

Geovisor implementation for visualization of geodynamic and geomorphological properties of the subsoil: Case study Cuenca, Azuay, Ecuador

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Abstract. Globally, the development of cities and the increase in their population accelerate construction processes, significantly contrasting with soil studies of the soils on which buildings are built, whose research results advance at a slower pace than required, often resulting in the occupation of spaces without these previous studies. Mainly due to the null or limited available information is scattered across different sources, files, and formats, and searching for it is a long and difficult process that generates unproductive spaces. This leads to high vulnerability of structures to different events that modify soil behaviour. To address these limitations, the present study aims to generate a standardized database that compiles existing information and processes it so that it can be easily and quickly accessed. A geovisor (based on geographic information systems GIS) is proposed as an ideal way to geographically display on the web the collected data from the studied region (for this work: Cuenca – Azuay – Republic of Ecuador). The information for this study has a seismic focus, being the variables of interest: primary wave speed V_p , secondary V_s , soil type according to the classification of local regulations (NEC-SE-DS) and international SUCS, and soil period. It also incorporates geological and geotechnical information, and stratigraphic subsurface profiles. This constitutes the first national-level database that combines all this information in a single format, forming a great tool for professionals and the community in general in making decisions when infrastructures are emplaced. This information is presented in a geovisor designed for quick access and easy understanding, avoiding the omission of important processes in civil works.

1 Introduction

Currently the study of the soil characteristics is essential prior to build up any type of civil works. Since, over time the growth of the population in terms of its distribution and demographic concentration has been significant, thus the higher the development index of a sector, the higher the population growth, directly leading in the urban expansion [1]. A particularity of how settlements grow in Latin America is their dispersed and fragmented distribution, building infrastructure in disorderly manner near urban areas to not lose contact with the services that they offer [2], defaulting the territories administration due to the

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absence of land studies and urban planning before being used [3], as a consequence, vulnerability problems of the population arise from effects of external natural factors such as landslides, floods relief, among others, as well as internal factor that include tsunamis, earthquakes, volcanic eruptions, erosion and temperature.

Soil studies with a global approach permit to reduce vulnerability risks and include seismic threats assessments. However, this information is often limited by conditions such as geopolitics, reduce economy in research, complex tectonic contexts, insufficient technologies [4], and on which works this study, the preservation of information over time, that often isn't registered or stored correctly and lacks adequate maintenance, suffering physical or digital damage, and even getting lost [5].

For seismic consideration, the geosciences explain its origin, mechanism and the effects that result from the propagation of energy released as waves through the soils, which can generate damage or structure collapse. The level of this damage is known as seismic vulnerability in structures [6], and is mainly associated with factors such as recurrence ratios, return periods, energy attenuation phenomena, and infrastructure fundamental periods [4]. Therefore, studies should include the influence of site-specific conditions such as its response, wave speeds, geomorphology, topography geology, geotechnical properties and of secondary threats [7]. These site effects commonly ignored [8], are the main amplifiers of the magnitude of the seismic wave effects [5,9,10].

The Republic of Ecuador isn't immune to seismic event, it's located on the fringe of the Pacific Ocean's Ring of Fire, whose seismic activity is representative, and has a high degree of active faults [11], therefore, the risk by natural threats has a great impact. In the last years, the growth of the hazards has been considerable, arousing interest for study with more attention the local effects of these events [12], aggravated by bad processes control, monitoring and construction, since it has been identified that in several seismic areas there are infrastructures built without this criteria or with outdated codes, generating a high vulnerability [13].

An example of this can be seen in a sector of the country, where there were no studies on hazards or soils, and to cover its population growth, the buildings grew vertically. As a consequence, important damage were identified in structural elements, differential settlements, constructions without technical data, poor-quality soils, among others [14]. This shows how rapid infrastructure expansion without previous studies increases vulnerability in structures [7], in contrast, including them allows a correct urban development of cities with planning for different types of events [15].

In the Cuenca city the problems are similar, with infrastructures built in risk zones (floods areas, high slopes, landslides areas, unstable soils in a static state and under seismic excitations). These problems are accentuated by the location of the city on volcanic and sedimentary basements with a high presence of geological faults [16], with expandable, saturated soils and low cohesive conglomerates, generating a high presence and susceptibility to mass movements. It's so, from 2017 to 2022, about 670 events have been identified, 120 of them are of special interest due to their magnitude and location in inhabited areas [17]. These events have left considerable economic and human losses [18].

With this background, the importance of grouping all possible soil information and having quick access to it, is evident. In many cases, this information doesn't exist or is minimal, due to a lack of studies or its loss over time, therefore its search becomes a process that consumes significant time and technical and economic resources. To store the information, it's ideal to create digital databases, that consist of elements that are related to each other and at the same time include data about themselves [19].

For geographic information, it is efficient to group it into thematic maps that integrate and characterize the physical environment, its inventory, and susceptibility [20]. The seismic-geotechnical zoning maps allow understanding the dynamic soil characteristics and are

constituted as a primary information to be used by professionals in design and construction of appropriate structures for each type of soil [8].

Currently, computer systems strengthen the management of geographic data due to the amount of information they can process, with GIS systems positioning themselves over other tools. These consist in instruments composed of technological and human elements [21], reduce time and costs, and can face social, economic, and environmental limitations [22]. Their standardized structure and integration with databases optimize processes [23].

In civil engineering, GIS improves control in construction works, and with a geotechnical approach, the scope is broadened towards seismic, as done by Perez [24], Tehseen et al. [25], Nyimbili et al. [26], Debiche et al. [27], who applying different techniques have achieved microzoning, predictions, soil behaviours, among others, maximizing their potential thanks to the use of databases and servers. A server stores the database through an external connection to access it through a URL address. In the case of geographic data, they are known as map servers or geovisors [28,29], and to create them, geoservices are used, which, together with internet protocols and programming languages, offer an integrated system [30].

2 Methodology

To start, information is collected from different sites in the city of Cuenca, Azuay province. The data to be displayed is stored in a centralized database. The amount of records depends on the data density present in the studies [31]. This information comes from seismic zoning and geotechnical studies, allowing to establish dynamic characteristics, with the aim of having within reach important parameters in decision-making in construction and their typology in study and expansion areas [8].

For the development of the geovisor, the information is properly geoprocessed and the necessary digital cartography is created. This, in turn, will have the data properly standardized, with the aim of being used or visualized by any general public [32,33], and that it complies with the free access to information, as stipulated by the Law Organic of transparency and access to public information issued by the Ecuadorian National Congress [34], and the 2008 Constitution [35].

This allows local manner complies with the objective 16 of UNESCO [36] in the 2030 Agenda for Sustainable Development on free access to scientific information, which emphasizes its importance for the development of peoples and their technologies.

The standardization of the information is carried out in matrix arrays, where the columns represent each variable, and the rows a new geographical site. In this study, the interest variables are: the coordinates of the geographical site, primary wave speed V_p and secondary or shear wave speed V_s at different depths (including V_{s30} at a depth of 30 m), soil period, and classification according to local regulation NEC-SE-DE issued by the Urban Development and Housing Ministry [37] and international SUCS. Once ordered, it is taken to a single format for its cartographic representation [38].

The information is represented in a map management system, using GIS-type software to create the necessary layers. With support from geoserver platforms, it's taken to the web to a platform with a design of easy technically and visually understanding, conforming to an intuitive interface [33,38]. In this study, "Geoserver" is used, which is an open-source server for sharing geospatial data from any source using open standards. It can handle very large data sets, whether raster or vector type [39].

The compilation considers theses by Encalada [40], Bermeo [41], Delgado and Rivera [42], Domínguez and Vargas [43], Coronel and Ortíz [44] and Galarza and Rojas [45], who carry out soil studies and microzoning in the Cuenca city. Public and private consultancies with geophysical and geotechnical studies are also considered, carried out by Albarracín [46–48], Almache [49,50], Baculima [51], Cárdenas [52,53], Escandón [54], Gad Chiquintad

[55], Ordoñez [56], Ortega [57], Vásquez [58], N. Pesántez [59–62], R. Pesántez [63,64], Pozo [65], Quezada [66], Raster Ingeniería de Proyectos [67,68], Rivera [69–71], Roura [72], Vázquez [73,74], C. Vintimilla [75–87], M. Vintimilla [88–90] and Zambrano [91]. Additionally, the geology of Cuenca at scale 1: 25 000 from the Precupa project [92] and the Geological and Energy Research Institute - IIGE [93] at a scale 1:200000, as well as the isoperiod curves taken from Quinde [94], are also included.

Thus, adapting and reconfiguring the process established by Pérez [24]; for the needs of the present study, the methodology is grouped into three stages: (1) compilation, organization, and standardization of information into matrix arrays; (2) georeferencing data and creation of layers using GIS; (3) using programming logic in conjunction with the “GeoServer” server, the technical and visual environment is created for displaying information in a GeoPortal.

3 Results

With the organized information, the following layers were generated: geology of the Azuay province in scale 1:200000, geology of the city of Cuenca in scale 1:25000, geodynamic properties of the soil, isoperiods for the Cuenca parish, stratigraphic profiles, and soil stratigraphy based on direct explorations such as test pits, SPT tests, and perforations, including the parish boundaries of Azuay. All these layers are available for visualization on the final site designed for the geovisor in the GeoPortal, and can be turned on or off according to the user's needs (Fig. 1).

The geology of Azuay at a scale of 1:200 000 summarizes 5 variables: soil lithology, the formation to which they belong with their symbolic representation, as well as the main geological group of which they are part, and the source from which the information was obtained (Fig. 2). Two additional variables, such as soil susceptibility to landslides and its behaviour, are included in the geology of the city of Cuenca at a scale of 1:25 000 (Fig. 3). In both layers, the geological groups are represented with unique colours.

The isoperiod curves group 3 variables: the value of the soil period, the source, and the name of the document from which the information was obtained for its digitization, each line is identified with a different colour according to its value (Fig. 4). It is important to mention that in Figures 2, 3, and 4, a legend is included, but sometimes it can be uncomfortable for the user's visual. Therefore, to avoid the conflict, it has been configured so that it can be hidden and shown with a click on it.

The stratigraphic profiles include the source and the name of the base document, as well as a thumbnail image that shows the 2D stratigraphic profile, which may also include stability analysis of themselves (Fig. 6), where the safety factors are compared with local regulations. In the case of stratigraphy obtained through direct explorations, their coordinates are also displayed (Fig. 7). In both layers, by clicking on the images, a new page opens that displays them in a much larger resolution and size, thanks to a virtual cloud service called 'Cloudinary,' which generates a unique URL link for each image existing in its storage.

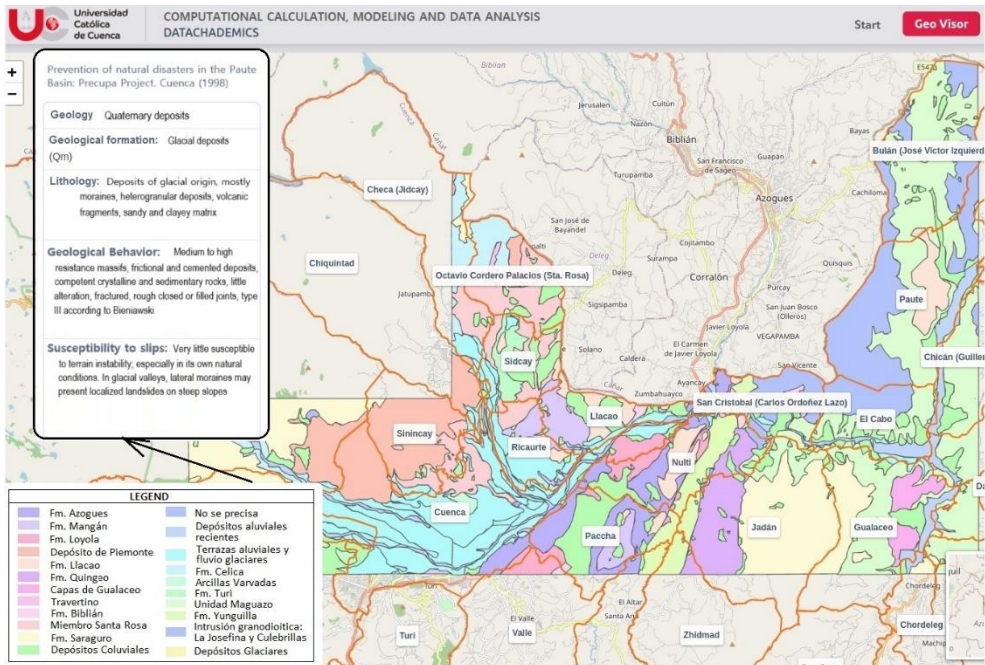


Fig. 3. Visualization of the digitalized geology based on the Precupa project.

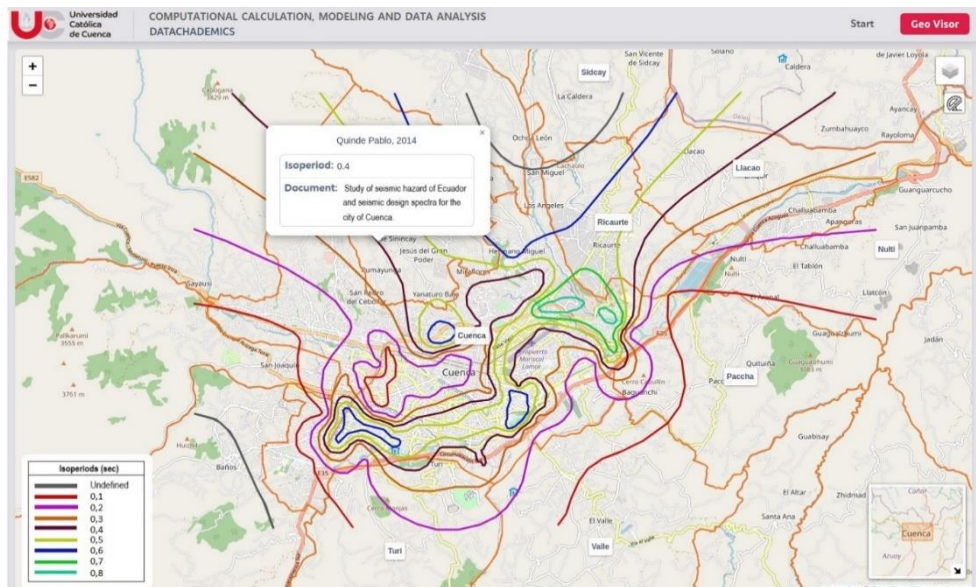


Fig. 4. Visualization of the isoperiods of the Cuenca parish, Azuay province.

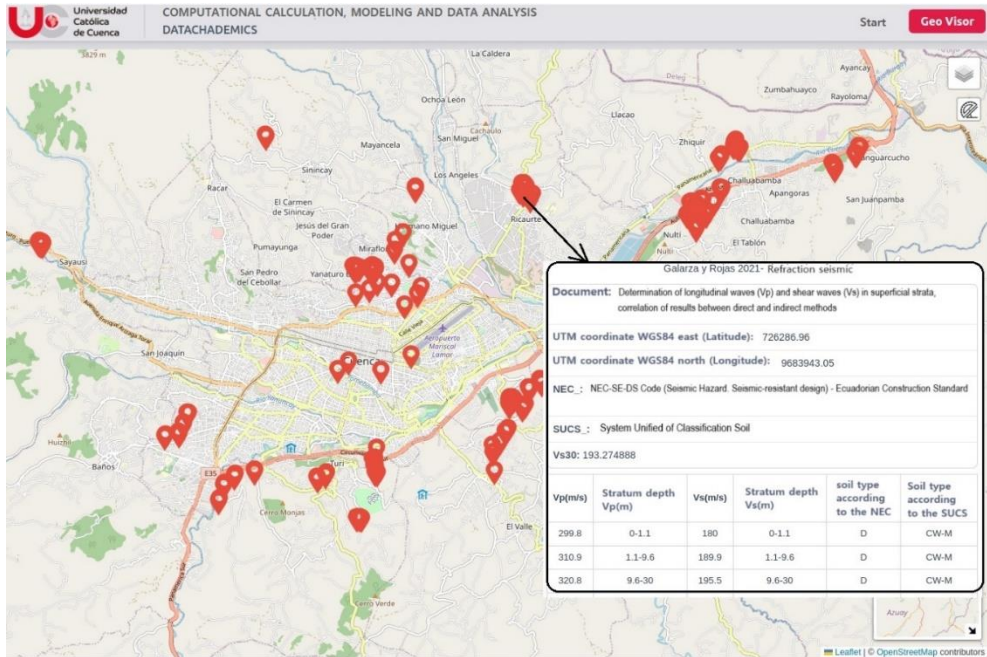


Fig. 5. Visualization of the geoseismic information of the soil.

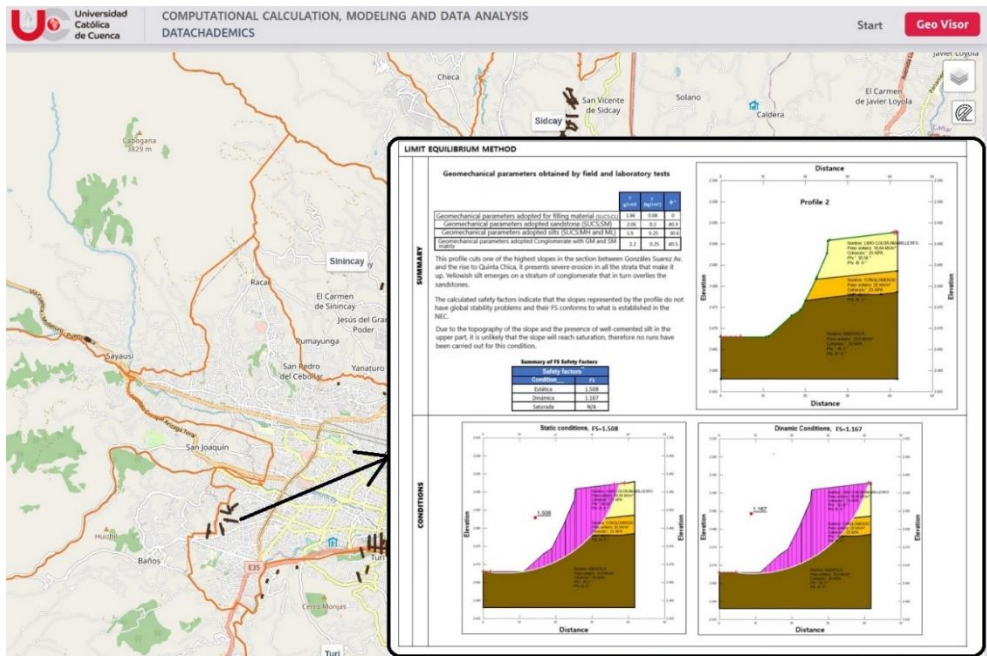


Fig. 6. Visualization of the stratigraphic profiles, depth > 30 m.

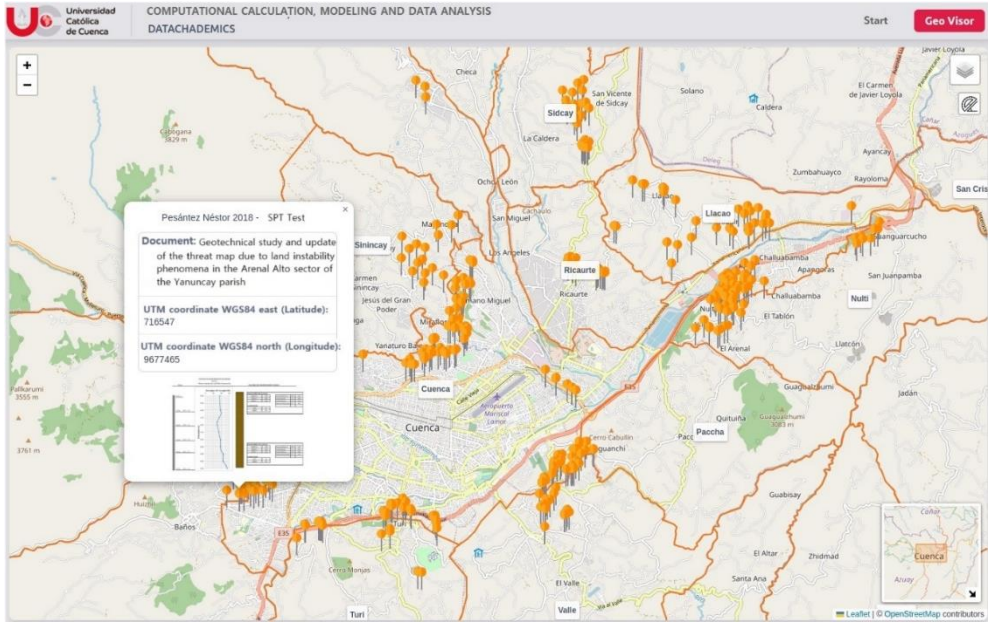


Fig. 7. Visualization of soil profiles obtained through direct exploration.

It is observed that the geovisor fulfils its objective, accessing to the information just by clicking on the elements of each layer, where there are around 800 points of information. It also offers services to measure horizontal distances, change the base maps, and a smaller location box for quickly navigating on the map.

4 Discussion

4.1 Relevance of the geovisor generation and its importance for the Azuay province

The geovisors are an important tool in the interaction with geographic information, and have a high potential for dissemination and research, they are collaborative environments and contribute to urban and territorial planning processes [95]. In the design and planning of construction projects, they optimize technical and economic resources and help detect possible errors or events early on [96]. In the case of civil engineering and the present study, in addition to forming an important database, they pave the way for the generation of stratigraphic structures and wave speed in three-dimensional models, essential for estimating the necessary parameters in seismic design [97].

The Cuenca city has been established as a heritage city, therefore from planning and management it has been sought that the city becomes a model of sustainability [98], extending to public and private companies and academia, which together have led the city to a good organization and management.

Thus, the generation of information about the city is wide, constantly updated, and it's ordered in various storage bases (libraries, academia, public and private digital services). Geographic systems are not separate from the structuring of this city, and institutions have invested efforts to provide broad coverage of topics, such as demographic information, orthophotos, forest inventories, green areas, political delimitations at the parish and cantonal

level, geomorphology, urban and rural cadastres of the city of Cuenca, among others. However, in civil engineering, focused on construction and seismic, the information is limited, with geomorphology being the variable that can provide certain criteria. The absence and dispersion of information is similar for the rest of the provinces in Ecuador. In response to this, by compiling different studies in this work, the search for this information is facilitated, providing both professionals and citizens in general with the first database with this combined and standardized approach to the city. It also becomes the first model at a national level that collects this information and processes it for a geovisor.

5 Conclusions

The central objective of this research focuses on two main axes: the recovery, compilation, and standardization of information, as well as the creation of the web environment (geovisor) to visualize it. This type of study proposes to guide other cities in the province to form their databases of soil studies, and with adequate interaction, a large model can be generated that is feeds and expands continuously towards more sectors of the country. This would form a potential tool for the generation of three-dimensional models of the subsurface at a larger scale, as shown by Ramón [99], who developed a three-dimensional model for a specific sector, based on data from this portal (Fig. 8). The objective of these models is the ability to create simulations for different events in the soil, as carried out by Antonietti et al. [100] and Pauselli et al. [101] who, together with mathematical models, manage to recreate the behaviour of the soil through different geographical areas.

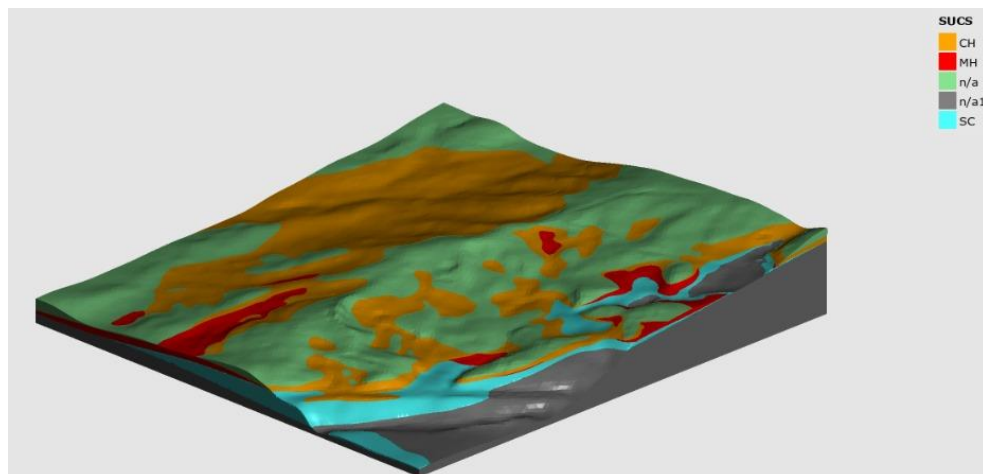


Fig. 8. Three-dimensional model with subsoil properties by Ramón [99].

Another objective of this service is to promote collaboration of the different professionals in the field who have this information privately and can release it in this space without disregarding their authorship. The new information collected can be updated through a reviewing intermediary. The next step is to turn it into a dynamic network where different professionals can also directly enter their information and create a great collaborative network for the fields of engineering, geotechnics, and seismicity, supporting and strengthening the permanence of data over time.

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