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Artículo de investigación científica y tecnológica

Environmental effects of avocado farming in two hamlets of Apía, Risaralda

Efectos ambientales del cultivo de aguacate en dos veredas del municipio de Apía, Risaralda

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ABSTRACT

The cultivation of avocados in Apía has grown from 71 hectares in 2012 to 1019 hectares in 2021, causing significant environmental changes, such as the loss of humid forests, excessive use of agrochemicals, and extreme tillage. Analyses were conducted on the deforestation rate in relation to the increase in avocado cultivation and water quality. For this, land use data from 2011 to 2016 were collected, processed with QGIS, and analyzed with R. Eight physicochemical parameters of water were also evaluated in the study areas. The results showed a decrease in "Forestry" land use and an increase in "Forestry or Tree Crops" related to avocado cultivation. Additionally, alterations in specific water parameters were observed in streams near the crops. These findings highlight the need for further studies to guide rural land use without harming natural resources.

Keywords: Deforestation; pollution; intensive agriculture; water quality.

RESUMEN

El cultivo de aguacate en Apía ha crecido de 71 hectáreas en 2012 a 1019 hectáreas en 2021, provocando cambios ambientales significativos, como la pérdida de bosques húmedos, el uso excesivo de agroquímicos y la labranza extrema. Se realizaron análisis del índice de deforestación en relación con el aumento del cultivo de aguacate y la calidad del agua. Para ello, se recopiló datos de uso del suelo entre 2011 y 2016, procesándolos con QGIS y analizándolos con R. También se evaluaron ocho parámetros fisicoquímicos del agua en las veredas de estudio. Los resultados mostraron una disminución en el uso de suelo "Forestal" y un aumento en "Cultivos Forestales o Arbóreos" relacionado con el cultivo de aguacate. Además, se observaron alteraciones en parámetros específicos del agua en afluentes cercanos a los cultivos. Estos hallazgos subrayan la necesidad de más estudios para guiar el uso del suelo rural sin dañar los recursos naturales.

Palabras clave: deforestación; contaminación; agricultura intensiva; calidad de agua.

JEL: Q200; Q250

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INTRODUCTION

Persea americana, commonly known as avocado, thrives in the tropical region. In Colombia, avocado production increased by 89% over the past five years due to a 62% increase in cultivated area and a 17% improvement in yield (Ministry of Agriculture and Rural Development [Minagricultura], 2020, p.7). Despite its small area, Risaralda ranks second in avocado production. In 2019, Antioquia led with 49% of the exported fruit, followed by Risaralda and Valle del Cauca at 30% and 7%, respectively (Minagricultura, 2020, p.14). Within Risaralda, Apía has shown significant growth in avocado cultivation, attributed to its fertile soils and diverse climate, ranging from 1400 to 3200 meters above sea level. Apía stands out for its natural richness, including key reserves like Tatamá National Natural Park and the Cuchilla de San Juan Integrated Management District (Palacios & Fuentes, 2016).

These environmental conditions have attracted investors who implement intensive high-altitude avocado production systems, pushing farms closer to protected areas without proper environmental feasibility studies or land use assessments. The municipal economic development office must provide obligatory production and land use data for rural areas, published in institutional reports titled "Evaluación Agropecuaria (EVA)." The 2021 report showed a change from 71 hectares planted with avocados in 2012 to 1019 hectares in 2021, with 981 hectares devoted to the Hass variety, primarily in high-altitude areas close to forests, notably in the Las Cabañas and Campo Alegre hamlets. The report accounted for 131 properties cultivating this variety, covering 915 hectares in production and 66 hectares under development, yielding an average annual output of 8235 metric tons.

Historically, intensive and extensive high-altitude production models were limited to small plots of cold-climate crops like passion fruit, naranjilla, blackberry, and tree tomato. The 2021 EVA report noted a drastic reduction in these crops and a significant expansion of Hass avocado farming, transitioning from family to intensified agriculture. According to Troyo et al. (2010), extensive agriculture involves large-scale cultivation, typically in monoculture, aimed at increasing production. Reigada et al. (2017) describe intensive agriculture as technologically advanced exploitation using inputs and products to enhance specific crops. These intensive methods are known for their heavy use of agrochemicals; Burgos (2011) identified avocado cultivation as highly dependent on synthetic pesticides for pest control, which often contain solvents and adjuvants that can be more toxic than the active ingredients.

Using these agrochemicals has led to water source contamination and direct ecosystem damage, as application methods allow for environmental dispersion. Pesticide particles can become airborne, spreading with the wind and causing widespread damage to animal and plant species and natural resources (Vélez & Tobón, 2019). Additionally, they pose risks to water quality through agrochemical infiltration to the groundwater level.

Land use in rural areas is also a critical issue, as the hamlets under study influence the Cuchilla de San Juan Integrated Management District (SJIMD), which holds a special status in Apía's Land-Use Planning Scheme or EOT (Esquema de Ordenamiento Territorial). The 2000 EOT decree defines "producer-protected forest areas" as zones that should be preserved permanently with natural or planted forests to protect renewable natural resources, allowing sustainable production activities without compromising their protective function (EOT, 2000, Article 14). Córdoba et al. (2021) regard changes in rural land use and vegetation transformation as the second most significant environmental problem globally.

This article aims to analyze deforestation trends in the highlands of Apía, particularly within the Cuchilla de San Juan DMI, encompassing Las Cabañas and Campo Alegre hamlets. Using satellite imagery and land use data from 2011 to 2016 published by the Regional Autonomous Corporation (CARDER) and employing QGIS, an open-source geographic information system software, this study also examines water quality near avocado

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farms in Las Cabañas and Campo Alegre using samples analyzed with the Hanna HI98194 multiparameter meter at the National Open and Distance University (UNAD). This rugged, waterproof device measures up to 12 primary water quality parameters, including temperature, pH, electrical conductivity, turbidity, ORP, and dissolved oxygen, making it an invaluable tool for environmental monitoring.

METHODOLOGY

This study utilizes a mixed methodology, incorporating quantitative land distribution and use parameters in Apía municipality and physicochemical water parameters. Additionally, it integrates Colombian and international regulatory information to enrich the analysis of the territory's characteristics, fostering an integrated process analysis.

Spatial and Temporal Land Use Analysis

Researchers assessed the impact of avocado cultivation on forest resources through a chronological analysis of satellite images; this involved calculating land use frequency and its relation to deforestation. Data from Apía's land use maps for 2011-2016 are in the public repositories of the Corporación Autónoma Regional (CARDER). Researchers collected data in the MAGNA-SIRGAS format, Colombia's official reference system for high-quality spatial data generating; this ensures compatibility with global positioning systems like GNSS and international georeferenced datasets (IGAC, 2020).

Researchers processed post-collection data using the free QGIS software, transforming satellite signals into a data matrix related to land occupation and analyzing specific vector data for the DMI Cuchilla de San Juan reserve area, which includes Las Cabañas and Campo Alegre for 2011-2016. RStudio, with the "tidyverse" and "ggplot2" libraries, was used to illustrate land use frequency, including variables such as shrubland, forest, agroforestry crops, permanent tree crops, and wooded pastures between 2011 and 2016 for changes in their area measured in hectares (Ha).

Water Sampling and Physicochemical Analysis

Sampling sites were determined after field visits, identifying the nearest water sources to the crops —one per hamlet, totaling two samples. Optimal sampling times were chosen after harvest when agrochemical use peaks (December-January), based on consultations with fruit sector professionals and technicians.

Two samples were collected using sterile jars to ensure water quality and transported within a cold chain to the laboratory at the Centro de Innovación y Productividad (CIP) of the Universidad Nacional Abierta y a Distancia (UNAD) in Dosquebradas, Risaralda. Sampling occurred on July 13, 2023, at 6:40 am for Campo Alegre and 7:40 am for Las Cabañas, with arrival at the laboratory by 9:40 am.

Researchers took the Campo Alegre Creek sample near its source at the Sierra de Greenwich farm, a large-scale Hass avocado plantation at 2263 meters above sea level, located at latitude N 5°7'6.16764" and longitude W 75°55'36.40764". The sampling point was approximately 70 meters from the avocado crop. The Las Cabañas creek sample was sourced from its spring on La Divisa property, at an elevation of 2283 meters, latitude N 5°7'4.84536", and longitude W 75°55'34.89744", about 80 meters from the avocado cultivation.

Researchers assessed water quality using eight physicochemical parameters: temperature, pH, electrical conductivity, total dissolved solids (TDS), oxidation-reduction potential (ORP), dissolved oxygen (DO), ammonia content, and nitrite and nitrate concentration. The first six parameters were measured using the Hanna HI98194 portable multisensor device, capable of digital data transmission to the meter for display and recording up to 100 meters away.

The Centro de Investigación en Agricultura y Biotecnología (CIAB) of UNAD provided this equipment.

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RESULTS

Researchers processed the information to produce the graph below after converting data from Shape format to a data matrix as in the methodology. Figure 1 displays a density graph to visualize data distribution for 2011 and 2016 against the designated land use areas. On the x-axis, the variable "Hectares" is plotted, while the y-axis shows density, illustrating the distribution of "land use variables." Here, density peaks help indicate where values concentrate or where land use is recorded most frequently from satellite data.

It is notable in the graph that the forest variable, crucial for identifying deforestation, shows high density in 2011 but is significantly less in 2016; this indicates a substantial reduction in forest land use over these five years, suggesting a decrease in forested areas within the sample. Similarly, the high density of forests recorded in 2016 is replaced by shrubland and agroforestry crops, potentially including Hass avocado cultivation, which, as shown by the EVA, saw a sharp increase during the same period, particularly in the Las Cabañas and Campo Alegre areas, which represent a significant number of avocado-producing properties.

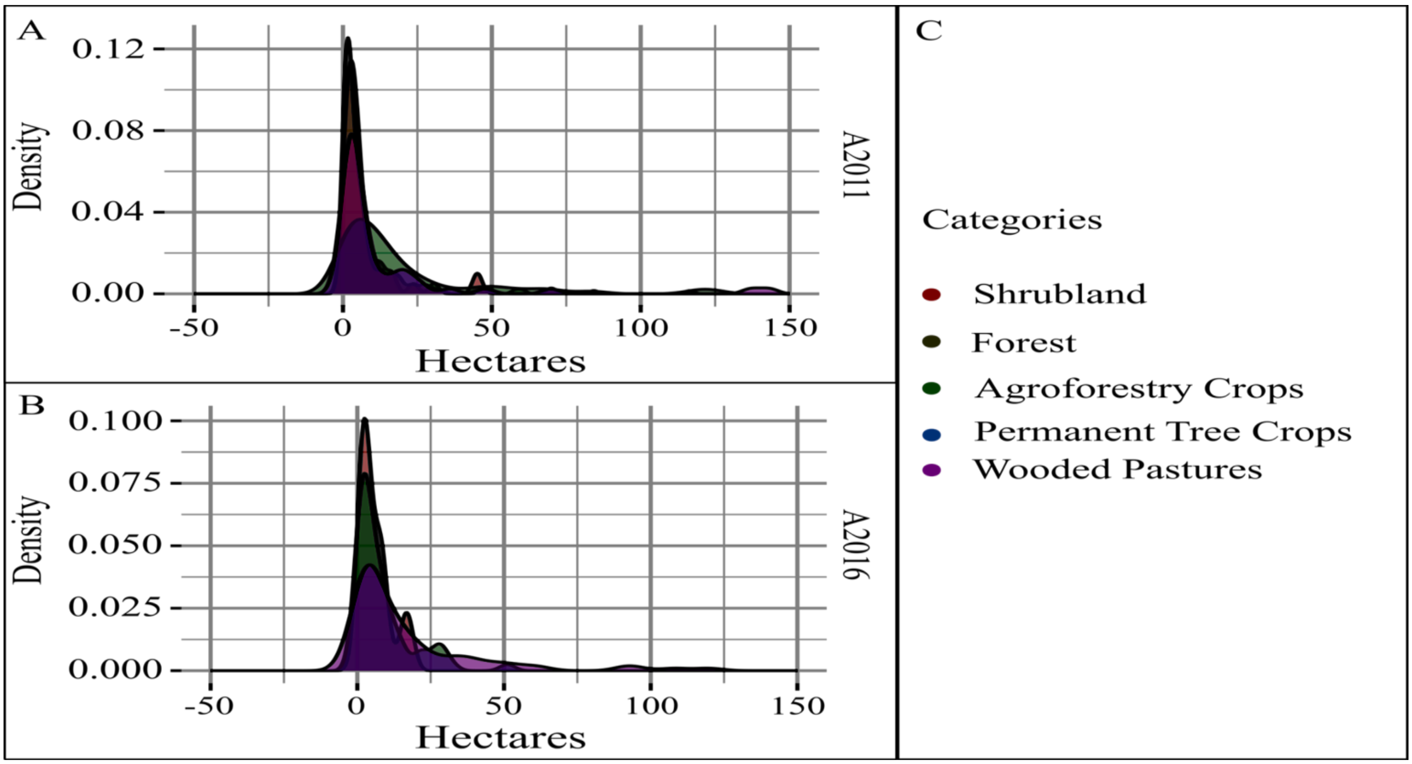

Figure 1. Land Use Frequency Analysis: A Comparison between 2011 and 2016 with Emphasis on Forest Area Reduction. 1A, Land Use Frequency 2011. 1B, Land Use Frequency 2016.1C: Categories.

Source: Own elaboration.

The analysis correlates the influence of the study area with the "Cuchilla de San Juan" reserve, where geographical and altitudinal conditions align with the CARDER spatial data. This information is corroborated by the municipal agricultural assessment, confirming that Hass avocado is the sole permanent crop in these areas. Therefore, avocado cultivation is associated with forest reduction. Integrating and discussing these processes in the territorial analysis points to a mixed model in the study (Hernández, Fernández, & Baptista, 2014).

Regarding water quality, multiparametric analysis systems allow easy access to remote areas to determine essential physical and chemical characteristics (Uriburu, 2018) suitable for this study's conditions. Specifically, the Campo Alegre stream sampling point has good vegetative cover and appears natural. This spring is used by

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at least 12 peasant families for consumption and downstream agricultural activities without any control or treatment because it is not considered a rural aqueduct, and water is taken directly.

Below, the physicochemical parameters found for the sample are detailed (table 1).

Table 1. Water Analysis Results for Campo Alegre Hamlet

Method	Parameter	Result
Multiparameter	pH	7.20
	ORP	394.7 mv
	DO (%)	44
	DO (ppm)	3.62
	Conductivity	1 013
	T°	17.6 C°
	TDS	1 ppm
KIT Freshwater Master Test	pH	7.2 - 7.4
	Ammonia	0
	Nitrites	0
	Nitrates	5 ppm

Source: Own elaboration.

There is good vegetation at the Las Cabañas Creek sampling site, though it is slightly more exposed and has a less steep slope. The water source serves about 15 peasant families in the Las Cabañas and San Andrés areas, with no treatment for potabilization.

The results for the sample corresponding to the Las Cabañas area are detailed next (table 2). Generally, the values obtained for each parameter are compared with regulatory standards for drinking water, considering both Colombian regulations and the WHO-recommended values. According to Pole (2009), result descriptions are strengthened when considering different references.

Table 2. Water Analysis Results for Las Cabañas Hamlet

Method	Parameter	Result
Multiparameter	pH	5.7
	ORP	400 mv
	DO (%)	62.7
	DO (ppm)	4.9
	Conductivity	36 µS/cm

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	Temperature	18.6°C
	TDS	18 ppm
KIT Freshwater Master Test	pH	6–7.4
	Ammonia	0
	Nitrites	0
	Nitrates	5 ppm

Source: Own elaboration.

Resolution 2115 of 2007 outlines characteristics, basic instruments, and frequencies for the monitoring system for drinking water quality used to evaluate pH, conductivity, nitrites, and nitrates, as specified in the document and included in the analyzed variables. Researchers will compare Dissolved Oxygen (DO) with the standards set in Resolution 1096 of 2000, which adopts the Technical Regulation for Drinking Water and the Basic Sanitation Sector – RAS, as it is unspecified in Resolution 2115. Parameters such as Total Dissolved Solids (TDS), Redox Potential (ORP), and Temperature (T°) will refer to the WHO-suggested values.

Thus, researchers present a comparative analysis of the results with the permissible ranges for the mentioned parameters, as described above (table 3).

Table 3. Results and Permissible Ranges.

	Campo Alegre	**Las Cabañas**	**Allowed Values**
pH	7.20	5.7	Permissible value in Resolution 2115 is between (6.5 - 9.0)
ORP	394.7 mV	400 mV	Established value by WHO is (+650 mV)
DO	3.6 ppm	4.9 ppm	Established value in Resolution 1096 of 2000 is (> 4 ppm)
Conductivity	1 013	36	The established value by Resolution 2115 of 2007 is (< 1000)

Source: Own elaboration.

DISCUSSION

Considering the frequency of land use between 2011 and 2016, it is essential to note that for the points recorded in the 2016 classification, high-density forests were replaced by shrublands and agroforestry crops, among which the Hass avocado cultivation could be classified. This crop, as demonstrated by EVA, saw a dramatic increase during the same period, particularly in the study area of Las Cabañas and Campo Alegre, which had the highest number of avocado-producing properties.

This phenomenon may occur due to the lack of control by environmental authorities and the imprecision in measuring total forest areas, which generally show patterns of partial deforestation; this is often conducted through a method known as "socolado" by producers or through the partial expansion of tree crops like avocado, which can "conceal" the reduction of native forests. Mas et al. (2017) found that the avocado region of Sierra Costa experienced the highest deforestation in the Michoacán state, Mexico, during 2004-2007. Researchers arrived at this conclusion from a study that analyzed satellite images and identified fragmented loss possibly influenced by cultivation.

The accelerated changes in rural land use may be associated with intensive production models that tend to occupy areas where soil quality can enhance production levels (Berrelleza et al., 2021). The model of expansion and intensification, coupled with the proximity of cultivation to forests, indicates a higher risk of deforestation at the points identified as avocado producers. Acevedo-Charry et al. (2021) demonstrated in the middle basin of Caquetá-Putumayo, in the southern Colombian Amazon, that anthropogenic intervention through agricultural activities led to significant deforestation in jungle fragments near crops and pastures between 2015 and 2020.

The increase in cultivation areas and the transition to intensive models usually occur gradually, resulting in fragmented deforestation. This process begins with avocado cultivation associated with other crops and then expands into more forested areas (Vásquez Santa, 2020). The category of permanent arboreal crops is not very significant in the frequency graph, showing a slight density in 2011 and disappearing in 2016, which is understandable as the monoculture of cold climate fruits like avocado only began to be introduced after 2010, according to the economic development secretary of the municipality of Apía in consultation carried out in 2021.

Regarding water quality analysis, it is crucial to highlight that the pH level in Las Cabañas was 5.7. This pH is not within the ranges permitted by Colombian law for human consumption. According to Cortijo-Herrera (2013), "at pH values lower than 6.3, the water is corrosive due to the presence of CO2 concentrations higher than the bicarbonate ion concentration; and at pH values higher than 8.3" (p.227).

Given the acidic pH of the sample from Las Cabañas, potential health effects are relevant since at least 15 peasant families rely on this water source. [4]According to the 2010 GIRH Policy, collective human consumption is always the prioritized use, thus it is relevant that actions are proposed by the environmental authority. One possible cause is glyphosate, a product used a month before taking the sample in the avocado cultivation near the analyzed water source. Fares-Taie et al. (2015) refer to the commercial formulation of glyphosate as "an aqueous mixture of isopropylammonium (IPA) salt, a surfactant, and several minor components, including anti-foaming agents, biocides, and organic ions, which are present to adjust the pH."

The WHO recommends that the ORP value for microbiological surveillance of water should be higher than 650 mV. This standard was established in 1971, considering it the appropriate value for drinking water, ensuring that values above 650 mV can guarantee proper water disinfection. The WHO adopted the ORP measure in 1972 as the most reliable method for assessing the sanitary quality of drinking water.

The results for the ORP parameter in both analyzed water sources were below the value established by the WHO, with the source in Campo Alegre showing the lowest value at 397 mV and Las Cabañas at 400 mV. These results raise alarms regarding the risk of contamination, especially considering the direct consumption from the source without any treatment, as is the case for the peasant families that use the two water sources described in the study.

Dissolved oxygen (DO) is the amount of gaseous oxygen dissolved in water, essential for the health of surface water sources. Low levels indicate water contamination (Aguilar & Isabel, 2007).

Resolution 1096 of 2000 states that dissolved oxygen should be equal to or greater than 4.0 ppm for acceptable water sources in Colombia. The results for DO in the samples show a value of 4.9 ppm in the water source of Las Cabañas, meeting the standards established in the sanitary regulation, and the water emergence in Campo

[4] https://www.minambiente.gov.co/gestion-integral-del-recurso-hidrico/

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Alegre showed a result of 3.6 ppm, below the value specified in the regulation.

Meanwhile, the parameter of electrical conductivity can be considered an indicator of the degree of water mineralization and directly relates to the concentration of total dissolved solids (TDS) (Boyd, 2017); in this variable, the water source evaluated in Las Cabañas complies with the values established in the regulations, while the water source analyzed in Campo Alegre presents values above the permitted limit, although not very distant from the allowed thresholds.

The parameters not discussed in this discussion fall within the permitted reference ranges for human water consumption. However, the lack of historical or chronological data hinders the assessment of the impact of agricultural activities on the physicochemical variables of water. The need for continuous water quality monitoring in rural areas is evident, given the persistent presence of environmental elements that can influence its characteristics (Parra & Roncancio, 2020).

CONCLUSION

In general terms, researchers concluded that the areas influencing the DMI Cuchilla de San Juan protected zone are undergoing gradual and considerable deforestation while confirming the establishment and increase of permanent arboreal crops, specifically Hass avocado. This situation demands a more detailed analysis to precisely identify the environmental damage in terms of deforestation and the action of the relevant authorities for their control tasks.

With the water quality analysis, there are some slight alterations in the water results. For example, the pH, ORP, and OD may be related to avocado cultivation and could mean potential public health problems. However, the implemented methodology provides primary data, making it necessary to study more in-depth, considering techniques such as chromatography, to obtain precise information about the substances present in the water sources and their direct relationship with the active components of the inputs used in avocado cultivation.

The research process reveals shortcomings in infrastructure and quality control for human water consumption in rural areas, demanding more state presence and health authorities to provide better support to the peasant population.

Declaration of Conflict of Interest

The responsibility for the opinions expressed in this document lies exclusively with its authors and in no way compromises the official thinking of the affiliated institutions. Likewise, during the work and the drafting of this document, researchers did not incur in conflicts of interest.

Authors' Contribution

Herman Hincapié: Main author and researcher, information gathering, analysis, and preparation of this article.

Jade Li: Technical advice, preparation of geographic information system data.

Martha Zuluaga: Technical advice, data analysis, and classification.

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