SOIL DEGRADED BY ALLUVIAL GOLD MINING IN THE PERUVIAN AMAZON: CLASSIFICATION APPLYING SOIL TAXONOMY (2014) AND WRB (2015)

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Abstract

Alluvial gold mining in the Peruvian Amazon has become a key driver of land degradation and deforestation. In the Madre de Dios region, known as “the capital of the Peruvian biodiversity”, more than 95,750 ha of old growth forest were degraded in the las twenty years, at the rate of 6000 ha every year. In Fortuna Community, located in this region of the Peruvian Amazon, we classified soils of mine spoils and compared them with nearby soil profiles of undisturbed old growth forest, founding that both impacted and non-impacted soils are young soils classified as Fluvisols and Regosols according to the WRB system (2005) and Entisols according to Soil Taxonomy (2014). Soils of mine spoils have low plant cover, low fertility, strong acidity, low cation exchange capacity, and high content of rock fragments in impacted soils; so the impacts on soils are remarkable decreasing the fertility and soil productivity compared to non-impacted soils. However, impacted soils are being improved as time passes by natural regeneration, interaction between plants and animals, pluvial precipitation and flooding that improve soil characteristic like organic soil matter and cation exchange capacity, developing a new soil. In spite there is limited information about these soils in the Amazon, this research contributes to characterized certain impacted sites in order to support making decision on how to best reclaim, rehabilitate or restore these Amazon ecosystems.

INTRODUCTION

Gold industry in the world has experienced a surge over recent years with the record mine production of 4,490t (World Gold Council, 2018a) and reaching great international price of 1,456.85$ OZ TR^{-1} (World Gold Council, 2019). Peru occupies 1st place in Latinoamerica and the 6th place in the world gold production, which represents 4.4% overall world gold production (Ministerio de Energía y Minas, 2019). Gold is an extremely scarce element (World Gold Council, 2018b), which in the Amazon need the extraction of thousands tons of sediments to get goldbearing gravel, leading to a large scale deforestation and Hg pollution (Alvarez, Solano, Brack, & Ipenza, 2011). In Madre de Dios Region, also known as the “Peruvian Capital of Biodiversity”, artisanal and small gold production accounts for 7% of the total annual gold production in Peru of approximately 144 metric tonnes (Ministerio de Minas y Energía, 2019). Deforestation caused by gold mining industry has become a major threat to some of the most remote and better-conserved old-growth forests in tropical South America. Between 2001 and 2013, there was a loss of 1680,000 ha of forest at 177 gold mining sites (Alvarez-Berríos & Mitchell Aide, 2015). Here the Peruvian Amazon constitutes part of the highest biodiversity region in the global tropics (Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000). Unfortunately, gold mining activities in Madre de Dios has resulted in the deforestation of 95,750 ha (Caballero Espejo et al., 2018), annual deforestation rates have fluctuated between 6,000 ha (Asner, Llactayo, Tupayachi, & Luna, 2013) leading to an estimated topsoil loss of 1.3 t ha^{-1}year (Gomez, 2013). Moreover, It was reported that gold market prices were close correlated with mining rates on interannual timescales (R2 =0.43; $p < 0.05$) (Asner & Tupayachi, 2017). This pattern of mining in tropical forested regions continues to rise globally with similar consequences as observed in Madre de Dios (Alvarez-Berríos & Mitchell Aide, 2015). Alluvial gold mining in Madre de Dios old growth forest generally involves slash and burn deforestation, sediment extraction, amalgamation of gold with Hg, burning, Hg evaporation and gold recovery (Alvarez et al., 2011; Salinas, 2007). All these stages of gold production are typically carried out on site, hence generating an importance source of Hg pollution in the local environment. It is estimated that between at least 1 and 2 grams of Hg is lost to the environment for every gram of produced gold (Mallas & Benedicto, 1986; Veiga & Baker, 2004). Sediment extraction is accomplished through the use of highly mechanized mining and minimally mechanized technology level. Highly mechanized mining uses heavy machinery such as excavators, front loaders, and dump trucks, and minimally mechanized mining uses suction pumps, high pressure water cannons to liquify stream-side sediments which are transported to sluice boxes via diesel-powered water/sediment pumps (Caballero Espejo et al., 2018). During this process the topsoil, characterized by a fine texture, is scattered and coarse gravel, stones and boulders from deeper soil layers become to predominate at the surface (Salinas, 2007). In spite of the degraded conditions of mine spoils, natural succession also happens in most of them resulting in the formation of secondary forests in different stages of development, and with it the formation of new soil profiles with different physical and chemical characteristics. However, limited information exists in the Amazon about the composition of such new soil profiles, hampering decision making on how to best reclaim, rehabilitate or restore the ecosystem in these areas. Our aim was to support further effective restoration experiences by classifying these soils in Madre de Dios according to the Soil Taxonomy (Soil Survey Staff, 2014) and World Reference base (Working Group WRB, 2015) to verify how they differ from soils under undisturbed old-growth forest. We primarily focused on a local area, such as Fortuna Community, which is the most characteristic model of Artisanal and Small Scale Gold Mining (ASGM) in the Peruvian Amazon.

MATERIALS AND METHODS

Study area

The research was carried out in the Fortuna Community, located in the Peruvian Amazon region of Madre de Dios (Figure 1), which is one of the oldest areas were Artisanal and Small Scale Gold Mining (ASGM) has traditionally been practiced with minimally mechanized technology level. In this selected area Velásquez Ramírez et al. (2020) confirmed severe impacts caused by alluvial gold mining activities on soil structure and texture, jeopardizing the soil fertility and productivity. Concentrations in gold mine spoil soils of all heavy metals were below upper limits for agricultural use as stipulated in Peruvian and Canadian environmental quality standards (Canadian Council of Ministers of the Environment, 2007; Ministerio del Ambiente, 2017). Environmental and climate characteristics of the selected areas were determinated. Annual precipitation, temperature and relative humidity in Fortuna vary between 2000 - 2610 mm, 18 – 24 °C and 87 – 97%, respectively (Servicios Generales y Medio Ambiente, 2006). It is located between at 188 – 332 m.a.s.l. and is characterized by a perhumid, megathermal, with little or no water deficiency and Saturated climate (Feddema, 2005) according to Thornthwaite Climate classification (Thornthwaite, 1948) with a climax vegetation of very humid tropical forest and humid tropical forests (Senamhi, 2017) according to Holdridge Life Zones System classification (Holdridge, 1967). The soil moisture content is not dry in any part for more than 90 cumulative days per year, classified as Udic soil moisture regime. The soil temperature regime is classified as hyperthermic with mean annual soil temperatures above 22 °C (Soil Survey Staff, 2014). Its parent material is composed by deposits from quaternary period (40,000 years to 176,000 year). The natural plant cover is composed by heliophilous like *Erythrina, Tabebuia and Jacaranda*; palm trees are S*ocratea, Iriarte, Jessenia, Phytelephas, Sheelea and Astrocaryum.* Mainly its plant cover is composed by *Cedrelinga catenaeformis, Brosimum sp., Juglans neotropica, Cedrela sp. Cordia, Tabebuia, Sapium, Croton, Aspidosperma, Schizolobiu, Pithecolobium, Cecropia, Chorisia, Calophyllum, Matisia, Hura, and Guazuma* (Servicios Generales y Medio Ambiente, 2006).

Field Work

According to the geomorphologic landscape (Zinck, 2013) the study area is located in a Sedimentary Basin (Geosyncline), Depositional Environment, Plain, Alluvial Facies and Alluvial Terrain form. Through the combination of the Peruvian ecological map 1:100 000 (Life zone), the geological map 1:100 000 (geology) and the topographic map 1:100 000 (topography) a base map was developed choosing one Consociation (Soil Science Division Staff, 2017) named "Fortuna", located in a mining sector surrounded by forest from which we selected an area of 13 ha for carrying out field work. We established five pedon in degraded areas with natural regeneration and reference natural forest (Schoeneberger, Wysocki, Benham, & Soil Survey Staff, 2012); soil pits were made as shown in Table 1.

Laboratory work

Soil samples were air dried, crushed and passed through a 2.00 mm sieve. Then, the following analyses were carried out: particle size distribution (sedimentation method); actual soil acidity in water extract 1:1, electrical conductivity in water extract 1:1, organic matter content (Walkley Black Method), exchangeable bases, effective cation exchange capacity (CEC) (Sum of bases), available phosphorous (Bray I), available potassium (Ammonium acetate pH=7) and exchangeable aluminum and hydrogen (Yuan).

RESULTS

Profile soil evaluation

In the following Table 2 we describe the five soil profiles (Figure 2) sampled in impacted and non-impacted areas.

N1 soil profile – Non impacted

Soil sampled from Laberinto District, Fortuna Community, altitude 208 masl, alluvial parent rock, primary forest and non-impacted area:**A** - 0 to 7 cm - , 2.5Y 5/4 (dry), granular structure, silty clay texture, with fine roots diameter, gradual transition, 0% rock fragments at the surface;**AC** -7 to 40 cm-, 2.5Y 6/4 (dry), granular structure, silty clay texture, with fine roots diameter, diffuse transition, 0% rock fragments;**C1** - 40 to 68 cm -, 2.5Y 6/4 (dry), 10% mottling (2.5Y 4/4), massive structure, loam texture, with medium roots diameter, diffuse transition, 0% rock fragments;**C2**– more than 68 cm- , 2.5Y 6/4 (dry), 30% mottling (2.5Y 4/4), with massive structure, loam soil, with medium roots diameter, 0% rock fragments. Soil physic characteristic are moderately low permeability, moderately well drained, nearly level slope class (<2%), slight erosion, motley and water table raised from its initial level of 0.68 m. Their chemical characteristics are strongly acid, non-saline and very slightly effervescent, with low to medium organic matter and potassium content, low effective cation exchange capacity (CEC) and high phosphorus content.

N2 soil profile – Non impacted

Soil sampled from Laberinto District, Fortuna Community, altitude 208 masl, alluvial parent rock, primary forest and non-impacted area:**A** - 0 to 10 cm - , 2.5Y 5/4 (dry), granular structure, silty clay loam texture, with fine roots diameter, gradual transition, 0% rock fragments at the surface;**AC** - 10 to 21 cm -, 2.5Y 6/4 (dry), granular structure, silty clay texture, with fine roots diameter, gradual transition, 0% rock fragments;**C1** - 21 to 42 cm -, 2.5Y 6/4 (dry), massive structure, silty clay loam texture, with medium roots diameter, gradual transition, 0% rock fragments;**C2** – 42 to 65 cm - , 2.5Y 6/4 (dry), massive structure, silty clay texture, with coarse roots diameter, gradual transition, 0% rock fragments;**2C3** – more than 65 cm- , 2.5Y 6/4 (dry), massive structure, silty clay texture, 0% rock fragments. Soil physic characteristic are moderately low permeability, moderately well drained, nearly level slope class (<2%), slight erosion, motley and water table raised from its initial level of 0.75 m. Their chemical characteristics are strongly acid, non-saline and very slightly effervescent, with low to medium organic matter and potassium content, medium effective cation exchange capacity (CEC) and high phosphorus content.

N3 soil profile – Non impacted

Soil sampled from Laberinto District, Fortuna Community, altitude 208 masl, alluvial parent rock, primary forest and non-impacted area:**A** - 0 to 12 cm - , 2.5Y 5/4 (dry), granular structure, silty clay soil, with very fine roots diameter, gradual transition, 0% rock fragments at the surface;**AC** - 12 to 15 cm -, 2.5Y 6/4 (dry), granular structure, silty clay loam texture, with very fine roots diameter, abrupt transition, 0% rock fragments;**C1** - 15 to 48 cm -, 2.5Y 6/4 (dry), massive structure, silty clay loam texture, with very fine roots diameter, diffuse transition, 0% % rock fragments;**C2** – 48 to 70cm - , 2.5Y 6/4 (dry), massive structure, silty clay loam texture, with coarse roots diameter, gradual transition, 0% rock fragments;**C3** – more than 70 cm- , 2.5Y 6/4 (dry), massive structure, silty clay loam texture, with coarse roots diameter, 0% rock fragments. Soil physic characteristic are moderately slow permeability, moderately well drained, nearly level slope class (<2%), slight erosion, motley and water table raised from its initial level of 0.90 m. Their chemical characteristics are strongly acid, non-saline and very slightly effervescent, with low to medium organic matter and potassium content, medium effective cation exchange capacity (CEC) and high phosphorus content.

T1 soil profile - impacted

Soil sampled from Laberinto District, Fortuna Community, altitude 208 masl, alluvial parent rock, secondary forest and 6 to 7 year impacted area:**A** - 0 to 10 cm - , 2.5Y 5/3 (dry), granular structure, sand texture, con raíces finas, gradual transition, 10% rock fragments at the surface;**C1** - 10 to 25 cm -, 2.5Y 5/3 (dry), single grain structure, sand texture, with fine roots, diffuse transition, 30% rock fragments;**C2** - 25 to 42 cm -, 2.5Y 5/3 (dry), single grain structure, sand texture, diffuse transition, 10% rock fragments;**2C3** – more than 42 cm - , 2.5Y 5/4 (dry), single grain structure, sand texture, 50% rock fragments. Soil physic characteristic are rapid permeability, excessively drained, nearly level slope class (<2%), slight erosion, and water table raised from its initial level of 1.50 m. Their chemical characteristics are very strongly acid, non-saline and very slightly effervescent, with low organic matter, potassium effective cation exchange capacity (CEC) content and high phosphorus content.

T2 soil profile - impacted

Soil sampled from Laberinto District, Fortuna comunidade, altitude 208 masl, alluvial parent rock, secondary forest and 7 to 8 year impacted area:**A** - 0 to 7 cm - , 2.5Y 5/4 (dry), granular structure, sandy clay loam texture, with very fine roots diameter, clear transition, 5 % rock fragments at the surface;**C1** - 7 to 40 cm -, 2.5Y 5/3 (dry), single grain structure, sand texture, with very fine roots diameter, diffuse transition, 0% rock fragments;**C2** - 40 to 48 cm -, 2.5Y 6/4 (dry), 35% mottling (2.5Y 4/4), single grain structure, loam texture, with fine roots diameter, diffuse transition, 0% rock fragments;**C3** – 48 to 77 cm - , 2.5Y 5/6 (dry), 60% mottling (2.5Y 5/6), single grain structure, sand texture, diffuse transition, 0% rock fragments;**C4** – more than 77 cm - , 2.5Y 5/4 (dry), 80% mottling (2.5Y 5/4), single grain structure, loamy sand texture, 0% rock fragments. Soil physic characteristic are rapid permeability, excessively drained, nearly level slope class (<2%), slight erosion, and water table raised from its initial level of 1.50 m. Their chemical characteristics are very strongly acid, non-saline and very slightly effervescent, with low organic matter, potassium effective cation exchange capacity (CEC) content and high phosphorus content.

DISCUSSION

Comparison of Soil Taxonomy (2014) and WRB (2015)

We applied the diagnostic criteria of Soil Taxonomy (Soil Survey Staff, 2014) and WRB (Working Group WRB, 2015) to the 5 five pedons. Their morphological features and basic date (Table 3) were applied to classify these profiles. Pedons N1, N2 and N3, obtained from non-impacted areas, are classified as Entisols and Fluvisols according to Soil taxonomy (2014) and WRB (2015). Their sub order is Fluvents because there is no densic, litic and paralitic contac, no transported material by man, and a slope lower than 2%. The presence of more than 50 cm of mineral soil surface, redox depletions and also aquic conditions for some time in normal years determinated their classification as Aquic Udifluvents. Soils having fluvic material and either more than 25 cm thick and which starts from less than 25 cm from surface (68 cm, 75cm and 90 cm of effective depth of N1, N2 and N3 respectively) were classified as Fluvisols. Their base saturation ratio of less than 50% in between 20 and 100 cm from the mineral soil surface, having a layer more than 25 cm thick and starting at 75 cm from the mineral soil surface with gleyic properties (saturated with groundwater and more than 5 % mottles) and fluvic materials, classifies, principal qualifiers, as Dystric, Gleyic and Fluvic respectively. Furthermore, their supplementary qualifiers are Loamic (Pedon N3), Clayic and Ochric because they have a texture class of silty clay loam in a layer more than 30 cm thick within less 100 cm of the mineral soil surface, have a texture class of clay in a layer more than 30 cm thick within less 100 cm of the mineral soil surface and more than 0.2 % soil organic carbon (weighted average) in the layer from the mineral soil surface to a depth of 10 cm from the mineral soil surface. Pedons N1 and N2 were classified as Dystric Gleyic Anofluvic Fluvisols (Clayic, Ochric) and Pedon N3 Dystric Gleyic Anofluvic Fluvisols (Loamic, Ochric). Polipedon T1, in impacted areas from 6 to 7 years, is classified as Entisols and Regosols according to Soil Taxonomy (Soil Survey Staff, 2014) and WRB (Working Group WRB, 2015). It's a typical Anthroportic Udorthents which has more than 50 cm of human transported material (Soil taxonomy, 2014). Its principal qualifiers are Dystrict (base saturation 18.15%) and Protic which refers to no soil horizon development. Its supplementary qualifiers are Arenic, Ochric and Relocatic because it has a texture class of sand in a layer more than 30 cm thick within more 100 cm of the mineral soil surface, more than 0.2 % of soil organic carbon (weighted average) in the layer from the mineral soil surface to a depth of 10 cm from the mineral soil surface and it is being *in situ*remodeled by human activity (alluvial gold mining activity) to a depth of more 100 cm with no horizon development. So this soil is also classified as Dystric Protic Regosols (Arenic, Ochric, Relocatic) (WRB, 2015). Finally, the polipedon T2, in impacted areas from 7 to 8 years, is also classified as Entisols and Regosols according to Soil taxonomy (2014) and WRB (2015), but is quite different from polipedon T1. It is also a typical Anthroportic Udorthents (Soil taxonomy, 2014). Its principal qualifiers are Dystrict, Protic and also Gleyic which indicates gleyic properties (saturated with groundwater and more than 5 % mottles). Its supplementary qualifiers are also Arenic, Ochric and Relocatic. So the polipedon T2 WRB (2015) classification is Dystric Protic Gleyic Regosols (Arenic, Ochric, Relocatic). Both classification systems could determine impacted soil. The Soil Taxonomy (Soil Survey Staff, 2014) and WRB (Working Group WRB, 2015) only identify impacted soils in sub groups of human-altered and human-transported soil. WRB provides more details: impacted soil texture is mainly sand with no profile development (Protic) and is referred as being *in situ* remodeled by human activity (Relocatic). Alluvial gold mining management remodels the soil profile putting sand and rock fragments from deeper soil layers to the surface. Gold content is higher in gravel particles (rock fragment modifiers) (Palacios, Molina, Galloso, & Reyna, 1996). Silty clay and silty clay loam soil are dispersed and deposited in certain places. So two soil profiles might be found, one as T1 with higher rock fragments and sand texture and other as T2 characterized from sand to sandy clay loam texture without rock fragments. Furthermore, according to the soil texture and water table, raised impacted soils might be classified as Gleyic for its saturation with groundwater like T2 soil profile. It is remarkable that while natural soils are classified as Fluvisols, alluvial gold mining affects their properties classifying it as Regosols, which is the last soil group with no soil development evidence. Impacted soil here starts to develop. Impacted soils (T1 and T2) by alluvial gold mining are subject to natural regeneration, owing to the combination of relatively stable water availability (pluvial precipitation or sub-surface water) and seed rain from neighboring vegetation. Plant growth affect the soil matrix which is composed of plasma, skeletons grains and voids (Buol, Hole, Mc Cracken, & Southard, 1997). In skeletons, impacted soils are characterized by inert soil material like sand particles (table 2), through plant root segregation, litter production, animal manure and other organic material resource deposits its organic fragments augment, simultaneously increasing its colloidal properties. Water improves soil plasma which enables colloidal properties like electronegative charge, soluble (cation exchange capacity) and chelation properties. Furthermore, the soil organic matter affects soil pores improving its permeability and drainage, increasing water retention. Organic and water inputs increase its pedologic features like coatings (cutans) where fine particles move within the soil solution from upper layer or horizons through the soil profile changing its characteristics and properties as time passes. Roots plants turns single grain structure in recent impacted soil to granular structure (T1 and T2). These features indicate soil formation and evolution.

Land Capability Classification

The results show a great impact on the soil profile (T1 and T2) in contrast to the natural area (Na, N2 and N3). Alluvial gold mining management remodels the soil profile putting coarse soils (sandy, loamy sand and sandy clay loam soils) and rock fragments from deeper soil layers to the surface. Silty clay and silty clay loam soil are dispersed and deposited in certain places. During this process, impacted areas are also influenced by natural regeneration of vegetation that increases the organic soil matter in the surface. T1 and T2 soil profile are characterized sand to sandy clay loam soil texture, low organic soil matter below 2.04% to 0.17, low effective cation exchange capacity below 8.91 to 2.19 Cmol (+) kg $^{-1}$ and also lower content of available P and K. In contrast natural soils profile (N1, N2 and N3) are characterized by silty clay to loam texture class, higher organic soil matter content between 4.01 to 0.20 to %, higher effective cation exchange capacity between 17.82 to 7.36 Cmol (+) kg^{-1}, and also higher available P and K, without any rock fragment. So the impacts of the alluvial gold mining on soils are remarkable decreasing the fertility and soil productivity. According to the USDA (1961) Land Capability Classification, non-impacted soils like N1, N2 and N3 are classified as Class II. These are soils with some limitations that reduce the choice of plants and require moderate conservation practices. Some limitations are occasional damaging overflow, wetness and medium soil fertility (Table 2). These soils may require special soil – conserving cropping systems, prioritized for preservation of natural forest or water control devices. Impacted soil like T1 and T2 are classified as Class V, soils with limitations that can be used largely as woodland, wild life food and cover or pasture. Its limitations are frequently overflowing rivers, level or nearly level stony or rock soils and also its medium soil fertility (Table 2). The USDA Land Capability Classification refers to efforts and inputs dedicated to make a specific land productive. Ecological restoration broadens the scope by adding the importance of ecosystem service production (goods and products) for human wellbeing and nature. Some approaches to promote restoration in impacted land by the alluvial gold industry are protection to prevent degradation, assisted natural regeneration, enrichment planting with species valued for their social and ecological importance and also plantations to protect, restore, produce wood and forest products, like agroforestry systems. The ecological restoration of gold mine spoils need to incorporate, SER (2004) and Chazdon, (2008) proposed: returning an ecosystem to its historic trajectory; the trajectory begins with the unrestored ecosystem and progresses towards the desired state of recovery that is expressed in the goals of a restoration project and embodied in the reference ecosystem. The trajectory is a process which needs to be focused in its structure and function with sustainable cultural practices. There are two possible alternatives, natural landscape for protection and conservation, or cultural landscape which might offer alternative economical activities for inhabitants.

CONCLUSION

Impacted soil (pedons T1 and T2) by the alluvial gold mining in Fortuna Community were classified as Anthroportic Udorthents (Soil Survey Staff, 2014) and Dystric Protic Regosols (Arenic, Ochric, Relocatic) and Anthroportic Udorthents and Dystric Protic Gleyic Regosols (Arenic, Ochric, Relocatic) for T1 and T2 soil profile respectively (Working Group WRB, 2015). The non-impacted soils (pedons N1, N2 and N3) were classified as Aquic Udifluvents (Soil taxonomy, 2014) and Dystric Gleyic Anofluvic Fluvisols (Clayic, Ochric) (pedons N1 and N2) and Dystric Gleyic Anofluvic Fluvisols (Loamic, Ochric) (pedon N3) (Working Group WRB, 2015). Both impacted soil and non-impacted soils are young soils (Entisols, Fluvisols and Regosols) but gold mining produces extreme alteration in the soil profile with low plant cover, low fertility, strong acidity, low cation exchange capacity, and high content of rock fragments in impacted soils; so the impacts on soils are remarkable decreasing the fertility and soil productivity compared to non-impacted soils. Impacted soils are being improved as time passes by natural regeneration, interaction between plants and animals, pluvial precipitation and flooding that affects soil characteristic, developing a new soil. Its Land Capability Classification (USDA, 1961) for impacted soil were classified as Class V, soils with limitations that can be used largely as woodland, wild life food and cover or pasture. This research contributes to characterizes these type of degraded soil in a local site in the Peruvian Amazon. Further researches need to be performed under different conditions of degraded areas to achieve a base line to support effective land restoration experiences in the Amazon. A base technology needs to be develop to overcome these limitations for land restoration; natural regeneration like enrichment with species valued by social and ecological importance, plantation to protect, restore, produce wood and forest products, and Agroforestry are alternative to develope.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

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Table 1: Field work characteristic

Field work name	Main vegetation	Soil pits / pedons
Old-growth reference forest Non impacted	Primary forest	N1 N2 N3
Impacted from 6 to 7 years ago Impacted from 7 to 8 years ago	Secondary forest	T1 T2

Table 2: Physical and Chemical characteristic and properties of pedons of impacted and non-impacted soil by the alluvial gold mining in Fortuna Comunity, Madre de Dios, Peru

Horizons depht (cm)	**Granulometry (%)**	**Granulometry (%)**	**Granulometry (%)**	**Color (Dry)**	**Textural class**	**pH**	**$CaCO_2$ (%)**	**C.E. (dS m^{-1})**	**Soil organic Matter (%)**	**Organic carbon (%)**	**P (mg kg^{-1})**	**K (mg kg-1)**	**Effective CEC (Cmol (+) kg $^{-1}$) $^{-}$**	**Ca^{++}**	**M**
	Sand	Silt	Clay												
N1 polipedon Non impacted soil	**N1 polipedon Non impacted soil**	**N1 polipedon Non impacted soil**	**N1 polipedon Non impacted soil**	**N1 polipedon Non impacted soil**	**N1 polipedon Non impacted soil**	**N1 polipedon Non impacted soil**	**N1 polipedon Non impacted soil**	**N1 polipedon Non impacted soil**	**N1 polipedon Non impacted soil**	**N1 polipedon Non impacted soil**	**N1 polipedon Non impacted soil**	**N1 polipedon Non impacted soil**	**N1 polipedon Non impacted soil**	**N1 polipedon Non impacted soil**	**N1 polipedon Non impacted soil**
A 0-7	12.56	46.00	41.44	2.5 Y 4/4	Silty clay	5.16	0.00	0.34	2.8	1.62	109.05	105.00	17.43	13.4	3.1
AC 7-40	14.56	44.00	41.44	2.5 Y 4/4	Silty clay	5.28	0.00	0.13	1.5	0.87	187.67	74.00	14.36	10.8	2.6
C1 40-68	26.56	48.00	25.44	2.5 Y 4/4	Loam	4.76	0.00	0.04	0.75	0.44	161.04	55.00	8.71	5.64	2.1
C2 >68	50.56	34.00	15.44	2.5 Y 4/4	Loam	4.65	0.00	0.04	0.48	0.28	43.11	45.00	7.36	4.19	1.9
N2 polipedon Non impacted soil	**N2 polipedon Non impacted soil**	**N2 polipedon Non impacted soil**	**N2 polipedon Non impacted soil**	**N2 polipedon Non impacted soil**	**N2 polipedon Non impacted soil**	**N2 polipedon Non impacted soil**	**N2 polipedon Non impacted soil**	**N2 polipedon Non impacted soil**	**N2 polipedon Non impacted soil**	**N2 polipedon Non impacted soil**	**N2 polipedon Non impacted soil**	**N2 polipedon Non impacted soil**	**N2 polipedon Non impacted soil**	**N2 polipedon Non impacted soil**	**N2 polipedon Non impacted soil**
A 0-10	10.56	56.00	33.44	2.5 Y 5/4	Silty clay loam	5.18	0.00	0.21	3.21	1.86	127.9	93.00	13.88	10.8	2.3
AC 10-21	8.56	50.00	41.44	2.5 Y 6/4	Silty clay	5.18	0.00	0.08	1.06	0.61	151.99	80.00	10.64	7.38	2.4

Horizons depht (cm)	Granulometry (%)	Granulometry (%)	Granulometry (%)	Color (Dry)	Textural class	pH	$CaCO_2$ (%)	C.E. (dS m^{-1})	Soil organic Matter (%)	Organic carbon (%)	P (mg kg^{-1})	K (mg kg-1)	Effective CEC (Cmol (+) kg $^{-1}$) –	Ca^{++}	M
C1 21–42	10.56	58.00	31.44	2.5 Y 6/4	Silty clay loam	5.10	0.00	0.16	3.28	1.90	375.35	96.00	11.41	8.73	1.9
C2 42-65	8.56	50.00	41.44	2.5 Y 6/4	Silty clay	5.15	0.00	0.1	1.09	0.63	153.44	83.00	14.46	10.9	2.7
2C3 > 65	18.56	58.00	23.44	2.5 Y 6/4	Silty loam	5.22	0.00	0.5	0.2	0.12	211.77	78.00	9.22	5.66	2.7
N3 polipedon: Non impacted soil	**N3 polipedon: Non impacted soil**	**N3 polipedon: Non impacted soil**	**N3 polipedon: Non impacted soil**	**N3 polipedon: Non impacted soil**	**N3 polipedon: Non impacted soil**	**N3 polipedon: Non impacted soil**	**N3 polipedon: Non impacted soil**	**N3 polipedon: Non impacted soil**	**N3 polipedon: Non impacted soil**	**N3 polipedon: Non impacted soil**	**N3 polipedon: Non impacted soil**	**N3 polipedon: Non impacted soil**	**N3 polipedon: Non impacted soil**	**N3 polipedon: Non impacted soil**	**N3 polipedon: Non impacted soil**
A 0-12	18.56	40.00	41.44	2.5 Y 5/4	Silty clay	5.6	0.00	0.24	4.01	2.33	183.69	141.00	17.82	14.2	2.7
AC 12-15	10.56	62.00	27.44	2.5 Y 6/4	Silty clay loam	4.64	0.00	0.07	1.09	0.63	149.63	101.00	7.5	4.39	1.4
C1 15-48	12.56	48.00	39.44	2.5 Y 6/4	Silty clay loam	4.7	0.00	0.06	0.85	0.49	100.18	106.00	11.26	6.35	2.8
C2 48-70	16.56	52.00	31.44	2.5 Y 6/4	Silty clay loam	5.15	0.00	0.06	0.41	0.24	69.74	80.00	9.47	5.89	2.5
C3 >70	12.56	58.00	29.44	2.5 Y 6/4	Silty clay loam	5.21	0.00	0.06	0.61	0.35	91.3	47.00	9.89	6.45	2.6
T1 polipedon: Impacted area 6 – 7 years ago	**T1 polipedon: Impacted area 6 – 7 years ago**	**T1 polipedon: Impacted area 6 – 7 years ago**	**T1 polipedon: Impacted area 6 – 7 years ago**	**T1 polipedon: Impacted area 6 – 7 years ago**	**T1 polipedon: Impacted area 6 – 7 years ago**	**T1 polipedon: Impacted area 6 – 7 years ago**	**T1 polipedon: Impacted area 6 – 7 years ago**	**T1 polipedon: Impacted area 6 – 7 years ago**	**T1 polipedon: Impacted area 6 – 7 years ago**	**T1 polipedon: Impacted area 6 – 7 years ago**	**T1 polipedon: Impacted area 6 – 7 years ago**	**T1 polipedon: Impacted area 6 – 7 years ago**	**T1 polipedon: Impacted area 6 – 7 years ago**	**T1 polipedon: Impacted area 6 – 7 years ago**	**T1 polipedon: Impacted area 6 – 7 years ago**
A 0-10	86.56	12.00	1.44	2.5 Y 5/3	Sand	5.13	0.00	0.05	0.17	0.10	92.57	22.00	3.32	1.95	0.8

Horizons depht (cm)	Granulometry (%)	Granulometry (%)	Granulometry (%)	Color (Dry)	Textural class	pH	$CaCO_2$ (%)	C.E. (dS m^{-1})	Soil organic Matter (%)	Organic carbon (%)	P (mg kg^{-1})	K (mg kg-1)	Effective CEC (Cmol (+) kg $^{-1}$) –	Ca^{++}	M
C1 10 - 25	92.56	6.00	1.44	2.5 Y 5/3	Sand	4.78	0.00	0.04	0.20	0.12	87.5	24.00	2.19	1.10	0.3
C2 25-42	94.56	4.00	1.44	2.5 Y 5/3	Sand	5.26	0.00	0.04	0.48	0.28	81.16	25.00	3.16	1.75	0.5
2C3 >42	92.56	6.00	1.44	2.5 Y 5/4	Sand	4.63	0.00	0.04	0.14	0.08	110.32	27.00	2.83	1.45	0.4
T2 polipedon: Impacted area 7 – 8 years ago	**T2 polipedon: Impacted area 7 – 8 years ago**	**T2 polipedon: Impacted area 7 – 8 years ago**	**T2 polipedon: Impacted area 7 – 8 years ago**	**T2 polipedon: Impacted area 7 – 8 years ago**	**T2 polipedon: Impacted area 7 – 8 years ago**	**T2 polipedon: Impacted area 7 – 8 years ago**	**T2 polipedon: Impacted area 7 – 8 years ago**	**T2 polipedon: Impacted area 7 – 8 years ago**	**T2 polipedon: Impacted area 7 – 8 years ago**	**T2 polipedon: Impacted area 7 – 8 years ago**	**T2 polipedon: Impacted area 7 – 8 years ago**	**T2 polipedon: Impacted area 7 – 8 years ago**	**T2 polipedon: Impacted area 7 – 8 years ago**	**T2 polipedon: Impacted area 7 – 8 years ago**	**T2 polipedon: Impacted area 7 – 8 years ago**
A 0-7	52.56	26.00	21.44	2.5 Y 5/4	Sandy clay loam	4.88	0.00	0.08	2.08	1.21	171.19	86.00	8.91	6.4	1.6
C1 7-40	92.56	4.00	3.44	2.5 Y 5/3	Sand	4.69	0.00	0.03	0.17	0.10	120.47	28.00	2.78	1.68	0.5
C2 40-48	38.56	52.00	9.44	2.5 Y 6/4	Loam	4.77	0.00	0.05	0.31	0.18	102.71	40.00	4.33	2.68	0.9
C3 48-77	92.56	6.00	1.44	2.5 Y 5/6	Sand	4.36	0.00	0.04	0.17	0.10	95.11	17.00	2.17	1.18	0.4
C4 >77	78.56	18.00	3.44	2.5 Y 5/4	Loamy sand	4.6	0.00	0.04	0.34	0.20	173.73	35.00	3.86	2.06	0.7

Table 3: Soil classification according to Soil Taxonomy y WRB system in impacted and non-impacted areas by the alluvial gold mining in Fortuna Community Madre de Dios, Peru.

Pedon	Detail	Soil Taxonomy (2014)	WRB (2015)
N1	Non impacted	Aquic Udifluvents	Dystric Gleyic Anofluvic Fluvisols (Clayic, Ochric)

Pedon	**Detail**	**Soil Taxonomy (2014)**	**WRB (2015)**
N2	Non impacted	Aquic Udifluvents	Dystric Gleyic Anofluvic Fluvisols (Clayic, Ochric)
N3	Non impacted	Aquic Udifluvents	Dystric Gleyic Anofluvic Fluvisols (Loamic, Ochric)
T1	Impacted	Anthroportic Udorthents	Dystric Protic Regosols (Arenic, Ochric, Relocatic)
T2	Impacted	Anthroportic Udorthents	Dystric Protic Gleyic Regosols (Arenic, Ochric, Relocatic)