



Original article

Socio-environmental impact of mining concessions in Mexico: a spatial analysis

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ABSTRACT

Mexico is globally recognized for its rich mineral resources. While mining is often seen as a driver of economic development, it is crucial to consider its short-, medium-, and long-term impacts on biodiversity, as well as on the surrounding rural and Indigenous communities that are frequently overlooked. Information on mining projects in Mexico is fragmented and incomplete within official institutions, complicating access. A significant lack of transparency in mining operations further obscures their effects on biodiversity. Therefore, this study aimed to analyse, using geographic information systems, the distribution of current mining concessions in Mexico and their spatial overlap with environmental and social variables in order to identify areas potentially vulnerable to the impacts of mining activities. Research was conducted on mining concessions in Mexico to assess their spatial relationship with eight environmentally and socially significant variables. The findings indicated that 8.24% of the national territory is under concession. The regions classified as Priority Land Regions and Priority Hydrological Regions exhibited the highest overlap with mining concessions, at 84% and 75%, respectively. Moreover, Protected Natural Areas designated as Biosphere Reserves were identified as the most potentially affected by these activities. Additionally, there was a 10.37% overlap of concessions within communities characterized by a high to very high degree of social vulnerability, including Indigenous communities of 39 ethnic groups. This analysis highlighted specific sites that could be particularly susceptible to the detrimental impacts of mining due to their environmental or social conditions.

KEY WORDS: biodiversity, Indigenous communities, mining concessions, conservation areas, spatial overlap

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1. Introduction

Mexico is a megadiverse and mineral-rich country, largely due to its geographic location and ongoing volcanic and tectonic activity. Approximately two-thirds of the country consists of mineralized areas, making it one of the most significant mining regions

in the world (DELGADO-RAMOS, 2013; ARMENDÁRIZ-VILLEGAS ET AL., 2015). Mexican laws have been regularly updated to permit unrestricted exploration and exploitation by both domestic and foreign companies. Mining concessions were regulated until the 19th century, by the Mining Law of 1884, this was repealed and replaced by the Mining Law of

1992, which promoted foreign investment, granted uncontrolled concessions and provided full access to land and water resources. Consequently, the Indigenous communities and biodiversity in and around mining sites have suffered due to these extractive policies (CONGRESO DE LA UNIÓN, 1992; TETREAULT, 2015; STOLTENBORG & BOELEN, 2016; HOLLAND, 2018; VÁZQUEZ-GARCÍA ET AL., 2020).

Extractivism is an economic model based on the intensive, large-scale extraction of natural resources, such as minerals, oil, and other primary commodities (PUYANA-MUTIS, 2017; TETREAULT ET AL., 2020). Although extractive industries are commonly promoted as drivers of economic growth and development, their environmental and socio-territorial impacts disproportionately affect rural and Indigenous communities. These activities require access to and control over vast territories, as well as large volumes of water and biodiversity, leading to significant ecological, social, and territorial changes. From the perspectives of political ecology and environmental justice, the expansion of mining is viewed as a process of territorial restructuring associated with socio-environmental conflicts over the access, use, and control of natural resources (BASTIDAS-ORREGO ET AL., 2018; MUÑOZ-DUQUE ET AL., 2020).

Under the discourse of development and modernization, mining can lead to social fragmentation, loss of livelihoods, territorial dispossession, and the erosion of cultural practices and traditional forms of land organization (TETREAULT, 2015; STOLTENBORG & BOELEN, 2016). Additionally, policies and legal frameworks often favour the extractive sector, which limits community participation in the governance of territories and natural resources. This has resulted in processes of territorial appropriation and human rights violations (TETREAULT, 2015; MUÑOZ-DUQUE ET AL., 2020). In this situation, mining concessions can be seen as mechanisms of territorial appropriation that may overlap with areas prioritized for bio-cultural conservation.

Previous studies conducted in countries such as China, Brazil, and Colombia have demonstrated that mining leads to habitat loss, fragmentation, and degradation. Additionally, it contributes to greenhouse gas emissions, depletes water resources, and causes pollution related to the dispersion of fine particulates from mining tailings through air and water (FLÓREZ-YEPES ET AL., 2017; RUDKE ET AL., 2020; WANGHE ET AL., 2020; WU ET AL., 2020; SUN ET AL., 2022).

In Mexico, information about mining is limited and primarily focuses on the social conflicts occurring

in the states of Sonora and San Luis Potosí (BASTIDAS-ORREGO ET AL., 2018; MUÑOZ-DUQUE ET AL., 2020; LUTZ-LEY & BUECHLER, 2020; LYN, 2021; LUGO-GIL & LARA-ENRÍQUEZ, 2022). Only a few studies have addressed the environmental consequences of mining, and these have mainly concentrated on protected natural areas (ARMENDÁRIZ-VILLEGAS ET AL., 2015; GODÍNEZ-GÓMEZ ET AL., 2020) as well as the loss of habitat for some species of reptiles and amphibians (MAYANI-PARÁS ET AL., 2019). PÉREZ-JIMÉNEZ (2016) provides an economic context for metal mining and reviews the conflicts associated with this activity in some of Mexico's biodiverse areas.

Information about mining projects in Mexico is often fragmented and incomplete within official institutions, making it difficult to access. This lack of comprehensive information hinders the analysis of their impact on biodiversity. Consequently, decisions regarding mining exploitation have frequently been inadequate, resulting in nearly 50% of the national territory being granted concessions during the 2000s. Therefore, this study aimed to analyse, using geographic information systems, the distribution of current mining concessions in Mexico and their spatial overlap with environmental and social variables in order to identify areas potentially vulnerable to the impacts of mining activities.

2. Method

2.1. Study area

Mexico is situated on the North American continent and spans approximately 1.9 million square kilometres. It lies at the intersection of the Nearctic and Neotropical biogeographic regions, which contributes to its remarkable biodiversity. It is estimated that Mexico is home to about 10% to 12% of the world's total biodiversity, with nearly 200,000 recorded species (MORRONE, 2019).

Mexico's geology is diverse and complex, and shaped by various geological processes over time. The country features mountain ranges, volcanoes, fault systems, as well as sedimentary and igneous rocks, which create favourable conditions for the formation and accumulation of minerals in different regions. Consequently, Mexico plays a significant role in the global mining industry, with mining activities contributing 2.05% to the National Gross Domestic Product (SE, 2024).

Mexico is not only known for its geological wealth but also for its rich cultural heritage. The country is

home to 69 ethnolinguistic groups, which are essential to its identity and history. According to the 2020 Population and Housing Census (INEGI, 2020), 19.4% of the population identifies as Indigenous.

2.2. Data collection

A request was submitted to the Ministry of Economy through the National Institute for Transparency, Access to Information, and Protection of Personal Data (INAI), to obtain information on current mining concessions in Mexico. Mining concessions are legal titles granted by the State

that confer the right to explore and exploit mineral resources within a defined area and period (LÓPEZ BÁRCENAS & ESLAVA GALICIA, 2022). The database includes records of 23,453 valid concession titles issued since 1900, detailing the concession title number, lot name, municipality, state, surface area, owner, date of issue, validity date, and polygon. To evaluate the potential effects of mining on regions designated for the conservation of biocultural wealth in Mexico, shapefile layers representing priority areas were acquired, along with additional layers that included social factors (Table 1).

Table 1. Description of priority regions for conservation and social development in Mexico

Variable	Description	Source
Protected Natural Areas (PNA)	Regions of the national territory, both terrestrial and aquatic, where the environments have not been significantly altered and require preservation or restoration.	CONANP, 2023
Priority Land Regions (RTP For its acronym in Spanish)	Areas with physical and biological characteristics create stable environmental units that showcase a unique wealth compared to the rest of the country.	CONABIO, 2004
Important Bird Areas (IBAS)	Regions that create a regional network for bird conservation.	CIPAMEX, 2015
Priority Hydrological Regions (PHR)	The primary hydrographic basins of the country.	Arriaga et al., 2002
Basal water stress	Is the measure of total annual water withdrawal (municipal, industrial, and agricultural) expressed as a percentage of the total annual available flow.	Gassert et al., 2015
Potential map of species at risk	A map illustrating the potential richness of species at risk of extinction in Mexico.	CONABIO, 2021
Degree of social vulnerability	Social vulnerability index related to disasters highlights communities with greater susceptibility due to their socioeconomic conditions.	CENAPRED, 2011

2.3. Spatial analysis of mining concessions and their spatial overlap with sites of biocultural importance

We first identified the states potentially most affected by mining activities. Next, we analysed the issuance and validity of mining concessions, organizing this data by decade from 1900 to 2022 to identify patterns in their distribution. We used QGIS software, version 3.28 Firenze (QGIS DEVELOPMENT TEAM, 2023), to layer information about the eight priority regions for conservation and social development alongside the mining concessions. By applying set theory, we identified intersections between these layers to extract overlapping areas.

During the spatial intersection process between mining concessions and social and conservation variables, we conducted a visual verification, an

attribute consistency check, and a geometric review to ensure the proper execution of the overlays and the integrity of the resulting spatial entities. Through the attribute review, we identified some concessions with validity periods that exceeded the limits established by Mexican mining legislation, with durations of up to 159 years. We did not remove these cases from the analysis as they correspond to concessions that are officially registered as valid. This may indicate administrative inconsistencies, accumulated extensions, or specific legal conditions reflected in the government database. Therefore, we retained these concessions in the spatial analysis to preserve the integrity of the original dataset.

The spatial datasets used in this study come from different institutions and vary in terms of years, cartographic scales, and methodologies. This leads

to inherent differences in their resolution and detail. Nevertheless, these datasets represent the official information available at the national level for Mexico and are used in environmental and territorial studies (ARMENDÁRIZ-VILLEGAS ET AL., 2015; MAYANI-PARÁS ET AL., 2019; GODÍNEZ-GÓMEZ ET AL., 2020). The temporal differences among the datasets also reflect the varying update periods of this official information. Despite these minor discrepancies, the identified spatial intersections allow us to recognize general patterns of territorial overlap between mining concessions and priority regions for conservation and social development, which is the main objective of this analysis. We believe that the differences arising from the sources of the variables did not significantly impact the results.

An overlap map was created for each layer, and descriptive statistics were used to analyse the potential impacts associated with mining, focusing on the number of affected areas and the percentages of overlap. The areas that are at greatest risk of being affected, based on the percentage of overlap, were also identified.

3. Results

According to data from the Secretary of Economy, as of 2022, there were 23,453 mining concessions, of which 22,871 remain legally valid. These concessions cover an area of 163,419.93 km², accounting for 8.24% of Mexican territory. Mining activities are conducted in all 32 states of Mexico, placing the country second in terms of the geographic extent of mining on an international scale (SUPPEN ET AL., 2006). The states with the largest areas designated for concessions are Colima, Zacatecas, and Sonora, which have 35.86%, 17.23%, and 16.27% of their territories allocated to mining activities, respectively.

The mining law of 1992 allowed for the granting of concessions to foreign companies, resulting in a significant increase in such concessions that peaked in the 2000s. By the 2010s, concessions granted to foreign companies covered more than 50% of Mexican territory. Under the approved mining law, over 50% of these concessions remain valid until 2060. However, some irregularities were discovered, including 17 concessions with validity durations of up to 159 years.

As of September 2023, there were 303 state and 203 federal areas designated as protected, aimed at conserving the country's terrestrial and marine ecosystems. Data indicate a 36% overlap between mining concessions and these protected areas, which includes 78 state and 72 federal administrations (Fig. 1a). This overlap encompasses 27 biosphere reserves and 20 Flora and Fauna Protection Areas (FFPAs). The areas with the highest percentage of overlap include Rayón National Park (PN) in Tlalpujahua, Michoacán, where 100% of the area has been concessioned. Following this is San Quintín National Park in Baja California at 60.35% and FFPA Sierra de Quila in Jalisco with 52.78%. These findings raise concerns about the ability to achieve the conservation objectives of these protected areas.

Mining concessions overlap with 84% of the designated RTPs (Priority Land Regions), potentially affecting 128 areas (Fig. 1b). For instance, Cañón del Zopilote in Guerrero has 77.7% of its area under mining concessions. Similarly, RTP-33 Bassaseachic, in Chihuahua, has 70.9% of its area subject to mining concessions. In the case of IBAS (Important Bird Areas), there is a 52% overlap with mining concessions; 127 areas could be affected (Fig. 1c). The IBA Mineral de Nuestra Señora in Sinaloa shows the highest level of overlap, with 86.75% of its area covered by mining concessions. Additionally, Laguna Cuyutlan and Estero Palo Verde in Colima experience significant overlaps, at 86.27%.

The analysis of mining concessions in relation to Priority Hydrological Regions (PHR) indicates a significant overlap of 75%, encompassing a total of 110 PHR (Figure 1d). The region surrounding the Río Yaqui-Cascada de Bassaseachic, located between the states of Sonora and Chihuahua, holds the highest concentration of mining concessions, with 1,419. The areas facing high to extremely high-water stress are mainly located in central-northern and north-western Mexico, where 63% of mining concessions are found (Fig. 2).

Our analysis indicates that 10% of mining concessions overlap with regions that support up to 140 species of flora and fauna classified as at risk. The risk categories include Probably Extinct in the Wild (EW), Endangered (E), and Threatened (T). This overlap is primarily found in the western and southwestern regions of the country (Fig. 3).

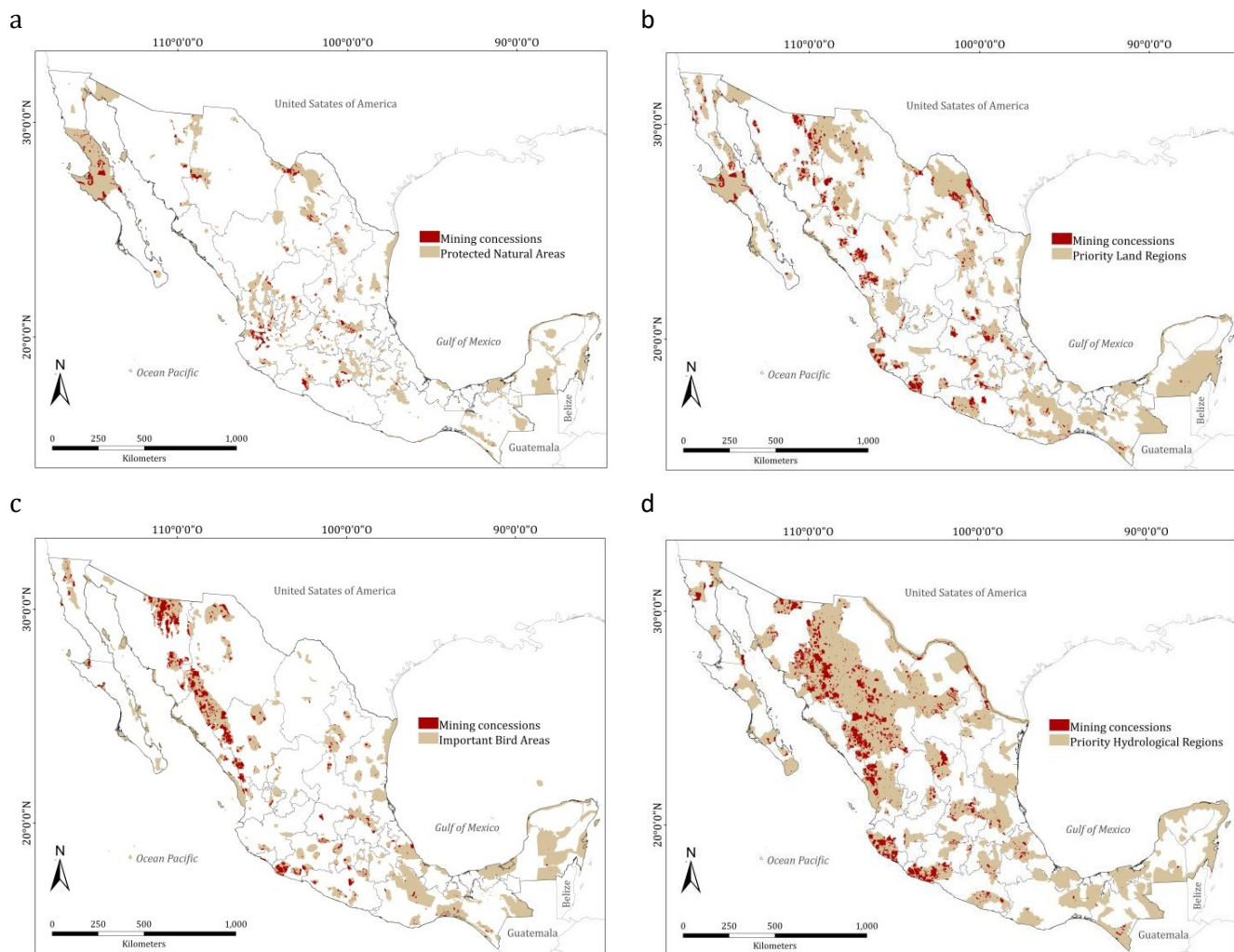


Fig. 1. Spatial overlap of mining concessions with priority sites for conservation in Mexico: a) Protected Natural Areas, b) Priority Land Regions, c) Important Bird Areas and d) Priority Hydrological Regions

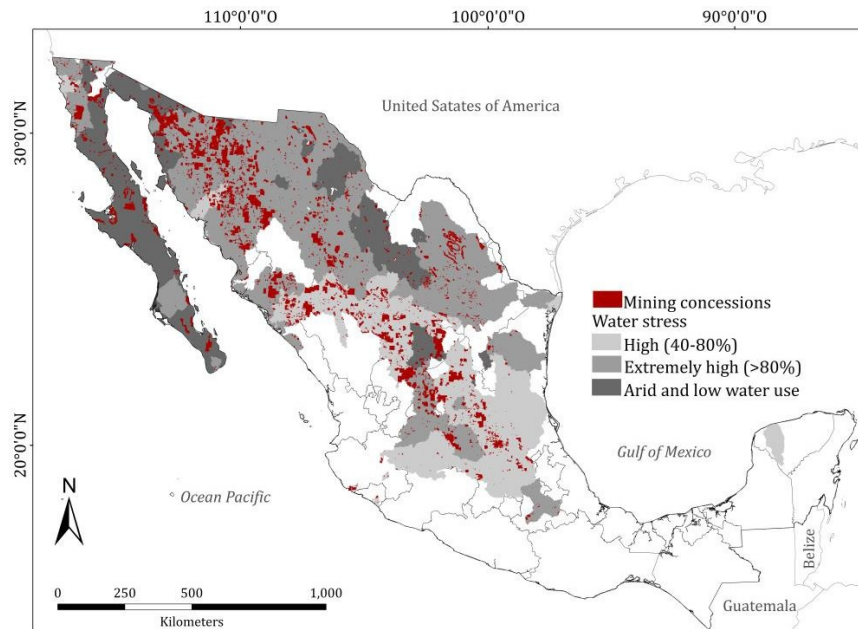


Fig. 2. Spatial overlap of mining concessions with regions with high and extremely high percentages of basal water stress in Mexico

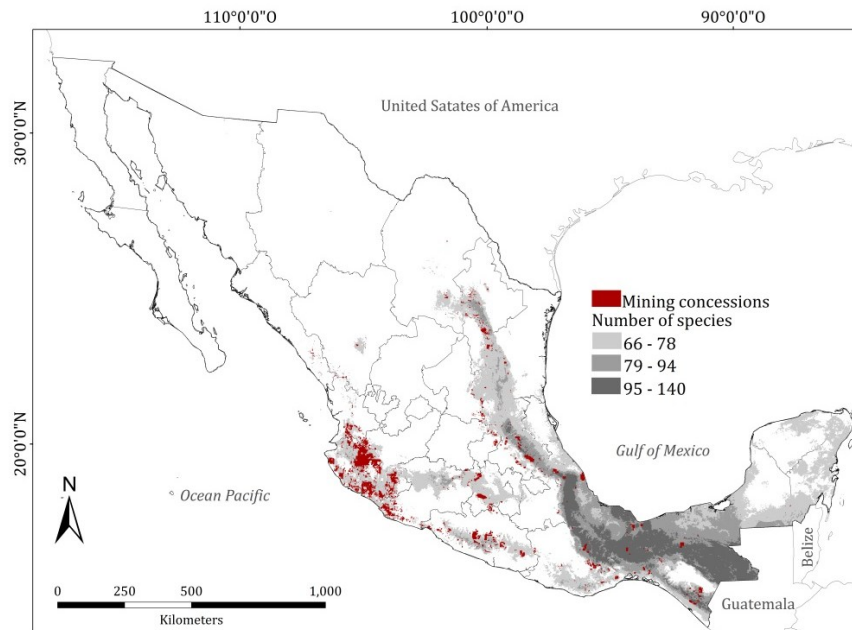


Fig. 3. Spatial overlap of mining concessions and areas with the most species of flora and fauna in risk categories in Mexico

Mining concessions significantly overlap with communities that have high to very high levels of social vulnerability, affecting 10.37% of these areas (Fig. 4a). There are 1,391 mining concessions located within Indigenous communities, which could potentially impact 39 ethnic groups (Fig. 4b). Among these groups, Nahuatl-speaking communities would eventually be the most affected, with a 58.76% overlap, followed by Pima-speaking communities, which have a 28.66% overlap.

4. Discussion

According to the Federal Law on Transparency and Access to Public Government Information, as well as the Mining Law, information generated from mining records and activities must be made public and accessible to all interested parties. However, this information is often scattered and incomplete across the various agencies that regulate and manage mining. This disorganization presents a significant barrier to data analysis, negatively impacting environmental and social management and limiting citizen participation. Therefore, it is essential to promote and ensure transparency and accountability in this sector.

During the data collection process, inconsistencies were identified in the official records of mining concessions in Mexico. These inconsistencies included concessions with terms that exceeded the legally established limits, duplicate records, and discrepancies

in the administrative dates of granting and renewing concessions. Such issues highlight some of the challenges within the country's mining management system. Processes like updates, changes in ownership, and adjustments to polygon boundaries can create spatial overlaps in official databases. In this context, the legal validity of a concession does not always correspond to its level of operational activity. As a result, the concession system includes both active titles and inactive or speculative concessions, which can impact the analysis of their spatial distribution (RAMÍREZ & MORALES-RAMÍREZ, 2023).

Exploration of areas with mining potential typically lasts around 10 years, while the exploitation phase can extend from 20 to 30 years (LYN, 2021). However, these timeframes do not align with the established legal validity periods; there is a discrepancy between the technical durations of the mining cycle and the legal length of concessions. Before 2022, Mexico's Mining Law provided an initial concession period of 50 years, with the option for a 50-year renewal. Recent legislation has reduced the maximum concession duration to 30 years, with a renewal option for an additional 25 years. Under this new framework, over 50% of the analysed concessions have projected validity periods extending to 2060. Additionally, 17 concessions were identified with validity periods of up to 159 years, which do not comply with the regulatory framework. Other inconsistencies and errors were also detected in

the updating and maintenance of administrative records. These elements indicate that Mexico's mining concession system can incorporate dynamics of

territorial accumulation, institutional reconfiguration, and challenges related to transparency in available information.

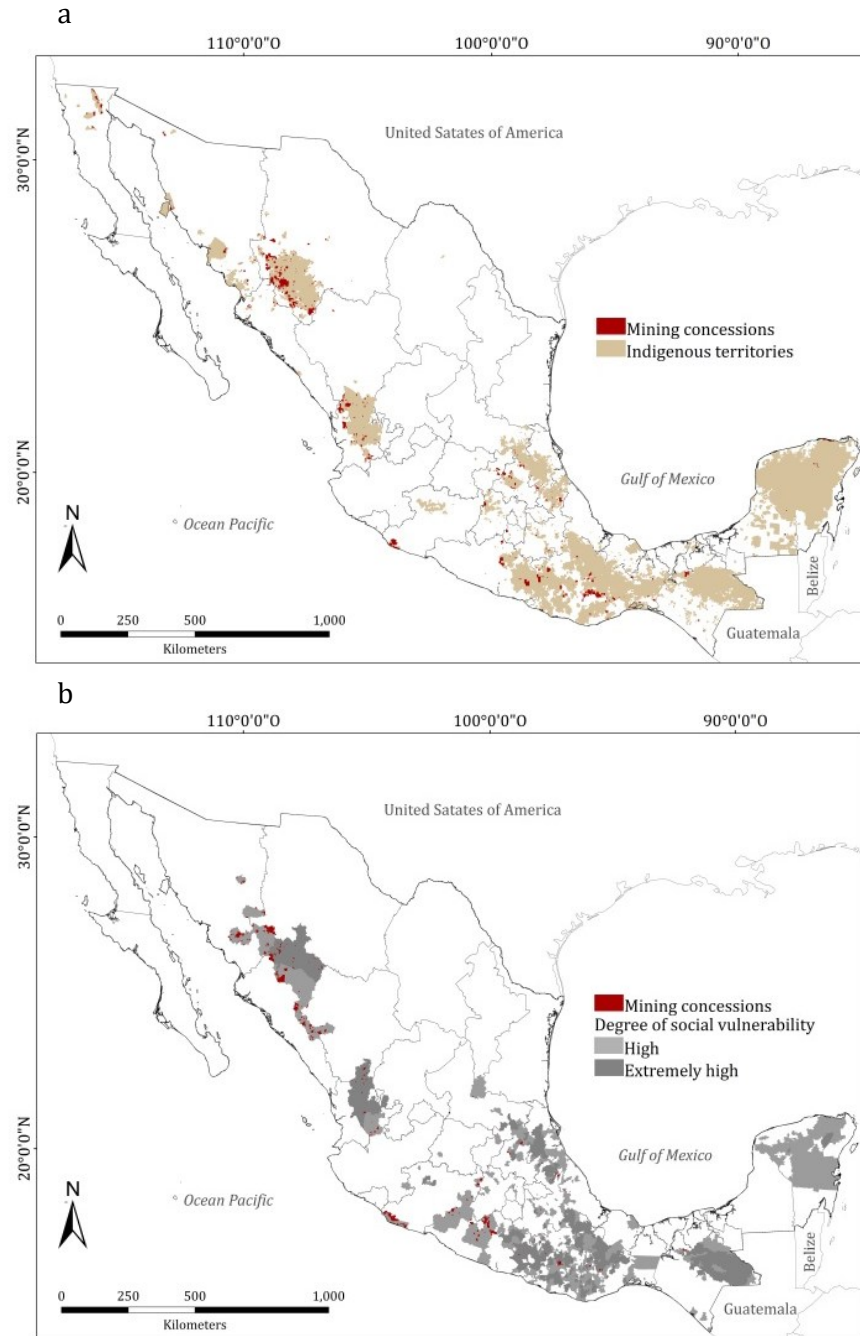


Fig. 4. Overlap of mining concessions with important social and cultural variables: a) Degree of social vulnerability and b) Indigenous territories

The decree on protected areas is intended to conserve specific sites within Mexican territory that hold significant biological and cultural value (CONANP, 2023). However, this decree may be insufficient in situations where mining activities take place or are located near these areas, as mining represents one of the main threats to biodiversity. Our overlap

analysis reveals that there are nine additional protected areas intersected by mining concessions compared to those reported by ARMENDÁRIZ-VILLEGAS ET AL., in 2015.

Previous studies indicate that Biosphere Reserves (BR) are potentially affected by mining concessions (ARMENDÁRIZ-VILLEGAS ET AL., 2015, PÉREZ-JIMÉNEZ,

2016). These reserves represent the highest category of Protected Natural Areas (PNAs), and are characterized by their large size, rich ecosystem and species diversity, and relatively low levels of disturbance. The overlap between BRs and mining concessions may be influenced by geological factors that promote the presence of minerals alongside diverse habitats. Globally, research has shown that approximately 23% of mines are in areas of high biodiversity (MURGUIA ET AL., 2016).

Parque Nacional Rayón is notable because it is entirely overlapping with mining concession areas, which raises concerns about its conservation status despite the decree aimed at protecting its coniferous forest. This forest is home to several endemic species, including the cinnamon-capped tortoise (*Atlapetes pileatus*), the mountain matraca (*Campylorhynchus gularis*), the Mexican thrush (*Catharus occidentalis*), and the blue mulatto (*Melanotis caerulencens*), among others (SEMARNAT, 2018).

The Priority Land Regions (RTP) were selected based on biological criteria that focus on the threats to biodiversity and the opportunities for conserving priority ecosystems. Areas like RTP-118, Cañón del Zopilote in Guerrero, are particularly at risk due to significant overlaps with mining concessions, which can compromise the ecological integrity of these regions. Cañón del Zopilote is recognized as a biological corridor that facilitates connectivity among low deciduous forests and serves as a habitat for endemic species of plants, amphibians, and reptiles (ARRIAGA ET AL., 2017). Furthermore, the Mexico-Acapulco highway divides this region, which increases the risk of losing connectivity with surrounding areas and hinders the movement of individuals between habitats. Similarly, RTP-33, Bassaseachic, functions as a biological corridor, especially for migratory birds. This region is noteworthy for its coniferous and mesophilous forests. However, it is the second area with the greatest overlap with mining concessions (ARRIAGA ET AL., 2017).

Mexico has joined the global initiative for bird conservation by establishing 243 Areas of Importance for Bird Conservation (IBAS). These sites are considered irreplaceable and potentially vulnerable "hotspots" (CIPAMEX & CONABIO, 2015). Notable IBAS such as El Mineral de Nuestra Señora and Laguna Cuyutlán and Estero Palo Verde provide habitats for at least 41 and 69 species of birds, respectively. All species, including birds, are highly sensitive to the disturbances that could occur if

mining activity is carried out. These disturbances can lead to birds fleeing due to noise and habitat destruction. Additionally, some scavenger bird species in the area may be affected by consuming animals poisoned with heavy metals (BUEKERS ET AL., 2009).

Mining activities are associated with habitat destruction and water shortages due to the large amounts needed for mineral extraction. Although there are no official records, it is estimated that mining in Mexico consumes approximately 2.9 cubic metres of water per second (MONGE ET AL., 2013). In 1998, the National Commission for the Knowledge and Use of Biodiversity (CONABIO) initiated the Priority Hydrological Regions program to identify the main sub-basins and aquatic systems. Region 016, which includes the Río Yaqui-Cascada de Bassaseachic, represents the northern limit for Neotropical species and the southern limit for boreal species. This region also supplies water for agriculture in the Yaqui Valley, making it crucial for sustaining agricultural production and human health. However, mining activities in this area may pose a risk due to the potential contamination of water with heavy metals (HOLLAND, 2018; VÁZQUEZ-GARCÍA ET AL., 2020). Unfortunately, the Mining Law and the National Water Law enacted in 1992 prioritized the mining industry, allowing the exploitation of vital water resources for these activities (CONGRESO DE LA UNIÓN, 1992).

In countries such as Chile, Bolivia, Argentina, and Mexico, arid zones play a significant role in the economy due to their favourable geology, limited vegetation, and flexible government regulations concerning mining (OCAMPO-MELGAR ET AL., 2023). According to data from the Mexican Institute of Water Technology, the mining industry is one of the largest consumers of water, which restricts its availability, especially in regions that face water scarcity (PIÑA ET AL., 2021). The central-northern and northwestern regions of Mexico are mountainous, acting as a natural barrier that limits moisture from the Pacific Ocean, and causing a reduction in precipitation. Additionally, these areas are classified as desert regions, with low rainfall and more frequent droughts (LÓPEZ DE LLERGO, 2003). These conditions contribute to basal water stress, which may be exacerbated under mining activity conditions (GASSETT ET AL., 2015).

The SEMARNAT NOM-059 aims to identify species or populations of wild flora and fauna that are at risk due to increasing disturbances in regions with significant biodiversity (GODÍNEZ-GÓMEZ ET AL.,

2020). Currently, advanced technology has made it easier for humans, machinery, and extractive activities to access these areas, posing a potential threat to various species. Therefore, it is essential to effectively enforce the laws protecting these sites to safeguard the integrity of the natural habitat and the species that depend on it.

The lives of human communities around mining sites are affected in various ways. In Mexico, these communities often consist of rural families with limited economic resources. In recent years, peasant and Indigenous groups have engaged in resistance movements at locations such as the San Xavier mine in San Luis Potosí, San José del Progreso in Oaxaca, and Peñasquito, which is Mexico's largest gold mine. These groups are defending their land, water, and natural resources. These movements have led to arrests, threats, human rights violations, and even murders (TETREAULT, 2015; STOLTENBORG & BOELEN, 2016; BASTIDAS-ORREGO ET AL., 2018; CAMACHO-GARZA ET AL., 2022). According to the Mexican Civil Council for Sustainable Forestry (CCMSS, for its acronym in Spanish), mining is one of the most environmentally intense activities affecting rural areas. In some states, such as Sonora, historical and cultural factors have caused the negative impacts of mining to be overlooked. A significant turning point occurred on August 6th, 2014, when the Buenavista del Cobre mine spilled 40,000 cubic meters of acidulated copper sulphate into the Bacanuchi River, drawing widespread attention from the general population (LUGO GIL ET AL., 2022).

In 1992, reforms were made to Article 27 of the Constitution, allowing for the privatization of land and permitting foreign investors to acquire mining concessions (CONGRESO DE LA UNIÓN, 1992). In response to the violations of their rights by the companies granted these mining concessions, communities and Indigenous groups have engaged in social movements. These communities have lost control over their lands and are facing a contaminated environment, water shortages, health problems linked to environmental degradation, and a lack of suitable land for primary activities. As a result, many are compelled to migrate to urban centres, leading to the loss of their traditions, which are a heritage of thousands of years (TETREAULT, 2015; STOLTENBORG & BOELEN, 2016; MUÑOZ-DUQUE ET AL., 2020). A reform to the mining law in 2023, supported by the National Institute of Indigenous People, now mandates that citizen consultations must be conducted in areas inhabited by Indigenous

communities before any mining concession can be granted.

These findings underscore the urgent need to enhance public policy mechanisms that improve transparency in mining concession databases and ensure that land-use planning instruments accurately reflect real conditions. From a conservation standpoint, the overlap between mining concessions and ecologically and socially sensitive areas highlights the necessity of reinforcing territorial restrictions and prioritizing biodiversity protection during the process of granting mining rights. Additionally, the previously documented impacts on rural and Indigenous communities emphasize the importance of strengthening consultation processes. It is crucial to ensure that free, prior, and informed consent is genuinely implemented, going beyond mere formal compliance to provide substantive protection of Indigenous peoples' territorial rights.

5. Conclusion

Currently, there is a lack of transparency and accuracy regarding mining concessions and projects in Mexico, with irregularities identified in their validity. Laws designed to regulate mining activities are being ignored, allowing concessions to be granted in areas critical for biodiversity conservation, particularly affecting Biosphere Reserves. Notably, 84% of Priority Terrestrial Regions and 75% of Priority Hydrological Regions overlap with mining concessions. Furthermore, 10.37% of these concessions are in communities with high social vulnerability, including 39 Indigenous ethnic groups. This analysis pinpointed specific sites that are especially at risk from the potential impacts of mining activities.

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