Site-specific management approach for reclamation of waste deposits generated by alluvial gold mining in Colombia

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Agroforestry systems have been established for reclamation of these deposits in the gold mining area of El Bagre, Antioquia, Colombia. The main objective of this study is to understand spatial variability of properties of these waste deposits that might affect plant growth and crop productivity to support farmer's decision making regarding fertility management. For this purpose, site-specific management zones were delineated to identify areas within the field with homogeneous characteristics.

Accurate spatial distribution of soil properties was generated through spatial interpolation with ordinary kriging. Spatial principal component analysis and fuzzy cluster classification were performed to delineate management zones. For validation of the management zones, multispectral aerial images captured with an unmanned aerial vehicle were used. Combined analysis of NDVI maps and physicochemical properties of each management zone allowed to classify areas with scarce vegetation associated to highest contents of sand and compaction. The classification of these reclamation areas relates to differences in organic fertility and particle size distribution of the soil, reflected also in the extent of vegetation cover. This integrated analysis can be used to direct site-specific management for the ongoing reclamation process.

1 Introduction

Approximately 80,000 ha are covered by alluvial gold mining waste in Colombia.

Agroforestry systems have been established for reclamation of these areas to support agricultural land use by establishing crops in more fertile areas while bringing non-fertile areas to productivity through the planting of trees.

Figure 1. Dredging operations in alluvial gold mining area (top-left). Waste flattened with heavy machinery (lower-left). Initial stages of restoration through Agroforestry (top-right:). Family of farmers who work in the area (lower-right).

2 Methods

Spatial interpolation, spatial PCA and fuzzy cluster classification were performed to delineate zones with homogeneous characteristics . For validation, multispectral aerial images were used to elaborate maps of vegetation indices and integrate them with ground-based measurements of physicochemical soil properties.

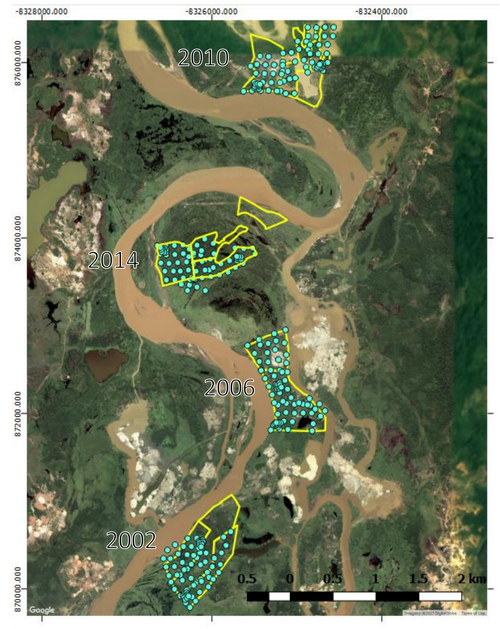

Figure 2. Areas undergoing restoration through agroforestry systems since 2014, 2010, 2012 and 2006.

3 Results

Delineation of homogeneous zones (Figure 3) was carried out in areas covered by gold mining waste undergoing restoration through the establishment of agroforestry systems.

In spite of the high contents of N and OM, there is a lack of the other required nutrients for almost the entire area, explained by the nature of the alluvial deposits that cover the area. Geostatistical analysis (Table 2) show that spatial variability of soil properties reduces with time period since establishment of the restoration areas.

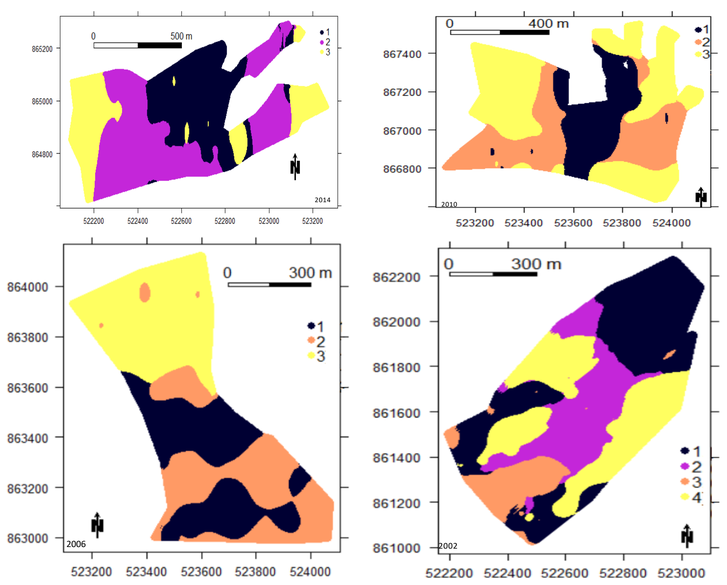

Figure 3. Homogeneous zones map for optimum clusters in areas undergoing restoration since 2014, 2010, 2006 and 2002.

Year	Zone	N (%)	OM (%)	P (mg/kg)	K (cmol/kg)	Sand (%)	Silt (%)	Clay (%)	NDVI
0	1	0.3	7.5	15.1	0.18	84	6	11	0.46
	2	0.3	7.2	12.6	0.04	88	5	5	0.49
	3	0.4	11.2	5.8	0.11	50	31	16	0.77
	p	***	***	***	***	***	***	***	***
12	1	0.2	4.8	9.6	0.13	60	12	14	0.85
	2	0.2	7.2	11.8	0.23	81	8	8	0.84
	3	0.2	11.2	7.0	0.30	45	31	24	0.87
	4	0.1	2.7	17.5	0.11	86	4	6	0.88
	p	***	***	***	***	***	***	***	***

Significance codes: 0 '***', 0.001 '**', 0.01 '*', 0.05 '.'

Table 1. Comparison of delineated homogeneous zones for each time period since establishment of the restoration plots. Mean values of soil properties and NDVI are shown for each delineated homogeneous zone.

4 Conclusion

- The areas undergoing restoration are highly heterogeneous, as shown by geostatistical analysis.
- Heterogeneity represents a challenge for the farmers as identifying areas for crop establishment is difficult.
- High spatial variability of OM, exchangeable cations and P, suggests that the application of amendments should consider this spatial heterogeneity, as the nutrient requirements may significantly differ even within areas of few hundreds of meters.
- Identification of homogeneous zones is the first stage to implement site-specific soil management strategies.
- The delineation of homogeneous zones are a helpful approach to support the farmers in their decision making regarding soil fertility management.
- The spatial heterogeneity of soil properties has to be overcome with the use of amendments prior to revegetation, including fertilizer, organic waste, compost or the use of cover crops.

Property	pH	N	OM	P	K	Ca	Mg	Sand	Silt	Clay	BD	PR
0 years												
τ^2	0.14	0	5.09	-	0.15	0	0.36	0.02	0.01	0	0.01	0.6
σ^2	0.09	0.015	12	-	0.25	4.83	0.58	0.06	0.03	0.01	0.04	0.46
φ (m)	200	173.1	262.1	-	383.3	163.1	202.8	567.1	100	146.5	402.8	77.9
12 years												
τ^2	0.12	0.012	10	20	0.01	1	0.6	0	0.005	0.001	0.03	0.8
σ^2	0.091	0.006	2.74	44.02	0.006	1.22	0.88	0.074	0.035	0.015	0.03	0.86
φ (m)	524.7	178.3	201.2	768.6	200	119.2	526.7	482.8	745.7	157.5	259.9	185.2

Table 2. Geostatistical analysis result for soil physicochemical properties. Maximum likelihood estimation of the parameters of the theoretical variogram: nugget variance (τ^2), partial sill (σ^2), practical range (φ, m).

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