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Utopia: critical zone observatory as a scientific tool in Colombia to reduce social violence and investigate environmental crimes

Abstract

Utopia Observatory is a social and scientific project led by La Salle University in a rural area in Colombia (South America) called Casanare. This area has recently suffered extreme climate events and recurrent social violence outbursts, with the consequence of leaving the locals in a situation of persistent poverty. The project aims at creating a positive impact on food security, economic development and sustainability through the training of young people from Casanare as agricultural engineers. We decided to create a Critical Zone Observatory in Utopia in order to study the social violence impact and the environmental crimes caused by the use of land and climate extreme conditions. This, by identifying the biogeochemical cycles through characterizations a comprehensive way (climate, physicochemical data from river and soil, satellite imagery) to generate reports for the community and government. Two campaigns (2015-2016) were make and we are working to define the environmental baseline impacts.

Keywords: Colombia, La Salle University, utopia Project, critical zone, biogeochemical cycles, flooded savannas

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Introduction

La Salle University, Colombia, is a private, common-good oriented, non-profit tertiary education institution inspired in a Christian vision of the self, of the world, of history and of knowledge that does research with a vocation of social impact and pertinence. The university has as its social mission the promotion of dignity and the holistic development of the human being, with the goal of achieving the transformation of society, the encouragement of cultural expressions and the search for truth.[1] The university is currently working on the Utopía project, which is develop in the rural area of the Yopal municipality (Casanare province, Colombia). The project offers entrepreneurship program and learning opportunities to rural, low-income young men and women who have been affected by the endemic violence of the country, with the purpose of helping them become capable leaders that can promote social, political and economic improvements for Colombia, by means of an important and attractive platform able to lead to the reconfiguration of Colombian agriculture, i.e., the conversion to sustainable agriculture based on participative research and transference of new technologies.[2] Within the project, the students are support with all the available resources in order to help them become agricultural engineers and make them return to their home municipalities with a seed capital to build a new agricultural start-up, as part of their undergraduate thesis. This zone, a flooded savanna, has been experiencing extreme climate conditions and uncontrolled land use, a problem that is aggravated by the fact that many municipalities within its boundaries do not have access to drinking water and still suffer from the consequences of past outbursts of political violence, a situation that has led to extreme poverty and a large proportion of people with unfulfilled basic needs. Figure 1 depicts several images from the press that show the situation of this territory.

Source: El Tiempo[3] Source: El Tiempo[4]

Source: Revista Semana[5] Source: Revista Semana[5]

Figure 1 Some images of the environmental tragedy that recently took place in Casanare.

Due to the aforementioned situations, many voices have risen, such as the Head of the Instituto Geográfico Agustín Codazzi (the official institution dedicated to geographic studies), who pointed out in an interview that the country. "Had to boost its scientific research on how to make the use of natural resources more efficient, as well as on how to exert better control over state-granted businesses and their water use, by determining which zones in each geographical region would be considered for aquifer storage and recovery". A report from the same institution stated that. "The environmental tragedy could be related to impacts on high-mountain páramos, where the rivers that provide water to Casanare are born; to intensive animal husbandry, which compacts the soil and obstructs rainwater infiltration and surface runoff; to the low water-retention capacity caused by the sandy texture of the soil; to the land's limited productive capacity; and to the use of groundwater by oil companies; [all those] aggravate the situation in addition to the impacts of climate change".[6]

The critical zone

The mentioned environmental phenomena have been a warning that applies not only to Colombia, but that also has a global audience, since, according to Banwart et al.,[7] in the last four decades, demand for food, oil and drinking water has increased by more than 50%, which has caused rapid changes in land use, in the climate and in the chemical composition of the atmosphere, thus directly affecting rural development and calling for a sustainable intervention, coordinated between researchers, scholars and the communities, in order to jointly achieve harmonious paths of development. In addition, though the rural sector is the source of food all around the world, it has often been relegated to oblivion, and therefore it is necessary to create changes through sustainable mechanisms of action, like national and international networks and alliances that help maximize the benefits for the rural sector. This vision requires a holistic model able to reflect the dynamic relations that occur between the physical, chemical and biological components of the soil, without leaving out the environmental, social and cultural dimensions, and keeping account of the attrition and transformation of natural services, which threatens the very existence of the system. Embracing this global tendency, Carpenter et al.[8] introduced a paradigm, here adopted, and named the *critical zone*. In Colombia, there have not been developments of this concept until now. Fisher[9] defines the critical zone as our planet's skin, as the place where rock, soil, water, air and living organisms interact, thus regulating the environment, so fundamental for life. Moreover, according to Banwart,[10] the zone supports all human activity and suffers the pressure created by the growth of human populations and its effects. This zone, Brantley et al.[11] explain, contains most of the life on Earth and is conceived as the space between the canopy and the lower part of aquifers, and is studied in time scales ranging from very fast-paced ones as the time rainwater needs to infiltrate the ground to geological scales like those of mountain-formation. The following image shows a scheme of the critical zone (Figure 2).

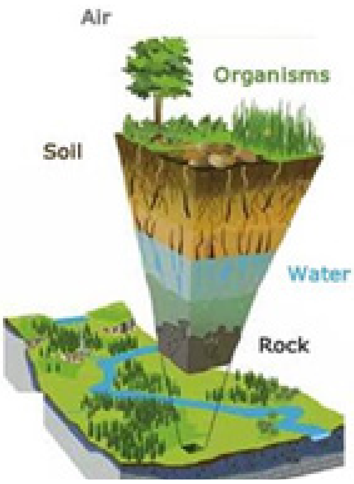

Figure 2 The critical zone. Source: Critical Zone Observatories, U.S. NSF National Program.[12]

The study of the critical zone emerged, as Anderson et al.[13] recall, due to the recognition of the fact that life on the planet depends on the 'services' of that zone, services like suitable and sufficient water for the natural processes of the environment and human activities like food production to sustain demographic growth. This idea of the services of the critical zone was introduced as a conceptual frame for the understanding of natural ecosystems as well as ecosystems that have been intervened by humans.[8] Accordingly, the two aspects that have a greatest impact on the critical zone and are a clear object of study are climate change and land use. However, this zone is not well characterized and the immediate challenge for its study is the development of predictive abilities to determine how it responds to the changes that occur due to the aforementioned climate and land factors. In order to achieve this goal, it is imperative to create a database with all the information needed to work. One strategy consists in generating the appropriate data in a systematic way through mechanisms capable of coordinating the research community in an interaction-rich environment. It is important that this community direct its endeavors to climate change mitigation and prevention of biodiversity loss, given that these are a key social challenge for the 21st century.[10] The mechanism suitable for confronting these issues is the creation of critical zone observatories (CZOs), which are environmental laboratories that focus on the interconnectivity of the chemical, physical and biological processes that take part on the Earth's surface.[14] These necessarily interact in a dynamic way not only with environmental consequences, but also within social, political, cultural, economic and educational frames, since they affect the critical zone. With the CZO we try to understand the interaction between the environmental factors that are linked to the relevant agents through the use of monitoring tools and modelling techniques that help build the intervention and improve sustainability. As for the educational aspect of this approach, the COZ allows us to bring students to field research and school-based research.[15]

Utopía: a critical zone observatory in the orinoquía[1]

La Salle University, understanding that these problems were occurring inside its educational intervention zone, has allowed the setting up of the first critical zone observatory in Colombia, located in the Yopal venue, a strategically-placed location under the influence of the Utopía social project in a typically tropical ecosystem.[16] As mentioned before, this zone has not been thoroughly studied and needs more scientific research if we want to understand the phenomena that take place inside it and arrive at the answers that the nation is in need of. The Utopía Critical Zone Observatory does not need a physical infrastructure since it is in itself a 'study greenhouse' that has laboratories and specialists in several knowledge areas. The observatory also gives many young high-schoolers that have been victimized by the violence the chance to become agricultural engineers.[2] They will become researchers able to change the current state of things. In addition, we have a benchmark in the Environmental Research Observatory ORE HYBAM, which is composed by researchers from Brazil, Peru, Ecuador, Bolivia and France, and aims at doing research on the topics of geodynamic, hydrologic and biochemical control of erosion, matter transferences and alteration in the basin of the rivers Amazonas, Orinoco and Congo.[17] La Salle

[1]Orinoquía is a denomination of the geographical zone that encompasses the Orinoco River in Colombia.

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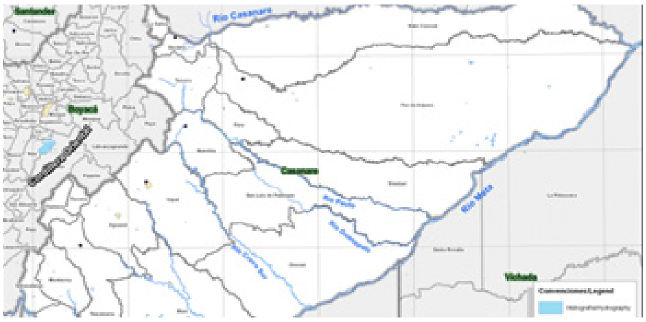
University's critical zone observatory is intending to become part of this project, considering that Utopía has tributary rivers of the Río Cravo Sur, which in turn is tributary of the Río Meta that is itself a tributary of the Río Orinoco, as shown by Figure 3.



Source: Colombia Mapas.[18]

Source: HCDC.[19]

Figure 3 Tributary rivers to the Orinoco River: Meta River, Cravo Sur River.

Biochemical cycles: a first foray

With the purpose of doing environmental research in the zone and in order to create reports for the community and the local and national governments, we visited the place to find the baseline by using surveys and interviews, after which it became evident that there were no antecedents of environmental measurements at the desired scale, which is the integrated study of the critical zone, specifically the study of the biochemical cycle, given its importance for the availability of the elements and compounds in the ecosystems that are vital for the existence of species. Biochemical cycles are natural processes that recycle elements in various chemical forms, taking them from the environment to the organisms, and vice versa. Thanks to the biochemical cycles, the elements are available to be used once and again by other organisms, connecting the living and non-living objects of the critical zone.[20] We therefore decided to do an environmental monitoring session to determine the baseline and start gathering insight on the biochemical cycles. We planned two campaigns and two projects. The first campaign took place in 2015, and another one is to be done in March 2016, both serving as data surveys of climate conditions and the physiochemical traits of the studied rivers and soils. In the latter, we plan to integrate satellite images to predict land production depending on climate factors. As for the projects, since the violence has left behind many landmines buried in the ground, the observatory decided to work on a parallel strategy consisting on the determination of the environmental crime impact that the mines had on recently demined fields destined to agricultural use, which will be handed down to many rural workers. One of the projects, in accordance with this desire, was the optimization of the predictive multilinear model applied to the final destination of substances used in explosives,[21] which estimated the influence of organic matter (humic and fulvic acids in soils). The second project, currently in progress, seeks to apply this model for the first time in Colombian soil, specifically in Utopia, and aspires to predict the environmental destination of nitrated agrochemicals whose characteristics are similar to those of the explosive substances'.

Methodology used in the campaigns

Sample collection of surface water was done according to the sampling method recommended by the Colombian competent authority, the IDEAM (Institute for Hydrology, Meteorology and Environmental Studies), method established in the guide for the pouring of surface water and groundwater (supplementary material) that required the selection of the location where the samples were to be taken, which was determined taking into account whether farmers were taking water from it or not. Water level was measured using floats in straight sections of the river. We defined some distances as benchmarks. A floating element was softly placed upon the surface and, simultaneously, a chronometer was activated; then we measured the time that had passed until the object reached the assigned distance. This procedure was repeated three times, and then we computed an average. Surface sampling was of the integrated type, which involved the simultaneous collection of several specific samples (all of them having the same volume) across the river, samples that were then homogenized in order to facilitate parameter measurement in the field. Our sampling equipment included multi-parameter Hanna HI 991300 (to measure pH, conductivity and total dissolved solids), multi-parameter Hach HQ40d (pH, conductivity and dissolved oxygen), oxygen meter Hanna HI 9146 (dissolved oxygen and temperature), turbidity meter Hach 2100N (turbidity), Colour Test Kit-CO1 (apparent colour), and Imhoff cones for sedimentable solids. In every stage of the analysis we secured and preserved the samples for analysis in the lab, in which we used Photometer Hach and Nanocolor for salts, metals and organic matter expressed as COD (Chemical Oxygen Demand). All the equipment were calibrated and used according to the manufacturer's instructions, and the chain of custody was done in compliance with the IDEAM manual's forms. The parameters that were analyzed in the laboratory were nitrates, nitrogen and COD. Utopía has its own meteorological station. For April the 25th, 2015, when the sampling was made, the values found were: mean temperature with values between 23,3°C and 23,4°C; relative humidity 97.8%; Dew point 23; TWH index of 25.3, rain rate of 1.6; and solar radiation of 51.8.[22]

We additionally conducted a diagnostic test applying a methodology to find biological alteration, especially in macroinvertebrates in water and soil. For water, we used the Biological Monitoring Working Party index (BMWP), which consists in assigning a score (which goes from 1 to 10) to a given family. The number indicates a greater sensibility of the family to the changes in its environment and its habitat, that is, a waterbody will have a better water quality if the summation of all the families found in the sampling gives a number (assessed with the information of the supplementary material) that is greater than 150. Its waters will be considered of good quality, class I and very clean. If the number is less than 15, the water is said to be much polluted (critical situation of class V).[23] For the study of soils the sampling method was that of the IGAC (Agustín Codazzi Geographic Institute) (supplementary material), which requires to classify similar areas according to the following criteria: slope, erosion, types of vegetation (agricultural exploitation timespan, former crops), previous management (fertilization, soil preparation) and presence of rocks and water bodies, among other factors. We later verified that the sampling unit was not larger than 10 has. To do the actual sampling, we used a shovel, a bucket and a canvas, all of them clean, and then took 15 subsamples (zig-zag) of soil in similar quantities at each point, at a depth of 20 cm (the sample was taken in a 25 x 25 cm square). We removed the first 2 centimeters of soil and then proceeded to extract the sample. After that, we mixed the subsamples in a bucket until we obtained a homogeneous composite sample, and we packed approximately 1 Kg of it in plastic bags. The only in situ tests were the pH test (with the pH meter HI99121) and the texture test (organoleptic). As for the characterization of macroinvertebrates in the soil there was an impasse, given that at the appointed time to do the sampling of the individuals, it rained, which caused an alteration in the ideal sampling conditions and forced us to do it on a later date.

Projects on soils methodology

As mentioned earlier, we studied the influence of organic compounds (humic and fulvic acids) on the soils, as part of the determination of the environmental destination of the explosives used in landmines, which reach the soil and groundwater. We wanted to optimise the multilinear model. The model was applied to six mixed explosives: HMX, RDX, nitroglycerin (NG), nitroguanidine (NQ), TNT and 2,4-DNT, which are shown in Figure 4. We worked in 25 soils of diverse physiochemical characteristics with clay ranges between 4.0 and 43.2% and total organic carbon between 0.07 and 18.23%. The data were processed using the multilinear model described in equation 1.

$$Kp_{s,e} = Koc_e(foc)_s + K_{CEC\,e}\,(f_{CEC})_s + K_{Fe\,e}\,(f_{Fe})_s \quad (1)$$

Where $Kp_{s,e}$, is a coefficient representing the concentration of explosives in the soil in relation to water (1:1) for each soil (s) and each explosive (e); Koc, K_{CEC} y K_{Fe} are the partition coefficients of the explosives along the diverse components and characteristics of the soil (organic carbon OC, cation exchange capacity CEC and extractable iron Fe), which were computed for every explosive and soil; foc, f_{CEC} and f_{Fe} are the fractions of those components and soil characteristics, determined directly from the soil. To optimize the model we took 14 of the 25 soils of the multilinear model and performed an acid-base extraction to determine the humic and fulvic acids (HA and FA, respectively) and, with these data of the fractions we recomputed the model as it appears in equation 2, replacing the value of organic carbon by HA and FA.

$$Kp_{s,e} = K_{HAe}\,(f_{HA})_s + K_{FAe}\,(f_{FA})_s + K_{CEC\,e}\,(f_{CEC})_s + K_{Fee}\,(f_{Fe})_s \quad (2)$$

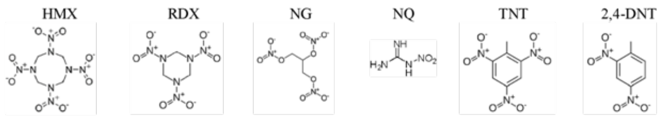


Figure 4 Explosives used in the multilinear model.

Results

Environmental monitoring campaigns

Next we show in Table 1 the results of the obtained physiochemical parameters, which were the first to be obtained in the river in the water intakes that supply the different crops. We can see in the table that these values are within the acceptable boundaries, though we do not have access to previous measures, limitation that does not allow a comparison of values or levels. We are waiting for the results of the 2016 campaign in order to be able to make an estimate of change. As for the aquatic macroinvertebrates analysis we could identify organisms of the Leptoceridae, Dixella and Chordodidae families, which are characteristic of clean, not very polluted waters and that usually thrive at riversides, thus indicating a good waterbody condition. Figure 5 depicts one of the organisms we found.

Table 1 Results of the physicochemical parameters obtained in the first campaign

			CROP				
Parameter	**Method**	**Unit**	**CACAO 1**	**CACAO 2**	**CASSAVA**	**MAIZE**	**COFFEE**
Sediment solids	Imhoff cone	ml/L		0,8	0,5	0,5	1
Temperature	Multiparameter	°C	23	24	25	25	26,1
Conductivity	Multiparameter	µs/cm	70,6	58,5		109,8	111,3
OD	Oxygen meter	mg/L	7,56	7,87	7,74		6,74
pH	Multiparameter	pH units	6,8	6,24	8	6,92	6,83
Nitrates	Spectrophotometer	mg/L	14,5	0,7	23,2	4,9	1,21
Nitrogen (N-NH3=	Spectrophotometer	mg/L	0,23	0,26	0,31	0,19	0,31
COD	Spectrophotometer	mg/L	47	36,33	32	119	31
Colour	Colour kit	UPC		10	15		45
Turbidity	Turbidity meter	NTU	263,5	205,6	158,8	209,3	251,5

Figure 5 Organism found in the macroinvertebrate study.

Project on soils

In Figure 6 we show the results of the mean values of the squared errors (RSME) for each one of the models of HA and FA that we run. Here it is evident that the model of equation 2 returns much lower values than the other models, oscillating between 0,4 and 0,6 (both less than 1), which indicates a good correlation between the experimental data and the proposed model. We conclude, then, that this model can be used as an effective predictive tool applied to concentrations of explosive substances in soil and water, that is, that the obtained Kp value can be used to determine the environmental impact that takes place in landmine soils.

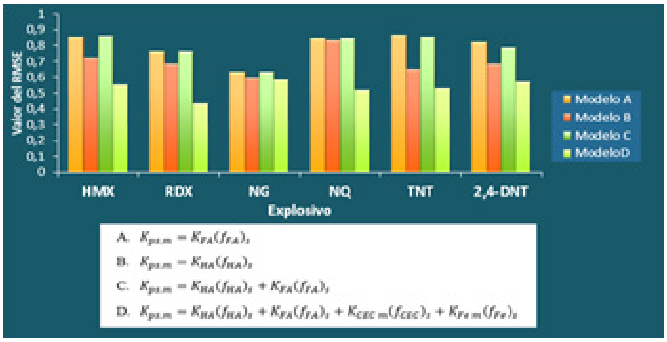


Figure 6 RSME values for the models of HA and FA computed with the collected information.

Conclusion

The CZO proposals in the Casanare province in Colombia, framed within the social and scientific project Utopía is a good opportunity to gather climate and environmental information useful for the formulation of mitigation policies in the future, taking into account the zone's vulnerability.[24,25] The environmental monitoring campaign that we did gives baseline values that should be compared with new data and should be submitted to the environmental authorities of the zone for inspection, in order to define local environmental regulations. We were able to estimate the partition coefficient by using the information of the physiochemical variables of the soil in terms of HA and FA for organic matter, which indicates its potential use to predict the environmental destination of the explosives. This development implies that we can create interventions to mitigate the impact of these substances in the studied zone in a simple way, just tracing the behaviour of the explosives.

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Conflict of interest

Authors declare that there is no conflict of interest.

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