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Nuestros Suelos: exploring new forms of public engagement with polluted soils

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Abstract

Despite being a critical environmental problem, soil pollution is not usually considered as a relevant issue by the general public. This disinterest derives from traditional procedures to assess soil pollution that are quite complex and costly, not considering any form of citizen involvement. Seeking to challenge this situation, the project “Nuestros Suelos” (Our Soil) aimed at designing and testing a low-cost participative soil pollution assessment toolkit. The final prototype included several participative modules, going from an assessment of the history of local soils to measuring heavy metals such as Arsenic and Copper. Tested with low-income communities in northern Chile, the toolkit was able not only to produce multiple kinds of data but also a public that started to understand and care about the issue.

Keywords

Citizen science; Public engagement with science and technology; Risk communication; Soil pollution; Open hardware technologies; Chile

DOI

https://doi.org/10.22323/2.21010801

Submitted: 20th August 2021
Accepted: 22nd December 2021
Published: 14th February 2022

Forgotten soils

At its general assembly in June 2015, the UN approved the “World Soil Charter” which begins by stating that “soils are fundamental for life on Earth, but pressures on soil resources are reaching critical limits” [FAO and ITPS, 2015, p. 4]. This charter was the result of widespread concern among experts and international organizations regarding the issue of soil pollution caused by human action.

Technically understood as “the presence in soil of a chemical or biological substance out of place and/or present at a concentration above the norm that has adverse effects on any non-target organism” [Rodríguez-Eugenio, McLaughlin and Pennock, 2018, p. 1], this form of pollution affects both humans and the environment. Although its full global extent is currently unknown, the partial data available are of quite concerning. For example, the report “The Lancet Commission on pollution and health" [Landrigan et al., 2018], the first global analysis of the issue, states that "around 61 million people in the 49 countries surveyed so far are exposed to heavy metals and toxic chemicals at contaminated sites" [p. 18]. Their harmful effects of these chemicals tend to be experienced primarily by low-income populations in rural areas, adding to a host of other socio-environmental problems.

Despite the seriousness of the problem, and in contrast to other forms of pollution such as water and air, soil pollution is usually ignored when discussing the environmental problems affecting our planet. Up to this point "the multiple declarations and proposed action programs have not led to increased public attention or effective political action that would recognize the central role of soils [in the fight against the harmful environmental effects of human action]" [Bouma and McBratney, 2013, p. 130]. As a result, "despite their central roles in the emergence of life and the maintenance of humanity soils have long been forgotten or treated in a simplistic manner" [Lin, 2014, p. 1831], a forgetfulness that is especially critical in the case of contaminated soils and their socio-environmental effects.

This neglect of soil contamination starts from the basic fact that "soil contamination often cannot be directly assessed or visually perceived, making it a hidden hazard" [Rodríguez-Eugenio, McLaughlin and Pennock, 2018, p. 1]. This difficult perception stems from the simple fact that "soil is, by its nature, a refractive medium; it resists analysis of its complex components" [Smith, 2011, p. 24]. Along with this character, a significant number of soil contamination situations correspond to "slow disasters" [Nixon, 2011], i.e., environmental disasters that occur gradually and surreptitiously, usually being difficult to notice even for people living in areas affected by them.

However, the lack of public knowledge, interest and action about the issue is also directly connected with the way soil pollution is usually measured. In most countries worldwide, soil pollution is evaluated though procedures based on the environmental risk assessment (ERA) model. Originating in the U.S. in the 1970s, this model aims at "estimat[ing] and characteri[zing] the probability that harm to human health or ecosystems will occur from exposure to substances in the environment" [Holifield, 2012, p. 594]. As explored by Boudia [2014], the development of ERA procedures was in the hands of technical personnel whose main focus was the production of detailed quantifications of pollutants' concentrations, resulting in costly and highly "complex procedures that includes many variables and parameters, many of them difficult to analyze" [Galán et al., 2019, p. 96]. Given such complexity, historically soil pollution assessment has been almost insulated from any kind of citizen involvement, even in the form of basic risk communication [Hope, 2006]. Then the application of the ERA model regarding soil pollution not only produced highly detailed quantified data but also different forms of "strategic ignorance" [McGoey, 2012], or a situation in which the general public cannot really apprehend or even access the scientific knowledge being produced, resulting in a general inaction about the issue.

This situation is especially critical in middle-to-low income countries, where the complexity of the procedures must face low levels of scientific literacy and a culture of highly technocratic approach to environmental regulation [Barandiaran, 2015]. Besides, the relatively low availability of funds to run such assessment mean that the problem of soil contamination becomes in practice "invisible to the community" [Rodríguez-Eugenio, McLaughlin and Pennock, 2018, p. 2]. This has repercussions at multiple levels, from a general public that do not perceive the problem as peremptory to the very communities living besides — even above — polluted soils which regularly ignore their presence and potential effects [Ureta, Mondaca and Landherr, 2018].

Aiming at start dealing with such lack of public involvement on the issue, in 2017 the authors of this piece started in Chile the project "Nuestros Suelos" (Our Soil). The motivation for such initiative was the recognition that one of the most negative consequences of the current industrial production model in Chile are the multiple forms of soil pollution [Centro de Análisis de Políticas Públicas, 2013]. What makes this problem especially pressing is that such pollution affects especially vulnerable communities, which are already experiencing a series of other environmental and social problems.

However, the growing recognition of this problem by the academic community has not translated into the issue becoming a matter of concern for the general public or the authorities in the country. Again, this lack of interest and action is intimately connected with the fact that the only official tool available in the country to assess soil pollution [MMA and Fundación Chile, 2012] rest heavily on the ERA model, contemplating an evaluation process that is quite complex, costly and does not involve any kind of citizen participation. Nuestros Suelos was enacted as a way to start exploring a citizen-led alternative to such procedure and the ignorance its produces.

Objectives and principles

A main source of inspiration for Nuestros Suelos has been the citizen science movement, especially the one focused on environmental pollution. Regarding soil pollution issues, the impact of citizen science initiatives has increased importantly lately given the growing availability of low-cost scientific hardware for use in citizen science projects [Gabrys, 2019]. The inclusion of these devices allows citizen science projects to become not only participatory exercises, but also producers of scientific data, which is especially relevant for issues that have not yet been investigated with conventional scientific approaches such as soil pollution.

Regarding polluted soils, a particularly inspiring case for us was the Gardenroots project, a citizen science experience carried out with a community living next to a site contaminated by heavy metals in Arizona, U.S.A. [Ramirez-Andreotta et al., 2015]. Another interesting initiative was led by a group of environmental scientists from Columbia University, U.S.A. [Landes et al., 2019], who developed a low-cost kit for measuring lead in soils, working in collaboration with artisanal miners in Peru. In both cases, the combination of a citizen science model with low-cost technologies allowed communities living near contaminated sites to start engaging differently to the issue, becoming in the process producers of scientific knowledge.

Taking inspiration from such initiatives, in 2017 the authors of this piece started Nuestros Suelos with the aim of designing and testing a toolkit for the participative assessment of soil pollution based on a citizen science model and low-cost technologies. The use of this toolkit involves a series of stages, ranging from a reconstruction of the history regarding local soils to the production and evaluation of exploratory data regarding a series of key aspects of soil biochemistry. Each stage is focused on balancing the production of quality exploratory data with broad levels of citizen participation, seeking to produce both sound qualitative estimates and a community that knows and understands their implications. Together with the concrete results of each local implementation, Nuestros Suelos seeks to make visible the existence of alternatives to traditional soil pollution assessment procedures such as those included in Chile's official methodology especially in contexts where there are no economic and/or technical means to apply methodologies that involve complex and expensive laboratory analyses.

Following from this, the development of Nuestros Suelos was based on a set of key principles:

- Accessibility: Nuestros Suelos sought to develop a qualitative assessment methodology for potentially polluted soils that is truly accessible, in two key senses. Firstly, in terms of costs, seeking to generate a methodology whose monetary cost of application is as low as possible. Secondly, in terms of application, seeking to generate a methodology that is simple to apply, so that local governments, organizations and interested communities can use it with only basic technical assistance.
- Multidimensional character: we sought to generate a methodology that approaches soil and its problems in a multidimensional manner, especially by interrelating qualitative data on heavy metal concentrations with (1) soil fertility aspects and (2) environmental and geopolitical aspects of the areas in which these soils are located.
- Self-contained: the aim was to generate a self-contained methodology, in the sense that its application would make it possible to obtain results in situ, without having to depend on subsequent processes such as sending samples to the laboratory and/or carrying out further research.
- Reflexivity: following an analytical framework of science and technology studies (STS), our approach to citizen science and low-cost technologies is imminently reflexive in nature, in the sense of seeing them as very valuable tools, but which can also become potentially ineffective, even harmful. For this reason, they have to be always critically observed and analyzed, seeking continuous improvements and adaptations.
- Interdisciplinary: the materialization of these principles into a concrete toolkit demanded high levels of interdisciplinary collaboration, especially between disciplines such as soil science, geology and engineering with those of the social sciences and design, collaborations that rarely occur in relation to soil pollution assessment.

In all, the Nuestros Suelos toolkit aimed at offering an accessible methodology through which communities — especially in countries such as Chile — could start properly engaging and acting upon an urgent environmental problem such as polluted soils.

Components

In its current version, the Nuestros Suelos toolkit consists of three main components. Each of these components has been designed in an interrelated manner, so as to constitute an integrated whole.

3.1 *Methodologies for the systematization of local knowledge and practices regarding soils*

As mentioned above, a key objective of Nuestros Suelos is to place the potentially polluted sites under study in a broader environmental and socio-political context in order to further explore causes and possible solutions to the problem. To assist in this task, this first component seeks to gather key information about this context through the systematization of the participants' knowledge and recollections about processes that have affected local soils. This is done by adapting three tools from Participatory Action Research methods [McIntyre, 2008]: participatory mapping, practice mapping and territorial timelines.

First, participatory mapping [Chambers, 2006] seeks to identify together with the participants the most relevant geographic, socio-political and environmental processes of the areas in which the specific soils under study are located. This is done through working collectively on a map of the area, which participants are invited to fill by writing/drawing and/or putting stickers on it based on their personal knowledge and in situ discussions. Secondly, and taking as a reference the participatory diagnostic tools developed on natural resource management [Geilfus, 2002], the participants are invited to make a detailed list of quotidian practices that involve interacting with local soils, from agriculture to leisure. Finally, in order to recover the historical evolution of local soils [CES, 2011], participants are invited to draw up a timeline indicating the main events that could have influenced the current characteristics of local soils, both natural (floods, droughts, etc.) and social (emergence of new productive developments, housing construction, etc.).

3.2 *Devices for the qualitative estimation of key biochemical parameters regarding soil pollution and fertility*

Based on basic analytical chemistry processes, these devices allow a quick and in-situ exploratory diagnosis of the state of some key soil parameters. Each parameter is analyzed through a specific chemical reaction (redox reactions, Eh-pH, decarbonation) that take place when a soil reacts to a specific chemical substance generating a product that is analytically determinable and measurable. In line with the multidimensional principle behind Nuestros Suelos, as a whole these devices aim at connecting issues of soil pollution with more general themes regarding soil fertility.

Regarding pollution, the kit includes two methodologies.[1] First, it has a procedure to determine the relative concentration of copper (Cu). Cu is a metal naturally present in soils that upon contact with HCl produces a reaction that causes a color change by oxidation on a contrast metal. The intensity of the color change is easily identifiable through a colorimetric scale that is indicative of the Cu content of the sample. Secondly, it has a procedure to determine the relative concentration of arsenic (As). As is also a metal naturally present in soils, especially in Chile. Based

[1] A new prototype of the toolkit, currently under development, will also include a test for lead.

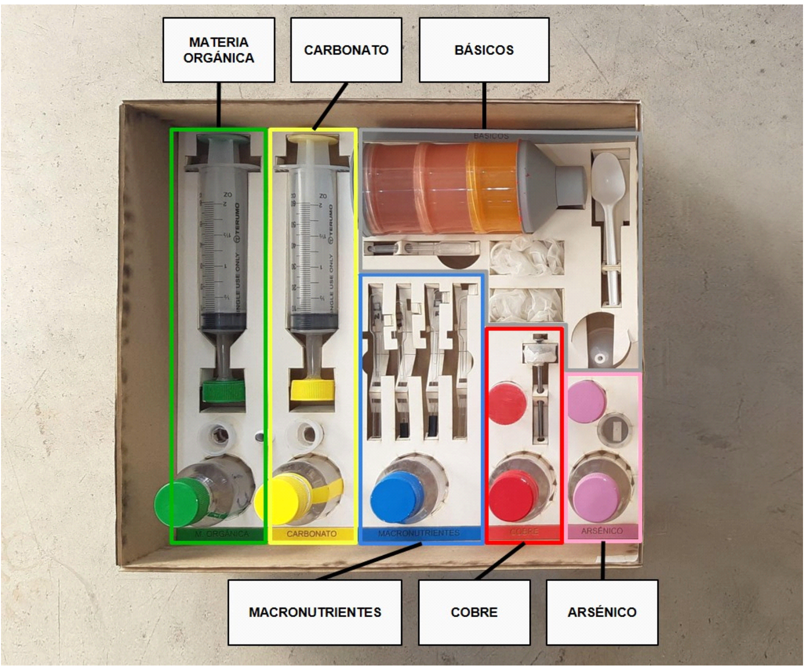

Figure 1. Biochemical evaluation kit. Source: the authors.

on commercial As measuring stripes and that have a series of specific reagents and catalysts, we have generated a new simplified test in terms of handling and instructions that allows identifying the As content of the soil sample by means of an strip of paper that reacts to the As present on the soil and then can be compared with a colorimetric scale.

Regarding soil fertility, the kit includes four methodologies. First, a methodology that seeks to determine the organic matter of the soil samples. The organic matter in soils is degraded to “humus” which reacts violently when it comes into contact with hydrogen peroxide (H_2O_2) producing an effervescence that generates O_2. In the instrument, this reaction is evaluated by volumetric displacement of a plunger. Secondly, the macronutrient content of the soluble fraction of the soil — in this case nitrogen (N), potassium (P) and phosphorus (K) — is determined by means of a change in color of strips of litmus paper, which is compared with a colorimetric scale. Along with this, the acidity or alkalinity of the soil (pH) is measured using also litmus paper. Thirdly, calcium carbonate is evaluated by volumetric displacement of a plunger, which reacts with acid substances such as hydrochloric acid (HCl) producing an effervescence reaction that generates CO_2.

3.3 *Board game for integrating and using the knowledge acquired to deal with concrete challenges related to soil pollution*

Inspired by current developments that see gaming as a privileged space for socio-environmental research and intervention [Damman, 2018; Flanagan, 2009; Glas et al., 2019], this board game aims at generating a playful experience that facilitate group reflection and discussion on the best ways to take care of local soils based on the information gathered in the two previous stages of Nuestros Suelos. In particular, this gaming experience invites participants to (1) consider and

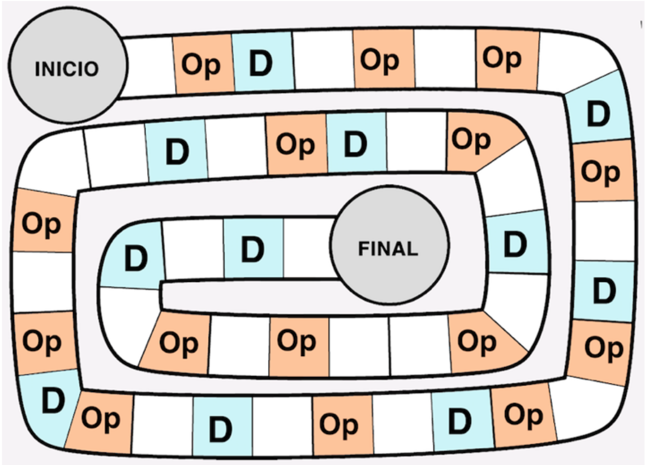

Figure 2. Board of Nuestros Suelos game. Source: the authors.

integrate the heterogeneous data (socio-environmental, biochemical, productive, etc.) collected in the previous stages and (2) use it to face a series of hypothetical future challenges regarding local soils.

The game has a "roll and move" structure whereby participants are divided into teams of 4–6 people and have to advance across a board by rolling the dice, with the winner being the first to reach the end ("Final" in Figure 2). As they advance on the board they can land on three types of squares, neutral, opportunity boxes and challenge boxes.

When falling into the opportunity boxes (Op on the board), participants have to randomly draw an opportunity card from a pool of 30 cards. Each opportunity card presents the group with a positive opportunity regarding soil condition improvement, sorted into social (e.g. "There is a strong and active neighborhood association"), productive (e.g. "There is public funding for agricultural soil remediation"), physical-biological (e.g. "Material for active amendments (guano, humus, etc.) is available") and chemical (e.g. "Reagents are available to neutralize heavy metals in soils") dimensions. The selected card is saved, to be used as a wild card when facing a challenge.

When falling into the challenge boxes (D, for "desafío", on the board), participants have to randomly draw a challenge card from a group of 15 cards. Each card briefly explains the challenge to be faced, specifying which dimensions of the soil it affects following the distinction between social, productive, physical-biological and chemical dimensions, always affecting more than one of these. Most of these challenges are negative (e.g., "there is a flood in the valley"), but they can also be positive (e.g., "there is a high demand for crops in the sector").

In order to overcome the challenge and move forward, the team must briefly discuss and present to the other participants, who act as judges, a strategy to meet this challenge. In this strategy they must necessarily use the information gathered in the two previous stages of Our Soils, integrating socio-environmental elements gathered in the mapping with qualitative indicators of the physical-biological and chemical characteristics of the soils obtained in the second stage. In this strategy, they can also use the opportunity cards available to them.

Testing

In order to test the prototypes of the different components with potential users, two complete applications of the Nuestros Suelos kit were carried out with members of low-income communities living in the Copiapó river basin of Chile (800 km north of Santiago), on the verge of the Atacama Desert. This area was selected because it concentrates a great deal of Chile's mining industry, an activity that has left behind a considerable legacy of waste, which have tended over time to disperse, leaving the soils in many areas — among them the ones selected for the testing — with very high levels of heavy metals [Carkovic et al., 2016]. The tests were conducted with members of a community of low-income farmers (June 2019) and with members of a neighborhood association in a semi-rural area (September 2019).

The dynamics of both tests were similar. First, contacts were made with the leaders of both associations to explore their interest in participating in the initiative. Once these contacts were fruitful, a first meeting was held with interested participants to explain the general logic of the exercise. In addition to describing the different components of the kit, a central function of these preparatory meetings was to explain the scope of the process and answer in detail their doubts, in order not to generate expectations that could not be fulfilled. Before departing, each participant was asked to arrive on the day of the workshop with a sample of about one kilo of the soil whose potential toxicity they were interested in assessing, explaining in detail how these samples should be extracted to enhance representativeness and reduce risks of cross-contamination.

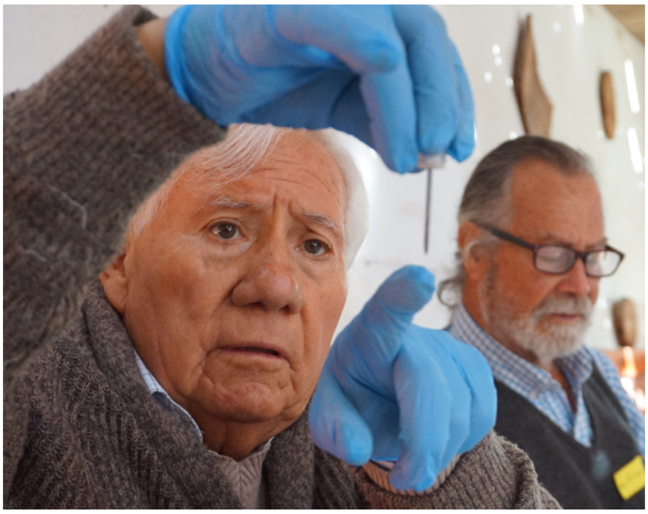

Figure 3. Testing in San Pedro. Source: the authors.

In both cases, the test itself was divided into two days, a Friday afternoon and a Saturday morning (these days were previously agreed with the participants). After a welcome and general presentation, Friday afternoon (starting at 17:00 hrs) was dedicated to develop the first component of the kit, the participatory methodologies for the systematization of local knowledge and practices regarding soils. This process lasted approximately 3–4 hours and the participants had no major difficulties in carrying out the activities. On Saturday morning (starting at 10:00 hrs) we started by applying the second component of the kit, the devices for qualitative estimation of key biochemical indicators of soil pollution. This process lasted on average about 3 hours and was much more challenging for the participants to perform (see below), although they were all very enthusiastic about it. Finally, the workshop was closed playing the board game. This activity lasted an hour and was easily understood by the participants. After the workshop, the participants showed great enthusiasm and appreciation for the toolkit, frequently asking how they could use it on their own.

The tests also identified a number of key issues that should be dealt with in future prototypes of the toolkit:

– Need for technical support. In the early design stages, the toolkit was conceived as a tool to be applied autonomously by the users, without requiring any technical assistance other than that the provided by manuals and tutorials. However, one of the lessons learned from the testing is that, although this toolkit is considerably simpler to apply than any other conventional methodology, it still presents some difficulties, especially for older users and those with low levels of schooling. For this reason, the toolkit started to be seen no longer as an autonomous entity, but as part of a workshop in which people with some technical training would act as monitors, helping users to use correctly its different components.

– Difficulty in standardizing results. In relation to the biochemical parameters, resulted quite complex to standardize the different individual results with the measurement scales prepared in the lab. As a consequence, it was recognized the need to locally calibrate these measurement scales before each workshop, adjusting them to the different components and structures of local soils.

– Emphasis on user-friendly design. Another key issue that appeared in the tests was the difficulty of some participants (especially those of older age) to manipulate some components of the biochemical kit, especially those of smaller size. For this reason, several designs were changed to make them easier to manipulate and use.

– Playfulness. A positive surprise was the playful character of the whole experience for the participants. Beyond the seriousness of the topic and the fact that none of them had had previous experience with methodologies of this type, in general the application was marked by a playful spirit among the participants, almost as if it were a game, which undoubtedly made easier to dedicate long hours to the experience.

– Fatigue. Despite the enthusiasm at the end of the experience, both the participants and the monitors were quite tired, which meant that not enough quality time was devoted to the third component, the board game. This pointed out to us the importance of constant time control and the introduction of frequent breaks in order to be able apply all the components in a good way.

– The weight of data. Another lesson was the great relevance that the participants ended up giving to the results of the biochemical indicators. Although it was explained to them several times that this data was only qualitative and exploratory, it persisted on them a strong belief about its ultimate scientific validity. This fact was of concern to the research team, since it can lead to over-interpretation of the results, giving a definitive character to data that were only intended to be exploratory.

These two tests provided the research team with several key lessons that are being considered in a current new iteration of the project.[2]

Conclusions

Soil pollution is an urgent environmental problem in many parts of the world, menacing the health of populations and the long-term future of activities such as agriculture. However, most of the population — even groups living in areas of heavy pollution — does not recognize the issue as relevant, most of the time acting as if the soil was merely a static background for their everyday lives. As discussed above, a great deal of this public inattention to soils is derived from conventional methodologies for the assessment of soil pollution — such as the ones based on the ERA model — that are highly complex, expensive and don't consider any kind of citizen involvement.

Nuestros Suelos sought to explore an alternative to these instruments through the design of a low-cost and simple-to-use toolkit for exploratory soil pollution assessment, a tool that could be directly used by the very communities affected by soil pollution in order to start knowing and taking action about the problem. Its multidimensional character allows to put biochemical estimates of pollution by some key heavy metals in dialogue with a series of other elements that are not usually considered in risk assessments, such as factors related to soil fertility and historical and geopolitical events affecting local soils. The production of this more holistic look at the problem of soil contamination aims to help interested communities to understand soil problems in a more complex way, a first step towards taking action regarding its improvement.

Although the results of the project so far are encouraging, important challenges remain. A key issue is how to generate more reliable estimations about some of the biochemical parameters, results that can then be used in standardized comparative studies. Another issue to be resolved is how to integrate the use of this instrument with long-term work by governments, local organizations and affected communities, in order to really contribute to dealing with the problems related to soil pollution. Finally, a key challenge is not just to create an interesting prototype — as is often the case in citizen science initiatives using low-cost technologies — but a tool that is easily available to communities and organizations wanting to start dealing with soil pollution. These challenges are of diverse characteristics and scales, motivating new efforts in exploring this issue.

The enormous challenges posed by the multiple socio-environmental crises we face (usually subsumed under the term Anthropocene) should force us to reimagine the ways in which we design and implement devices for public engagement with contentious environmental issues such as soil pollution. Replacing the usual practice of leaving the assessment of these issues on the hands of technical personnel, the Anthropocene should lead us to develop new, denser and more speculative, interdisciplinary and democratic modes of public engagement with environmental science. We hope that projects such as Nuestros Suelos will serve as

[2] In 2019, the National Science Foundation (U.S.A.) approved an application led by Professor Abby Kinchy of Rensselaer Polytechnic Institute to carry out a new iteration of Nuestros Suelos, further developing its components and running new tests in the U.S. and Chile. More information here: https://oursoil.wp.rpi.edu/.

motivation for further developing these new modes of public engagement with science.

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How to cite

Ureta, S., Llona, M., Rodríguez, D., Valenzuela, D., Espinoza, C. T., Guiñez, C., Rebolledo, A., Maiza, M. J. and Beltrán, C. R. (2022). 'Nuestros Suelos: exploring new forms of public engagement with polluted soils'. *JCOM* 21 (01), N01. https://doi.org/10.22323/2.21010801.

ISSN 1824-2049. Published by SISSA Medialab. jcom.sissa.it