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Disseminating Soil Alterations Using Geoportal on Natural Phenomena: The Case of Cotopaxi-Ecuador Volcano

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***Abstract*— The Cotopaxi Volcano is one of the most active stratovolcanoes in the world. It is located in the center of Ecuador, surrounded by densely populated cities as Latacunga, Machachi, or Sangoquí, in which the agricultural sector is very important for economic development. Ash emissions and phreatomagmatic eruptions characterized the eruptive process of Cotopaxi volcano in august 2015. A mineralogical study of the ashes showed the presence of heavy metals, which could have been transferred to the soil and could affect agricultural and livestock activities. To evaluate the relationship between the concentrations of Cd, Cu, Pb, Hg, Cr, Co, Ni, Zn and as between the soil, ash and the comparison with local regulations, three farms (Altamira farm, San Ramon farm and La Laguna farm) in the Canton of Mejía were defined as the study area. In those locations, the soil samples were georeferenced with a handheld GPS. The analysis was carried out before acid digestion (EPA 3050B1 method) in an ICP-OES and AMA 254 atomic absorption spectrophotometer. The metals analyzed were kept within limits defined in TULSMA Book VI: Annex 2 Soil Resource local regulations. In order to improve the visibility of the study, the presentation of the results was carried out in an open-access geoportal implemented in proprietary software. This geoportal allows the dynamic and interactive visualization of the different concentrations of heavy metals in their corresponding location.**

***Keywords*— geoportal; heavy metal; agricultural soils; Cotopaxi volcano; ICP-OES.**

I. Introduction

The stratovolcano Cotopaxi at 5897 meters above sea level is considered one of the most active volcanoes around the world. He had five major eruptive processes in: 1532-1534, 1742-1744, 1766-1768, 1853-1854 and 1877-1880 [1]. An eruptive cycle like 1877 was most likely to be repeated, what would generate: a) Ashfall; b) Emission of pyroclastic flows unrelated to the collapse of an eruptive column of the "boiling over" type; c) Lahars, caused by the melting of glacial ice [2].

On May 27, 2015, the Geophysical Institute (GI) of Ecuador reported: "The seismic activity of the Cotopaxi volcano has been showing changes since mid-April of this year. It picked up in May and especially since the 21st, recording the biggest peak of activity with more than 180 events on Saturday 23rd. In May, a total of 3000 events were counted, including 9 volcano-tectonic (VT), 2220 long-term (LP) and 36 hybrid type (HB). Concerning the 628 events recorded in April, this increase is considered important with the highest peak since the instrumental monitoring of Cotopaxi" [3].

In the process of reactivation of Cotopaxi in 2015, GI reported the ash emission until November of the same year [4]. The composition and size of volcanic ash particles are different; these characteristics are related to the composition of the lava and the degree of fragmentation that can occur inside the volcano [5]. Initially, IG described the explosions as groundwater, but a more detailed study of the ash established that type of explosions was phreatomagmatic. In

August, the Cotopaxi volcano activity was characterized by continuous ash emission [4].

On August 14, there were two explosions in the morning, causing ash to fall in Jambelí, Machachi, Pedregal, Boliche, Alóag, Tambillo, and Amaguaña. At 10:25, another ash emission occurred, with a column located between 6 and 8 km above the crater level. Winds carried ash to the Northeast and Southeast of the crater. Even areas located more than 100 km from the volcano, such as “Santo Domingo de Los Colorados”, The Carmen, Quevedo, Portoviejo, and Bahía de Caráquez, have also been hit by the ashes [4].

Mineralogical and multi-elemental analysis of the Cotopaxi volcanic ash was performed in samples collected from a farm located in the parish of Machachi, Mejia Canton [6]. This study made it possible to determine the concentrations of several heavy metals present in the ashes. Also, [7], in their analytical studies of ash made during the eruptive process of the volcano from August 14 to September 23, 2015, established the presence of Na, Mg, Al, Si, P, S, K, Ca, Ti, Mn and Fe at different concentrations during the eruptive process.

The soils of Machachi acted as a protective barrier against the ashes of the Cotopaxi volcano, favoring the transfer of the entire mineralogical composition of the ashes to the ground. Due to biogeochemical processes, a metal transfer could take place from the ash to soil. For this reason, the concentrations of heavy metals in soil are compared to the maximum allowable limits determined by the TULSMA (Unified Text of the Secondary Legislation of the Environment - Ecuador). Tools for locating, evaluating, and using geospatial information are recognized by agricultural producers [8], [9], [10], [11]. In this study, it is planned to present the results of heavy metal concentrations via a Geoportal for public access.

A. Study Area

In the canton of Mejia, generally known as Machachi, there are three marked natural areas: valley, moorland and western forests; each area is having it is natural and even cultural characteristics [12].

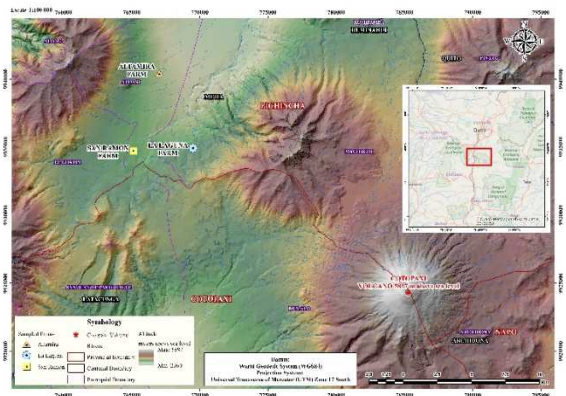

Fig. 1 Location of the study zone

The study area included three farms affected by ashes in 2015. Altamira and San Ramón farms are located in the parish Aloasí, 24.5 km and 23 km northwest of the Cotopaxi volcano, respectively. While, La Laguna farm is located in the parish of Machachi, 19 km northwest of the volcano. Location of the study zone is shown in Figure 1.

B. Characterization of Soils

In Soil Survey Manual published by the staff of the Soil Science Division in 2017, the soil reaction class was established based on pH and EC. This classification is adopted by the regulations for agricultural soils of Ecuador [13], [14].

Also, heavy metals are defined as metal elements whose atomic number is greater than 20, or their specific weight is higher than 5 g.cm-3. From an environmental point of view, heavy metals are those which due to their toxic effects and their persistence, are qualified as environmental pollutants. The presence of metals is more significant in igneous rocks than in sedimentary. The amount of metal that will be incorporated naturally into the soil depends on the degree of resistance of each mineral constituting the rock [15].

The soil is considered as a natural deposit, where anything that reaches it tends to interact. Soils with a high flow of water resources are more likely to carry out the precipitation and/or leaching process. In some studies, based on soil pH values, the mobility of specific metal ions was defined [15], [16]. Was determined the presence of Chrysobalin, Andesite, Anortita, and Ortoclasa as predominant minerals in the ashes from Cotopaxi eruption at 2015 [17].

II. Material and Method

A. Sampling

Soil sampling was conducted using the TULSMA Book VI Annex 2 and NT004 Soil Technical Standard from the Metropolitan District of Quito as reference. For each sampling point, one surface soil sample, one medium soil sample (depth at 30 cm), and one deep soil sample (depth at 70 cm) were collected. Three sampling sessions were conducted in April, May, and June of 2018. Each session, three sampling points were established for each farm, and finally, 27 sampling points were obtained taken in 3 different times. The positioning of sampling points was done using GIS tools, such as ArcGIS Pro, ArcGIS Online, and Collector for ArcGIS.

B. Database Design

In an ArcGIS Pro project, a spatial database was created, in which the following Feature Class were stored: a) haciendas, feature class with point geometry with location of Altamira, San Ramón, and La Laguna farms, b) sampling points, function with point geometry used to store point location.

C. Web Feature Service (WFS)

A WFS with the above features class was published in ArcGIS Online Cloud storage using ArcGIS Pro. This process is called service publishing. The sampling point Feature class7 was enabled for editing, downloading and synchronization operations. The ability to attach files, specifical photographs was also enabled.

D. Web Map Service

In ArcGIS Online, a Web Map (WMS) was created from the WFS. The display layout was also made using scale control, and BookMarks was stored in the WMS of farm location.

E. Collector App for ArcGIS

Collector for ArcGIS was used on a smartphone. WMS was accessed from the farms. If synchronization enabled on WFS, the application could be used offline. A copy of the geodatabase and BaseMap feeding the WMS was downloaded. The sampling points were thus geographically positioned using the GPS of the mobile device (Fig. 2). Photographic records of each sample taken were also attached to geodatabase (see Fig. 3).

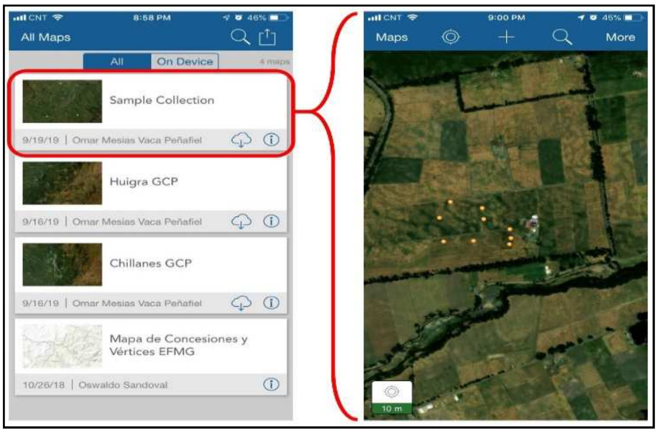

Fig 2. Sampling points using collector for ArcGIS.

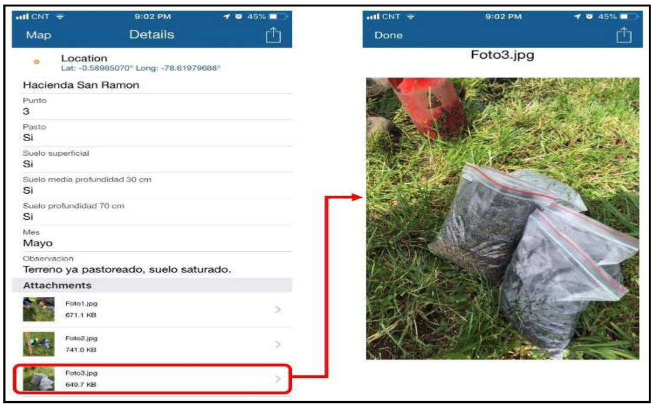

Fig 3. Details and photographic recordings stored at each sampling point.

F. Characterization of Soil

Sample preparation, pH determinations, moisture content and electrical conductivity, were carried out following the "Protocol of analysis methods for soils and sludge" of the Universidad de Concepción de Chile in 2007. The process of acid digestion was performed based on digestion method used: Soil Digestion EPA 3050B1. AMA 254 Advanced Mercury Analyzer model equipment was used to determine Hg and the Perkin Elmer Optima 8300 ICP-OES equipment to determine the concentration of Tl, Pb, Cd, As and C.

III. Results and Discussion

A. Soil sampling

The coding of each sample was assigned according to the depth of soil: SS: surface soil, SM: medium soil and SP: deep soil. The farm where the sample was taken was also coded: HA: Altamira, HR: San Ramón and HL: La Laguna. And point number: 1, 2 and 3. Also, the month in which sampling was done: A: April, M: May and J: June. The coding makes it possible to identify in the Geoportal the type of sample and its concentrations in metals. Locations are shown in Table 1.

On Altamira Farm, the sampling focused on the area for grazing cattle. The spatial distribution of points is illustrated in Fig. 4. For San Ramon farm, sampling points are shown in Fig. 5. Fig. 6 shows the location of sampling at La Laguna farm.

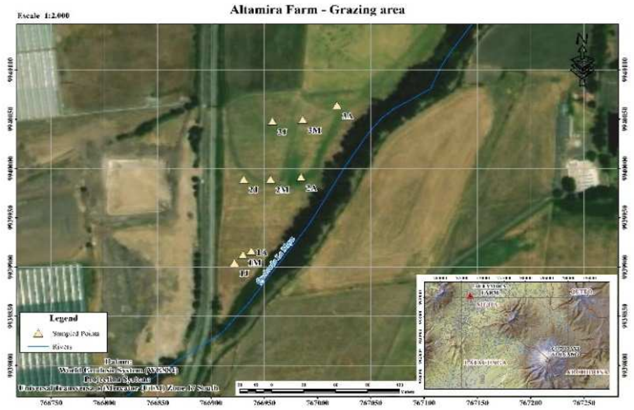

Fig 4. Sampling points in Altamira.

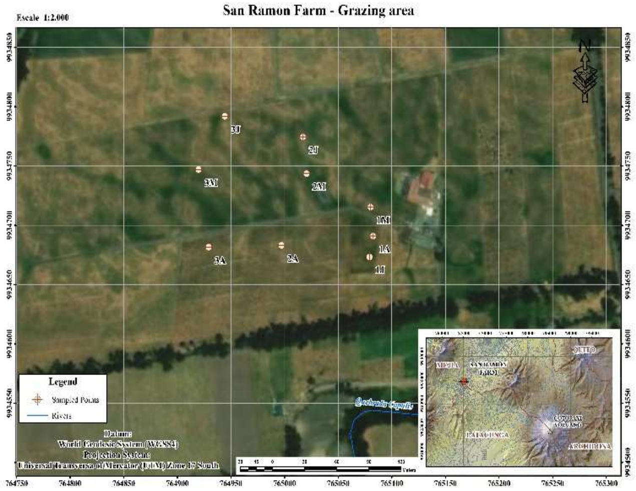

Fig 5. Sampling points in San Ramon.

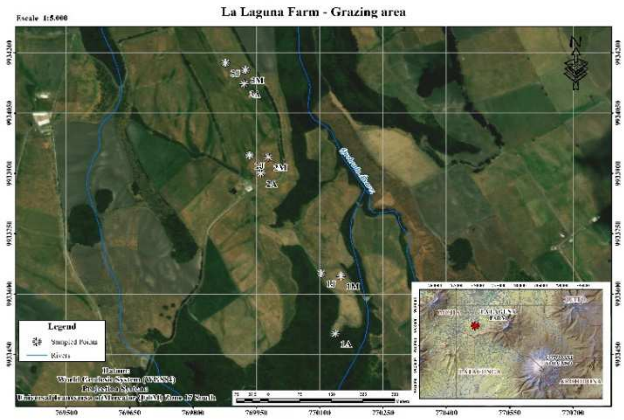

Fig 6. Sampling points in La Laguna.

B. Moisture, pH and electrical conductivity

Moisture content and pH (see Table 2) make a metal leaching process on San Ramón farm likely. Cd. Cu and Hg would be metals that move from easily mobile to moderately mobile as soil depth increases. Pb could go from moderately mobile to virtually immobile. On the other hand, As would move from moderate mobility in superficial soil to easy mobility in deep soil (70 cm).

TABLE I
LOCATION OF SAMPLES.

Reference		WGS84 UTM 17 S	
Farm	Point	East (m)	North (m)
Altamira	1A	766937.85	9939916.21
	2A	766984.53	9939991.13
	3A	767018.33	9940064.18
	1M	766930.04	9939912.42
	2M	766956.04	9939989.15
	3M	766986.10	9940049.65
	1J	766922.03	9939904.34
	2J	766930.73	9939989.13
	3J	766957.70	9940048.01
San Ramón	1A	764997.13	9934683.17
	2A	765082.60	9934690.88
	3A	764929.28	9934681.62
	1M	765080.29	9934715.41
	2M	765020.49	9934743.70
	3M	764919.78	9934747.08
	1J	765079.26	9934673.35
	2J	765017.16	9934774.51
	3J	764944.31	9934792.00
La Laguna	1A	770137.21	9933501.47
	2A	769960.72	9933900.38
	3A	769921.31	9934123.32
	1M	770150.49	9933644.80
	2M	769978.36	9933940.74
	3M	769924.23	9934157.78
	1J	770103.21	9933651.53
	2J	769934.07	9933945.63
	3J	769876.88	9934175.43

TABLE II
MOISTURE CONTENT (% H) AND pH-H2O VALUE (1: 2.5 RATIO) OF THE ANALYZED SOILS (SS: SURFACE SOIL. SM: MEDIUM SOIL. SP: DEEP SOIL).

Date	Kind	Altamira		San Ramón		La Laguna	
		% H	pH	% H	pH	% H	pH
April. 2018	SS	4.02	5.27	35.82	5.93	30.83	5.33
	SM	3.85	5.72	15.88	6.58	15.33	5.67
	SP	6.84	6.47	11.25	6.78	9.60	6.03
May. 2018	SS	5.78	5.69	22.59	5.18	2.08	5.07
	SM	6.29	6.09	10.36	6.18	4.57	5.68
	SP	5.24	6.53	19.66	6.32	6.35	5.66
June. 2018	SS	1.00	5.72	2.73	5.04	2.91	4.86
	SM	1.07	6.12	1.58	5.71	5.43	5.66
	SP	0.94	6.69	1.39	6.21	6.74	5.88

The electrical conductivity is shown in Table 3 and compared with the regulations in Ecuador (TULSMA) in which the maximum permissible limit for agricultural soils are 2 mmhos.cm-1.

TABLE III
ELECTRICAL CONDUCTIVITY IN MMHOS.CM-1 (SS: SURFACE SOIL. SM: MEDIUM SOIL. SP: DEEP SOIL).

Date	Kind of sample	mmhos.cm-1		
		Altamira	San Ramón	La Laguna
April. 2018	SS	0.291	0.984	0.521
	SM	0.096	0.103	0.088
	SP	0.053	0.116	0.049
May. 2018	SS	0.187	0.539	0.168
	SM	0.127	0.105	0.056
	SP	0.091	0.059	0.078
June. 2018	SS	0.143	0.526	0.164
	SM	0.061	0.081	0.045
	SP	0.044	0.058	0.040

EC had its maximum value in SS, and the lowest values were presented in SP. The values of all samples are within the allowable limits of Ecuadorian regulations. Soils were classified as non-saline according to the EC.

C. Analysis of heavy metal concentrations

The metal concentration is shown in Table 4. The average values of ash concentration obtained from the mineralogical study conducted by Sánchez (2017) and the maximum values allowed for agricultural soils established in TULSMA are also presented: Book VI Annex 2.

TABLE IV
HEAVY METAL CONCENTRATIONS IN SOIL, ASH AND LIMITS ALLOWED IN THE STANDARD FOR HA: ALTAMIRA FARM, HR: SAN RAMÓN FARM. HL: LA LAGUNA FARM. SS: SURFACE SOIL, SM: MEDIUM SOIL, SP: DEEP SOIL.

Farm	SS	SM	SP	*Ash	TULSMA **(Agricultural Soil)	
HA	Cu	24.066 ± 3.282	27.346 ± 6.155	24.859 ± 5.596	14.435 ± 0.866	63.00
HR		24.830 ± 5.079	24.863 ± 6.204	30.526 ± 10.927		
HL		20.261 ± 5.723	25.232 ± 6.805	38.529 ± 10.668		
HA	Hg	0.017 ± 0.02	0.019 ± 0.005	0.017 ± 0.008	N/D	0.80
HR		0.017 ± 0.003	0.019 ± 0.005	0.017 ± 0.007		
HL		0.017 ± 0.002	0.018 ± 0.002	0.017 ± 0.006		
HA	Pb	< 0.003	< 0.003	< 0.003	1.088 ± 0.040	16.00
HR		< 0.003	< 0.003	< 0.003		
HL		< 0.003	< 0.003	< 0.003		
HA	As	< 0.050	< 0.050	< 0.050	1.045 ± 0.107	12.00
HR		< 0.050	< 0.050	< 0.050		
HL		< 0.050	< 0.050	< 0.050		
HA	Cd	< 0.005	< 0.005	< 0.005	N/D	2.00
HR		< 0.005	< 0.005	< 0.005		
HL		< 0.005	< 0.005	< 0.005		

Farm	SS	SM	SP	*Ash	TULSMA **(Agricultural Soil)	
HA	Co	7.251 ± 0.238	7.500 ± 0.426	7.583 ± 0.451	5.330 ± 0.110	40.00
HR		6.331 ± 1.039	7.579 ± 1.040	7.140 ± 0.599		
HL		7.560 ± 1.783	7.325 ± 1.454	7.661 ± 2.072		
HA	Cr	9.845 ± 0.883	9.553 ± 1.013	10.070 ± 1.485	5.990 ± 0.082	65.00
HR		9.322 ± 1.606	9.516 ± 1.997	8.274 ± 2.265		
HL		12.244 ± 2.692	10.347 ± 2.916	9.480 ± 6.116		
HA	Ni	7.328 ± 1.327	6.929 ± 0.634	7.163 ± 0.679	3.278 ± 0.186	50.00
HR		6.825 ± 0.320	7.064 ± 1.072	6.035 ± 0.890		
HL		6.528 ± 1.102	7.222 ± 1.018	7.976 ± 3.463		
HA	Zn	33.117 ± 6.805	31.232 ± 3.183	26.752 ± 5.158	15.59 ± 0.325	200.0
HR		33.405 ± 1.343	31.404 ± 5.024	30.429 ± 10.000		
HL		37.581 ± 5.384	28.836 ± 4.677	32.767 ± 7.780		

*Source: *(Sánchez E., 2017). **(Ministerio de Ambiente, 2015).*

Natural concentration on earth's crust of Cu is 50 mg.kg-1 [18] and Hg is 100 µg.kg-1 [19] The analyzed soils are kept below background levels concerning Cu. For its part, Hg exceeds background level. Although the mercury concentration is above the reference values of earth's crust, copper and mercury levels in the soils of analyzed farms do not exceed the maximum limits allowed by current applicable environmental regulations of Ecuador (TULSMA Book VI Annex 2). Although the contribution of ground ash in the Cu concentration is between a range of 37% to 71%, the levels remain between the natural levels of earth's crust and are below the maximum allowable limits for agricultural soils of Ecuadorian regulations.

Pb, As and Cd concentrations are below PerkinElmer Optima 8300 equipment detection limits. They do not exceed the maximum allowable limits set in the standard for soils intended for agricultural activities. Since Pb being a virtually immobile metal under given pH conditions, it could be said that the contribution of Pb from the ashes to the ground is insignificant. For its part, As could undergo a leaching process or joined the trophic chain. As could be precipitated towards water resources or has been absorbed by the grass. Volcanic ash does not contribute to the ground Cd.

It was determined the existence of Magnetite in the mineralogical composition of Cotopaxi volcano ash [17]. Magnetite has Co, Cr, Ni and Zn, which are found in igneous and metamorphic rocks. Therefore, ash could contribute to the concentration of these metals in the soil.

In all rocks, chromium is naturally present, mainly in basic or ultra-basic rocks. The concentration of chromium in limestones and sandstones can vary between 100 and 110 mg.kg-1 [20] – [22]. The Chromium concentration in the soils of the farms studied may be due to a geogenic origin. Maybe the ashes contributed to the accumulation of Cr on the ground. The Cr contribution of ash to the ground is between a range of 48% to 72%.

Ni is present in soils derived from volcanic or basic rocks and having a high clay and organic matter content [22]. Although this element is necessary the growth and metabolism of plants, for mammals it is not considered an essential trace element because the biochemical function it plays has not been clearly defined [22], [23]. The origin of Ni from soils of Altamira, San Ramón and La Laguna could probably be due to the eruptive processes of Cotopaxi volcano, in this case, the volcanic ash could contribute to a concentration ranging from 41 to 54% of the total concentration of Ni.

Zn can be found in magmatic rocks. It is directly related to the presence of Cadmium and Lead. All three metals may be present when problems are detected in the soil with one of them [24]. The contribution of Zn from the volcanic ash to the ground is in a range of 41% to 58%.

The concentrations of Co, Cr, Ni and Zn do not exceed maximum allowable limits for agricultural soils. Even considering the possible contribution of heavy metals by Cotopaxi ashes to the ground, these could not be classified as contaminated soils. They are within the natural limits and below limits established in Ecuadorian norm.

D. Geoportal

The geodatabase was loaded in Collector for ArcGIS. From ArcGIS Online, the points were uploaded to the WFS. Each point stored location and concentrations of heavy metals analyzed. Using ArcGIS Pro, WFS was published so that it is stored in Cloud. All concentrations of all heavy metals presented in Geoportal are in mg.kg-1, and the link to access is: http://geoint-ec.maps.arcgis.com/apps/webappviewer/index.html?id=b6793a0bcbb64b02ba8311b839991d23

Through ArcGIS Online, a Web Map was created, in which presentation of information was configured using scale controls and pop-up windows showing the concentrations of all the results obtained (Fig. 7). Through Web AppBuilder, a geoportal was created in which it presents widgets of bar graphs of results of concentration of heavy metals of soil, through the pop-up concentration of all elements analyzed with ICP is shown -OES and AMA254.

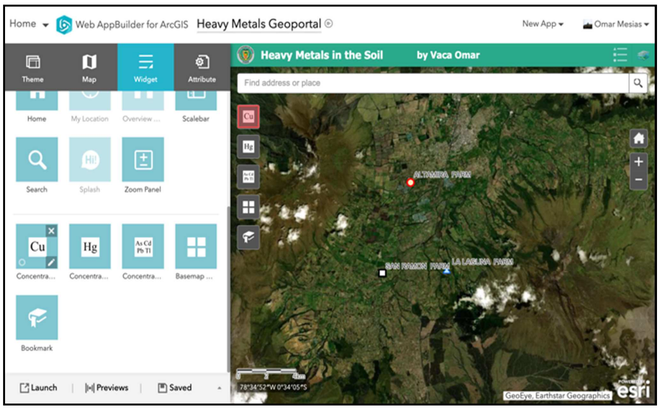

Fig 7. Creation of Geoportal through Web AppBuilder for ArcGIS

The Geoportal uses bar graph widgets to compare metal concentrations (Fig 8). Pop-up windows in which all concentrations of every metal analyzed in this study are stored. BookMarks to access location of farms. The pop-up also details: Ca. Fe. Mg. Si and Mn (Fig 9).

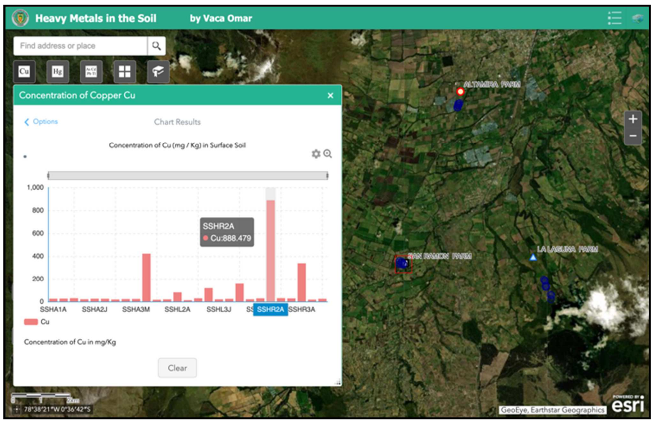

Fig. 8. Geoportal and bar graph widget for the presentation of heavy metal concentration.

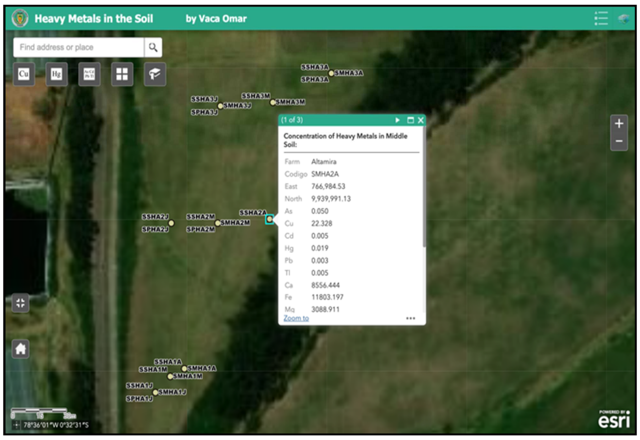

Fig. 9. Pop-up and the information that details.

BookMarks were created in Geoportal to allow predefined access to the location of farm of this study (Fig. 10). Widgets were incorporated that allows choosing a BaseMap different from the one defined by default in WebMap service and a layer control that allows activating or deactivating the display of defined layers according to the depth of sample (Fig. 11).

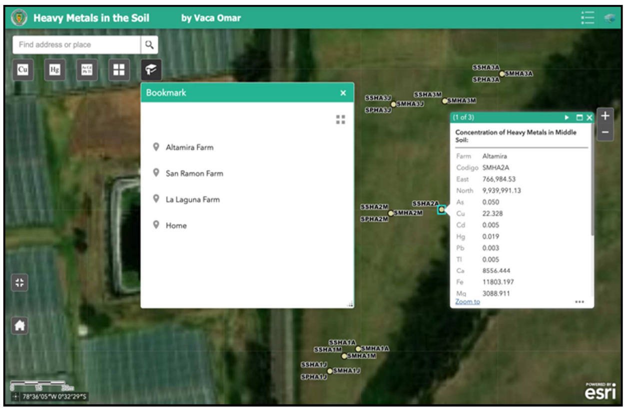

Fig. 10. BookMarks with the location of the Farms.

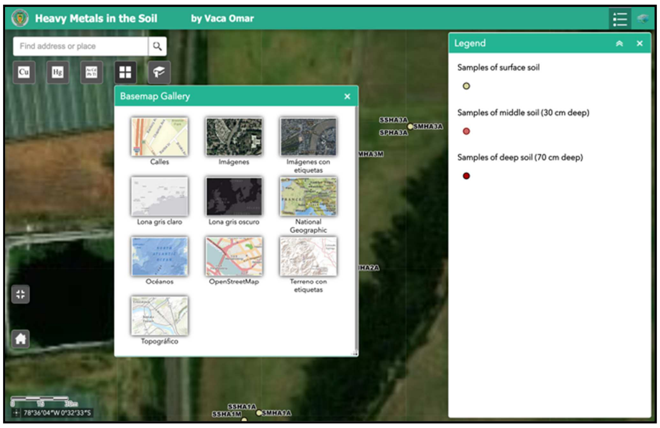

Fig. 11. Widgets of BaseMap and Layer list.

IV. Conclusion

Metal concentrations in mg.Kg-1 were: Cd <0.005, Tl <0.005, Pb <0.0025, As <0.050, Hg = 0.018 and Cu = 26.58. None of them exceeds the maximum limits allowed by TULSMA Book VI: Annex 2 standard for agricultural soils. The metals are even kept below background levels, and their visualization is presented in pop-up windows of Geoportal.

Copper tends to be easily mobile in ashes, while in the soil, its mobility is reduced because the copper pH value in ash is below 5.5 and in soil greater than 5.5. Therefore, ash could contribute between 37% and 71% of the concentration in soil. The Cu concentration in soil did not exceed the maximum limit set the current regulations of Ecuador.

According to pH, As went from being moderately mobile in ash to be easily mobile in soil. As could have been absorbed by the vegetation of the area and could be leached. The concentration of as in the soil remains below the maximum allowed limit for agricultural soils.

Pb was moderately mobile in the ashes, according to pH. It also was practically still in the soil. For this reason, grass has likely absorbed this metal. If Pb from the ashes could be transferred to soil, it would be held at the surface, which would be easily absorbed by small-rooted vegetation. According to the detection limit of the study, the concentration of Pb in the soil is less than 0.0025 mg. Kg-1 and does not exceed the limit established in the standard.

Both Co and Ni are moderately mobile in soil and in ash. It is therefore probable that the ashes contributed with the Co between 69 to 84% and with the Ni between 41 to 54%. These metals are not considered harmful, and in fact, Co is necessary for dietary requirements of cattle. The contribution of Cr and Zn to the concentration of ash in the soil is respectively between 48%-72% and between 41%-54%. These elements do not exceed the limits set by the regulations, so it can be said that soils are suitable for agricultural activities.

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