Multicriteria Analysis Based on GIS for the Potential Zoning of Artisanal Tilapia Aquaculture (Oreochromis sp)

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Abstract. The present research is entitled "MULTICRITERION ANALYSIS BASED ON GIS FOR THE POTENTIAL ZONING OF ARTISANAL TILAPIA AQUACULTURE (Oreochromis eng) IN GUAYAS, ECUADOR" and bases its application on the establishment of a significant potential to improve the productivity and sustainability of tilapia aquaculture by identifying suitable areas within the geographic and environmental factors through the use of the geographic information system (GIS) to represent and overlay the cartographic information. 1) The identification of geographic and environmental factors allowed to identify the best areas for aquaculture. Data were collected and categorized on natural and artificial water sources, temperatures (from 23 °C to 30 °C), altitudes (from 0 to 1,200 m above sea level), slope levels from 0 to 7%, and exclusion zones that included protected areas, anthropogenic zones, and flood zones. 2) Representation of Cartographic Information, this was carried out through the GIS, which provided the elements required to implement a detailed spatial analysis, where the areas were classified as "Suitable", "Moderately Suitable" and "Not Suitable". On the other hand, the zoning criteria were integrated, which allowed the design of individual maps of each of the variables identified in advance, which facilitated the spatial visualization for the development of aquaculture in the province of Guayas. 3) Application of the Cartographic Information Overlay System, in this process multiple layers of geospatial data were combined, considering the suitability criteria for the determination of fish farming areas and performing a presence-absence check to corroborate the identified spatial data, which allowed the categorization and integration of the polygons, facilitating the identification of the most suitable areas (with a range of 0 to 6, where 6 is the most suitable area) for tilapia aquaculture in the province of Guayas. According to the overlay of geographic data, of the 15,338.06 km^2 that make up the province of Guayas, 7,606.64 km^2, or 49.28%, are suitable for tilapia aquaculture. Zones of geographic-environmental suitability and exclusion zones (protected areas, protective forests and vegetation, anthropic zones and flood zones) were established. Finally, the reality that the area presents particular conditions in terms of flood zones where both agricultural and aquaculture activities are carried out is highlighted, and that these must be considered

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and analyzed, especially within the 4,501.80 km^2 that make up the "Prone" area (river overflow or heavy rainfall).

Keywords: Multicriteria analysis · GIS (Geographic Information System) · Potential zoning · Artisanal aquaculture · Tilapia (Oreochromis sp)

1 Introduction

The Organic Law for the Development of Aquaculture and Fisheries (LODAP, 2020) defines aquaculture as the activity of reproduction, breeding and cultivation of hydrobiological resources in continental areas, inland waters and marine zones. This implies, on the one hand, intervention in the breeding process to improve production, and on the other, individual or business ownership of the cultivated stock. On the other hand, it characterizes aquaculture carried out by individuals, family groups or communities, peoples, nationalities and actors of the popular economy and solidarity, oriented to the consumption familiar for he improvement nutritional and Small-scale trade is considered as: "Artisanal aquaculture", if its production scale generates a volume maximum of six (6) tons of total biomass per year and that don't be greater than three (3) hectares; and "Artisanal subsistence aquaculture" when it is of a family nature for self-consumption and whose maximum production is five hundred (500) kilograms of fish per year and area productive equal either minor to three hundred (300) meters squares (RLODAP, 2022).

The production fish farming of the country is a of the activities with a good profitability that can be exercised throughout the national territory, with easy access especially for the population of the popular and solidarity economy. According to data from the fishing census (2010) at the national level there were about 4.514 producers fish farming, of the which he 97% were cataloged as artisanal producers with the breeding of cachama, trout and tilapia. In base to the data of producers fish farms identified in 2017 show a 15% growth in fish farming activity nationwide (MPCEIP, 2020). By 2022, an estimated 5,022 productive units with 937.45 hectares used are estimated (MPCEIP, 2020).

The aim is for suitable zoning to allow for a more optimal planning of land spaces based on the compatibility and incompatibility with the multiple uses that are carried out on them and the specific cultivation to be carried out for an effective promotion of any productive activity whose purpose is the cultivation or breeding of living organisms. This zoning must be approved by the national authority (LODAP, 2020). Determining a potential distribution through study and analysis is another effective way of determining the areas of interest for specific cultivation of hydrobiological species, which determines a distribution potential, by through the study and analysis of the optimal physical requirements for their growth, which conditions them to various factors, mainly associated with the climate, topographic variations, availability of resources such as water and temperature It constitutes one of the determining factors in the distribution of species (Márquez & Chacón-Moreno, 2021).

Success in aquaculture production depends largely on the correct choice of the site for the project. In order to select the area or land, it is important to have as much information as possible about the area where the facilities will be located. Consider the

availability of water, topography of the land, access, hand of local work, basic services (water, electricity, communication) and type of agricultural practices (MAG-Paraguay & FAO, 2011).

Tilapia (*Oreochromis sp*) is a teleost fish, of the Perciforme order belonging to the Cichlidae family, endemic to the African continent. They are poikilothermic organisms of warm waters, with a natural temperature range of between 20 to 30 °C that stop growing if the temperature drops below 15 °C and die if it drops below 10 °C (Martin and Guerrero, 2004; Saavedra, 2006; Cantor, 2007). Rural artisanal fish farming with tilapia is an important activity for food security and the diversification of the economy of the sector, due to the characteristics of the species that make it attractive for this type of farming, such as: rapid growth, closed cycle, good reproduction, easy handling, adaptation to a diversity of foods, resistant to diseases and supports high crop densities (Saavedra, 2006).

1.1 Problem of Investigation

Tilapia production not only contributes significantly to the local economy, but also has a positive impact on rural communities within projects and programs of support to the aquaculture sustainable, this includes the promotion of practices responsible aquaculture, which strengthens the technical capacity of producers and improves the infrastructure and access to markets, which fixed a potential of development of the economy of those involved in this activity.

Considering it indicated, inside of the problem of investigation HE established the need to determine the geographic zoning factors suitable for the establishment of tilapia production pools as a tool for the development of aquaculture (Wicki and Gromenida, 2016).

The objetive: apply a multicriteria analysis based on GIS to determine the suitable areas for rural artisanal aquaculture with tilapia (*Oreochromis sp*) in the province of Guayas, Ecuador

Identify the geographic and environmental factors of potential areas for tilapia aquaculture

Representing cartographic information to establish spatial distribution for tilapia aquaculture

Apply a cartographic information overlay system to determine areas suitable for tilapia aquaculture

2 Methodology

The methodology for the determination of suitable areas for the aquaculture rural artisan with tilapia In the province of Guayas, it allowed to establish the geographic-environmental characteristics linked to the administrative division of the province. In addition, with the aim of spatially representing the official cartographic information, and subsequently achieving the determination of zoning, through a multivariate superposition system of the characteristics main for the development of the aquaculture (suitable, moderately suitable, unsuitable), compared with a presence-absence study (if they intercept, do not intercept) within a geographic region (concepto, 2024).

2.1 Research Design in Function of the Goals

The line of the investigation HE I structure in base to the categorization, he guy and he level investigative, that is, each factor (element - variable) was operationalized according to each level of aptitude, or presence - absence relationship(Fonseca et al., 2015).

Inside of the categorization the multicriteria research based on GIS, was structured in base to the items of area and aspect field, like this:

Field: Rural Geography **Area:** Planning territorial **Aspect:** Aquaculture

The type of research was structured using quantitative methods, in this way the measurements and coordinates were ensured, resulting in precision and objectivity in the results. Within the georeferenced modeling, HE employment he software of geoprocessing ArcGIS for to identify coordinates, patterns and correlations between geographical elements and environmental factors for tilapia production. The level of research proposed was exploratory, descriptive, relational (multivariate) because HE focused in characterize the factors geographic and environmental that influence the production of tilapia as the coordinates, the sources water and restrictions that each element had to meet to understand the relationships between these factors and determine the polygons (X, Y) of the suitable areas (Cantor, 2007).

Finally, the investigation fulfills a level of application, by how much he deliverable end is a tool of planning territorial, is say, a system which was programmed on the territorial layers (overlay of cartographic information) of each incorporated variable (Espinoza, 2001).

2.2 In Function of the Requirements and Factors

According to the requirements cartographic, HE analyzed the characteristics fit physical and their ranges for each established element (Water source, Temperature, Altitude, Slope, Exclusion zones) for the development of aquaculture with tilapia (*Oreochromis sp*) described by the Food and Agriculture Organization of the United Nations, as well as tilapia breeding manuals (MAG-Paraguay & FAO, 2011). With these ranges, the cartographic areas suitable for the location of ponds for aquaculture were defined. The elements analyzed were:

2.2.1 Factors

To determine the areas suitable for artisanal rural tilapia aquaculture, multiple geographic zoning variables were considered. (Garza-Martínez et al., 2021). According to management manuals for tilapia farming, the main geographic and environmental conditions to be analyzed were determined: water sources, temperature, altitude and slope. for their cartographic representation, suitability ranges were determined, categorizing them into: suitable, Moderately Suitable and not Suitable, assigning them a color in traffic light format

Geographically and administratively, there are areas where it is not possible to carry out productive activities such as fish farming, either because they are natural conservation areas, they are risk areas or they already have other anthropogenic activities

incompatible with rural artisanal aquaculture with tilapia. These areas were determined as Exclusion Zones and are made up of: natural System of Protected Areas SNAP, Forests and Protective Vegetation BVP, Anthropic Zones and Flood Zones.

In this way, the zoning for rural artisanal fish farming with tilapia was established in the province of Guayas, geographically detailing the areas of suitability and the exclusion zones, according to the following table (**Error! Reference Source not Found.**).

Factors Geographic - Environmental

Water Sources: Regarding water sources, both the origin and type of source were assessed. Suitable natural rivers and estuaries were located, providing a favorable environment due to their constant flow and natural conditions (Ramírez et al., 2019). Artificial canals were also considered, offering control over water supply, although additional caution is needed to maintain water quality and minimize environmental risks.

Temperature: This parameter is considered essential for aquaculture, its variations are linked to the types of fish that develop according to their temperature and altitude, such as cold water fish, temperate water fish and warm water fish. Its ranges will determine the optimal conditions for the effective breeding of tilapia (Cantor, 2007). The country does not have maps with territorial temperature ranges, so it was taken as a reference for the temperature environmental, related to the temperature of the water (AUNAP & FAO, 2013).

Altitude: Altitude is a geographical factor that limits the distribution of aquaculture in general, not because of the pressure changes that may occur but because of its relationship with the ambient temperature, therefore, the water temperature. Altitudes between 0 and 1,200 m above sea level were identified as suitable, providing stable and favorable climatic conditions for aquaculture production (Cantor, 2007).

This relationship between ambient temperature and altitude is represented in Table 1, where the water temperature is referenced for the analysis in zoning.

Table 1. Altitude relationship with ambient temperature.

FISH	HEIGHT	TEMPERATURE
Cold waters	2000 to 3000	8 to 18 °C
Temperate waters	1200 to 2000	18 to 22 °C
Warm waters	0 to 1200	22 to 30 °C

Fountain: (Cantor, 2007).

Earring: The inclination of the floor is important already that facilitates either makes difficult the functionality of the ponds and has a direct relationship with the construction costs. If possible, completely flat land should also be avoided, (Martin and Guerrero, 2004) since a slight slope facilitates the management of the water flow with the action of gravity. It was classified between the following ranges: 26–99%, 8–25%, 0–7% (AUNAP & FAO, 2013).

Table 2. Cartographic information

Factors	Classification / Rank	Categories
Water source	Origin (FH)	Rivers
		Estuary
		Channel
		Ravine
	Type (FH)	Artificial
		Natural
Temperature	23 - 30 ^{0}C	Suitable
	18 - 22 ^{0}C	Moderately suitable
	8 - 17 ^{0}C	Unfit
Altitude	0 to 1,200 meters above sea level	Suitable
	1,201 to 2,000 meters above sea level	Moderately suitable
	2,001 to 3,000 meters above sea level	Unfit
Earring	0 – 7 %	Suitable
	8 – 25 %	Moderately suitable
	26 - 99 %	Unfit
Exclusion zones	Protected areas	SNAP Areas
		BVP Areas
	Anthropic zone	Populated areas
		Areas with infrastructure
	Flood zones	Permanent (Mangroves and swamps)
		Storms (rainy seasons)
		Prone (river overflows or heavy rainfall)

Exclusion Areas: Finally, exclusion areas were delimited, such as protected areas of the National System of Protected Areas (SNAP) and protective forests and vegetation (BVP), as well as anthropogenic zones with populations and structures, which are not suitable for aquaculture due to human interference and the need for environmental conservation (suia.ambiente, 2024). Flood zones, both permanent (such as mangroves and swamps) and temporary and prone to overflow, were also identified as unsuitable due to the risks associated with abrupt changes in water level.

Area of Those Involved. For carry to cape the activities of investigation HE considered to the project emblematic: Improving the Competitiveness of the Aquaculture and Fisheries Sector, from the Ministry of Production, Foreign Trade, Investments and Fishing, approved by Agreement No. MPCEIP-DMPCEIP-2020–0029 and developed between 2019 and 2022. Where, its main objective was to increase the competitiveness

Table 3. Official sources of the Shapes

Factors			Fountain
Water source	Origin (FH)		IGM
	Type (FH)		IGM
Temperature			SEMPLADES
Altitude			RASTER-INV
Earring			RASTER-INV
Exclusion zones	Protected areas	SNAP Areas	MAATE-SUIA
		BVP Areas	MAATE-SUIA
	Anthropic zone	Populated areas	MAATE-SUIA
		Areas with infrastructure	MAATE-SUIA
	Flood zones	Permanent (Mangroves and swamps)	IGM
		Storms (Rainy seasons)	IGM
		Prone (River overflows or heavy rainfall)	IGM

Table 4. Water Sources

Variable	Perennial/permanent	Non-perennial/intermittent/fluctuating	Dry
Water Sources	11,474.51 km (78.76%)	2,867.74 km (19.68%)	226.47 km (1.55%)

Table 5. Temperature

Variable	Suitable 23–30 °C	Moderately suitable 18–22 °C	Unfit <17–>31 °C
Temperature	15,207.52km^2 (99.15%)	122.50 km^2 (0.85%)	8.03 km^2 (0.05%)

Table 6. Altitude

Variable	Suitable 0–1,200 masl	Moderately suitable 1,201–2,000	Unfit >2.001
Altitude	15,184.73 km^2 (99.00%)	134.93 km^2 (0.88%)	18.40 km^2 (0.12%)

Table 7. Slopes

Variable	Suitable 0–7%	Moderately suitable 8–25%	Unfit 26/99%
Earring	15,001.75 km^2 (97.81%)	325.02 km^2 (2.12%)	11.29 km^2 (0.07%)

Table 8. Protected Areas

Variable	Exclusion area	Suitable area
SNAP - BVP	1,048.06 Km^2 (6.83%)	14,290.00 Km^2 (93.17%)

Table 9. Anthropic Zones

Variable	Exclusion area	Suitable area
Anthropic zones	1,864.66 km^2 (12.16%)	13,473.00 Km^2 (87.84%)

Table 10. Flood Zones

Variable	Exclusion area	Suitable area
Flood zones	6,413.50 km^2 (45.59%)	8,345.27 km^2 (54.41%)

Table 11. Zoning (Temperature, altitude and slope)

Assessment	**Area Km ^{2}**
6	14,327.72
5	259.28
4	251.96
3	58.76
2	424.98
1	14.30
0	1.06
Total	15,338.06

of the national and export aquaculture and fishing sector of Ecuador through promotion, regulation, control and monitoring, where, as component 2, it established: promote

Table 12. Overlap Area Presence Absence (Exclusion Zones)

Variable	Exclusion area	Suitable area
Exclusion zones	7,829.66 km^2 (51.05%)	7,508.06 km^2 (48.95%)

Table 13. Overlap Zone - Area Presence Absence

Assessment	Area Km ^{2}
6	7,134.92
5	150.25
4	220.92
3	41.45
2	52.42
1	6.29
0	0.39
Total	7,606.64

the productivity and competitiveness of the aquaculture and fishing sector (production. 2023).

The Undersecretariat of Aquaculture is the in charge of the promotion aquaculture in the country, benefiting to fish farmers framed in the economy popular and solidarity, of the which annually are About 2,000 fish farmers nationwide receive training and assistance services technique in topics of aquaculture. Through the project HE look for increase in 40% the production average annual for attend it required by the sector fish farmer that HE supplies fry (trout, tilapia, cachama) through the supply and sale processes.

Finally, the project of investment Strengthening Comprehensive and Sustainable of the Sector Aquaculture and Fishing, is a project of the Ministry of Production, Trade Abroad, Investments and Fishing, approved through Agreement No. MPCEIP-MPCEIP-2022-0037-A projected for his execution in the period 2023 to 2025. Its main objective is to promote the development of aquaculture and fishing activities in all their production phases, for achieve the sustainability of the sector and guarantee access to new markets.

From the geographical location, the fish farmers related to the project were considered of the Ministry of Production, Trade Abroad, Investments and Fishing framed, with a record of 56 representatives of families and an association that are recorded within the cantons of the province and that have received, according to the capacity of their pools, a quantity of fry as part of the project of production (MPCEIP, 2020). Saying record allowed identify the coordinates of georeferencing and others information, the same that allowed provide of a Updated data matrix on the 57 locations between swimming pools in the province of Guayas.

P = 57 locations (X, AND).

Geographical Area. From a spatial perspective, the province of Guayas was considered with its geographical and environmental characteristics and its already established aquaculture activity, for this reason the province presents a favorable scenario for the development of artisanal rural production of tilapia (*Oreochromis sp*). Availability of water sweet, is presented as the "sine qua non" condition that enhances the success of this activity in the region (Maestu, 2015).

He climate of the province of the Guayas is tropical monsoonal (bioweb, 2024), with a temperature average annual average of 25 °C. The average annual rainfall is 1,000 mm, concentrated mainly in the months of winter (January to April). The relief of the province of the Guayas is varied, with mountainous areas in the east, hills in the centre and plains in the west. The mountainous area corresponds to the Western Cordillera of the Andes, while the plains form part of the lower basin of the Guayas River.

The province of the Guayas account with a extensive hydrographic network, composed by rivers, estuaries and channels. The main rivers are he Guayas, Daule, Babahoyo and Vinces. Account with several important estuaries, in addition to a fundamental hydrographic network for the development of aquaculture activities, including tilapia production.

The soils of the province of Guayas are mostly sandy loam or clay loam, with good permeability and drainage. The clay loam soils are suitable for tilapia farming, provided they are properly managed to prevent erosion and salinization.

2.3 Data Collection Instruments

Geographic Information Systems (GIS): Using GIS software (such as ArcGIS or QGIS) to map and analyze geospatial data (aeroterra, 2024).

Geospatial Database: For the creation and management of a database containing all relevant variables to complement and verify the information collected.

Site Suitability Analysis: To carry out the evaluation of potential areas by weighing the geographic and environmental factors of the polygons related to the suitable areas. Finally, the data analysis process was carried out to effectively identify and evaluate the zoning for tilapia aquaculture in the province of Guayas, providing a cartographic basis for the identification of the coordinates of the suitable areas by means of:

1. Data collection
2. Data preparation
3. Exploratory data analysis
4. Spatial distribution analysis
5. Overlay system
6. Verification of polygons

3 Results

3.1 Identification of Geographical and Environmental Factors

The identification of geographic and environmental factors represented a crucial stage in determining the zoning for rural artisanal tilapia aquaculture in the province of Guayas. The geographic distribution of these factors (water source, temperature, altitude, slope, exclusion areas), related to the geography of the province of Guayas, is essential to establish, after its multivariate analysis, the suitable, moderately suitable and unsuitable areas for the promotion of rural artisanal aquaculture in Guayas (FAO, 2013).

3.2 Representation of Cartographic Information

The cartographic representation facilitated the prior visualization of the spatial distribution for the sustainable development of aquaculture in the province of Guayas (Dias & Oliveira, 2022).

3.2.1 Areas

Water Sources The water source conditions in the province of Guayas are favorable for rural artisanal aquaculture of tilapia (*Oreochromis sp*) due to the availability of various natural and artificial water sources. The province has artificial canals that provide a controlled and constant water supply, which is ideal for the efficient management of aquaculture. In addition, there are natural estuaries and rivers that enrich the aquatic environment, offering quality water. These natural water sources are essential for sustainability and food productivity (CELAC, 2023), as they provide a water supply for tilapia farming in pools.

Water sources were grouped into three categories: perennial/permanent, non-perennial/intermittent/fluctuating, and dry. The majority of water sources, totaling 11,474.51 km (78.76%), are perennial or permanent, indicating a constant availability of water in these areas. A total of 2,867.74 km (19.68%) are non-perennial, intermittent, or fluctuating, indicating that these water sources are not available throughout the year and may vary depending on the season or weather conditions. Finally, a total of 226.47 km (1.55%) correspond to dry sources, where, for a large part of the year, water is not available.

Temperature The province of Guayas has temperature conditions mostly suitable for rural artisanal aquaculture of tilapia (*Oreochromis sp*), with 99.15% of its surface (15,207.52 km^2) within the optimal range of 23–30 °C. This wide extension ensures a favorable environment for tilapia productivity, since these temperatures promote efficient growth and development of the fish. However, a small percentage of the province, specifically 0.85% (122.50 km^2), is within the moderately suitable temperature range (18–22 °C), which could imply certain limitations in productivity without being completely unfavorable. Only a tiny fraction, 0.05% (8.03 km^2), has unsuitable temperatures (<17 °C–>31 °C), suggesting a minimal risk of unsuitable areas for tilapia farming in this region. It is highlighted that the province of Guayas offers highly favorable thermal conditions for tilapia aquaculture, which positions it as a strategic area to promote its productivity.

Altitude The province of Guayas has altitude conditions predominantly suitable for rural artisanal aquaculture of tilapia (*Oreochromis sp*), with 99.00% of its surface (15,184.73 km^2) located between 0 and 1,200 m above sea level, a range considered suitable for the development of this activity. These altitudes favor tilapia farming due to the stable and adequate environmental conditions for its growth. A small percentage of the province, 0.88% (134.93 km^2), is located at moderately suitable altitudes (1,201–2,000 m above sea level), which may present certain restrictions, but is still viable for aquaculture with adequate management. Finally, only 0.12% (18.40 km^2) of the province is at altitudes above 2,001 m above sea level, considered unsuitable for tilapia farming due to extreme conditions that can negatively affect its development. It is noteworthy that the province of Guayas has highly favorable altitudinal conditions for tilapia aquaculture, which contributes significantly to its productive potential in the region.

Pending The province of Guayas shows slope conditions mostly suitable for rural artisanal aquaculture of tilapia (*Oreochromis sp*), with 97.81% of its surface (15,001.75 km^2) having slopes between 0 and 7%, an optimal range for this activity due to the ease of management and construction of ponds, as well as the minimization of erosion and sedimentation risks. 2.12% of the province (325.02 km^2) has moderately suitable slopes (8–25%), where, although aquaculture is possible, more careful management is required to prevent stability and erosion problems. Finally, only 0.07% (11.29 km^2) has unsuitable slopes (26–99%), which make aquaculture impossible due to the difficulty of building and maintaining adequate infrastructure. It is noteworthy that the province of Guayas has highly favorable slope conditions for tilapia aquaculture, consolidating its productive potential in the region.

3.2.2 Exclusion Zones

Protected Areas Only 6.83% of the area (1,048.06 km^2) is designated as exclusion zones, which include the National System of Protected Areas (SNAP) and protective forests and vegetation (BVP). The province of Guayas has a vast majority of its territory suitable for rural artisanal aquaculture of tilapia (*Oreochromis sp*), with 93.17% of its surface (14,290.00 km^2) available for this activity. These areas are protected due to their ecological value and biodiversity, and are not suitable for aquaculture in order to preserve the environmental balance. The availability of a large suitable surface ensures the potential to expand tilapia aquaculture in the province, as long as the protected areas are respected to maintain sustainability and the conservation of the natural environment.

Anthropic Zones In the province of Guayas, the conditions of anthropic zones reflect that 12.16% of the area (1,864.66 km^2) is occupied by exclusion zones, which include populated areas and infrastructure, and 87.84% of the territory (13,473.00 km^2) is suitable for rural artisanal aquaculture of tilapia (*Oreochromis sp*), indicating a wide availability of areas that can be used for this activity. These anthropogenic areas are unsuitable for aquaculture due to population density and the presence of structures that do not allow the development of ponds and other aquaculture facilities. Despite these restrictions, the extensive suitable area offers significant potential for increasing rural artisanal tilapia

aquaculture in the region, always considering appropriate planning to avoid conflicts with urbanized areas and existing infrastructure.

Flood Zones In the province of Guayas, the conditions of the flood zones show that 45.59% of the area (6,413.50 km^2) is subject to flooding, including permanent areas (mangroves and swamps), temporary areas (during rainy seasons) and areas prone to river overflows or heavy rainfall; and 54.41% of the territory (8,345.27 km^2) is suitable for rural artisanal aquaculture of tilapia (*Oreochromis sp*), offering a considerable extension of suitable areas for this activity. These exclusion zones present significant challenges for aquaculture due to the instability of the terrain and the risk of loss of infrastructure and fish. Despite these limitations, the considerable proportion of suitable areas provides opportunities for the development and expansion of tilapia aquaculture in the province, provided that appropriate management and mitigation strategies are implemented to minimize the risks associated with flooding.

3.3 Application of the Cartographic Information Overlay System

This overlay system allowed the integration of polygons in a precise manner, facilitating the identification of the most suitable areas for artisanal rural tilapia aquaculture in the province of Guayas. In turn, it allowed combining and analyzing multiple layers of geospatial data with their respective criteria (suitability, presence - absence) to combine and identify the general suitable areas for tilapia aquaculture in the province of Guayas.

3.3.1 Consolidation Suitability Zone (Temperature, Altitude and Slope)

Consolidation of the data overlay of suitable areas for rural artisanal tilapia aquaculture reveals a varied layered distribution through the establishment of range/colors (See Table 14) of suitability in different areas. Out of the 15,338.06 km^2 assessed, a small portion of 1.06 km^2 was classified as unsuitable for aquaculture. An area of 14.30 km^2 is considered moderately suitable, while 424.98 km^2 and 58.76 km^2 are suitable and moderately suitable, respectively. Areas with clear and definite suitability for aquaculture cover 251.96 km^2 and 259.28 km^2. The largest portion of land, 14,327.72 km^2, was identified as suitable, establishing that the majority of the provincial territory has favorable geographical conditions for tilapia farming. Under these conditions and up to this point, the analysis indicates that the province of Guayas would have a large area suitable for promoting aquaculture production in the region.

3.3.2 Overlapping Exclusion Zones (Protected Zones, Anthropic Zones, Flood Zones)

To optimize the productivity of tilapia aquaculture in the province of Guayas, it is crucial to analyze the suitable and excluded areas according to the identified geographic factors. According to the established data, the exclusion zones, which include protected areas, anthropic zones and flood zones, occupy approximately 51.05% of the studied territory, totaling 7,830 km^2. On the other hand, the areas considered suitable for aquaculture occupy the remaining 48.95%, equivalent to 7,508.06 km^2. This overlap reveals

a delicate balance between environmental preservation and productive use of space, highlighting the need for integrated management strategies that maximize productive potential without compromising the environmental sustainability of the region.

3.3.3 Overlapping Suitability Zones Without Exclusion Zones

The overlay of data to determine suitable areas and the presence or absence of favourable geographical factors shows a diverse distribution of suitability (by layers). Out of a total of 7,606.64 km^2 assessed, only 0.39 km^2 was classified as unsuitable, while 6.29 km^2 are considered moderately suitable and unsuitable. The areas that combine suitability and medium suitability cover 52.42 km^2 and 41.45 km^2, respectively. The clearly suitable and moderately suitable areas for aquaculture total 220.92 km^2 and 150.25 km^2, respectively. The majority of the territory, with 7,134.92 km^2, was identified as fully suitable, confirming that the province has a large area for tilapia farming, providing a solid basis for the development and expansion of this activity in the region.

3.3.4 Checking the Suitability Zones and Exclusion Zones on Site

Of the 57 tilapia pools registered in the province of Guayas, 31 pools are located in the Zone of Greater Suitability (Rating 6) and 26 in the Exclusion Zone. Of the 26 in the exclusion zone, all are in the Yahuachi canton and almost all (25) are located in the exclusion zone because it is an area prone to flooding due to river overflow. One pool is located in a temporary flood zone due to the rainy season.

4 Conclusions

The identification of geographic and environmental factors allowed to outline the most suitable areas for rural artisanal tilapia aquaculture in the province of Guayas. Variables such as types of water sources, temperature, altitude, and slope of the terrain were considered, in addition to exclusion zones (protected areas, anthropogenic zones and flood zones), which were linked with the sequence to define zones that presented optimal conditions for aquaculture productivity.

The use of geographic information system (GIS) provided detailed spatial data of the areas into suitability categories (“Suitable”, “Moderately Suitable”, and “Unsuitable”) based on established indices. The cartographic representation allowed a clear visualization of the spatial distribution of these areas, providing a fundamental tool for planning and management of aquaculture in the province.

The cartographic information overlay technique allowed the integration and analysis of multiple layers of information, consolidating the polygons of the areas suitable for tilapia aquaculture. Using this technique, it was established that, of a total of 15,338.06 km^2 that make up the province of Guayas, of which 7,606.64 km^2 (49.28%) are suitable for aquaculture. The overlay methodology highlighted a balance between geographical suitability and the exclusion of protected or anthropogenic areas, confirming that the province of Guayas has a solid base for the development of tilapia aquaculture. It is highlighted that this area presents particular conditions in terms of flood zones where aquaculture activities are currently carried out, and that they must be considered

and analyzed, particularly within the 4,501.80 km^2 that make up the "Prone" area (river overflows or heavy rainfall).

A total of 57 pools, the zoning of geographical and environmental factors has allowed to identify suitable and unsuitable areas for the implementation of cultivation pools. The results reveal that 54.39% of the pools are located in suitable areas, which represents a favorable environment for the development of aquaculture. However, 45.61% of the pools (most of them with a barrage system) are located in areas prone to flooding due to river overflow, where environmental conditions would present significant risks. Of these, 1.75% are located in areas that are temporarily flooded during the rainy season.

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