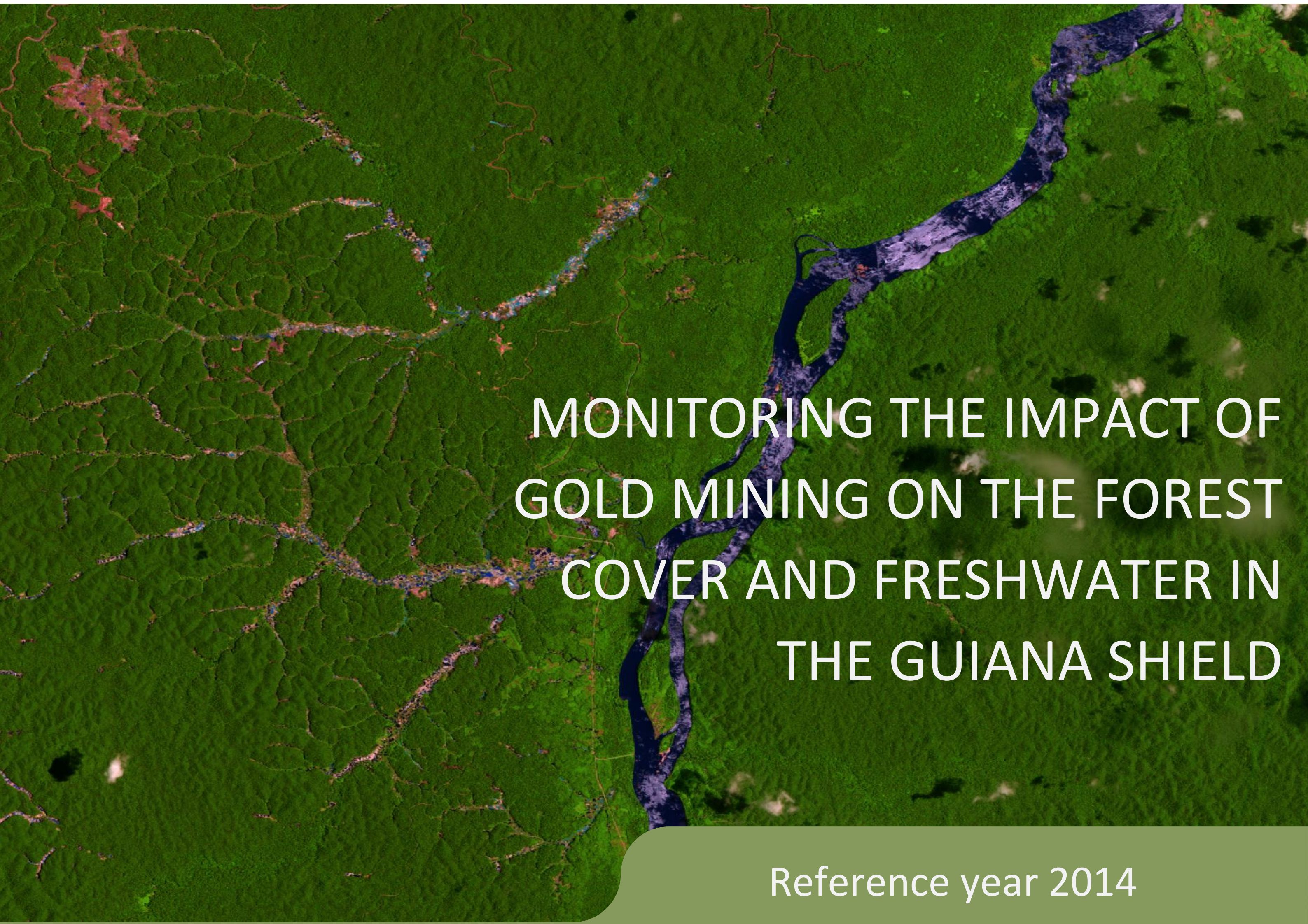

MONITORING THE IMPACT OF GOLD MINING ON THE FOREST COVER AND FRESHWATER IN THE GUIANA SHIELD

Reference year 2014

2015

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Study implemented in the framework of the *REDD+ for the Guiana Shield* project and co-funded by WWF Guianas

This regional collaborative study has been carried out by a team of experts from forestry and environmental services of Suriname (SBB), Guyana (GFC), Amapá (SEMA) and French Guiana (ONF). Co-funded by WWF Guianas, it was conducted under the supervision of ONF International in the framework of the *REDD+ for the Guiana Shield* project.

The *REDD+ for the Guiana Shield* project (http://reddguianashield.com/) is an initiative funded by the European Regional Development Fund (FEDER Interreg Caraïbes IV), the French Global Environment Facility (FFEM), ONF-Guyane and Région Guyane. It aims at increasing regional technical cooperation on forest and REDD+ related issues between Suriname, Guyana, the State of Amapá in Brasil and French Guiana.

This study was made possible thanks to a cooperative agreement signed in the framework of the *REDD+ for the Guiana Shield* project, between ONF-Guyane (project owner) and Airbus Defense & Space, as well as between SEAS-Guyane and Airbus DS, for providing all collaborators of the study *MONITORING THE IMPACT OF GOLD MINING ON THE FOREST COVER AND FRESHWATER IN THE GUIANA SHIELD* with access to SPOT 4 and 5 archives, as well as some SPOT 6.

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Abbreviations

BRGM	Bureau de Recherches Géologiques et Minières de France
CIRAD	Center for International Research on Environment and Development
CGTIA	Coordenaria de Geoprocessamento e Tecnologia de Informação Ambiental do Amapá, Brasil
CPRM	Companhia de Pesquisa de Recursos Minerais do Brasil
DEAL Guyane	Direction de l'Environnement, de l'Aménagement et du Logement de la Guyane
DIREN	Direction Régionale de l'Environnement
HFLD	High Forest Low Deforestation
GFC	Guyana Forestry Commission
GGMC	Guyana Geology and Mines Commision
GIS	Geographic Information System
IBAMA	Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renovavéis
ICMBio	Instituto Chico Mendes de Conservação da Biodiversidade
IEF	Instituto Estadual de Florestas do Amapá, Brasil
LCCS	Land Cover Classification System
LCML	Land Cover Meta Language
LU LC	Land Use Land Cover
MMU	Minimum Mapping Unit
MRVS	Monitoring, Reporting & Verification System
NDWI	Normalized Difference Water Index
NIR	Near Infrared
ONF	Office National des Forêts
ONFI	ONF International
REDD+	Reducing emissions due to deforestation and forest degradation, forest conservation, sustainable management of forest and enhancement of forest carbon stocks
SBB	Stichting voor Bosbeheer en Bostoezicht van Suriname - Foundation for Forest Management and Production Control
SEAS	Surveillance de l'Environnement Amazonien assistée par Satellite
SEMA	Secretaria de Estado do Meio Ambiente do Amapá
SRTM	Shuttle Radar Topography Mission
USGS	United States Geological Survey
WWF	World Wildlife Fund

Executive summary

Suriname, Guyana, French Guiana and the Brazilian state of Amapá are included in the larger Guiana Shield ecosystem. Under little threat until fifteen years ago in comparison with other tropical forests, deforestation and forest degradation are of increasing concern in the Guiana Shield, in particular in relation to gold mining activities which has experienced a significant boom. This intensification of gold mining activities was influenced by the increase of gold price, the economic depression, the political instability and the influx of Brazilian miners after increased national enforcement of tribal land integrity and land-use laws (Hammond *et al*., 2007). Although gold mining is contributing to economic development in the region in terms of revenues and job creation, it also has negative impacts on forest, freshwater and biodiversity. Forest recovery following mining is slow and qualitatively inferior compared to regeneration following other land uses. Unlike areas in nearby old-growth forest, large parts of mined areas remain bare ground, grass, and standing water (Peterson and Heemskerk, 2001). Mercury, often used and released in large quantities in the environment during the gold extraction process, contaminates the soil, water and air, and impacts human health.

In 2010, ONF showed by processing high resolution satellite images that gold mining activities' impacts on forest cover and freshwater of the region increased approximately by a factor three between 2001 and 2008. More recently, Alvarez-Berríos *et al*. (2015), used low resolution data to point out a sustained acceleration of deforestation due to gold mining in the region between 2007 and 2013. However, the detection of deforestation by coarse spatial resolution data is limited, especially in the Guiana Shield high forest cover where small- and medium-scale operations account for most of the deforestation.

Using appropriate satellite data, this study aims at updating the ONF 2010 previous study over the period 2008-2014. The study, implemented in the framework of the REDD+ for the Guiana Shield project and co-funded by WWF Guianas, was conducted following a unique collaborative and participatory approach involving a core team of experts from the forestry and environmental services of each territory covering the study area, namely SEMA (Amapá-Brazil), ONF (French Guiana-France), GFC (Guyana), and SBB (Suriname). Under ONFI coordination, the objective was to develop a robust, reliable and transparent regional methodology and to encourage regional cooperation, dialogue and knowledge sharing.

Following three weeks of regional meeting and capacity building sessions, and one mission of the ONFI/ONF coordination team in each partner's institution to ensure the appropriation of the methodology, SEMA, ONF, GFC, and SBB produced the results of the impact of gold mining activities on forest cover and freshwater for their own territory. These results were then compiled at the regional level, and verified and assessed in terms of accuracy by the ONFI/ONF team.

A total area of 160,850 hectares (i.e. 0.3% of the study site) of gold mining areas have been digitized based on the observation of hundreds of medium-, high- and very high resolution satellite images acquired between beginning of January 2012 and end of December 2014 . This total deforestation is unequally distributed over the study area, with about 50% located in Guyana, 34% in Suriname, 15% in French Guiana and 1% in North of Amapá.

The comparison with the previous study results confirmed the alarming observation done by Alvarez-Berríos *et al*. (2015). Deforestation due to gold mining has doubled between 2008 and 2014 (+92,406 ha) compared to 2001-2008 period (+46,144 ha). However, the evolution of deforestation during the last period differs from a territory to another. It doubled in Suriname (+97%) and multiplied by 4.5 in

Guyana (+354%), which offsets the slowdown observed in French Guiana (+16%) and Amapá (-14%) compared to the previous period.

The spatial analysis of the results shows that gold mining activities are moving westward in the region where 84% of total deforestation is now located in Suriname and Guyana, compared to 66% in 2008 and 61% in 2001. It appears also that deforestation caused by gold mining is strongly correlated with the presence of the Greenstone belt, geological formation known for its large reserve of gold, especially in Suriname where the overlap reaches 99%. French Guiana has by far the most conflict zones with protected areas (4000 ha) but also the highest proportion of protected areas overlapping the Greenstone belt (18%), making these areas especially vulnerable to gold mining activities.

The proportion of deforestation caused by small-, medium- and large-scale gold mining, defined in terms of impacted surface in this study, has evolved over years. Although the trend is different among territories, large-scale operations (>100 ha) are more and more contributing to deforestation over the years, representing now the major contributor at the regional scale with 50% compared to 35% in 2001. Medium-scale operations (10-100 ha) which were contributing the most to deforestation in 2001 with 52%, follow an opposite trend and contributes now to 36%. The proportion of deforestation caused by small-scale gold mining (<10 ha) is stable over the years (around 15%).

The cross analysis performed between gold mining areas and the watershed highlighted 39,805 km of waterways potentially impacted by gold mining, from which 22.5% are in direct contact with gold mining activities (9,347.9 km).

While Guyana possess the higher network of rivers potentially impacted (13,534 km), it also has one of the lowest ratio of direct / indirect impact (about 1/6), partly explained by the few small gold mines located in the extreme south of the country (far from the coast) which generate a potential indirect impact long of approximately 2,500 km. Suriname possesses the highest direct / indirect impact ratio (about 1/2) and by far the longest network of waterways in direct contact with gold mining activities (4,989.1 km). This can be explained by the presence of larger mining sites in comparison with the other territories but also by the high concentration of the activity around the Brokopondo hydro dam near the border with French Guiana. In French Guiana, while the direct impact is much lower, the indirect impact is closer to the one in Suriname, due to the wide distribution of the activity over the territory compared to Suriname, where it is concentrated near the border with French Guiana. This high concentration of Surinamese and French activities near the border suggest high impact on the rivers of the region, especially on the Maroni River which is located at the border of the two territories. Many communities in the interior of Suriname are not connected to the public water net. Hence especially in the dry season when people cannot rely on rainwater, the poor water quality is a large problem as causes diarrhea and other waterborne diseases (Heemskerk and Olivieira 2003).

Comparing the results of the potentially impacted waterways for the reference year 2014 with the 2001-2008 study represented a challenge, especially because the accuracy of the SRTM data used to generate the watershed was three times higher in 2014 (30m) than in 2001-2008 (90m). Nevertheless, a significant increasing impact occurred over the years in the region. The increase in direct impact is especially high as it raised by 541% since 2001, compared to 171% for the indirect impact. This is mainly due to the increase of the activity over the years around existing historic mining sites, especially driven by the presence of the greenstone belt and the accessibility of the area. These new mining areas indirectly impact rivers which were already impacted by older sites.

The results of the impact of gold mining on waterways provides indication about the potential dispersion of contaminants such as mercury released by the activity in the environment through the river system, however, evidence recently gathered indicates that the impact of mercury use in gold mining are underestimated when only considering downstream impacts (Ouboter *et al*., 2012) and some specific research need to be carried out to better understand the inter-relationship between mining activities and the environment.

The figures provided in this report should be linked with more available data such as field data but also with more specific contextual elements that could help to better decrypt it, especially with regard to local practices, legal framework (which differs from a country to another) and policies and measures developed by countries to limit the impact of gold mining on the environment. Improving monitoring tools and the analysis that can be made from the produced data first requires to replicate this type of study in the future, which should be done following the same collaborative approach. Transboundary approaches and analysis are essential to better understand the effect that new policies and measures can have on gold mining activities' displacement such as observed in this study. Working together allowed the development of robust and reliable tools and capacity building of organizations that were directly involved in the data production and analysis. Most of all, it enabled to develop a consistent and shared vision of the situation in the region.

Given the sustained intensification of gold mining activities since 2001 in the region and the critical concerns it poses in terms of deforestation, water quality, environment and human health, it is becoming urgent for countries to improve their knowledge and understanding of what are the impacts of gold mining activities, including to enforce the regulation.

1. Introduction

1.1 Background

Situated in the northeastern part of South America, the Brazilian state of Amapá and the Guianas are included in the larger Guiana Shield. The Guiana Shield ecoregion houses a spectacular biodiversity, with high species richness and high levels of endemism. With more than 85% of forest cover and historical rates of deforestation below 0.1%, the Guianas composed by Guyana, Suriname and French Guiana[1] are classified, with only three other countries in the world, as "high forest cover, low deforestation (HFLD)" countries (Griscom *et al*., 2009). These HFLD countries, with which the state of Amapá shares similar attributes (da Fonseca *et al*., 2007), represent 10.5% of the global forest carbon stock. Together, the four administrative entities form a unique ecosystem which plays a critical role in mitigating climate change, preserving biodiversity, regulating enormous volumes of freshwater and providing an important source of goods and services for many local and indigenous communities.

Under little threat until fifteen years ago in comparison with other tropical forests, the Guiana Shield region is burgeoning economically and demographically, leading to growing pressures on this fragile natural ecosystem. Deforestation and forest degradation are of increasing concern in the region, in particular in relation to gold mining activities which represent nowadays one of the main drivers in the region. The rock formation of the Guiana Shield region is a continuation of the African Gold Coast which is rich in gold and other minerals including bauxite, diamonds and iron (Hammond *et al*., 2007). While the extraction of most minerals has reduced since the late 1980s, gold production has experienced a significant boom (Hammond *et al*., 2007). The phenomena began in the early 1990s when the Brazilian government reinforced the monitoring and regulation of small-scale mining leading to the leakage of Brazilian miners, called Garimpeiros, to the Guianas where the bureaucracy and control was lighter (WWF Guianas, 2012). The gold rush started a couple of years later when the Garimpeiros modernized the small-scale mining industry in the Guianas by replacing the concept of subsistence mining with mining for profit (Veiga, 1997). Between 1990 and 2004, gold mining activities expanded rapidly in this region driven by the sustained boom of gold price, the liberalization of the international gold market, the economic depression, the political instability and the influx of Brazilian miners after increased national enforcement of tribal land integrity and land-use laws (Hammond *et al* 2007). Since then, the forest cover loss due to gold mining in the Guiana Shield has not ceased to increase. Small- and medium-scale operations accounted for the majority of this deforestation in the past, but now large-scale operations, presumably operating under strict regulations, are more and more responsible for the forest loss in the region.

Whereas gold mining is an important factor contributing to economic development in terms of revenues and job creation, the direct and indirect impact on forests, freshwater, species and human health are very significant. The pollution of rivers and streams by mercury used in small-scale gold mining is expanding, which increases risks to local population health and freshwater biodiversity. Since the recent combination of the financial crisis of 2007-2008 and the sustained increase of gold price, additional forested areas and water systems come even more under pressure from gold mining, while the challenges associated with regulating the sector grow even further (WWF Guianas, 2012).

[1] French Guiana is not deemed a country in its own right and as such is not officially a HFLD country, despite similar high forest cover and low deforestation trends to Guyana and Suriname.

1.2 Previous studies

In 2010, ONF and CIRAD published the results of a first quantitative study, funded by WWF Guianas, on the gold mining impact on forest cover and freshwater at the Guiana Shield regional scale (ONF, 2010). The study site included Guyana, Suriname, French Guiana and the North of the Amapá state of Brazil. Two reference dates were compared: 2001 (beginning of the gold rush caused by the increase of gold price) and 2008. Hundreds of high and medium resolution satellite images, sourced from SPOT5 (10m), SPOT4 (20m) and Landsat 5 and 7 (30m) and acquired within a two years' time window, were photo-interpreted in order to quantify the impact of gold mining on the forest cover (Figure 1). The potential direct and indirect impact of gold mining on the water quality of rivers have also been assessed using a combination of the watershed (produced based on the freely available Shuttle Radar Topography Mission (SRTM) data at 90m resolution) with the spatial location of mining sites. The direct impact is characterized by the section of the waterway which is in direct contact with the mining site whereas the indirect impact is the downstream of the directly impacted section (Figure 2 and Figure 3).

The results of this first study showed increasing gold mining activities in the region. Deforestation caused by gold mining tripled in Guyana, Suriname and French Guiana, whereas the activity remained relatively stable in the North of Amapá. The direct impact of the activity on freshwater follows the same trend.

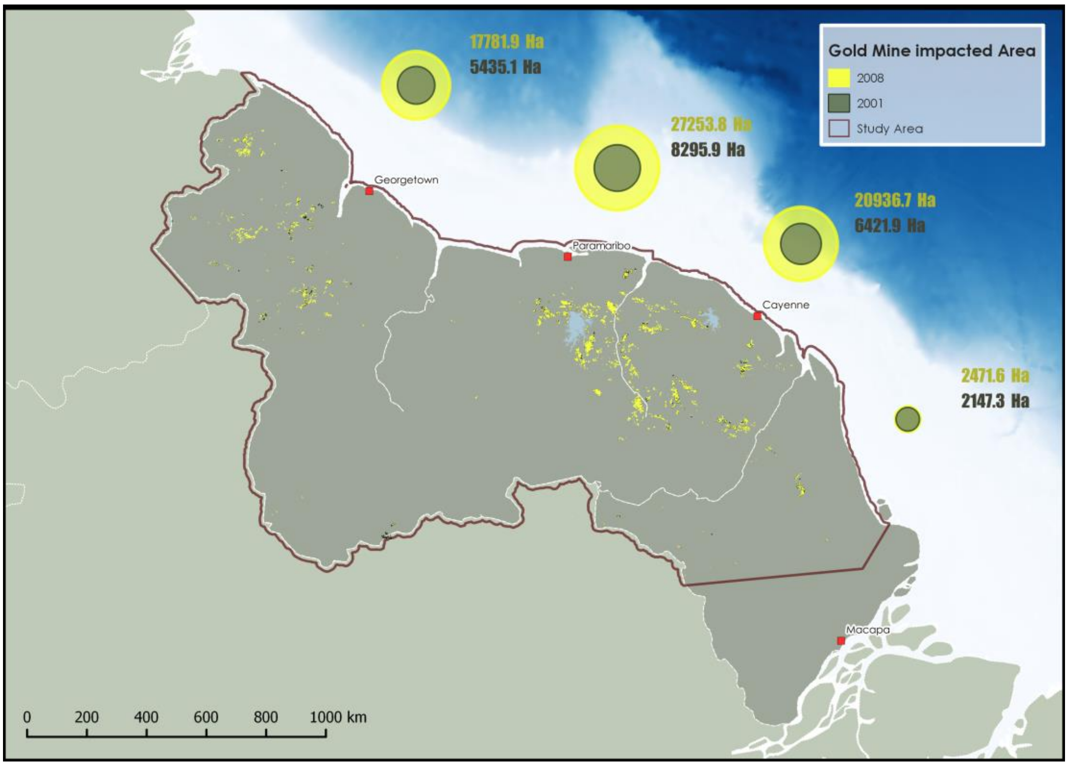

FIGURE 1 : IMPACT OF GOLD MINING ON THE TERRITORIES OF, FROM LEFT TO RIGHT, GUYANA, SURINAME, FRENCH GUIANA AND AMAPÁ FOR THE REFERENCE YEARS 2001 AND 2008

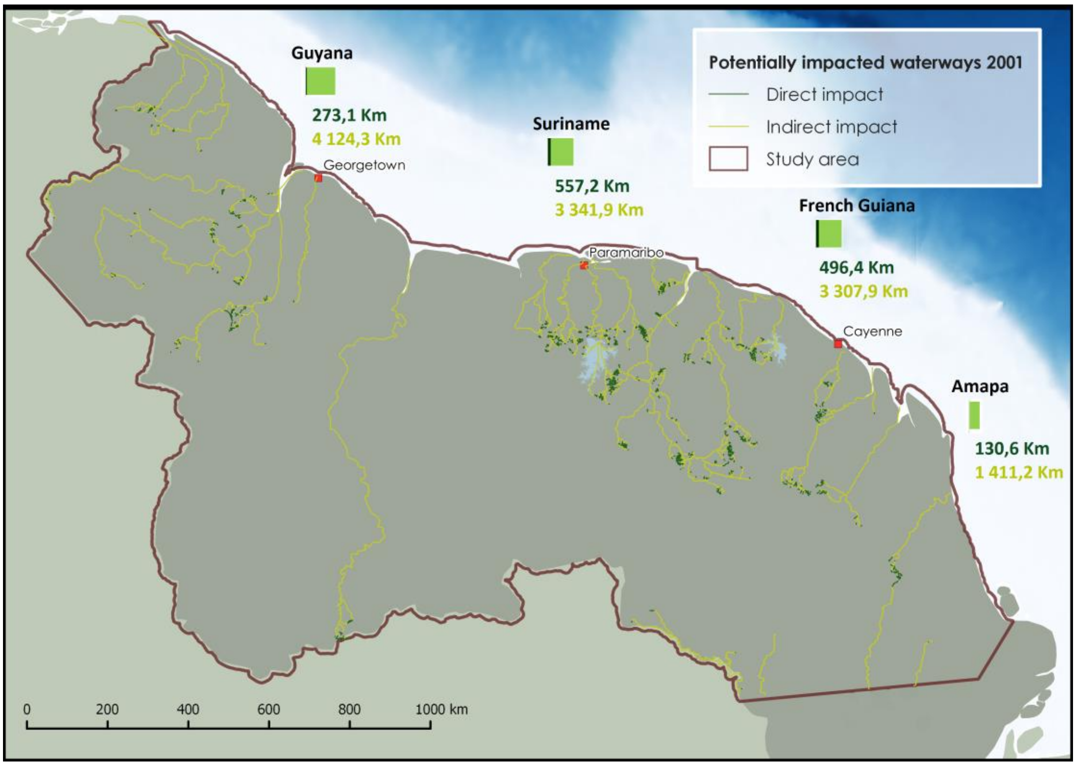

FIGURE 2 : POTENTIAL IMPACT OF GOLD MINING ON FRESHWATER IN 2001[2]

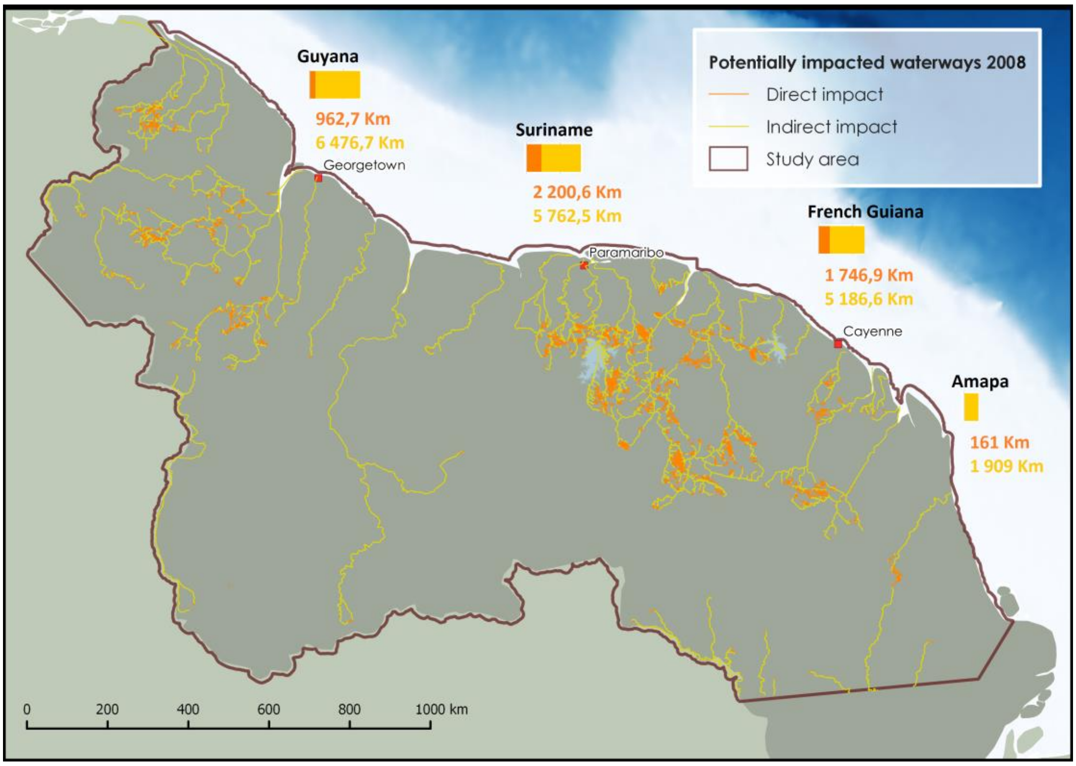

FIGURE 3 : POTENTIAL IMPACT OF GOLD MINING ON FRESHWATER IN 2008[2]

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[2] This map does not display any country boundary but only waterways impacted by gold mining activities.

Recently, Alvarez-Berríos *et al.* (2015) published a study on the extent of forest changes associated with gold mining between 2001 and 2013 in the below 1000m moist broadleaf forest biome of South America (Olson *et al.,* 2001). MODIS satellite images at 250m resolution were used to map gold mining-related forest cover changes during the periods 2001–2006 and 2007–2013, i.e. before and after the 2007-2008 global financial crisis.

The results of this study show that the deforestation was significantly higher during the 2007–2013 period. Authors are associating this acceleration with the increase in global demand for gold after the international financial crisis. More than 90% of deforestation occurred in four major hotspots: Guianan moist forest ecoregion (41%), Southwest Amazon moist forest ecoregion (28%), Tapajós–Xingú moist forest ecoregion (11%), and Magdalena Valley montane forest and Magdalena–Urabá moist forest ecoregions (9%). Given this current gold rush and the presence of gold mining in remote areas of high biodiversity, especially in the Guiana Shield, the paper emphasizes the urgent need of better information on the distribution of gold mines in the region. While MODIS data is useful for monitoring mining activities at large scale such as the Amazon biome, its low spatial resolution is not appropriate to detect deforestation in the Guiana Shield where small- and medium-scale operations account for most of the deforestation, and where the use of higher resolution data is therefore mandatory to measure the impact of gold mining with reliable accuracy.

1.3 Organization and objectives of the study

This study, co-funded by the *REDD+ for the Guiana Shield project* and WWF Guianas, was conducted following a unique collaborative and participatory approach involving a core team of experts from the forestry and environmental services of each territory, namely the state of Amapá in Brazil, French Guiana, Suriname and Guyana. Through regional team meetings and capacity building sessions, the core team was involved in the whole production chain, from the development of the methodology until the final product delivery. The study was coordinated by ONF International and technically lead in collaboration with ONF Guyane, involved in the previous 2001-2008 study.

The main objective of production was twofold:

1. Quantifying and mapping forest areas and extent of waterways impacted by gold mining in the Guiana Shield for the reference year 2014, using high resolution satellite data;

The output seeks to update the results released by ONF and CIRAD for the reference time points 2001 and 2008. As for those two time points, satellite images have been acquired for this study within a two years' time window, i.e. between 2012 and 2014.

2. Analyzing the results by extracting statistics and comparing it with the previous study to better understand the dynamic of gold mining activity in the region.

Beyond the data production objectives, the study aimed at:

- Encouraging regional cooperation, dialogue and knowledge sharing in order to enable a shared understanding of the context and stakes of monitoring gold mining at the regional scale;
- Developing a robust, reliable and transparent regional methodology to monitor the impact of gold mining on the forest cover and freshwater, making use of high resolution satellite imagery and open source software.

This report shows the outputs of this study through the three following main chapters: (2) Material and methods, (3) Results and discussions, and (4) Conclusion and perspectives.

2. Materials and methods

The material and methods used in this study to map the impact of gold mining on the forest cover and freshwater were defined following several prerequisites:

- The outcomes must be comparable with the results of the previous study performed by ONF/CIRAD in 2010;
- The experts of the forest services of each territory must use similar dataset characteristics and common methodology and tools.

A core team of experts from forestry services of Guyana (Guyana Forestry Commission (GFC)), Suriname (Stichting voor Bosbeheer en Bostoezicht van Suriname (SBB)), French Guiana (Office National des Forêts de Guyane (ONF)), and the environment secretariat of Amapá (Secretaria de Estado do Meio Ambiente do Amapá (SEMA)) has been created. Experts were in charge of implementing the methodology for their own territory. The core team of experts met for 3 weeks in French Guiana under ONF international and ONF coordination for technical discussions and capacity building sessions on the methodology. Following these sessions, detailed tutorials have been provided and the supervision team from ONF international and ONF visited each institution to ensure the appropriation of the methodology by each expert from the core team.

2.1 Study site

Similar to the previous ONF/CIRAD study area, the study site covers 521,949 square kilometers, including the northern part of Amapá state of Brazil, French Guiana (France), Guyana, and Suriname (Figure 4). The proportion of land covered by each territory is 15.5%, 16%, 40.2% and 28.2% respectively.

Included in the larger Guiana Shield ecosystem, the study site is part of the largest tract of continuous pristine tropical forest in the world. The forest cover, 92% of the study area in 2000 (Hansen *et al*., 2013), is among the highest in the world. Indeed, the Top 5 is led by French Guiana, which is a French department, followed by Suriname, which has the highest reported forest cover of any country in the world (FRA, 2010; GFC and Pöyry, 2011). About 95% of the forest of French Guiana and Suriname is classified as 'primary forest' (FRA, 2010).

Protected areas are found throughout the study site, while coverage of total land surface varies widely per country. The North of the state of Amapá contributes to a noteworthy 52.3% of its territory as protected areas, whereas respectively 29.3%, 13.3% and 5.5% of the territory of French Guiana, Suriname and Guyana are protected. Parc Amazonien de Guyane (PAG) in the south of French Guiana, which is the largest protected area of the Guianas, borders the network of protected areas of Amapá, including the Tumucumaque National Park. This connection creates a magnificent protected area of 12 million hectares, which makes it the largest protected tropical forest in the world. These large protected areas are important for the protection of rare habitat, the conservation of ecological processes, and the survival of species that require large territorial areas, such as the harpy eagle and the jaguar (WWF Guianas, 2012).

An extensive complex of wetlands, streams and rivers drains the savannas, rainforests and uplands of the study site into the Atlantic. Again, the region is leading top statistics here, in terms of water surplus. Water surplus countries are countries having in excess more than 100,000 cubic meters per capita per year. The top five surplus countries are Greenland, French Guiana, Iceland, Guyana, and Suriname (FAO- AQUASTAT, 2010).

The region is also rich in many minerals, with a clear industrial focus over the last years on gold, bauxite and petroleum exploration. Gold is leading the extractive sector in the region in terms of people involved and production levels. In Guyana, gold accounts for about 75% of the value of the output of the mining sector (GGMC, 2010). The Greenstone belt, geological formation known for its large reserve of gold, is covering approximately 50,000 square kilometers of the study site, representing about 9% of the area. The presence of this geological formation strongly influences the spatial location of gold mining activities as 74% of gold mining reported in this study are overlapping the Greenstone belt (see further below).

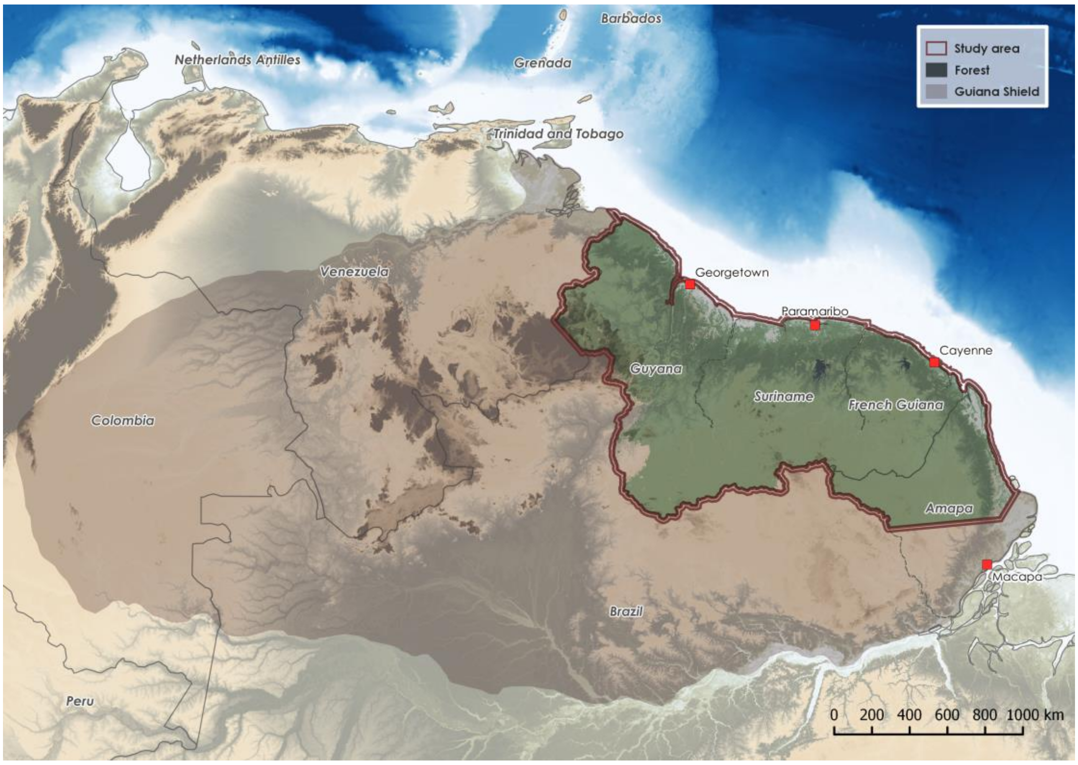

FIGURE 4 : STUDY AREA LOCATED WITHIN THE LARGER GUIANA SHIELD (SOURCE: FOREST (HANSEN *ET AL*. 2013); GUIANA SHIELD (ADAPTED FROM GUIANA SHIELD FACILITY (2012))

2.2 Forest areas impacted by gold mining

Figure 5 illustrates the main steps of the production chain that was developed to obtain a robust, reliable and transparent monitoring system at the regional level, from the image acquisition to the delivery of the results by each core team. The entire process has been discussed with the core team experts who have been trained to it during 3 weeks capacity building sessions organized in French Guiana at the beginning of the study (one week in November 2014 and two weeks in January 2015). Each step is detailed in the following sections according to the chronology of the production chain.

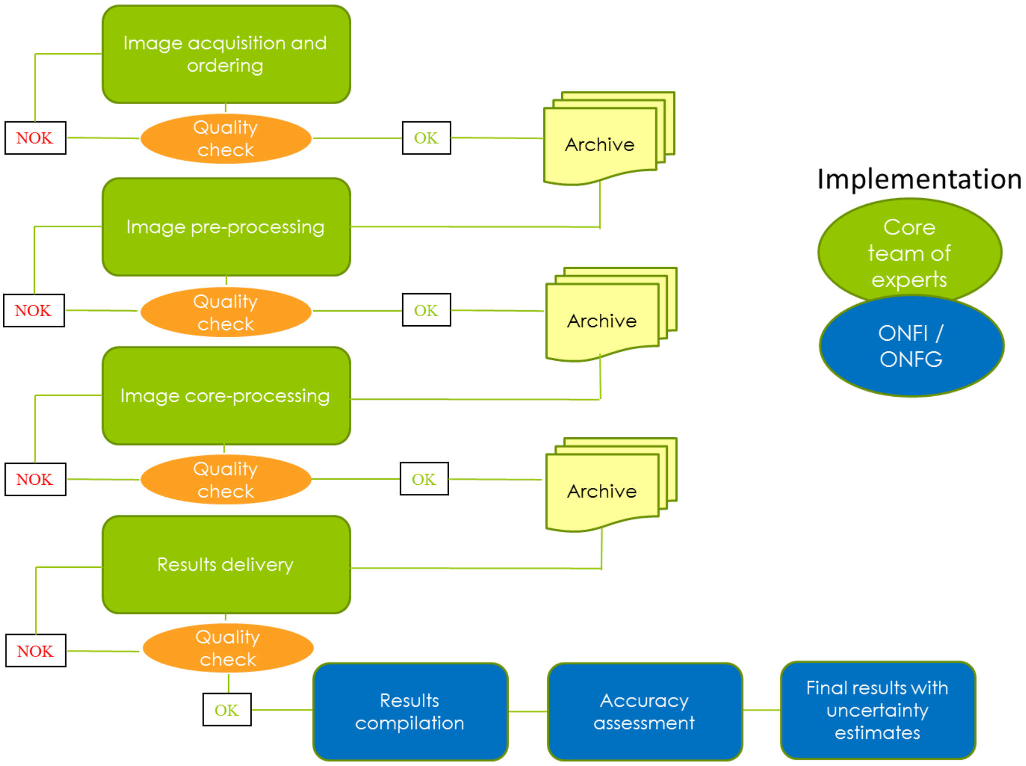

FIGURE 5: METHODOLOGICAL STEPS FOR MONITORING GOLD MINING BY REMOTE SENSING

2.2.1 Image acquisition and material

To overcome the problem of persistent cloud coverage in the region, a large number of satellite images and the combination of different sensors were needed for this study (Figure 6). Table 1 details for each sensor the number of images available and the number of images that were used to digitalize gold mining areas[3]. In total, 1,300 images acquired between 2012 and 2014 were selected with a maximum cloud coverage of 60%. Approximately 20% of the total images acquired were used to digitalize gold mining activities, and a lot more to visualize the full territory.

[3] SPOT6 is expressed in covered area and not in number of scenes

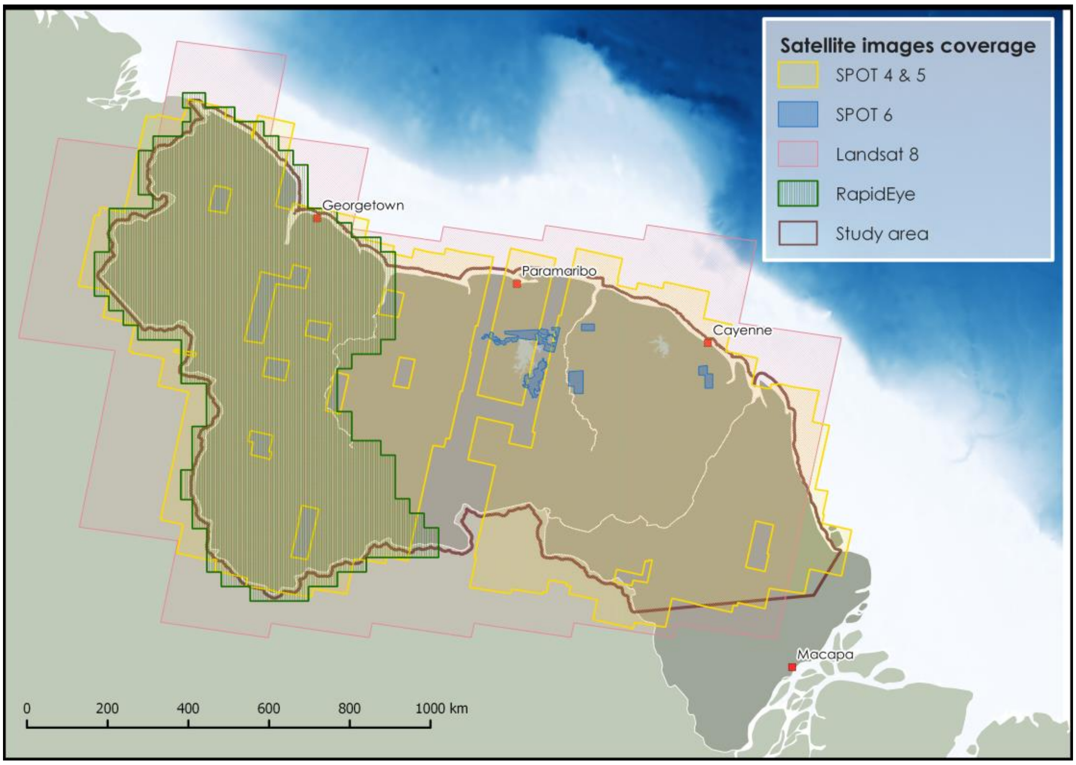

FIGURE 6 : COVERAGE OF THE SELECTED SATELLITE IMAGES ACQUIRED BETWEEN 2012 AND 2014 FOR THE STUDY AREA

	SPOT 4	SPOT 5	LANDSAT 8	RAPIDEYE	Total	SPOT 6
# Acquired images	194	619	31	456	1300	4500 Km²
# Images used for digitizing gold mining	10	84	19	123	236	3000 Km²

TABLE 1 : NUMBER OF IMAGES BY SATELLITE SENSOR ACQUIRED AND USED IN THE STUDY

The archive catalog of SPOT4 and SPOT5 data acquired between 2012 and 2014 was made available for the whole study area through a commercial agreement signed between ONF as the owner of the *REDD+ for the Guiana Shield* project, the SEAS[4] satellite receiving station of the French Guiana Region and Airbus Defense and Space. This agreement included a limited access to SPOT6 data for each territory. RapidEye images acquired end of 2013 by Guyana has also been used to complete the lack of SPOT coverage in the country. Landsat 8 data were freely downloaded via the EarthExplorer platform of the U.S Geological Survey (USGS)[5].

[4] Surveillance de l'Environnement Amazonien par Satellite

[5] http://earthexplorer.usgs.gov/

Priority has been given to the most recent scenes when selecting satellite images. However, a range of 2 years was accepted, from January 2012 to December 2014, in order to increase the coverage. Similarly, while the priority was given to images with the highest resolution such as SPOT 5 or Rapideye, medium resolution Landsat data was used to fill the gaps or to provide more recent information.

A catalogue has been created using QGIS[6] in order to organize the big amount of data that have been collected and facilitate the image identification process within the study area. The catalogue includes each SPOT and Landsat image's footprint with attributes information such as image ID, sensor, acquisition date, cloud cover percentage, spatial resolution and spectral information.

2.2.2 Pre-processing

Five pre-processing steps are included in the methodology, among which three are mandatory steps to be carried out before the image can be used for production.

The three mandatory steps consist in (i) defining the appropriate projection system, (ii) image-to-image co-registration using a defined spatial referential and (iii) cloud masking. These steps aim at ensuring accurate spatial information and reporting unobserved areas (i.e. areas registered as no-data) due to cloud coverage that could not be reduced.

The two last steps were optional and developed in order to help the operator with the detection of mining activities.

2.3.1.1 Projection system

Each expert used the official projection system of their territory in order to facilitate the use of GIS ancillary data when needed. Those official projection systems have been identified before starting the production by the supervision team.

Once delivered, the results from territories have been compiled and re-projected into the international projection system *WGS 84 / Pseudo-Mercator*.

2.3.1.2 Image co-registration

Image co-registration consists in geometrically aligning two or more images to integrate or fuse corresponding pixels that represent the same objects. Precise image-to-image co-registration has to be ensured for all multi-temporal and multi-sensor datasets, because insufficient spatial fit leads to various ambiguities, resulting in the detection of artefact changes (Sundaresan *et al.*, 2007), as well as inaccurate spatial delineation of gold mining sites. The resulting multi-temporal and multi-sensor images used in the study have to be of sufficient absolute positional accuracy related to an external spatial reference system, allowing the combination of information with other thematic GIS spatial data, such as protected areas, topographic maps or GPS-based field measurements, in order to perform subsequent analysis. Furthermore, long-term monitoring requires maintaining the geometric stability of the image database over several decades.

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[6] QGIS is the free and open source Geographic Information System (GIS) used to perform all the steps of the methodology.

All images used in the study were obtained in the form of orthorectified standard data products from the respective satellite data providers. Initial evaluation of the relative spatial fit between these higher-level data products has revealed significant spatial shifts between most of them, including data acquired by the same sensor. In this context, a spatially and temporally consistent spatial reference system is required, allowing spatial alignment of all datasets with sufficient relative and absolute accuracy. Therefore, the panchromatic band of Landsat Level 1T time series data was selected as the spatial reference data. The co-registration accuracy of Landsat images is sub-pixel throughout the whole time series (Kennedy *et al*., 2010), whereas the absolute accuracy of the global Landsat Level 1T database has been estimated to 15 m (Lee *et al.*, 2004). Both accuracies are considered to be sufficient for gold mining detection at a regional scale. Moreover, following the opening of the Landsat archive by the USGS (Woodcock *et al*., 2008), Landsat data represents the only free source of spatial reference information consistently and repeatedly covering the whole study area, allowing consistent spatial alignment of all datasets used in the study.

The image-to-image co-registration with the Landsat panchromatic band at 15 m resolution was performed in QGIS, using manually-defined anchor points and the Helmert transformation model type. Following some tests, this transformation appeared to provide the most accurate results. Analysis of the spatial shifts obtained from co-registration revealed sensor-specific alignments ranging between 5 m and 30m.

2.3.1.3 Cloud and cloud shadow mask

Dealing with persistent cloud cover of humid tropical regions such as the Guiana Shield is always a challenge when using optical satellite images. Clouds and cloud shadows limit the interpretation of the data by hiding parts of the territory. These areas permanently covered by clouds and cloud shadows must be quantified and localized in order to provide reliable information on spatial extent and localization of gold mining activities.

Given the high amount of images to be processed within this study, an automated procedure had to be developed for classifying clouds and cloud shadows. Such a method was developed by ONFI using the supervised pixel-based SVM classifier of the Orfeo toolbox available in QGIS. The Support Vector Machine (SVM) classifier compiles the spectral values of the pixels within the user-defined training sites and image statistics to discriminate clouds and cloud shadows from other land cover classes. Multi-temporal images are processed for the same location to reduce the cloud cover of the area of interest. The resulting cloud and cloud shadow mask of each multi-temporal images and adjacent overlapping images are eventually compiled all together to obtain a final cloud mask containing only the persistent clouds and cloud shadows, which are reported as “no data”. To organize and facilitate the process, each territory was divided in production units using a grid. The final cloud and cloud shadow mask is performed cell by cell (Figure 7). At the end of the process the final masks are merged to obtain one cloud and cloud shadow layer, i.e. one “no data” mask, for each territory.

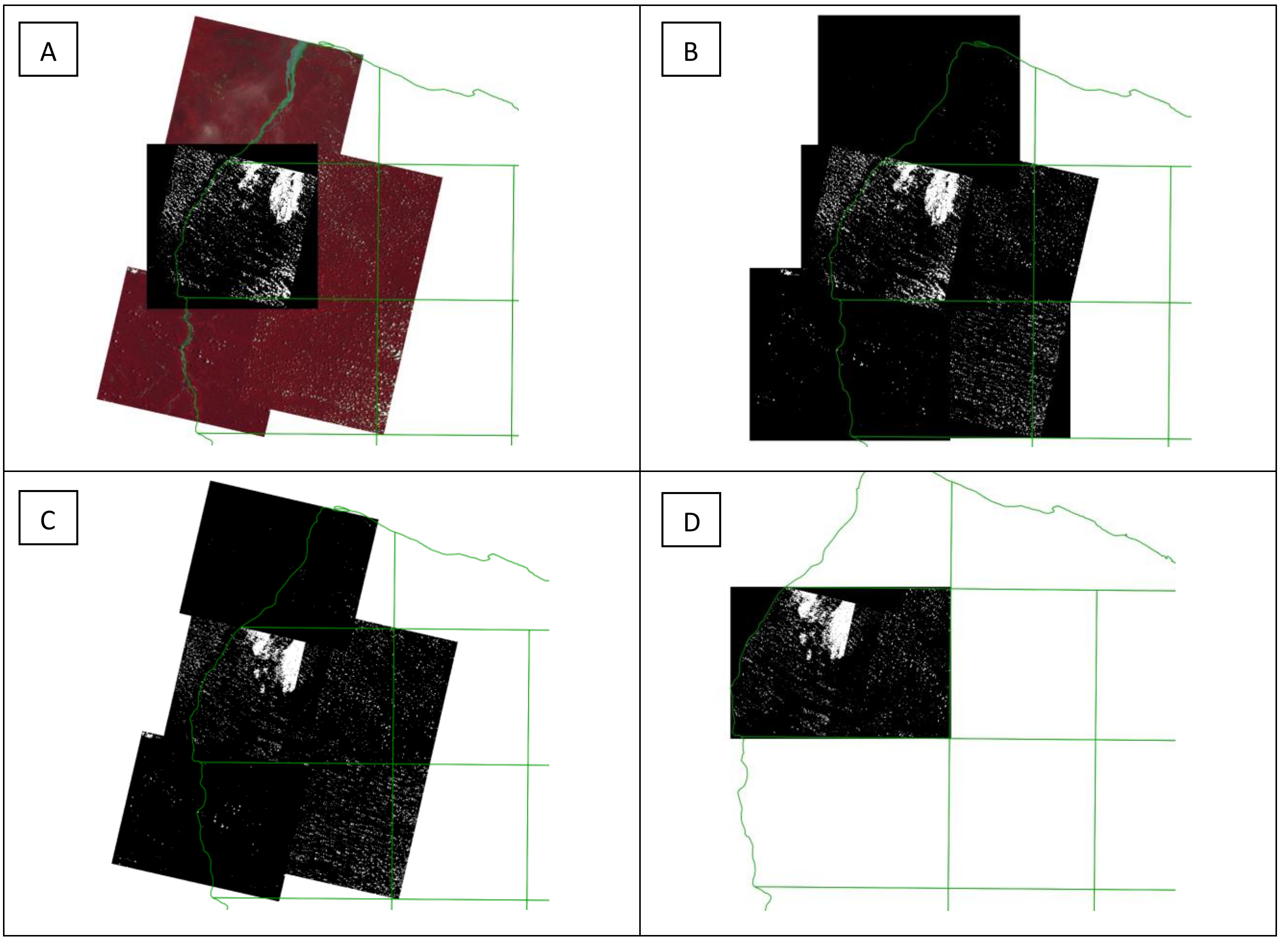


FIGURE 7 : PROCESSING STEPS OF THE CLOUD AND CLOUD SHADOW MASK, NAMELY THE "NO DATA" MASK (IN WHITE). A) "NO DATA" MASK FOR ONE SCENE. B) "NO DATA" MASK FOR ALL SCENES COVERING THE PRODUCTION UNIT. C) COMPILATION OF THE MASKS (ONLY PERMANENT "NO DATA" IS VISIBLE). D) CLIP OF THE "NO DATA" MASK MOSAIC BY THE PRODUCTION UNIT AREA.

2.3.1.4 Image Pan-sharpening

The pan-sharpening technique is based on pixel-level fusion method, in which the high resolution panchromatic and the lower resolution multispectral imagery are merged to create a single high resolution colour image. Pan-sharpening methods can result in spectral distortions because of the lower spectral quality of the panchromatic image (Liu *et al*. 2011). Therefore, pan-sharpened images are only used for visual interpretation and for validating the observations. This step is optional in the process.

2.3.1.5 Bare soil filter

In 2010, for the purpose of their study, ONF and CIRAD developed a method to create an additional raster from the original image that aims at facilitating the detection and delineation of bare soil, one of the main elements characterizing the gold mining class. The raster, hereafter called bare soil filter, was obtained by combining the results of a histogram thresholding method applied on the near infrared (NIR) band and the NDWI indices. The Normalized Difference Water Index (NDWI) is defined by a simple ratio between the near infrared band (NIR) and the short wave infrared band (SWIR) with the following band equation: NDWI = (NIR - SWIR) / (NIR + SWIR).

The resulting bare soil filter, raster binary information obtained by merging the outputs of NIR and NDWI thresholds, aims to guide the operator and to facilitate decision-making when delineating gold mining sites. Using a defined threshold for all images, a quality check of the resulting bare soil filter was mandatory to avoid any over- or under-estimation of the impacted areas.

2.2.3 Core-processing

Two practices are used to extract gold in the Guiana Shield: primary gold mining and alluvial gold mining.

The primary gold mining consists in hard rock mining. The aim is to selectively remove gold bearing rock by digging, drilling or blasting it into small pieces. These rock pieces are then grinded until the ore becomes very fine. After initial washing with water to reduce waste, ore amalgamation is performed using a cyanide-type solutions or mercury to the remaining rock powder.

Alluvial gold mining consists in extracting gold from the creaks, rivers and streams. The first stage in alluvial gold mining is to take the dredged river bed material and separate the small sand fraction (where the gold is found) from the larger mineral fraction. In a typical alluvial mining process physical separation methods such as screening and gravity separation are employed to separate the gold from the mineral fraction.

The second method, alluvial, is more commonly applied in the Guiana Shield. The objective of the study is to detect, map and quantify both types of gold mining activities, knowing that small-scale illegal primary mining can be hard to detect by remote sensing methods as the activity is underground and the sites can be hidden by the canopy.

Given the regional scale and the involvement of a lot of experts in the production chain of this study, it was important to first and clearly define what land cover elements are composing a gold mining site. Figure 8 illustrates the alluvial gold mining class defined within the study using the last version of the Land Cover Classification System (LCCS3) developed by FAO and UNEP in 1998 to facilitate the understanding of the classes of land cover regardless of the scale of mapping, the type of coverage, method of data collection, or geographic location. LCCS3 is a standard ISO since 2012 with the identification 19144-2:2012. It is based on the Land Cover Meta Language (LCML) which provides a common reference structure for the comparison and integration of data for any generic land cover classification system, and describes different land cover classification systems based on the physiognomic aspects[7].

The gold mining site is composed by vegetation and abiotic land cover elements, such as bare soil, water (pits), vegetation regrowth and in specific cases degraded forest. Small settlements sparsely distributed on the mining site can be included when the area covered is below the MMU. Otherwise, infrastructures (human settlements, runaway, roads etc.) and agriculture in the vicinity of gold mining sites are not considered in this study, as the link of these land cover and land use classes with mining activities is not always obvious and might lead to misinterpretations.

[7] http://plugins.qgis.org/plugins/LCCS3_BasicCoder/

The sites are manually digitized in QGIS using a minimum mapping unit (MMU) of 0.5 ha. Based on the experience of the team and the availability of high resolution images, 0.5 ha was indeed identified as the optimal minimum object size that can be digitized. For Guyana, the results of the national Monitoring Reporting & Verification System (MRVS) on forest area change assessment produced by the Guyana Forestry Commission were used as a basis to produce the results of this study. Deforestation caused by mining was extract from the MRVS results and updated, mainly with RapidEye images of 2013 and Landsat images of 2014, to meet the methodology requirements of this study.

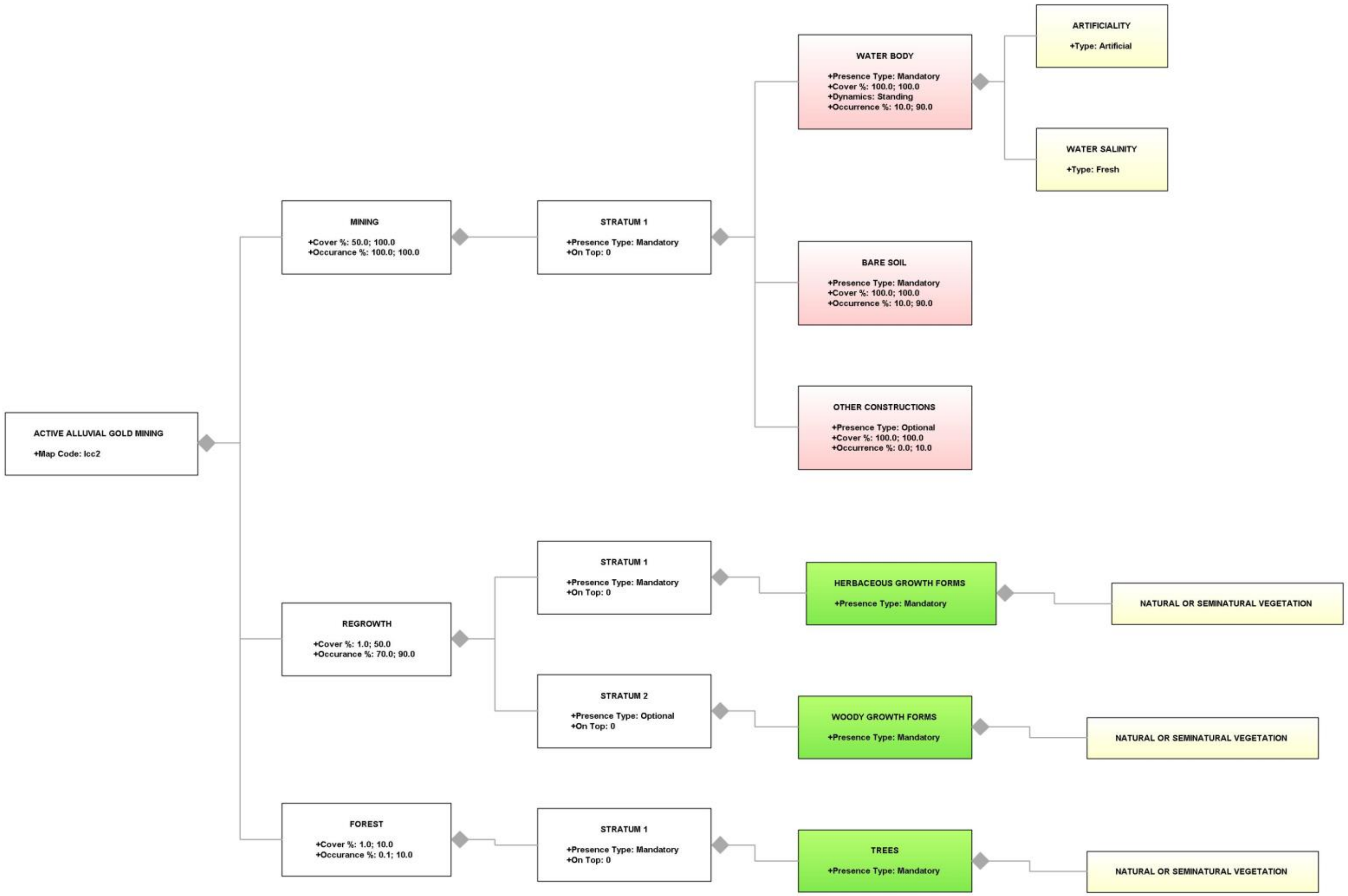


FIGURE 8 : DEFINITION OF THE CLASS ALLUVIAL GOLD MINING USING THE LAND COVER CLASSIFICATION SYSTEM VERSION 3 SOFTWARE DEVELOPED BY FAO

2.2.4 Delivery, quality control and compilation

The results were delivered by SEMA, GFC and SBB to ONF, consisting in two GIS layers: a shapefile layer with the polygons of the gold mining sites and a raster layer with the cloud mask. ONF was responsible of verifying and compiling those results. The quality of the delivered results has been double checked, first by the core team of experts who has produced the data and secondly by ONF. The quality control methodology aims at verifying the completeness of shapefile layers attributes information, as well as the geometric and topological accuracy of the produced GIS data. In case of errors or inconsistencies, the information was systematically communicated to the producer who validated or modified it. No corrections or modification were made to the delivered data without the final verification and validation by the producer.

At the end of the quality control process, the results were all compiled within two regional scale layers (a shapefile with the polygons of the gold mining sites and a raster with the cloud mask) for further analysis.

2.2.5 Accuracy assessment

Area estimates from land cover maps may be biased by misclassification error resulting in flawed assessments and inaccurate valuations. Adjustment for misclassification error is possible for maps subjected to a rigorous validation program including an accuracy assessment (Foody, 2015). In thematic mapping from remote sensing data, the term accuracy is generally used to express the degree of "correctness" of a map or classification. A thematic map derived with a classification can be considered accurate if it provides a biased representation of the land cover of the area it depicts (Foody, 2002).

For this study, accuracy has been assessed and validated by separated experts from ONF International, using a methodology based on sampling points. Sampling points are randomly distributed among gold mining areas and the rest of the territory. The number of control points itself is determined for each territory based on the extent of gold mining areas (Table 2). Higher density of control points were taken in gold mining areas to increase the probability of detecting commission errors (misclassified gold mining areas).

Country	Gold mining area (ha)	Controls points
Guyana	80,770	3,500
Suriname	53,668	2,500
French Guyana	24,282	1,500
Amapá	2,189	500
Total	160,909	8,000

TABLE 2 : NUMBER OF CONTROL POINTS NEEDED FOR EACH TERRITORY TO VALIDATE THE MAP OF DEFORESTATION CAUSED BY GOLD MINING IN 2014

For each control point, the validator is photo-interpreting the entire gold mining polygon wherein the point lies. The point is considered validated if more than 75% of the polygon complies with the satellite image. In the opposite case the point is considered as misinterpreted.

The presence of freely accessible high spatial resolution imagery online through Google Earth™ presents low cost interpretation options (Olofsson *et al.* 2014). Both the SPOT Image® and DigitalGlobe® archives can be accessed through Google Earth™, with the image extents by year portrayed.

However, when other sources of higher resolution data were not available, the accuracy assessment was performed using the same satellite images used in the framework of the study.

The results were summarized in an error matrix providing estimates of overall accuracy, user's accuracy (or commission error), and producer's accuracy (or omission error), as shown later in this report.

2.3 Waterways potentially impacted by gold mining

Alluvial gold mining involves digging the rivers beds for extracting the substrate which is crushed and washed with water streams. This process exerts vast impacts on fresh water, river and creek ecosystems. The main impacts are related to, but not restricted to, small-scale gold mining, especially as related to the quantities of mercury often used for amalgamating gold particles (Legg *et al.*, 2015).

The results of satellite-based monitoring of gold mining are used to detect waterways potentially impacted by contaminants such as mercury. Two potential impacts are measured by remote sensing:

1. The direct impact, defined by the sections of waterways included within the gold mining sites, in direct contact with the gold mining site.
2. The indirect impact, characterized by the downstream section of the directly impacted section, likely to transport contaminants to the ocean.

Figure 9 illustrates the main steps of the methodology used to produce the impacted waterways.
These steps are detailed in the coming sections.

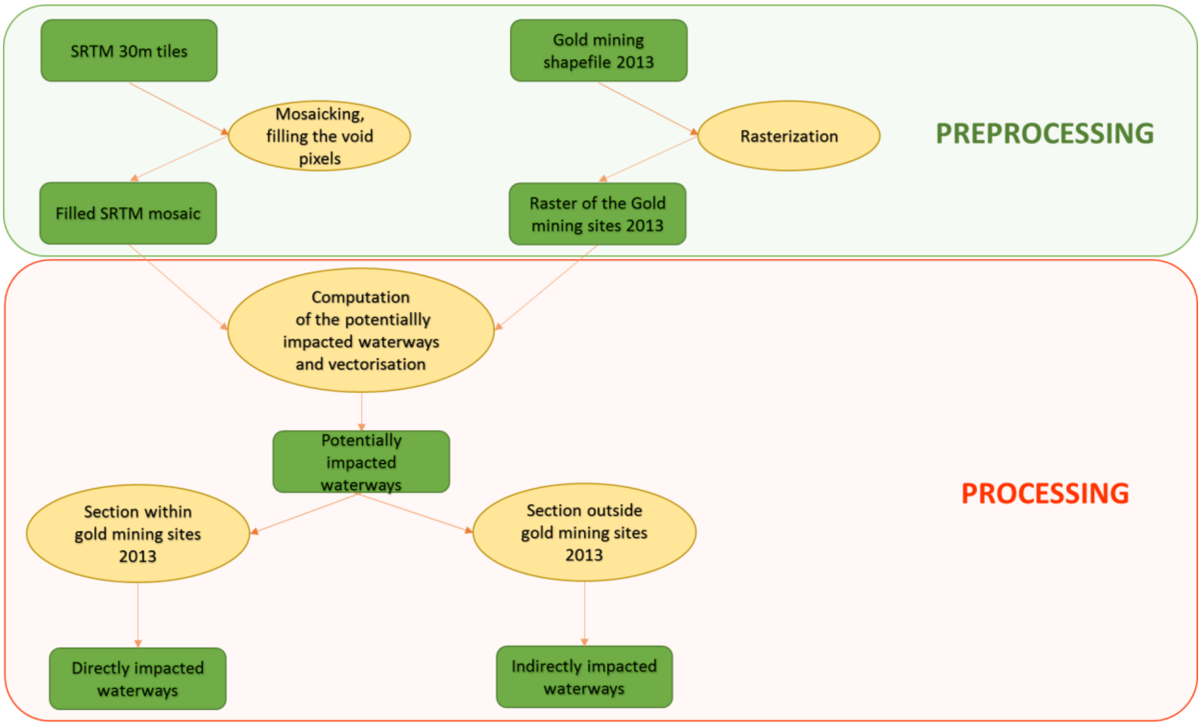


Figure 9 : Methodological process for producing the potentially impacted waterways by gold mining

2.3.1 Data and material

Two input data were required to map and measure the waterways potentially impacted by gold mining: the gold mining GIS layer 2014 and the SRTM 30m data[8].

Since November 2014, SRTM data at 30m resolution are globally freely available on the USGS website[9], replacing the 90m resolution available so far. This Digital Elevation Model (DEM) at 30m was used in GRASS 7.0 open source software to generate the theoretical watershed at the regional scale.

2.3.2 Pre-processing

The preprocessing steps of the methodology include the rasterization of the gold mining vector layer, mosaicking SRTM tiles and filling the voids of the SRTM mosaic data.

2.3.2.1 Rasterization of gold mining vector layer

The produced GIS vector layer of gold mining sites is rasterized at 30m pixel resolution to fit with the SRTM resolution.

[8] The Shuttle Radar Topography Mission (SRTM) data consist in Radar imageries providing for each pixel ground elevation value compared to the sea level.

[9] http://earthexplorer.usgs.gov/

2.3.2.2 SRTM tiles mosaicking

A mosaic of SRTM tiles is first created for each territory to limit the machine processing time and memory requirements. The mosaic is then clipped to fit the administrative boundaries and merged together to obtain one layer covering the entire study area.

2.3.2.3 Voids filling

The SRTM contains pixels for which the elevation information is missing and that need to be filled by interpolating values of adjacent pixels for avoiding errors in the generation of the watershed. The origin of these voids can diverse, e.g. the radar signal cannot reach the area because of the combination of high relief and the image acquisition angle or the radar signal can be disturbed by the presence of waves on coastal areas.

2.3.3 Core-processing

The core-processing aims at producing the theoretical watershed where only waterways crossing mining areas are created.

Using the combination of the rasterized gold mining shapefile and the SRTM mosaic, the GRASS *watershed* function calculates a direction flow taking into account the elevation difference between pixels included within a gold mining area. The accumulation threshold for generating the watershed was set to 75, within the range suggested by Rennó *et al*. (2008).

The resulting watershed represents the waterways potentially impacted by gold mining at the regional scale, where the directly impacted sections are located within the gold mining sites and the indirectly impacted sections represent the downstream of it (Figure 10).

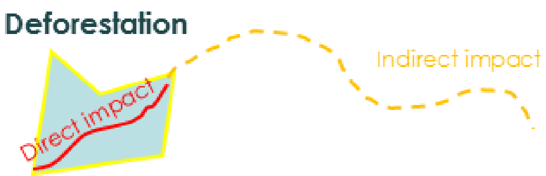


FIGURE 10 : ILLUSTRATION OF DIRECTLY AND INDIRECTLY IMPACTED WATERWAYS BY GOLD MINING

2.3.4 Delivery and Quality control

Given the high computer's memory requirements needed for generating this watershed, it was produced by ONF for the whole study area. The quality of the results, visually verified and manually edited, were validated by ONF before delivering it to each core team for further verification and edition.

2.3.5 Accuracy assessment

The process being completely automated using remote sensing data, the accuracy of the output is mainly based on the accuracy of the input data and processing tools, i.e. the SRTM data and GRASS functionalities. We provide below some elements which might generate a bias in the accuracy of the results that need to be taken into account when reading it:

- The wavelength used by the SRTM sensor does not allow the radar signal to penetrate completely the canopy and reach the ground. Therefore, the ground elevation value of areas located in high canopy density might be overestimated, which might lead to errors in the flow calculation.

- Automatic calculation of flows on flat surfaces (lakes, large gold mining sites) generates an overestimation of the length of the impacted waterways and can be the source of errors in the waterway flows.

Unfortunately, the lack of field data or validated and verified watershed in the region does not allow us to estimate the uncertainty of the resulting impacted waterways. However, the results were visually checked, compared with optical satellite imagery and manually edited based on photo-interpretation and the field knowledge of each partner.

3. Results and discussions

3.1 Forest areas impacted by gold mining

This section illustrates the impact of gold mining on the forest cover for the 2014 reference year, the data source used for delineating it and the extent of unobserved areas due to permanent cloud cover. The results are then compared with the previous 2001-2008 study to show the evolution of the activity over time at local and regional level. To better understand the dynamic of the activity, we performed several spatial analysis to identify conflict areas between mining activities and protected areas, the spatial distribution of gold mining sites, and the distribution of small-, medium- and large-scale gold mining.

3.1.1 *Reference year 2014*

Figure 11 shows the results of the gold mining impact on forest cover for the reference year 2014, based on the use of high resolution optical imageries acquired between 2012 and 2014.

The impact of gold mining, which varies widely per territory, totalizes 160,850.7 ha.

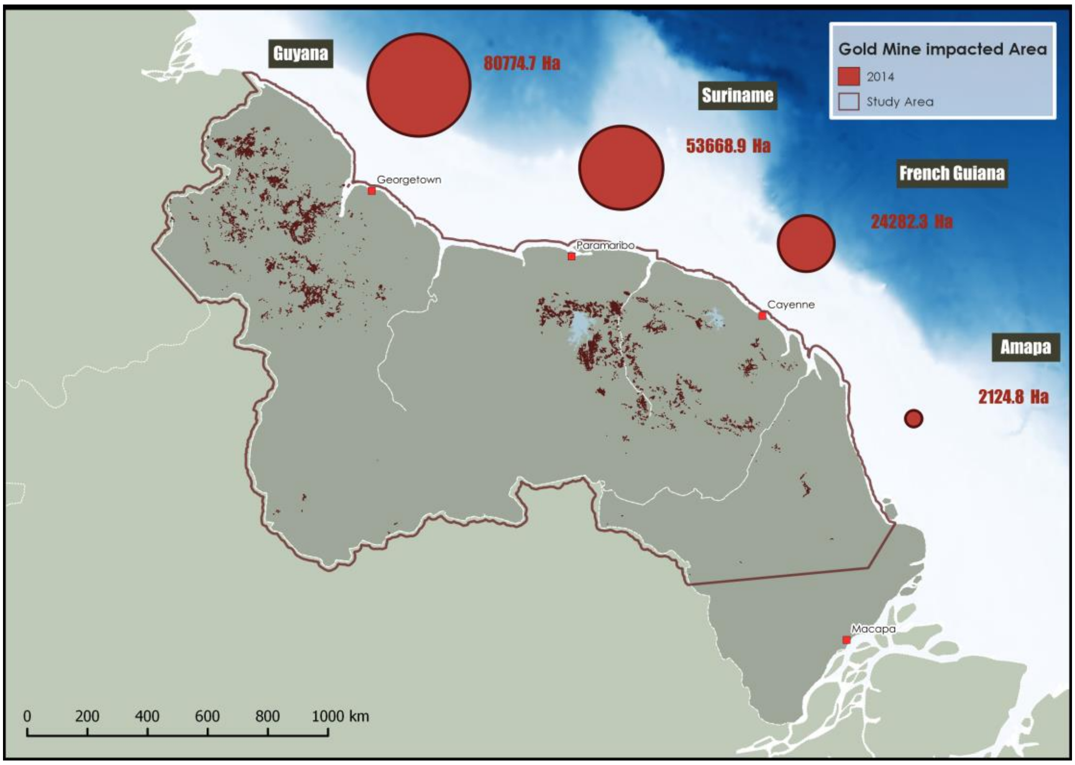


FIGURE 11 : FOREST AREAS IMPACTED BY GOLD MINING FOR THE REFERENCE YEAR 2014

3.1.1.1 *Distribution of satellite data source used for delineating gold mining areas*

Figure 12 illustrates the source of data that was used for delineating gold mining sites in each territory. As archives of SPOT data in Guyana's hotspot areas was very limited, the detection was mainly based on the duo RapidEye and Landsat 8. Almost 60,000 hectares of gold mining areas were digitalized with RapidEye imagery in Guyana, which represents 37.3% of the total gold mining impact in the study area. Landsat 8 data from 2014 was largely used by the Guyana Forestry Commission to update the results obtained with the 2013 Rapideye data. French Guiana, Suriname and Amapá that disposed of good SPOT coverage in hotspot areas, digitalized 28.3% of total gold mining with SPOT 5 data. In Suriname, the lack of SPOT5 data in two hotspot areas was filled with available SPOT6 very high resolution images to digitize about 18,000 ha (11.5% of total gold mining). Finally, the availability of SPOT data, made through the agreement between Airbus Defense & Space and ONF-Guyane and SEAS-Guyane, allowed to detect 40.2% of gold mining activity in the region.

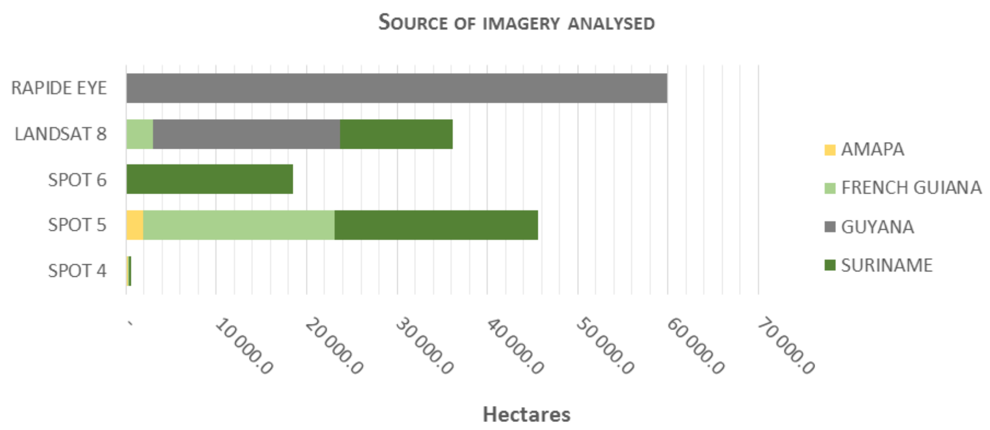


FIGURE 12 : DISTRIBUTION OF DATA SOURCE USED IN EACH TERRITORY FOR DELINEATING GOLD MINING AREAS

3.1.1.2 *Persistent cloud cover*

Figure 13 shows the inhomogeneity in the distribution of persistent cloud cover in the region. This result comes from the disparity in amount and quality of images available in each territory. Guyana and French Guiana have both a commercial agreement with an image provider, respectively BlackBridge (RapidEye) and Airbus Defence and Space (SPOT images), who prioritize the image acquisitions on their territory. More image acquisitions mean more chance to obtain cloud-free images, but also more images available for the same area allowing multi-temporal processing chains for reducing the cloud cover. Consequently, the remaining cloud cover in Guyana and French Guiana is almost insignificant, respectively 0.2 and 0.3% of the territory, whereas, in Suriname and Amapá respectively 7.1 and 8.1% of the territory was unobservable (Figure 14). Despite a higher level of cloudiness in Suriname and Amapá, the surface covered by clouds remains low thanks to the use of multi-temporal images. At the study site level, 96.4% of the territory was observed. Moreover, cloudy areas, particularly in Suriname, are located in areas where mining is known to be non-existent which reinforces the accuracy of the results provided.

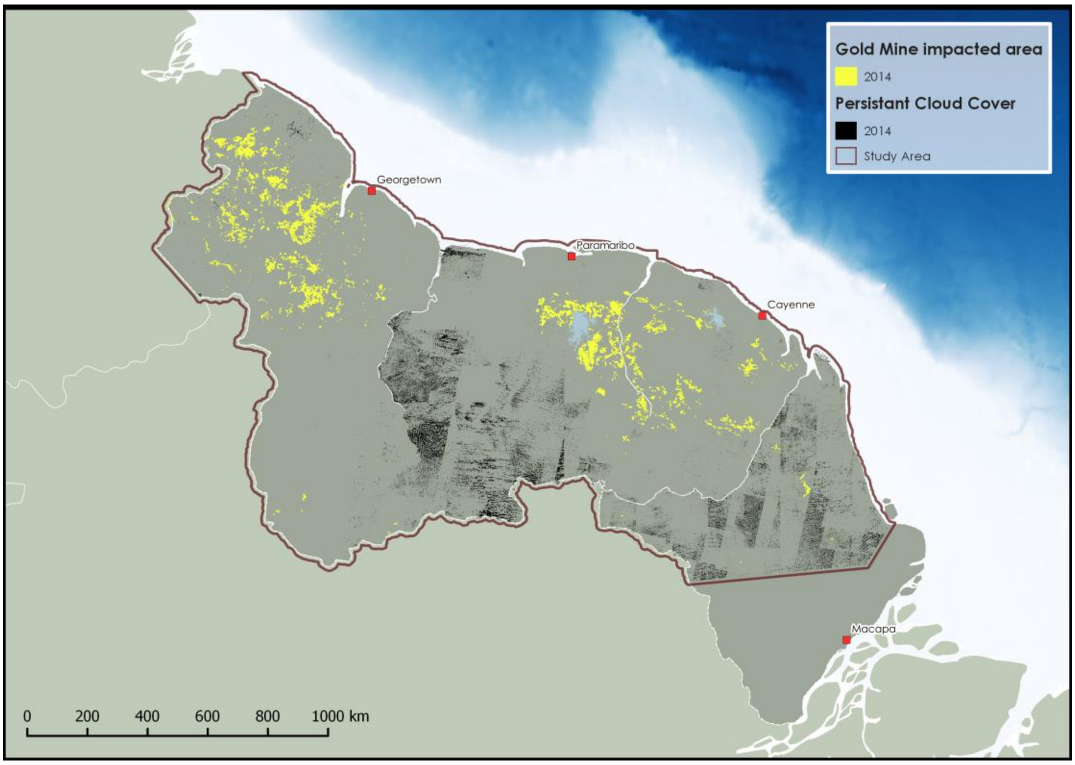


FIGURE 13 : PERSISTENT CLOUD COVER OVER THE STUDY AREA

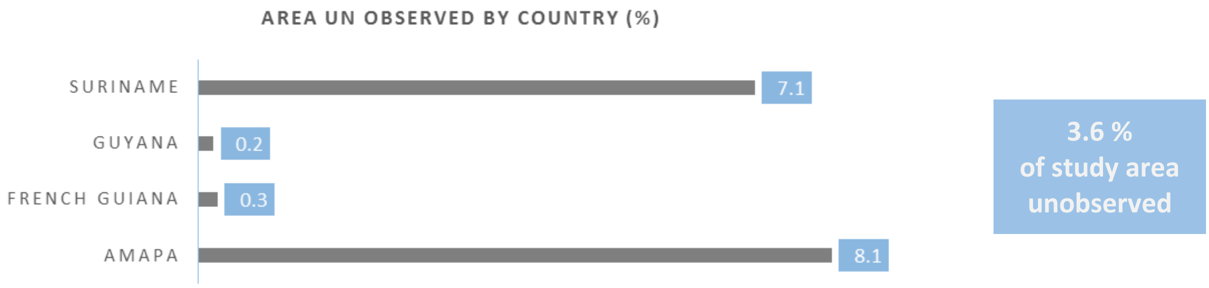


FIGURE 14 : PERCENTAGE OF PERSISTENT CLOUD COVER IN EACH TERRITORY AND OVER THE WHOLE STUDY AREA

3.1.1.3 Accuracy assessment

Table 3 provides the producer, user and overall accuracy of the gold mining mapping results for each territory with the compilation at the regional level. The confusion matrices show very good and similar accuracy between territories, resulting in a general overall accuracy at the regional level of 91.5%. These error matrices are also provided in Annex 1 with a higher level of details for each territory, where the main diagonal highlights correct classifications while the off-diagonal elements show omission and commission errors.

In Guyana, the MRVS of forest area changes includes an in-depth accuracy assessment analysis of the results produced, which provides confidence intervals. The MRVS results, which were used as a basis to produce the results of this study, consistently show high accuracy on detection, even higher than the one reached within this study[10].

French Guiana			
	Producer Accuracy	User Accuracy	Overall Accuracy
Gold Mining	98.4%	93.9%	**91.1%**
No Gold Mining	83.8%	95.5%	

Amapá			
	Producer Accuracy	User Accuracy	Overall Accuracy
Gold Mining	97.7%	92.9%	**92.8%**
No Gold Mining	88.0%	96.0%	

Guyana			
	Producer Accuracy	User Accuracy	Overall Accuracy
Gold Mining	97.1%	95.2%	**91.7%**
No Gold Mining	86.4%	91.5%	

Suriname			
	Producer Accuracy	User Accuracy	Overall Accuracy
Gold Mining	97.2%	94.0%	**90.4%**
No Gold Mining	83.6%	92.0%	

Study area			
	Producer Accuracy	User Accuracy	Overall Accuracy
Gold Mining	97.6%	94.0%	**91.5%**
No Gold Mining	85.4%	93.7%	

TABLE 3 : ACCURACY ASSESSMENT CONFUSION MATRIX OF THE GOLD MINING MAPPING PRODUCT FOR EACH TERRITORY AND THE STUDY SITE

[10] For the 2013 (Year 4) forest change mapping conducted by GFC, results show a correspondence (prevalence) of 99.93% between reference image interpretation and GFC mapping based on a sample of 55,119 one-hectare circular plots. This demonstrates a very high level of correspondence between the MRVS maps and results, and the reference data.

3.1.1.4 *Analysis of areas impacted by gold mining*

Figure 11, illustrated before, clearly shows that the activity is unequally distributed over the study area. The intensity of the activity gradually increases when we move from the east to the west. Amapá accounts only for 1% of the deforestation observed in the study area, whereas French Guiana, Suriname and Guyana are responsible for 15%, 34% and 50% respectively (Figure 15). However, the wide disparity of this distribution has to be weighted by the area covered by each territory, since Guyana represents 40% of the study area followed by Suriname (31%), French Guiana (16%) and the north of Amapá (15.5%). Taking this information into account, the extent of gold mining can be expressed in terms of proportion by territory. Guyana, Suriname, French Guiana and the north of Amapá have respectively 0.38%, 0.33%, 0.29% and 0.03% of their land covered by gold mining. The trend remains the same but the gap between Guyana, Suriname and French Guiana is smaller. At the study site level, 0.31% of land are impacted, from which 84% is located in Guyana and Suriname.

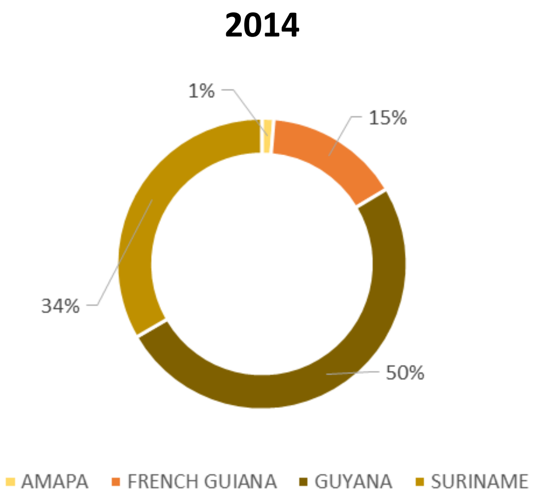


FIGURE 15 : PERCENTAGE OF MINING AREAS COVERED BY EACH TERRITORY AT THE STUDY SITE LEVEL FOR 2014

3.1.2 *Results comparison with reference years 2001 and 2008*

Although deforestation from gold mining appears modest in comparison with other documented tropical forest land uses, it represents the fastest growing cause of forest loss in the region, more typically known for having the lowest deforestation rates in the world (Hammond *et al.*, 2007). Figure 16 shows the evolution of deforestation over the three reference years, 2001-2008-2014. If the deforestation caused by gold mining still represents a low proportion of the study area (~0.3%), its rapid expansion is alarming. Between 2001 and 2008 the first study (ONF, 2010) showed that areas impacted by gold mining increased by 207% in the region. Considering 2014 data, this brings to 621% the increase of forest lands impacted by gold mining between the beginning of the monitoring (2001) and this study (2014). Despite a slower trends (135% increase), deforestation due to gold mining continued to increase over the second period (2008-2014). **In terms of impacted surface, while 22,300 ha of land were classified as gold mines in 2001, this figure has been tripled in 2008 with 68,444 ha. In 2014, gold mines surface was totaling 160,850 ha. In other words, it has been multiplied by 2.3 compared to 2008 figures and by more than 7 compared to 2001 data.**

This regional trend is translated differently from a territory to another. The spatial mutation of the phenomenon now seems to clearly progress westward, where deforestation caused by gold mining is continuing to increase significantly over the years.

Figure 17 illustrates this displacement of the activity. Where in 2001 Amapá and French Guiana respectively accounted for 10% and 29% of the deforestation caused by gold mining in the study site, they now represent only 1% and 15% of the activity. With a slight increase from 34% to 40%, Suriname remains quite stable over the years. Consequently, the reduced proportion of the activity according in French Guiana and Amapá is mostly compensated by the increase proportion of Guyana, which now accounts for 50% of the regional gold mining activity compared to around 25% in the past (years 2001 and 2008).

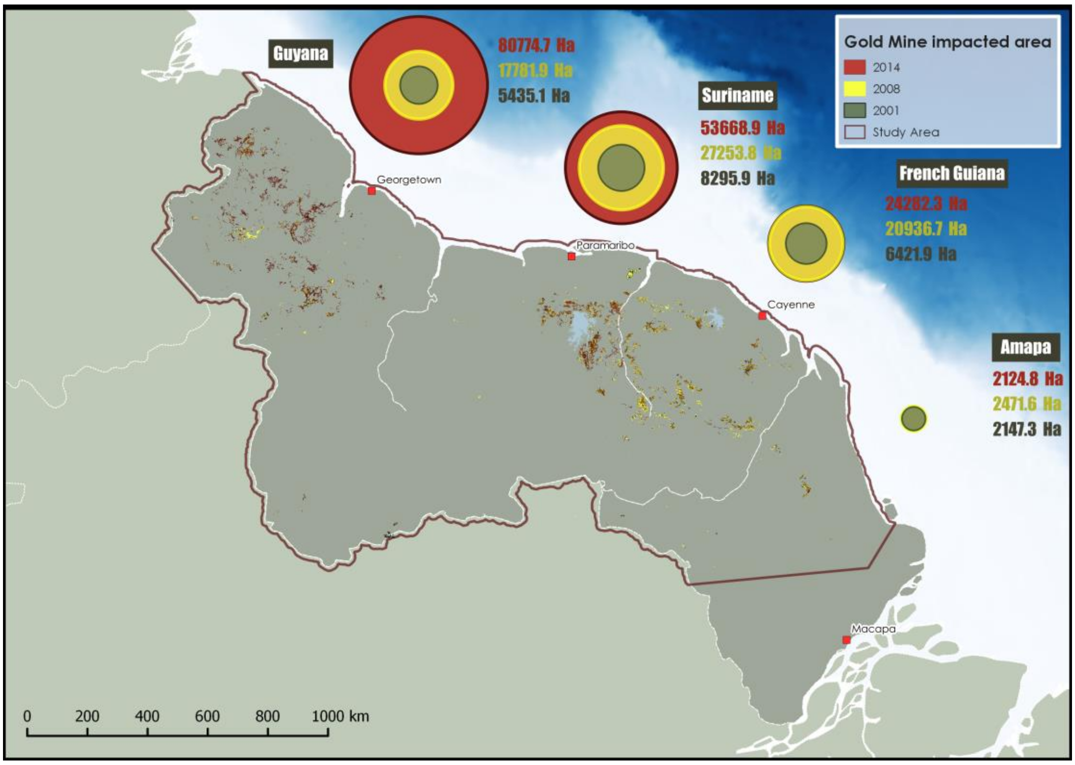


FIGURE 16 : EVOLUTION OF GOLD MINING IMPACT ON THE FOREST COVER BY TERRITORY SINCE 2001 FOR THE THREE REFERENCE YEARS 2001-2008-2014

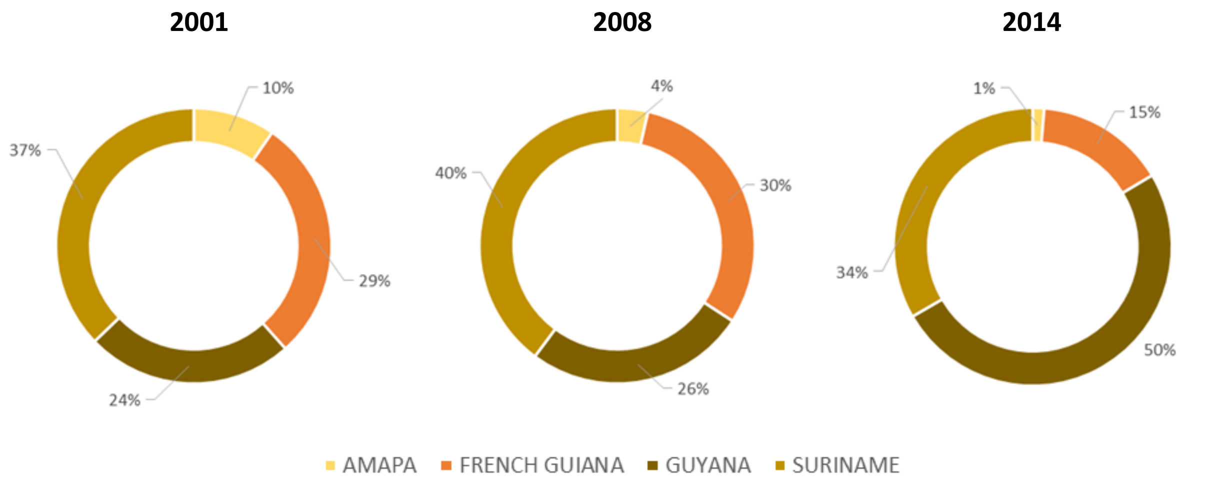


FIGURE 17: PERCENTAGE OF MINING AREAS COVERED BY EACH TERRITORY AT THE STUDY SITE LEVEL FOR 2001, 2008 AND 2014

Figure 18 provides detailed information over the trend of deforestation caused by gold mining for each territory. Between 2001 and 2008, deforestation reached more than 200% increase in Suriname, Guyana and French Guyana, whereas North of Amapá seems to have reached its peak activity already at this time and recorded just a slight increase of 15%. Over the last period (2008-2014), northern part of Amapá remains quite stable (-14%, i.e. -347 ha) while Suriname and Guyana are showing respectively an increase in activity of 97% (+26,415 ha) and 354% (+62,993 ha). In French Guyana, gold mining continues to increase (+3,346 ha) but at a much slower rhythm than during the previous period (16%).

Looking at the entire reference period (2001-2014), we can say that in 13 years, deforestation caused by gold mining has increased approximatively by a factor fourteen for Guyana, six for Suriname and three for French Guiana, whereas it has been slightly reduced for Amapá.

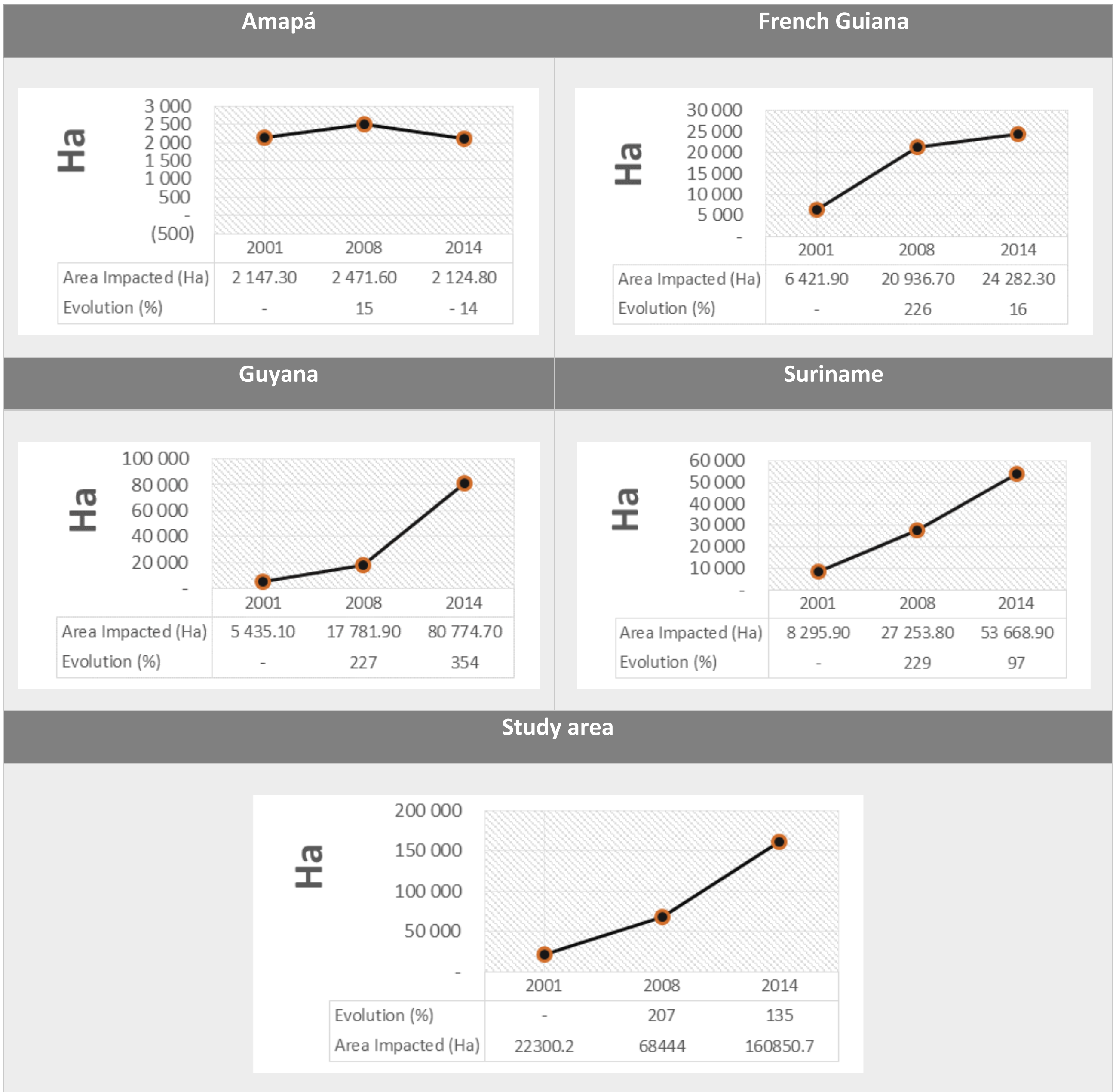


FIGURE 18 : TREND OF DEFORESTATION CAUSED BY GOLD MINING ACTIVITY IN AMAPÁ, FRENCH GUIANA, GUYANA, SURINAME AND THE STUDY AREA, OVER THE REFERENCE YEARS 2001-2008-2014

Differences that are observed from a territory to another can be explained by different local contexts.

In Amapá, there were important changes at federal and state level in the governance of the land from the beginning of the 2000’s, with the creation of protected areas, especially in the north of the state where the Tumucumaque national park was created in 2002. Reduction of the predatory use of gold and other natural resources was part of the federal government’s strategy. Though, the positive impact of these conservation policies was only visible after the creation of the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) in 2007, in charge of monitoring and controlling protected areas, with the support of the Instituto Brasileiro do Meio Ambiente e dos Recursos

Naturais Renovavéis (IBAMA) and the Army. At the same time, some gold-mining companies established in non-protected areas since the beginning of the 1990's entered in crisis after 2008. The trend of deforestation caused by gold mining in North of Amapá clearly highlights this evolution of context, with a slight increase of the activity between 2001 and 2008 and a reduction of the impact between 2008 and 2014. However, those data should be complemented with further processing in order to ensure that this reduction is not due to a displacement of pressure on other part of the State.

French Guiana has significant gold potential (Theveniaut *et al.*, 2011). The first discoveries date back to the mid-19th century in the region of the Approuague which is relatively close to the Coastline. This discovery triggered a veritable gold rush until the turn of the century, but at the time operating conditions, isolation of sites and supply difficulties limit this fever. The production reached its lowest point in the middle of the 20th century. Gold production was reignited by the increase in gold prices in the 1970s and further driven by migration from Brazil. In the 1990s, the gold activity gradually experienced a resurgence, firstly because of the increase of gold price and the development of new mechanized techniques and transport, but also because of the publication in 1995 of the mining potential inventory by the French Geology and Mining Department (BRGM).Declared production remained consistently above 2 tons per year from 1992 until 1999 and reached a peak in 2000 to decrease since then (3,469 kg in 2000; 2,576 kg in 2005; 1,300 kg in 2012 and 2013) (DRIRE, 2010; USGS, 2012; IEDOM, 2014). However, according to Horth (2011), declared production of around 1.2 tons in 2010 was hampered by approximately 10 tons of illegal production. This considerable portion of gold, which mainly comes from small-scale mining operations, is traded further in Suriname, where the gold from these illegal sources enters the formal markets (WWF Guianas, 2012). French Guiana is striking for years against illegal gold mining dominated by garimpeiros. Armed operations to combat illegal miners started in 2003 with Operation Anaconda, followed by Operation Harpie[11] since 2008. Since the launch of the SEAS program (Surveillance de l'Environnement Amazonien par Satellite) in 2006 which provides free satellite images from SPOT4 and 5, ONF started an almost real time analysis of the territory to detect water pollution (release of large amounts of suspended matters) and deforestation caused by mining. The same year, the government banned the use of mercury in gold mining and elaborated more ambitious environmental procedures (Lefebvre, 2009), such as the restoration of degraded lands after exploitation (which is now required by law). In 2008, the *Observatory of Mining Activity (OAM)* was created, a platform of sharing and exchange of real-time data from the processing of satellite images, field missions and other sources of information on mining and its impacts coming from all state department concerned, i.e. ONF, the Police, the Armed Forces of French Guiana (FAG), the State Department of Environment (DEAL), and the national Park (PAG).

In 2009, Guyana launched its Low Carbon Development Strategies (LCDS), which provides a framework by which the country will transition its economy along a green and low carbon path, whilst mitigating the global risks faced from climate change through sustainable management of its forest. The extractive sector has a key role to play in this strategy as gold mining is the second largest contributor to Guyana's gross domestic product (GDP), after agriculture, forestry and fishing (G.B.o.Statistics, 2012), and mining is the largest contributor to deforestation. Figure 19 illustrates the steep rise of gold mining contribution to Guyana's GDP between 2006 and 2011. This trend is in

[11] French interministerial operation performed in French Guiana against illegal gold mining since February 2008, conducted jointly by the police and the army.

line with the trend of deforestation caused by gold mining illustrated in Figure 18, showing an alarming increase of the deforestation caused by gold mining in Guyana since 2008.

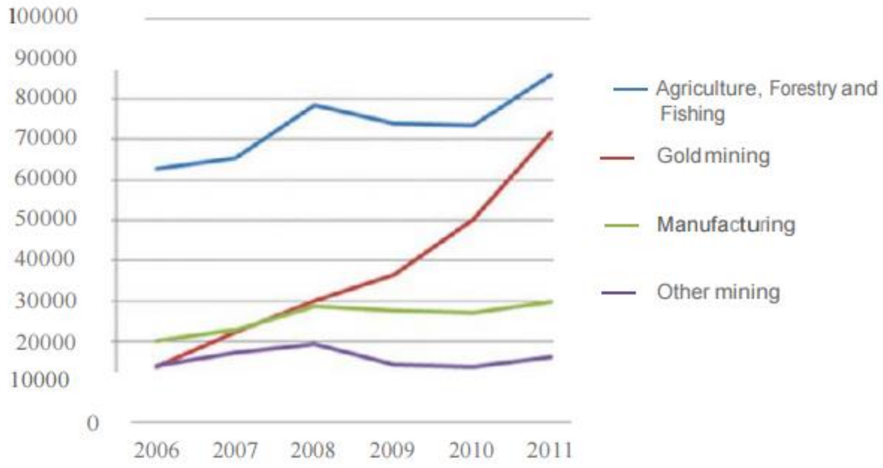


FIGURE 19 : GUYANA'S GROSS DOMESTIC PRODUCT (GDP) IN CURRENT PRICES AGRICULTURE, FORESTRY AND FISHING, GOLD MINING AND MANUFACTURING 2006-2011 (SOURCE: SINGH *ET AL*., 2013)

In addition, the fact that the mining sector accounted for approximately 90% of all recorded deforestation in the country in 2013 needs to be taken into account (Annex 2). In annual reporting on forest area change for January 1 to December 31, 2013, the area of deforestation attributed to mining (which includes mining infrastructure) decreased slightly compared to 2012 with approximately 11 518 ha deforested (Annex 2). This decrease is also in line with the decline in annual revenues of the mining sector in 2013 compared to 2012 as a consequence of falling price (CI-Guyana, 2014) (Figure 20). The Guyana Gold and Diamond Miners Association (GGDMA) has proposed committing itself to mining no more than a certain percentage of the total land mass of Guyana which they believe would not impede the sustainable development agenda (CI Guyana, 2014).

FIGURE 20 : PRICE FOR 1KG OF GOLD FROM JANUARY 2000 UNTIL JULY 2015 (SOURCE : COMPTOIR NATIONAL D'OR – AVAILABLE AT: WWW.GOLD.FR)

As in French Guiana, gold production in Suriname reached its lowest point in the middle of the 20th century and a new stage of growth driven by the rising gold price beginning in the 1970s was disrupted by the Interior War (1986–1992) (Heemskerk, M. and Duijves, C., 2013). Since the end of the war, jointly with the rise of gold price, the now safer gold fields attract immigrants, foreign prospecting companies and urban Surinamese to the interior of the country (Legg *et al*., 2015). The trend of gold mining activity shows a relatively constant progression of land deforested between 2001 and 2014, however, the level of deforestation was higher during the last period 2008-2014 (around 26,000 ha) compared to 2001-2008 (approximately 19,000 ha). This seems to follow the annual gold production, which is relatively stable between 2004 and 2013 with a slight increase since 2008 (Figure 21).

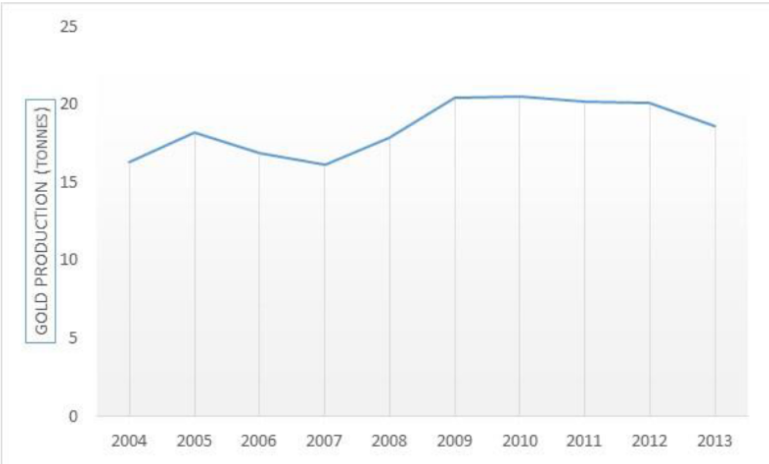


FIGURE 21 : ANNUAL GOLD PRODUCTION IN SURINAME (SOURCE: THOMSON AND REUTERS, 2014 IN: LEGG ET *AL*., 2015)

In terms of evolution of the activity, the trend is different as the deforestation approximately tripled comparing the level of 2008 with 2001, whereas it doubled comparing 2014 with 2008. According to a report published by the Central Bank of Suriname (CBvS, 2014), the year 2003 represents a turning point in global gold production. The high increase in gold production that year was not only linked to the international gold prices, but also to the liberalization of the gold market, as well as the establishment of the Rosebel Goldmine in Suriname which started its commercial production in 2004. Large scale gold mining contributed to about 40% of the gold production at that time. To regulate the gold mining sector, a commission was established in 2011, directly under the Kabinet of the President. This "Commission Regulation Gold Sector (OGS)" has as a main objective the maximization of the national incomes from gold mining while minimizing the environmental and social impact. They are complementary to the Geological Mining Service (GMD), who are, as a technical work arm of the Ministry for Natural Resources, responsible for issuance of mining concessions, and geological mapping.

3.1.3 Spatial distribution of gold mining

3.1.3.1 Influence of the Greenstone belt

Both regionally and at local scale, it is very clear that deforestation due to gold mining is widely influenced by the spatial location of the Greenstone belt, known for containing large reserves of gold. At the study site level, 74% of the deforestation caused by gold mining occur within the Greenstone belt, this overlap even reaches 99% in Suriname (Table 4). This influence seems to predominate over land tenure constrains such as the existence of Protected Areas.

Territory	Total area impacted by Gold mining in 2014 study (Ha)	Gold mining overlapping Greenstone belt (Ha)	Gold mining overlapping Greenstone belt (%)
AMAPÁ	2 124.8	1 633.8	77%
FRENCH GUIANA	24 282.3	14 970.8	62%
GUYANA	80 774.7	49 145.5	61%
SURINAME	53 668.9	53 026.7	99%
TOTAL	**160 850.7**	**118 776.8**	**74%**

TABLE 4 : OVERLAP BETWEEN GOLD MINING DEFORESTATION AND THE GREENSTONE BELT

3.1.3.2 Conflict with protected areas

Figure 22 shows the spatial localization of the conflict zone between gold mining activities and protected areas, as well as the overlap with the Greenstone belt.

Large disparities exist among the territories regarding the part of land covered by protected areas but also on the extent of conflict zones between gold mining and protected areas. More than half of the north of Amapá is protected whereas 29.3%, 13.3% and 5.5 % is protected respectively in French Guiana, Suriname and Guyana (Table 5). The North of Amapá and Guyana show the least overlap between gold mining and protected areas, with 467.5 ha for Amapá and only 12.9 ha for Guyana, which represent 0.01% and 0.001% of their protected areas respectively. While 1,238.4 ha of forest have been cleared in the Brownsberg nature park in Suriname, protected areas of French Guiana are the most impacted by gold mining with more than 4,000 ha deforested; accounting for 70% of the deforestation caused by gold mining within protected areas at the study site scale.

French Guiana has also by far the largest proportion of protected areas overlapping with the Greenstone Belt (18%; Annex 3). Moreover, in French Guiana 68% of the deforestation due to gold mining in protected areas are overlapping the Greenstone belt (Annex 4). In Suriname, even if only 1% of protected lands are covered by the Greenstone belt, all the deforestation caused by gold mining in protected areas takes place within this 1%. The situation is different in Guyana where very few deforestation occur in the Kaieteur National Park which does not overlap the Greenstone belt, and in North of Amapá where only 3% of the deforestation in protected areas overlaps the Greenstone belt. At the study area scale, 69% of the deforestation caused by gold mining in protected areas overlaps the Greenstone belt.

Several protected areas throughout the study area are partly located within the Greenstone belt, making them potentially vulnerable to gold mining activities that can conflict strongly with the conservation objectives. Examples are Tumucumaque National Park in Amapá, Parc Amazonien de Guyane in French Guiana, Brownsberg Nature Park in Suriname, and Kanuku mountains in Guyana. To prevent extractions and alteration of these habitats, measures need to be implemented such as the prevention of major development, a rejection to grant mining concessions in the area and its buffer zones, and regular monitoring. The success of these interventions will affect not only the viability of the protected areas, but also the entire protected area system in the region, wherever it overlaps with (known) gold reserves (WWF Guianas, 2012).

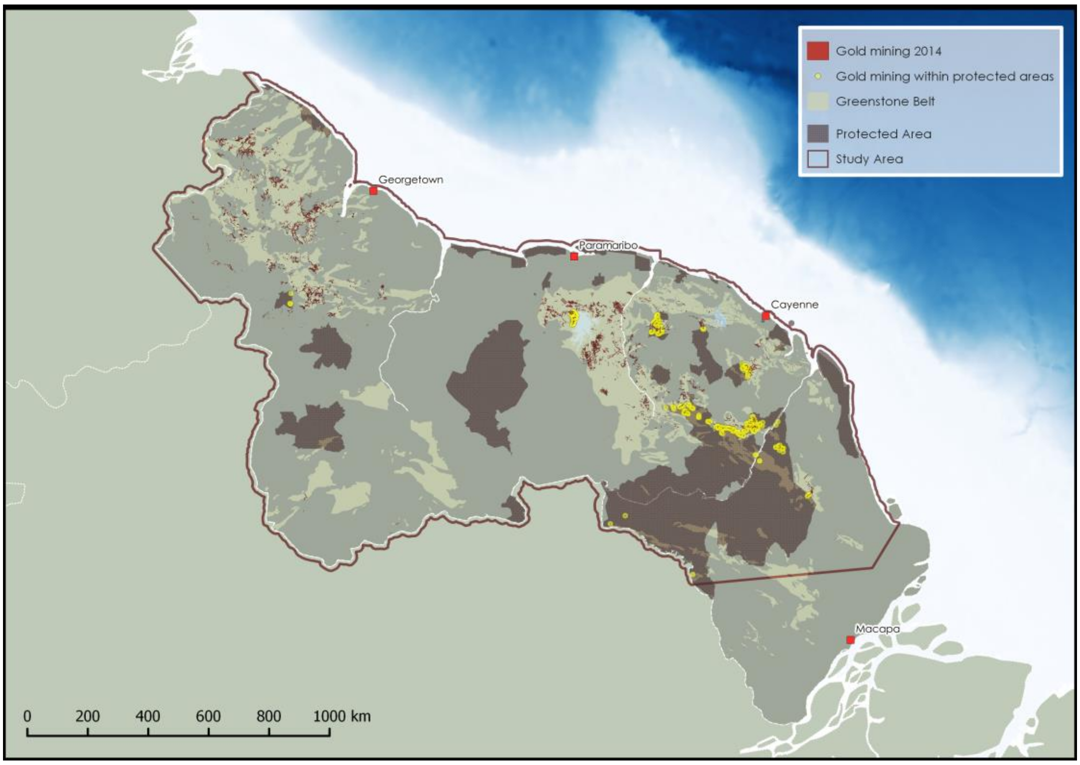


FIGURE 22 : OVERLAP BETWEEN GOLD MINING ACTIVITIES, PROTECTED AREAS[12] AND THE GREENSTONE BELT[13]

Territory	Protected areas (Ha)	Territory covered by protected areas (%)	Overlap with Gold mining (Ha)	Overlap with Gold mining (%)
AMAPÁ	4 233 574.9	52.3	467.5	0.011
FRENCH GUIANA	2 451 425.9	29.3	4 088.1	0.167
GUYANA	1 144 237.0	5.5	12.9	0.001
SURINAME	2 182 528.4	13.3	985.3	0.045
TOTAL	10 011 766.2	19.2	5553.8	0.055

TABLE 5 : PROTECTED AREAS IMPACTED BY GOLD MINING

[12] Source: State of Amapá (Coordenaria de Geoprocessamento e Tecnologia de Informação Ambiental (CGTIA), 2011); French Guiana (ONF, Parc amazonien de Guyane, DEAL and Conservatoire du Littoral and DIREN (2007-2012), available at: http://www.geoguyane.fr/catalogue/); Suriname (Stichting voor Bosbeheer en Bostoezicht (SBB)); Guyana (IUCN and UNEP-WCMC (2015)).

[13] Source : State of Amapá (Companhia de Pesquisa de Recursos Minerais, CPRM ; available at : http://geobank.sa.cprm.gov.br/pls/publico/geobank.download.downloadlayouts?p_webmap=N); French Guiana (Digitized from the Geological map of French Guyana (BRGM, 2001); available at: http://gisguyane.brgm.fr/sig_geologie2001.htm); Suriname (SBB); Guyana (Digitized from the Geological map of Guyana (Guyana Geology and Mines commision 1982-2001; Map authors: E.Cole and L.J.Heesterman); available at: http://www.ggmc.gov.gy/Documents/PDF/GeoServices/guy_geol.pdf);

3.1.3.3 *Barycenter of gold mining activity*

In geometry the term barycenter is a synonym for centroid. The analysis of the barycenter of gold mining activities allows to summarize the distribution of deforestation patches over the years. The national and regional barycenters of the distributed gold mining sites for each reference year help us to analyze the displacement of the activity. Figure 23 illustrates these barycenters weighted by the area covered by each mining site.

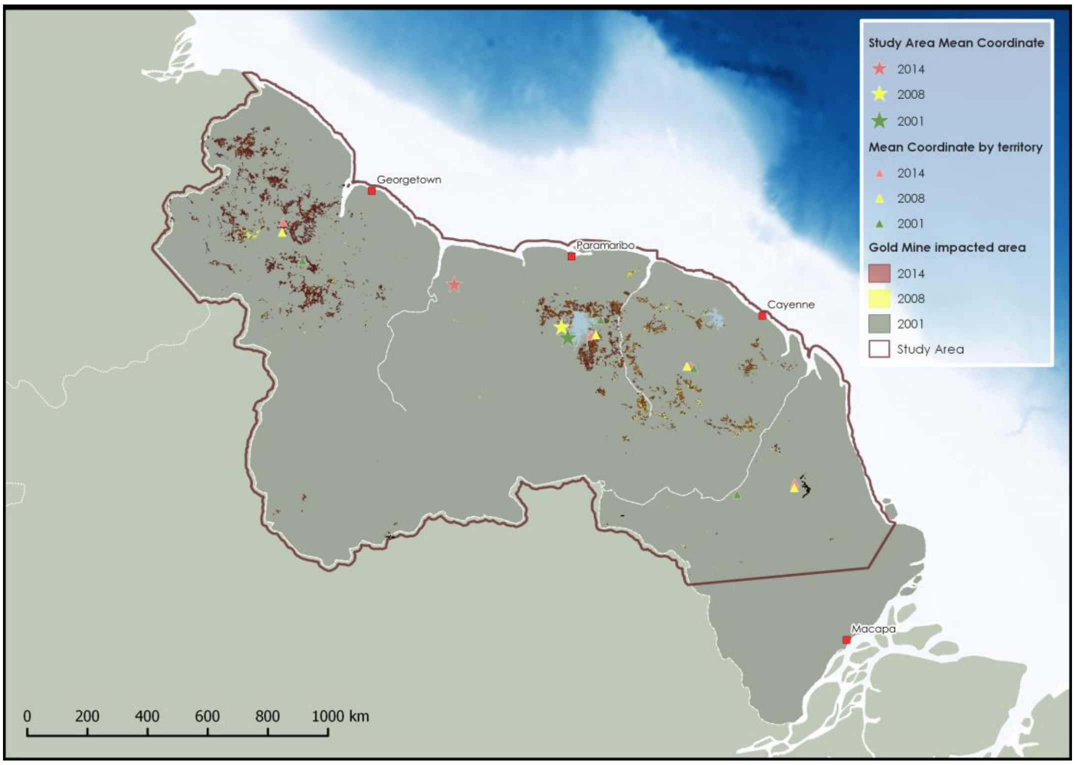


FIGURE 23 : BARYCENTER OF GOLD MINING ACTIVITY (WEIGHTED BY THE AREA OF GOLD MINING SITES) AT THE TERRITORY AND STUDY AREA LEVEL FOR REFERENCE YEARS 2001, 2008 AND 2014.

Two main observations can be made from the analysis of this indicator. First, we observe a strong correlation between the barycenters of 2001 and 2008 at the regional level, which does not always reflect local situations, especially in Amapá and Guyana. Secondly, the regional barycenter show a significant displacement westward of the activity for the reference year 2014, which confirms what was highlighted before in the text, i.e. the fact that intensity of gold mining activity is increasing much more in the west than in the east part of the study area. This movement of the activity to the west is a regional phenomenon that is not observed locally, where the barycenters are very similar between 2008 and 2014 for all territories. This means that, in each territory, the new areas of deforestation in 2014 were equally distributed around the centroid of the activity in 2008, suggesting that deforestation occurred around the same locations than before.

In Amapá, since 2008 the activity focuses around Lourenço and Regina, where most impacted areas are concentrated. In French Guiana, although gold mining is widespread over the territory, the centroid is very stable over the years, due to the homogeneous distribution of the activity in very concentrated large mining areas. In Suriname, since 2001 the barycenter of the activity is moving closer to the Van Blommenstein hydropower lake, in direction to the south of the reservoir where there is a peak of activity especially since 2008 around the Tapanahony River. In Guyana, the activity is more and more concentrated in the North of the country where we find the most impacted areas. This particularly influences the 2014 regional trend by displacing the centroid of the activity to the West but also to the North.

3.1.3.4 Distribution and impact of small-, medium- and large-scale gold mining

It is not possible from remote sensing analysis to clearly distinguish industrial mining sites from artisanal ones, especially because the practices vary from a territory to another. However, the size of sites can be used as a proxy for practices and we can make the assumption that larger sites are symptomatic of a process under industrialization.

Looking at the evolution of mining sites' size over time, we can see that in Suriname and French Guiana, more and more large-scale mining operations seem to substitute medium-scale operations. As shown in Table 6, between 2001 and 2014, the size of the largest mining site in French Guiana multiplied by a factor three, extending from 313.6 to 1,230 hectares. Suriname now has the largest site of the region with 2,558 ha which is almost five times bigger than its largest site in 2001. The mean area of the sites in both territories has also significantly increased over the years with 15 ha and 18 ha in 2001 compared to 20.5 and 25.9 ha in 2014, respectively for French Guiana and Suriname. In Amapá and Guyana, trends are very different. In Amapá, where the activity is in decline, the maximum and mean area of the sites have been reduced. In Guyana, the size of the largest site is stable over the years. However, the mean area of its sites has been divided by a factor two. This suggests that the mode of exploitation linked to the size of the sites might vary from a territory to another.

Gold mining impact on forest cover in 2001 / 2008 / 2014

Year	Territory	Total Gold mining area (Ha)	Largest mining site (Ha)	Smallest mining site (Ha)	Mean mining site (Ha)	Standard Deviation (Ha)
2001	AMAPA	2 147.3	758.3	0.3	31.9	94.0
	FRENCH GUIANA	6 421.9	313.6	0.3	15.0	30.7
	GUYANA	5 435.1	1 146.3	0.6	24.7	82.2
	SURINAME	8 295.9	474.7	0.3	18.0	41.6
	TOTAL	22 300.2	1 146.3	0.3	22.4	30.7
2008	AMAPA	2 471.6	709.5	0.5	29.2	89.0
	FRENCH GUIANA	20 936.7	925.6	0.1	13.8	48.2
	GUYANA	17 781.9	1 146.3	0.1	10.8	41.0
	SURINAME	27 253.8	1 222.6	0.1	18.2	66.9
	TOTAL	68 444.0	1 222.6	0.1	18.0	21.4
2014	AMAPA	2 124.8	353.6	0.7	26.2	58.5
	FRENCH GUIANA	24 282.3	1 230.0	0.5	20.5	78.5
	GUYANA	80 774.7	1 237.7	0.5	11.7	42.2
	SURINAME	53 668.9	2 558.3	0.5	25.9	131.7
	TOTAL	160 850.7	2 558.3	0.5	21.1	38.9

TABLE 6 : STATISTICS OF GOLD MINING AREAS BY TERRITORY AND AT THE STUDY SITE LEVEL FOR THE REFERENCE YEARS 2001, 2008, 2014

There is no set definition of what is meant by small-, medium- and large-scale gold mining. The definition can vary depending on the purpose for which the term is being used, e.g. amount of material moved per annum, number of employees and level of mechanization, extent of the exploitation, etc. The working definition used in this study to analyze the distribution of small-, medium- and large-scale gold mining activities is based on the forest area impacted (correlated with the size of the exploitation), defined as 0.5 to 10 ha for small-scale, 10 ha to 100 ha for medium-scale and larger than 100 ha for large-scale gold mining.

According to Legg et al. (2014), several international mining companies have productive working concessions in the region but the industry is still dominated, in terms of geographic extent, numbers of miners and environmental impacts, by the small-scale sector. In Latin American gold-producing countries, the small-scale sector is thought to make up between 20% and 60% of gold production (Hammond et al., 2013). The grand majority of small-scale gold miners in the Guiana Shield are highly mechanized, employing heavy duty digging equipment and high pressure hoses. Most of them use mercury to separate the gold from other soil particles. After mining, the area is left behind with –in most cases- no efforts at rehabilitation (Heemskerk, 2011). Peterson and Heemskerk (2001) concluded based on fieldwork on abandoned mining sites that forest recovery following mining is slow and qualitatively inferior compared to regeneration following other land uses. Unlike areas in nearby old-growth forest, large parts of mined areas remain bare ground, grass, and standing water. A side effect of deforestation near waterways is that it causes erosion, which in turn causes turbidity and re-circulation of historic and/or natural mercury.

Figure 24 and Figure 25 illustrates respectively for each territory, the evolution in the number of gold mining sites by defined categories and the proportion of deforestation caused by these categories, over the years 2001, 2008 and 2014. Whereas the number of mining sites gradually increase over the years for each category in Guyana and Suriname, the trend is different in Amapá and French Guiana.

In Amapá, the number of medium- and large-scale sites is stable since 2001 while the number of small-scale sites increased, especially between 2001 and 2008. Making the assumption that medium- and large-scale sites mainly refer to official and legal mining concessions, this might suggest an increase of small-scale illegal activity. However, small-scale sites should not be automatically associated with illegal mining as they can belong to larger legal concessions or be explained by scattered land-tenure. On the other hand, the high increase of small-scale sites before the establishment of the ICMBio monitoring institute in 2007 and the slight reduction of this number after its creation could be explained by repression measures against illegal gold mining. In terms of deforestation, the trend reversed between both periods 2001-2008 and 2008-2014 for medium- and large-scale categories, i.e. the proportion of deforestation caused by medium-scale sites dropped in 2008 to 21% compared to 41% in 2001, whereas in 2014 the proportion of deforestation caused by medium-scale sites raised to reach again the same level as in 2001 (41%). In both cases, this was linked to the proportion of deforestation caused by large-scale operations. Large scale operations remain in 2014 the major contributor to deforestation with 49%, compared with 41% for medium- and 10% for small-scale.

In French Guiana, the high increase of small-scale gold mining sites between 2001 and 2008, followed by a significant decrease in 2014 is reminiscent of the positive impact of repressive measures implemented by the French government to combat illegal gold mining activities. The high decrease in the proportion of deforestation caused by small- and medium-scale gold mining in profit to larger scale operations reinforce this idea. However, according to Legg et al. (2013), 10,000 illegal miners were still thought to be at work in 2012 compared to 550 people directly employed in the legal mining industry as a whole. Most of illegal miners were immigrants suggesting that income is the main socio-economic incentive (Heemskerk, 2011).

The number of mining sites in Guyana have been approximately multiplied by five in each category this last period (2008-2014). The steep rise in the number of small-scale mining sites is particularly impressive, accounting in 2014 for 5,525 compared to 1,066 in 2008 and only 111 in 2001. In 2014, the small-scale mining sector in Guyana was thought to employ around 35,000 people (McRae, 2014). Guyana is the sole territory where large scale mining is not the major contributor to deforestation, even if it is more contributing than in the past as it is the case for French Guiana and Suriname.

In Suriname, even if the number of sites is constantly growing in approximately the same proportion for each category, large scale operations are more and more contributing to the deforestation of the sector. In 2014, it represents 64% of the total deforestation compared by 40% in 2001.

This trend is similar at the study site scale where large scale gold mining is more and more contributing to deforestation over the years, representing now the major contributor with 50% compared to 35% in 2001 (Figure 26). Medium-scale operations which were contributing the most to deforestation in 2001 with 52%, follow an opposite trend and contributes now to 36%. The proportion of deforestation caused by of small-scale gold mining is stable over the years (around 15%).

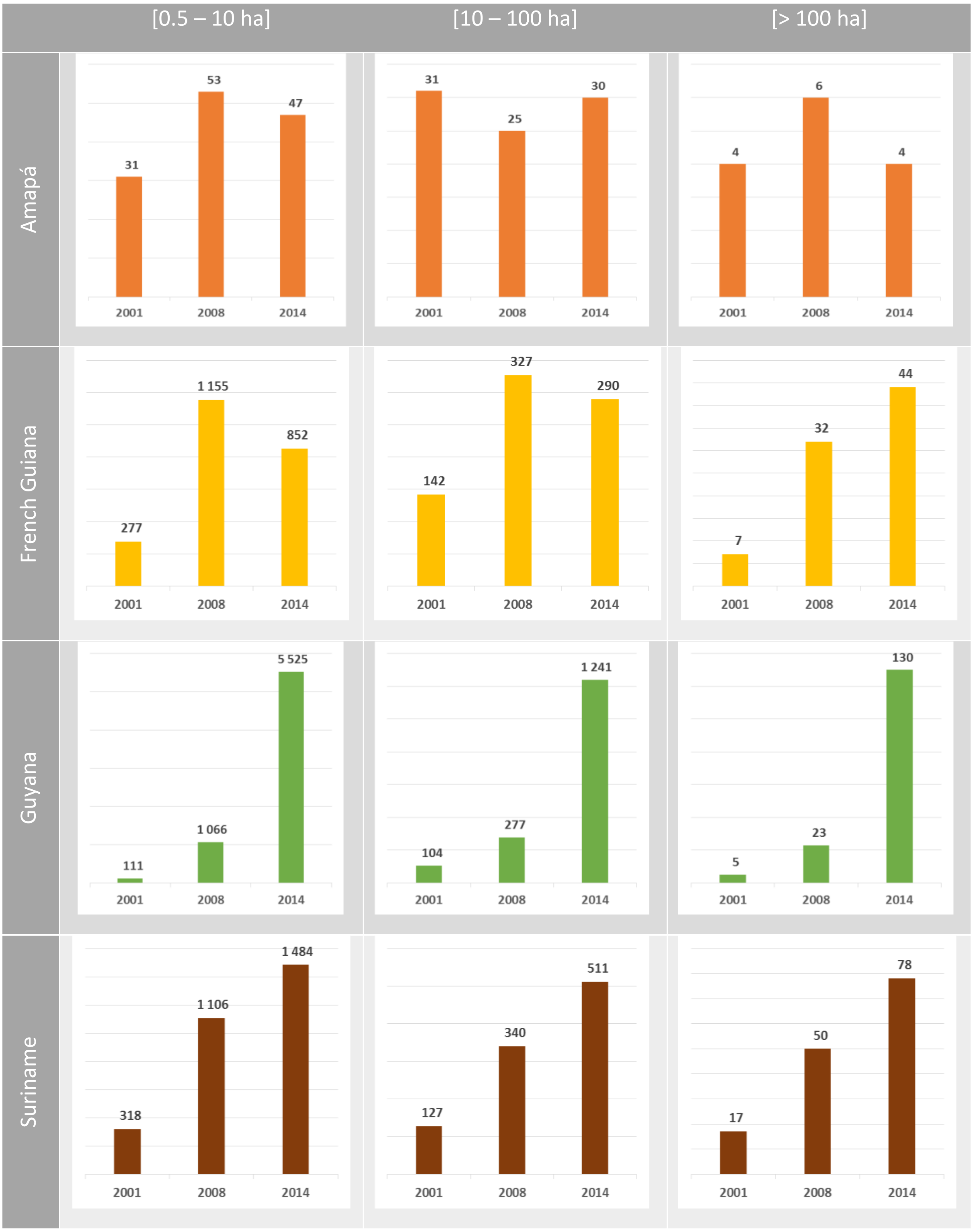


FIGURE 24 : NUMBER OF GOLD MINING SITES BY SIZE CATEGORIES, SMALL- (0.5-10 HA), MEDIUM-SCALE (10-100 HA) AND LARGE-SCALE (>100 HA) FOR AMAPÁ, FRENCH GUIANA, GUYANA AND SURINAME IN 2001, 2008 AND 2014

FIGURE 25 : PROPORTION OF GOLD MINING DEFORESTATION CAUSED BY SMALL-SCALE (0.5-10 HA), MEDIUM-SCALE (10-100 HA) AND LARGE-SCALE (>100 HA) ACTIVITIES FOR AMAPÁ, FRENCH GUIANA, GUYANA AND SURINAME IN 2001, 2008 AND 2014

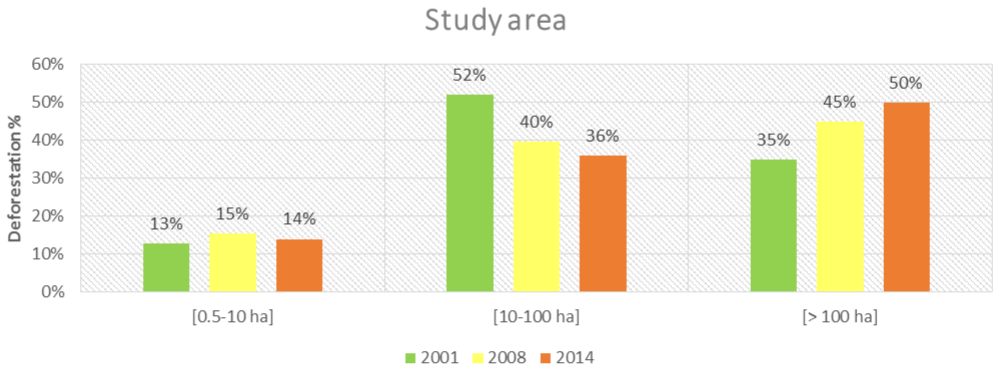


FIGURE 26: PERCENTAGE OF DEFORESTATION CAUSED BY SMALL-SCALE, MEDIUM-SCALE AND LARGE-SCALE GOLD MINING FOR 2001, 2008 AND 2014

3.2 Waterways potentially impacted by gold mining

According to WWF Guianas (2012), the main impacts on rivers are related to, but not restricted to, small-scale gold mining, especially as related to the quantities of mercury used in the chemical process of gold extraction. Mercury is a heavy metal that is highly toxic to virtually all biodiversity. It enters the aquatic ecosystems in dissolved form in the water column, but can also form toxic products such as methylmercury (monomethylmercury), which are highly stable and can remain in the ecosystem for long periods (possibly up to thousands of years). Mercury contaminates the river sediment and works its way up the food chain in a process called bioaccumulation, reaching high concentrations in predatory species such as some fish species, among which some are consumable. Another major disturbance to the aquatic environment is the increased turbulence and turbidity (Figure 27), which in themselves impact the ecosystem and can increase the adverse effects of mercury pollution. Most small-scale activities are located in close proximity to creeks and streams, where the ecosystem is directly impacted and disrupted by these practices. Natural regeneration of the degraded aquatic ecosystems is a very slow process, taking up to hundreds of years. Anthropic restoration could be faster but would be very hard to implement and very costly.

The results of this analysis on the impact of gold mining on waterways provides indication about the potential dispersion of contaminants such as mercury released by the activity in the environment through the river system, however, evidence recently gathered indicates that the impact of mercury use in gold mining are underestimated when only considering downstream impacts (Ouboter *et al.*, 2012) and some specific research need to be carried out to better understand the inter-relationship between mining activities and the environment.

The following subsections present first the results of the potentially impacted waterways in the region for the reference year 2014 and secondly, compare these results with the reference years 2001 and 2008.

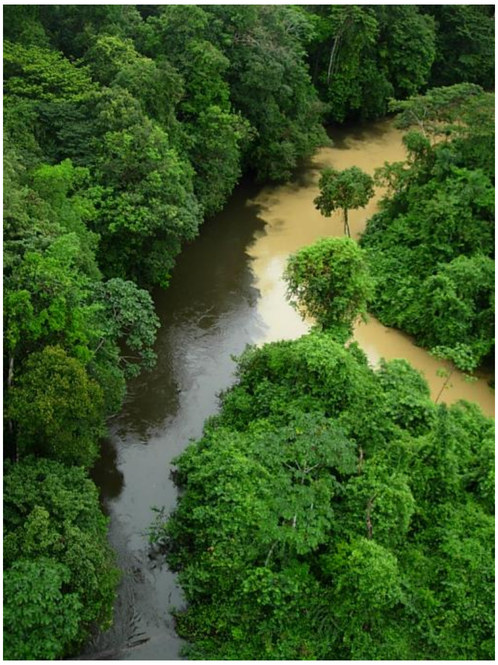


FIGURE 27 : RIVER IMPACTED BY GOLD MINING ACTIVITY (VISIBLY TURBID AND APPEARING AS A COFFEE WITH-MILK NON-TRANSPARENT COLOR – SOURCE: ©ONF)

3.2.1 Reference year 2014

At the scale of the study area, the length of waterways directly impacted by gold mining totalizes 9,347.9 km, whereas the indirect network potentially impacted covers 30,457.1 km. In total[14], 39,805 km of waterways are potentially affected by gold mining, from which 22.5% are in direct contact with gold mining activities (Figure 28 and Figure 29).

Guyana has the higher network of rivers potentially impacted. However, the low ratio of direct / indirect impact can partly be explained by the few small gold mines located in the extreme south of the country (far from the coast) which generate a potential indirect impact long of approximately 2,500 km. Suriname, while totaling the second largest impacted distance, possesses by far the longest network of waterways in direct contact with gold mining activities (4,989.1 km). This can be explained by the presence of larger mining sites in comparison with the other territories but also by the high concentration of the activity around the Brokopondo hydro dam near the border with French Guiana. In French Guiana, while the direct impact is much lower, the indirect impact is closer to the one in Suriname, due to the wide distribution of the activity over the territory compared to Suriname, where it is very concentrated near the border with French Guiana. This very high concentration of Surinamese and French Guiana activities near the border suggest high impact on the rivers in the region, especially on the Maroni River which is located at the border of the two territories. Many communities in the interior of Suriname are not connected to the public water net. Hence especially in the dry season when people cannot rely on rainwater, the poor water quality is a large problem as causes diarrhea and other waterborne diseases (Heemskerk and Olivieira 2003).

[14] This total does not equal the sum of the waterways impacted in each territory, because waterways shared by two territories was only counted once.

The French Institute of Research and Development is conducting a study in the region to evaluate the level of suspended matter and the impact of gold mining in the main rivers of French Guiana, including the Maroni River. Given the low level of gold mining activity and the small-scale of the sites in Amapá, the watershed is potentially much less impacted than in the other territories.

As described in the methodology, the results provided here are based on a theoretical watershed generated by remote sensing methods. The watershed generated might slightly be overestimated in some places, especially in flat areas. However, evidence recently gathered indicates that the impact of mercury use in gold mining are underestimated when only considering downstream impacts (Ouboter *et al*., 2012). It appears that atmospheric transportation of mercury, by (northeastern trade) winds followed by wet deposition, may account for significant quantities of mercury entering both gold mining impacted and even pristine aquatic ecosystems. In several locations throughout Suriname, even in areas without gold mining and historical accounts of gold mining, mercury levels in fishes and sediment are found to be very high, often higher than international standards used for human consumption. It has been suggested that pristine areas may be more sensitive to mercury than areas affected by gold mining, because mercury is freely available for bio-accumulation and uptake by the ecosystem. Negative impacts are expected on aquatic life as well as reptiles, birds and mammals, and indirectly on human populations.

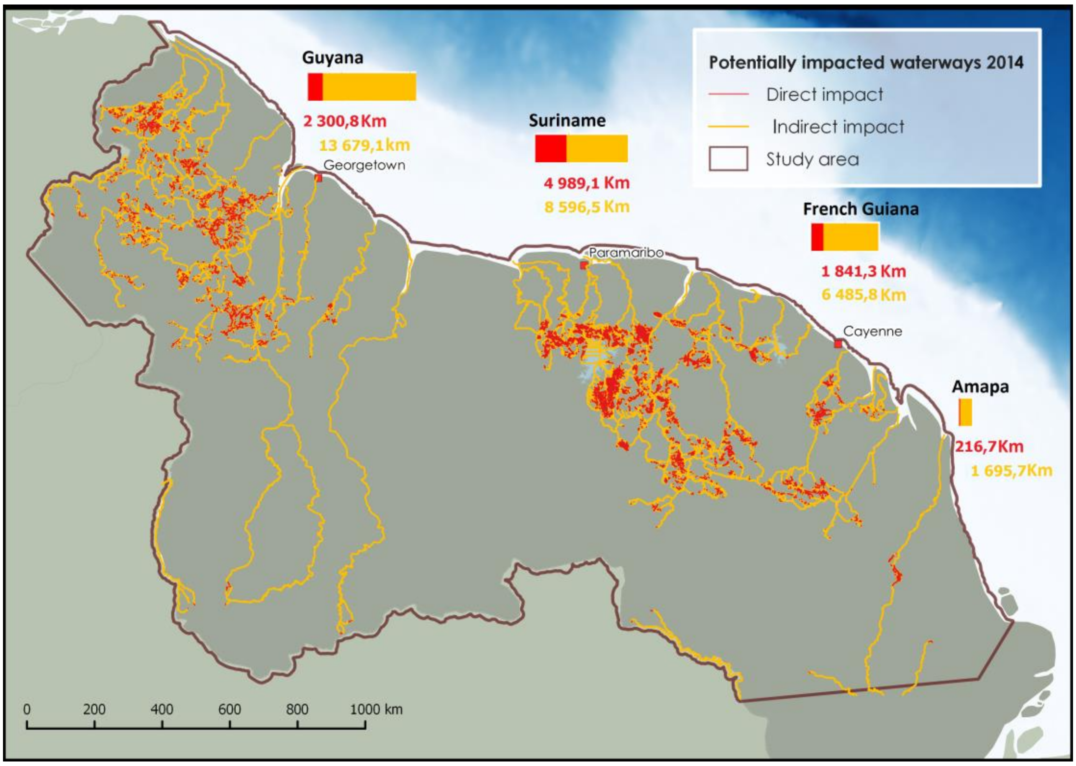


FIGURE 28 : WATERWAYS POTENTIALLY IMPACTED BY GOLD MINING FOR THE REFERENCE YEAR 2014[15]

[15] This map does not display any country boundary but only waterways impacted by gold mining activities.

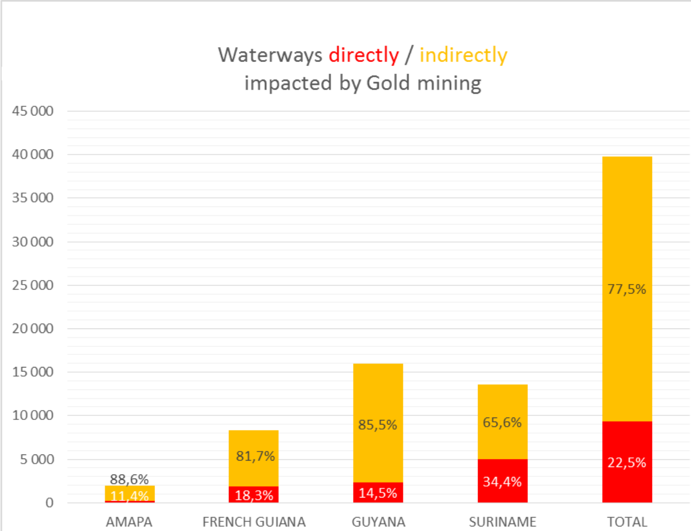
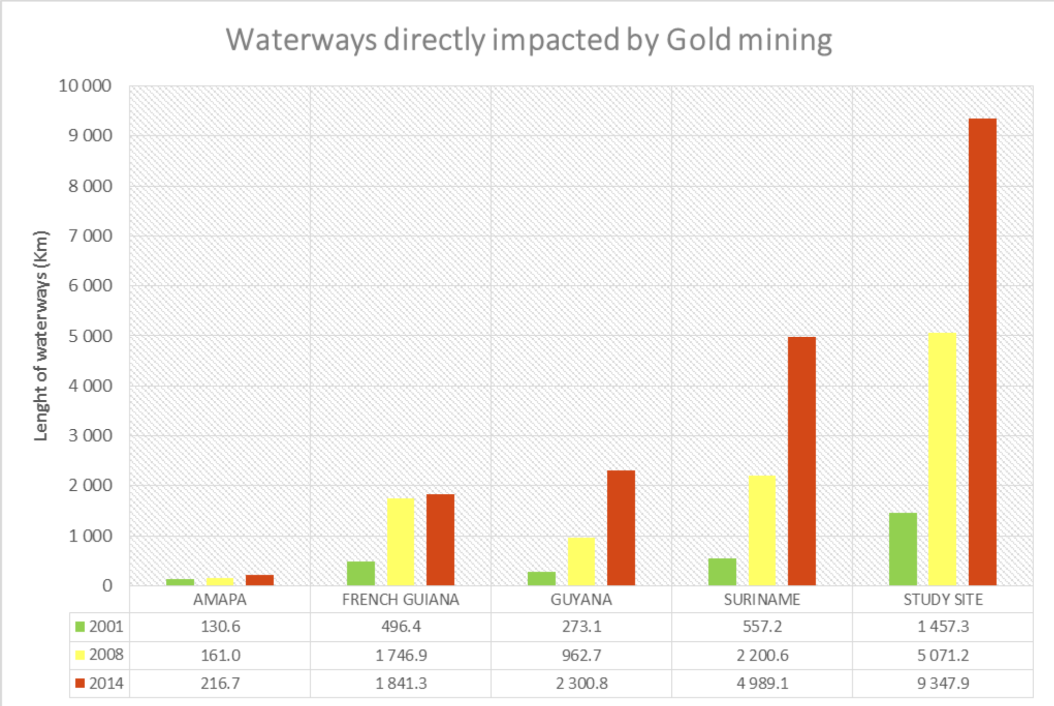


FIGURE 29 : LENGTH AND PROPORTION OF WATERWAYS POTENTIALLY DIRECTLY AND INDIRECTLY IMPACTED BY GOLD MINING FOR THE REFERENCE YEAR 2014

3.2.2 Results comparison with reference years 2001 and 2008

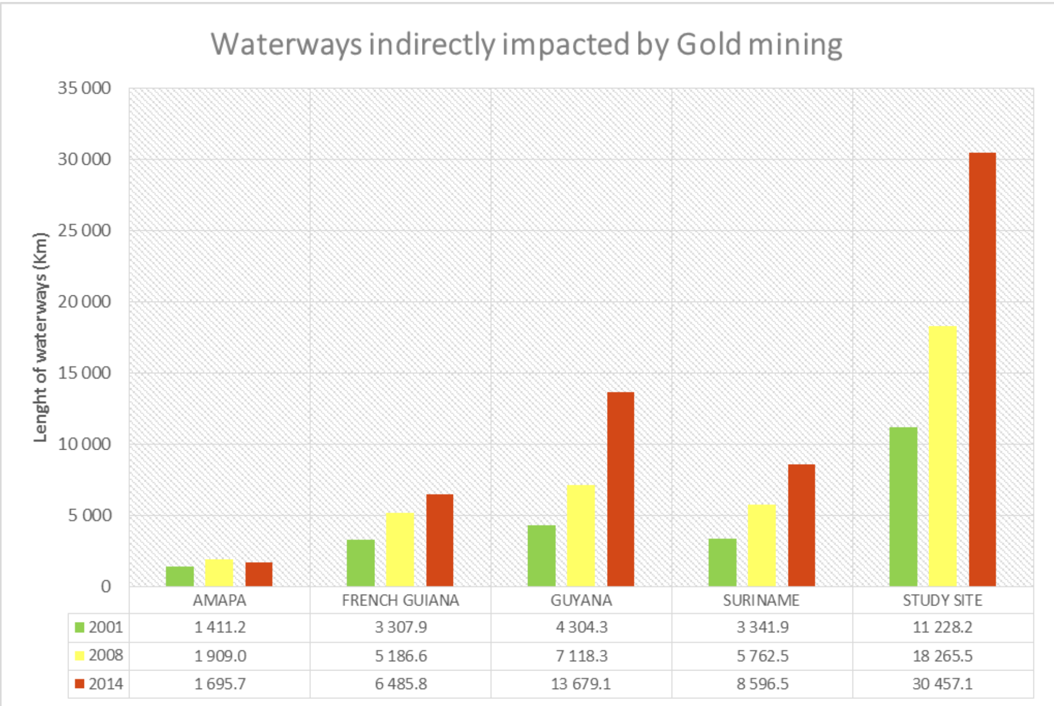
Comparing the results of the potentially impacted waterways for the reference year 2014 with the 2001-2008 study represents a challenge, especially because the accuracy of the SRTM data used to generate the watershed is three times higher for this study (30m) than the previous one (90m). This might have a significant impact on the accuracy of the results provided by both studies. The 2014 study might slightly overestimate the impact in some flat areas, whereas the 2001-2008 study using coarser resolution might underestimate the impact because of the lack of details provided by the generated watershed.

Nevertheless, Figure 30 and Figure 31 show a significant increasing impact on waterways over the years at the study site level. The increase in direct impact is especially high as it raised by 541% since 2001, compared to 171% for the indirect impact. In consequence, the direct / indirect impact ratio also tends to increase over the years: approximately 1/7 in 2001, 1/5 in 2008 and 1/3 in 2014. This is mainly due to the increase of the activity over the years around existing historic mining sites, especially driven by the presence of the greenstone belt and the accessibility of the area. These new mining areas indirectly impact rivers which were already impacted by older sites.



	AMAPA	FRENCH GUIANA	GUYANA	SURINAME	STUDY SITE
2001	130.6	496.4	273.1	557.2	1 457.3
2008	161.0	1 746.9	962.7	2 200.6	5 071.2
2014	216.7	1 841.3	2 300.8	4 989.1	9 347.9

FIGURE 30 : DIRECT IMPACT OF GOLD MINING ON WATERWAYS FOR THE REFERENCE YEARS 2001, 2008 AND 2014



	AMAPA	FRENCH GUIANA	GUYANA	SURINAME	STUDY SITE
2001	1 411.2	3 307.9	4 304.3	3 341.9	11 228.2
2008	1 909.0	5 186.6	7 118.3	5 762.5	18 265.5
2014	1 695.7	6 485.8	13 679.1	8 596.5	30 457.1

FIGURE 31 : POTENTIAL INDIRECT IMPACT OF GOLD MINING ON WATERWAYS FOR THE REFERENCE YEARS 2001, 2008 AND 2014

4. Conclusion and perspectives

Guiana Shield forests and waterways are more and more impacted by gold mining activities. This trend that was already visible between 2001 and 2008, has been dramatically confirmed over the 2008-2014 period with more than 92,000 ha of forest lands newly impacted by gold mining, compared to approximately 46,000 ha deforested during the first period.

Behind those results are hidden various situations and practices among the territories involved in this study. Despite strong repressive policies and measures that enabled to slow down or even stabilize the phenomenon in the East part of the region, in a general perspective, deforestation due to gold mining has been obviously influenced by the increasing gold price and global demand, especially since the international 2007-2008 financial crisis.

Beyond deforestation issues, gold mining activities poses critical concerns in terms of water quality, environmental pollution and human population health. In 2014, more than 9,000 km of waterways were in direct contact with mining sites, which is approximately 6.5 times more than in 2001. This suggests that pollution is deeper and deeper disseminating and consequently more and more difficult to address and reverse, especially knowing the very high persistence of mercury in the environment. This persistence means that, even if actions were taken today to stop its use, its negative impacts will continue to be felt for many decades.

In such a critical situation, it is becoming urgent for countries to improve their knowledge and understanding of what are the impacts of gold mining activities, including to enforce the regulation. Monitoring tools and methods such as the one developed in the framework of this study are a must to achieve that and it should be improved and continued in the future.

In a constant improvement perspective, it would be useful to cross cut the results of this study with field data such as on mercury pollution or gold mining practices to better define assumptions and analysis that are made in this report. On the same way, feeding this work with more specific contextual elements could help to better decrypt data that have been produced, especially with regard to local practices, legal framework (which differs from a country to another) and policies and measures developed by countries to limit the impact of gold mining on the environment. Transboundary approaches and analysis are essential to better understand the effect that new policies and measures can have on gold mining activities' displacement such as observed in this study. For example, could the slowdown of gold mining impact on forests land observed in French Guiana between 2008 and 2014, as well as the stabilization in Amapá, partly explain the acceleration that is observed in Guyana and Suriname? Evidence of such leakages have already been demonstrated in the past with garimpeiros (gold miners), expelled from natural reserve areas and indigenous territories in Brazil, crossing the border to try their luck elsewhere in the Guiana Shield ecoregion. Likewise, when the French gendarmerie holds raids in the forest to expel garimpeiros, one notices a temporary increase in the number of garimpeiros at the Suriname side of the border (Heemskerk, 2011).

Improving monitoring tools and the analysis that can be made from the produced data first requires to replicate this type of study, which should be done following the same collaborative approach. Working together allows the development of robust and reliable tools and it reinforces the capacities of organizations that are directly involved in the production and analysis of data. Most of all, it enables to develop a consistent and shared vision of the situation in the region. This shared vision is an essential step in developing regional dialogue on gold mining. The data that have been produced here, but especially the fact that they have been produced in a collaborative way, clearly promotes the good practices exchange and the replication of successful measures implemented to mitigate the impact of gold mining on the environment. Common and shared results facilitates regional and transboundary dialogue, as it becomes possible to consider a longer-term form of cooperation to jointly cope with global and regional influences on gold mining.

Of course, reproducing this regional collaborative study will require efforts and commitments of all partners. But, this will only be possible with the support of the international community to facilitate these regional trade and to ensure access to technology (including satellite imagery) required for such analyzes

5. Annexes

Annex 1 : Confusion matrix of the accuracy assessment of the gold mining mapping product performed for each territory

French Guiana					
	classification points				
		Gold_Mining	No Gold_Mining	total	user Accuracy
Control points	Gold_Mining	1057	69	1126	93,9%
	No Gold_Mining	17	357	374	95,5%
	Total	1074	426	1500	
	Producer Accuracy	98,4%	83,8%		
	Overall Accuracy	**91,1%**			

Amapá					
	classification point				
		Gold_Mining	No Gold_Mining	total	user Accuracy
Control points	Gold_Mining	302	23	325	92.9%
	No Gold_Mining	7	168	175	96.0%
	Total	309	191	500	
	Producer Accuracy	97.7%	88.0%		
	Overall Accuracy	92.8%			

Guyana					
	classification points				
		Gold_Mining	No Gold_Mining	total	user Accuracy
Control points	Gold_Mining	2502	126	2628	95,2%
	No Gold_Mining	74	798	872	91,5%
	Total	2576	924	3500	
	Producer Accuracy	97,1%	86,4%		
	Overall Accuracy	**91,7%**			

Suriname					
	classification points				
		Gold_Mining	No Gold_Mining	total	user Accuracy
Control points	Gold_Mining	1765	112	1877	94,0%
	No Gold_Mining	50	573	623	92,0%
	Total	1815	685	2500	
	Producer Accuracy	97,2%	83,6%		
	Overall Accuracy	**90,4%**			

Annex 2 : Annualized Rate of Forest Change by Period & Driver from 1990 to 2013 (Source: Guyana MRVS Interim Measures Report for Period January 1 to December 31, 2013)

Change Period	Change Period	Annualised Rate of Change by Driver						Annual Rate of Change (ha)
		Forestry	Agriculture	Mining	Infrastructure	Fire	Settlements	
	(Years)	Annual Area (ha)						
1990-2000	10	609	203	1 084	59	171		2 127
2001-2005	5	1 684	570	4 288	261	47		6 850
2006-2009	4.8	1 007	378	2 658	41			4 084
2009-10	1	294	513	9 384	64	32		10 287
2010-11	1.25	186	41	7 340	298	46		7 912
2012	1	240	440	13 664	127	184		14 655
2013	**1**	**330**	**424**	**11 518**	**342**	**96**	**23**	**12 733**

Annex 3 : Overlap between protected areas and the Greenstone belt

Territory	Protected areas (Ha)	Overlap with Greenstone belt (Ha)	Overlap with Greenstone belt (%)
AMAPÁ	4 233 574.9	382 992.4	9%
FRENCH GUIANA	2 451 425.9	438 64.7	18%
GUYANA	1 144 237.0	77775.8	7%
SURINAME	1 940 695.7	24 011.0	1%
TOTAL	**10 011 766.2**	**924 350.1**	**9%**

Annex 4 : Influence of the presence of the Greenstone belt to deforestation within protected areas

Territory	Gold mining within protected areas (Ha)	Gold mining overlapping Greenstone belt within protected areas (Ha)	Part of gold mining overlapping greenstone belt within protected areas (%)
AMAPÁ	467.5	14.7	3%
FRENCH GUIANA	4 088.1	2 772.0	68%
GUYANA	13.2	-	0%
SURINAME	1 238.4	1 238.4	100%
TOTAL	**5 807.1**	**4 025.2**	**69%**

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