Ecuadorian Amazon Deforestation Hotspots Due to Oil Infrastructure Development in the 21st Century

José Agustín García-Romero[1], Isabel Adriana Chuizaca-Espinoza[2,3], Andrés Velastegui-Montoya[1,3], Yasmim Carvalho Guimarães[4], Luciana das Dores de Jesus da Silva[5], Fabiola D. Yépez-Rincón[6], Kevin Rodriguez González[6], Aylet Veja Aguilar[6]

[1] Faculty of Engineering in Earth Sciences, ESPOL Polytechnic University, Guayaquil, Ecuador – josaggar@espol.edu.ec
[2] Earth Observation and Geoinformatics Division, National Institute for Space Research (INPE), São José Dos Campos, Brazil – isabel.espinoza@inpe.br
[3] Laboratory of Geoinformation and Remote Sensing, Faculty of Engineering in Earth Sciences, ESPOL Polytechnic University, Guayaquil, Ecuador – dvelaste@espol.edu.ec
[4] Graduate Program in Natural Disasters (Unesp /CEMADEN), São José dos Campos, SP, Brazil – yasmim.guimaraes@unesp.br
[5] Departament of Aquatic Systems, Concepción University, Concepción, Chile – lucisilva@udec.cl
[6] Universidad Autónoma de Nuevo León, Faculty of Civil Engineering, Department of Geomatics, San Nicolás de los Garza, Nuevo León, México – (fabiola.yepezrn, krodriguezge, aylet.vegaglr)@uanl.edu.mx

Keywords: Ecuadorian Amazon, Oilfields, Petroleum Exploration, Kernel Density Estimation, Protected Areas, Hotspots.

Abstract

The Ecuadorian Amazon hosts remarkable biodiversity and cultural richness but faces increasing pressures from the expansion of oil-related activities. This study evaluated the distribution and concentration of deforestation hotspots between 2000 and 2023, analyzing their relationship with existing oil infrastructure and environmentally significant areas Land Use and Land Cover data from MapBiomas Ecuador were combined with Kernel Density Estimation (KDE) analyses based on the spatial distribution of oil blocks, pipelines, wells, and the limits of environmentally sensitive areas. The results indicate a net loss of 391,303 ha (4%) of forest cover, with 80% of the hotspots located within a 10 km radius of hydrocarbon infrastructure. However, intangible zones, protected areas, and water protection zones showed minimal impacts. The findings of this study provide technical evidence to support land-use management and conservation efforts in ecologically vulnerable Amazonian regions.

1. Introduction

The western Amazon constitutes one of the most biodiverse and culturally rich biomes on the planet, yet it remains among the most vulnerable regions due to the expansion of extractive activities, particularly those related to the hydrocarbon sector (Campos et al., 2024; Finer et al., 2008). The Ecuadorian Amazon represents a strategic location because of its importance in providing ecosystem services, energy resources, and climate regulation, which local and Indigenous communities have traditionally managed in a sustainable manner (Codato et al., 2019). Nevertheless, reliance on natural resources has led to irreversible degradation of the biome, mainly driven by the expansion of mining activities, deforestation, and oil extraction (Silveira et al., 2025). Regarding the latter, hydrocarbon exploration and production began in Ecuador during the 1920s, followed by a production boom in the 1970s (Cepak, 2005).

The extraction technologies used during the 1970s led to an accelerated increase in pollution across the northern Ecuadorian Amazon (San Sebastián and Karin Hurtig, 2004). Throughout the 1990s and 2000s, Ecuador experienced a large number of adverse events related to crude oil spills, primarily in the Yasuní region (Kimerling, 1991). The development of this industry has generated environmental and social impacts, including deforestation linked to the construction of roads, drilling platforms, and oil infrastructure, as well as pollution from oil spills and contaminated water discharges into aquatic systems (O'Rourke and Connolly, 2003; Rosenfeld et al., 2001; Wunder, 2005). Previous studies show that oil exploration, extraction, and transport require extensive infrastructure development, significantly altering land use and land cover patterns and affecting ecosystem services and environmental quality (Velastegui-Montoya et al., 2023).

The installation of infrastructure (including the construction of roads, platforms, and multiproduct pipelines) has been identified as a critical factor in the fragmentation of biomes and, consequently, in the opening of new fronts of deforestation activities (Hansen et al., 2013). This situation not only drives the loss of forest cover but also poses risks to ecological sustainability and the integrity of local communities, including the diverse Indigenous peoples and nationalities inhabiting the region.

Few studies have systematically quantified the spatial and temporal impacts of deforestation associated with oil infrastructure using long-term satellite data (Peña-Villacreses et al., 2024; Velastegui-Montoya et al., 2024). Although environmental regulations exist to control extractive activities (Ministerio de Energía y Minas, 2023), deforestation continues to expand in areas with oil infrastructure, particularly in biodiverse regions and Indigenous territories. Therefore, it is important to identify which of these oil zones (oil blocks) (Finer et al., 2008) exhibit the highest concentrations of forest cover loss and how this loss relates to existing hydrocarbon infrastructure.

This study provides technical evidence based on satellite-derived Land Use and Land Cover (LULC) data, enabling the spatial identification of critical deforestation hotspots (Singh and Yan, 2021). These hotspots are analyzed in relation to oil-related structural variables, such as the location of pipelines, wells, operating blocks, and oil fields, as well as environmentally significant areas, including protected and intangible zones. The objective is to identify deforestation hotspots since the year 2000, prior to the construction of the Heavy Crude Oil Pipeline (OCP) (OCP Ecuador, 2023), assessing their relationship with current hydrocarbon infrastructure and natural areas of interest, in order to generate evidence that supports environmental and territorial management in socio-environmentally sensitive or vulnerable areas. Furthermore, the use of consistent multi-temporal data and spatial techniques, such as density analysis, allows for precise interpretation of deforestation patterns and magnitudes, contributing to a better understanding of its dynamics and the driving factors behind it.

Within this framework, the analysis focuses on the Ecuadorian Amazon, where the interaction between oil infrastructure and tropical ecosystems shapes complex environmental dynamics. The spatial characterization of operating blocks, infrastructure, and ecologically valuable areas is key to understanding deforestation processes associated with extractive activities.

2. Study Area

The analysis focuses on the oil blocks located in the Ecuadorian Amazon (Figure 1a), comprising a total of 65 blocks situated in the provinces of Morona Santiago, Napo, Pastaza, Sucumbíos, and Orellana (Lessmann et al., 2016) (Table 1). These include active and historical concessions, oil transport infrastructure, and protected-area buffer zones.

Block name	ID	Block name	ID
Coca-Payamino	7	Charapa	51
Villano	10	Ocano-Pena Blanca	52
Lumbaqui	11	Singue	53
Eden-Yuturi	12	Eno-Ron	54
Nantu	14	Armadillo	55
Indillana	15	Lago Agrio	56
Iro	16	Shushufindi-Libertador	57
Hormiguero	17	Cuyabeno-Tipishca	58
Palo Azul	18	Vinita	59
Pungarayacu	20	Sacha	60
Yuralpa	21	Auca	61
Block 22	22	Tarapoa	62
Mirador	28	Palanda-Yuca Sur	64
Block 29	29	Pindo	65
Apaika-Nenke	31	Tiguino	66
ITT	43	Tivacuno	67
Pucuna	44	Blocks 70-87	70-87
Puma	45	Perico	88
MDC	46	Iguana	89
PBHI	47	Sahino	90
Punino	48	Araza Este	91
Bermejo	49	Espejo	92
Chanangue	50	Pañayacu Norte	93

Table 1. Oil Blocks of Interest in the Ecuadorian Amazon

Two major pipelines are highlighted: the Trans-Ecuadorian Oil Pipeline System (SOTE), operating since 1972 and managed by EP Petroecuador; and the Heavy Crude Oil Pipeline (OCP), whose construction began in 2001 and started operations in 2003 (EP Petroecuador, 2023; OCP Ecuador, 2023). In addition, other oil-related structures are considered within this area of interest, including smaller pipelines, gas and multiproduct pipelines, oil fields, terminals, extraction stations, refineries, and wells (Figure 1b) (Ministerio de Energía y Minas, 2022).

Regarding environmentally significant areas (Figure 1c), this includes Protected Areas within the National System of Protected Areas (SNAP) along with their adjacent buffer zones, as well as Water Protection Areas (APEs) established by the Ministry of Environment, Water, and Ecological Transition (MAATE, 2022). Other key elements are the Intangible Zones, delineated by Executive Decree 2187 of 2007 (Tagaeri-Taromenane Intangible Zone – ZITT) (Pappalardo et al., 2013). These are protected areas of exceptional cultural and biological importance, where no extractive activities are allowed due to their value for the country, the world, and present and future generations (De Marchi et al., 2013).

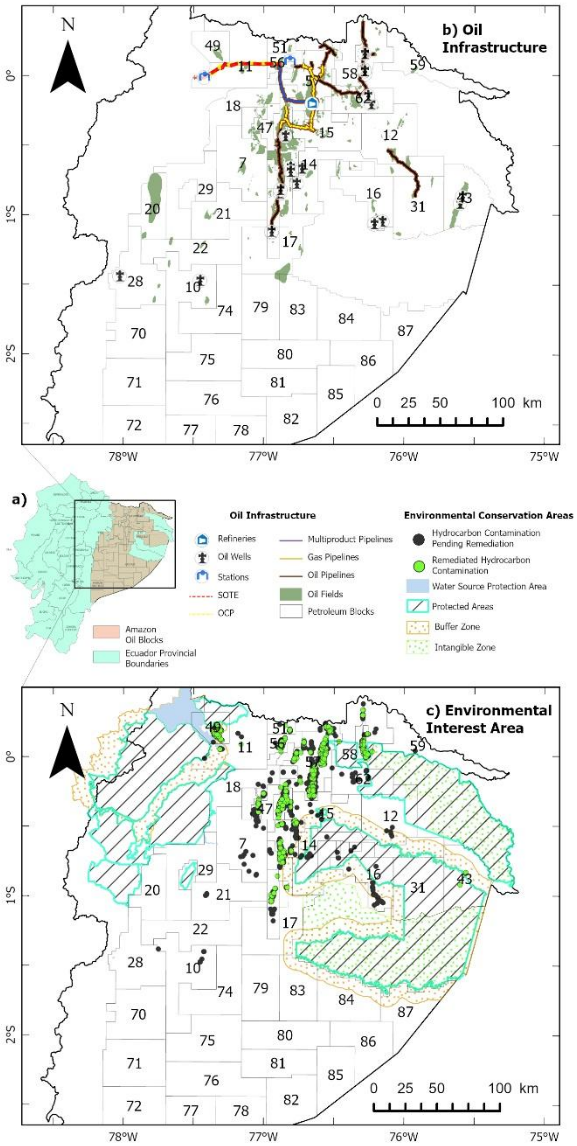

Figure 1. Map of oil infrastructure and environmentally significant areas within the oil blocks of the Ecuadorian Amazon.

Overall, this spatial framework, covering oil blocks, infrastructure, and ecologically significant areas, provides a foundation for analyzing deforestation patterns and understanding the interactions between extractive activities and tropical ecosystems within the Ecuadorian Amazon.

3. Methodology

3.1 Data Selection and Definition of the Analysis Period

The analysis of deforestation hotspots was conducted from the year 2000, which marks a starting point prior to the construction of the OCP (2001–2003). This allowed for capturing the forest cover conditions before the expansion associated with this infrastructure, while also focusing on a more recent dynamic using consistent satellite data. Furthermore, this period coincides with the intensification of oil projects and increased interaction with conservation policies and the establishment of protected areas (Lessmann et al., 2016; MAATE, 2022; Ministerio de Energía y Minas, 2022; Pappalardo et al., 2013). The final year of analysis was set to 2023, as it represents the most recent period with complete and updated Land Use and Land Cover (LULC) data from MapBiomas Ecuador (MapBiomas Amazon Project, 2022). This period ensured an analysis with current and comparable information, linking deforestation processes to natural areas of high ecological value and incorporating recent social variables that influence territorial management.

As previously specified, LULC data from MapBiomas Ecuador were used, as they allow for a consistent monitoring of land cover changes over time, making them ideal for accurately detecting deforestation activities (MapBiomas Amazon Project, 2022). Similar multi-temporal remote sensing approaches have been widely applied to evaluate long-term land-use dynamics and their implications for territorial sustainability and environmental management (Benítez-Ramírez et al., 2026), and to evaluate land use and land cover dynamics in response to large-scale infrastructure development and associated environmental processes in the Ecuadorian Amazon (Velastegui-Montoya et al., 2024). The extraction of the Forest Formation classes (Forest and Flooded Forest) was carried out entirely in ArcGIS Pro, selecting these variables for each year of analysis (2000 and 2023). Then, by performing an Erase operation, the deforestation variable was generated through the creation of a new feature layer obtained by removing the portions of the input features corresponding to the 2000 Forest layer that overlap with the erase features corresponding to the 2023 Forest layer. The centroids of each pixel were then extracted to characterize the spatial distribution and intensity of deforestation processes (Ferreira et al., 2007) within the oil blocks of the Ecuadorian Amazon between 2000 and 2023.

3.2 Spatial Distribution of Deforestation Intensity

To visualize the impact of deforestation induced by oil activities, the Kernel Density Estimator (KDE) was used. This type of spatial analytical approach is consistent with geomatics-based methodologies that integrate GIS and spatial analysis techniques to identify patterns of environmental change and support decision-making processes (Escandón-Panchana et al., 2025). This tool calculates a magnitude per unit area from point or line features, applying a kernel function to fit a smoothly conical surface over each point or line under analysis (Rudke et al., 2020; Wang et al., 2020). The KDE is defined by the following equation (1):

$$f(x) = \frac{1}{n.h} = \sum_{z=1}^{n} k\left(\frac{x - x_z}{h}\right), \quad (1)$$

where $f(x)$ = estimated density at the point
n = number of samples
h = smoothing parameter
k = kernel function

The kernel function (k) determines the shape of each sample's contribution. The parameter h controls the smoothing range, where smaller values can provide more detailed estimates but may lead to overestimation, while larger values produce smoother curves that may obscure relevant details, resulting in underestimation. The following adjustment parameters were defined: cell size = 1500 m and search radius = 6000 m (Silverman, 2018).

The selection of the KDE parameters was based on preliminary tests that demonstrated a balance between the accuracy in detecting deforestation hotspots and the reduction of noise in areas with low change intensity. These KDE-derived hotspots were then analyzed in relation to oil infrastructure and environmentally significant areas to assess spatial patterns of deforestation.

4. Results and Discussions

4.1 Kernel Density Estimation

The KDE methodology proved to be a useful tool for the spatial representation of phenomena associated with deforestation intensity. This process allows for the association of intensity hotspots with infrastructure and the estimation of the potential influence of activities related to the establishment of facilities such as platforms, wells, roads, and pipeline routes, among others. Similarly, it enables the assessment of their relationship with environmentally significant variables, including Protected Areas, Water Protection Areas, and Intangible Zones.

The selection of a 1,500 m cell size is suitable for the overall analysis across most of the Ecuadorian Amazon, as it adequately captures the spatial distribution of oil infrastructure and environmentally significant variables. This also prevents potential over-smoothing that could lead to over- or underestimation of areas with the highest concentration of deforestation activity. Therefore, the choice of parameters ensures a precise and robust spatial analysis of the hotspots (Silverman, 2018; Wang et al., 2020).

Some alternative methodological approaches could include the use of supervised classification algorithms (Random Forest) (Belgiu and Drăguţ, 2016) or landscape fragmentation analysis (connectivity metrics using FRAGSTATS) (McGarigal and Marks, 1995; Saura and Pascual-Hortal, 2007), which would allow for a more detailed assessment of the spatial structure of deforestation fronts. However, KDE was prioritized in this study due to its robustness in continuously representing spatial intensity patterns at large regional scales.

Figure 2 shows the spatial analysis of deforestation activities between 2000 and 2023, allowing their association with oil infrastructure that may have induced these land cover changes, and enabling the assessment of their impact on environmentally significant areas.

https://doi.org/10.5194/isprs-archives-XLIX-B4-2026-597-2026

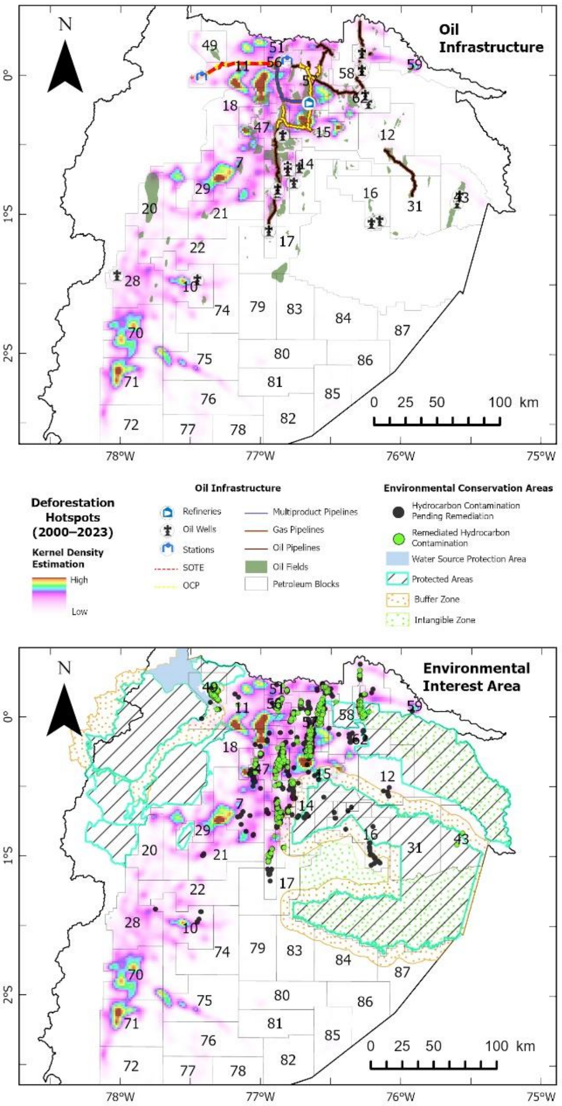

Figure 2. Map of deforestation hotspots calculated between 2000 and 2023 within the oil blocks.

4.2 Spatial Analysis of Deforestation Intensity

Between 2000 and 2023, a total loss of 391,303 ha of forest formation was recorded, resulting in an approximately 4% reduction in forest cover over a 23-year period. This reduction can be associated with various activities or operational fronts in the Ecuadorian Amazon, but it is important to analyze the spatial distribution of these hotspot points. The hotspots show the highest intensity and occurrence in the blocks located in the northern Ecuadorian Amazon, with particular relevance in blocks 07 (Coca-Payamino), 11 (Lumbaqui), 15 (Indillana), 17 (Hormiguero), 18 (Palo Azul), 29 (Block 29), 46 (MDC), 48 (Punino), 51 (Charapa), 54 (Eno-Ron), 56 (Lago Agrio), 59 (Vinita), 61 (Auca), 62 (Tarapoa), 88 (Perico), 92 (Espejo), and 93 (Pañayacu Norte). Other blocks located in the southern study area include 10 (Villano), 70 (Block 70), 71 (Block 71), and 75 (Block 75). Approximately 90% of these blocks are managed by the Ecuadorian state (operations under Petroamazonas EP, Petroecuador EP, and the Ministry of Energy and Mines).

The main characteristic is that the majority of deforestation hotspots occur near infrastructure of interest, with a maximum distance of 10 km (buffer) between structures such as pipelines, gas and multiproduct pipelines, stations, wells, terminals, refineries, oil fields, the SOTE, and the OCP. This pattern aligns with observations reported for the western Amazon in general (Finer et al., 2008). Although not all deforestation hotspots are directly associated with extractive activities or their infrastructure, as in the isolated cases of blocks 70, 71, and 75, where no nearby oil infrastructure exists, approximately 80% of the deforestation fronts between 2000 and 2023 are spatially related to the establishment and operation of hydrocarbon infrastructure and the territorial processes derived from its presence. In many of these blocks, forest cover change is linked to the expansion of agricultural areas, rural settlements, or secondary access roads, connected to local development dynamics and economic activities induced by the oil industry, reflecting an indirect impact of this sector on the Amazonian landscape.

It is also important to note that there are areas with oil infrastructure, mainly wells and pipelines (blocks 12, 14, 16, 31, and 43), where deforestation intensity is low or negligible. Several reasons may explain this. One reason could be that part of this infrastructure was constructed before the analysis period, and the initial deforestation already occurred beforehand, so surrounding forests have largely been transformed and land cover change in recent decades is minimal. Another factor may be that the existing infrastructure has a low visible impact; pipelines or internal roads may be stabilized and not involve large-scale clearing during the study period, or deforestation associated with them may have occurred only during construction, not operation. However, one of the most relevant factors is environmental management and control within these areas, which is linked to the Environmental Interest Areas section in Figure 2.

In the previously mentioned blocks (12, 14, 16, 31, and 43), environmental protection areas have been established. For example, block 43 (ITT) (Prime, 2025) is located almost entirely within a Protected Area along with its respective Buffer Zone, demonstrating that there are areas where environmental regulations are effectively enforced, as in this case. In general, Protected Areas, spaces designated for the long-term conservation of nature, its ecosystem services, and associated cultural values (MAATE, 2022), are exempt from deforestation fronts, or at least from those with high intensity. However, within the buffer zones of these areas, several hotspots with moderate to high intensity are observed. On the other hand, Intangible Zones, areas where no extractive activities are allowed, such as the ZITT (De Marchi et al., 2013), show no deforestation hotspots. Similarly, Water Source Protection Areas exhibit low intensity of deforestation hotspots.

The absence of significant hotspots in these blocks can be explained, first, by the stricter environmental management governing Protected Areas, where planning and control of oil activities tend to comply with higher standards of ecological protection and restoration. Second, a potential methodological effect should be considered: since the Kernel density analysis used a search radius of 6000 m, blocks with a small deforested area, such as Block 43, may present density values insufficient to be detected as hotspots, even though local land cover change processes are occurring.

For this analysis, hydrocarbon contamination points were also considered, categorized as Remediated or Pending Remediation. It is evident that the highest concentration of these contamination points is located within high-intensity deforestation hotspots, primarily of the remediated type. This suggests that in areas where deforestation fronts occurred, such contamination points may have been generated. Therefore, it should be emphasized that not all contamination events should be associated solely with exploitation or extraction operations, but also with earlier stages, such as the construction of oil infrastructure and related activities, including deforestation fronts.

The patterns detected in blocks with deforestation presence coincide with dynamics reported in the Brazilian and Peruvian Amazon, where the construction of roads and pipelines facilitates anthropogenic expansion and the conversion of forests to agricultural uses (Finer et al., 2008; Lessmann et al., 2016). This similarity reinforces the hypothesis that linear infrastructure (pipelines and roads) constitutes an indirect driver of deforestation in Amazonian biomes by fragmenting habitats and opening access to previously inaccessible areas. Therefore, the results of this study can serve as a reference for understanding deforestation processes induced in other similar contexts with extractive activities, such as oil or mining operations.

Although in most cases the hotspots are located more than 10 km from Protected Areas, i.e., in the peripheral or adjacent zones corresponding to buffer areas, they still pose a risk to biodiversity as well as to the territorial security of indigenous communities. The proximity of these deforestation fronts to such areas highlights the need to strengthen monitoring and control measures, especially in a context where the Yasuní Popular Consultation (2023) reflected a citizen mandate for conservation against oil exploitation, as is the case in Block 43-ITT (García Orellana and Siguenza Orellana, 2024).

4.3 Limitations and Future Perspectives

One limitation of the present study is the reliance on satellite data, which in this case consisted of the MapBiomas Ecuador Land Use and Land Cover (LULC) collection with a 30 m resolution. This resolution may underestimate smaller-scale deforestation processes, such as small clearings or narrow linear infrastructure openings. Similarly, the annual frequency of this collection does not allow for the identification of deforestation hotspots within intra-annual timeframes, which could be associated with infrastructure construction over short periods (Silva et al., 2022), or even illegal activities, such as unauthorized connections to major pipelines like the SOTE and OCP, an activity that can sometimes be a determining factor in oil spills and subsequent contamination hotspots (León-Cabrera et al., 2018; Valencia, 2024).

Future research could integrate higher-resolution data, such as Sentinel-2 imagery or multitemporal radar (SAR) analysis (Karaman et al., 2023), to improve deforestation detection under high cloud cover. In addition, complementary methodologies, such as Random Forest or landscape connectivity analysis (Keeley et al., 2021), could provide greater robustness in understanding forest cover fragmentation.

Despite these limitations, the findings of this study provide valuable insights into the spatial patterns and drivers of deforestation in the Ecuadorian Amazon, which can inform conservation and management strategies.

5. Conclusions

The spatial analysis of deforestation in the Ecuadorian Amazon between 2000 and 2023 reveals a loss of 391,303 ha of forest cover, equivalent to 4% of its forested area. The results show a concentration of hotspots in oil blocks of the northern Amazon, where approximately 80% of the fronts are associated with the presence and operation of hydrocarbon infrastructure, particularly within a 10 km influence radius. These findings confirm the role of linear infrastructures, such as pipelines and roads, as catalysts of forest fragmentation and habitat loss. However, blocks such as 43 (ITT) exhibit low or negligible recent deforestation, demonstrating the effectiveness of environmental control measures and legal restrictions in Protected Areas, Intangible Zones, and Water Protection Areas. Nevertheless, the proximity of deforestation fronts to buffer zones and indigenous territories highlights the persistent ecological and socio-cultural risks that require stricter and more sustainable management strategies.

Methodologically, the combination of MapBiomas Ecuador satellite data and Kernel Density Estimation (KDE) proves to be an effective approach for the multitemporal characterization of deforestation in Amazonian contexts. This approach demonstrates the potential of spatial analysis applied to territorial management and suggests that future research should integrate higher-resolution sources, such as Sentinel-1 and Sentinel-2, along with advanced classification algorithms such as Random Forest and landscape connectivity metrics. The generated evidence represents a valuable technical input for environmental planning in Ecuador and a replicable reference for other tropical regions where extractive processes, forest loss, and conservation converge.

References

Belgiu, M., Drăguţ, L., 2016. Random forest in remote sensing: A review of applications and future directions. ISPRS Journal of Photogrammetry and Remote Sensing 114, 24–31. https://doi.org/10.1016/j.isprsjprs.2016.01.011

Benítez-Ramírez, D.M., Alfonso Romero-Toledo, F., Escandón-Panchana, P., Velastegui-Montoya, A., 2026. Spatiotemporal dynamics of land use applied to sustainability in the Andes mountain range. Global Journal of Environmental Science and Management. https://doi.org/10.22034/gjesm.2026.03.15

Campos, M.S., Anjos, L.J.S., Souza, E.B. de, Bezerra, F.G.S., Lima, A.M.M. de, Galbraith, D.R., Adami, M., 2024. Prioritizing Amazon Forest conservation: Assessing potential biomass under climate change. Glob Ecol Conserv 54, e03106. https://doi.org/10.1016/j.gecco.2024.e03106

Cepak, M.C., 2005. Crude Chronicles: Indigenous Politics, Multinational Oil, and Neoliberalism in Ecuador. Tipití: Journal of the Society for the Anthropology of Lowland South America 3. https://doi.org/10.70845/2572-3626.1074

Codato, D., Pappalardo, S.E., Diantini, A., Ferrarese, F., Gianoli, F., De Marchi, M., 2019. Oil production, biodiversity conservation and indigenous territories: Towards geographical criteria for unburnable carbon areas in the Amazon rainforest. Applied Geography 102, 28–38. https://doi.org/10.1016/j.apgeog.2018.12.001

De Marchi, M., Pappalardo, S.E., Ferrarese, F., 2013. Zona intangible Tagaeri Taromenane (ZITT): ¿Una, Ninguna, Cien Mil?

EP Petroecuador, 2023. Historia del Sistema de Oleoducto Transecuatoriano (SOTE [WWW Document]. SOTE.

Escandón-Panchana, P., Velastegui-Montoya, A., Pico-Saltos, R., Martínez-Cuevas, S., 2025. Applications of geomatics in multidisciplinary knowledge fields. A review for decision-makers. Discover Applied Sciences 7, 1409. https://doi.org/10.1007/s42452-025-07928-9

Ferreira, N.C., Ferreira, L.G., Miziara, F., 2007. Deforestation Hotspots in the Brazilian Amazon: Evidence and Causes as Assessed from Remote Sensing and Census Data. Earth Interact 11, 1–16. https://doi.org/10.1175/EI201.1

Finer, M., Jenkins, C.N., Pimm, S.L., Keane, B., Ross, C., 2008. Oil and Gas Projects in the Western Amazon: Threats to Wilderness, Biodiversity, and Indigenous Peoples. PLoS One 3, e2932. https://doi.org/10.1371/journal.pone.0002932

García Orellana, D., Siguenza Orellana, S., 2024. La Consulta Popular sobre explotación petrolera en el Yasuní ITT como resistencia a los planes de desarrollo en el Ecuador. DICERE Revista de Derecho y Estudios Internacionales 1, 27–38. https://doi.org/10.33324/dicere.v1i1.743

Hansen, M.C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S. V., Goetz, S.J., Loveland, T.R., Kommareddy, A., Egorov, A., Chini, L., Justice, C.O., Townshend, J.R.G., 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change. Science (1979) 342, 850–853. https://doi.org/10.1126/science.1244693

Karaman, K., Sainte Fare Garnot, V., Wegner, J.D., 2023. DEFORESTATION DETECTION IN THE AMAZON WITH SENTINEL-1 SAR IMAGE TIME SERIES. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences X-1/W1-2023, 835–842. https://doi.org/10.5194/isprs-annals-X-1-W1-2023-835-2023

Keeley, A.T.H., Beier, P., Jenness, J.S., 2021. Connectivity metrics for conservation planning and monitoring. Biol Conserv 255, 109008. https://doi.org/10.1016/j.biocon.2021.109008

Kimerling, J., 1991. Amazon Crude. Natural Resources Defense Council.

León-Cabrera, J., Shubert, W., Sarah, E., 2018. In Ecuador, a pipeline cuts a trail of misery through indigenous land. Mongabay.

Lessmann, J., Fajardo, J., Muñoz, J., Bonaccorso, E., 2016. Large expansion of oil industry in the Ecuadorian Amazon: biodiversity vulnerability and conservation alternatives. Ecol Evol 6, 4997–5012. https://doi.org/10.1002/ece3.2099

MAATE, 2022. Sistema Nacional de Áreas Protegidas (SNAP) y Áreas de Protección Hídrica (APH). Ministerio del Ambiente, Agua y Transición Ecológica del Ecuador.

MapBiomas Amazon Project, 2022. Collection [5] of Annual Land Cover and Land Use Maps [WWW Document]. Via https://github.com/mapbiomas-brazil.

McGarigal, K., Marks, B.J., 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. https://doi.org/10.2737/PNW-GTR-351

Ministerio de Energía y Minas, 2023. Decreto Supremo No 2967, Ley de Hidrocarburos, Registro Oficial No 711. Ecuador.

Ministerio de Energía y Minas, 2022. Mapa de bloques e infraestructura petrolera del Ecuador. Bloques e infraestructura petrolera.

OCP Ecuador, 2023. Historia y operación del Oleoducto de Crudos Pesados [WWW Document]. OCP Ecuador.

O'Rourke, D., Connolly, S., 2003. Just oil? The distribution of environmental and social impacts of oil production and consumption. Annu Rev Environ Resour 28, 587–617. https://doi.org/10.1146/annurev.energy.28.050302.105617

Pappalardo, S.E., De Marchi, M., Ferrarese, F., 2013. Uncontacted Waorani in the Yasuní Biosphere Reserve: Geographical Validation of the Zona Intangible Tagaeri Taromenane (ZITT). PLoS One 8, e66293. https://doi.org/10.1371/journal.pone.0066293

Peña-Villacreses, G., Ayala-Hidalgo, S., Braga, D., Guimarães, Y., Santos, M.R. da S., Pereira, M. de A., Velastegui-Montoya, A., 2024. Trends of Remote Sensing applications for Amazon monitoring. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLVIII-3–2024, 393–399. https://doi.org/10.5194/isprs-archives-XLVIII-3-2024-393-2024

Prime, L., 2025. Blocking Oil Development in Yasuní National Park: Ecuador's Unprecedented Strides Towards Environmental Justice. Consilience. https://doi.org/10.52214/consilience.vi27.12100

Rosenfeld, A.B., Gordon, D., Guerin-McManus, M., 2001. Reinventing the Well: Approaches to Minimizing the Environmental and Social Impact of Oil Development in the Tropics, in: Footprints in the Jungle. Oxford University Press, pp. 55–71. https://doi.org/10.1093/0195125789.003.0005

Rudke, A.P., Sikora de Souza, V.A., Santos, A.M. dos, Freitas Xavier, A.C., Rotunno Filho, O.C., Martins, J.A., 2020. Impact of mining activities on areas of environmental protection in the southwest of the Amazon: A GIS- and remote sensing-based assessment. J Environ Manage 263, 110392. https://doi.org/10.1016/j.jenvman.2020.110392

San Sebastián, M., Karin Hurtig, A., 2004. Oil exploitation in the Amazon basin of Ecuador: a public health emergency. Revista Panamericana de Salud Pública 15. https://doi.org/10.1590/S1020-49892004000300014

Saura, S., Pascual-Hortal, L., 2007. A new habitat availability index to integrate connectivity in landscape conservation planning: Comparison with existing indices and application to a case study. Landsc Urban Plan 83, 91–103. https://doi.org/10.1016/j.landurbplan.2007.03.005

Silva, C.A., Guerrisi, G., Del Frate, F., Sano, E.E., 2022. Near-real time deforestation detection in the Brazilian Amazon with Sentinel-1 and neural networks. Eur. J. Remote Sens. 55, 129–149. https://doi.org/10.1080/22797254.2021.2025154

Silveira, F., Romero, J.P., Queiroz, A., Freitas, E., Stein, A., 2025. Economic complexity and deforestation in the Brazilian Amazon. World Dev 185, 106804. https://doi.org/10.1016/j.worlddev.2024.106804

Silverman, B.W., 2018. Density Estimation for Statistics and Data Analysis. Routledge. https://doi.org/10.1201/9781315140919

Singh, M., Yan, S., 2021. Spatial–temporal variations in deforestation hotspots in Sumatra and Kalimantan from 2001–2018. Ecol Evol 11, 7302–7314. https://doi.org/10.1002/ece3.7562

Valencia, A., 2024. Fuel theft, violence siphoning $215 million from Ecuador oil industry. Reuters.

Velastegui-Montoya, A., Chuizaca-Espinoza, I.A., Alberto Falquez-Chávez, C., Aguilar-Aguilar, M., Bulatov, D., Carrión-Mero, P., 2024. Assessment of Land Use/Land Cover Changes Due to Mining Activity in the Ecuadorian Amazon, in: IGARSS 2024 - 2024 IEEE International Geoscience and Remote Sensing Symposium. IEEE, pp. 5469–5473. https://doi.org/10.1109/IGARSS53475.2024.10642414

Velastegui-Montoya, A., Escandón-Panchana, P., Peña-Villacreses, G., Herrera-Franco, G., 2023. Land use/land cover of petroleum activities in the framework of sustainable development. Clean. Eng. Technol. 15, 100659. https://doi.org/10.1016/j.clet.2023.100659

Velastegui-Montoya, A., García-Romero, J.A., Chuizaca-Espinoza, I.A., Quevedo, R.P., Santana-Cunha, C., Ochoa-Brito, J.I., Arias-Hidalgo, M., 2024b. Assessing regressive erosion effects: Unveiling riverside land use land cover changes post hydroelectric project construction. Environmental Challenges 15, 100882. https://doi.org/10.1016/j.envc.2024.100882

Wang, Z., Ginzler, C., Waser, L.T., 2020. Assessing structural changes at the forest edge using kernel density estimation. For Ecol Manage 456, 117639. https://doi.org/10.1016/j.foreco.2019.117639

Wunder, S., 2005. Oil Wealth and the Fate of the Forest. Routledge. https://doi.org/10.4324/9780203986677