Inputs and application of an automated multi-class segmentation of the Cassini land use map (XVIIIth c.) to the understanding of landscape and river dynamics at the end of the LIA

Apports et application d'une segmentation multi-classes automatisée de la carte d'occupation des sols de Cassini (XVIIIe s.) à la compréhension de la dynamique paysagère et des rivières à la fin du LIA.

Martinez T[1], Hammoumi A[2], Ducret G[1], Berger JF[3], Moreaux M[2], Deschamps R[1]

1 : IFP Energies nouvelles, 1 et 4 avenue de Bois-Préau, 92852 Rueil-Malmaison, France.
2 : IFP Energies nouvelles, Rond-point de l'échangeur de Solaize, 69360 Solaize, France
3 : EVS, Université Lumière Lyon II, CNRS : UMR5600, 18 Rue Chevreul 69007 Lyon, France
* theo.martinez@ifpen.fr

RÉSUMÉ

Dans le cadre d'une modélisation stratigraphique et volumétrique de la construction du delta du Rhône, il est nécessaire de connaitre l'évolution du bassin versant associé, le bassin rhodanien. Pour les derniers siècles, de nombreuses cartes géographiques, reflétant l'occupation des sols, ont été réalisées et sont aujourd'hui géoréférencées. Elles permettent d'observer l'état du bassin versant rhodanien à différents stades de son évolution récente. La carte de Cassini est la première carte nationale d'occupation des sols. Réalisée à la fin du XVIIIe siècle, elle offre une vision des différents types d'occupations avec une précision convenable. Les forêts, les landes et les zones d'arboriculture ont été segmentées automatiquement pour obtenir leur répartition sur l'ensemble du bassin (100 000 km^2). Pour faciliter l'observation de la structuration des paysages et de l'état de l'occupation des sols, plusieurs sous-bassins ont été définis. Une comparaison est faite avec des données récentes à partir de la carte du Corine Land Cover 2018, reflet du paysage actuel. Les résultats illustrent cette période de faible boisement et de forte activité hydrologique, responsable d'une métamorphose prolongée de son lit vers le tressage dans la majorité de son cours. Ces résultats sont la première étape d'une étude visant à reconstituer le potentiel d'érosion dans le bassin versant à la fin du XVIIIe siècle et l'évolution des volumes sédimentaires alluviaux en transit, lors du Petit Age Glaciaire.

ABSTRACT

Within the framework of a stratigraphic and volumetric modeling of the construction of the Rhone delta, it is necessary to know the evolution of the associated watershed, the Rhone basin. For the last few centuries, many maps reflecting land use have been made and are now georeferenced. They allow us to observe the state of the Rhone basin at different stages of its recent evolution. The Cassini map is the first national land use map. Made at the end of the 18th century, it offers a vision of the different types of occupations with a suitable precision. Forests, moors and arboriculture areas (vineyards, olive groves) were automatically segmented to obtain their distribution over the entire basin (100,000 km2). To facilitate the observation of the landscape structure and the state of land use at the end of the 18th century, several sub-basins have been defined. A comparison is made with recent data from the Corine Land Cover 2018 map, reflecting the current landscape structuring. The results illustrate this period of low afforestation and high hydrological activity, responsible for a prolonged metamorphosis of its bed toward braiding in most of its course. These results are the first step of a study aimed at reconstructing the erosion potential in the watershed at the end of the 18th century, and the evolution of the alluvial sedimentary volumes in transit, in the middle of the Little Ice Age crisis.

KEYWORDS

Cassini map, Corine Land Cover, Land use, Rhone basin, Semantic segmentation

1 INTRODUCTION

Understanding the current state of a territory's occupation requires knowledge of its state in past periods. Tracing the landscape evolution of a territory over time allows us to understand the physical parameters that interact, such as the alteration and erosion of soils, the transport of liquid and solid flows, or the formation and evolution of sedimentary deposits in transitional storage areas, after having passed through the filter of the vegetation cover and its different spatial structures. Moreover, the knowledge of the state of the land cover allows to measure the modalities of the anthropic pressure such as the displacement in space and in time.

The Rhone delta is a zone at the land/sea interface directly impacted by variations in sedimentary inputs from the watershed and eustatic variations modulating the coastline. It is therefore essential to trace the land-use over the last few centuries in the entire watershed, to better estimate the human spatial imprint in the middle of the paleo-anthropocene. This will provide a substantial information database for assessing natural risks and hazards in the past, and thus help to define guidelines for forecasting.

The Little Ice Age (LIA) is an extensive climatic crisis between the 14th and 19th centuries, characterized by a temperature decrease of 0.6°C across the northern hemisphere, inducing an advance of glaciers in the Alps, a general metamorphosis of river systems in the floodplain of the Rhone and its main tributaries, land-use changes with a high rate of deforestation in the main part of the basin up to high elevations, a high frequency of floods, and a high rate of erosion in the watershed.

2 MATERIALS AND METHODS

2.1 Cartographic support

The first national map made in France is the Cassini map. It was made in the second half of the 18th century AD, King Louis XV having entrusted this work to the Academy of Sciences to specify the limits and organization of the kingdom of France. These maps represent cities, villages, hamlets, communication routes, artisanal activities, industries, forest cover and vegetation as well as the topography. This work was made possible by the combination of two processes, topographic rendering, and triangulation work with a resolution of 1/86.400. This map was designed to present a comprehensive view of the land use of the French territory at the peak of the climatic crisis of the LIA and during the strongest historical anthropic pressure on the Rhone-Western Alps and Central Massif landscapes.

Several classes were defined to quantify the state of land use at the end of the 18th century. The segmentation of the Cassini map was done considering 4 classes: Forest, Heath, Arboriculture, Hydrological network. The classes are composed of several subtypes: The forest gathers the figures of trees, wood, garenne, pines, fir trees; Health gathers the moors, the scrub and the marshes; Arboriculture gathers olive trees and vineyards. They were defined based on their soil erosion potential for future studies throughout the watershed. To allow a spatial comparison of soil distribution, 7 sub-basins have been defined: Saône, Durance, Isère, Cévennes, Rhône Upstream, Middle Rhône valley, Rhône Downstream. These sub-basins are characterized by different morphostructural and hydroclimatic conditions (Bravard et al., 2008a).

2.2 Semantic segmentation

To analyze the Cassini map, a deep convolutional neural network approach was chosen. It allows to detect texture variations on the map and to associate each pixel with a class or to the map background. The U-Net++ is an improved version of the U-Net which is a famous encoder-decoder network architecture. In both architectures, spatial resolution lost during the contraction path is partially recovered through skip connections, enabling the concatenation of approximative and abstract feature maps of the encoder with accurate and low-level feature maps of the decoder. However, U-Net++ has proposed redesigning skip pathways to minimize the semantic gap between the encoder and decoder. In this configuration, the two paths are connected through a series of nested, dense skip pathways fast-forwarding high resolutions features maps from the encoder to the decoder.

The training dataset contains 30 images of the size (2571 x 1743) for each class with a manual segmentation. Due to the limited number of images, a patch-based training was conducted by using a set of (128 x 128) half-overlapping patches. During inference, a stochastic distribution process of patches is performed to overcome artifacts at the edges (Hammoumi et al., 2021). For 20 epochs, the

network was monitored using the binary cross entropy loss function and the Adam optimizer with a learning rate of 3e-4. On a laptop with a processor Intel(R) Core(TM) i7-8850H CPU @ 2.60GHz 2.59 GHz, the execution time of the training is less than 4 hours per class.

3 RESULTS AND DISCUSSION

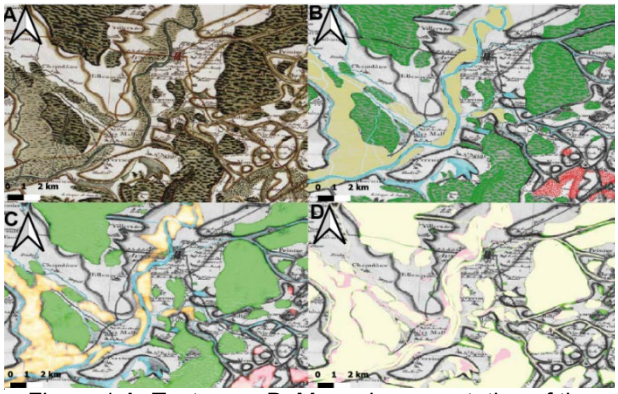

Figure 1 A: Test area, B: Manual segmentation of the different classes, C: Results of the semantic segmentation, D: Comparison between the two segmentations, yellow = same detection, red = missing detection, green = additional detection

The main interest of the segmentation of the Cassini map is to obtain a global surface quantification of the Rhône watershed during a climatic crisis at a time when aerial photographies and satellite imagery did not exist (Figure 1). On 4 test areas, the correspondence between manual and semantic segmentation is 94.7% for forests, 88.2% for heaths, 91.4% for arboriculture and 84.2% for hydrology with an average confidence index for all classes of 96.7%. A direct comparison is possible with the Corine Land Cover (CLC) map (Table 1). The data show a forest area 2.5 times smaller at the end of the eighteenth century than today, the moors 1.7 times smaller, the arboriculture 1.8 times smaller. For the hydrological network it is the opposite, it is 5.8 times more extensive in the eighteenth century than today. This work is carried out within the framework of a geomorphological study of the Rhone delta requiring an understanding of the recent evolution of the Rhone watershed. The results of the semantic segmentation indicate a good representativeness on the whole Rhône watershed. They provide first results for a quantification of the erosive potential of the Rhône watershed at the end of the 18th century. However, it is not possible to do this immediately because the total of the identified classes covers 28.1% of the watershed surface, as the Cassini map presents numerous areas which seems to correspond mainly to arable land and grassland areas. Moreover, the departments of Savoie and Haute-Savoie are missing because they were independent at this period (Duchy of Savoy). To fill this lack, the complementary study of old maps like the Napoleonic cadastre (onset of 19th century) or the Sardinian map (end of 18th century) should be considered. A first spin-off of this work of surface restitution of river beds will be to estimate the volumes of sedimentary flux in transit in the Rhone corridor, from the Cassini river width projections, the geophysic (radar images) and sedimentary cores records already obtained in the middle and upper Rhone valley (OHM and OSR 4/5 data). Then in a second step, when the whole watershed of the late eighteenth century will be associated with the land use, the erosion model RUSLE (Panagos et al., 2015) already used on the CLC will be associated with the Cassini map. This will then provide an erosive budget for the Rhone basin the end of the LIA climate crisis.

B		Forest	Heaths	Arboriculture	Hydrology	Total
Saône	Cassini	17,1%	3,1%	0,6%	7,2%	28,1%
	2018	34,5%	0,8%	1,9%	0,9%	38,1%
Upstream Rhone	Cassini	19,6%	1,5%	0,3%	7,5%	29,0%
	2018	44,0%	2,8%	0,3%	1,4%	48,5%
Middle Rhone	Cassini	14,0%	2,3%	2,2%	8,3%	26,7%
	2018	35,5%	5,4%	6,6%	1,0%	48,5%
Isère	Cassini	16,3%	6,1%	1,4%	7,0%	30,8%
	2018	34,3%	11,2%	1,0%	0,6%	47,2%
Durance	Cassini	12,9%	3,2%	3,2%	5,4%	24,7%
	2018	39,1%	18,9%	2,9%	0,5%	61,5%
Cévènnes	Cassini	7,7%	5,6%	4,7%	5,2%	23,3%
	2018	51,5%	12,9%	9,0%	0,3%	73,8%
Downstream Rhone	Cassini	8,4%	17,9%	6,5%	9,0%	41,8%
	2018	15,0%	14,3%	17,2%	6,9%	53,4%
Watershed	Cassini	14,7%	4,3%	2,1%	7,0%	28,1%
	2018	36,8%	7,6%	3,8%	1,2%	49,4%

Table 1 Presentation of the results for each class and each sub-basin.

4 CONCLUSION

The Cassini map gives us a lot of information about the occupation of the land at the end of the 18th century. Thanks to the semantic segmentation, precise results are obtained quickly. Forests cover 14.7% of the watershed, 2.5 times less than today. The moors 4.3% or 1.7 times less than today. Arboriculture 2.1% or 1.8 times less than today. Hydrology 7% or 5.8 times more than today. There is therefore a very low afforestation rate and a very important hydrological activity in the 18th century compared to today. The contribution of new data thanks to the Sardinian and Napoleonic cadastral maps are very good supports to try to calculate an erosion potential on a basin of 100 000km2 during the climatic crisis of the Little Ice Age.

LIST OF REFERENCES

Bravard, J.P., Provansal, M., Arnaud-Fassetta, G., Chabbert, S., Gaydou, P., Dufour, S., Richard, F., Valleteau, S., Melun, G. and Passy, P. (2008a). Un atlas du paléo-environnement de la plaine alluviale du Rhône de la frontière suisse à la mer. Collection EDYTEM6, Cahiers de Paléoenvironnment, Chambéry, 101-106

Hammoumi, A., Moreaud, M., Ducotter, S. and Desroziers, S. (2021). Adding geodesic information and stochastic patchwise image prediction for small dataset learning. Neurocomputing, Volume 456, 481-491

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., ... and Alewell, C. (2015). The new assessment of soil loss by water erosion in Europe. Environmental science & policy, 54, 438-447