

Análisis multitemporal de la dinámica de cobertura/uso de suelo de la cuenca del río Esmeraldas

Multi-temporal analysis of the land cover/use dynamics in the Esmeraldas River basin

- ¹ Jesmar Jandry Corozo Hurtado  <https://orcid.org/0009-0003-0908-129X>
Luis Vargas Torres Technical University, SeasonMutile Experimental, Esmeraldas, Ecuador.
jesmar.corozo@utelvt.edu.ec
- ² Patricio Alejandro Merino Cordova  <https://orcid.org/0000-0001-5068-8673>
Luis Vargas Torres Technical University, SeasonMutile Experimental, Esmeraldas, Ecuador.
patricio.merino@utelvt.edu.ec
- ³ Byron Fabricio Estupiñán Cox  <https://orcid.org/0000-0001-6523-667X>
Luis Vargas Torres Technical University, SeasonMutile Experimental, Esmeraldas, Ecuador.
byron.estupinan@utelvt.edu.ec
- ⁴ Joel Darvin Velasco Quiñonez  <https://orcid.org/0000-0001-8864-9557>
Luis Vargas Torres Technical University, SeasonMutile Experimental, Esmeraldas, Ecuador.
joel.velasco@utelvt.edu.ec

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Palabras

claves: Cuenca hidrográfica del río Esmeraldas, uso de suelo, zona antrópica, análisis multitemporal, proyección.

Keywords:

Esmeraldas River watershed, land use, anthropic zone, multitemporal analysis, projection.

Resumen

Introducción: El análisis multitemporal de la cobertura y uso de suelo de la cuenca del río Esmeraldas se realizó para el periodo del año 2000 al 2022, junto con una proyección para el año 2044 que fue elaborada en el software Idrisi Selva v.17 y ArcGIS 10.8. **Objetivo:** Analizar los cambios de cobertura y el uso del suelo de la cuenca del río Esmeraldas para el periodo del año 2000 al 2022 con proyección para el año 2044. **Metodología:** Para esta investigación se establecieron 2 etapas: Delimitación del área de estudio, seguido de la obtención de la información cartográfica de las coberturas y uso de suelo, las que fueron adquiridas del portal del ministerio de ambiente, agua y transición ecológica. **Resultados:** La tasa de cambio de cobertura y uso de suelo fue la siguiente: Bosque -73.94%, tierra agropecuaria 12.68%, zona antrópica 100.00%, Vegetación Arb y Herb -98.70%, Otras Tierras -82.48%, Cuerpo de Agua -89.21%. **Conclusión:** El análisis multitemporal demostró los cambios que tuvieron las coberturas de la cuenca del río Esmeraldas en un periodo de 22 años con el fin de dar a conocer como las actividades humanas influyen en los cambios de cobertura y el uso del suelo. **Área de estudio general:** Ecología y medio ambiente. **Área de estudio específica:** Hidrología.

Abstract

Introduction: The multitemporal analysis of the land cover and land use of the Esmeraldas River basin was conducted for the period from 2000 to 2022, along with a projection for the year 2044 that was prepared in the Idrisi Selva v.17 and ArcGIS 10.8 software. **objective:** To analyze changes in land cover and land use in the Esmeraldas River basin for the period from 2000 to 2022 with a projection for 2044. **Methodology:** For this research, 2 stages were established: Delimitation of the study area, followed by obtaining cartographic information on land cover and use, which were acquired from the portal of the Ministry of Environment, Water and Ecological Transition. **Results:** The rate of change in land cover and land use was as follows: Forest -73.94%, Agricultural Land 12.68%, Anthropic Zone 100.00%, Arb and Herb Vegetation -98.70%, Other Land -82.48%, Water Body -89.21%. **Conclusion:** The multitemporal analysis demonstrated the changes in the coverage of the Esmeraldas River basin over a period

of 22 years to show how human activities influence changes in land cover and land use. General area of study: Ecology and environment. Specific area of study: Hydrology.

Introduction

In Ecuador, through agriculture and the expansion of urban areas, there have been intense changes in land coverage and use. The population increase is acting directly on these areas, because more and more area has to be sacrificed to establish crops and urban areas.(Pines, 2016).

The coverage and land use of the Esmeraldas River basin is a matter of common interest due to the demographic growth that society has had in recent years and as a result of this, variations have occurred between the coverage and land use.(Garcia, 2022).

Multitemporal analysis is a process that allows us to predict future scenarios and determine how the progress of society is related to the loss of natural areas. Nowadays, with GIS tools we can perform coverage analysis and obtain information on land uses, while at the same time seeking to demonstrate to society that soil degradation and water pollution is an irreversible problem.(Pesantez, 2015).

According to Harbaugh (1972 cited in Vasconez et al., 2019), the watershed is a topographically defined area, drained by a watercourse or a connected system of watercourses, which has a simple outlet for all the effluent flow to be discharged.

The Esmeraldas River basin corresponds to the Pacific slope, and is formed by three large tributaries: the Guayllabamba River, the Blanco River and the Quinindé River, with an area of 21,669 km². Approximately 70 rivers and numerous ravines drain into this territorial unit. Its course is navigable from its confluence with the Guayllabamba River to its mouth in the Pacific Ocean.(Reyes et al., 2022).

The objective of this work is to carry out a multitemporal analysis of the land cover and use of the Esmeraldas River basin in the period from 2000 to 2022 with a projection for the year 2044 using geographic information systems, through the tools Idrisi Selva v.17 and ArcGIS 10.8, at the same time this research seeks to make citizens aware of how human activities influence land change and use.

Methodology

Area of study

The Esmeraldas River basin is located in the northwest of the Province of Esmeraldas and covers the territory of Pichincha, Santo Domingo, Imbabura, Manabí and Cotopaxi. The topography of the basin ranges from 0 to 5,896 m above sea level, occupying the 5th place in the national basins. This territorial unit has an area of 21,658.4 km² where the water sources are located: Blanco, Guayllabamba, Toachi, Pilatón and Esmeraldas. It should be noted that the Esmeraldas River flows into the Pacific Ocean (Dorigo, 2012).

Figure 1

Location of work area



Obtaining cartographic information

The cartographic information on land cover and use was obtained from the portal of the Ministry of Environment, Water and Ecological Transition (MAATE). The selection of the coverage was made on the interactive map of (MAATE). Proceeding to choose the layer of land cover and use for the year 2000 and 2022 considering that these covers are in a scale of 1:100,000 and then download them in Shapefile format to process the information in the ArcGIS 10.8 software, Once the information was loaded in ArcGIS, the general coverage was cut based on the Shapefile of the Esmeraldas River basin, continuing with the processing of the information, we select the covers and go to layer properties in the symbology option and then in categories place the covers that in this

case are: forest, agricultural land, other lands, shrub and herbaceous vegetation, anthropic zone and body of water, once the layers were categorized and symbolized, the map of covers and uses was prepared. of soil for the years 2000 and 2022.

The coverage projection for the year 2044 was made with the land cover and use projections for the years 2000 and 2022 by converting the Shapefile format files to raster to reclassify them and convert them into ASCII format files to process them in Idrisi Selva v.17 software.

In the Idrisi Selva v.17 software, the ASCII format layers for the year 2000 and 2022 were loaded, to convert them into format files (RST), to use them with the Markov chain to predict the future change that land cover and use may have for the year 2044.

The multitemporal analysis was carried out by comparing the coverages from 2000-2022 and the projection for the year 2044 in order to compare the changes in coverage and land use that have occurred in these time periods. With the results of the data processing, the transition matrix was made with the Excel software (Table 1). For the transition matrix, a code will be assigned for each coverage, taking into account that the rows correspond to the coverages of the first period (time 1), and the columns correspond to the second period (time 2). When completing the transition matrix, the coverage values shown diagonally are those that have not changed in this period of time (Niño, 2020).

Table 1

Cross-tabulation code matrix between the years 2000-2022

| Land Cover/Use | | Code | Year 2 | | | | | |
|----------------|-------------------------|------|--------|-------------------|-------------------------|----------------|-------------|---------------|
| | | | Forest | Agricultural Land | Arb and Herb Vegetation | Anthropic Zone | Other Lands | Body of water |
| | | | 10 | 20 | 30 | 40 | 50 | 60 |
| Year 1 | Forest | 1 | 11 | 21 | 31 | 41 | 51 | 61 |
| | Agricultural Land | 2 | 12 | 22 | 32 | 42 | 52 | 62 |
| Year 1 | Arb and Herb Vegetation | 3 | 13 | 23 | 33 | 43 | 53 | 63 |
| | Anthropic Zone | 4 | 14 | 24 | 34 | 44 | 54 | 64 |
| | Other Lands | 5 | 15 | 25 | 35 | 45 | 55 | 65 |
| | Body of water | 6 | 16 | 26 | 36 | 46 | 56 | 66 |

Results

Vegetation cover and land use 2000-2022

In the land coverage and use for the year 2000 (figure 2), it can be observed that the agricultural land category was the category that had the greatest proportion for that year with an area of 1,163,157.20 hectares, which corresponds to 53.71% of the total area of the basin. The second category with the largest area was forest with 681,048.22 hectares, which would be 31.45% of the total area, the category of shrub and herbaceous vegetation occupied 3rd place with 265,309.25 hectares, which in percentage corresponds to 12.25% of the area, the anthropic zone category in 2000 had 31,480.92 hectares or 1.45% of the area of the basin, other lands had an area of 11,925.31 hectares, which in percentage is 0.55% and the water body category had 0.60% of the total area of the basin, which is 12,900.76 hectares (table 2).

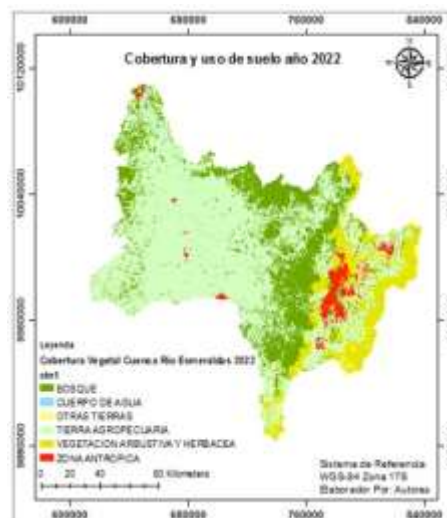
In the land coverage and use of the year 2022 (figure 3) it can be seen that the agricultural land category continued to be the category with the largest area in the Esmeraldas River basin, the agricultural land category in 2022 had an area of 1,310,623.06 hectares, which corresponds to 60.51% of the coverage, the forest category has 23.25% of the coverage of the basin, which is 503,584.00 hectares, shrub and herbaceous vegetation had 261,865.37 hectares for the year 2022, which would be 12.09%. These data can be verified in table 2. Continuing with the coverage, we have the anthropic zone with 68,395.52 hectares, which corresponds to 3.16% of the total area, other lands have 9845.50 hectares, which corresponds to 0.45% of the basin and the water body category has 11,508.21 hectares, which is 0.53% of the basin area.

Figure 2

Figure 3

Land use and coverage in the year 2000

Land use and coverage for the year 2022



Change in vegetation cover and land use 2000-2022

The change in coverage for the period 2000-2022 (table 2), it is observed that the agricultural land category has a net change of 147465.86 hectares and a change rate of 12.68%, the forest cover in 2000-2022 had a net change of 177464.22 hectares with a change rate of -73.94%, the shrub and herbaceous vegetation category had a net change of 3443.88 hectares, with a change rate of -98.70%, the anthropic zone category has a net change of 36914.60 hectares and a change rate > 100%, the cover of other lands has a net change of surface 2079.81 hectares with a change rate of -82.56%, water body has a change of 1392.55 hectares with a rate of -89.21% (table 2 and figure 4).

Table 2

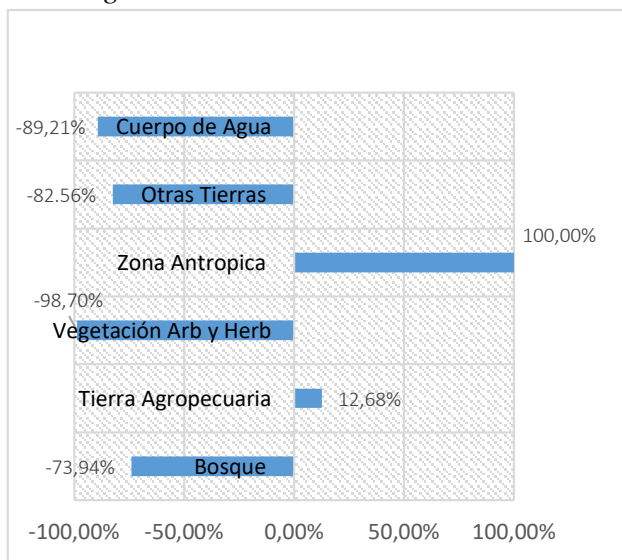
Change in land cover and use from 2000 to 2022

| Category | Forest | Agricultural Land | Arb and Herb Vegetation | Anthropic Zone | Other Lands | Body of water |
|------------------------------------|-----------|-------------------|-------------------------|----------------|-------------|---------------|
| Land cover and use in 2000 (Ha) | 681048.22 | 1163157.20 | 265309.25 | 31480.92 | 11925.31 | 12900.76 |
| Land coverage and use in 2022 (Ha) | 503584.00 | 1310623.06 | 261865.37 | 68395.52 | 9845.50 | 11508.21 |
| Net change between 2000-2022 (Ha) | 177464.22 | 147465.86 | 3443.88 | 36914.60 | 2079.81 | 1392.55 |
| Exchange rate (%) | -73.94% | 12.68% | -98.70% | 100.00% | -82.56% | -89.21% |

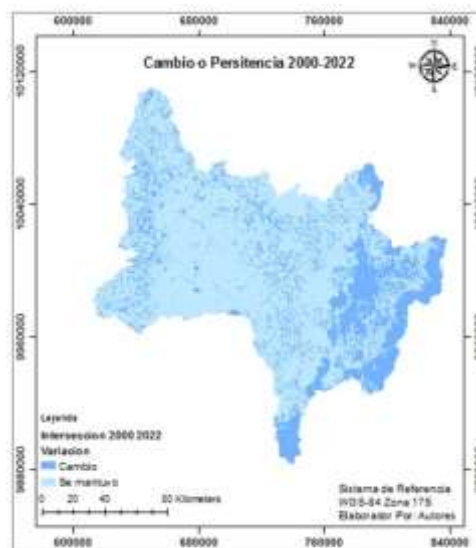
Figure 4

Figure 5

Exchange rate 2000-2022



Change or persistence 2000-2022



Land cover and land use gain and loss 2000-2022

The results in Table 3 correspond to the transition matrix for the year 2000-2022. The areas shown in time row 1 (2000) correspond to the following categories' surface loss: Forest has lost 221,570.10 hectares in 22 years, the agricultural land category has lost 106,354.80 hectares, shrub and herbaceous vegetation 48,680.50 hectares, the anthropic zone category has not lost any surface area 0.00 hectares, the Other land category lost an area of 5,288.90 hectares and water bodies lost an area of 4,020.20 hectares. The surfaces in the time column 2 (2022) correspond to the gains that the following categories have had: Forest has gained 44,113.20 hectares, Agricultural land 253,822.30 hectares, shrub and herbaceous vegetation, 47,103.76 hectares, anthropic zone 36,914.60 hectares, other lands 1,332.96 hectares and water body gained 2,667.64 hectares.

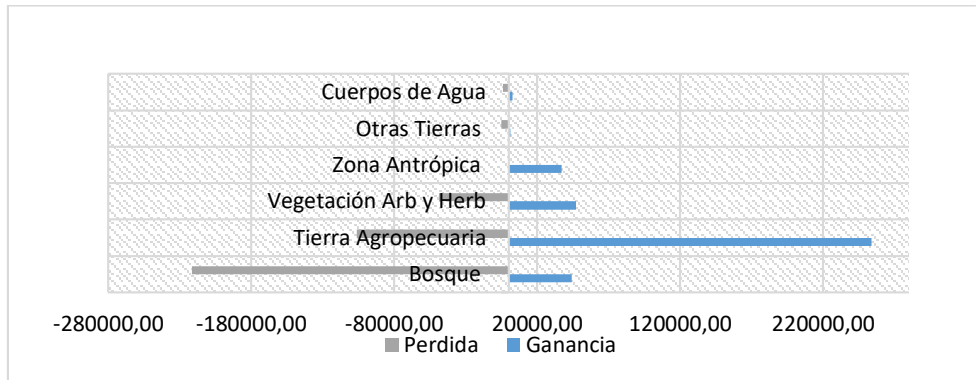
Table 3

Cross-tabulation code matrix between the years 2000-2022

| Coverage / Land use | Time 2 (2022) | | | | | |
|-------------------------|---------------|-------------------|-------------------------|----------------|-------------|---------------|
| | Forest | Agricultural Land | Arb and Herb Vegetation | Anthropic Zone | Other Lands | Body of water |
| Time 1 (2000) Forest | 459478.10 | 208204.20 | 11094.20 | 1836.60 | 223.30 | 211.90 |
| Agricultural Land | 40460.90 | 1056802.40 | 31419.60 | 31621.70 | 551.30 | 2301.40 |
| Arb and Herb Vegetation | 3507.30 | 41249.50 | 214761.60 | 3283.70 | 551.30 | 88.80 |
| Anthropic Zone | 0.00 | 0.00 | 0.00 | 31480.90 | 0.00 | 0.00 |
| Other Lands | 92.50 | 683.50 | 4452.10 | 35.20 | 6636.50 | 25.60 |
| Bodies of Water | 52.60 | 3685.20 | 137.80 | 137.50 | 7.10 | 8880.60 |
| Total 2000 | 681048.20 | 1163157.20 | 263442.10 | 31480.90 | 11925.30 | 12900.80 |
| Total 2022 | 503591.30 | 1310624.70 | 261865.40 | 68395.50 | 7969.40 | 11508.20 |
| Loss | 221570.10 | 106354.80 | 48680.50 | 0.00 | 5288.90 | 4020.20 |
| Revenue | 44113.20 | 253822.30 | 47103.76 | 36914.60 | 1332.96 | 2627.60 |

Figure 6

Loss - gain in land use and coverage 2000-2022



Vegetation cover and land use 2022-2044

In the land coverage and use of the year 2022, it can be observed that the agricultural land category is the surface that is found in the greatest proportion with an area of 1,310,623.06 hectares, which corresponds to 60.51% of the area of the basin. The second category with the largest area is forests with 5,03584.00 hectares, which corresponds to 23.25% of the total area. In 3rd place is the category of shrub and herbaceous vegetation with 261,865.37 hectares, which in percentage corresponds to 12.09% of the area. In 4th place is the anthropic zone category with 68,395.52 hectares or 3.16% of the total area of the basin, the other lands category has an area of 9,845.50 hectares which would be 0.45% of the total area, and the water body coverage has 0.53% of the total area which in hectares would be 11508.21 (Table 4).

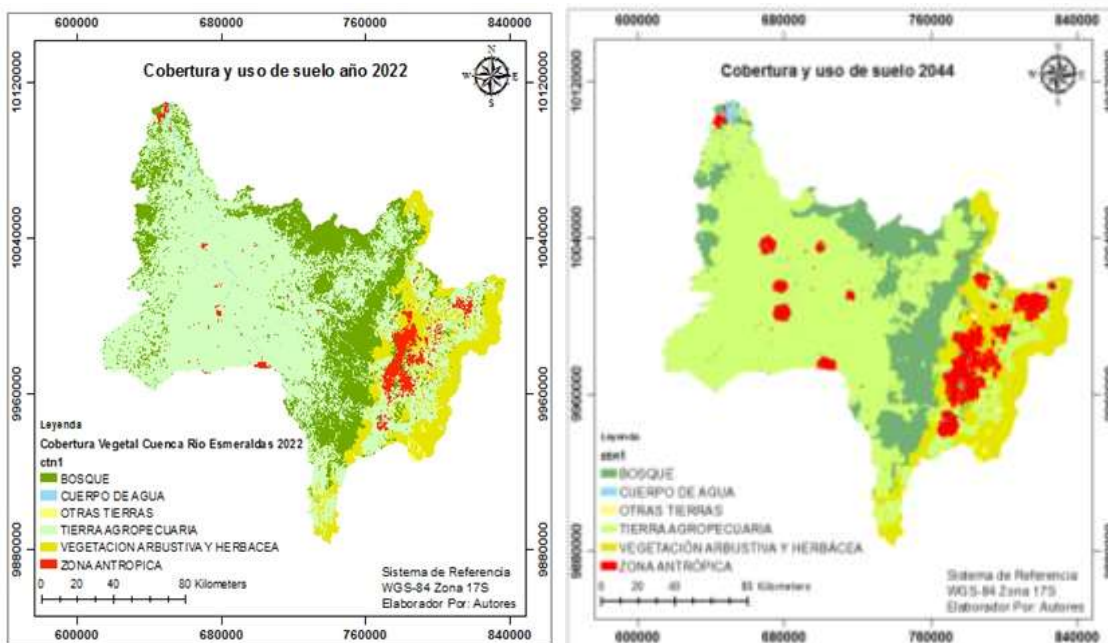
In the land coverage and use for the year 2044, it can be seen that the 1st place will be held by the agricultural land category with an area for 2044 of 1,294,589.49 hectares, which will correspond to 59.77% of the area; the 2nd place will be held by the forest category, which will have 411,372.71 hectares, which corresponds to 18.99%; 3rd place will be held by the category of shrub and herbaceous vegetation, which will have 288,465.83 hectares by 2044, which in percentage would be 13.31%, data that can be verified in table 4. In 4th place is the anthropic zone coverage with 147,758.47 hectares, which corresponds to 6.92% of the area of the basin, the category of other lands will have 9,672.86 hectares, this surface corresponds to 0.44% of the area of the basin, the category of water body will have 13,962.30 hectares, which in percentages is 0.64% of the total area of the Esmeraldas River basin for the year 2044.

Figure 7

Land use and coverage for the year 2022

Figure 8

Land use and coverage in 2044



Change in vegetation cover and land use 2022-2044

The change in coverage for the period 2022-2044 (table 4), it is observed that the agricultural land category will have a net change of 16033.57 hectares and a change rate of -98.78%, in forest cover it can be seen that from 2022-2044 it will decrease by 92211.28 hectares with a change rate of -81.69%, the shrub and herbaceous vegetation category will reduce by 26600.46 hectares with a change rate of 10.16%, in the anthropic zone category it has a change of 79362.95 hectares and a change rate of 100%, the cover of other land will make a surface change by 2044 of 172.64 hectares with a change rate of -98.25%, water body will have a change of 2454.09 hectares with a rate of 21.32% (figure 9 and 10).

Table 4

Change in land cover and use for the year 2022-2044

| Category | Forest | Agricultural Land | Arb and Herb Vegetation | Anthropic Zone | Other Lands | Body of water |
|------------------------------------|-----------|-------------------|-------------------------|----------------|-------------|---------------|
| Land coverage and use in 2022 (Ha) | 503584,00 | 1310623,06 | 261865,37 | 68395,52 | 9845.50 | 11508.21 |
| Land cover and use in 2044 (Ha) | 411372,71 | 1294589,49 | 288465,83 | 147758,47 | 9672.86 | 13962,30 |

| | | | | | | |
|-----------------------------------|----------|----------|----------|----------|---------|---------|
| Net change between 2022-2044 (Ha) | 92211,28 | 16033,57 | 26600,46 | 79362,95 | 172.64 | 2454.09 |
| Exchange rate | -81.69% | -98.78% | 10.16% | 100.00% | -98.25% | 21.32% |

Figure 9

Exchange rate (%) 2022-2044

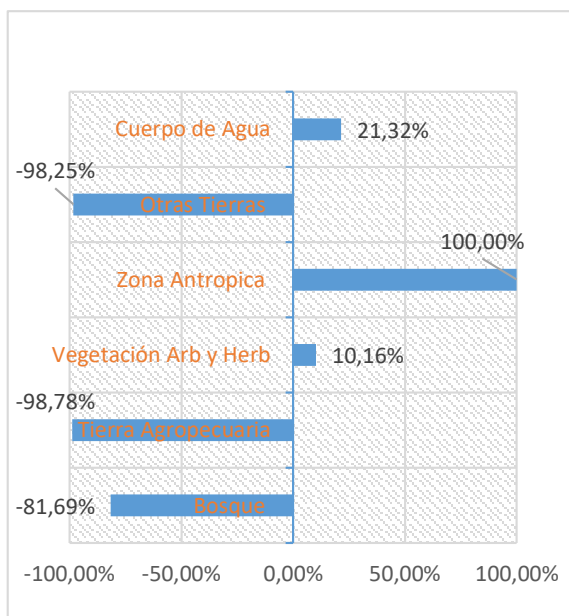
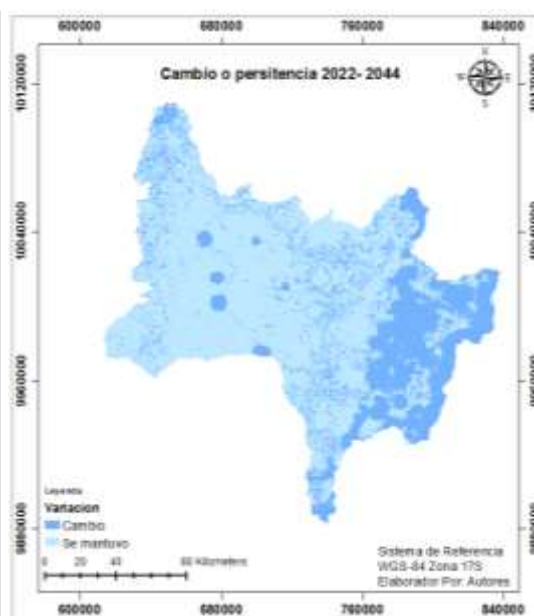


Figure 10

Change or persistence 2022-2044



Land cover and land use loss and gain 2022-2044

The results observed in (table 5), correspond to the transition matrix of the year 2022-2044, the surfaces shown in time row 1 (2022), correspond to the surface of the following categories: forest will lose 156,973.98 hectares in 22 years, the agricultural land category will lose 187,852.35 hectares in 2044, shrub and herbaceous vegetation will lose 35,052.43 hectares, anthropic zone will lose 11,360.99 hectares, the other land category will lose an area of 4,753.13 hectares, water bodies will lose an area of 8,498.17 hectares. The surfaces observed in time column 2 (2044) correspond to the gains that the following categories have had: forest will gain 65,442.26 hectares in 22 years, agricultural land will gain 171,617.48 hectares, shrub and herbaceous vegetation 61,447.89 hectares, anthropic zone will gain 90,525.45 hectares, other land will gain 4,640.75 hectares and water body will gain 10,817.21 hectares. Based on the projection made of the loss and gain of cover and land use for the year 2044, taking into account that the results obtained from the change in land use are scenarios that are worrying because in 22 years a large area of

forests will disappear due to population increases. According to Mieles & Jaramillo (2020), an uncontrolled population increase leads to deforestation of the forest in order to obtain wood for construction, areas for grazing land or agricultural activities.

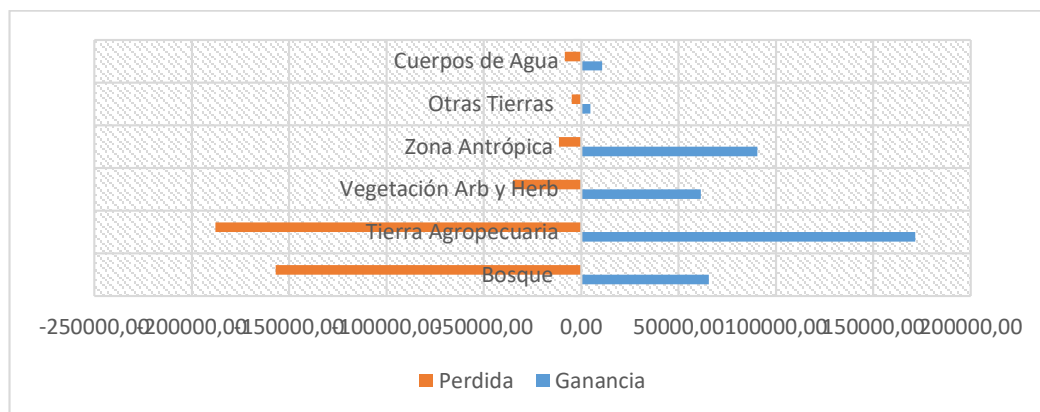
Table 5

Transition matrix of land use categories between 2022-2044

| Coverage / Land use | Time 2 (2044) | | | | | |
|-------------------------|---------------|-------------------|-------------------------|----------------|-------------|---------------|
| | Forest | Agricultural Land | Arb and Herb Vegetation | Anthropic Zone | Other Lands | Body of water |
| Forest | 343675,58 | 138906,56 | 11856,04 | 4879,03 | 125,48 | 1206,88 |
| Agricultural Land | 59275,96 | 1119268,24 | 42746,29 | 77486,17 | 1033,13 | 7310,79 |
| Arb and Herb Vegetation | 4487,00 | 20740,45 | 224194,54 | 7545,50 | 1949,95 | 329,53 |
| Anthropic Zone | 1050,33 | 4107,85 | 2711,36 | 56756,52 | 1532,19 | 1959,26 |
| Other Lands | 85,81 | 1031,12 | 3610,67 | 14,78 | 4819,90 | 10,75 |
| Bodies of Water | 543,16 | 6831,51 | 523,54 | 599,96 | 0,00 | 3000,19 |
| Total 2000 | 500649,56 | 1307120,59 | 259246,97 | 68117,51 | 9573,03 | 11498,36 |
| Total 2022 | 409117,84 | 1290885,72 | 285642,44 | 147281,96 | 9460,65 | 13817,40 |
| Loss | 156973,98 | 187852,35 | 35052,43 | 11360,99 | 4753,13 | 8498,17 |
| Revenue | 65442,26 | 171617,48 | 61447,89 | 90525,45 | 4640,75 | 10817,21 |

Figure 11

Loss or gain in land coverage and use 2022-2044



Discussion

The multitemporal analysis of the land cover and use of the Esmeraldas River basin allowed us to know that the Esmeraldas River basin in 2000 had an area of 681,048.22 hectares of forest, which by 2022 was 503,584.00 hectares, therefore it had a net change of 177,464.22 hectares, these results represent a worrying case due to the loss of forest taking into account what García (2016) mentioned, forests are of great importance in food security, for the reason that they are an essential part to reserve food to cover food needs in the future, by affecting our forests consequently we will have to migrate to other fertile lands with water availability in order to cover our essential needs but we must remember that the search for other lands due to deforestation and desertification are increasingly common situations that we face if we do not take due precautions when managing forests (Falcon, 2014).

The category of agricultural land, as opposed to forest, has increased in area from 1,163,157.20 hectares in 2000 to 1,310,623.06 hectares in 2022. When we refer to land use, it is known that more and more surface area is needed for agricultural production, but we must bear in mind that the agricultural sector in Ecuador is essential for the country's economy because it represents 29.4% of the economically active population (Pino et al. 2018).

The anthropic zone category in 22 years went from having 31,480.92 hectares to 68,395.52 hectares, therefore within the categories of land cover and use I consider that these three are the ones that have the greatest influence on the changes in land cover and use that occur in the Esmeraldas River basin, for the reason that the percentages of forest deforestation that have occurred in Ecuador are linked by 99.4% to the transformation of forests into agricultural areas, 0.37% to the creation of infrastructure, urban areas, rural areas and 0.37% to others (Sierra, 2013). As society grows, forests lose surface area and agricultural and anthropic lands increase their area. On the other hand, I consider that the categories analyzed such as: shrub and herbaceous vegetation, other lands and bodies of water do not have a great influence on the changes in category and land use of the Esmeraldas River basin.

The loss of surface area of land cover and use was carried out by comparing the covers of the period 2000-2022, according to the multitemporal analysis we have that the forests lost 221,570.13 hectares, agricultural land 106,354.82 hectares, shrub and herbaceous vegetation 48,680.46, anthropic zone did not lose surface area, the other land category lost 5,288.86 hectares and water body lost 4,020.19 hectares. These results were obtained through the transition matrix since in a land cover/use analysis the transition matrix identifies the changes or persistence of each of the covers considering that it is a methodology where two maps or covers from different periods are compared (García, 2016). Analyzing the 2000 and 2022 coverages where the soil loss results were obtained,

considering that the analysis is in an interval of 22 years, society has influenced the coverage and land use, it is known that the population that is within this basin takes advantage of the resources that the basin offers, but at the same time the population is producing effects that may be irreversible for the hydrographic basin as Blacio (2015) mentions, the contamination of the hydrographic basins is produced by the inadequate management of human waste, accumulation of wastewater, agrochemicals, the mining sector, lack of a water purification system for human consumption and lack of environmental education programs to mitigate the contamination of hydrographic basins.

The gains in surface coverage for the period 2000-2022 according to the multitemporal analysis we have that the forests gained 44113.19 hectares, agricultural land 253822.30 hectares, shrub and herbaceous vegetation 47103.76, anthropic zone won 36914.60, the other lands category won 1332.96 hectares and body of water 2627.64 hectares. In this case, it can be seen that the forest cover, shrub and herbaceous vegetation, other land and water bodies have lost more area than they gained, but in the case of agricultural land and anthropic zones, they gained more area than they lost, considering that human settlements have caused impacts on land use, the inhabitants of the watersheds by building their homes near water wells and agricultural producers who build irrigation systems for crops in these areas due to their activities can cause soil degradation, in turn affecting flora and fauna (Pérez & Oviedo, 2019). Therefore, agricultural land and anthropic zones are the covers that have benefited the most from the changes that occur in the basin.

The 2044 projection was made with the 2000 and 2022 coverages, projecting that for 2044 the categories and land use will have the following surfaces: agricultural land will have 1,294,589.49 hectares, forests will have 411,372.71 hectares, shrub and herbaceous vegetation will have 288,465.83 hectares in 2044. We will also have the anthropic zone with 1,47,758.465 hectares, "other lands" will have 9,672.858 hectares and water bodies will have 13,962.299. This projection for 2044 is worrying because in 22 years, according to the projection, 156,973.98 hectares of forest will be lost, therefore we will have serious problems with natural areas, for this reason, at present, the territory is one of the most important elements, for this reason, the natural resources that are within this territory are They can be used as long as sustainability is not affected, otherwise this could lead to an uncontrolled increase in land change and use, food crises, pollution and deforestation (Vidal, 2023).

Conclusion

- In the multitemporal study, the change in land cover/use of the Esmeraldas River basin was demonstrated and projected over 22-year periods, 2000-2022, 2022-2044, to verify how activities influence changes in land cover. This was supported by maps made in Arcgis and by projection with Idrisi v17 software, which allowed

modeling the number of hectares that each category of land cover/use will have for 2044.

- The study was carried out with the help of geographic information systems (GIS), which are tools that are becoming increasingly important for engineering and other areas that are responsible for the study of the earth.
- This study also aims to demonstrate to society how watersheds can change over time and due to the activities carried out by inhabitants.

Conflict of interest

The authors declare that there is no conflict of interest in relation to the submitted article.

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