Feasibility of remote sensing techniques for assessing an open-cast coal mine reclamation project in La Jagua de Ibirico, Colombia

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1.Introduction

It is a fact that mining activities produce direct and indirect impacts to natural environment around the mineral extraction sites and it affects the population who live in communities nearby. Subsequently it grows a necessity of palliate the intensity of these impacts in order to maintain and improve the state of the ecosystems and wellbeing of people who is perturbed by the mining activities.
Remote sensing act as a fundamental tool for assessing the land management in order to maintain an equilibrium between the production to cover the necessities of the society and the conservation of the ecosystems.

2. Aim & objectives

Aim:

- To assess the feasibility of remote sensing techniques for assisting the decision-making process in an open-cast coal mine reclamation project near the town of La Jagua de Ibirico, Colombia.

Objectives:

1. Create a 2015 land cover map (CORINE Land Cover adapted to Colombia) using supervised classification of 2015 Landsat 8 OLI imagery.
2. Generate a stratified random sampling to validate the map through fieldwork.
3. Perform a land cover change analysis (since before the mine started to be industrially exploited until present days) including Landsat 5 TM imagery from 1986 and 2001, along with the 2015 Landsat 8 OLI imagery.
4. Eventually stablish recommendations regarding the feasibility of remote sensing techniques for future reclamation projects in Colombia.

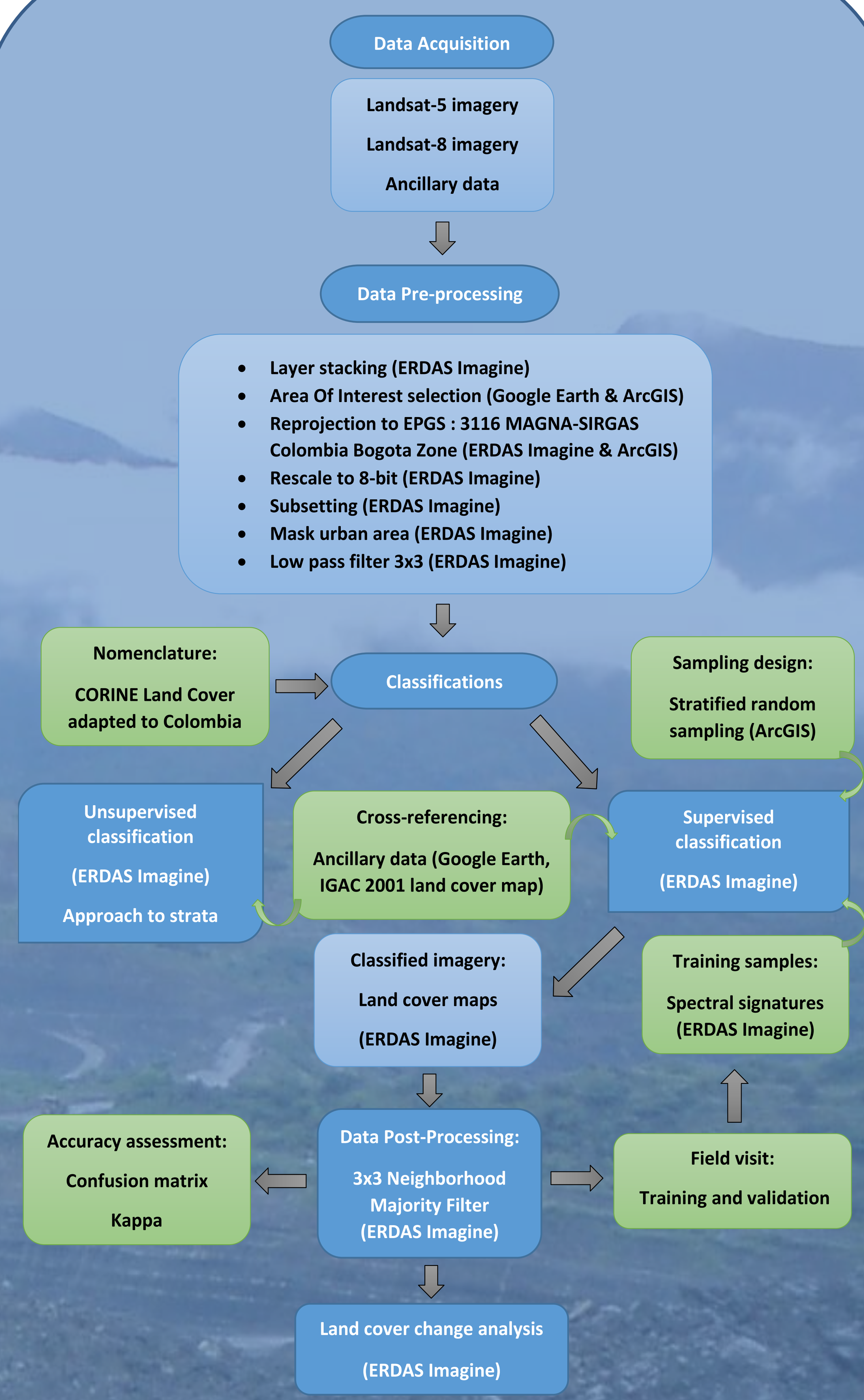

Figure 6. Land cover change analysis methodology

3. Methods

The area of study is located inside the area of influence of La Jagua open-cast coal mine (9° 34' 59'' N, 73° 17' 04''W), at Northeast of Colombia, in Cesar department. This area includes the towns La Jagua de Ibirico, La Victoria de San Isidro and Estados Unidos (Figure 3). The 2015 supervised land cover classification of Landsat 8 OLI image is shown in Figure 5. The methodology followed for the land cover analysis is shown in Figure 6.

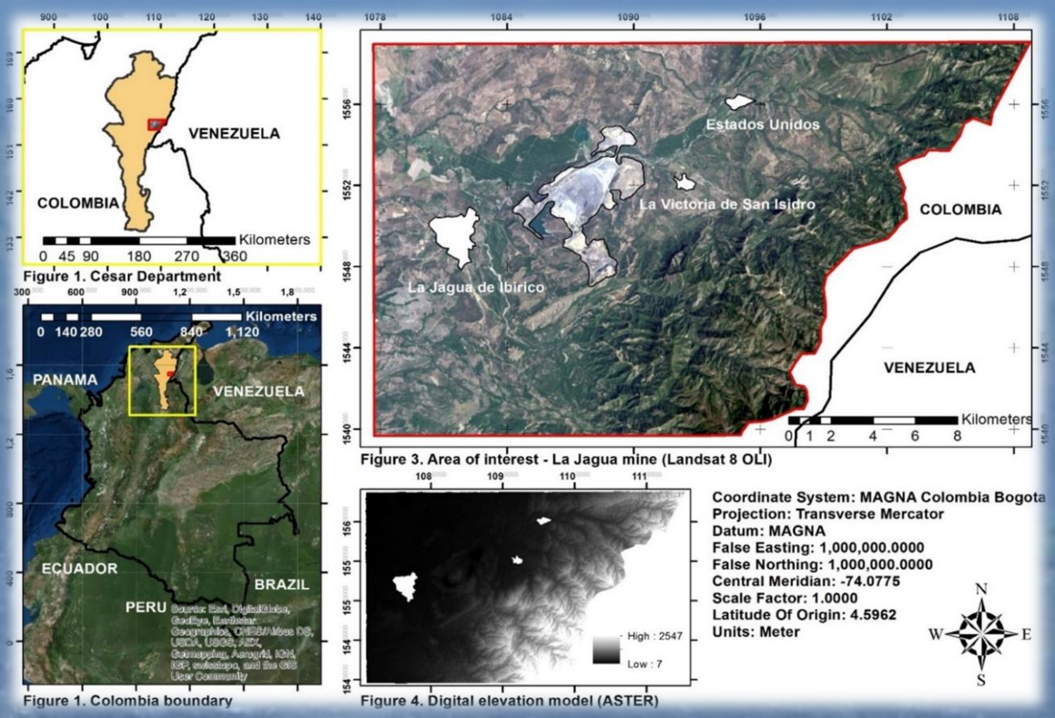

Figure 1. Colombia boundary
Figure 3. Area of interest - La Jagua mine (Landsat 8 OLI)
Figure 4. Digital elevation model (ASTER)

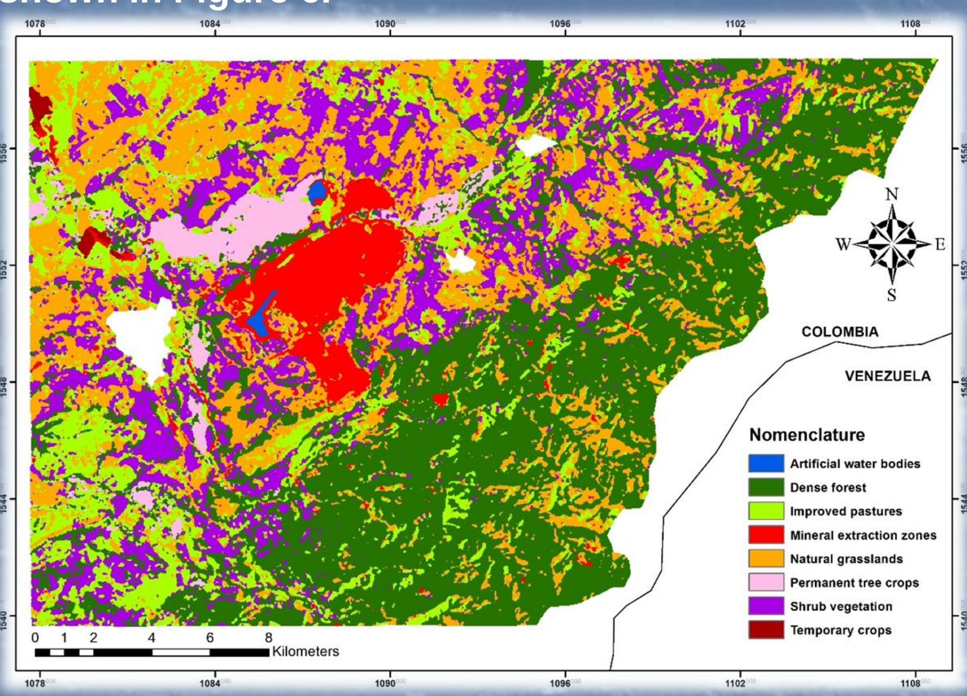

Figure 5. Supervised classification 2015 Landsat 8 OLI

Land cover nomenclature	CLCC Code
Mineral extraction sites	1.3.1
Temporary crops	2.1.1
Permanent tree crops	2.2.3
Improved pastures	2.3.1
Dense forest	3.1.1
Natural grassland	3.2.1
Shrub vegetation	3.2.2
Artificial water bodies	5.1.4

Table 1. Nomenclature scheme

Land cover nomenclature used in this study (Table 1) is based on CORINE Land Cover adapted to Colombia (CCLC) by Institute of Hydrology, Meteorology and Environmental Studies (IDEAM, 2010).

4. Results & discussion

Satellite	Sample points	Training & validation	Date	Accuracy Measures: Nomenclature	CLC Code	Producer's (Omision)	User's (Commision)	Overall	KHAT
Landsat 8 OLI	51	Fieldwork & Google Earth	2015 Feb	Artificial water zones	5.1.4.	100%	100%	84.3%	0.81
				Dense forest	3.1.1.	78%	88%		
				Improved pastures	2.3.1.	100%	86%		
				Mineral extraction sites	1.3.1.	100%	83%		
				Natural grasslands	3.2.1.	71%	71%		
				Permanent tree crops	2.2.3	100%	67%		
				Shrub vegetation	3.2.2	78%	88%		
				Temporary crops	2.1.1	100%	100%		
Landsat 5 TM	51	Google Earth & IGAC land cover map 2001	2001 Jan	Artificial water zones	5.1.4.	100%	100%	80.4%	0.76
				Dense forest	3.1.1.	92%	75%		
				Improved pastures	2.3.1.	60%	86%		
				Mineral extraction sites	1.3.1.	100%	83%		
				Natural grasslands	3.2.1.	75%	86%		
				Permanent tree crops	2.2.3.	100%	100%		
				Shrub vegetation	3.2.2.	78%	88%		
				Temporary crops	2.1.1.	0%	0%		
Landsat 5 TM	51	Landsat 5 TM	1986 Jan	Dense forest	3.1.1.	94%	88%	76.5%	0.70
				Improved pastures	2.3.1.	75%	67%		
				Mineral extraction sites	1.3.1.	0%	0%		
				Natural grasslands	3.2.1.	50%	67%		
				Shrub vegetation	3.2.2.	80%	89%		
				Temporary crops	2.1.1.	80%	100%		

Table 2. Accuracy assessment

After collecting data for 102 points in the field (51 training + 51 for validation), a confusion matrix was calculated along with a kappa analysis, obtaining results shown in Table 2. The overall accuracy and KHAT statistic for 2015 is the highest, due to the use of fieldwork for training and validation, along with the availability of modern imagery in Google Earth, used for cross-referencing the classifications.

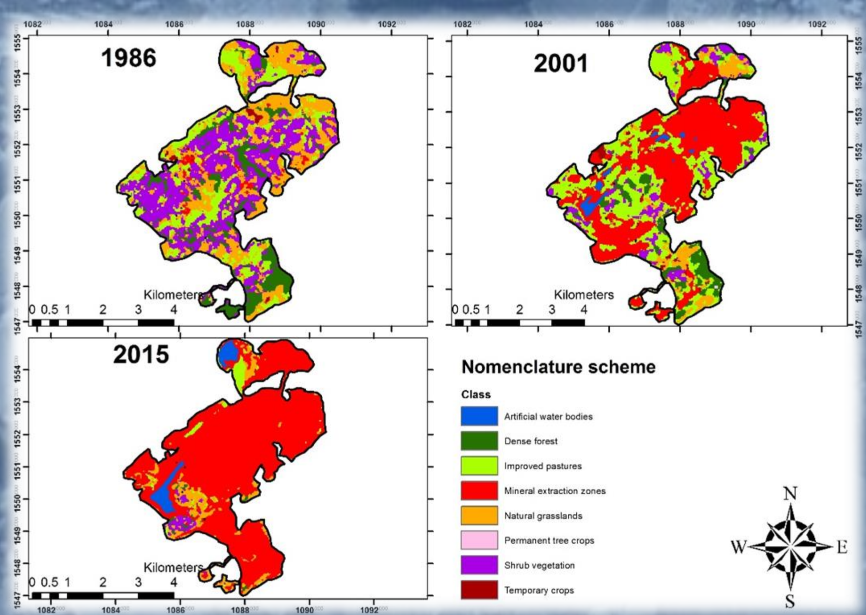

Figure 7. Land cover change over the mine area

Displayed in figure 7 we see land cover change produced inside La Jagua mine area from 1986 to 2015. It is possible to observe a place at the Southwest of the mine where natural vegetation occupies space previously active for mineral extraction. There is natural revegetation in this area along with a reforestation process started in the early 2000's with native tree species, trying to revegetate the rock dumps of waste material produced in the mine.

In figure 8 is examined the quantification of the area of La Jagua mine in hectares (x-axis) and Corine Land Cover Code used (for the supervised classification y-axis) of the three dates.
The mineral extraction sites have increased in 1739ha from 1986 to 2015. The overall vegetation has decreased but has increased around reforested areas.

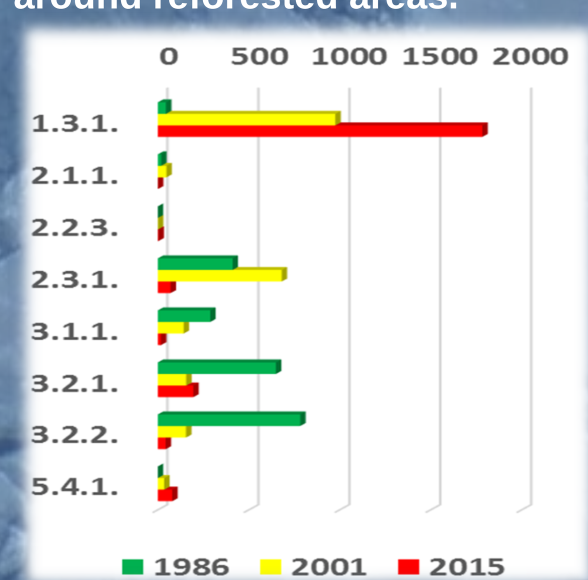

Figure 8. Mine area change (ha)

5. Conclusions & Recomendations

Conclusions:

1. Mid-resolution optical remote sensing techniques, along with the use of Google Earth, are suitable to monitor and assess an open pit reclamation project, although there is some spectral confusion between certain classes such as 1.3.1. Mineral extraction sites and 2.1.1. Temporary crops.
2. The mineral extraction area has increased in 1739ha from 1986 to 2015.
3. It is possible to distinguish between mineral extraction sites and natural or reforested vegetation in the mine. It is useful in this process the use of vegetation indices such as the NDVI (Normalized Difference Vegetation Index).

Recommendations:

1. Validation of the classification accuracy may report better results when using more than 7(*n*) samples, being *n* the number of multispectral bands used for the layer stacking in the image (7 bands for Landsat-8 OLI and 6 bands for Landsat-5 TM for this study).
2. To create more accurate land cover maps some features not defined as classes in the nomenclature of this study (such as rivers, roads, riparian vegetation or bare fields), should be digitized after the supervised classification process.
3. Further investigation about RADAR and objet-oriented classifications is desirable and should be perform in order to test the improvements that they may contribute to this kind of study.

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