

Multitemporal Analysis of Urban Expansion by Remote Sensing in the Area of Huacachina Lagoon in Ica, Peru

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Globally, the soil resource has undergone several changes associated with human activities and climate change, being urban expansion one of the main authors. Therefore, the present research analyzed by remote sensing the changes of urban expansion in the Huacachina lagoon area in Ica, Peru from 1988 to 2023. For the study, 7 spectral indices (BAEI, NDBI, BU, NDWI, MNDWI, NDVI, MSAVI2) were evaluated in a supervised manner with Support Vector Machine (SVM) classifier and in accordance with the thematic evaluation guide of the General Directorate of Land Management (GDLM), considering the BAEI index to quantify the urban cover, the MSAVI2 index to quantify the vegetation cover and the MNDWI index to quantify the body of water. The images used correspond to an image free of clouds and in the hottest season of the study area. The results indicated growth of the urban center and variation of vegetation cover and water mirror. The results indicated growth of the urban center and variation in vegetation cover and water mirror. The growth of the urban center was constant throughout the analyzed timeline, but intensified in the period from 2009 to 2016. The same happened with the water body, according to the MNDWI index, in this period the surface extension decreased faster. With respect to vegetation cover for this period, in 2009, vegetation cover occupied part of the lagoon surface, and by 2016, it covered the entire surface of the Huacachina Lagoon. The multitemporal analysis concludes that vegetation cover will continue to decrease in the coming years, causing climatic variations in the area, and this allows alerting the competent authorities to take measures to value the ecosystem from the approach of sustainable land use, being unsustainable that the urban area continues to grow in the area of the Huacachina Lagoon.

1. Introduction

The supply of available soils globally has decreased, 60% of this decrease is associated with direct human activities and 40% with climate change (Song *et al.*, 2018). Activities such as agricultural expansion, commercial development, and infrastructure development affect soil availability (Gidey, 2023; Ying *et al.*, 2017). These activities negatively affect the services provided by soil at both regional and global scales, especially as a consequence of a steadily increasing population (Wu *et al.*, 2023; Tao *et al.*, 2023). Growth is expected to intensify over the last 5 decades, especially in less developed countries, where sustainability has become an urgent social and economic issue (UN-HABITAT, 2020; Szoke & Jankovits, 2023).

Urban development in Peruvian cities between 2000 and 2015, compared to cities in other Latin American countries such as Cuba, Colombia, Venezuela, Brazil, Nicaragua, Argentina, Guatemala and Chile, followed a faster pace. This accelerated growth implied that 90% of infrastructure development is informal, significantly affecting the quality of life of urban residents (Espinoza & Fort 2020). Peru experienced a population growth of 24,214,274 inhabitants between 1940 and 2017, this translated into an average increase of 4.4 times per year (INEI, 2018; INEI, 2020). In the department of Ica, 46.6% of the total population is settled on the soils of the district of Ica, the location of the Huacachina Lagoon (INEI, 2018).

In Ica, over time, urban expansion has put increasing pressure on the ecosystems, leading to progressive deterioration and making the lagoon vulnerable due to the pressure exerted by entrepreneurs with economic activities seeking to build closer and closer to the lagoon (Housing Commission, 2009). Population growth brings with it infrastructure development, use of energy resources and demand for a greater water supply, but also

causes groundwater to be exploited in the Huacachina lagoon area and vegetation to be displaced by urban land, affecting the use activities provided by the lagoon, the dunes and tourism in the area (Tao *et al.*, 2023; Argota & Doroteo, 2021).

The effects of climate change and rapid urban expansion can be felt directly, and environmental plans to address these effects are a high priority (Ayra *et al.*, 2021; Yesquen *et al.*, 2021; Sipos *et al.*, 2023). To manage the urban and environmental crisis as a consequence of rapid population expansion, remote sensing and Geographic Information Systems (GIS) are tools that allow rapid monitoring of urban growth (Stoica, Zamfir & Virghileanu, 2023; & Elmdari *et al.*, 2021). For this purpose, there are different methods to monitor land changes such as the geodetic method using satellites with active and passive sensors (Guido *et al.* 2022), and classification methodologies for data either supervised (Garcia & Culma 2020; Amine *et al.* 2023), and unsupervised (Mertes *et al.* 2015 & Popa *et al.* 2022).

The research, from the environmental approach contributes to the preservation of biodiversity, giving an integral monitoring of urban growth in the Huacachina Lagoon area, thus allowing the detection of natural disasters. In the economic approach, it helps the efficient management of the Huacachina Lagoon area within the framework of the development of strategies for ecosystem preservation and sustainable urban development, allowing to increase the income of the local population. And, from the social approach, it allows informed decision making, thus providing the opportunity to value the Huacachina Lagoon in the face of changes in this environment.

Therefore, this research analyzed multitemporally by remote sensing the changes of urban expansion in the area of Huacachina Lagoon in Ica, Peru from 1988 to 2023, considering a mixed classification with spectral indices.

2. Materials and methods

2.1 Study area

The study was conducted in the Huacachina Lagoon area, which is a regional conservation area located in the district of Ica, Peru. The studied area is delimited by 4 geographical coordinates: 414530.28E, 8445310.99S; 420702.20E, 8445330.97S; 420713.76E, 8441624.72S and 414542.74E, 8441604.71S, having a total area of 21 km². This area of the Huacachina lagoon is shown in Figure 1.

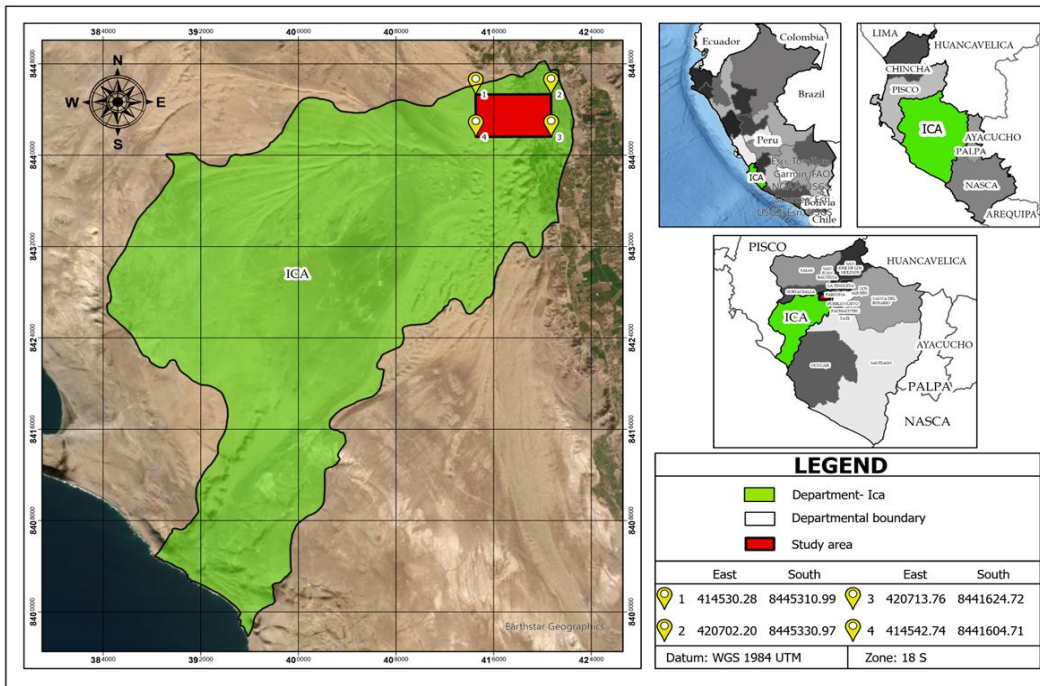


Figure 1: Study area

2.2 Dataset

The satellite images were downloaded from the Google Earth Engine (GEE) platform, starting from the period 1988 to 2023 (Table 1). In addition, these images had a 5% cloud filter and top of atmosphere (TOA) corrections. The downloaded images correspond to the month of April, being the warmest period for the district of Ica.

Table 1: Satellite images from the Google Earth Engine (GEE) platform

Acquisition date	Satellite/Sensor	ID	Satellite/Sensor
17/04/1988	Landsat 5 TM	LANOSAT/LT05/C02/T 1_TOA/LTOS_006070_19880417	Green, Red, NIR y SWIR 1
21/04/1995	Landsat 7 ETM	LANDSAT/LT05/C02/T 1_TOA/LT05_006070_19950421	Green, Red, NIR y SWIR 1
16/04/2002	Landsat 7 ETM	LANDSAT/LE07/C02/T1-TOA/LE07-006070-20020416	Green, Red, NIR y SWIR 1
3/04/2009	Landsat 5 TM	LANDSAT/LT05/C02/T1_TOA/LT05_006070_20090427	Green, Red, NIR y SWIR 1
14/04/2016	Landsat 8 OLI	LANDSAT/LC08/C02/T 1_TOA/LC08_006070_20_160414	Green, Red, NIR y SWIR 1
18/04/2023	Landsat 8 OLI	LANDSAT/LC08/C02/T1_TOA/LC08_006070_20230418	Green, Red, NIR y SWIR 1
30/04/2023	Sentinel 2a MSI	COPERNICUS/S2_SR/20230430T 151711_20230430T15 1705_T18LVK	Red, Green, Vegetation Red Edge y SWIR

2.3 Data processing

Data processing was performed in ArcGIS PRO software and started by identifying the accuracy of 7 spectral indices, 3 for urban cover (BAEI, BU and NDBI), 2 for vegetal cover (MSAVI2 and NDVI) and 2 for water body (MNDWI and NDWI) (Mendieta Torres, 2023). The spectral indices are shown in Table 2.

Table 2: Spectral indices used in the research

Equation	Reference
$BAEI = \frac{(Red - L)}{(Green + SWIR1)}$	(Bouzekri, et al., 2015).
$NDBI = \frac{(SWIR - NIR)}{(SWIR + NIR)}$	(Ji et al., 2023)
$BU = \frac{(NDBI - NDVI)}{(NDBI + NDVI)}$	(Chunyang et al, 2010)
$NDWI = \frac{(Green - NIR)}{(Green + NIR)}$	(Ziyuan et al., 2023)
$MNDWI = \frac{(Green - SWIR)}{(Green + SWIR)}$	(Singh et al., 2023)
$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$	(Sharma et al., 2023)
$MSAVI2 = \frac{(2 * NIR + 1 - \sqrt{(2 * NIR + 1)^2 - 8 * (NIR - RED)})}{2}$	(Fabijańczyk & Zawadzki, 2022)

Data classification was developed by unsupervised and supervised classification. The unsupervised classification considered 4 strata (vegetation cover, urban cover, water body and bare soil) with 450 random control points. In the supervised classification, the results of the 7 spectral indices were evaluated using 420 precision points that were validated with the support of a Garmin 64 S GPS (Mendieta Torres, 2023). The results of both processes allowed the identification of spectral indices that reflect data from reality with an acceptable error, in accordance with the thematic evaluation guide established by the General Directorate of Land Management (DGOT, 2014).

3. Results and discussion

3.1 Distribution and dynamics of urban areas using the BAEI spectral index

The processing of the satellite images, the data and the superimposition of the spectral indices made it possible to analyze the evolution of the urban area and other land cover in the Huacachina Lagoon area. In the last 35 years, the growth of the urban area is significant. In addition, the data reveal that the urban area presented an overall growth of 85.46% at a rate of 14.98% per year. This occurred in 5-time intervals with a time jump of 7 years (1988-1995, 1995-2002, 2002-2009, 2009-2016 and 2016-2023). Figure 2 shows the behavior of urban expansion in the area of the Huacachina Lagoon in Ica, Peru.

Figure 2 show the behavior of the urban area for the 7 years under evaluation, showing in dark blue, the urban coverage of 1988; in red, the urban coverage of 1995; in purple, the urban coverage of 2002; in yellow, the urban coverage of 2009; in orange, the coverage of 2016; in a red mesh, the urban coverage of 2023. It is evident that the urban center was settled in the east and west zone (1988) to later expand towards the northwest zone (2023), going from 448.11 ha to 972.45 ha. Taking the 1988 urban area as a starting point, it was found that the urban center developed around the Huacachina Lagoon, mainly because of the sources of work and tourist income.

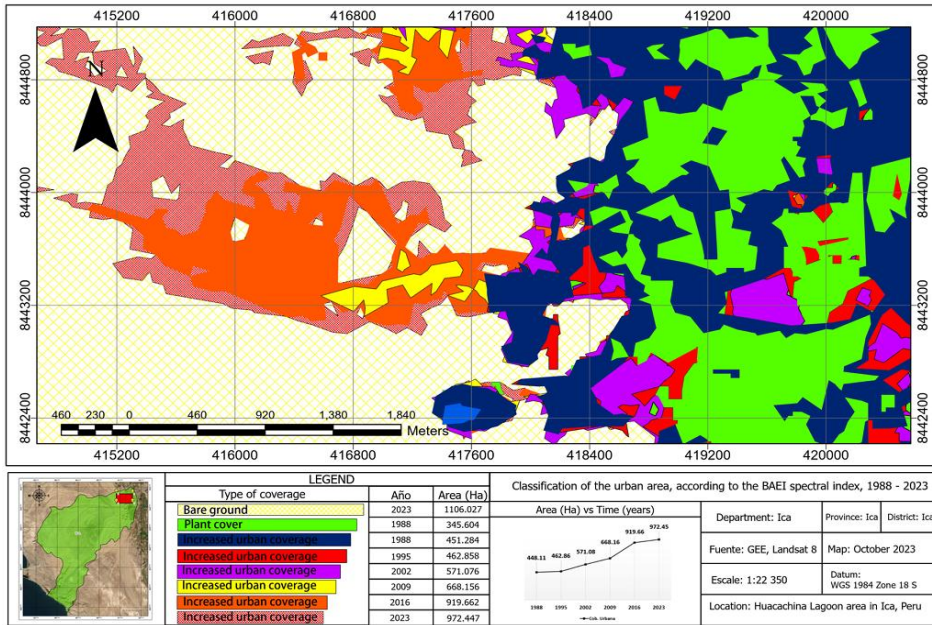


Figure 2: Representation of urban expansion according to the BAEI index (1988 to 2023)

3.2. Discrimination of urban areas through the spectral index MSAVI2 and MNDDWI

According to the spectral index MSAVI2 for vegetation cover and MNDDWI for the water body, it was recorded that the growth of urban cover was related to these coverages, so it was more intense in the first 4 intervals of study years (1988 - 1995, 1995 - 2002, 2002 - 2009 and 2009 - 2016), and in the last interval of study year (2016 - 2023) it was appreciated that there was recovery of the boundaries of vegetation cover and water body with respect to previous years. Figure 3 summarizes the 5 study year intervals, with the period from 1988 to 2016 representing the first 4 study year intervals, and the period from 2016 to 2023 representing the last study year interval.

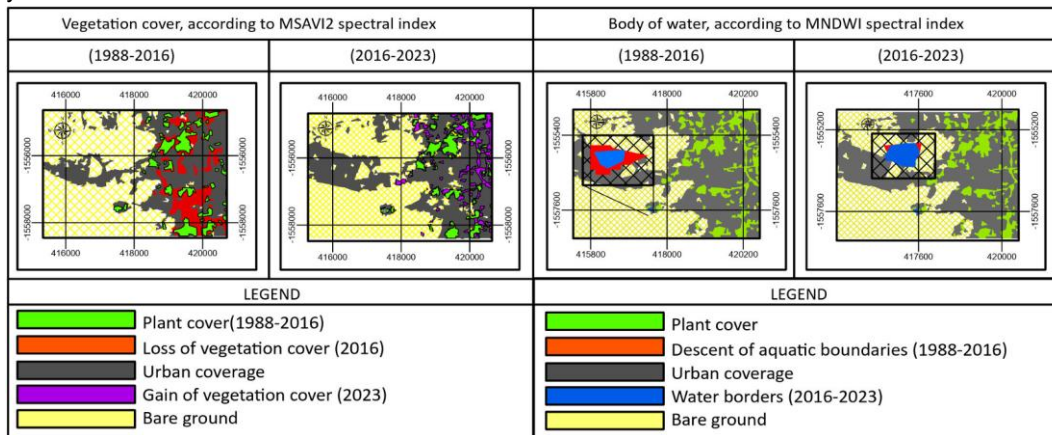


Figure 3: Representation of vegetation cover and water body for the study period 1988 to 2023

Between 1988 and 1995, urban growth passed from 448.11 to 462.86 ha at a rate of 2.11% per year, and the lagoon experienced a loss of 3.75 to 2.85 ha, representing a negative rate of change of 0.13% per year. In the period from 1995 to 2002, urban coverage increased from 462.86 to 571.08 ha, a growth of 108.218 ha at a rate of 15.46% per year, and the aquatic boundaries in the lagoon decreased from 2.85 to 2.78 ha with a loss of 0.07 ha, at a rate of change of -0.01% per year. In the period from 2002 to 2009, urban cover expanded by 97.08 ha at a rate of 13.87% per year, while the loss scenario in the lagoon continued, going from 2.78 to 1.99 ha, representing a loss of 0.79 ha, at a negative rate of change of 0.11% per year. Between 2009 and 2016, the growth in urban cover compared to the other periods was higher, going from 668.16 to 919.66 ha, with an annual growth of 35.93%, and the lagoon passed from 1.99 to 1.44 ha at a negative rate of change of 0.08% per year. Finally, between 2016 and 2023, the urban coverage increased from 919.66 ha to 972.45 ha, with a growth of

7.54% per year, and in the lagoon, there was an increase in extent of 0.15 ha, which may be the result of conservation efforts and artificial water injection by local authorities. In this context, artificially reacting to water scarcity would only generate competition between water for human consumption and water for other uses. Moreover, this would only cure the symptoms in the short term and not in the long term. All this behavior of urban growth in the five-year intervals of the study is shown in Figure 4a.

Figure 4b shows the prediction of the behavior of the lagoon to the year 2045. This prediction was based on a linear regression model using numerical data obtained from vector image processing for each year of the study period.

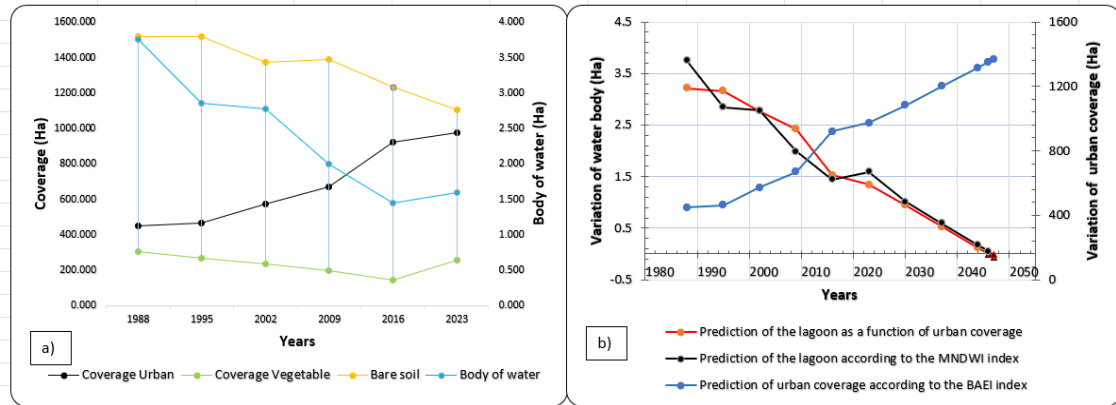


Figure 4: a) Variation of vegetation cover as a function of urban growth; b) Prediction of the behavior of the lagoon in 2045

Espinoza & Fort (2020) argue that between 2009 and 2023, Peru has experienced a remarkable informal growth. This distribution and growth recorded during that period responds to sources of work, tourist income and handicrafts, both formal and informal that had as their initial focus the west side of the Huacachina Lagoon area (Obeso, 2019). The variation in coverages occurred at different rates of change, following a linear distribution. In addition, given the increasing urban expansion in the study area, the hypothesis of a relationship between urban development and ecosystem loss is born (Minnig *et al.*, 2018). Figure 4b showed two extinction scenarios, one based on remote sensing data and the other based on the strength of correlation between the expansion of urban coverage and the variation of the Huacachina Lagoon. According to the strength of correlation between the expansion of urban coverage and the variation of the Huacachina Lagoon, it is anticipated with 84% certainty that there could be a total extinction of the Huacachina Lagoon by the year 2046. With 16% certainty it could be stated that urban growth alone is not sufficient to explain the loss of this ecosystem (Reyes & Isu, 2020). With this approach, it is assumed that the water stress generated by the urban area to the Huacachina Lagoon remains constant, indicating that both the indirect demand for water resources by the population and the pressure that may be generated by meteorological changes over the years remain constant.

4. Conclusions

The multi-temporal analysis of urban expansion allowed us to detect changes in the Huacachina Lagoon area by remote sensing, indicating that from 1988 to 2023, urban growth increased from 448.11 to 972.45 ha, at a rate of change of 14.98% per year, with the most intense growth between 2009 and 2016. In addition, it was predicted with 84% certainty that the Huacachina Lagoon could be extinct by 2046, alerting the competent authorities to take measures to value the ecosystem from the approach of sustainable land use in the area of the Huacachina Lagoon in Ica, Peru. It should also be emphasized that these studies should have a systematic analysis that articulates the interrelationships of the components on the ground and in the lagoon's hydrological cycle in order to correlate the different variables that characterize this natural system.

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