

# THE PREVALENCE OF ILLEGAL GOLD PRODUCTION IN BRAZIL

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## ABSTRACT

The exploitation of gold in Brazil has been constantly and rapidly expanding to the core of the Amazon region, and even penetrating into its Indigenous Lands and Conservation Units. Despite rising rates of deforestation due to gold mining, few analyses have attempted to assess the level of illegality in producing and trading gold in Brazil. This study examines high-resolution imagery, DETER data, records from the National Mining Agency, and gold purchase/selling transactions to assess the level of illegality in the gold production chain in Brazil. Between 2019 and 2020, 174 metric tons of gold were traded, from this total 38% were from unknown origin, 28% with evidence of irregularities and 34% apparently of legal origin. The irregularities identified were divided into two categories. Gold is considered potentially illegal when the mining area detected using satellite images goes beyond the authorized title area. In total 42.5 tons (24%) were classified as potentially illegal. Gold is considered illegal when satellite images indicate no evidence of mineral exploitation or the mining title is within a protected area, and as such it has clear evidence of laundering. In total 6.3 tons (4%) were identified as illegal gold. We estimated that the illegal gold produced in Brazil between 2019 and 2020 came from illegal "garimpos" (wildcat miners), located in conservation units, indigenous lands and areas without authorization, which in the Amazon region generated a socioenvironmental cost between USD 3.5 and 10.2 billion. Most of the illegal activities are in the hands of a few actors. Roughly 61% of the illegal gold may be assigned to only six gold mining companies and 71% of this produced gold was purchased by only three financial

institutions accredited by the Central Bank of Brazil. Our study also points out that 96% of mining sites encompassing 21 thousand hectares are in fact located outside of the mining titles purportedly attributed to the origin of traded gold. 72% of Brazilian exports have been acquired by Canada, the United Kingdom, and Switzerland. While it is not possible to determine the exact proportion of illegal gold exported, it is very likely that those countries have imported gold linked to destructive activities in the Amazon. Our results demonstrate not only the failure of the Brazilian government in controlling the gold production in Brazil, but also the lack of control of importing countries.

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# INTRODUCTION

Brazil sits squarely under international scrutiny due to rising rates of deforestation and forest fires, especially in the Amazon. While deforestation and forest fires steadily rise (1) due to the dismantling of environmental policies by the current government, the country faces an increasing risk of commercial sanctions (2). The official discourse has encouraged landowners to break the law (1), permeating throughout the nation the notion of impunity. Mining is a major driver of deforestation in the Amazon, which has directly and indirectly impacted 1.2 million ha of forests between 2005 and 2015 (3).

Gold mining, specifically wildcat miners, are publicly supported by the presidency of Brazil (4, 5), which proposed a bill (Bill 191/2020) to open the indigenous lands (ILs) for mining (6, 7). If approved by the Congress, the new law could further spur deforestation up to 20% higher than under the current weak governance scenario, resulting in losses of ecosystem services of USD 5 billion annually (8). ILs and Conservation Units (CUs) are essential for the conservation of the Amazon Forest and its sociobiodiversity, as well as for mitigating climate change (9, 10). However, weak institutional and normative frameworks for regulating mining allow illegal gold trading and mining operations, especially in the Amazon (11, 12).

In 2020, According to the Brazilian Mineral Yearbook (AMB) (13) by the National Mining Agency (ANM), unwrought gold production in the country totaled 121 metric tons (hereafter tons). In turn, the amount of gold exported (Harmonized System: 7108) reported by the Ministry of Economy (14) reached 98 tons for the same year, with Canada, Switzerland, and the United Kingdom accounting for 73% of exports.

The main gold producer is the state of Minas Gerais that accounts for 32% of the 2020 national production, the equivalent to 38.5 tons coming from large-scale mining companies. However, two other states also stand out as major producers. Pará with 32.7 tons (27%) and Mato

Grosso with 14.6 tons (12%), both located in the Legal Amazon (15), with production mainly coming from “garimpos” (wildcat miners).

The gold extracted by wildcat miners must be, by law, sold to a financial institution authorized by the Central Bank of Brazil (Bacen) (17) called “Distribuidora de Títulos e Valores Mobiliários” (DTVM). However, in practice, the gold is sold to commercial establishments that resell it in the form of manufactured goods. The seller in both cases is the one who asserts the origin of the gold based on presumption of good faith. This exchange based on a supposedly good faith allows loopholes in the system, enabling as result an entry door for laundering the gold illegally extracted (16).

In order to quantify the illegal production of gold incorporated into the legal market, federal prosecutors of the Public Prosecutor’s Office (MPF) in collaboration with researchers from the Federal University of Minas Gerais (UFMG) developed a verification protocol based on geospatial analyses (16). This protocol enabled us to quantify the level of illegality of the gold traded between 2019 and 2020 for all mining titles available in the Financial Compensation for the Exploitation of Mineral Resources (CFEM) database (18).

There are two main actors involved in the “laundering” illegal gold into the legal market. A seller that extracted the gold illegally needs to inform a valid mining title in order to sell the gold to a financial institution (DTVM). In order to do so, the seller may provide a false statement, informing that the gold has come from a given mining title, whereas in reality it came from somewhere else. The DTVM, by receiving gold from an unknown source, may also falsely claim its origin by informing a mining title. In both cases this could be done with or without knowledge of the real owner of the mining title, and since those statements are not systematically checked a false statement could go unnoticed. Yet, this study has been able to detect only but a small fraction of the illegal gold laundered using this mechanism. If the mining title falsely attributed as the



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gold's source is located in a valid area (i.e. outside protected areas), allows gold extraction, and presents evidence via satellite images of mining activity within the bounds of the title, then this study will still classify the transaction as "legal".

The study is structured as follows. The next section briefly introduces the Brazilian mining legislation. Next, we present our geospatial protocol that employs satellite imagery, land cover maps, and georeferenced information from the Mining Geographic Information System (SIGMINE) (19). Finally, to deal with uncertainties from the government data, we developed our gold production system that allows the visualization of results without outliers or null values.

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# BRAZILIAN MINING LAW

According to the Constitution of the Federative Republic of Brazil, all mineral resources are property of the State (art. 20, IX). Any mining initiatives must go through a prior environmental licensing process. The law also establishes that any environmental damage from mining be repaired - art. 225, §1, IV, and §2 of the National Environmental Policy Law (Law 6.938/1981) and Resolutions no. 01/1986, n. 09/1990 and n. 237/1997 of the National Environment Council.

Mineral exploitation, therefore, requires two authorizing acts. In order to extract minerals, mining companies, cooperatives and individuals must obtain a mining title issued by the National Mining Agency. The procedure for obtaining a mining title is equivalent to an act of disposal of assets of the Federal Union, whereby it assigns to third parties the right to exploit a mineral deposit. At the same time, miners must obtain an environmental license, which establishes the environmental obligations for mining. The environmental license is a three-phase process, covering the planning, installation, and operation of the mining, and is granted under the framework of procedures conducted either by federal, state, or municipal environmental agencies, depending on the size and impact of the activity (Complementary Law n. 140/2011).

To grant a party the right to exploit the mineral deposit which is owned by the Federal Government, Brazilian law establishes different types of mining titles, granted by the National Mining Agency. Among these types, there are the Mining Concession (MC) for conventional/large-scale mining and the “Garimpeira” Mining Permission (GMP) originally for artisanal and small-scale alluvial mining (20, 21). The creation of GMP in 1989 intended to recognize, protect and encourage the figure of the autonomous pan miner, already mentioned in the previous Mining legislation (Decree-Law No. 227/1967 (22)). However, legislative changes after the creation of the GMP and subsequent normative acts reduced the importance of these characteristics of rudimentary and handicraft mining (16). The main points of the GMP are: a) the immediate exploitation of the mineral deposit regardless of

previous research, that is, the evaluation of its size and economic viability; b) exploitation area of up to fifty hectares for individuals, or, in the case of cooperatives, up to ten thousand hectares in the legal Amazon and one thousand hectares outside the region; and c) extension of those criteria to a long list of minerals (21). There are no restrictions related to the mining techniques, leading to environmental predatory practices. Under the GMP title, the only existing prior assessment is carried out during the environmental licensing procedure. However, the environmental agencies of each state responsible for issuing environmental licenses have different criteria for licensing procedures. Thus, in the case of the GMP, the main licensing assessments, such as the Environmental Impact Study (EIS) and the Environmental Impact Report (EIR), as required in the MC, are subject to different criteria by the state licensing agencies. In this context, the historical figure of the lonely prospector or pan miner was replaced by industrial or semi-industrial mining, diverting thus from the original idea of artisanal mining while maintaining the lower legal requirements.

Other Federal laws also forbid mineral exploitation in indigenous lands and conservation units. For the former, the Federal Constitution establishes in art. 231, §3º that the mining of minerals in indigenous lands can only be carried out with authorization from the National Congress, after hearing the affected communities and ensuring their participation in the mining economic benefits. In the absence of a law regulating the matter, mining on indigenous lands is in fact prohibited. Law 9,985/2000 establishes that mineral exploitation and other activities that involve collection or damage to natural resources in a strictly protected category of conservation unit (CU) is also prohibited. The same prohibition applies to extractive reserves (type of sustainable use CU), as stated in art. 18, §6 of the same law. In turn, mining in other types of sustainable use CU may be permitted conditional to a management plan.

In addition to specific mining and environmental legislation, mining is also regulated by tax

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legislation. Since the subsurface belongs to the Union, it is mandatory to pay the Financial Compensation for the Exploitation of Mineral Resources - CFEM (Laws No. 7,990/1989, and 8,001/1990 and amendments). The payment of CFEM must be made by the person responsible for the extraction or directly by the first purchaser if the mineral was extracted under GMP title. For doing so, either the producer or buyer (in the case of GMP) of the minerals needs to inform the ANM the number of a valid mining title. If the gold in question is destined to the financial market or as a means for Brazil's exchange rate policy, there is a tax on the financial transaction ("IOF Ouro"). The Law no. 7,766/1989 fixes the current rate at 1.5% and the tax is shared by 70% for the municipality of origin of the gold and 30% for the state of origin.

The commercialization of gold of unknown origin, but associated in the first commercial transaction, to a mining title that, in practice, was not exploited, is considered a felony of money laundering (Law no. 9,613/1998). Also, selling gold produced in areas without a valid mining title or produced in strictly protected CU or IL represents a felony of improper appropriation of the Union's assets (article 2 of Law no. 8,176/1991).



# METHODS

The gold production between 2019 and 2020 was classified according to the evidence of irregularity under the current legislation by cross-referencing the mining origin of the gold stated in the CFEM with the mining site recorded at the geospatial database of the ANM (SIGMINE). The gold from a valid mining title (i.e., GMP or MC), whose mining area has evidence of exploitation on satellite images was considered legal. On the other hand, the gold was classified as illegal if it has come either from an invalid mining title (e.g., mining without mining permission), from places where the activity is prohibited (e.g., indigenous lands and strictly protected conservation units) and from a mining title without evidence of mining activity. This last case exemplifies the attempt to “launder” the gold extracted from illegal gold mines. Finally, we consider as potentially illegal gold the ones from mining sites with a valid MP and evidence

of exploitation, but where we identified that the mining site extends beyond the geographical limits of the title granted by the ANM. In turn, gold production without an identified mining site at SIGMINE was classified as undefined.

The classification of the illegality of the gold production was performed in three stages: 1) verification of regularity of the mining title; 2) locating the mining title and activity; 3) land use mapping within the mining titles and around it. First, we began by cross-checking the ANM data on the origin of gold recorded in CFEM with the active mining title at the SIGMINE between March 2020 and January 2021. We analyzed each individual mining title to ensure that there was not exceptional authorization. The gold is considered illegal if it is linked to a mining license that does not allow extraction for commercial purpose

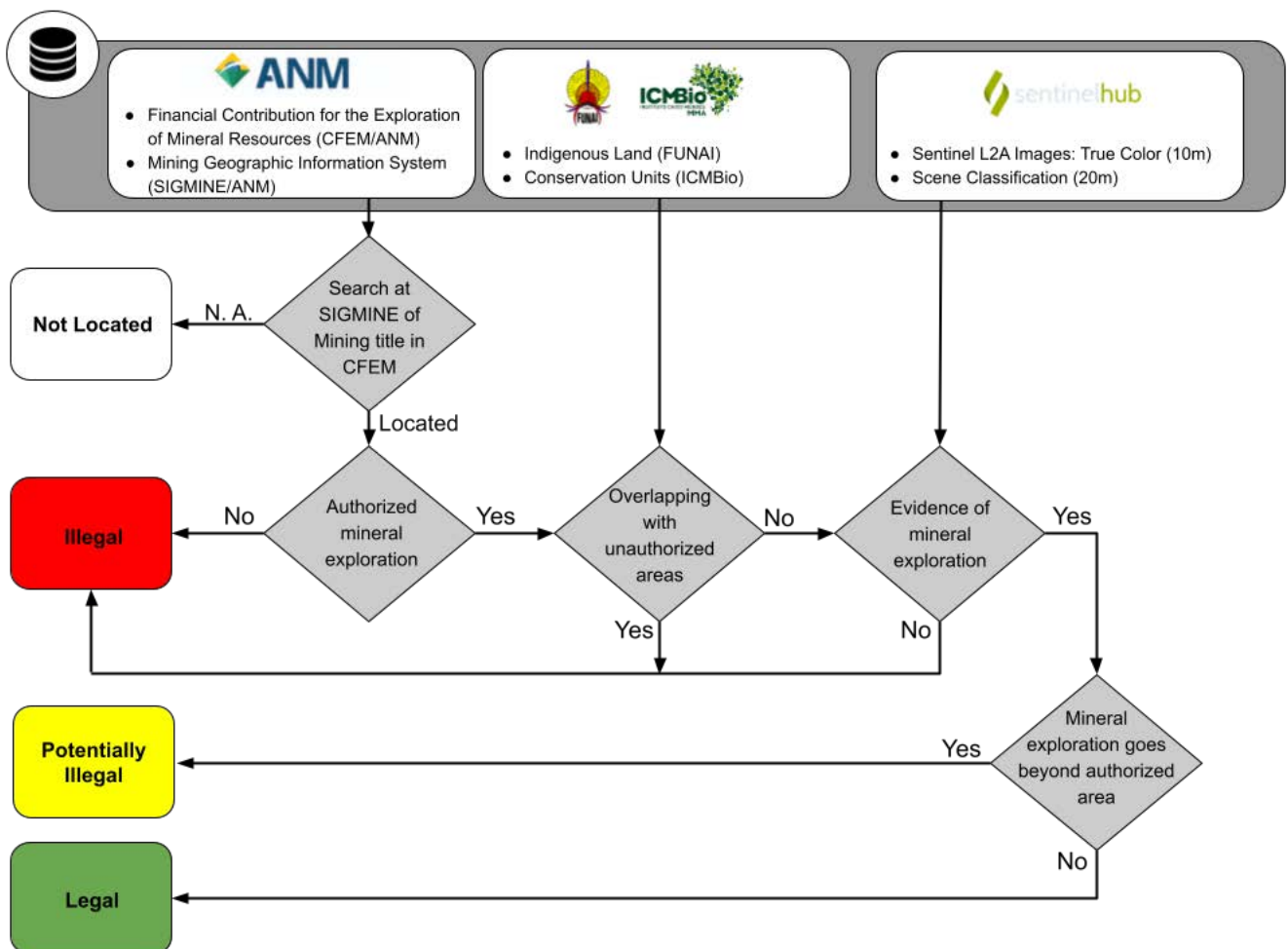


Figure 1: Flowchart with the data source, stages of analysis and classification criteria for gold mining.

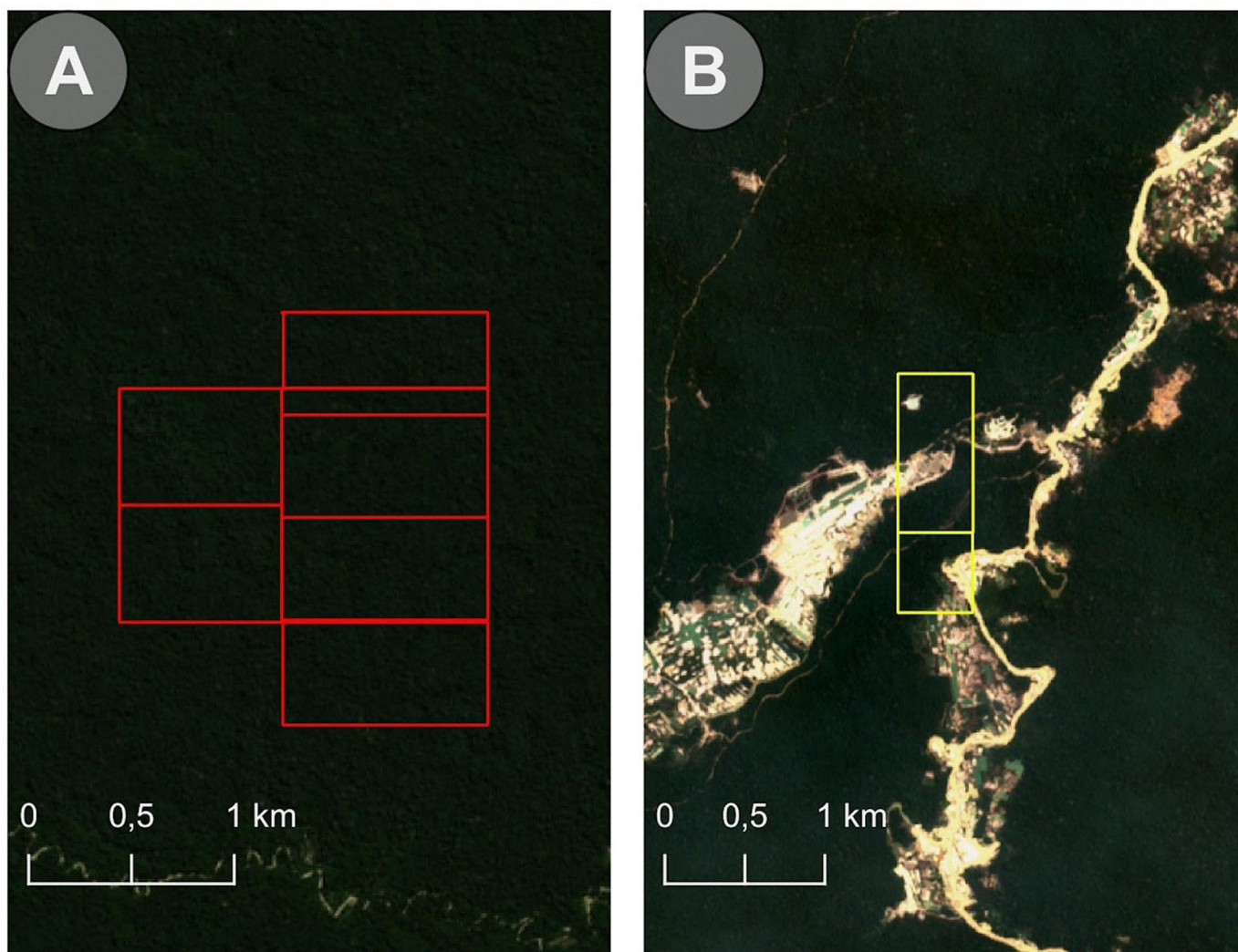
(e.g., request for prospection only or without environmental licensing). At this stage, if the title number recorded at CFEM is not found at SIGMINE, the status of gold production is considered as undefined.

If the mining title number registered at CFEM as the origin of the gold is identified at SIGMINE, the analysis proceeds to verifying the location of the mining title. At this stage, we verified if the mining title has more than 10% of its area overlapping demarcated indigenous lands, strictly protected conservation units or extractive reserves. The gold recorded at CFEM as coming from those areas was considered as illegal. Due to the absence of a database of management plans, this step does not consider the other types of conservation units.

At the third and final stage we mapped the land use within the mining titles area considered valid in the previous stages. Although there are data from

PRODES (23) on annual deforestation, for mapping the mining sites, we used higher spatial imagery from Sentinel-2 satellite (25) with 10 meters of spatial resolution. For gold production as of 2019, we used images acquired between January and December 2020 with 0% of cloud cover. For gold production as of 2020, we used images with low cloud cover from February 2021. We began by applying a classification algorithm developed by the European Space Agency (26) and then visually validated the results using visual interpretation of the areas with evidence of mining. For urban areas, we applied data from OpenStreetMaps to identify underground mines.

We considered illegal gold coming from mining areas totally covered with native vegetation, hence without evidence of mining and potentially illegal gold coming from mining titles where mining sites extrapolate the title's geographic limit. Figure 1). For the spatial analyses, we used QGIS software



**Figure 2:** Areas where production was classified as illegal due to the absence of mining sites (A), and as potentially illegal where exploitation exceeded the limits of the mining title (B).

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(27) together with the Sentinel Hub plugin (28). We also performed a detailed reading of CFEM records for checking and correcting typing errors.

We calculated the value of gold for each transaction recorded at CFEM using as input the 1.5% of tax and average monthly gold price. For cases in which the amount recorded at CFEM was ten times greater than the amount calculated by us, we used the latter. Although those cases may indicate tax evasion, we chose to consider them as typos. We then aggregated the transactions of CFEM per name of individual, association, or company registered as a gold producer, and the company registered as a buyer. In this way, we assessed the amount of illegal gold traded and could identify key actors. Finally, to quantify the total deforestation for mining, even outside the area of mining titles, we applied DETER's alerts for the years 2019 and 2020.



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# RESULTS

We estimated a production of 82 tons of gold for 2019 and 92 tons for 2020, hence a 12% increase. Production in Bahia, Goiás, Mato Grosso, and Minas Gerais has remained stable over the two years. Production from industrial-scale mining also remained virtually unchanged. The growth in national production was thus a consequence of large expansion of GMP in Pará, whose annual production leapt from 9.7 to 17.2 tons from 2019 to 2020. As a result, the production coming from these purportedly wildcat miners in Pará reached a gross value of USD 774 million in 2020, considering the monthly value of gold.

Our analysis encompassed 17.5 thousand gold transactions records at ANM and CFEM payments, between 2019 and 2020, totaling 174 tons of gold. We could not locate 51 mining titles from SIGMINE, which corresponded to 421 transactions and 48.7 tons of gold. This indicates the inability of the State to trace production, although it does not necessarily point to illegality. We did not analyze transactions performed after the acquisition date of the satellite images, except for cases previously classified as illegal due to absence of mining authorization or in areas where the activity is prohibited. As a result, 2,279 transactions equivalent to 16.5 tons of gold could not be verified, leaving outside of our analyses 5.7 and 4.2 tons of gold originated in Pará and Mato Grosso, respectively. Of the 108 tons of gold from records at SIGMINE, we determined that 48.9 tons showed evidence of irregularity, totaling 28% of the national production between 2019 and 2020. The total amount of gold with evidence of irregularity traded in the period is worth USD 2 billion. On the other hand, we could only assert the legality for 34% of the country's gold production.

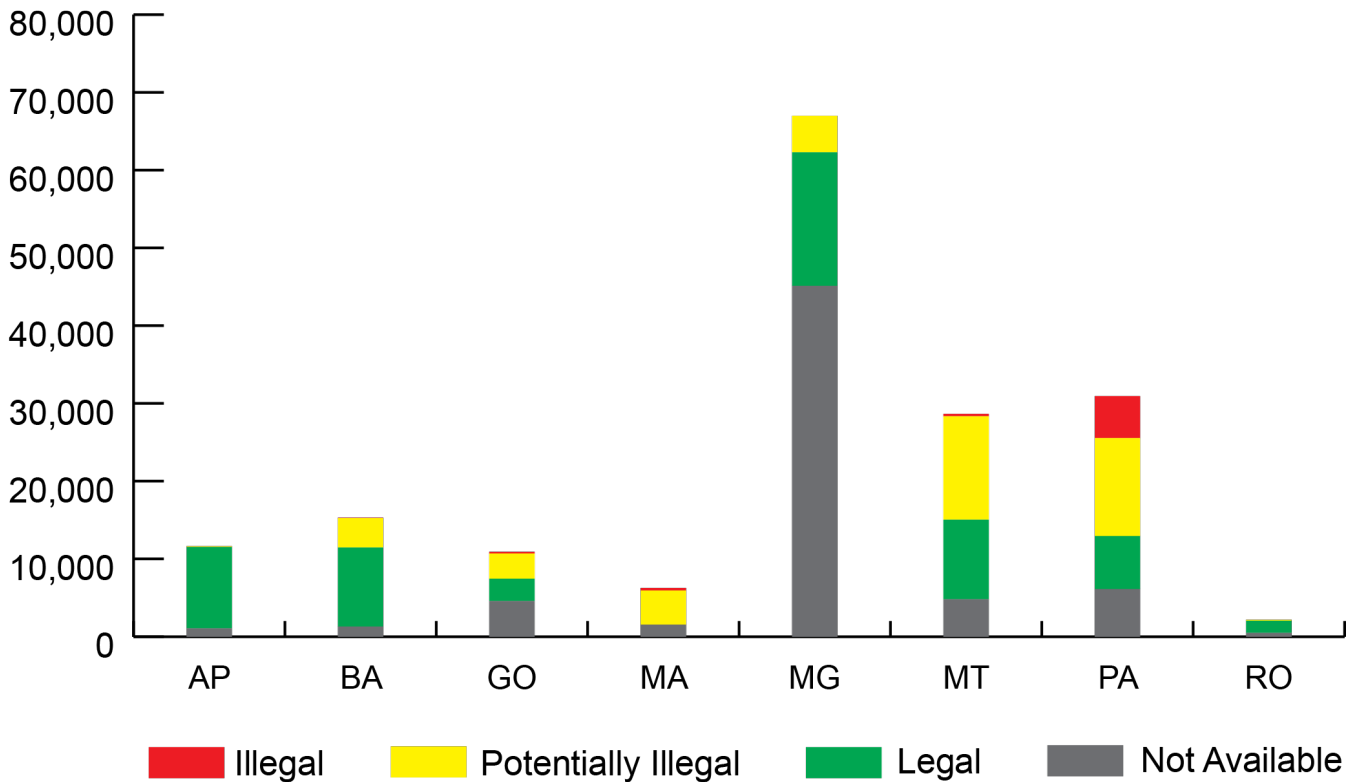
Of the gold classified as irregular, most are potentially illegal, typifying the cases where the mining activity exceeds the geographical limits of the MP granted by the ANM. In this category we identified 20.4 tons from MCs and 20.7 tons from GMPs. We also determined the trading of 6.3 tons of illegal gold, because there was either no evidence of mining activity in the areas stated when issuing CFEM (93%), the mining occurred

without legal authorization or within a protected area that does allow mining activity (7%). Almost all of these types of irregularity are associated with the small-scale wildcat miners (*garimpeiros*), which amount to USD 229 million. Most irregularities are located in Pará and Mato Grosso, in the Legal Amazon, which produced 17.7 and 14.2 tons of gold with irregularity, respectively (Figure 3). The predominant titles in both states are the GMP: together, Pará and Mato Grosso concentrate 94% of all GMP titles in operation in the country and, consequently, also the largest areas available for exploitation. In total, 54% of gold production from GMPs was classified as irregular.

In 2019, 7.8 tons of gold originated in areas within or overlapping protected areas; in 2020, this amount rose to 13.6 ton indicating a growing defiance of the law. Of the 21.5 tons originated in conservation units, 13.8 tons could be assigned as irregular, with 4.7 tons considered as illegal and 9.1 as potentially illegal.

As of March 2020, SIGMINE registered 10 active mining titles, with areas overlapping more than 10% of demarcated indigenous land. Among the total two are the MC title, four prospection authorizations, two GMP titles, and two MC titles. As of January 2021, this figure rose to 24 valid titles, 15 for GMP, 5 prospection authorizations, 2 MC, and 2 MC titles. However, none of these titles was registered as the origin of gold; on the other hand, 665 kg of gold was produced on indigenous lands whose demarcation process has not yet been finished. Although this production is not considered illegal, the fact that the ANM authorized production and that the mining activity is already taking place raises questions about the legal security of these authorizations and the impact on the local population.

DETER data provide evidence on the environmental impact of illegal mining, that is from where the real origin of the gold was concealed. From the beginning of 2019 until the end of 2020, DETER identified 21 thousand hectares of deforestation from mining, 84% of which is located in the state of Pará, 7% in Mato Grosso, and 6% in Amazonas



**Figure 3:** Classification of gold production by state between 2019 and 2020. Values in kilograms.

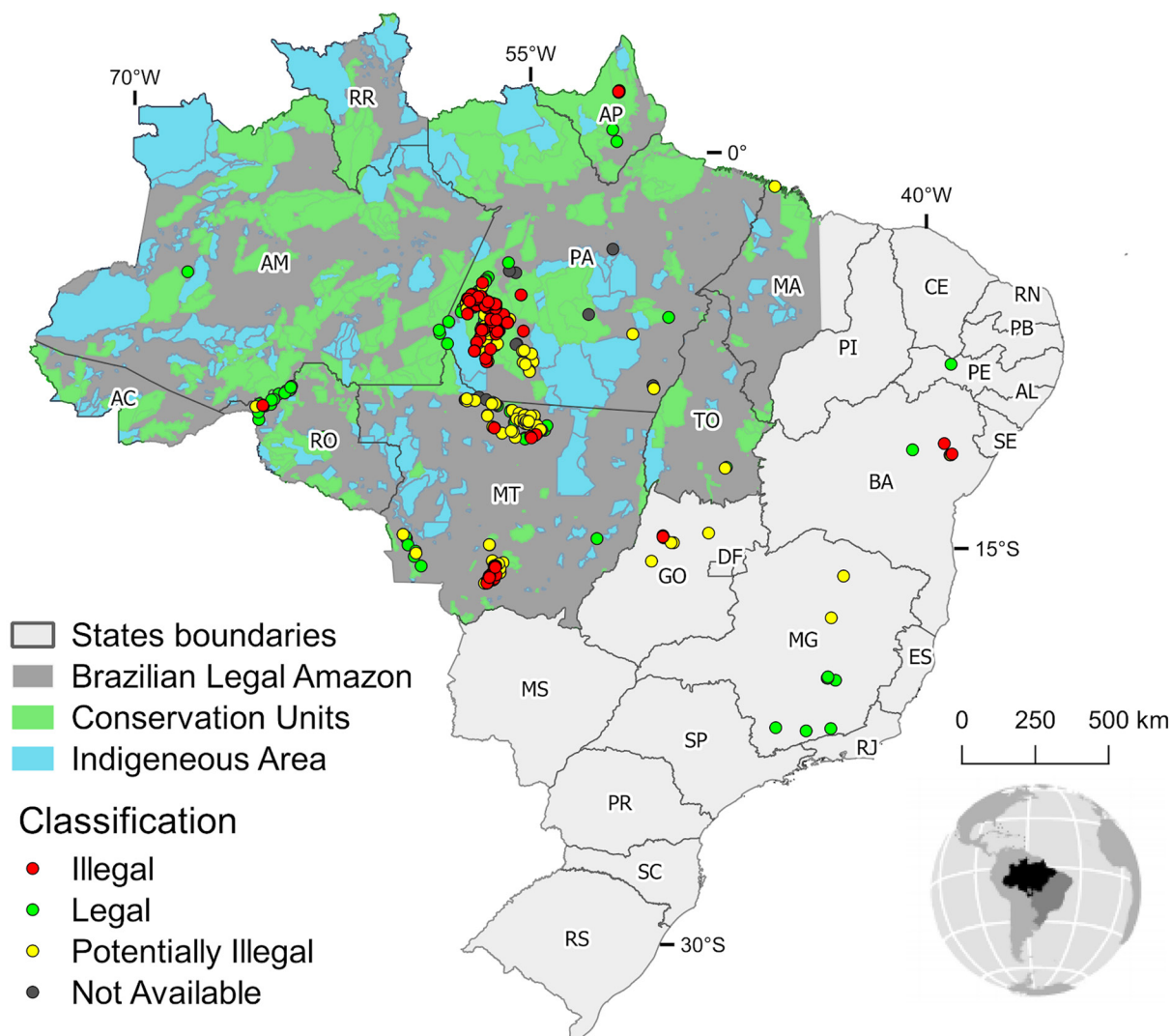
(Table S17). Only 4% of this area is located in the areas stated as the origin of the gold at CFEM. Also, 5 thousand ha of deforestation occurred within demarcated indigenous lands, mainly, within Kayapó and Munduruku, both located in Pará.

Our method also enables tracing the chain of illegal gold, that is, who is responsible for the mining title of origin of the gold and who collected the CFEM, which in case of the GMP, is also the first gold buyer of the supply chain. Of the 6.3 tons of illegal gold, 71% of this amount was purchased by only three financial institutions (DTVM) accredited by the Central Bank of Brazil. The six main holders of the mining titles associated with illegal production or trading, among 74, account for 60% of illegal gold production, with 31% of this gold originating from only one holder who traded 1.5 tons with a single buyer. The ANM and export data also suggest that almost all gold production in the country is exported, with the main destination being Canada, Switzerland, and the United Kingdom, which together account for 72% of exports. Although we could not accurately pinpoint the origin of the exported gold, given the few main actors and prevalence of irregularities in the supply chain, it is likely that a substantial amount of illegal or potentially illegal gold is reaching the North American and European markets.

# DISCUSSION AND CONCLUSION

Different studies and journalistic investigations have already pointed to an expansion of illegal mining in the Amazon as well as associated impacts, such as deforestation. This scenario coincides with the dismantling of environmental policies that gained momentum after 2012, still during the Brazilian Worker Party (“Partido dos Trabalhadores - PT”) government, but in the current government, this dismantling has steeply accelerated by presidential decrees and interference in the environmental agencies, defaulting as a result inspections actions (29, 30, 31, 32). Also, An escalation of the price of gold and the expectation of changes in the law to allow the exploitation of mineral resources within indigenous lands have stimulated the expansion of illegal mining in areas of high ecosystem value and biodiversity. (33, 34).

Here we provided an unprecedented quantitative assessment of the regularity of gold production at the national level. In particular, 28% of gold production was identified as illegal or potentially illegal in 2019 and 2020, totaling 48.9 tons. We observed the predominance of cases (illegal and potentially illegal) concentrated in the Legal Amazon (states of Pará and Mato Grosso) and associated with GMP (Figure 4). Of this total, 6.3 tons were classified as illegal due to production in illegal areas or lack of evidence of mining activity, with strong evidence of attempts to launder the gold originated in areas without authorization. Despite representing only 4% of national production, this illegal production is worth USD 262 million and is probably linked to the 21 thousand hectares of deforestation caused by mining detected by DETER between 2019 and 2020 in the Amazon.



**Figure 4:** Spatial distribution of mining titles with gold production records in 2019 and 2020 classified as illegal, potentially illegal, legal, and without information.



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Nevertheless, our figures are conservative since they are limited to transactions recorded at ANM and to data from the SIGMINE database. For 38% of the gold production, we could not identify the geographic location of the mining sites. Although a large part of this production comes from large-scale mines in Minas Gerais and Goiás, 0.6 tons come from areas of Pará and Mato Grosso, which show evidence of irregularities. It is also necessary to point out that even the production identified as legal might come from illegal areas, given that the origin is stated based on the good faith of the seller.

As a result of the absence of stricter controls by the ANM, environmental agencies, and the Special Department of Federal Revenue of Brazil (“Receita Federal”), this illegal gold generates social conflicts (36, 37) and the destruction of environmental resources and pollution by mercury used in mining (38, 39). Using the illegal mining impact calculator (40), a tool developed by the MPF and the non-governmental organization Conservação Estratégica (CSF-Brasil), it is possible to estimate the economic cost generated by each gram of illegal gold. The 5.9 tonnes laundered using mining titles from areas with no evidence of exploitation probably are originated from protected areas, including indigenous lands. By considering the water pollution, carbon emissions, contamination by mercury, amongst other impacts, it is possible to estimate that the illegal extraction of 6.3 tonnes have generated a social cost USD 3.6 and USD 10.1 billion, adopting, respectively, a conservative methodology (average values) and the precautionary principle (maximum values). In comparison, the Brazilian government had a tax revenue that same amount of illegal gold of only USD 136.6 million, considering both CFEM and IOF-Ouro (41). In addition to environmental damage, illegal gold is often used to launder money from drug trafficking, weapons, land grabbing, and corruption. In sum, while the illegal gold activity concentrates profit in the hands of a few actors, the environmental damage is externalized to the society as whole.

To curb the high levels of irregularity, there is a need for greater cooperation between different government agencies, civil society, and domestic and international buyers. To this end, it is urgent to develop a system that truly guarantees the origin of gold, based on the methodology of this study. With this novel system, ANM would be able to cancel all mining titles and respective titles located in conservation units and indigenous lands. Also, ANM should introduce filters that automatically refuse mining requests in those areas. ANM has to ensure the application of environmental and indigenous legislation in the context of its internal titles, since the failure to do so has allowed illegal production and encouraged the invasion of indigenous lands and conservation units. ANM and environmental licensing agencies should also adopt this system to automatically monitor mining operations, canceling titles that did not enter operation within a defined time period, or that extrapolated the areas of the respective titles. And given the opportunities for investigating environmental crimes and money laundering, these tools should also play a leading role in police enforcement and investigation activities.

A system that guarantees the legal origin of gold should also be adopted by buyers in Brazil and abroad. Given the approval of different “due diligence” laws in 2021 in France, Germany, the United Kingdom, the European Union, and the United States, Brazil may lose its most important export markets (2, 42). Thus, It is becoming increasingly important to develop science-based systems so that the gold chain can be an inducer of development, rather than causing environmental damage and social conflicts.

Finally, it is necessary to review the current legislation to replace the buyer’s presumption of good faith with a traceability system. A new law must not only require the implementation of a more transparent and rigorous control system, but also assign civil and criminal liability to those who benefit from the purchase of illegal gold.



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# SUPPLEMENTARY MATERIALS



# SUPPLEMENTARY MATERIALS

§15. A The Financial Compensation for Mineral Exploration (CFEM) base, which contains all contributions paid per transaction, was definitively

collected on march 2021, covering the years 2019 and 2020.

Data	Type	Description
“Ano de Referencia” (Reference Year)	Numeric	Year in which the CFEM was paid
“Mes de Referencia” (Reference Month)	Numeric	Month in which the CFEM was paid
“Processo” (Process Number)	Numeric	Process number registered as origin of the substance
“Ano do Processo” (Title Year)	Numeric	Year of the mining title of gold origin
“Tipo PF/PJ” (Type PF/PJ)	Alphanumeric	Type of the person who paid the CFEM (PF: Natural Person / PJ: Legal Person)
“CPF/CNPJ”	Alphanumeric	Identification number of the Natural ou Legal Person
“Pessoa Física/Jurídica” (Name)	Alphanumeric	Name of the person who paid the CFEM
“Fase do Processo” (Title)	Alphanumeric	Actual phase of the mining title E.g.: Mining Concession (MC), “Garimpeira” Mining Permission (GMP), etc
“Substância” (Substance)	Alphanumeric	Commercialized substance
“Uf” (State)	Alphanumeric	Mine location (state)
“Município” (City)	Alphanumeric	Mine location (city)
“Unidade de Medida” (Unit of Measurement)	Alphanumeric	Unit of measurement of the substance
“Quantidade Comercializada” (Quantity traded)	Numeric	Quantity marketed according to the unit of measurement of the substance.

**Table 15.1:** CFEM Metadata

The column “Quantity Traded” has an average of 295.6 kg of gold, the maximum value of 279,986.3 kg and a minimum of 1.0 gram (150 missing data), a standard deviation of 6,477.8 kg, and some outliers with values way above a reality for just one transaction, for example, the maximum amount mentioned above. Even so, this should be the “preferred” column to adopt the final value as it has not been changed by any calculation, but it is also necessary to have a comparison base to eliminate and replace the outliers, which will originate from the calculation base, the fee and the amount collected on each transaction.

The next base, collected in March 2020 and later in January 2021, was the Geographical Information System for Mining (15), in which it is possible to spatially visualize all active mining titles through GIS software. In addition to the title number and its location in space, information about the total area released, the current phase, among others, is also present. After filtering all the titles that traded gold, we transferred this set to the QGIS software (26) and filtered the SIGMINE titles to display only the titles mentioned in the CFEM database. However, it was also necessary to perform another filtering of SIGMINE, that of titles in the MC and GMP (for substance “MINÉRIO DE OURO”, “OURO”,

“OURO PIGMENTO” and “OURO NATIVO”) so that it would be possible to visualize both the areas declared as the origin of the gold and the titles

in the Concession of Lavra or Lavra Garimpeira phase, but without the production record, as in Figure 18.1.

Data	Type	Description
“PROCESSO” (PROCESS)	Alphanumeric	Mining title identifier. Composed of the number and year of the title: NNNNNN/YYYY. E.g. 800715/2010
ID	Alphanumeric	Unique polygonal identifier of the mining title
“NÚMERO” (NUMBER)	Numeric	Mining title number. Composed of six digits
“ANO” (YEAR)	Numeric	Year of mining title. Composed of four digits
“AREA_HA”	Numeric	Polygonal area authorized in hectares (ha)
“FASE” (TITLE)	Alphanumeric	Title of the mining title
“ULT_EVENTO” (LAST_EVENT)	Alphanumeric	Last event of the mining title at the ANM registered in the SIGMINE
“NOME” (NAME)	Alphanumeric	Name of the applicant/holder of the mining proceedings
“SUBS”	Alphanumeric	One of the substances associated with the mining title
“USO” (USE)	Alphanumeric	Final use of the substance described in the SUBS attribute
“ESTADO” (STATE)	Alphanumeric	State of the mining title

**Table 15.2:** SIGMINE Metadata



**§16.** In the QGIS software, the union of attributes between CFEM and SIGMINE data was carried out, thus it was possible to visualize, in addition to the information already present in SIGMINE, the commercialization data of each specific title. All titles that would be analyzed are located into five UTM zones, from 20 to 24 south, so the appropriate rejections were made for the plane coordinate system of each zone. To finalize the preparation of data referring to Mining Titles, a buffer of 100 meters was applied to all titles that were

registered as the origin of the gold. This buffer, then, was cut by the areas that had authorization for mineral exploration and by the original area of the title, so that the generated polygon can only touch the area under analysis and overlapping the unauthorized regions, as seen in Figure 18.2.

The primary key used to cross-reference the information was the mining title, that is unique and appears in both tables:

Financial Compensation for Mineral Exploration (CFEM):

Mining title	Year	CPF/CNPJ	Name	Title	State	City	Amount traded (g)	Value paid (BRL)
850672/2015	2020	XXX	XXX	Lavra Garimpeira	PA	Itaituba	8,504,313	606,878.80
850261/2018	2020	XXX	XXX	Lavra Garimpeira	PA	S. M. das Barreiras	316	2,355,214.13
850154/2000	2020	XXX	XXX	Lavra Garimpeira	PA	Itaituba	18	50,837.21

Mining Geographic Information System (SIGMINE):

Mining title	Area (ha)	Title	Last_Event	Name	State
850672/2015	30.27	Lavra Garimpeira	1403 - PLG/LICENÇA AMBIENTAL PROTOCOLIZADA EM 27/08/2020	XXX	PA
850261/2018	494.01	Lavra Garimpeira	805 - PLG/OPÇÃO REGIME AUTORIZAÇÃO PESQ PROTOC EM 10/06/2020	XXX	PA
850154/2000	50.00	Lavra Garimpeira	572 - PLG/TRANSF DIREITOS -CESSÃO TOTAL EFETIVADA EM 14/01/2020	XXX	PA

§18.

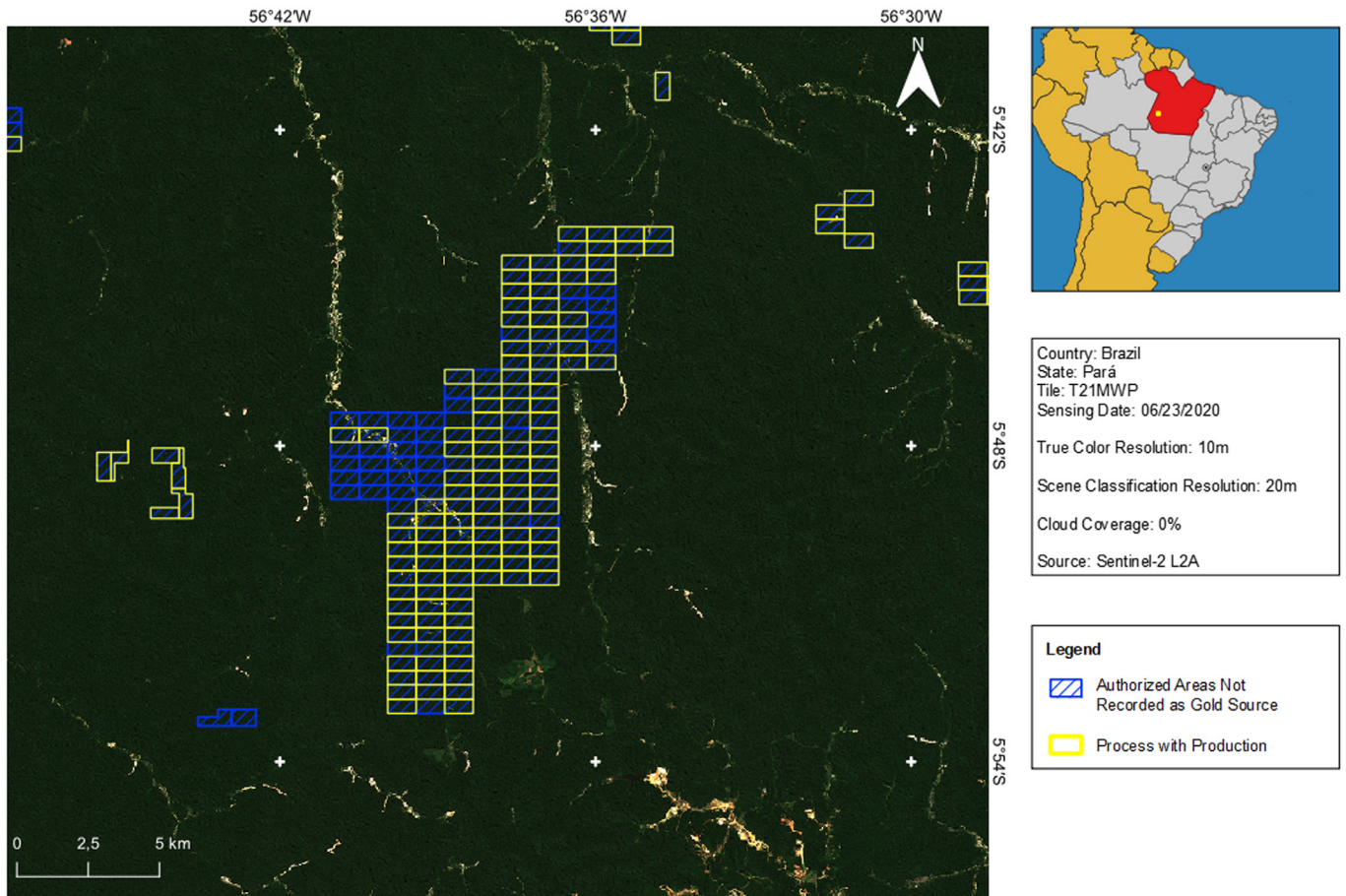


Figure 18.1: Plotting the result of merged bases of CFEM and SIGMINE

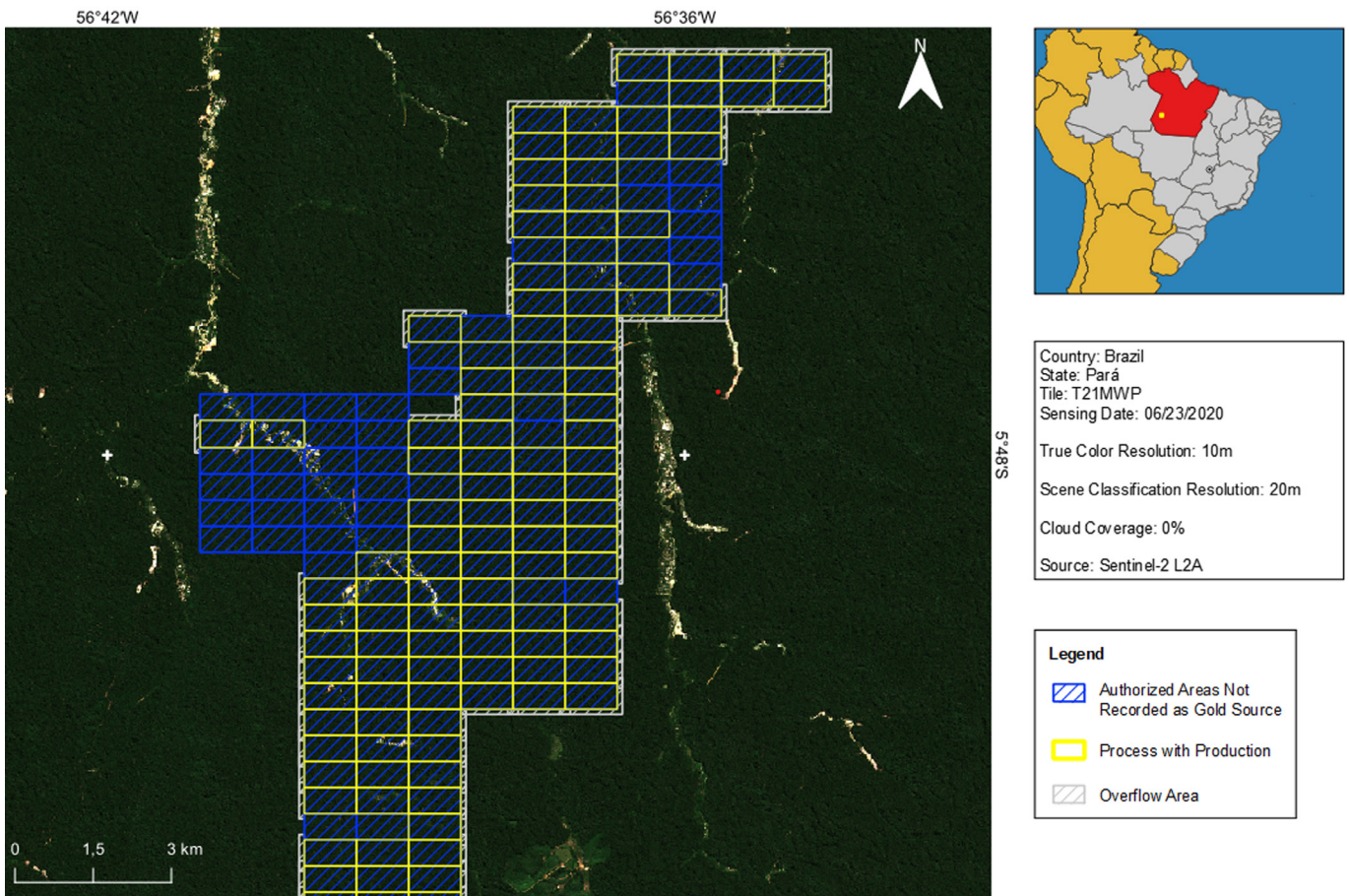


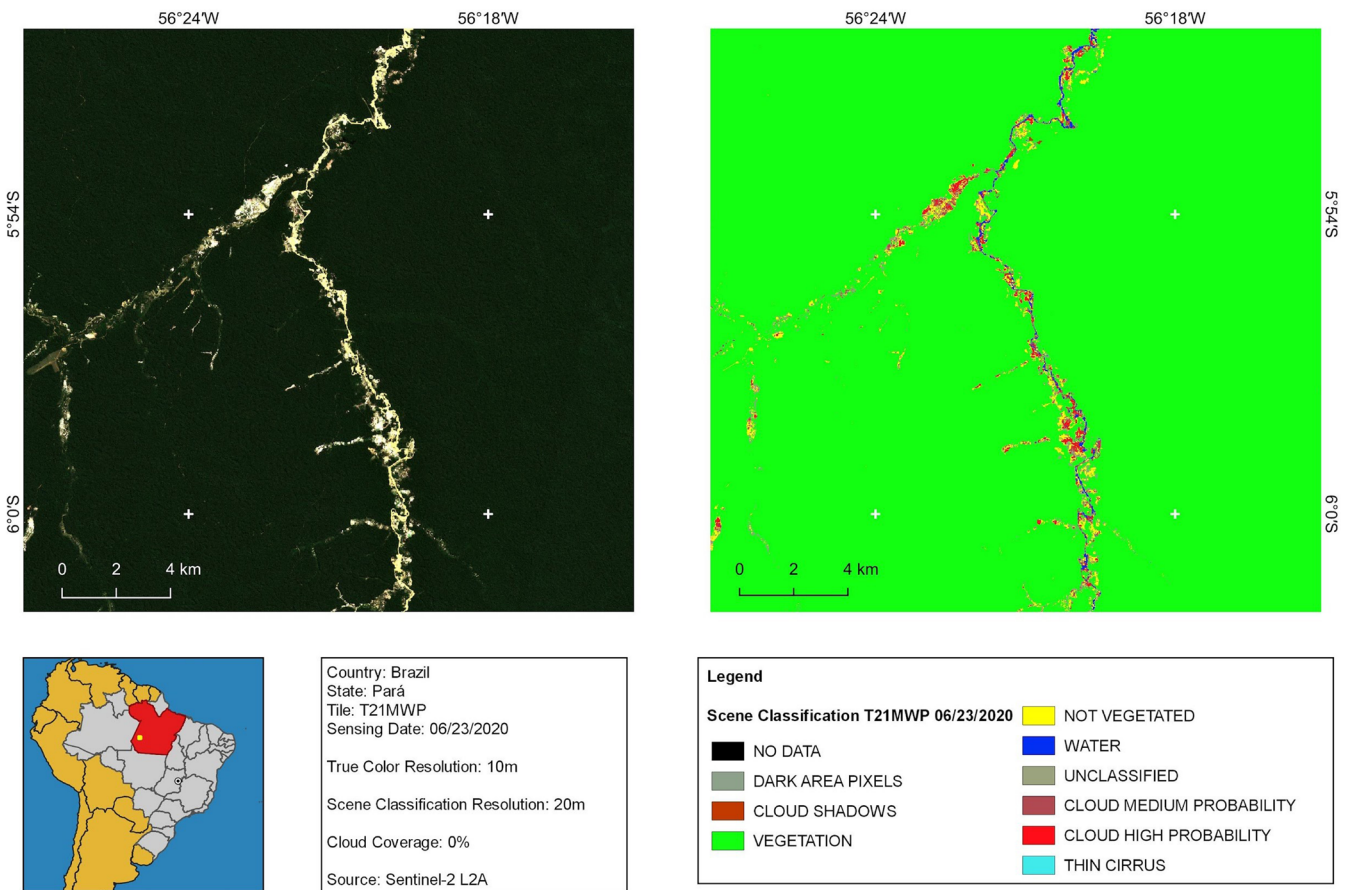
Figure 18.2: Demonstration of the area used to identify cases with potentially illegal production



The tiles used for 2019 are described below:

Sensing Date (D/M/Y)	Mission ID	Relative Orbit Number	Tile Number Field	Sensing Date (D/M/Y)	Mission ID	Relative Orbit Number	Tile Number Field
02/03/2020	S2A	R067	T21LWC	08/09/2020	S2A	R067	T21LYK
02/03/2020	S2A	R067	T21LWD	09/09/2020	S2A	R081	T22LFJ
31/05/2020	S2A	R067	T21LWK	13/09/2020	S2A	R138	T23KNR
31/05/2020	S2A	R067	T21LXJ	18/09/2020	S2A	R067	T22NCG
02/06/2020	S2A	R095	T23KPR	07/10/2020	S2A	R052	T24LVN
04/06/2020	S2A	R124	T22LCJ	08/10/2020	S2A	R067	T22NCF
10/06/2020	S2A	R067	T21LWJ	10/10/2020	S2A	R095	T24LVN
14/06/2020	S2A	R124	T22LER	12/01/2020	S2B	R138	T23KPA
14/06/2020	S2A	R124	T22MFU	12/01/2020	S2B	R138	T23LPC
22/06/2020	S2A	R096	T20LLQ	08/05/2020	S2B	R096	T20LKQ
23/06/2020	S2A	R110	T21MVP	15/06/2020	S2B	R067	T21MXM
23/06/2020	S2A	R110	T21MWN	15/06/2020	S2B	R067	T21MYM
23/06/2020	S2A	R110	T21MWP	17/06/2020	S2B	R096	T20LLR
23/06/2020	S2A	R110	T21MWQ	18/06/2020	S2B	R110	T21LVK
23/06/2020	S2A	R110	T21MXN	18/06/2020	S2B	R110	T21MVM
23/06/2020	S2A	R110	T21MXR	18/06/2020	S2B	R110	T21MVN
02/07/2020	S2A	R095	T24MVS	22/06/2020	S2B	R024	T22MDT
03/07/2020	S2A	R110	T20LRJ	27/06/2020	S2B	R095	T23KPT
10/07/2020	S2A	R067	T21LXJ	27/06/2020	S2B	R095	T23KPU
23/07/2020	S2A	R110	T20LRK	05/07/2020	S2B	R067	T21LYL
23/07/2020	S2A	R110	T21LTC	15/07/2020	S2B	R067	T21LXK
23/07/2020	S2A	R110	T21MXP	17/07/2020	S2B	R096	T20LKP
30/07/2020	S2A	R067	T22NDH	18/07/2020	S2B	R110	T21MWM
02/08/2020	S2A	R110	T21MVN	19/07/2020	S2B	R124	T22LEH
02/08/2020	S2A	R110	T21MVQ	31/07/2020	S2B	R010	T21MUN
09/08/2020	S2A	R067	T21MXM	04/08/2020	S2B	R067	T22NDF
02/08/2020	S2A	R081	T23MMU	15/10/2020	S2B	R095	T24LUN
08/09/2020	S2A	R067	T21LYJ				

**Table 18.1:** Identification of the tiles used during the study



**Figure 18.3:** Comparison of the same region from the perspective of true colors and the land use classification algorithm

We ran the QGIS zonal statistics tool five times using the land scene classification, that is, for each UTM zone, and then collected the information within each process, the result was exported as a table and null results were excluded, maintaining only the titles of the analyzed UTM zone. After completed all zones, we compiled the results in a single table and if the title had the same maximum and minimum values for the vegetation class (Class = 4), this title would have its production considered illegal. In the areas beyond the authorized limits, the same title mentioned above was applied, the difference is that if the border area shows only the vegetation class, the production may be legal but if it presents any other class concomitant to the internal area of the title, as potentially illegal. Three columns were added to the table with the titles registered as origin of the gold, one of illegal, potentially illegal, and legal, with a value of 1 for positive and 0 for negative according to the criteria mentioned above.

We adopted the same criterion of images for the

visual validation that was used before, however, to facilitate the visualization, we used the Web Map Service (WMS) of the Sentinel Hub platform. In each analyzed mining title, we assign three boolean variables, the first for the occurrence of mining activity within the authorized area, the second, if the extraction exceeds the legal limits, and thirdly the presence of rivers that may justify the extraction by rafts. As the gold mining in rivers results in less physical evidence we decided to classify the title as legal if they are located in an aquatic environment.

The 2020 analysis suffered from some limitations due to the data available so far, especially with satellite images in the requirements here predetermined, such as cloud cover and capture date. However, this does not imply the impossibility of partially evaluating the evolution of gold production until a certain moment in 2020. For this, the collection of images with low cloud cover was maintained, but with the processing date as close as possible to 2021. Consequently, a



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filter was made in the CFEM database, so that only transactions carried out up to the month before the image was captured, from the respective quadrant in which the title fits, was analyzed. Of the estimated 91.9 tonnes, 50.3 t (55%) were classified as 28.6 and 20.7 tonnes for the mining concession and mining permit, respectively. After collecting the images, we noticed that some titles were left out due to the established requirements. For these specific cases, we allow a higher value for cloud cover without compromising the analysis. There were seven titles, five in Amapá, one in Maranhão, and one in Goiás.

We also carry out only the visual analysis of each title. Due to the low time difference in the images used to classify the 2019 and 2020 production, and the negligible variation in the volume of mining titles registered as the source of the gold, we opted for the visual classification with the same criteria described above. The Sentinel Hub WSM was used, which returned the most recent images, and with the interval from 07/31/2020 to 12/01/2020, according to the quadrant of the mining title, that is, the first semester of 2020 was fully analyzed.

**§19.** To solve the problems found in the CFEM data, the contribution calculation base (1.5% of net sales) was used to calculate the transaction amount from the “Amount Collected” column. Then, the estimated quantity of gold is obtained by dividing the transaction value by the average gold price (R\$/g) in the respective

month of commercialization, serving as a basis for comparison with the column “Quantity Commercialized”. From the Investing.com website data, we obtain the average gold price per month in USD/oz that has been converted to BRL/g using also the average dollar value (Figure 19.1).

Gold price (BRL/gram)	2019	2020
January	R\$ 181.3350029	R\$ 233.470488
February	R\$ 181.0700735	R\$ 253.2685607
March	R\$ 185.3358317	R\$ 271.8292743
April	R\$ 185.3739858	R\$ 321.5002721
May	R\$ 189.1071995	R\$ 344.7270132
June	R\$ 190.8456384	R\$ 321.4317801
July	R\$ 195.5872352	R\$ 354.7011296
August	R\$ 214.0935692	R\$ 382.3377428
September	R\$ 225.6547404	R\$ 371.2531741
October	R\$ 219.6136643	R\$ 379.5729801
November	R\$ 219.4075231	R\$ 362.5182375
December	R\$ 221.1433203	R\$ 336.5059793

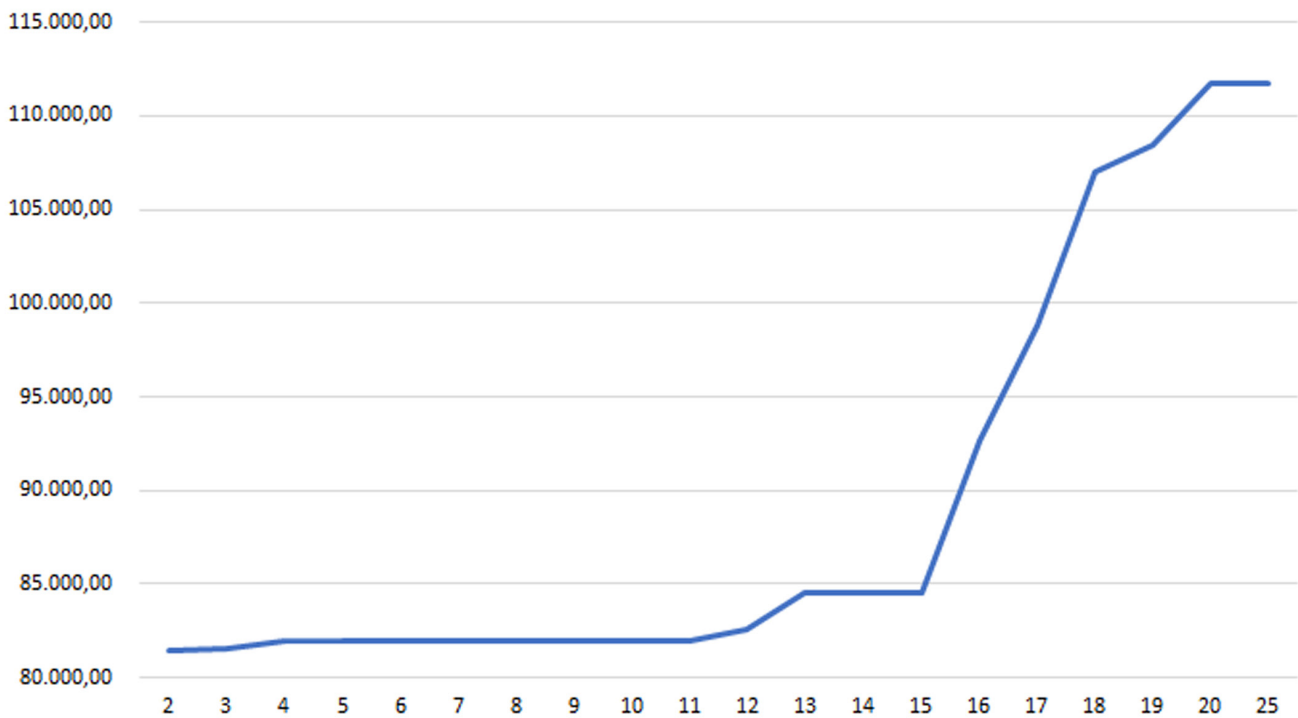
**Table 19.1:** Average price of the gram of gold in BRL.

Now, we have two bases that indicate a quantity of traded gold, and therefore, it is necessary to unify the data so that the new base is consistent with reality. As of January 2018, the CFEM calculation basis was changed, in addition to the increase in the rate from 1% to 1.5%, it started to adopt the value of net sales instead of gross revenue, so it is possible that costs such as transport, among others, are included in the transaction amount, causing the amount collected to increase compared to the formula by 2017, in addition to which, variations in negotiated prices for the sale and purchase of gold are significant. However, it is necessary to treat the outliers, replacing them with the values calculated from the collection. The identification of outliers must take into account the two points mentioned

above, therefore, we compare the values with a multiplicative factor, which cannot be too low so that the values registered in the column “Quantity Sold” were not discarded, but high enough to restrict unreal values. For this, we multiply the estimated value column ( $Y$ ) by different factors ( $k$ ), and compare it with the column of “Quantity traded” ( $X$ ) following the algorithm: If the value of  $X > k \times Y$ , we considered  $X$  an outlier and the value of  $Y$  is adopted. Otherwise, another comparison is made, in which the highest recorded value between  $X$  or  $Y$  is adopted. The choice of the highest value for final decision was made due to the 150 missing data for  $X$ , and the preference for adopting the data in the “Quantity traded” column.

Factor $k$	Total Sum (kg)	Factor $k$	Total Sum (kg)	Factor $k$	Total Sum (kg)
2	81,479.37	9	81,973.13	16	84,566.56
3	81,492.65	10	81,973.13	17	92,608.47
4	81,524.80	11	81,973.13	18	98,825.46
5	81,972.84	12	81,991.85	19	106,999.35
6	81,973.01	13	82,561.94	20	108,422.57
7	81,973.13	14	84,565.32	25	111,777.77
8	81,973.13	15	84,566.56	30	111,777.77

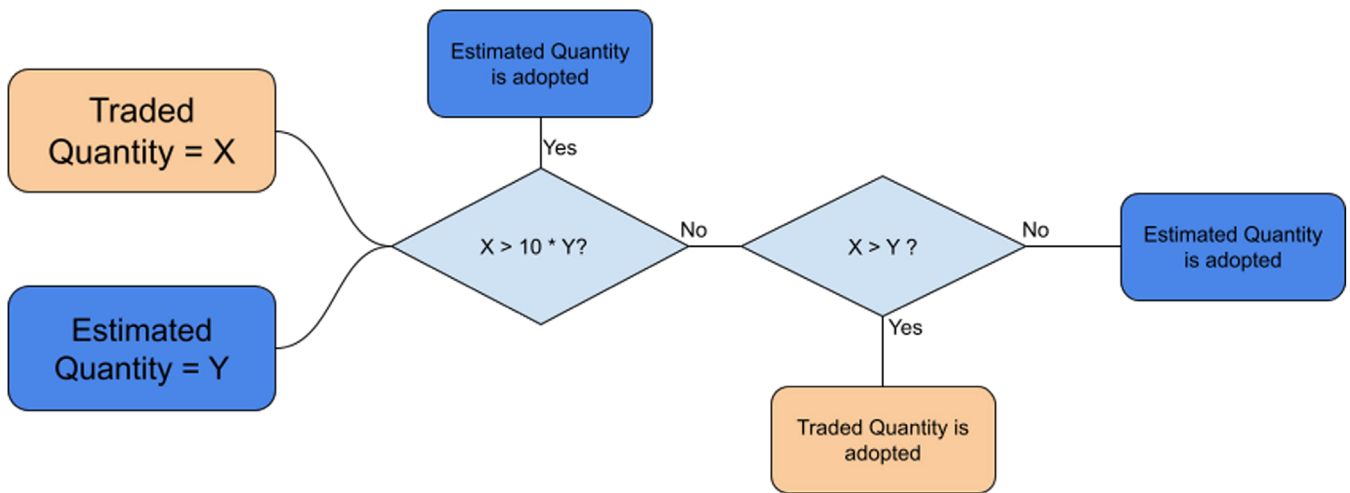
**Table 19.2:** Total amount of gold estimated by different multiplicative factors



**Graph 19.1:** Growth in total 2019 production based on multiplicative factors  $k$

We observed that from the factor  $k = 7$  until the factor  $k = 11$ , the value of the total sum is constant at the value of 81,973.13 kg. In addition, it maintains the production within the range consistent with reality, since the increase in the

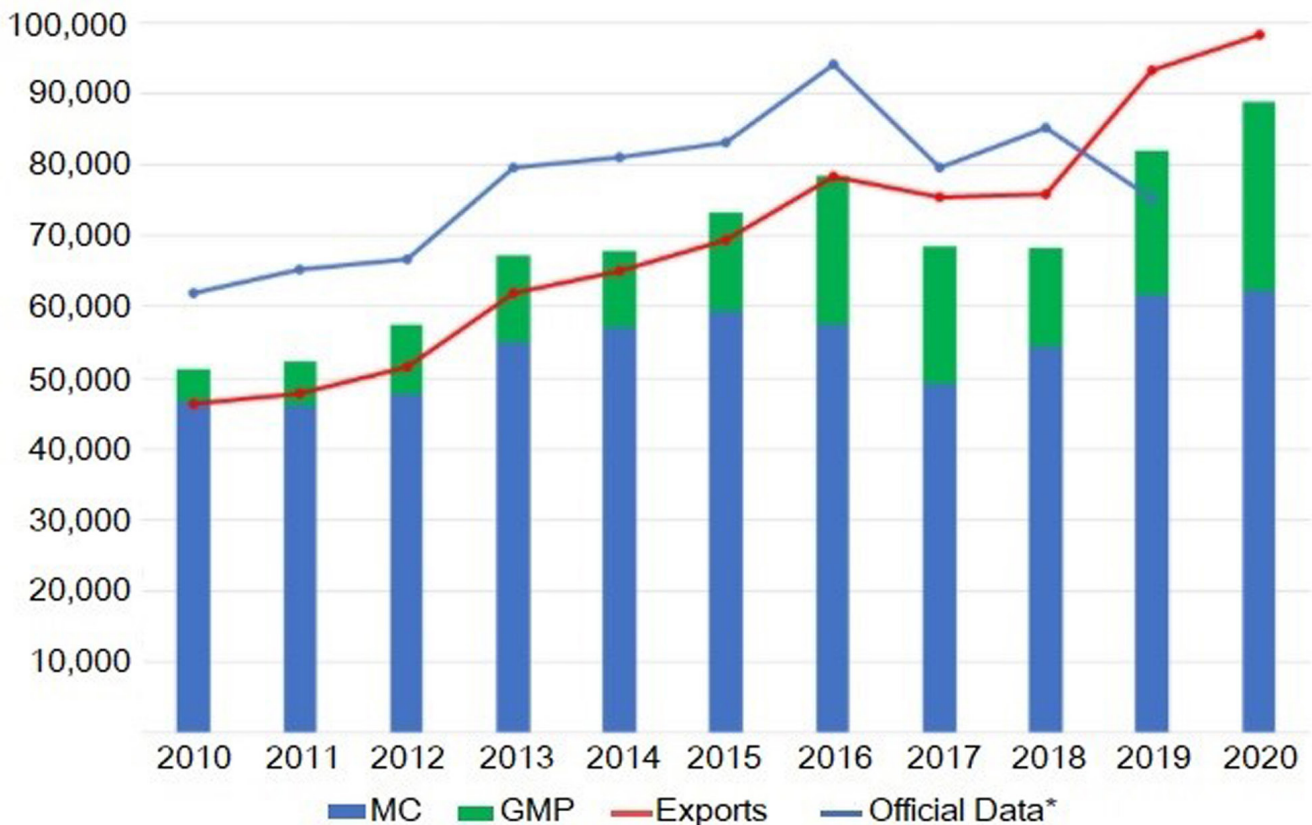
value of  $Y$ , along the increment of  $k$ , is justified by the inclusion of outliers in the total sum. Then, we adopted the value of  $k = 10$  to elaborate our production model for the years 2019 and 2020, following the flowchart below.



**Figure 19.1:** Algorithm for the final national gold production base

In our final model for 2019, 78 outliers among the 8,696 total records of the “Quantity traded” column were identified and replaced, an average of 9.4 kg, a standard deviation of 73.0, the variance of  $5,3 \times 10^9$ , a maximum value of 2.326,3 kg, and

a minimum of 0.05 g. Thus, 8,435 original values from the “Quantity traded” column were used in the final model, representing 76 tonnes of gold. The “Quantity Estimated” column had 261 values adopted, totaling 6 tonnes.



**Graph 19.2:** Comparison of the Elaborated Model with other data in kilograms. \*Official Data: Combination of data from the Brazilian Mineral Summary from 2010 to 2014 and Brazilian Mineral Yearbook from 2015 to 2020.



## §21. RESULTADO ESTATÍSTICAS ZONAIS

Of the 760 titles that were analyzed from the Scene Classification, 36 were not defined in the first phase, 7 of them were defined in the visual truthing, as explained above, and 29 titles were not included in the SIGMINE database, therefore, without the polygonal of the mining title, it is not possible to carry out the classification.

The hypothesis that legalized mining titles would be used to “wash” illegal gold was confirmed in the first stage, with 190 titles registered as the origin of the gold, but with only the vegetation class by

the ESA algorithm. The state of Pará concentrates the majority of cases in which there is no evidence of mining activity in the authorized area by the ANM, with 184 records.

In the border areas, 502 regions had some other class identified in addition to vegetation, which may indicate the extrapolation of area, and for this reason, the final classification is only given after visual confirmation. Already 222 titles presented only vegetation, which can result in a legal or illegal title if the area inside the title is also covered entirely by vegetation.

UF	Total Mining title	Zonal Statistics							Visual Truthing		
		Mining Title				Border Area			No Mining Activity (B)	Extrapolation of Legal Area	River
		Only Vegetation (A)	Accuracy (A / B)	Other Classes	Undefined	Only Vegetation	Other Classes	Undefined			
AP	9	-	-	-	9	-	-	9	-	3	-
BA	5	-	-	5	-	-	5	-	1	2	-
GO	10	-	-	8	2	-	8	2	1	3	-
MA	1	-	-	1	-	-	1	-	-	1	-
MG	13	-	-	9	4	-	9	4	-	2	1
MT	334	5	20%	314	15	15	304	15	25	150	9
PA	348	184	100%	161	3	207	138	3	184	82	22
PE	1	-	-	1	-	-	1	-	-	-	1
PR	1	-	-	-	1	-	-	1	-	-	-
RO	36	1	100%	1	-	-	36	-	1	-	35
SC	2	-	-	-	2	-	-	2	-	-	-
<b>Total</b>	<b>760</b>	<b>190</b>	<b>89.6%</b>	<b>534</b>	<b>36</b>	<b>222</b>	<b>502</b>	<b>36</b>	<b>212</b>	<b>243</b>	<b>68</b>

**Table 21.1:** Results of zonal statistics and visual confirmation for images collected in the 2019 production classification.

**Table S1**

PRODES data, provided by INPE, indicate an increase in the annual deforestation rate of 58.6% between the years 2010 and 2020, with an accumulated area of 7.9 million hectares. The years 2019 and 2020 had the highest rates of deforestation, with 1.0 and 1.1 million hectares respectively.

Year	Total Deforestation Area Legal Amazon (ha) PRODES	Deforestation for Mining Area (ha)
2010	700,000	-
2011	641,800	-
2012	457,100	-
2013	589,100	-
2014	501,200	-
2015	620,700	1,797
2016	789,300	4,657
2017	694,700	5,235
2018	753,600	8,546
2019	1,012,900	10,540
2020	1,108,800	10,026

Source: <http://terrabrasilis.dpi.inpe.br/>

**Table S2**

Summary of the MPs in the Titles: GMP and MC from SIGMINE collected in Mar/2020 and in Jan/2021.

State	2019						2020					
	MC	Area (ha)	GMP	Area (ha)	Total titles	Total Area (ha)	MC	Area (ha)	GMP	Area (ha)	Total titles	Total Area (ha)
AM	2	263.3	28	125,281.9	30	125,545.2	2	263.3	28	125,281.9	30	125,545.2
AP	4	5,474.9	3	1,074.172	7	6,549.1	4	5,474.9	3	1,047.2	7	6,549.1
BA	23	16,640.1	1	49.1	24	16,689.1	23	16,640.1	1	49.1	24	16,689.1
GO	26	17,962.2	4	145.8	30	18,108.0	26	17,962.2	4	145.8	30	18,108.0
MA	1	9,981.6	1	600.0	2	10,581.6	1	9,981.6	1	600.0	2	10,581.6
MG	100	83,232.1	15	1,392.8	115	84,624.9	100	83,232.1	15	1,392.8	115	84,624.9
MT	25	94,208.1	833	378,032.2	858	472,240.3	25	94,208.1	836	384,529.1	861	478,737.2
PA	12	58,567.2	840	130,469.9	852	189,037.2	12	58,567.2	846	130,655.7	858	189,222.9
PB	2	1,843.9	0	0	2	1,843.9	2	1,843.9	0	0	2	1,843.9
PE	4	4,000.0	3	1,624.9	7	5,624.9	4	4,000.0	3	1,624.9	7	5,624.9
PR	11	2,270.0	0	0	11	2,270.0	11	2,270.0	0	0	11	2,270.0
RN	3	2,907.2	0	0	3	2,907.2	3	2,907.2	0	0	3	2,907.2
RO	1	7,844.9	78	76,013.5	79	83,858.4	1	7,844.9	78	76,013.5	79	83,858.4
RR	1	4,422.4	0	0	1	4,422.4	1	4,422.4	0	0	1	4,422.4
RS	1	1,000.0	0	0	1	1,000.0	1	1,000.0	0	0	1	1,000.0
SC	4	2,537.3	0	0	4	2,537.3	4	2,537.3	0	0	4	2,537.3
TO	3	8,956.1	12	469.5	15	9,425.6	3	8,956.1	12	469.5	15	9,425.6
<b>Total</b>	<b>223</b>	<b>322,111.2</b>	<b>2</b>	<b>715,153.8</b>	<b>2</b>	<b>1,037,265.0</b>	<b>223</b>	<b>322,111.2</b>	<b>2</b>	<b>721,836.4</b>	<b>2</b>	<b>1,043,947.7</b>

**Table S3**

Summary of data for GMP and MC registered as gold origin in 2019 and 2020 based on Financial Compensation for Mineral Exploration (CFEM).

State	2019						2020					
	MC	Area (ha)	GMP	Area (ha)	Total titles	Total Area (ha)	MC	Area (ha)	GMP	Area (ha)	Total titles	Total Area (ha)
AM	0	0	0	0	0	0	0	0	1	9,175.7	1	9,175.7
AP	3	5,923.9	0	0	9	15,010.0	3	5,923.9	0	0	7	5,923.9
BA	3	2,764.9	0	0	5	4,434.7	3	2,764.9	0	0	4	2,764.9
GO	7	2,953.9	1	28.8	10	3,151.8	6	1,953.8	2	78.3	10	2,032.1
MA	1	9,981.6	0	0	1	9,981.6	1	9,981.6	0	0	2	9,981.6
MG	11	7,416.8	0	0	13	8,400.0	11	8,194.9	0	0	13	8,194.9
MT	8	34,172.5	305	231,537.5	334	291,054.5	9	33,301.7	290	241,211.2	314	274,512.9
NA	0	0	0	0	0	0	0	0	0	0	1	0
PA	2	8,440.7	342	93,561.8	348	103,419.0	2	8,440.7	339	97,206.3	347	105,647.0
PE	0	0	0	0	1	488.0	0	0	0	0	1	-
PR	1	-	0	0	1	-	1	-	0	0	1	-
RO	0	0	36	11,341.3	36	11,341.3	0	0	38	19,405.9	38	19,405.9
SC	0	0	0	0	2	-	0	0	0	0	2	-
TO	0	0	0	0	0	0	0	0	2	98.2	2	98.2
<b>Total</b>	<b>36</b>	<b>71,654.1</b>	<b>684</b>	<b>336,469.4</b>	<b>760</b>	<b>447,280.9</b>	<b>36</b>	<b>70,561.3</b>	<b>672</b>	<b>367,175.7</b>	<b>743</b>	<b>437,737.0</b>

For this table, in the "Total titles" column, the titles in other titles of the mining title were added, so it does not represent the sum of the GMP and MC columns. No data information, 16; Research Authorization 9; Mining Requirement, 7; "Garimpeira" Mining Requirement, 2 in 2020. In 2019, without information, 21; Research Authorization, 9; Mining Requirement, 10. .

**Table S4**

## Brazilian gold statistics and information (Raw Data).

Year	Raw Production (kg) (1)	Refined Production (kg) (2)	Production (kg) (3)	Production (kg) (4)	CFEM (kg) (5)	IOF Ouro Transfers (BRL) (6)	Exports (kg) (7)	Adjusted Model (kg)
2010	NA*	48,584.1	62,047	48,584.1	67,595.2	2,982,592.83	46,460.0	51,276.6
2011	NA	51,330.4	65,209	51,328.6	52,400.7	4,850,535.92	47,754.0	52,318.5
2012	NA	49,972.3	66,773	49,801.2	60,675.0	7,560,333.33	51,569.0	57,491.5
2013	NA	60,128.8	79,563	59,776.5	65,961.4	8,019,829.16	61,849.0	67,162.1
2014	NA	61,302.6	81,038	61,156.5	462,970,536.8	6,850,161.05	64,975.0	67,814.8
2015	83,124.0	61,274.6	84,814	61,230.0	81,599.10	12,122,023.19	69,402.0	73,349.6
2016	94,153.0	69,748.9	94	68,176.5	84,622.2	21,039,395.85	78,290.0	78,465.5
2017	79,717.0	55,395.7	NA	55,395.7	12,589,681,598.8	12,439,936.67	75,385.0	68,493.0
2018	85,301.0	63,558.0	NA	68,839.7	2,667,992.9	10,841,321.96	75,891.0	68,310.0
2019	107,762.0	70,904.2	NA	NA	2,570,265.6	17,931,687.88	93,375.0	81,973.1
2020	121,476.0	NA	NA	NA	60,422,375.3	43,227,140.16	98,418.0	91,929.3

(1): Agência Nacional de Mineração, Anuário Mineral Brasileiro (ANM, Brasília, 2020, <https://www.gov.br/anm/pt-br/centrais-de-conteudo/publicacoes/serie-estatisticas-e-economia-mineral/anuario-mineral/anuario-mineral-brasileiro>)

(2): Agência Nacional de Mineração, Anuário Mineral Brasileiro (ANM, Brasília, 2020, <https://dados.gov.br/dataset/anuario-mineral-brasileiro-amb>)

(3): Agência Nacional de Mineração, Sumário Mineral Brasileiro (ANM, Brasília, 2020, [https://www.gov.br/anm/pt-br/centrais-de-conteudo/publicacoes/serie-estatisticas-e-economia-mineral/sumario-mineral?b\\_start:int=0](https://www.gov.br/anm/pt-br/centrais-de-conteudo/publicacoes/serie-estatisticas-e-economia-mineral/sumario-mineral?b_start:int=0))

(4): Agência Nacional de Mineração, Relatório Anual de Lavra (ANM, Brasília, 2020)

(5): Agência Nacional de Mineração, Compensação Financeira pela Exploração de Recursos Minerais (ANM, Brasília, 2021, <https://dados.gov.br/dataset/sistema-arrecadacao>)

(6): Ministério da Fazenda, Valores do IOF-Ouro distribuídos aos municípios (MF, Brasília, 2021, <https://dados.gov.br/dataset/transferencias-obrigatorias-da-uniao-por-municipio/resource/4248cd95-6d79-4520-9e17-48322eab6259>)

(7): Ministério da Indústria, Comércio Exterior e Serviços, Brazilian foreign trade statistics (Comex Stat, 2021, <http://comexstat.mdic.gov.br/en/home>).

\*NA: Not Available

- A) The table above represents the compilation of official information in kilograms. In the Brazilian Mineral Yearbook prepared by ANM, the production in gold mining is estimated based on the payment of the Tax on Financial Operations (“IOF Ouro”). The yearbooks from 2010 to 2014 are not available.
- B) In 2019 and 2020, the extraction in specific gold mines was 75,226 and 93,789 tons. In the first production column, the values contained above were added to the quantities of gold extracted in other mines, 32,536 and 27,687 tons in 2019 and 2020, respectively.
- C) ANM also discloses data on processed and gross production through the Federal Government’s Open Data platform. The values are based on the Annual Mining Reports (RAL) and with adjustments made by the agency’s technical team.
- D) Like the yearbook, the Brazilian Mineral Summary is also prepared with statistics and basic information for each mineral explored in Brazil. For gold, the last summary was released in 2017 with 2016 as the base year.
- E) The Annual Mining Reports (RAL) was obtained through the Access to Information Law, which allows citizens to request non-classified information from the government. The RAL contains the compilation of production declarations by the municipality. However, from 2015 onwards the data of gold mining production in “garimpos” was removed.
- F) The Financial Compensation for the Exploration of Mineral Resources (CFEM) database presents information on the collection of royalties on all minerals. In addition to being constantly updated, the base also presents the origin of the gold (by the number of the Mining Process), the person who registered the tax, the total amount transacted and the date of the transaction. However, it presents outliers that were treated later and the result is characterized in the column of the adjusted model.
- G) From the base of the “IOF Ouro” (1% rate), the Federal Government transfers 70% of the

amount collected in each operation to the municipality of origin of the gold classified as a financial asset. The amount represented here is the sum of the amount transferred to the municipalities of the same state.

H) Exports are disclosed by the Ministry of

Industry, Foreign Trade, and Services through the COMEX STAT portal. It is then possible to collect gold export data, using the Harmonized System Position code (SH4) 7108 (Gold, including platinum gold, in raw or semi-manufactured forms, or powder).

**Table S5**

Official data of gold production and export origin by state without adjustment, 2019.

State	Production (kg) (1)	Production (kg) (2)	IOF Ouro Transfers (BRL) (6)*	CFEM (kg) (5)	CFEM Amount Collected (BRL)	Adjusted Model (kg)	MC (kg)	GMP (kg)	Other Titles(kg)**
AM	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0
AP	4,090.0	4,204.5	240,373.03	33,751.2	16,667,414.76	6,463.5	6,116.7	0,00	346.9
BA	7,242.0	7,242.1	570.55	6,979.9	18,107,944.65	7,386.8	7,357.7	0,00	29.2
DF	0	0,00	0,00	0	0,00	0,00	0,00	0,00	0
GO	5,009.0	5,008.7	4,924.33	5,745.5	13,380,593.07	5,764.7	5,736.4	2.6	25.8
MA	2,178.0	2,341.5	334.55	2,004.1	5,369,001.26	2,004.1	2,004.1	0,00	0,00
MG	32,743.0	33,695.5	2,069.51	533,226.3	87,655,786.47	34,477.8	34,477.8	0	5.0
MT	13,544.0	10,950.3	7,687,245.05	1,896,120.2	32,588,083.68	13,691.3	3,662.1	9,328.7	700.5
PA	9,127.0	6,304.1	8,357,158.10	91,189.5	25,151,076.54	11,191.7	822.8	9,717.6	651.3
PE	0	2.9	147.92	3.1	5,416.60	3.1	0	0	3.1
PR	278.0	278.4	571.01	163.8	397,931.37	163.8	163.8	0	0
RJ	0	0	53,383.97	0,00	0	0	0	0	0
RO	1,016.0	876.1	94,166.85	750.2	1,905,732.27	820.6	0	820.6	0
RR	0	0	1,016.75	0,00	0	0,00	0	0	0
RS	0	0	1.43	0,00	0	0	0	0	0
SC	0	0	6,356.55	0,00	1,776.87	0.5	0	0	0.5
SP	0	0	814,446.87	0,00	0	0	0	0	0
TO	0	0	1.75	0	0	0	0	0	0
<b>Total</b>	<b>75,227.0</b>	<b>70,904.2</b>	<b>17,931,687.88</b>	<b>2,569,933.8</b>	<b>201,230,757.54</b>	<b>81,973.1</b>	<b>60,341.4</b>	<b>19,869.4</b>	<b>1,762.3</b>

\*The states of PB, PI and RN had the total amount of BRL 3,166.75, BRL 4,064.02, BRL 661,688.89, respectively, transferred to their municipalities. \*\*titles in the titles of Research Authorization, Mining Requirement and "Garimpeira" Mining Requirement.



**Table S6**

Gold production in the GMP and MC in 2020.

State	Official Data: MC (kg)	Official Data: GMP (kg)	Official Data: Other Mines (kg)	Official Data: Total (kg)	CFEM (kg)	IOF Ouro Transfers (BRL)*	CFEM Amount Collected (BRL)	Adjusted Model (kg)	MC (kg)	GMP (kg)	Other Titles (kg)**
AM	0	108	0	108.2	89.7	193,697.31	372,305.12	89.7	0	89.7	0
AP	4,45	0	0	4,452.0	10,582.5	177,175.18	17,837,734.43	5,196.1	4,982.3	0	213.8
BA	8,26	0	244	8,507.0	7,920.8	0,00	31,256,453.13	7,920.8	7,899.1	0	21.7
DF	0	0	0	0	0,00	31,573.50	0	0	0	0	0
GO	6,95	28	6,91	13,895.0	556,924.2	39,146.15	19,749,102.50	5,139.3	5,103.0	27.1	9.3
MA	6,95	0	0	6,953.0	4,166.8	35,822.39	17,031,654.17	4,268.3	3,923.9	0	344.4
MG	38,47	0	0	38,467.0	45,663.1	403,610.11	131,281,336.72	32,510.4	32,492.0	0	18.4
MT	6,25	8,39	0	14,634.0	59,720,099.9	14,846,884.71	56,526,832.40	15,434.0	4,868.2	10,126.9	438.9
NA***	0	0	0	0	451	0	1,938,933.10	465.4	0	0	465.4
PA	2,44	9,75	20,53	32,725.0	74,764.9	22,700,700.25	68,981,966.46	19,175.7	700.1	17,190.5	1,285.2
PB	2	0	0	2.0	0	699.79					
PE	1	0	0	1.0	1.1	0	2,256.30	1.1	0	0	1.1
PR	305	0	0	305.0	320.4	146.30	1,217,250.54	320.4	320.4	0	0
RO	0	1,42	0	1,415.0	1,362.6	2,185,654.35	5,265,365.86	1,363.9	0	1,363.9	0
RS	0	0	0	0	0	512.51	0,00	0	0	0	0
SC	0	0	0	0	0,00	0,00	3,279.67	0.8	0	0	0.8
SP	0	0	0	0	0,00	1,821,739.45	0,00	0	0	0	0
TO	10	1.0	0	11.0	28.20	5,373.23	198,355.50	43.4	0,00	43.4	0,00
<b>Total</b>	<b>74,097.0</b>	<b>19,692.0</b>	<b>27,687.0</b>	<b>121,476.0</b>	<b>60,422,375.30</b>	<b>43,277,140.16</b>	<b>351,662,825.90</b>	<b>91,929.3</b>	<b>60,289.0</b>	<b>28,841.4</b>	<b>2,798.9</b>

\*The states of CE, PI and RN had the amount of BRL 327.55, BRL 466,466.53, BRL 317,610.85, respectively, transferred to their municipalities.

\*\*titles in the titles of Research Authorization, Mining Requirement and "Garimpeira" Mining Requirement.

\*\*\*NA: Not Available

**Table S7**

Classification of Mining titles of MC in 2019

State	Total titles	Undefined titles	Legal titles	Illegal titles	Pot. Illegal titles	Total Gold Mined (kg)	Rated amount of gold (kg)	Illegal Gold (kg)	Pot. Illegal Gold (kg)
AP	3	0	1	0	2	6,116.7	6,116.7	0	65.9
BA	3	0	2	0	1	7,357.7	7,357.7	0	2,368.2
GO	7	1	3	1	2	5,736.4	4,681.2	88.5	1,824.2
MA	1	0	0	0	1	2,004.1	2,004.1	0	2,004.1
MG	11	4	5	0	2	34,477.8	12,045.3	0	1,953.0
MT	8	0	5	0	3	3,662.1	3,662.1	0	1,515.8
PA	2	0	1	0	1	822.8	822.8	0	643.6
PR	1	1	0	0	0	163.8	0	0	0
<b>Total</b>	<b>36</b>	<b>6</b>	<b>17</b>	<b>1</b>	<b>12</b>	<b>60,341.4</b>	<b>36,689.9</b>	<b>88.5</b>	<b>10,374.9</b>

**Table S8**

Classification of Mining titles of GMP in 2019

State	Total titles	Undefined titles	Legal titles	Illegal titles	Pot. Illegal titles	Total Gold Mined (kg)	Rated amount of gold (kg)	Illegal Gold (kg)	Pot. Illegal Gold (kg)
GO	1	0	1	0	0	2.6	2.6	0	0
MT	305	2	144	26	133	9,328.7	9,320.6	242.8	5,592.3
PA	342	0	76	186	80	9,717.6	9,717.6	2,140.4	5,221.7
RO	36	0	35	1	0	820.6	820.6	2.9	0
<b>Total</b>	<b>684</b>	<b>2</b>	<b>256</b>	<b>213</b>	<b>213</b>	<b>19,869.4</b>	<b>19,861.4</b>	<b>2,386.0</b>	<b>10,813.9</b>

**Table S9**

Classification of Mining titles of Other Titles (Research Authorization, Mining Requirement and “Garimpeira” Mining Requirement and Not Available) in 2019.

State	Total titles	Undefined titles	Legal titles	Illegal titles	Pot. Illegal titles	Total Gold Mined (kg)	Rated amount of gold (kg)	Illegal Gold (kg)	Pot. Illegal Gold (kg)
AP	6	3	1	2	0	346.9	239.1	15.2	0
BA	2	0	0	2	0	29.2	29.2	29.2	0
GO	2	1	0	0	1	25.8	25.0	0	25.0
MG	2	0	2	0	0	5.0	5.0	0	0
MT	21	12	3	0	6	700.5	417.4	0	402.9
PA	4	3	0	0	1	651.3	616.3	0	616.3
PE	1	0	1	0	0	3.1	3.1	0	0
SC	2	2	0	0	0	0.5	0	0	0
<b>Total</b>	<b>40</b>	<b>21</b>	<b>7</b>	<b>4</b>	<b>8</b>	<b>1,762.3</b>	<b>1,335.2</b>	<b>44.3</b>	<b>1,044.3</b>

**Table S10**

Classification of Mining titles of MC in 2020

State	Total titles	Undefined titles	Legal titles	Illegal titles	Pot. Illegal titles	Total Gold Mined (kg)	Rated amount of gold (kg)	Illegal Gold (kg)	Pot. Illegal Gold (kg)
AP	3	0	2	0	1	4,982.34	4,049.54	0	21.00
BA	3	0	2	0	1	7,899.12	6,602.90	0	1,431.98
GO	6	1	2	1	2	5,102.96	1,575.76	126.49	1,350.68
MA	1	0	0	0	1	3,923.86	2,382.84	0	2,382.84
MG	11	4	6	0	1	32,491.99	9,810.00	0	2,754.23
MT	9	1	5	0	3	4,868.18	3,585.70	0	1,564.80
PA	2	0	1	0	1	700.09	619.17	0	478.62
PR	1	1	0	0	0	320.40	0	0	0
<b>Total</b>	<b>36</b>	<b>7</b>	<b>18</b>	<b>1</b>	<b>10</b>	<b>60,289.0</b>	<b>28,625.9</b>	<b>126.5</b>	<b>9,984.2</b>

**Table S11**

Classification of Mining titles of GMP in 2020

State	Total titles	Undefined titles	Legal titles	Illegal titles	Pot. Illegal titles	Total Gold Mined (kg)	Rated amount of gold (kg)	Illegal Gold (kg)	Pot. Illegal Gold (kg)
AM	1	0	1	0	0	89.7	58.9	0	0
GO	2	0	0	0	2	27.1	26.4	0	26.4
MT	290	15	128	19	127	10,126.9	7,332.4	58.3	4,763.3
PA	339	46	68	133	93	17,190.5	12,334.8	3,264.9	4,952.7
RO	38	1	35	1	1	1,363.9	871.2	1.4	130.0
TO	2	0	1	0	1	43.4	24.9	0	1.6
<b>Total</b>	<b>672</b>	<b>62</b>	<b>233</b>	<b>153</b>	<b>224</b>	<b>28,841.4</b>	<b>20,648.6</b>	<b>3,324.7</b>	<b>9,874.1</b>

**Table S12**

Classification of Mining titles of Other Titles (Research Authorization, Mining Requirement and “Garimpeira” Mining Requirement and Not Available) in 2020.

State	Total titles	Undefined titles	Legal titles	Illegal titles	Pot. Illegal titles	Total Gold Mined (kg)	Rated amount of gold (kg)	Illegal Gold (kg)	Pot. Illegal Gold (kg)
AP	4	2	1	1	0	213.8	191.0	7.3	0
BA	1	0	0	1	0	21.7	21.7	21.7	0
GO	2	1	0	0	1	9.3	3.1	0	3.1
MA	1	0	0	1	0	344.4	344.4	344.4	0
MG	2	0	2	0	0	18.4	9.4	0	0
MT	15	8	2	2	3	438.9	76.1	7.4	12.2
NA	1	1	0	0	0	465.4	0	0	0
PA	6	4	0	0	2	1,285.2	408.0	0	408.0
PE	1	0	1	0	0	1.1	1.1	0	0
SC	2	2	0	0	0	0.8	0	0	0
<b>Total</b>	<b>35</b>	<b>18</b>	<b>6</b>	<b>5</b>	<b>6</b>	<b>2,798.9</b>	<b>1,054.7</b>	<b>380.8</b>	<b>423.3</b>

**Table S13**

Comparison between the period 2020 analyzed with the year 2019.

State	2020 Production (kg)	2020/2019 Variation (%)	2020 Production Classified (kg)	2020/2019 Ratio Classified (%)	Irregular Production (kg)	2020/2019 Variation (%)
AM	89.7	-	58.9	-	0	-
AP	5,196.1	-19.6	4,240.5	-33.3	28.3	-65.1
BA	7,920.8	+7.2	6,624.6	-10.3	1,453.7	-39.4
GO	5,139.3	-10.8	1,605.3	-65.9	1,506.7	-22.2
MA	4,268.3	+113.0	2,727.2	+36.1	2,727.2	+36.1
MG	32,510.4	-5.7	9,819.4	-18.5	2,754.3	+41.0
MT	15,434.0	+12.7	10,994.2	-18.0	6,406.1	-17.4
NA	465.4	-	0	-	0	-
PA	19,175.7	+71.3	13,361.9	+19.8	9,104.2	+5.6
PE	1.1	-63.2	1.1	-64.5	0	-
PR	320.4	+95.6	0	-	0	-
RO	1,363.9	+66.2	871.2	+6.2	131.5	+4,462.0
SC	0.8	+44.4	0	-	0	-
TO	43.4	-	24.9	-	1.6	-
<b>Total</b>	<b>91,929.3</b>	<b>+12.1</b>	<b>50,329.3</b>	<b>-13.1</b>	<b>24,113.5</b>	<b>-2.6</b>

**Table S14**

## Summary of the results obtained

State	2019 Production (kg)	2020 Production (kg)	Total Production (kg)	Classified Gold (kg)	Ratio Classif. / Total (%)	Illegal Production (kg)	Potentially Illegal Production (kg)	Irregular Production (kg)	Ratio Irregular / Classified (%)	Ratio Irregular / Total Production (%)
AM	0	89.7	89.7	58.9	65.7	0	0	0	0.0	0.0
AP	6,463.5	5,196.1	11,659.7	10,596.3	90.9	22.5	86.9	109.3	1.0	0.9
BA	7,386.8	7,920.8	15,307.7	14,011.4	91.5	50.9	3,800.2	3,851.1	27.5	25.2
GO	5,764.7	5,139.3	10,904.0	6,314.1	57.9	215.0	3,229.5	3,444.4	54.6	31.6
MA	2,004.1	4,268.3	6,272.4	4,731.4	75.4	344.4	4,387.0	4,731.4	100.0	75.4
MG	34,482.9	32,510.4	66,993.2	21,869.7	32.6	0	4,707.3	4,707.3	21.5	7.0
MT	13,691.3	15,434.0	29,125.3	24,394.4	83.8	308.5	13,851.4	14,159.8	58.0	48.6
NA	0	465.4	465.4	0	0	0	0	0	0	0
PA	11,191.7	19,175.7	30,367.4	24,518.7	80.7	5,405.3	12,320.90	17,762.2	72.3	58.4
PE	3.1	1.1	4.2	4.2	99.1	0	0	0	0.0	0.0
PR	163.8	320.4	484.2	0	0.0	0	0	0	0.0	0.0
RO	820.6	1,363.9	2,184.6	1,691.8	77.4	4.3	130.0	134.4	7.9	6.2
SC	0.5	0.8	1.3	0	0.0	0	0	0	0.0	0.0
TO	0	43.4	43.4	24.9	57.3	0	1.6	1.64	6.6	3.8
<b>Total</b>	<b>81,973.1</b>	<b>91,929.3</b>	<b>173,902.4</b>	<b>108,215.7</b>	<b>62.2</b>	<b>6,350.7</b>	<b>42,514.7</b>	<b>48,865.4</b>	<b>45.2</b>	<b>28.1</b>

**Table S15**

## Gold Mining in Conservation Units

	State	Group*	2019 MC/GMP Process	2019 MC/GMP Area (ha)	2019 Production (kg)	2019 Irregular Production (kg)	2020 MC/GMP Process	2020 MC/GMP Area (ha)	2020 Production (kg)	2020 Irregular Production (kg)
APA do Tapajós	PA	SU	285	16,861.6	5,609.9	4,405.4	265	23,463.3	9,330.2	4,540.0
APA das Reentrâncias Maranhenses	MA	SU	1	9,778.4	2,004.1	2,004.1	1	9,778.4	3,923.9	2,382.8
APA Triunfo do Xingu	PA	SU	0	0.00	0.00	0.00	1	48.5	4.5	0.0
FE do Amapá	AP	SU	2	6.0	15.2	15.2	2	6.0	7.3	7.3
FN de Itaituba II	PA	SU	2	17.1	0.00	0.00	3	17.7	0.0	0.0
FN do Crepori	PA	SU	13	30.0	171.9	170.4	13	30.0	305.6	295.1
FN do Trairão	PA	SU	0	0.0	0.00	0.00	1	69.7	79.9	0.0
PN da Amazônia	PA/AM	IP	1	7.4	0.00	0.00	1	7.4	0.0	0.0
PN Mapinguari	RO/AM	IP	4	29.3	0.00	0.00	3	27.9	0.0	0.0
PN Montanhas do Tumucumaque	AP/PA	IP	1	2.4	0.00	0.00	1	2.4	0.0	0.0
PN do Rio Novo	PA	IP	1	1.7	0.00	0.00	1	1.7	0.0	0.0
PN da Serra do Prado	PA	IP	0	0.0	0.00	0.00	1	2.3	0.0	0.0
RE Riozinho do Anfrísio	PA	SU	2	98.0	1.3	1.3	2	98.0	3.4	3.4

Obs: The cases in which titles are registered in MC/GMP but production is not registered occur because the process overlaps more than one CU, being a production registered in the CU with a greater overlaid area. Cases in which the overlapping area of the MP to the CU / IL is less than 10% of the authorized area were classified only by the dynamics of land use, disregarding the restriction of areas where mining is not regulated.

\*SU: Sustainable Use; IP: Integral Protection



**Table S16****Gold Mining in Indigenous Land**

Type of Mining Process (MP)	Year of the PM	PM Area (ha)	Overlaid Area (%)	Indigenous Land	State	Phase	Modality	Classification	2019 Production (kg)	2020 Production (kg)	Classified Production (kg)
GMP	2013	651.6	17.1	Sawré Muybu (Pimental)	PA	Delimited	Traditionally Occupied	Legal	459.1	120.8	579.6
GMP	2013	45.0	100.0	Sawré Muybu (Pimental)	PA	Delimited	Traditionally Occupied	Image NA	0.00	84.8	0.0

**Table S17****Deforestation detected as related to mining by DETER and the location of mining titles**

State	2019			2020		
	Deforestation for mining identified by DETER (ha)	Deforestation outside mining titles (ha)	Share of deforestation inside mining titles (%)	Deforestation for mining identified by DETER (ha)	Deforestation outside mining titles (ha)	Share of deforestation inside mining titles (%)
AM	386.8	386.8	3.7	769.2	769.2	7.7
AP	22.8	0	0.2	37.7	37.7	0.4
MA	0	0	0	66.3	66.3	0.7
MT	817.6	556.2	7.7	703.6	513.6	7.0
PA	9,010.9	8,869.2	85.3	8,224.9	8,073.2	82.0
RO	131.2	131.2	1.2	103.1	103.7	1.0
RR	194.8	194.8	1.8	123.4	123.4	1.2
<b>Total</b>	<b>10,564.1</b>	<b>10,138.1</b>	-	<b>10,028.2</b>	<b>9,686.5</b>	-

### Graph S1

Historical series on the evolution of DETER alerts in the Legal Amazon superimposed on Conservation Units, Indigenous Lands, and areas without particular classification in hectares.

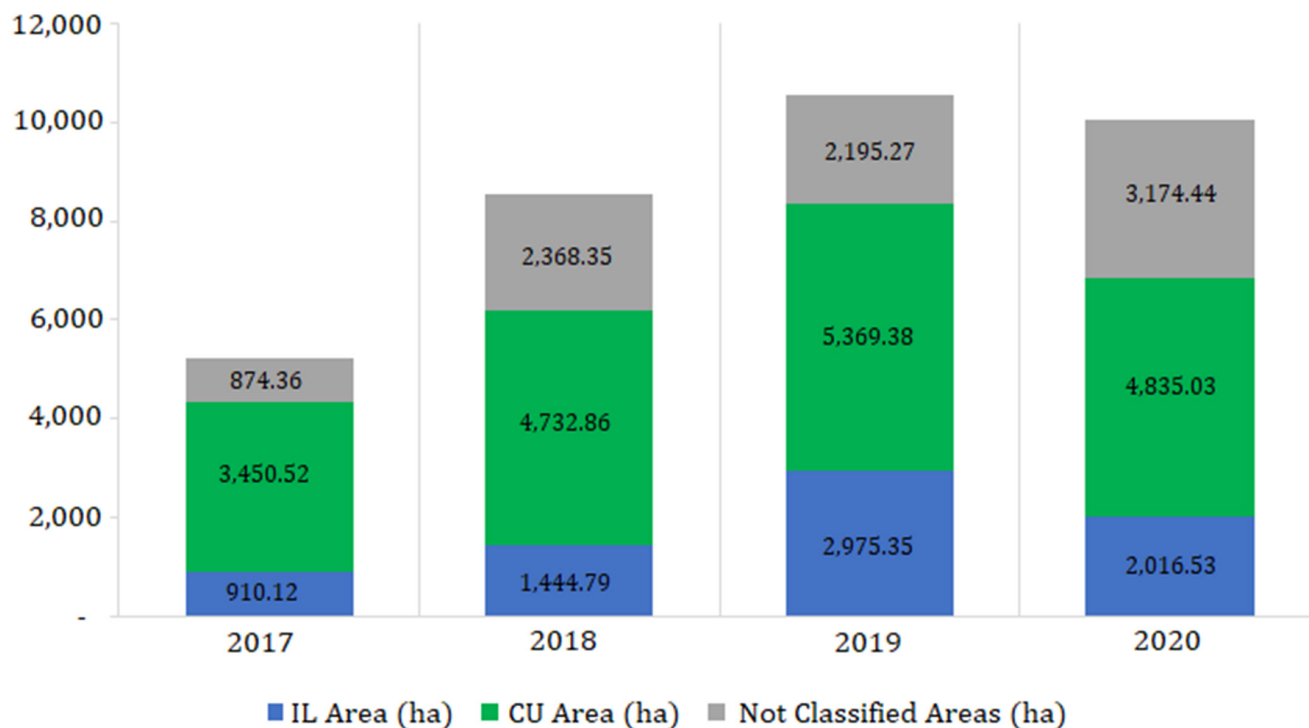
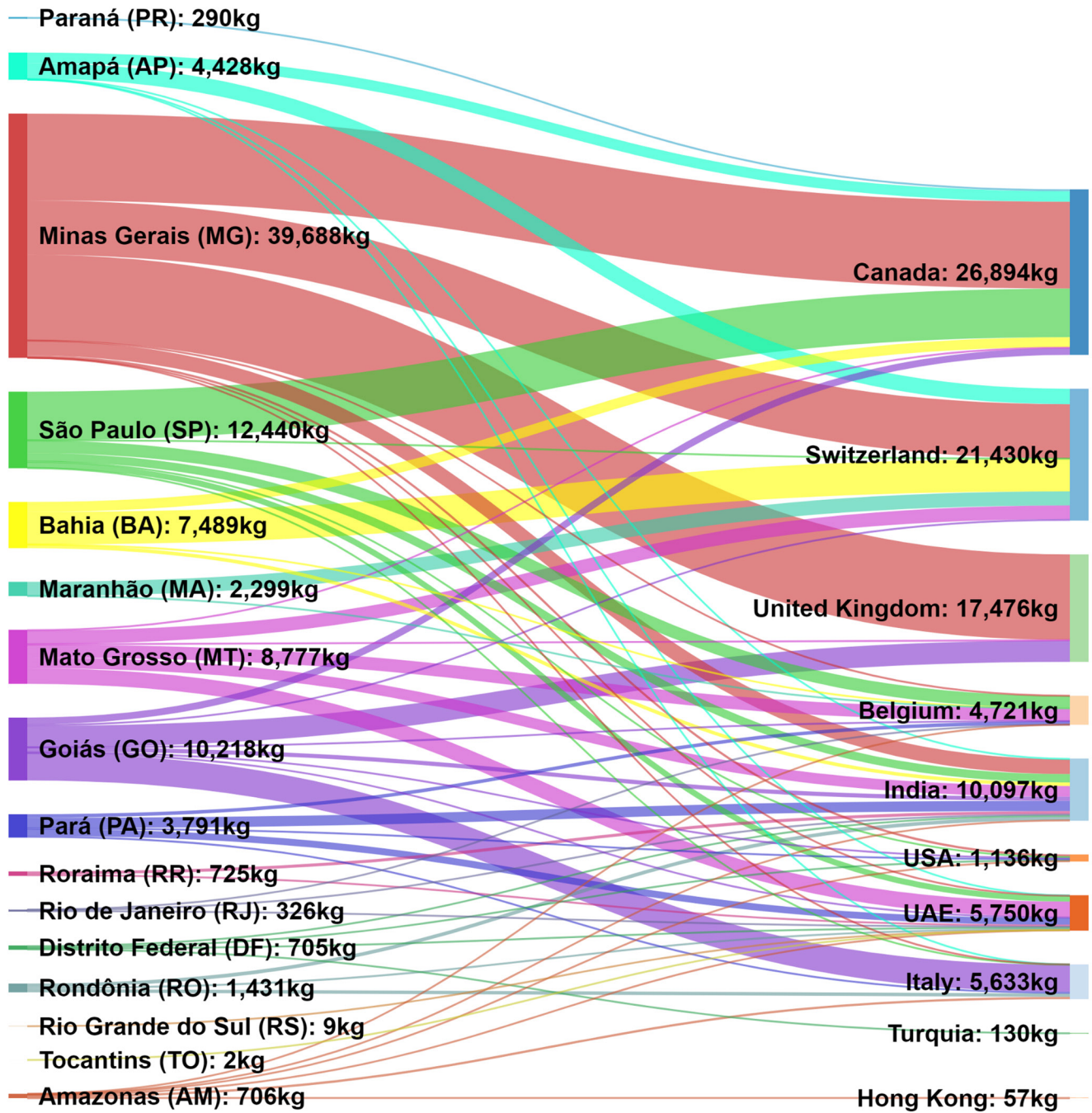


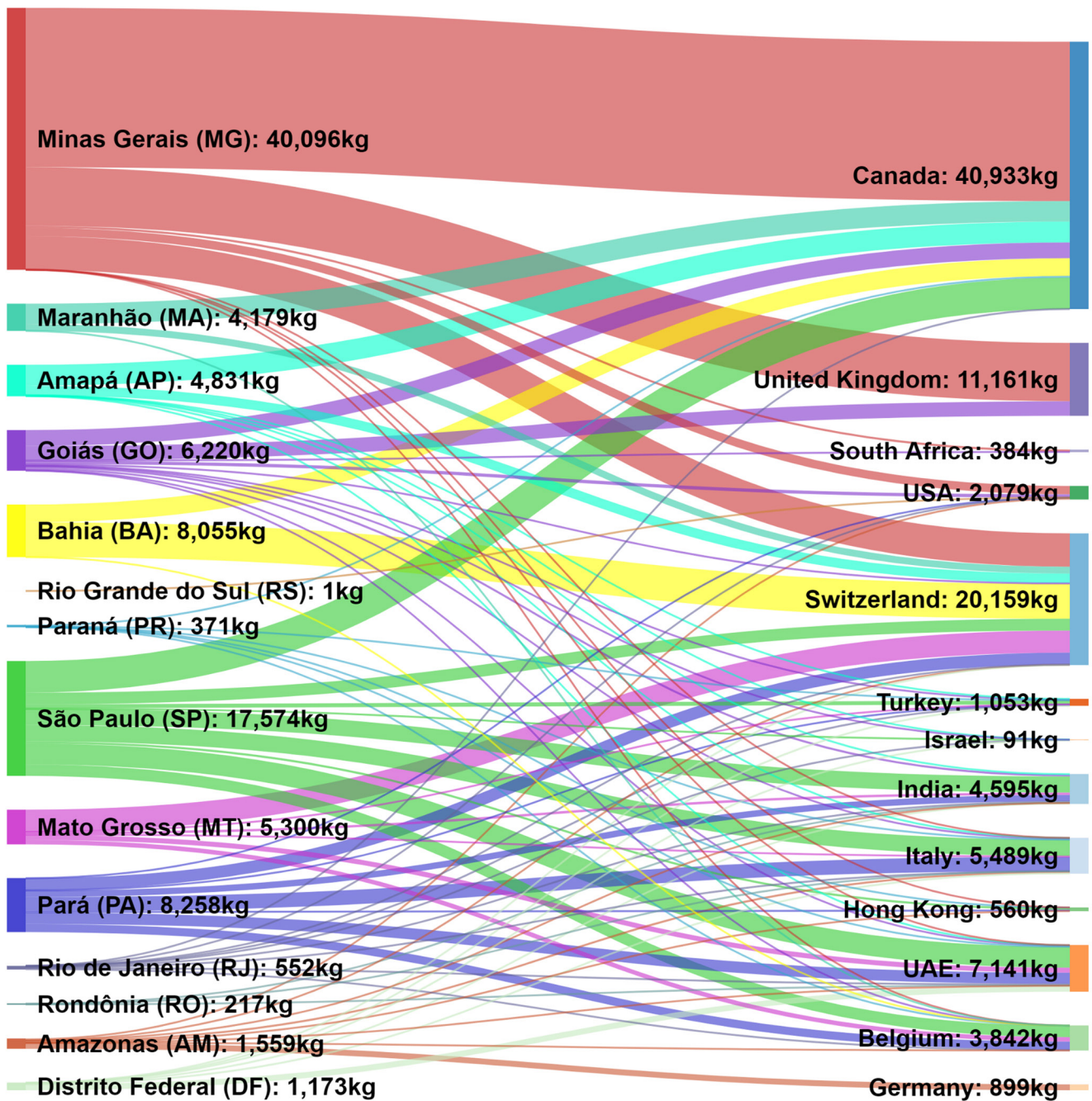
Figure S1

The flow of Brazilian states exports can be seen in the graph below with the country destination of gold traded in 2019, declared on the COMEX Stats portal.



**Figure S2**

The flow of Brazilian states exports can be seen in the graph below with the country destination of gold traded in 2020, declared on the COMEX Stats portal.





**Figure S3**

Examples of the classification of the titles, illegal (Figure A), potentially illegal (Figure B), and legal (Figure C).

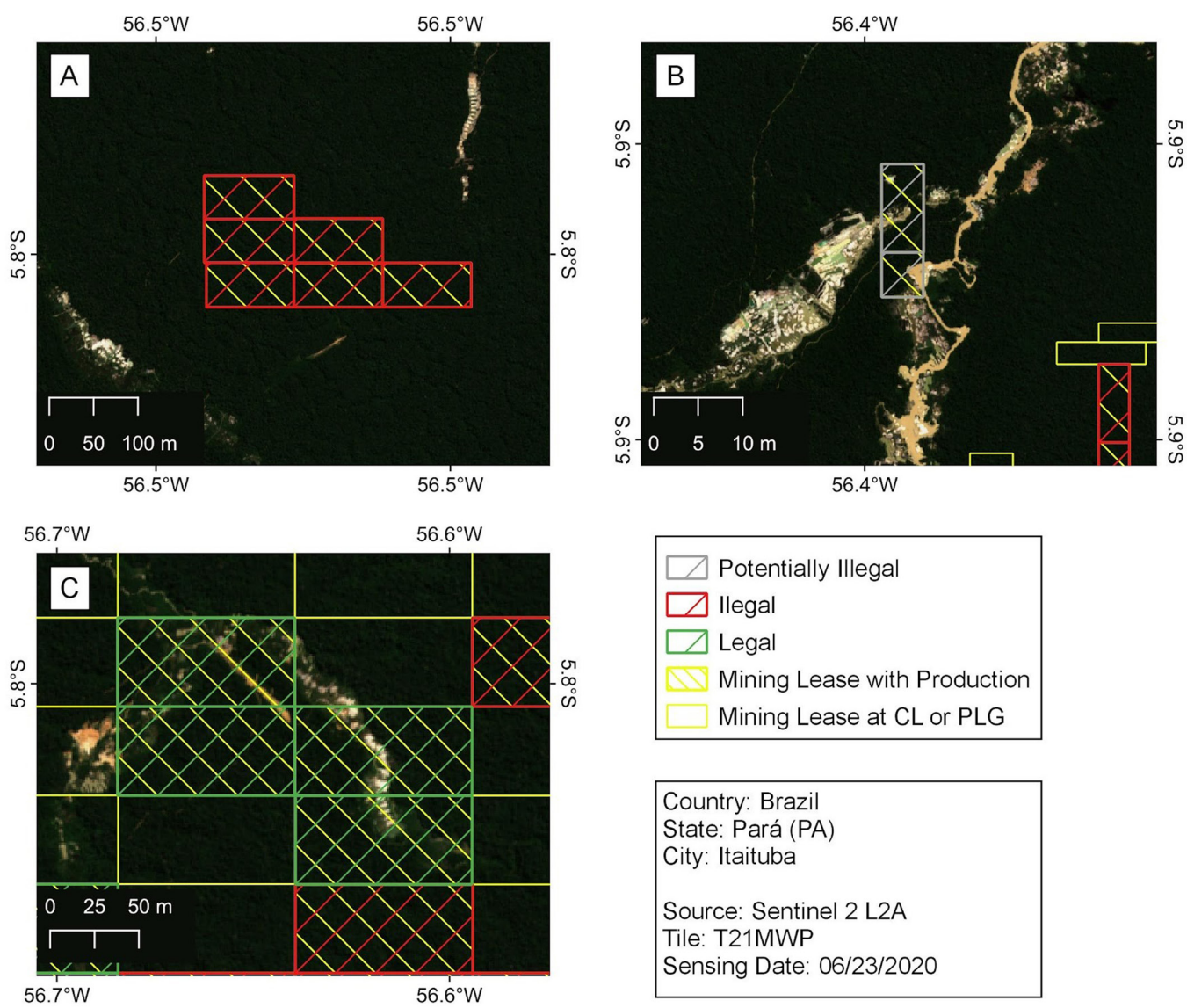


Figure S4

Example of the classification of mining titles in Itaituba in the state of Pará.

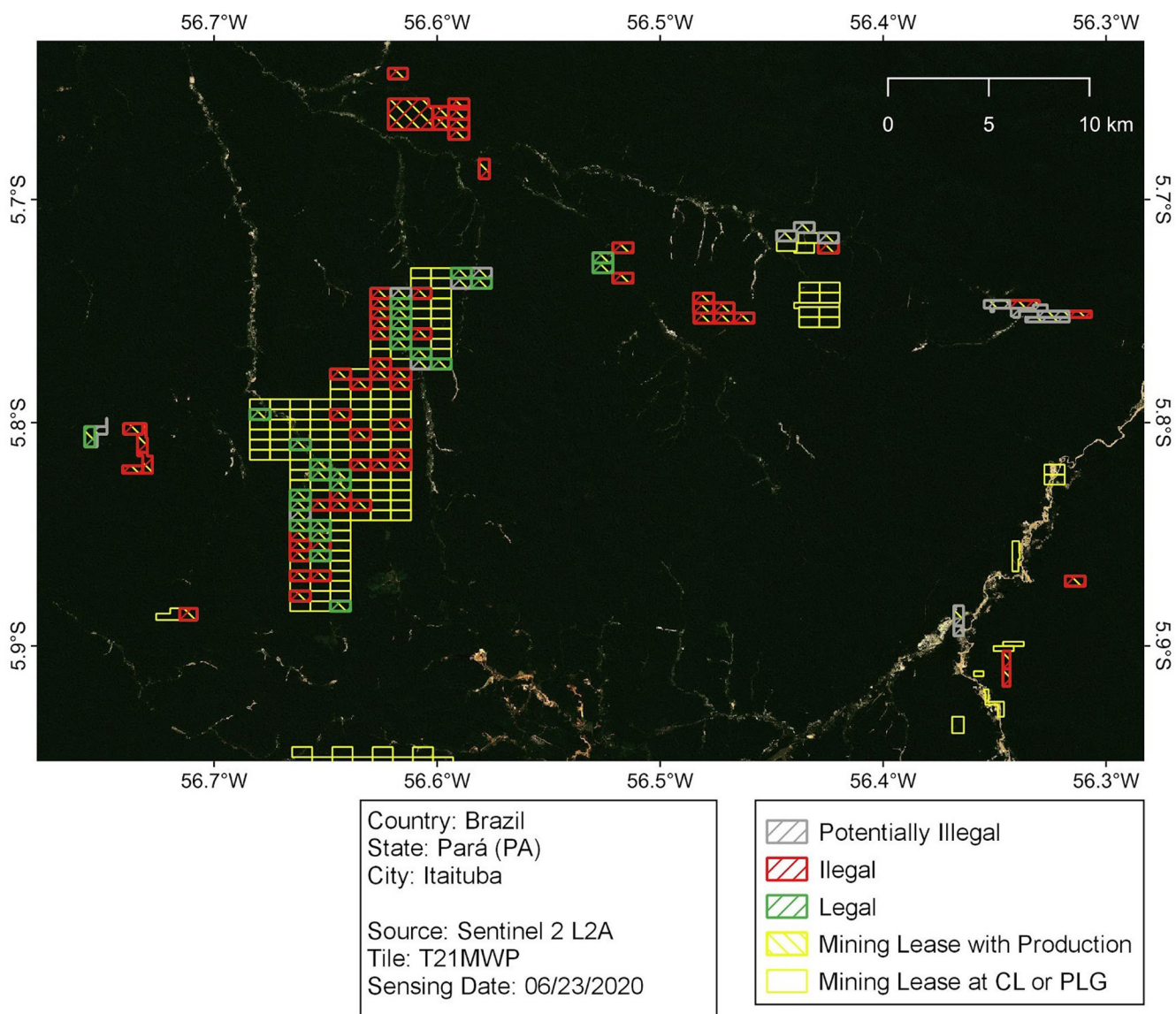
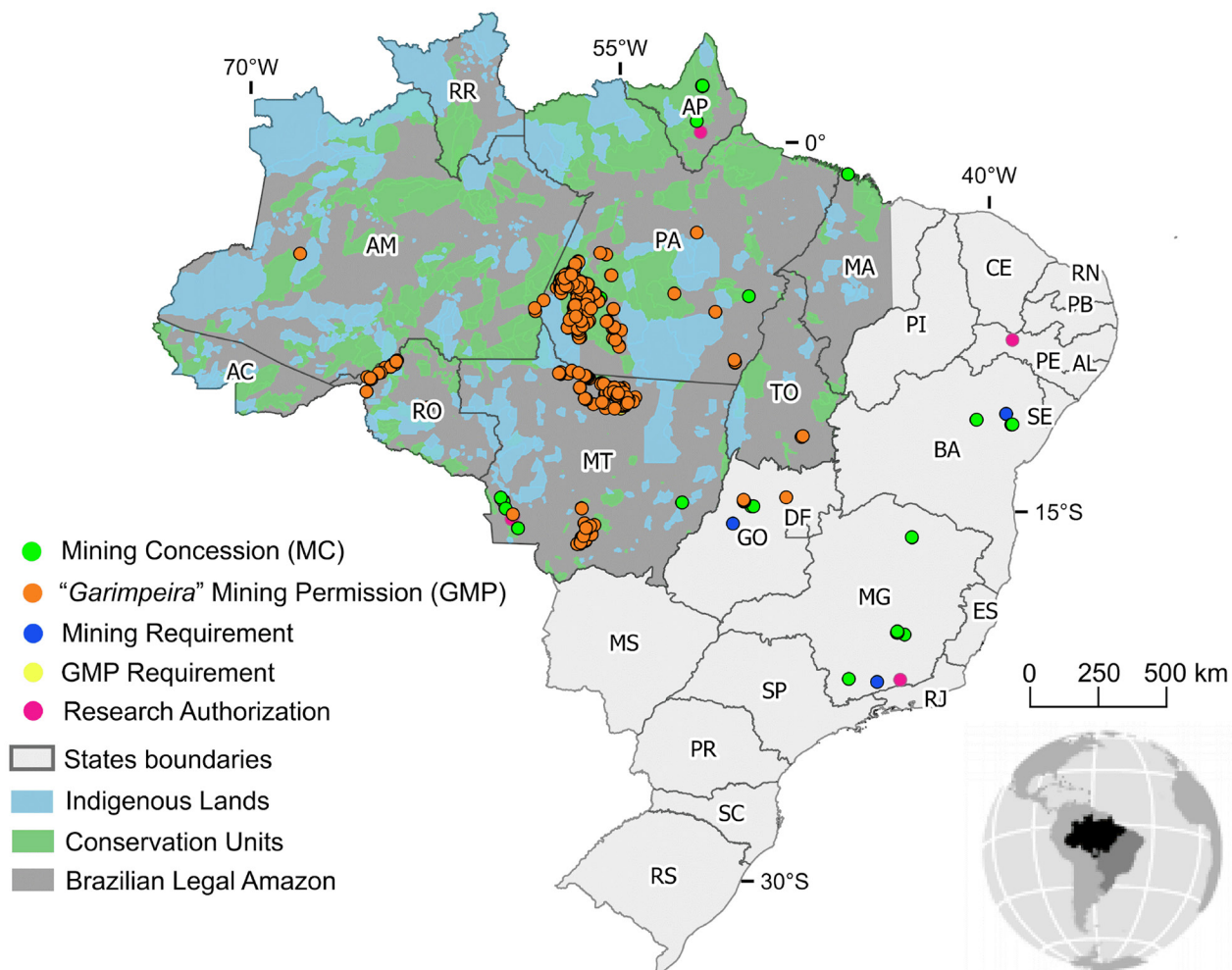


Figure S5

Spatial distribution of mining titles according to the title adopted in 2019 and 2020.





**Figure S6**

The flow of major illegal transactions between 2019 and 2020. The total amount of illegal gold: 6,350.74 kg.

