second scenario is the estimation of minor minerals based on the area calculated from the coordinates provided in the action plan. The assumptions used in this study to calculate the estimate of the mineable reserve are: bulk density of sand as 2000 kg/ m3, depth up to which mining can occur is taken as 1.5 meters as per the EIA regulations, and 20 percent of the area is curtailed as blocked reserves that need to be left. The detailed methodology flow chart is shown in Figure 1.

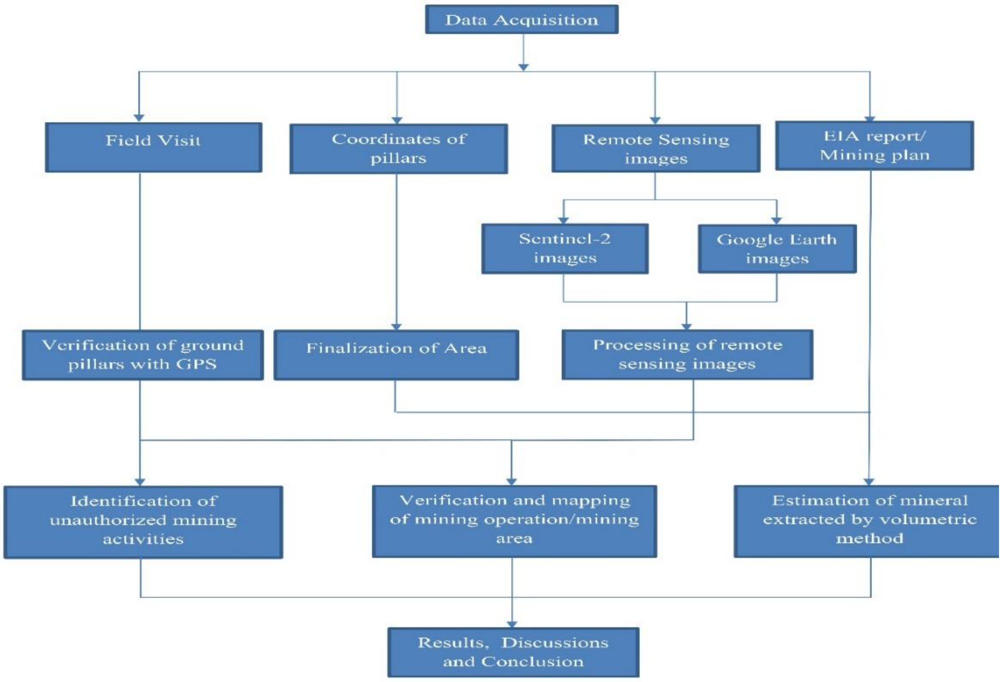

Figure 1. Methodology Flow Chart

3. Results and Discussions

3.1 Identification of unauthorized mining activities in the allotted mining sites and nearby areas

Mining was officially closed on the site in January 2017; the Main focus was to determine the mining activities after that period using Geospatial technologies. In this research, an attempt has also been made to identify mining practices beyond the polygon defined by the given coordinates. Satellite images from Sentinel-2 (Spatial resolution 10 m) were used to identify mining practices at the site and were also verified using Google Earth images.

3.1.1 Mining after January 2017

Sentinel images of the year 2020 have been analyzed on the GIS software (ERDAS IMAGINE 2014). Analysis of 2020 demarcated that the mining occurred throughout the ten months of 2020, i.e., from 9th Feb to 15th Nov 2020, as shown in Figure 2. In this figure, the dark patch in the first image (indicated by the arrow) increases continuously from February 2020 to November 2020. The continuous expansion of dark patches from February to November 2020 indicates a persistent removal of the riverbed's top sand layer, which prevents natural replenishment during the monsoon cycle. The identification of these signatures over a 10-month period suggests that mining activities are not merely seasonal but are sustained, potentially leading to long-term changes in the river's morphological structure. Similarly, different patches can be seen increasing throughout the polygon; this indicates that the white part, which is sand, decreased in 2020.

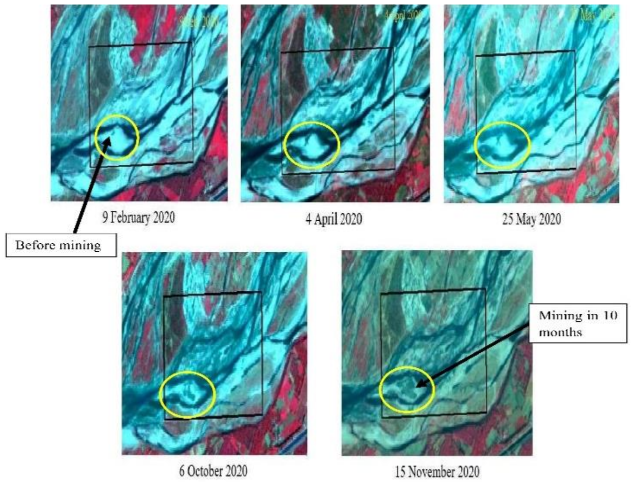

Figure 2. Sentinel images of site 2020 showing mining signatures

Similarly, different images from 2016 to 2019 were also analyzed. In those images, mining signatures (patches) have also been found inside the polygon of the study area provided, as shown in Figures 3 & 4. This indicates that mining was active even after the closed period, i.e., January 2017. To elaborate, if no mining activity has been done on-site, the entire area shown within the polygon would be replenished (white) rather than showing dark patches. The 2016 image shows the flow regime during the site's monsoon period.

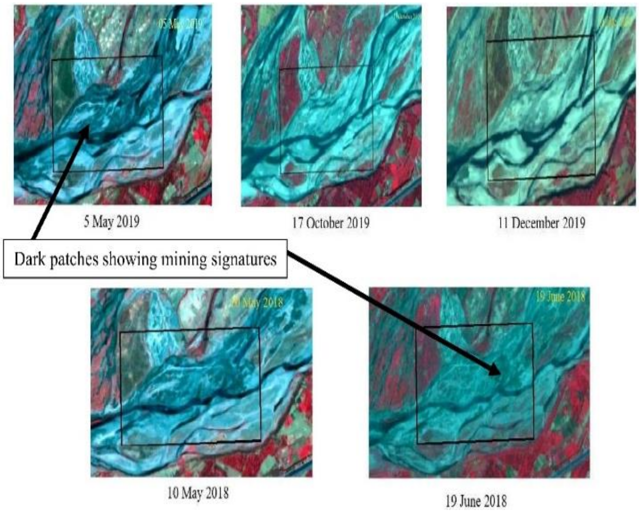

Figure 3. Sentinel images of site 2018-19 showing mining signature,

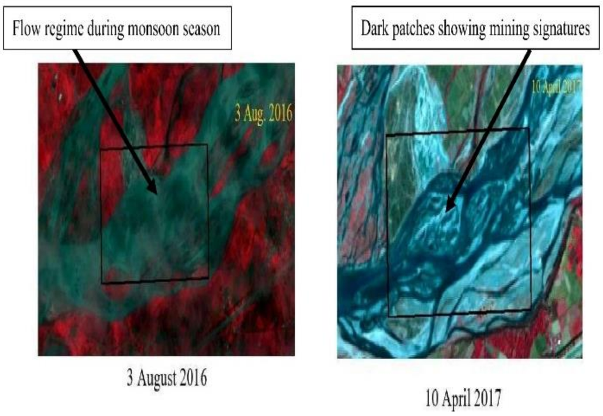

Figure 4. Sentinel images of the site showing mining signatures

The site was also analyzed using Google Earth Pro, and similar observations were made. Figure 5 shows a Google Earth image from 2020, in which mining signatures are easily visible. Figure 6 shows the pop-up view of the circled area of interest in Figure 5, where mining activities can be seen.

Figure 5. Google Earth image of the site showing mining signatures

Figure 6. Pop-up view of mining signatures shown in Figure

3.1.2 Mining occurring outside the polygon formed from the given coordinates

The coordinates provided were plotted in Google Earth Pro to form a polygon of the area of interest. The same polygon was later converted to a shapefile for export to GIS software. Different images have been analyzed to find the mining signatures outside the polygon formed. Figure 7 shows the Sentinel-2 images from 2017-2020 in which mining signatures can be easily demarcated outside the polygon. The arrows in the Figure indicate the places where mining signatures (dark patches) have been found. If no mining had occurred outside the polygon, then there would not have been any patches as shown below.

Google Earth images have also been used to identify mining signatures outside the polygon. In Figure 8, Mining signatures outside the polygon are visible in the Google Earth image.

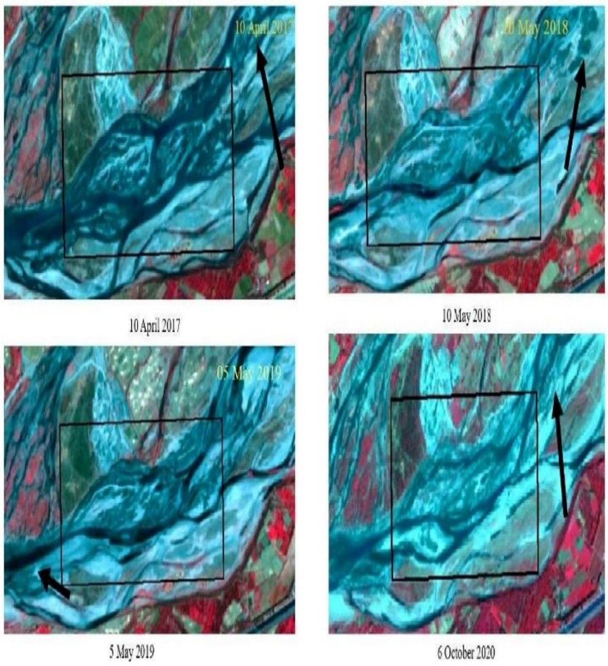

Figure 7. Mining signatures outside the concerned area of interest

Figure 8. Google Earth Images showing active mining signatures

3.2 Verification & Mapping of mining operations concerning the approved mining plans and environmental clearances

To verify the mining operations, general observations such as flow obstructions, mining along banks, and in-stream mining were made using remote sensing. Important mining operations criteria were recorded from the mining plan. The present study covers the criteria that are discussed in the preceding section.

a) As per the guidelines, a buffer of 7.5m should be taken from the lease boundary to minimize the riverbank erosion. To evaluate this condition, the Google Earth tool was used, and it was observed that no such practice is being followed. Continuous mining on both sides of the boundary has been observed and is shown in Figure 9(inside the red circle). The yellow line in the Figure below indicates the boundary of the lease area.

b) The next criterion states that mining should not be allowed on the concave side of the river to prevent bank erosion. As per the findings, mining is observed along both sides of the river channel, as shown in Figure 9-b.

c) Two additional requirements are to maintain the safety and stability of the banks of rivers, i.e., there should not be any type of stream diversion caused by sand mining, and 10% of the river's width or 3 meters, whichever is more, will be left untouched as a no-mining zone. No natural watercourse and/or water resources are obstructed due to mining operations, but as per our observation, no such buffer was taken, and flow was also obstructed, as shown in Figure 9-c.

d) As per the guidelines, the depth of mining shall be confined up to 1.5 meters below ground level or above the groundwater level, whichever is less. So, there should not be any waterlogging in the area. However, during the field visit, waterlogging and pits greater than 1.5 m were observed at the site, as shown in Figure 9-d. The height of the person standing below the Figure is approximately 6 feet (1.8 m), and the depth of the pit is greater than the person standing. Such violations often expose the groundwater table, leading to permanent waterlogging and the formation of stagnant pools. This not only alters the local hydrology but also creates breeding grounds for insects and poses a safety hazard to the local community and livestock.

Figure 9. Verification of Mining Operations

During the field visit, major mining signatures were observed near the site's pillar. Mining signatures were even present beyond the pillars shown during the field visit. Some fresh heavy vehicle tracks were also found between the pillars, indicating the passage of large-weight vehicles that may have been used to carry minerals. In some places, water pits formed, indicating mining practices on the site (Figure 10). This also validates the results from the remote sensing and GIS images.

Figure 10. General observations during field visit -15-Jan-2022

3.3 Estimation of the quantity of minor minerals extracted in the selected mining sites

The number of minor minerals was estimated using the volumetric method and is shown in Table 1. Two scenarios for the extraction of minor minerals have been considered. The first scenario is the calculation of minor minerals in the area given in the mining plan. The second scenario is the estimation of minor minerals based on the area calculated from the coordinates provided in the action plan. From scenarios one and two, the approximate weight of sand that can be mined per year (in Metric tons) is 1545216 and 3888000. In this study, the bulk density of sand (BD) is assumed to be 2000 kg/ m3, and the depth up to which mining can occur is taken as 1.5 meters, as given in the EIA report, and 20 percent of the area is curtailed, taking reference from mining plans/ EIA reports

Table 1 Criteria for Estimating Minor Mineral

S. no	Nature of Land	Lease Area in Ha	Total geological reserves (Metric Ton) = Area x Depth x BD (A)	20% blocked in the riverbank Area in Ha	Blocked geological Reserve (B)	Total Minable Reserves (A) – (B) = (C)	Allowable Minable Reserve per year (Metric Ton)
1	River Bed	64.384* (Mining Plan)	1931520	12.8768	386304	1545216	1545216
2	River Bed	162 (Polygon)	4860000	32.4	972000	3888000	3888000

A critical finding in this study is the significant disparity between the official lease area of 64.384 Ha and the actual mining polygon of 162 Ha, as identified using geospatial tools. This indicates that the extraction footprint is approximately 2.5 times larger than what was legally permitted. Consequently, the estimated mineable reserve per year jumps from 1.5 million metric tons to nearly 3.9 million metric tons. This scale of unauthorized extraction highlights a significant loss in state revenue and an environmental impact far beyond the scope of the original environmental clearance.

3.4 Validation of Geospatial Finding

The study used coordinates captured with a handheld GPS at the site to ensure the precise demarcation of the lease area polygon in the GIS environment. To validate the remote sensing analysis, a 'ground-truthing' approach was employed. The dark patches identified as mining signatures in the 2020 Sentinel-2 imagery were verified during a field visit on January 15, 2022. Physical indicators, such as fresh tyre tracks from heavy machinery and excavated pits at the plotted GPS locations, confirmed the accuracy of the satellite-derived mining signatures. This direct correlation between GPS-verified field observations and satellite data eliminates the need for a separate statistical error matrix, as the detection was 100% consistent with ground reality during the audit period. Table 2 below specifies the EIA/Mining Plan regulations alongside the corresponding field evidence of violations

Table 2 Regulatory Compliance V/s Observed Status

Regulation Parameter	EIA/Mining Plan Requirement	Observed Status (Geospatial & Field)	Remarks
Boundary Buffer	7.5m untouched zone from the lease boundary.	Violation: Mining occurs on both sides of the boundary.	Figure 9-A.
Mining Depth	Maximum 1.5m below ground level.	Violation: Pits observed exceeding 1.8m (6 feet).	Figure 9-D.
Riverbank Safety	No mining on the concave side of the river.	Violation: Mining active on both sides of the river channel.	Figure 9-B.
Flow Stability	No obstruction or stream diversion allowed.	Violation: Obvious flow obstruction observed.	Figure 9-C.
Lease Area	Mining is limited to the coordinates provided in the plan.	Violation: Significant mining signatures found outside the legal polygon.	Figure 7.

4. Policy Implications and Strategies

The findings of this study demonstrate a significant gap between existing regulations and ground-level enforcement. To mitigate environmental hazards such as soil pollution and resource exhaustion, the following policy strategies are proposed.

4.1 Mandatory Geospatial Auditing

State mining departments should adopt satellite-derived analysis as a standard operating procedure for seasonal inspections. As demonstrated, Sentinel-2 imagery provides a cost-effective means of detecting violations that field visits alone might miss due to geographic constraints.

4.2 Geofencing and Boundary Enforcement

Authorities should utilize GPS-derived shapefiles to "geofence" lease areas. Any mining signatures detected outside these digital polygons in periodic satellite updates should trigger automatic administrative queries or site suspensions.

4.3 Volumetric Revenue Management

Rather than relying on self-reported "pit passes" or vehicle counts, regulators should use the volumetric method to estimate total geological reserves. By comparing the permitted volume against the geospatial footprint, governments can accurately levy fines for over-extraction.

4.4 Ecological Buffer Compliance

Strict legislation is needed to enforce the 7.5m boundary buffer and 1.5m depth limit. Since depth violations (e.g., pits exceeding 1.8m) lead to permanent groundwater exposure and stagnation, automated alerts for waterlogged pits in satellite data can serve as early warning signs of environmental degradation.

5. Conclusion

The purpose of this research was to investigate and bring to light sand mining activities in the allotted areas with the help of Geo-Spatial technologies. The study's main objective was to use GIS and other image-processing tools to achieve all its goals. Typically, mining affects land surface areas, leaving large open pits that are expensive and physically challenging to repair once mining is finished. Resources in riverbeds and on open plains are depleted due to excessive mining. There is a pressing need to enact legislation worldwide to address environmental issues caused by poor mining practices. We can infer from this work that Remote sensing and GIS can provide an effective means of monitoring sand mining leases.

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