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Arnaud DUBOIS

Southern Province erosion characterization in New Caledonia for the year 2018

A management support tool ...

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Foreword

The present document was written within the framework of the validation of a university semester (Master GESPE UNC) carried out during an internship at the Observatoire de l'environnement en Nouvelle-Calédonie (OEIL). The data used as well as the documents cited and made available in this report are likely to change subsequently. In order to avoid any interpretation bias, particular attention has been paid to the temporalization of the versions of the data used, both for the data of the "Erosion in the Southern Province 2018" project and for the exogenous data used (BD-TOPO-NC; Mining Cadastre; ...). However, if any inconsistencies or questions are to be raised in relation to this document, please contact Arnaud DUBOIS (mail: arnaud.dubois@etudiant.univ-nc.nc).

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1 Introduction

New Caledonia is an island located in the Pacific Ocean east of Australia. It is composed of an archipelago of islands, the main one being called "La Grande Terre" and extending over 450 km long and 40 to 70 km wide. It is surrounded by a coral reef which delimits a lagoon. The Grande Terre is bordered to the east by three islands: Maré, Lifou and Ouvéa, called "the Loyalty Islands". New Caledonia is subdivided into three provinces: the North Province, the South Province and the Islands Province. The economic activities of the country revolve essentially around the exploitation of the ultramafic soils rich in nickel, then the agri-food industry (aquaculture, fishing, agriculture) and tourism which is largely based on the visit of natural areas.

Erosion is a phenomenon that affects the earth's crust, leading to its transformation by the displacement of matter.(Bertaud & Albouy, 2013). Mechanical soil erosion is a natural characteristic of soils in tropical islands subjected to heavy rainfall (Dumas, 2010, 2014). In New Caledonia, soil erosion is a problem that can be amplified by anthropogenic activities such as urbanization, mining activity and also the loss of vegetation caused either by invasive animal species[1] or by fires that can be triggered by practices such as crop burning or which can be criminal (Dumas, 2010, 2014; GNC DAVAR, 2019; Luneau, 2006; Printemps, 2007). Terrestrial inputs from watersheds contributes to the over accumulation of sediments in watercourses. This phenomenon can have consequences such as an increased risk of flooding, the alteration of aquatic ecosystems, a decrease in the quality of agricultural soils or a decrease in the quality of drinking water (Dumas, 2014; Garcin et al., 2018; GNC DAVAR, 2019). The material resulting from the soil destruction is transported by the runoff water to the nearest watercourses and then to the Caledonian lagoon. During this transport of material, the receiving waters may undergo a modification of their physico-chemical composition, the turbidity of the water may be modified as well as the content of metallic trace elements (e.g. nickel and chromium). These modifications may lead to disturbances in the coastal biocenosis (e.g. coral cover), organisms may be contaminated by metals and aquatic primary producers, essential in the food web (algae, microalgae, and phanerogams), may be affected by reduced light penetration due to increased turbidity or sedimentation.

[1] Invasive Exotic Species (IAS) such as pigs or deers

« Ce que l'on fait sur terre se voit en mer » What you do on land can be seen at sea

(Extract p 36 from « schéma d'orientation pour une politique de l'eau partagée de la Nouvelle-Calédonie PEPNC », DAVAR 2019)

Faced with erosion, the stakes are therefore multiple and are of an economic, social and environmental nature. Mining has a key role in the development of New Caledonia, it generates direct and indirect induced jobs and is also inscribed in the Caledonian culture. Drinking water resources are unevenly distributed on "Grande Terre", which sometimes implies long transport distances to points of consumption and supply problems for some municipalities. In New Caledonia, more than 90% of the water volumes used are surface water, which is more sensitive to pollution (GNC DAVAR, 2019). New Caledonia is rich in biodiversity known for its high rate of endemism, sometimes even micro-endemism with regard to terrestrial biodiversity. Labels and management measures that have been granted in certain areas testify to the importance given to this wealth: 440 km^2 in the south are registered under the RAMSAR[2] convention, 38,214 km2 of which 5,157 km^2 on land are listed as UNESCO[3] World Heritage, 1.3 million km2 encircling the territorial waters of the Grande Terre and the Loyalty Islands constituting the Coral Sea Natural Park, composed of atolls and unique and preserved reefs (pristines).

The mining code instructed by the government and the environmental codes[4] instructed by the provinces have established a regulatory framework around anthropogenic activities which can alter the soil and amplify the phenomenon of erosion. Management measures to address the erosion problem include the following:

- The abolition of practices such as the dumping of tailings[5] on the edge of the slopes (uncontrolled dumping) and the obligation to establish controlled waste rock piles as well as the implementation of runoff water management.
- The establishment of a legal and technical framework on restoration and re-vegetation of natural sites altered after exploitation. Between 2003 and 2016, in the rehabilitation of degraded mining sites, 1.4 millions of plants have been carried out for 327 ha of re-vegetated areas, to which must be added 352 ha that have been sown (Source: ISEE, according to the DIMENC).

[2] RAMSAR : Ramsar convention, is an international treaty for the conservation of wetland
[3] UNESCO : United Nations Educational, Scientific and Cultural Organization
[4] Environnemental codes : Province Sud, Province Nord, Province des Iles
[5] Tailings : it is soil corresponding of uneconomic fraction left after economic fraction extraction, called ore.

- The implementation of the "Fond Nickel" which aims to support the mining sector but also to finance and subsidize re-greening and management of the water aimed at rehabilitating degraded areas.
- The sanctuarization and protection of natural sites with high stakes (social-economic and environmental)

  Municipalities, assisted by the government, the state and the fire department, in the fight against fires.
- Research in the fields of environmental science, geology, hydrology and plant biology. Advances in these fields are leading to a better understanding of the problem of soil erosion and to the optimization of land use as well as new techniques for the rehabilitation of degraded sites.
- The associations, which participate in the re-greening of degraded sites and in the monitoring threats to the environment (fire, erosion, etc.).

In the continuity of these measures, the Observatoire de l'Environnement en Nouvelle-Calédonie (OEIL) has undertaken the process of monitoring the surfaces contributing to the erosive processes of physical origin at the scale of the South Province. After an inventory of existing data on the topic, revealing that 2/3 of the Southern Province have not been the subject of any precise mapping of erosion (Rouet, 2012), OEIL therefore launched, in 2019 a project to establish a fine mapping of erosive forms on the Southern Province of New Caledonia.

In this context, in order to conduct the study of erosive phenomena in the Southern Province, first of all, the control of the cartographic data was carried out. In a second step, the determination of the method of analysis and the characterization of erosive forms in the Southern Province has been carried out at different scales. Finally, a preliminary analysis of the sectors to be prioritized for the monitoring and management of erosion was conducted.

2 Materials & Methods

2.1 Materials

2.1.1 Erosion mapping data for the Southern Province in 2018

The mapping of the erosive forms of 2018 in the Southern Province was carried out by INSIGHT SAS. This mapping, ordered by OEIL, complies with specifications (available: HERE), during its realization 3 consultation workshops were held between the service

providers and the client to adjust the methodology. A production report was provided by INSIGHT explaining the methodology applied to carry out the mapping (available: HERE , version: 30/06/2020). A quality control of the data (in raster format) was carried out by Isabelle ROUET, specialist in erosion in New Caledonia (available: HERE; version: 02/06/202).

The mapping of 2018 was carried out by remote sensing from 12 SPOT 6/7 images combined into a mosaic to overcome the problems of cloud cover. SPOT 6/7 images have a spatial resolution[6] of 1.50 m and a ground swath[7] of 60 km. The SPOT 6/7 satellites have a daily revisit. The image capture range of the 2018 Erosion Mapping Project extends from 06/04/2018 to 02/12/2018. SPOT 6/7 image sensors record in the visible, red, green and blue (RGB) bands and in the non-visible, near-infrared (Pir) band. This spectral resolution has allowed to calculate various indices such as NDVI, NDWI, SARVI or BI (Cf. Acronyms). These indices have been used to discriminate bare or poorly vegetated soils and allowed a preliminary classification[8] to be established on the "raster" product (image) which was then vectorized (vector product). The classification was carried out according to 3 levels (N1, N2 and N3), level 1 being the least detailed and level 3 the most detailed using exogenous data to establish it.

The topographic database of New Caledonia (BD-TOPO-NC; transmitted in April 2020; source: DITTT; made available by OEIL) as well as the land use (MOS 2014; sources: OEIL, Georep.NC) were used to discriminate between infrastructure and watercourses. The digital elevation model (DEM 10 m resolution; source: GNC DITTT), was used to discriminate a part of the bare ground figures (i.e. Ravines on sloping areas). Sentinel-2 data from the COPERNICUS program were used to detect significantly burned areas.

The vector product is composed of geo-referenced polygons (and whose occupied surface on the ground is, therefore, known) which are filled in an attribute table according to the different attributes and possible values exposed in Tableau 1. Depending on the classification level (N1, N2 or N3) a different Minimum Mapping Unit[9] (MMU) was used. Levels 1 and 3 were mapped with a MMU of 100 m^2, level 2 was mapped with a MMU of

[6] Spatial resolution: determines the smallest detectable object. In this case one pixel corresponds to an minimum object contained in a square with 1.5 m sides.
[7] Grouns Swath : Corresponds to the width on earth, covered by the image capture, when the satellite passes..
[8] A classification: in remote sensing, a classification consists of a grouping, in a class, of pixels (or resampling MMU) having the same value for one or more spectral bands.
[9] Minimum Mapping Unit (MMU) : corresponds to the unit, of re-sampling of the image, in which the spectral value of the contained pixels is averaged in order to bring out the spectral dominance.

2500 m^2. As a comparison, the MMU of the 2014 land use is 10,000 m^2. The complementary attribute, origin, allow to evaluate the dominant origin of the detected erosive phenomenon. The origin is either directly attributed (ex: for an uncontrolled landfill the only possible origin is anthropogenic mining) or according to decision rules when several origins are possible. The different values that level 3 classes can take for the origin attribute are shown in Tableau 1.

Among the level two classes (Cf. Tableau 1), two main classes were considered in the "erosion" issue: "Infrastructures" and "Bare or sparsely vegetated undifferentiated soil". Among these two large classes, the grouped forms can have different behaviors with regard to erosive processes (Cf. Rapport de production). They can constitute areas of material departure (ex: gullies, gullying areas, uncontrolled discharge...) or constitute transit zones and material storage areas (ex: static and dynamic water, sediments and colluvium, ...). Depending on the nature and materials that make them up, as well as the slope, certain shapes (ex: breastplate[10], waterproofed surfaces) can facilitate an increase in the speed of rainwater runoff, which can have the effect of increasing soil loss on land crossed by this runoff (Luneau, 2006; Zingg, 1940).

Note : Note: The version of the erosion map data used here is the one delivered to OEIL on 16/10/2020, completed with the 27/11/2020 version of the decision rules for the attribution of origin. This version includes classification level 3 and is mapped at 100 m^2 MMU.

[10] Lateretic breastplate : is the inglish for « cuirasse lateritique »

Tableau 1 : Nesting of the different attributes (Classes N1, N2, N3 and Origin) applied to the data "Erosion in Southern Province 2018". Taken and adapted from the Production Report (INSIGHT)

N0	N1	N2	Libelle _N3	Origine
non-exploitable data	Clouds***			NA (Non Aplicable)
	topographic shadows***			NA
Exploitable data	Ohter ****			NA
	Water **		Dynamic water	NA
			Static water	undetermined
	Soil sparsely or not vegetated	Infrastructure	Quarry, construction zone, tailing stockpile	Anthropogenic (Anth.) mining * / Anth. undifferentiated *
			Uncontrolled discharge & levelling	Anthropogenic mining
			Track	Anth. mining * / Anth. probable mining * / Anth. non-mining *
			Built and other impermeable surfaces **	Anthropogenic non-mining
			Undifferentiated infrastructure	Anthropogenic non-mining
		Bare or sparsely vegetated undifferentiated soil	Soil sparsely vegetated	undetermined
			Significantly burnt surface	Anthropogenic probable
			Isolated gully	Anth. probable mining * / Anth. probable * / undetermined *
			Gullying areas	undetermined
			Cliff, active rocky escarpment	Natural
			Breastplate (lateritic)	undetermined
			Sediments & colluvium	Anthropogenic probable mining * / Indéterminé *
			Undifferentiated valley bottom	undetermined
			Undifferentiated bare soils	undetermined

*** : The allocation is made according to decision rules (Cf. 10.4.3. of Rapport de production)**

** : are not subject to erosion but may contribute to it

*** : are not important in the "erosion" statistics, but allow us to estimate the percentage of "masked" data (that could not be detected) by sector.

**** : Very heterogeneous data which includes a large part of vegetated soils but also undetected figures due to the limits imposed by the spatial resolution of the sensors and MMU used

2.1.2 *Exogenous data used for Souther Province erosion characterization*

The data presented in Tableau 2 are those used to apply the decision rules for origin attribution (Cf. 3.1). The data presented in Tableau 3 are those described in the methodology in 2.2.2 and those used to obtain the results in 3.2 and 3.3.

Tableau 2 : Exogenous data used to attribute the origin of erosive forms

Données	Sources	Versions	Mise à disposition	Corrections apportées
Type de substrat[11] (classe ultramafique)	SGNC[12] (Sevin, 2014)	2018	OEIL	-
BD-TOPO-NC couche VOIRIE	DITTT	2019	OEIL	INSIGHT
Cadastre minier & Titres miniers échus	GNC[13]	08/04/2020	Georep.NC	-
Zone de Sur-Engravement (PPI Creek)	Fond Nickel (Garcin et al., 2013)	13/05/2020	INSIGHT	-

Tableau 3: Exogenous data used to characterize and spatialize erosive forms

Types de limites	Limites	Sources	Mise à disposition	Versions
Administrative	Limites Provinciales (Terrestres & Maritimes)	GNC	Georep.NC	31/01/2020
Administrative	Limites Communales (Terrestres & Maritimes)	GNC	Georep.NC	31/10/2020
Gestion	Régions Hydrographiques	GNC	Georep.NC	04/09/2019
Environnement	Type de substrat	SGNC	OEIL	2018
Environnement	Classes de pentes (MNT-BD-ALTI-10m)	GNC DITTT	Georep.NC	03/01/2020

2.1.3 *Computer equipment*

In order to carry out the required cartographic treatments and analyses, the GIS software that has been used is ArcGIS Desktop 10.6.1.9270 (ESRI environment of OEIL) and QGIS 3.10.9 A Coruna. The reference coordinate system used is: RGNC91-93/Lamber New Caledonia (EPSG :3163). The Excel spreadsheet of the Microsoft office 365 suite was also used to process the data.

[11] Type of substrate : grouping in 3 different classes : Volcano-Sedimentary, Ultramafic, Other
[12] SGNC : Service de la Géologie de la Nouvelle-Calédonie (Geologic departement of DIMENC)
[13] GNC : Gouvernement de la Nouvelle-Calédonie (government of New Caledonia). GNC date are available one « plateforme de téléchargement Géorep de la Direction des Technologies et des Services de l'Information (DTSI) »

2.2 Methods

2.2.1 Controls

Before using the data, all the technical documents of the project were proofread. Then a verification by photointerpretation of the first delivery of the data was carried out on zones selected for the diversity of the classes present as well as for their different nature in terms of geology. This is a quick check to verify that there are no anomalies (ex: " Soil sparsely vegetated " on a water surface). The observations made were reported to the Technical Group in order to propose improvements to the data and technical documents.

A verification of the decision rules — described in Rapport de production— applied for the attribution of the origin of the classified forms has been carried out. When the reproduction of the decision rules was not feasible, the Technical Group was asked to complete the missing information in the technical documents and optimize the rules. The Expert Group was also questioned to validate certain decision rules (ex: decision rules for the classes "isolated gully" and "gullying area"). A technical methodology document was written to trace the evolution of the decision rules and the evolution of the changes in the results (see Part 2, HERE).

2.2.2 Selection of the analysis method according to the issues at stake

After consultation with the Expert Group, a set of analyses to be carried out was identified (Cf. Annexe 1). The "Erosion in the Southern Province 2018" data was analyzed according to administrative boundaries, environmental factors involved in the erosive processes as well as boundaries defining management perimeters (ex: water resource management). Among the identified analyses, only the following will be developed in this document:

- Provincial (LP) and communal (LC) administrative boundaries: the data was divided along the land boundaries of the Southern Province and along the communal land boundaries of the Southern Province. The forms classified as "sediment & colluvium" that can be located beyond the coastline[14] in estuarine areas, and therefore beyond the land administrative boundaries have been quantified. In order to do so, a treatment has been carried out to

[14] Coastline: corresponds to the last line of vegetation before the sea, with the exception of mangroves, which are integrated into the maritime limits. Beware, the erosion of the coastline is not the object of study of the cartography that has been carried out. However, the presence of large quantities of sediment accumulated inside or outside the coastline can, in some cases, be an indicator of significant erosive pressure.

preserve only those forms of this class that are located between the land and maritime administrative boundaries.

- Types of substrates: The data were divided according to the three main classes of substrates mapped in New Caledonia: the volcano-sedimentary substrate, the ultramafic substrate and the "other" substrate. Depending on the type of substrate, the soils do not have the same sensitivity to erosion. Ultramafic soils — with almost no humus[15] —, are more brittle, marked by relief and sources of metals. Plant species present on ultramafic soils are subject to these constraints. The volcanic-sedimentary substrate is more favorable to the development of the vegetation and less marked by the relief.
- Slope classes: The data has been cut according to slope classes with a 10° step made from the DEM. Slope is an aggravating factor in soil erosion. Sloping areas will more easily be subject to detachment of materials and will be more difficult to colonize by vegetation.
- The Hydrographic Regions (RH): The hydrographic regions — in New Caledonia — are represented by ridge lines[16] delimiting the whole relief concentrating runoff water towards one or more coastal outlets (except in special cases). They are globally functional sub-units, delimited by the relief, allowing, among other things, to analyze the transits of materials taking place from upstream to the lagoon. This scale of study is also important to analyze the erosion pressure on the sectors where water for consumption is captured.

The operations described above make it possible to obtain the area of each class and subclass of erosive form occupied by delimited sectors. The set of exogenous data used to carry out the previous analyses are listed in Tableau 3. A technical methodology document has been written to retrace the previous operations carried out on GIS software (Cf. Parts 3 and 4, HERE).

3 Results

3.1 Controls and data reshuffling

The control by photointerpretation allowed a familiarization with the data and allowed to visualize some points raised in the quality control performed by the thematic expert. The following observation (i) was identified: the presence of shapes classified as "undifferentiated infrastructure" within or bordering the shapes "quarry/work area/controlled slope" is not

[15] Humus: upper layer of soil created by the decomposition of organic matter.
[16] Ridge line (or watershed line): a line of high points separating two opposite moutain slop.

relevant (Cf. p. 34 of the quality control, HERE). The observation (i) above has contributed to the optimisation of the decision rules for attributing the origin of erosive forms classified as "isolated gullies". The presence, beyond the coastline, of relevant and important elements (i.e. "sediment & colluvium") or less important elements (i.e. beach) in the study of soil erosion has been noted (ii). The previous finding (ii) has allowed the method of analysis to be adapted to include those forms classified as "sediment & colluvium" which are outside the land administrative boundaries (Cf. 2.2.2).

The decision rules for the attribution of origin have been reproduced. The results obtained were compared with the temporary results delivered by the provider. Significant differences were found. The main source of these differences was related to the exogenous data used in the rules. A harmonization of the exogenous data to be used was therefore carried out (Cf. Tableau 2). A precision request, for missing parameters in the technical documents, was carried out with the provider. The decision rules were then optimized and schematized on a single diagram (Cf. Annexe 2), including a hierarchy based on the dependency of one rule on another. The evolution of the decision rules will be described below:

- Concerning the forms classified as "quarry, construction zone, tailing stockpile": The decision rules have not evolved, when an object of this class intersects the ultramafic substrate, it is classified as "anthropogenic mining" for the origin. The other objects of this class are classified as "undifferentiated anthropogenic".
- Concerning the forms classified in "track": The decision rules have evolved for this class. The topographic roadway[17] has been used to discriminate the origin of this class. The topographic roads of the type "unpaved axis" or "track axis", used here, are filled in for management, which can be either public (ex: municipalities), private, or not filled in. When an object classified as a "track" intersects only public roads, it is classified as "Anthropogenic non-mining ". For other objects "track":
    - When they intersect both a mining parcel[18] and a 250 m buffer zone realized on the objects "quarry, construction zone, tailing stockpile" previously classified as "anthropogenic mining" for the origin, they are classified as "anthropogenic mining".
    - When they intersect only a mining parcel, they are classified as "probable anthropogenic mining" for the origin.

[17] Topographic roadway: roadway mapped from a topographic survey (Source : DITTT)
[18] Mining parcel: mining cadastre and expired mining titles (Source : Georep.NC)

- When they do not instersect a mining parcel, they are classified as "anthropogenic non-mining" for origin.

- Concerning the forms classified as "sediment & colluvium": The decision rules have not evolved, when an object of this class intersects a creek declared as over-engraved[19], it is classified as "probable anthropogenic mining" for origin. The other objects in this class have been classified as "undetermined".

- Concerning forms classified as "isolated gully": The decision rules have evolved, when an object of this class intersects a 35 m buffer zone realized on mining infrastructures[20], it is classified as " anthropogenic probable mining" for origin. For the other objects of this class, if they intersect a 35 m buffer zone made on non-mining infrastructures[21], they are classified as "probable anthropogenic mining", otherwise they are classified as "undetermined". In this rule, the first optimization is the transition from an initial 250 m buffer zone to a 35 m buffer zone (considered acceptable to establish a notion of contact between objects). The second optimization is the integration of forms classified as "track" and "uncontrolled discharge & levelling" in mining infrastructures.

3.2 Erosion characterization and analysis in the Southern Province

3.2.1 Characterization at the the Southern Province scale

The South Province has a land area of 698,303 ha, 2% of which is occupied by infrastructures (i.e. 15,5548 ha) with an almost equal distribution between the subclasses with the exception of the subclass "uncontrolled discharge" which represents a smaller proportion of the infrastructures in the South Province (i.e. 340 ha). Excluding the subclass "built and other impermeable surfaces", which is not subject to soil erosion — but may contribute to it — the total surface area of infrastructures sensitive to erosion in the Southern Province is 12,381 ha. 5% of the surface area is occupied by bare land or little vegetation (i.e. 33,323 ha) with an uneven distribution among the subclasses, marked by a dominance of soils sparsely vegetated (2%), undifferentiated bare soils (1.2%) and gullying areas (0.8%). 0.6% of the surface is occupied by water (i.e. 4,425 ha). 5% of the surface is devoid of exploitable data (i.e. 33,314 ha). All of the above results are presented in Figure 1. In the Southern Province there are, in addition, a total of 144 ha of forms classified as "sediment & colluvium" which

[19] Creek declared as over-engraved: Creeks engraving mapping (Source : Fond Nickel)
[20] Mining infrastructures: Includes the classes "quarry, work zone, tailing stockpile", "track" and "uncontrolled discharge & levelling" which are classified as "anthropogenic mining" for origin.
[21] Non-mining infrastructures: Includes the classes "built-up and other impervious surfaces", "undifferentiated infrastructure" and "runway" which are classified as "anthropogenic non-mining" for origin.

are located beyond the coastline. Bare or poorly vegetated soils are visually and globally more present in areas close to the coasts and this is truer on the East coast (Cf. Figure 1).

In the Southern Province, 1.3% of the surface is occupied by forms whose origin is anthropogenic (undifferentiated and non-mining). 0.7% of the surface is occupied by shapes whose origin is anthropogenic mining. 0.2% of the surface is occupied by shapes whose origin is probably anthropogenic. 0.3% of the surface is occupied by shapes whose origin is probably anthropogenic mining. In the Southern Province, 5% of the surface, sensitive to erosion, could not be classified for origin (i.e. undetermined). 5% of the surface is identified as not applicable for the attribution of origin (i.e. clouds, topographic shadows and dynamic waters) (Cf. Figure 1).

3.2.2 Characterization at the substrate type scale

The ultramafic substrate represents 55% of the Southern Province surface (384,726 ha). 2% of this surface is occupied by infrastructures with a large dominance of the subclass "quarry, construction zone, tailing stockpile" (1%) (Cf. B and D Figure 2). 6 % of the ultramafic substrate in the Southern Province is occupied by bare or sparsely vegetated soils with a dominance of the subclass "soil sparsely vegetated" (2 %), followed by the subclasses "undifferentiated bare soil" (1 %) and "gullying zone" (1 %) (Cf. C and E Figure 2). Almost all of the uncontrolled discharges (334/340 ha) and isolated gullies (190/194 ha) are on ultramafic substrate (Cf. D and E Figure 2). The great majority of the class "significantly burned surface" is found on ultramafic substrates (1350/1441 ha; Cf. E Figure 2).

The volcano-sedimentary substrate represents 23% of the Southern Province surface (157,506 ha). 2% of this surface is occupied by infrastructures with a dominance of the subclass "track" (1%) (Cf. B and D Figure 2). 3 % of the volcanic-sedimentary substratum is occupied by bare or sparsely vegetated soils with a dominance of the subclass "soil sparsely vegetated" (2.5 %) (Cf. C and E Figure 2).

The "other" substrate type represents 22% of the Southern Province surface (154,710 ha). 3% of this surface is occupied by infrastructures with a dominance of the subclass "built and other impermeable surfaces" (1%) (Cf. B and D Figure 2). 4% of the "other" substrate is bare or sparsely vegetated soils, with the subclasses "soil sparsely vegetated" (2%), "undifferentiated bare soil" (1%) and a marked proportion of the subclass "sediment & colluvium" (0.5%) (Cf. C and E Figure 2).

3.2.3 Slope scale characterization

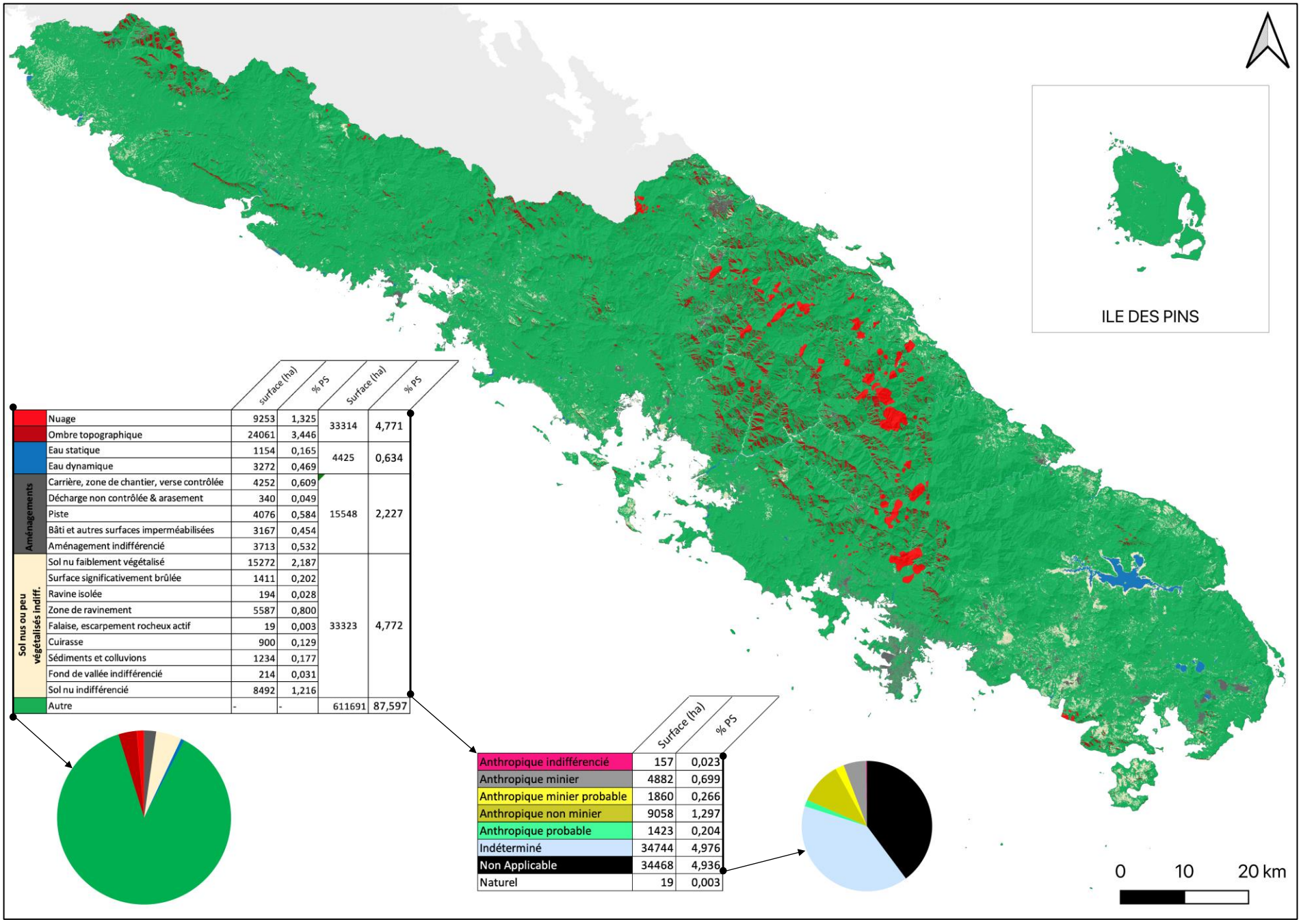
Figure 3 shows the detailed distribution of the erosive forms according to slope classes.

30% of Southern Province surface is located in areas where the slope is between 0° and 10°. 5% of this surface area is occupied by infrastructures where the subclasses "built and other impermeable surfaces", "undifferentiated infrastructure" and "track" are concentrated in almost equal proportions. 6% of the 0° to 10° slope class is occupied by bare or sparsely vegetated soils with a dominance of the subclasses " soil sparsely vegetated ", "undifferentiated bare soil". Almost all the forms classified as "sediment & colluvium" are between 0° and 10°.

More than 60% of Southern Province surface is between 10° and 40° slope. 1% of this surface is occupied by infrastructures with a dominance of the subclass " quarry, construction zone, tailing stockpile " (0.5%) followed by the subclass "track" (0.3%). 4% of the surface of the slope classes between 10° and 40° is occupied by bare or sparsely vegetated soils with a dominance of the subclass "soil sparsely vegetated" (2%) followed by the subclass "undifferentiated bare soil" (1%) and "gullying zone" (1%) (Cf. Figure 3).

For the subclass "uncontrolled discharge & levelling" almost all is located on a slope ranging from 10° to 50° (330/340 ha). 18% of uncontrolled landfills are located on areas in the 40° to 50° slope class, which represents 5% of the Southern Province. The same observation is made for the subclass "isolated gully", almost all of which is located on slopes ranging from 10° to 50° (175 ha out of 194 ha). 17% of the isolated gullies are located on surfaces of the slope class from 40° to 50°.

Beyond 30° of slope, due to clouds and topographic shadows, the data is often less usable. The surface with a slope greater than 30° represents 20% of the Southern Province.



		surface (ha)	% PS	Surface (ha)	% PS
	Nuage	9253	1,325	33314	4,771
	Ombre topographique	24061	3,446		
	Eau statique	1154	0,165	4425	0,634
	Eau dynamique	3272	0,469		
Aménagements	Carrière, zone de chantier, verse contrôlée	4252	0,609	15548	2,227
Aménagements	Décharge non contrôlée & arasement	340	0,049		
Aménagements	Piste	4076	0,584		
Aménagements	Bâti et autres surfaces imperméabilisées	3167	0,454		
Aménagements	Aménagement indifférencié	3713	0,532		
Sol nus ou peu végétalisés indiff.	Sol nu faiblement végétalisé	15272	2,187	33323	4,772
Sol nus ou peu végétalisés indiff.	Surface significativement brûlée	1411	0,202		
Sol nus ou peu végétalisés indiff.	Ravine isolée	194	0,028		
Sol nus ou peu végétalisés indiff.	Zone de ravinement	5587	0,800		
Sol nus ou peu végétalisés indiff.	Falaise, escarpement rocheux actif	19	0,003		
Sol nus ou peu végétalisés indiff.	Cuirasse	900	0,129		
Sol nus ou peu végétalisés indiff.	Sédiments et colluvions	1234	0,177		
Sol nus ou peu végétalisés indiff.	Fond de vallée indifférencié	214	0,031		
Sol nus ou peu végétalisés indiff.	Sol nu indifférencié	8492	1,216		
	Autre	-	-	611691	87,597

	Surface (ha)	% PS
Anthropique indifférencié	157	0,023
Anthropique minier	4882	0,699
Anthropique minier probable	1860	0,266
Anthropique non minier	9058	1,297
Anthropique probable	1423	0,204
Indéterminé	34744	4,976
Non Applicable	34468	4,936
Naturel	19	0,003

Figure 1: Erosion characterization of Southern Province scale (SP; 698,303 ha); (sources: INSIGHT, ŒIL; 2020)

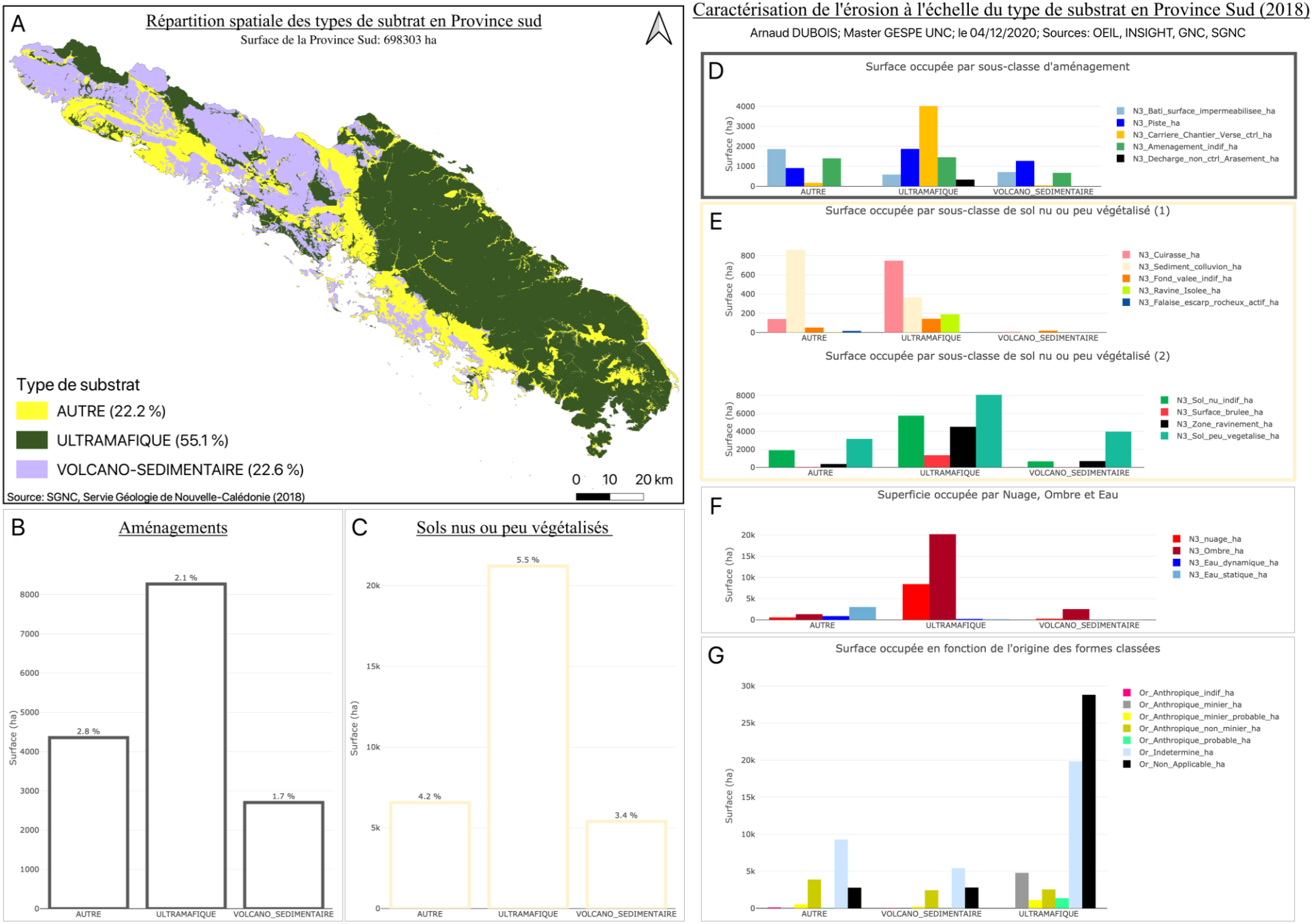


Figure 2 : Erosion characterization at the scale of the substrate type in the Southern Province

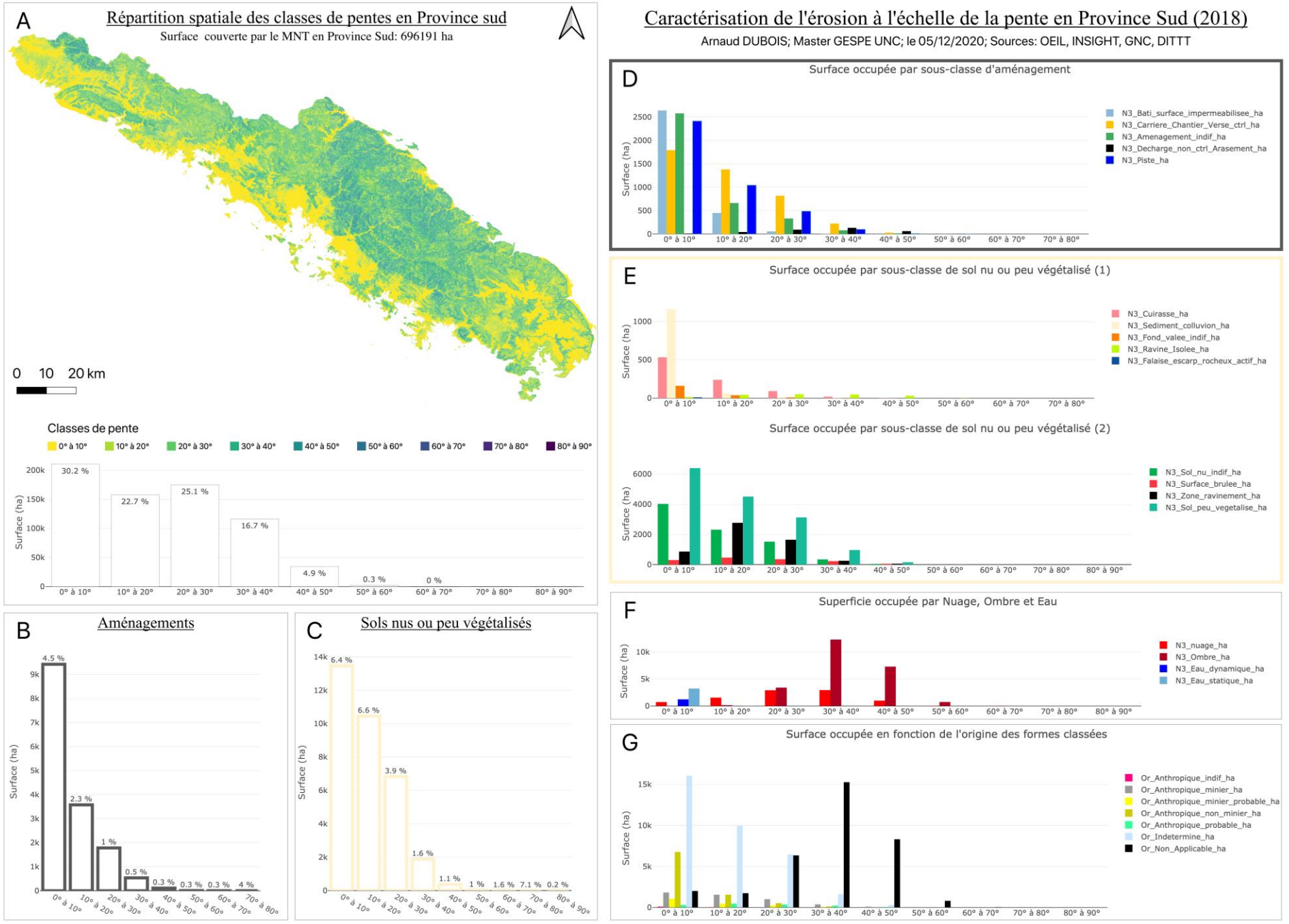


Figure 3: Erosion characterization by slope class in the Southern Province

3.3 Sector analysis for erosion management optimization

3.3.1 The municipality of Mont-Dore

The commune of Le Mont-Dore, which represents 9% (or 63,618 ha) of the Southern Province (Cf. A Annexe 3), is composed for the most part of ultramafic substratum (Cf. A Figure 2) where the relief is punctually marked. The commune has a dominance of surfaces where the slope is between 0° and 10°, and a non-negligible part of surfaces where the slope is between 10° and 20° located at the coastal level (Cf. A Figure 3). Overall, this sector is very little impacted by the non-exploitable data (clouds and topographic shadows) (Cf. F Annexe 3).

In the commune of Le Mont-Dore, 4% of the area is occupied by infrastructures with a dominance of the subclass "quarry, construction zone, tailing stockpile" (1.5%). Among the infrastructure surfaces, there are 82 ha of uncontrolled discharge at Mont-Dore. 14% of the municipality Mont-Dore's area is occupied by bare or sparsely vegetated soils with a dominance of the subclass " soil sparsely vegetated " (5%) followed by the subclasses "gullying zone" (4%) and "undifferentiated bare soil" (3%). The commune is also very marked by significantly burnt areas (1.5%). Among bare or sparsely vegetated soils of this municipality there are 204 ha of forms classified as "Brastplate", 121 ha of forms classified as "sediment & colluvium" (84 ha within the land limits and 38 ha between the land and sea limits) as well as 43 ha of forms classified as "isolated gully" (Cf. Annexe 3).

The Mont-Dore's municipality is mainly composed of the following hydrographic regions : Prony (code: 7200), Pirogues (code: 4400) and Coulée (code: 0300) (Cf. A Annexe 4). These three hydrographic regions each contain between 3% and 5% of infrastructure (Cf. B Annexe 4). They are also areas that are each occupied between 15 and 17% by bare or sparsely vegetated soils (Cf. C Annexe 4). Each of these three regions has been affected by fires (Cf. E Annexe 4). The Prony hydrographic region concentrates a significant part of bare or sparsely vegetated soils at the level of "île Ouen" Island (south of the région Figure 1) with a majority of forms classified as "gullying zone". 80 % of the forms classified as "Breastplate", in the commune of Le Mont-Dore, are located in the Prony region (156/203 ha). More than half of forms classified as "isolated gully" are also located in the Prony region (25/43 ha). The Coulée and Pirogues regions concentrate in equal proportions, 75% of the forms classified as "sediment & colluvium" in the commune (91/121 ha).

The origin of the erosive forms is in equal proportion between what is "mining anthropogenic" and what is "non-mining anthropogenic" (Cf. G Annexe 3). The "probable

anthropogenic" origin of the erosive forms of this commune is pronounced mainly because of the presence of significantly burnt surface[22]. 8000 ha of forms involved in erosive processes have an undetermined origin (this is related to the 3 dominant subclasses bare soil or little vegetation: "undifferentiated bare soil", "little vegetation" and "gullying area").

3.3.2 The municipality of Yate

The commune of Yaté represents 19% (or 133,288 ha) of the Southern Province (Cf. A Annexe 3). It includes the 43,970 ha zone inscribed in the RAMSAR convention as well as numerous protected areas. This commune is composed for the most part of ultramafic substratum and a minority of substratum of the "other" type (Cf. A Figure 2). The commune has a dominance of surfaces where the slope is between 0° and 10° and a non-negligible proportion of surfaces where the slope is between 10° and 40° (Cf. A Figure 3). The Yaté sector weakly impacted by the non-exploitable data (clouds and topographic shadows) (Cf. F Annexe 3).

1.5% of its surface area is occupied by infrastructures with a dominance of the subclass "quarry, construction zone, tailing stockpile" (0.6%) followed by the subclass "track" (0.4%). In the commune of Yaté, there are 33 ha of uncontrolled discharge. 6% of Yaté's commune's surface is occupied by bare or sparsely vegetated soils with a dominance of the subclass "undifferentiated bare soil" (2.5%) followed by the subclass "soil sparsely vegetated" (2%) and "gullying zone" (1%). Among the bare or sparsely vegetated soils of this commune there are also 520 ha of forms classified as "breastplaste", 269 ha of forms classified as "sediment & colluvium" (232 ha within the land limits and 37 ha between the land and sea limits) as well as 37 ha of forms classified as "isolated gully". The commune has a significant proportion of forms classified as "water" (2%) corresponding to the Yate's Lake[23] which is subject to variations in level according to rainfall. When the water level drops, this leads to the presence of a large part of bare soil on the lake's periphery (Cf. Figure 1).

The hydrographic region of Yaté occupies most of the commune of Yaté (Code: 5500; Cf. A Annexe 4). The large area of bare soil in this region, as explained above, is largely due to the variation of the water level in the lake. The eastern part of the commune of Yaté is exposed to the prevailing wind (the Alizé). Two hydrographic, coastal regions are widely exposed to these winds in Yaté: Ounia (code: 7300), Kouakoue (code: 9000) (Cf. A Annexe

[22] The origin of the significantly burned surfaces in the case of the commune of Mont-Dore is anthropogenic.
[23] Yate Lake is an artificial lake formed due to the presence of a dam used for the production of hydroelectric power (« Barrage de Yaté »).

4). They are among the regions with the highest average annual rainfall (between 2,500 and 5,000 mm per year; Source: GNC DAVAR, 2019). These two regions are poorly developped (± 1%) and have significant areas of bare or sparsely vegetated soils (± 10%). Ounia has a predominance of bare or sparsely vegetated soils of the "gullying zone" type, while Kouakoue has bare or sparsely vegetated soils of the "undifferentiated bare soil", "lightly vegetated soil", and "gullying zone" types in equal proportion

3.3.3 Dumbéa and Tontouta

The hydrographic region of Dumbéa (Code: 0500; Cf. A Annexe 4) is the main component of the commune of Dumbéa (Cf. A Annexe 3), with a surface area of 23,110 ha. It is composed mainly of ultramafic substratum but also of substratum of the "other" type at the coastal level (Cf. A Figure 2). The relief is pronounced on the inland part of the land (Cf. A Figure 3). 1 % of the surface of this region is occupied by infrastructures with a dominance of the subclass "built and other impermeable surfaces" (0.4 %) (Cf. B and D Annexe 4). 2% of the surface of the Dumbea hydrographic region is occupied by bare or sparsely vegetated soils with a dominance of the subclass "soil sparsely vegetated" (1%) (Cf. C and E Annexe 4). Among the bare or sparsely vegetated soils of this hydrographic region, there are also 37 ha of forms classified as "sediment & colluvium", 46 ha of forms classified as "gullying zone" and 3 ha of forms classified as "isolated gully". In the Dumbea region, 11% of the surface is masked by non-exploitable data (6% clouds and 5% topographic shadows; Cf. F Annexe 4).

The hydrographic region of the Tontouta (Code: 5200; Cf. A Annexe 4) straddles the communes of Païta and Bouloupari (Cf. A Annexe 3) and covers an area of 52,561 ha. It has more than 80% ultramafic substrate but also substrate of the "other" type at the coastal level and at the bottom of the valley (Cf. A Figure 2). 60 % of the surface of the Tontouta region lies between 20° and 40° of slope. 2% of the surface of this region is occupied by infrastructures with a dominance of the subclass "quarry, construction zone, tailing stockpile" (1%) (Cf. B and D Annexe 4). 3% of the surface area of the Tontouta hydrographic region is occupied by bare or sparsely vegetated soils with a dominance of the subclass "soil sparsely vegetated" (1%) (Cf. C and E Annexe 4). Among the bare or sparsely vegetated soils of this hydrographic region, there are also 423 ha of forms classified as "sediment & colluvium", 54 ha of forms classified as "gullying zone" and 21 ha of forms classified as "isolated gully". The study of Tontouta region is impacted by non exploitable data on up to 13% of its surface area (2% clouds and 11% topographic shadows; Cf. F Annexe 4).

The Dumbéa and Tontouta hydrographic regions present a major challenge in terms of drinking water resources. These are inhabited areas where drinking water resources allow to supply many households (drinking water supply for the communes of “Grand Nouméa”[24]). The hydrographic regions of Dumbéa and Tontouta include areas at risk of flooding that are inhabited (Sources: "Flood risk zone" DAVAR & Georep.NC).

3.3.4 Other sectors

In the Southern Province, other sectors are threatened by the erosive phenomena that have been little or not deepened in the result section. The communes of Bouloupari, Païta and Thio are areas where mining activities are widely present and also have scars inherited -from the mining past (Cf. D Annexe 3). These communes also present a marked relief (Cf. A Figure 3) involving loss of information due to topographical shadows. The commune of Poya Sud, almost entirely on volcano sedimentary substratum (Cf. A Figure 2), with a dominance of areas with a slope of 0° to 10°, presents non-negligible proportions of naked or sparsely vegetated soils (7.5% of its surface; Cf. C Annexe 3). In terms of infrastructure, the commune of Poya Sud has a high proportion of land occupied by tracks (Cf. D Annexe 3).

4 Discussion & Conclusion

4.1 Controls

The control of the data has proved to be essential before the exploitation of the data. Even if the controls by photo-interpretations were not exhaustive, they allowed to identify problematic situations that would have affected the analysis of the data at finer scales (ex: forms classified in "sediment & colluvium" at the scale of the communes). Controls carried out for the attribution of origin allowed to test the robustness of the decision rules and to optimize them. These decision rules were designed on a "conservative" principle so as not to attribute a formal origin in doubtful situations (i.e. indeterminate or probable origins).

Moreover, forms classified as "Undifferentiated infrastructure" would require the development of decision rules for the attribution of origin. If it is not possible to formally identify the type of infrastructure, it is possible to identify the proximity or not of these objects to other objects whose origin is known (ex: "quarry, construction site area, tailing stockpile"). The same improvements, for the attribution of the origin, could be made for shapes classified as "Built and other impermeable surfaces".

[24] Grand Nouméa: is composed of the communes of Païta, Dumbéa, Nouméa and Le Mont-Dore. These 4 communes were populated in 2019 by 182,341 inhabitants (Source: INSEE).

Optimization of decision rules for the attribution of the origin of forms classified as "isolated gully" was based on the reduction of buffer zones (reduction from 250 m to 35 m) applied to infrastructures (mining or not). This optimization was applied according to a conservative principle, so as not to include in the rule isolated gullies which would be located on slopes not communicating with infrastructures. The buffer distance of 35 m made it possible to establish a notion of physical connection (with regard to the scale of work and the limits imposed) of the objects included in the decision rules (isolated gullies and mining or non-mining facilities). However, this reduction of the buffer zone leads to the exclusion of objects (gully), physically connected in reality, but dissociated at the mapping level because of the production processes and data parameters (UMC, objects nested in a complex way).

In some cases, determination of origin was not possible (i.e., undetermined). Beyond attributing an anthropogenic origin (mining or not) to any form of bare or sparsely vegetated soils, it remains important to integrate the notion of proximity of this bare or sparsely vegetated soils to any anthropogenic facilities. Indeed, although certain forms of bare or sparsely vegetated soils may pre-exist nearby infrastructures, the implementation of infrastructures whatever they are (mining or not) requires the implementation of a runoff water management as well as a monitoring and maintenance of the infrastructure and the surrounding environment.

4.2 Characterization and analysis of erosive forms in the Southern Province

In the Southern Province, erosion is marked by two main types of forms, bare soil or little vegetation and anthropogenic infrastructuress which represent, respectively 5% and 2% of the Southern Province. A total of 45,704 ha of soil is sensitive to erosion (12,381 ha of infrastructures, excluding buildings and impermeable surfaces; 33,323 ha of bare soil or little vegetation). At any scale of analysis, the class of "bare or poorly vegetated soil" is composed in greater proportion of poorly vegetated soils, with the exception of certain localized regions (i.e. Prony, Yaté and Ounia; Cf. E Annexe 4).

The large dominance of the ultramafic substratum (55%) in the Southern Province where the relief (slope) is marked by its geological genesis and where mining activities are concentrated, gives rise to attention to the erosive forms that are sources of materials. Because of dominance of buildings and other impermeable surfaces on the "other" substrate, which constitutes the receiving environment for materials resulting from erosion, special attention is paid to the safety of the populations that may live there (flood risk, quality of drinking water).

The slope is an aggravating factor of soil erosion, the South Province is made up of more than 60% by areas where the slope is between 10° and 40°. Even if the zones where the slope is greater than 40° are very much in the minority, they are critical zones with regard to erosion and should be studied separately (particularly for the 70° to 80° slope class). The zones where the slope is greater than 30° in the Southern Province would require an approach, at the level of technical image acquisition (drone vs satellite), allowing to limit the impact of topographic shadows (i.e. Bouloupari, Thio and Païta). Although the areas with slopes of 40° to 50° constitute a small part of the Southern Province (5%), they are the focus of particular attention because of the significant proportions of critical forms of erosion found there (i.e. isolated gullies and uncontrolled discharges).

Among the sectors to be prioritized in erosion management, there are a number of possible scenarios. There are sectors where erosive pressure is significant (measurable by the proportion of bare or poorly vegetated soil), but where anthropogenic pressure (measurable by the proportion of infrastructures) is less (i.e. Ounia and Kouakoue). There are also sectors where erosive pressure and anthropogenic pressure are both significant (i.e. Mont-Dore) or moderate to low (i.e. Tontouta). In addition to these different scenarios, do exist aggravating natural factors such as, the high proportion of very sloped areas (i.e. Boulouparis, Thio and Païta), high annual rainfall (i.e. Ounia and Kouakoue) or the presence of ultramafic substratum (i.e. South and East coast of the South Province). Additional indicators, such as the proportion of sediments — visible because of their emergent nature — can testify to both the material transport and the intensity of that transport.

The importance of distinguishing between areas with a higher proportion of impermeable surfaces and those fitted out in greater proportion with other types of non-impermeable infrastructures (track, quarry, etc.) is crucial. Indeed, the waterproofed surfaces do not (no longer) release materials. On the other hand, surfaces on the periphery of waterproofed surfaces can constitute starting zones of erosive phenomena. In civil engineering and during road construction, the implementation of water management is a basis, above all, to preserve road integrity.

In the Southern Province, the hydrographic regions of Tontouta and Dumbéa are areas to be closely monitored due to flood risk and drinking water resources. Monitoring of areas upstream of dams (i.e. Dumbéa) or water catchment points is essential — and is already underway (Cf. DAVAR site).

The commune of Mont-Dore has proved to be an area where erosion has left its mark on the soil. It is an area high human presence, and it also has drinking water resources that are exploited. Facts that make it an area to be prioritized.

The commune of Yaté, although showing signs of erosion as well as anthropic activities, the areas of bare soil are mostly on gentle slopes (periphery of Lake Yaté) or then subjected to harsh conditions explaining the presence of bare soil (wind and rain). The commune of Yaté also has many sanctuarized zones (protected areas and areas inaccessible by land). The commune of Yaté is therefore a sector to be monitored.

5 General Conclusion

The provincial erosion mapping data for the year 2018, is a complete, complex and remarkably accurate data (i.e. 100 m2 CMU). The production and processing of this data has mobilized many means and resources (material and human). While the results presented here reveal the importance of developing this data, an overall analysis of erosion numbers and figures contributing to erosion in the Southern Province emerges. Thanks to the accuracy of this mapping, the study of erosion processes can be studied by focusing on key areas and a possible perspective. The observation and monitoring of erosion are essential points to apply adequate management.

With the sole, anthropocentric objective of maintaining a high life quality level for New Caledonians, management measures in front of soil erosion will need to be prioritized. First of all it is important, for the safety of the inhabitants, to avoid the risks linked to the contamination of drinking water as well as the risks of flooding in the inhabited areas. Secondly, and in order to avoid the spread of erosive phenomena, vigilance should be increased in areas where there is a high level of human activity and a high proportion of bare soil near humans facilities. It is also important to include in the prioritization the factors aggravating erosion (slope, wind, rain, substrate, ...). Equally important is the no less anthropocentric objective of conserving a unique natural heritage. The conservation of such areas offers the possibility of orienting economic activities towards the development of "green tourism" and preparing New Caledonia for the eventual "post-mining" period.

The management of bare soil against erosive processes is costly and can involve long processes (plant growth after re-vegetation). Therefore, the best management measure is to avoid soil degradation and when this is not possible the impact must be limited (water management, pouring control, ...). As far as already degraded areas are concerned, advances

in restoration and re-vegetation techniques (efficiency, cost reduction) can only be reinforced by projects such as the erosion mapping presented here.

Acronyms

BD-TOPO-NC : Base de Données Topographique de Nouvelle-Calédonie (New Caledonia topographic database)

BI : Brightness Index (Indice de Brillance)

DAVAR : Direction de Affaires Vétérinaire Alimentaires et Rurales de Nouvelle-Calédonie (department of veterinary affairs)

DEM : Digital Elevation Model (MNT : Modèle Numérique de Terrain)

DIMENC : Direction de l'Industrie des Mines et de l'Energie de Nouvelle-Calédonie (department of mining affairs)

DITTT : Direction des Infrastructures, de la Topographie et des Transports Terrestres de la Nouvelle-Calédonie (department of topographic and tranports affairs)

DTSI : Direction des Technologie et des Services de l'Information de la Nouvelle-Calédonie (Department of information an technology affairs)

EPSG : European Petroleum Survey Group (liste des systèmes de coordonnées géoréférencées et des codes associé pour les identifier, on parle de « Codes EPSG »)

GIS : Geographic Information System (SIG : Système Information Géographique)

HR : Hydropgraphique Region (RH : Région Hydrographique)

INRAE : Institut National de la Recherche pour l'Agriculture/l'Alimentaire et l'Environnement

MMU : Minimum Mapping Unit (UMC : Unité Minimale de Cartographie (ou Collecte))

NA : Non Applicable

NDVI : Normalized Difference Vegtation Index (indice de végétation par différence normalisée)

NDWI : Normalized Difference Water Index (indice d'eau par différence normalisée)

OEIL : Observatoire Environnemental en Nouvelle-Calédonie

SARVI : Soil and Atmospherically Resistant Vegetation Index (NDVI amélioré pour pallier les effets du sol et de l'atmosphère)

SP : Southern Province (PS : Province Sud)

SPOT : Système Probatoire d'Observation de la Terre

UNC : Université de la Nouvelle-Calédonie (University of New Caledonia)

UNESCO : United Nations Educational, Scientific and Cultural Organisation (Organisation des Nations unies pour l'éducation, la science et la cultur)

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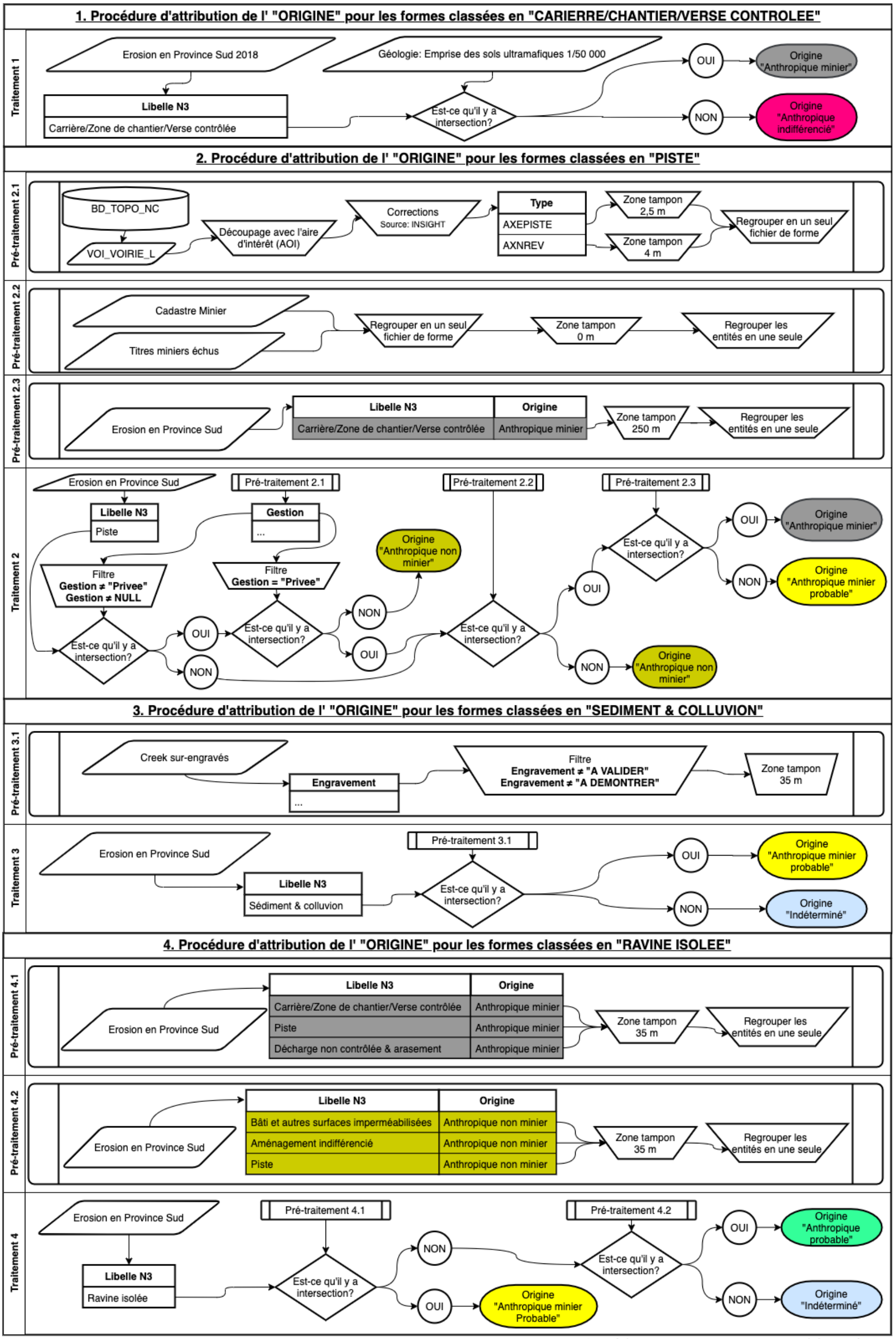
Annexes

Questions	Traitements	Echelles
Quel est le pourcentage/ la surface de formes érosives ?	• SIG sur la donnée • Excel (tableur) • Utilisation de l'attribut « Libelle_N3 »	Administratives : ☒ Province ☒ Communes ☒ Aires coutumières Environnementales : ☒ Géologie (les 3 grands types de roches) ☒ Hydro-Eco-Région ☒ Régions Hydrographiques ☒ Zones Clé de Biodiversité terrestre (ZCB) Gestion (zones protégées et labélisées) : ☒ Aires protégées ☒ Zone RAMSAR ☒ UNESCO zones tampons terrestres ☒ Périmètres de protection des eaux Pressions/Facteurs : ☒ Altitude (provinciale ; classes d'altitude avec un pas fixe) ☒ Pente (provinciale ; classe de pente avec un pas fixe) ☒ Pluviométrie (provinciale) ☒ Incendies
Dans quelles proportions et surfaces les formes érosives se répartissent-elles au regard de leur « origine » ?	• SIG sur la donnée • Utilisation de l'attribut « Origine »	
Quelles est le linéaire hydrographiques (Talwegs) sous influence de figures érosives ?	• SIG • Utilisation d'une couche Bassin versant développée par le BRGM • Utilisation de l'ordination des Talwegs (couche développée par le BRGM)	Administratives : ☒ Province
Quelles sont les caractéristiques moyenne des formes par classe de niveau 3 (surface, pente, altitude, pluviométrie) ?	• SIG sur la donnée • Utilisation de l'attribut « Classes_N3 »	Administratives : ☒ Province
Quels sont les objets remarquables ?	• SIG • Utilisation de l'attribut « Classes_N3 »	Administratives : ☒ Province
Quelles sont les différents moyens suplémentaires permettant de contrôler la donnée ?	• SIG • Croisement avec des cartographies « antagonistes » (i.e. là où il y a de la végétation il n'est pas censé y avoir de figures d'érosion détectées) • Calcule d'indice de forme (Gravelius, Morton) permettant de déterminer si les formes sont plutôt « allongées » ou « compactes »	Administratives : ☒ Province Couche de croisement « antagoniste » : ☒ Végétation en province sud (MOS 2014): herbacée, arbustive, arborée

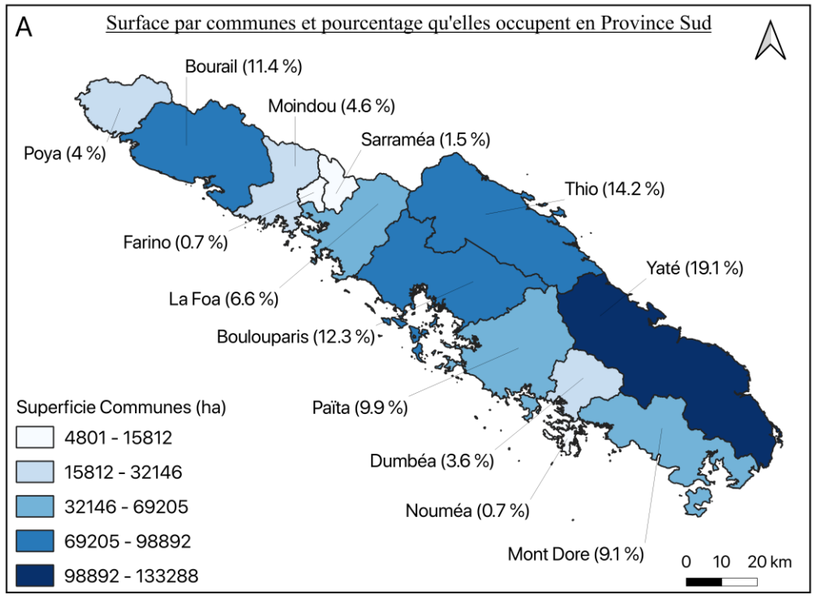
Annexe 1 : Table of identified analyses to be carried out

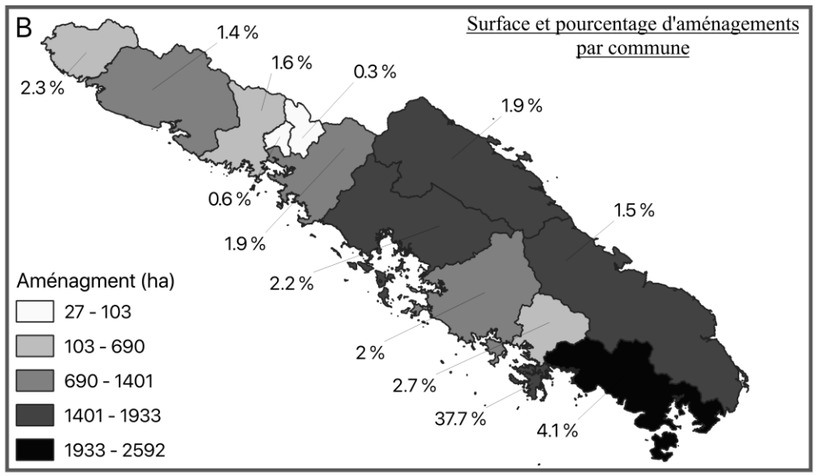


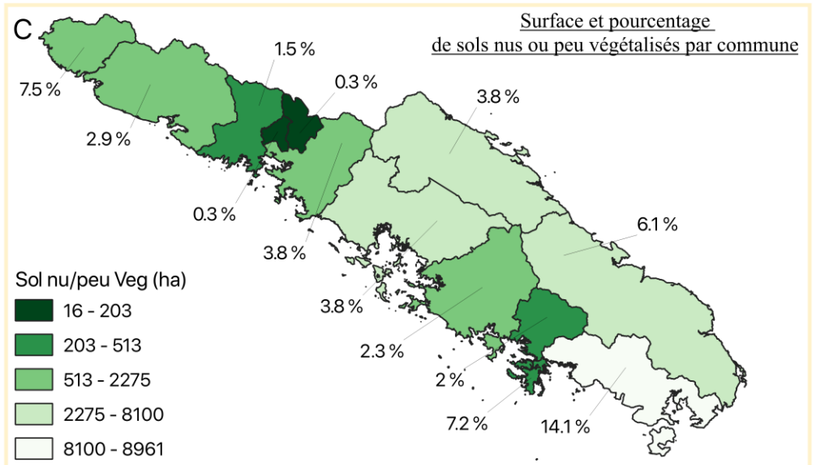
Annexe 2 : Decisionrules for origin attribution (Version : 27/11/2020)

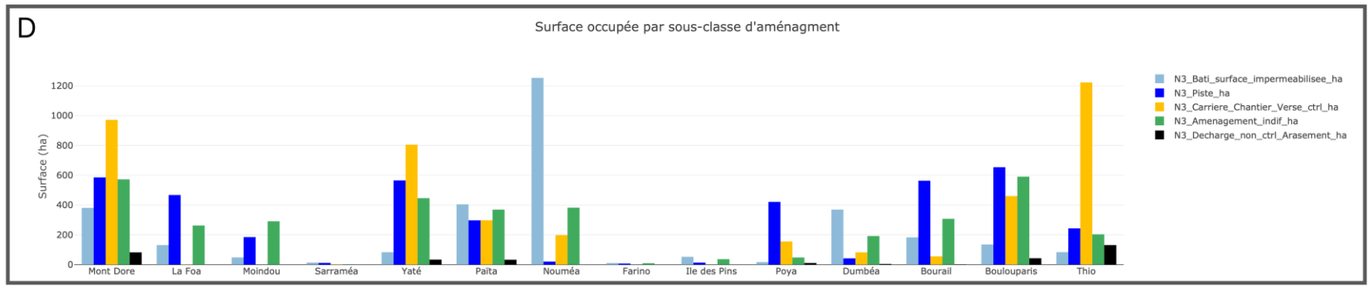
Caratérisation de l'érosion à l'échelle des communes en Province Sud (2018)

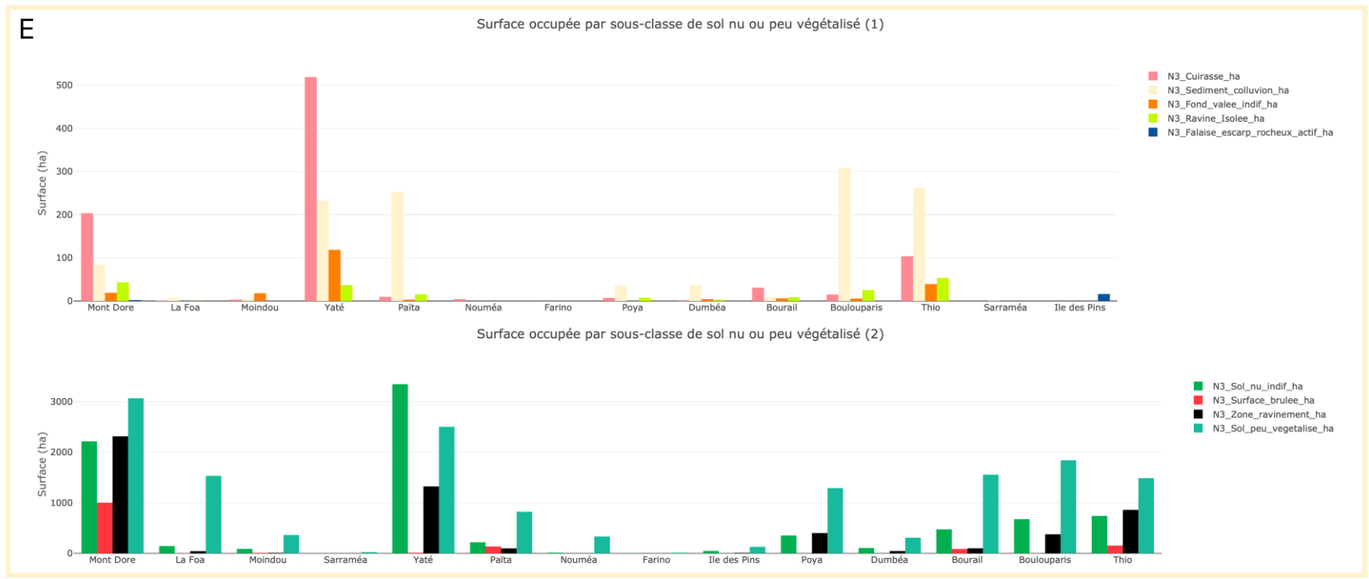
Arnaud DUBOIS; Master GESPE UNC; le 04/12/2020; Sources: OEIL, INSIGHT, GNC

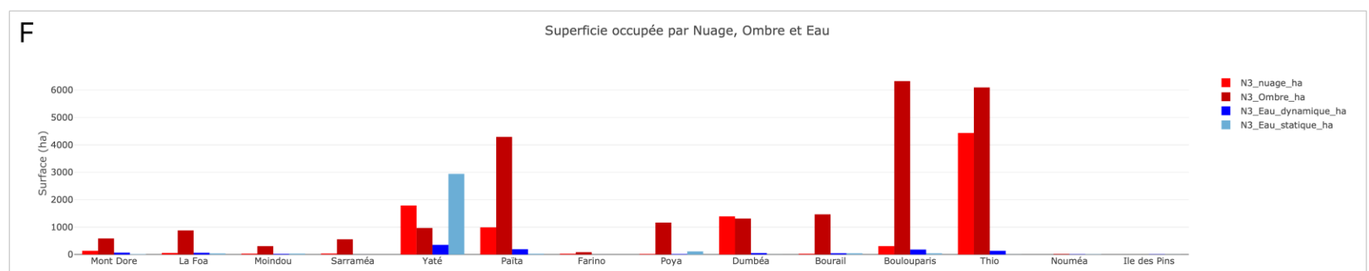


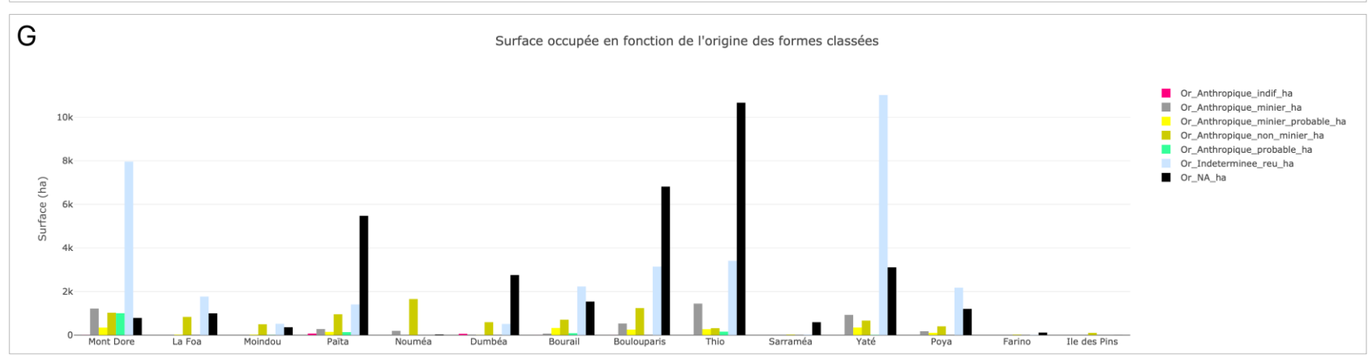








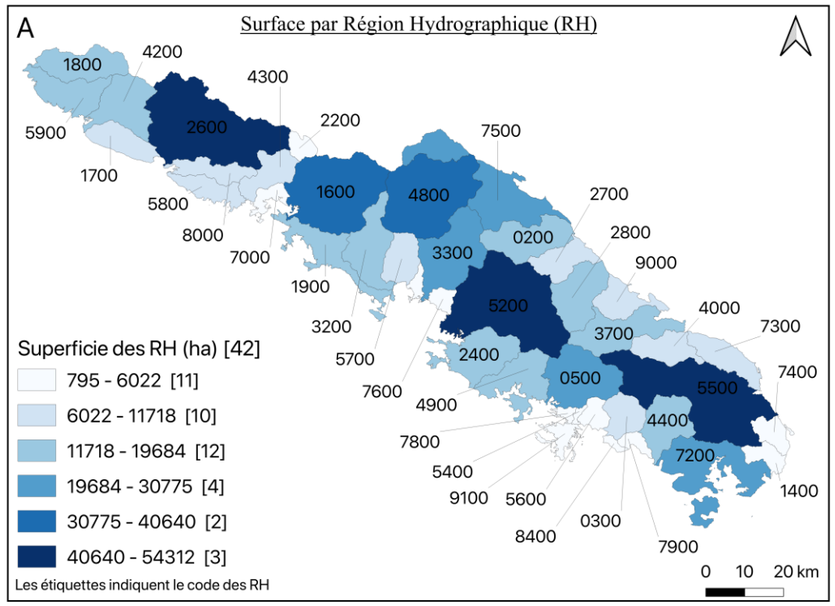


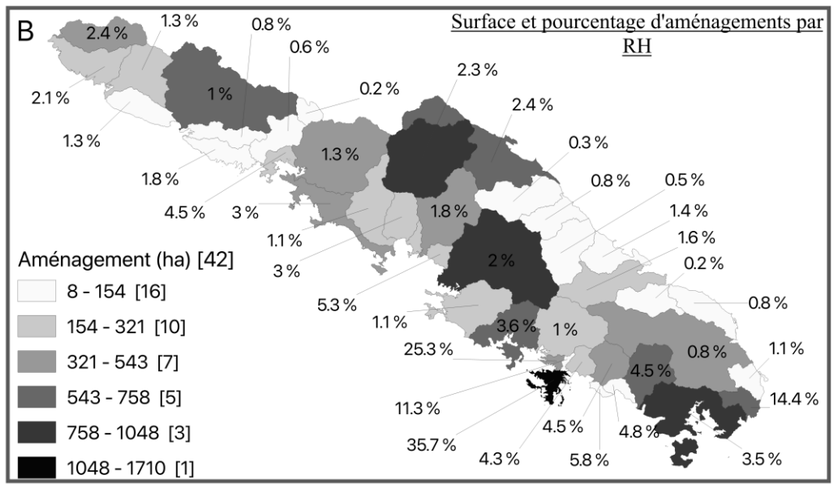


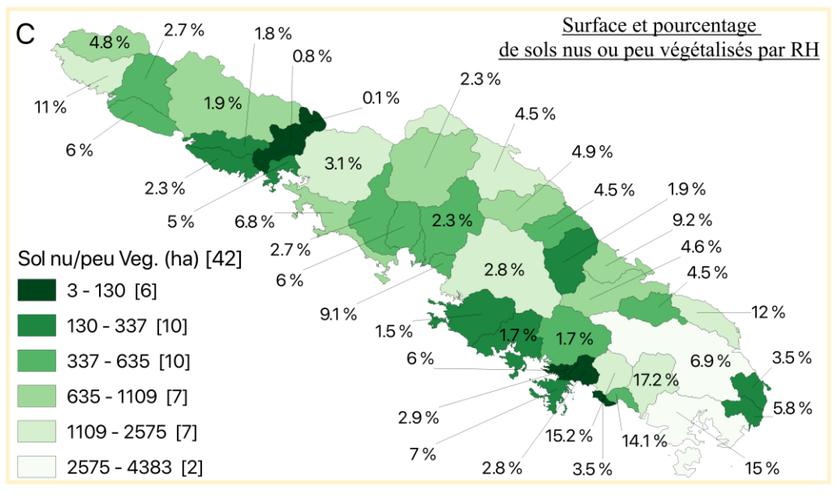
Annexe 3 : Erosion characterization at municipalities scale in the Southern Province

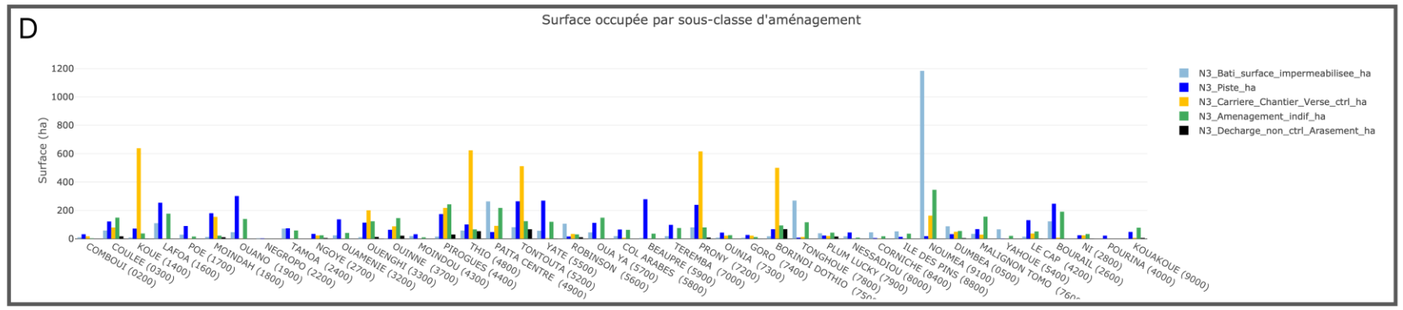
Caractérisation de l'érosion à l'échelle des Régions Hydrographiques (RH) en Province Sud (2018)

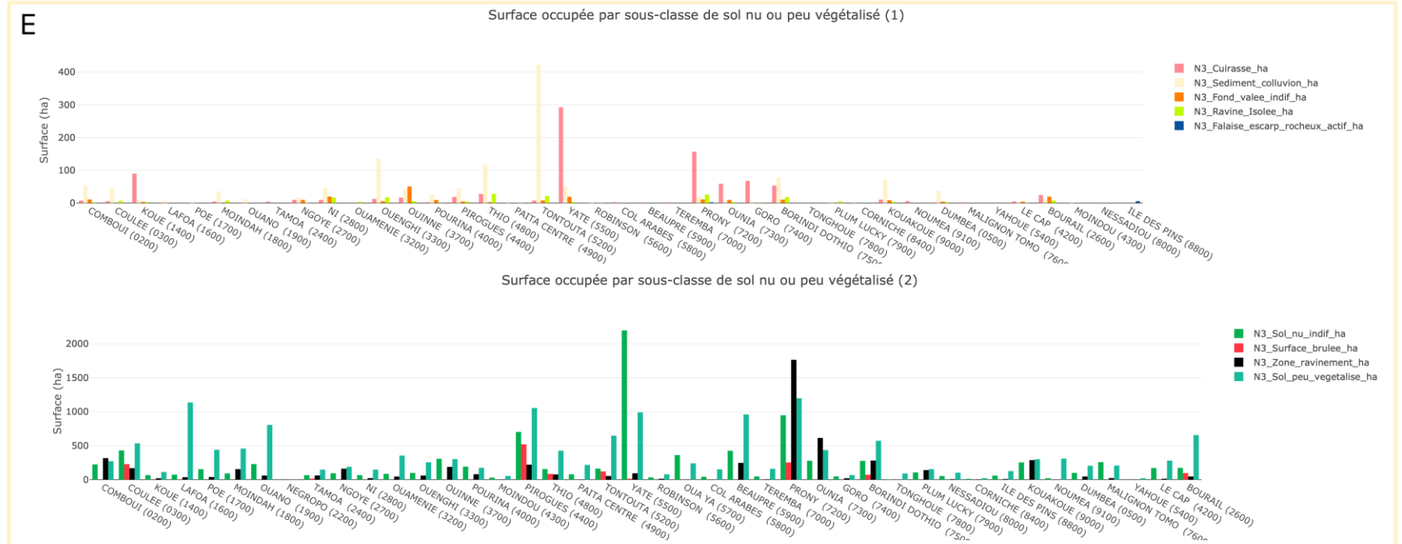
Arnaud DUBOIS; Master GESPE UNC; le 02/12/2020; Sources: OEIL, INSIGHT, GNC

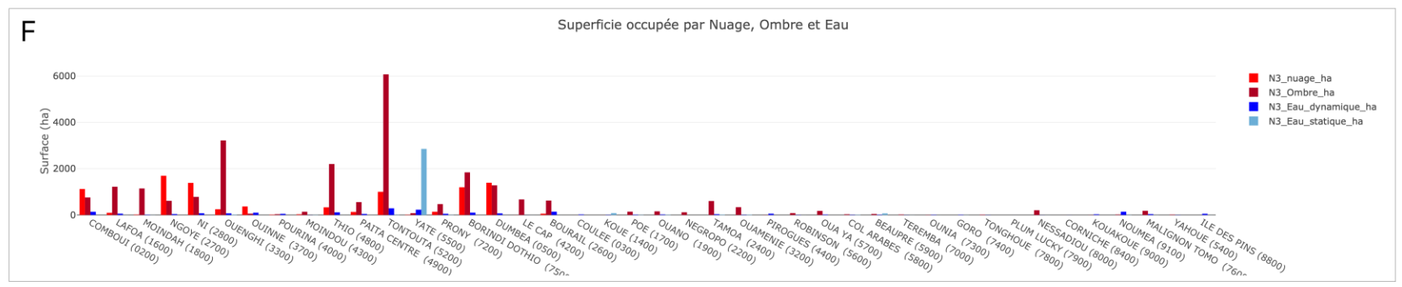


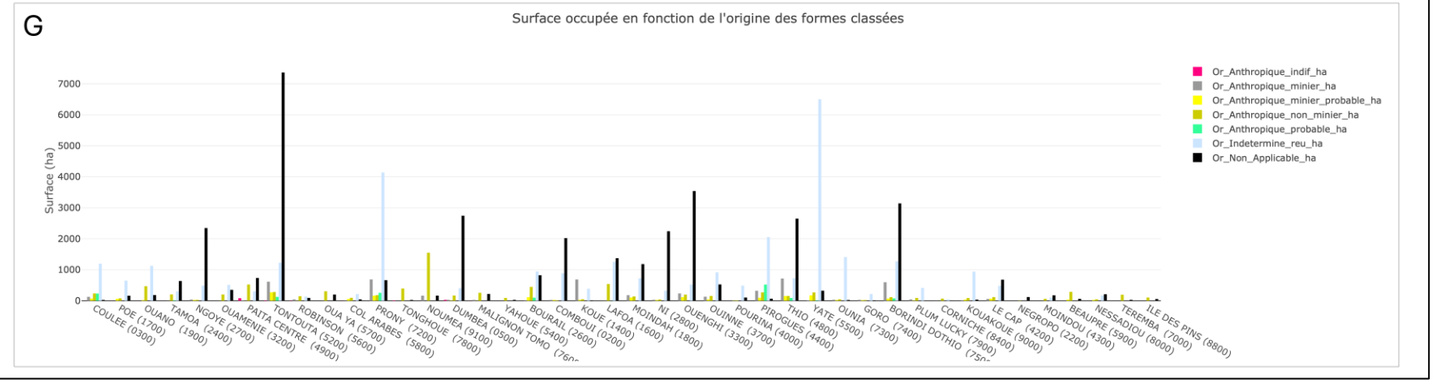












Annexe 4 : Erosion characterization at the scale of the Hydrographic Regions (HR) in the Southern Province