A proposal for the determination of a Protected Natural Area (PNA) of the Wirikuta zone in the state of San Luis Potosi, México

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Abstract. The Wixárika route was declared by the Government of the State of San Luis Potosí with a first proposal for a polygon as a state reserve area on 27th of October, 2000, and in 2001 the category of Natural Sacred Site is awarded. Initially, this region had an original area of 138,750 ha. Subsequently, the Federal Government of Mexico, through the National Commission of Protected Natural Areas (CONANP), creates the "Preliminary Justification Study", where a larger polygon is proposed, including the Sacred Natural Sites for the Wixárika within the reserve. On the 3rd of November 2012, a group formed by scientists and researchers discussed the study carried out, in which they argued that the limits of the Reserve should respond to natural criteria defined by the watersheds of the basins, rather than linear geometric criteria, thus protecting hydrogeological, eco-systematic and social dynamics. So it is proposed adding to the previous polygon the water area of the basin, which represented an increase of 65,437.41 ha to the previously recognized within the PNA, decreeing a total area of 256,946.32 ha, according to the basin limit. However, after analyzing the zone, it was observed that other important elements were not analyzed in-depth and must be considered, such as; physiological, hydrological and topographical elements, meteorological and climatological phenomena, hydrogeology of the area as an adequate element of the basin delimitation, establishment and location of mining concessions. Also, fauna, flora and vegetation of the area were not studied. Thus, an evaluation of the soil was considered recognizing its relationship with toxic elements that could persist in the area. Similarly, an attempt was contemplated, including economic and social elements of the place. Consequently, it was proposed to expand the polygon, covering a new area of 293,388.42 ha. This expansion included all the elements described.
1. Introduction
PNAs are instruments of environmental policy. Nowadays, PNAs constitute the best tool available in Mexico to conserve biodiversity and the environmental services provided to society. Wirikuta as cultural and spiritual sustenance of the Wixárika people, it has been recognized as a sacred place in order to be protected from all predatory threats [1] [2]. Since 1988, Wirikuta has been part of the World Network of Sacred Natural Sites and it is included on the tentative list to become a Cultural and Natural Heritage of Humanity. In 1991, the government of San Luis Potosí decreed it as Historical and Cultural Heritage Site, and also as Ecological Conservation Zone of the Wixárika ethnic group. In 1999, the financing of a Management Plan was materialized, contemplating funds from the World Wildlife Fund (WWF), and the recognition of the site was obtained by UNESCO as one of the 14 Sacred-Natural Sites of the World within the program of "Conservation of Sacred Natural Sites of the World". In April 2008, in the Hauxa Manaká Pact, held in Durango, the President Felipe Calderón Hinojosa and the governors of the States of Nayarit, Jalisco, Durango, San Luis Potosí and Zacatecas, commitment to respect and protect the historical pilgrimage routes and wixaritari sacred places. The following year, this pact was violated with the granting of mining concessions by the Ministry of Economy without prior, free and well-informed consultation, as indicated by international agreements for the towns and communities that inhabit the “Altiplano potosino”, as well as for the Wixárika people themselves. In October 2012, was created the Justifying Study for the Establishment of the Protected Natural Area and its Draft Decree through the National Commission for Natural Protected Areas (CONANP) [3], which is a decentralized body of the Ministry of Environment and Natural Resources (SEMARNAT) [4]. This document established for the site the category of Wirikuta Biosphere Reserve and a new polygon is proposed for its delimitation spread over an area of 191,504.36 ha.

1.1 Location of the study area
Wirikuta is located in the Northwest portion of the State of San Luis Potosí, Mexico, precisely in the Altiplano Potosino region, in the municipalities of Catorce, Villa de la Paz, Matehuala, Villa de Guadalupe, Charcas, Venegas and Villa de Ramos.

Figure 1. Location of the Wirikuta zone
The total area of the PNAs proposed by CONANP is 191,508.91 ha, which comprises 7 municipalities of the Altiplano area in the State of San Luis Potosí. The polygon includes two core zones with an area of 11,636.09 ha and 10,714.74 ha, respectively. Table 1 shows the percentages of the area corresponding to each of the 7 municipalities, within Wirikuta.

Table 1. Percentage area of the municipalities included in the “Wirikuta” zone

| Municipality        | Percentage area (%) | Total area (Ha)  |
|---------------------|---------------------|------------------|
| Catorce             | 66.85               | 128,037.23       |
| Charcas             | 13.18               | 25,248.4         |
| Villa de Guadalupe  | 9.75                | 18,666.26        |
| Villa de la Paz     | 4.53                | 8,679.37         |
| Cedral              | 2.20                | 4,226.89         |
| Vanegas             | 2.04                | 3,899            |
| Matehuala           | 1.44                | 2,751.77         |
| **Total**           | **100**             | **191,508.91**   |

From the appearance of Canadian companies in México, necessarily being understood in the context of the entry of foreign capital following the signing of the North American Free Trade Agreement (TLCAN) in 1994, as well as the entry into force of the new Mining Law in 1992 and its Regulations in 1993, which liberalized several controls on mining concessions such as the size of the concession areas and the duration periods of 50 years.

This Situation has implied a problem between the mining company and the Wixárika group, which until now has resulted in legal proceedings [5]. While this is happening, Wixárikas representatives, scientists, Ejido farmers and civil organizations are demanding the cancellation of all the mining concessions granted in the territory called Wirikuta, an area that covers more than 140 thousand hectares [6].

In this work, a spatial analysis of the area was performed, based on studies already carried out, a proposal for a new delimitation polygon of the PNA Wirikuta is considered, contemplating that the limits of the reserve should not respond to linear geometric criteria, but rather to natural criteria defined by the watersheds of the basins, thus protecting the hydrological, eco-systematic and social dynamics. At first, in previous studies the area of this zone was increased to 65,437.41 ha, resulting in a total polygon of 256,946.32 ha. However, the area of the proposed polygon was not determined adequately. Thus, in this work, initially was considered as fundamental elements of the topography of the area some elements such as the watershed of the basin and the divisions of the basic geographic areas [7] of the State (AGEB). Also, hydrography, land use, predominant vegetation, physiography, geology, climate and communication routes in the area and other important elements were included. Also, it was considered to perform a global analysis of toxic elements deposits in the area proposed for delimitation, based on the satellite images processing and geochemical data derived from the Mexican Geological Service in collaboration with CONABIO throughout the country. Similarly, it has been considered to analyze economic and social elements of the place.

2. Method
Firstly, vector and raster data for the area were collected from the National Institute of Statistics and Geography (INEGI), using the Universal Transverse Mercator (UTM) Zone 14 North coordinate system, a Horizontal Datum D_WGS_1984, an Ellipsoid WGS_1984 and the management of the information at a scale of 1:1,000,000. Also, a digital elevation model with a spatial resolution of 30
meters was used to carry out the procedures to define the basin and integrate the variables described above. Once the basin was delimited and the proposed polygon was determined, a spatial interpolation procedure was carried out, using the Inverse Distance Weighting (IDW) technique [8] in which the model points are estimated by assigning the weights of the surrounding data in inverse function to the distance. In other words, the points closest to the value to be calculated \( "z" \) intervene more than the furthest. The following formula shows this process:

\[
z = \frac{\sum z_i / d_i^p}{\sum 1/d_i^p}
\]

The main idea with this interpolation process including the "Weighted Overlay", was to superimpose several raster layers of information concerning the delimitation of the proposed polygon for the Wirikuta area, in order to integrate geochemical analysis layers taken from the National Commission for the Knowledge and Use of Biodiversity (CONABIO). This data was useful to analyze the current concentrations of various elements [9] such as; arsenic, barium, beryllium, cadmium, chromium, nickel, silver, lead, and sediment. Also, it was integrated layers at a scale of 1:250,000 of contour data, as well as hydrogeology, edaphology, and annual total precipitation layers. The purpose of the method was to determine the level of influence of geochemical elements in the soil, using a pixel resolution of 30 m. Therefore, it was necessary to reclassify the values of each process to obtain a common range in terms of representation on maps. The reclassification allowed performing a weighted overlay process. In other words, the values determined for the variables were normalized on a scale of 1, 2, 3, 4, and 5 (the pixels took values within this range), where 5 is very high; 4 high; 3 medium; 2 low; 1 very low. Assuming that the value of each pixel is 5, the following was multiplied in both variables:

\[
5 \times 0.16 = 0.8 + 5 \times 0.12 = 0.6 + 5 \times 0.12 = 0.6 + 5 \times 0.12 = 0.6 + 5 \times 0.12 = 0.6 + 5 \times 0.12 = 0.6 + 5 \times 0.12 = 0.6
\]

Finally, a summary of results was made, resulting in a value of 5, which represents the value of the output pixel.

3. Results and discussions
The proposed polygon in this work, for the delimitation of the Wirikuta Reserve, has an area of 293,388.42 ha. There are two core areas, the first is located on the left side of the map and has an area of 11,636.09 ha and the second core area has an area of 10,714.74 ha, the remaining area of the PNA serves as a buffer one.

![Figure 2. Extension of the Protected Natural Area (PNA) "Wirikuta" considering the basin limit and other elements](image-url)
Usually, anthropogenic activities are not carried out in the core areas, except for research and monitoring activities and, in certain cases, traditional harvesting activities implemented by local communities. In the buffer zones, the activities organized should not hinder the conservation objectives of core zones, but rather help to protect it. In the same way, the integration of the Digital Elevation Model allowed appreciating a maximum elevation of 3,181 m.a.s.l. and a minimum of 1,300 m.a.s.l., as well as the location of the municipalities included in the area.

Initially, the layers interpolated were considered in the established ranges, according to the described scales from very low to very high. In this way, it was possible to represent geostatistical processes to determine topographic elevations, hydrogeological units, soil degradation, and annual precipitation. Figure 3 shows an example of the variables used in the map to represent the annual precipitation concentrate.

In order to consider the existing mine deposits within the new Wirikuta PNA, the main persistent minerals of the mining work are described in the following table.

| Municipality                  | Predominant mineral | Municipality                  | Predominant mineral |
|-------------------------------|---------------------|-------------------------------|---------------------|
| Charcas                       | Antimony            | Catorce                       | Silver              |
| Villa de Guadalupe            | Antimony            |                                |                     |
| Catorce                       | Antimony            | Villa de Guadalupe            | Gold                |
| Catorce                       | Phosphorite         | Villa de la Paz               | Marble              |
| Catorce                       | Silver              |                               |                     |

3.1. Indicators of toxic elements persistence in the proposed polygon of the Wirikuta zone

Data extracted from the GS002 project: Elaboration of a regional map of background values of potentially toxic elements (EPT) of Mexico [10] [11] have been used. 1292 sites were located, for which the existence of geochemical data in sediments of the regulated elements was consulted. These, are governed by NOM-147 SEMARNAT SSA1-2004 (Ag, As, Ba, Be, Cd, Cr, Ni, Pb, Se) and such data belong to the database of the Mexican Geological Service. Moreover, the sites coincide with the regions sampled in the described project. So the geochemical data was used as a reference and to compare the background values obtained in the soil analyzes, the hydrogeological units, the soil degradation, and the annual precipitation. From the total points collected, only a part of this sample...
(42 points) is found within the reserve, just in the area of interest, in the northeast part. Units of measurement are in parts per million (ppm), thus concentrations of each element found will be described, but given the number of maps of each of the elements described, only a map will be integrated as an example.

Concentrations of arsenic in the soil are largely low (1-50 ppm), in the center there is a kind of strip, in which its values range from the medium category (50-100 ppm), high (100-150 ppm) and very high (150-180 ppm) distributed in this area.

As for the element Barium (Ba), in the area of interest, the categories range from low in a small portion to the east (18-46 ppm), medium (46-100 ppm) from the north to the southeast and close to the “Cerro el Quemado” area, so it is worrying, since most of it is in the high category (100-400 ppm). On the other hand, a small part to the south and another to the north present very high values (more than 400 ppm).

In the case of Beryllium (Be), within the area of interest, the low category (0.8659 - 1 ppm) and medium (1-1.05 ppm) predominate, however, in the PNA we also find the very low categories (0.8659 ppm), high (1.05-1.3 ppm) and very high (1.3-2 ppm), which indicates that the situation regarding this element is not harmful to this region.

According to Cadmium (Cd) levels, most of the area has shown low values (0.4-2 ppm), then there is the medium category (2-6 ppm), a small part has high values (6-8.2 ppm) and a very small part presents values in a very high category, with levels greater than 8 ppm.

In the case of Chromium (Cr) concentration in the soil, it has been occurring from the outside to the inside, where the levels of Cr are largely low (7-17 ppm). Also, in the central zone of the PNA, the category changes to medium (17-40 ppm), high (40-60 ppm) and lastly very high (60-102 ppm).

Nickel (Ni) categories recorded in the map analysis are low (11.5-15 ppm), medium (15-25 ppm), high (25-37 ppm) and very high (37-39 ppm) present in the zone.

Silver (Ag) concentrations in the area are low (0.08-3 ppm), medium (3-5.5 ppm), high (5.5-12.4 ppm) and very high (12.4-17.4 ppm).

Lead (Pb) concentrations in the area are low (11-47 ppm), medium (47-151 ppm), high (151-260 ppm) and very high (260-491 ppm).

From the integration of geochemical soil layers of all the elements analyzed, it is observed that in the area of interest the influence is mostly medium, followed by low category and finally the high category in a small area, which indicates, in this area is present the highest concentration of all the previous elements.

![Figure 4. Soil Arsenic Levels.](image)
3.2. Geostatistical indicators of the social and economic situation of the study area.

In order to consider other elements affecting the study area from the social perspective, the economic activities and the type of marginalization persisting, variables such as the Economically Active Population (EAP) were integrated, resulting in a total population in the area study of 293,711 inhabitants, from which 103,903 belong to the EAP. So, indicators of each analyzed element were described, but only the figure of a geostatistical analysis has been integrated through a map as an example. Figure 6 shows the EAP distribution. The highest concentration of EAP is located in the municipality of Matehuala, closely to the urban area. However, in most of the PNA, the levels are medium. To the north, small portions of low values are observed, and to the northeast, EAP concentration is low and very low. Where the highest category corresponds to 35,894 people and the lowest to 1,949 people.

Regarding the Economically Inactive Population (EIP), which includes individuals who are not performing activities that generate goods and services for the market. Usually, they dedicate their time to activities such as studying or household chores. It also includes people who have already left the workforce, such as pensioners and retirees and individuals who for any reason (health and disability) do not carry out any kind of activity. From the total population of the PNA, EIP category corresponds
to a total of 113,853 inhabitants. From the total inhabitants of EIP category, the Male Economically Inactive Population (MEIP) is derived, comprising a total of 14,857 people, which indicates the number of men who could be interested in obtaining a job. In this class are men who of working age were not employed or were not in a search situation in the reference period. Therefore, it is observed a very low of MEIP in the study area, except for some small parts, where low and medium values are present. The minimum number of inhabitants is 1 and the maximum is 7,657.

In the case of the literate population, the total reported in the study area is 182,469 people, where the minimum amount of inhabitants is 3,392 and the maximum is 59,801. Therefore, it is observed that the literate population is in a medium category in most of the area, which is located to the north and northeast. While to the southeast, the category is low and to the east, there are strips with high and very high categories in the study area. Finally to the northeast, is located a small area of very low category.

For the study, most of the time, poverty has been defined as the inability of a family to cover with their expenses a subsistence basic basket. The total population with extreme poverty reported in the study area is 40,709 people, where the minimum is 461 people and the maximum is 6,325. Therefore, it is observed, in most of the area, that the population with extreme poverty is in a medium category. In the same dimensions, to the north and centre of the area, the high category is located. However, in the study area near the hill “El Quemado”, a great number of people are in a low category.

When working with different types of variables, it was necessary to reclassify the values of each one, to obtain a common range and perform the weighted overlay process as previously described, so that in the next step influence weights to each variable were assigned. Weights were assigned as follows; 40% to the MEIP variable, 20% to extreme poverty, 15% to EIP, 15% to EAP, and lastly, 10% to the literate population. Subsequently, the value of each pixel was multiplied by the weight of each variable.

Assuming that the value of each pixel is 5, the following multiplications was performed in both variables:

\[ 5 \times 0.40 = 2 + 5 \times 0.20 = 1 + 5 \times 0.15 = 0.75 + 5 \times 0.15 = 0.75 + 5 \times 0.10 = 0.5. \]

Finally, as a result of the weighted superposition of the elements described above, the following map was obtained, showing the interaction of all the elements that were processed together.

![Greater influence areas in social and economic aspects.](image)
4. Conclusion
The proposed methodology considered deepening into more important variables for the Wirikuta PNA determination. Although the conflict is still in the legal process, an adequate study of the area has not been determined. The mining area that underlies the interior of the area that forms the Wirikuta polygon has concession permits that the Mexican federal government granted at the time. However, it has been neglected to go deeper into studies this area requires and evaluate the advantages or disadvantages of mining, to address the environmental, social, cultural and economic impacts caused by these activities [12] [13], based on the concessions assigned to Canadian companies. The proposal of a new polygon in the Wirikuta area, which integrates the elements described in this analysis, had two purposes; 1) considering the delimitation of a watershed in the hydrological basin of the area and 2) report that the soil types of the area have been subject to toxic elements over time, and possibly underlie by mining and/or the type of minerals the soil of the place contains. In addition, it was necessary to point out that the justifying study for the PNA declaration elaborated in 2012 lacks scientific support and the variables that were determined, were very poor in their analysis. It is important to consider that the seven municipalities in which the Wirikuta area converges, part of their populations benefit from the economy generated by mining companies [14]. Therefore, the search for a balance to reach consensus has not been carried out adequately, and the conflict has been imposed based on existing arguments, elements that require an expert opinion and exception of political environments without knowledge.

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