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COMPARISION OF THE GENERAL HYDROGEOLOGICAL CONDITIONS OF THE KARST WATER BODIES OF HUNGARY AND ECUADOR

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Abstract: Karst systems are highly vulnerable groundwater bodies due to the high rate of infiltration and fast travel times. In fact, the delimitation, protection and sustainable exploitation of karstic aquifers are matters of research around the world. This article presents an extended description of geographical location, geological features, geodynamic evolution, and geometric distribution of the karst aquifer systems of Ecuador and Hungary. Hungarian karst water bodies, which are widely utilized for water supply, are well known from a hydrogeological perspective compared to those of Ecuador, a country that makes less use of groundwater. In conclusion, the human necessities generated by the geographical location of the living place determine the investment of local governments in research concerning their natural resources as well as the ways for their utilization, in order to improve the quality of life and economy of their territories.

Keywords: *groundwater systems, karst systems, thermal karst, cold karst, Ecuadorian karst bodies, Hungarian karst bodies, karst hydrogeology*

1. INTRODUCTION

The groundwater budget supplies at least 50% of drinking water of the worldwide population and 43% of total water used in agricultural activities, resulting in a current over-exploitation of 20% of the Earth's aquifers [53]. This fact will unleash a future world challenge in the sustainable management of the water resources in order to control variations in the their distribution and availability. Achieving an effective groundwater management plan requires not only a technological understanding of infrastructure but also an integral knowledge of the non-structural needs. Among the non-infrastructural components, the characteristics of the aquifer (nature, definition, delimitation and potential) constitute a safeguard for sustainable development and a reduction of groundwater depletion risk.

Among the types of aquifers, karst water is considered a valuable water resource around the world, and the protection and preservation of their quality and availability is a permanent discussion topic. Nevertheless, karst groundwater systems [18] are particularly vulnerable to contamination due to the high percolation of water from the surface into the groundwater flow system, and the fast travel time in the conduits and fractures, making their management approach a challenging task for the hydrogeological community.

Based on the increasing importance of water conservation on a global scale, this report has the aim of contrasting the current state of art about the karst water resources of two countries: Ecuador and Hungary. They are in the focus of the study because they are not only different in its environment, but in their political and socio-economic systems, too. These differences create a suitable contrast to compare how their karst water sources and their management strategies fluctuate according to the socio-economic development.

Each country has its own approach to the sustainable management of the water sources based on needs of the population, political framework (institutions), economic level, and water resource availability. It is well known that Hungary has a long history in management of their groundwater resources, which are used all over the country to cover around 95% of the freshwater supply [7]. Also, Hungary belongs to the top 5 countries with a high amount of thermal water resources. Meanwhile, in Ecuador, the sustainable management of groundwater resources as freshwater supply is a relative new topic [17], even though the statistics of the National Institute of Meteorology and Hydrology (INAMHI) show around 5,000 of groundwater catchment points all over the Ecuadorian territory [11]; however, proper documentation and sustainability plans are lacking.

The importance of collecting information to analyze the contrast between both countries contributes to moving forward on the better management of water resources through basic research [54]. In addition, the knowledge transfer from countries with more experience in hydrogeological management like Hungary to countries like Ecuador, where there is incipient hydrogeological development, represents a symbiotic relation of learning.

2. GEOGRAPHICAL LOCATION

2.1. Ecuador

Ecuador is located in the northwest of South America *(Figure 1)* where three lithospheric plate boundary structures of the Earth can be found. The Ecuadorian territory is connected to: (1) the global system of ridges where the Nazca plate and Cocos plate are pulled apart, (2) the Ring of Fire or Circum-Pacific Belt with high volcanic activity and the Andes Mountains crossing the country from north to south, and (3) a transcontinental rift structure parallel to the Ecuador line and Amazon axis [1, 44, 50, 56].

The Ecuador mainland is divided into three geographical units: (1) the Coastal Plain, (2) the Amazon Basin; and (3) the Andes mountain range as a system of two parallel sub-mountain ranges that became one in the south of the country *(Figure 2)* [22, 50]. The Ecuadorian hydrological system is divided into two run-off surfaces, the Atlantic run-off surface and the Pacific run-off surface, with their watershed in the Andes range.

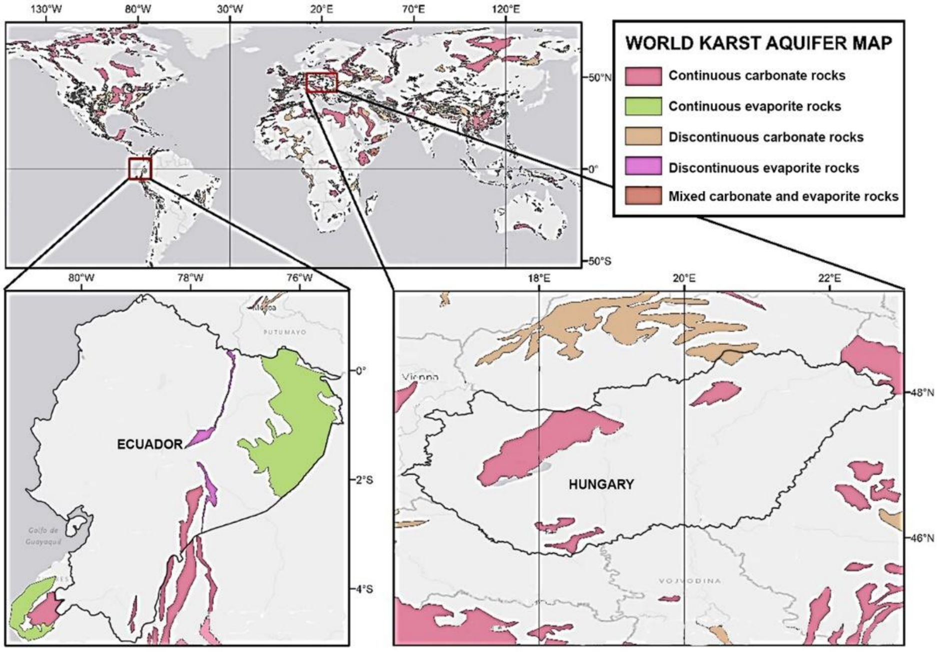

Figure 1

Geographical location of Ecuador and Hungary, and their karst aquifers from a global point of view, adapted from WHYMAP, 2017

2.2. Hungary

Hungary is located in Central Europe and in the Pannonian Basin *(Figure 1)*, where a collage of terranes of Alpine and Adriatic origin was created due to crustal and upper mantel processes inside and around the basin *(Figure 3)*. The Pannonian Basin is part of the Alpine orogenic system, filled with clastic sediments since Miocene. The sedimentation process was accompanied by intensive calc-alkaline magmatism during the climax of the rifting on Early and Middle Miocene [25].

Furthermore, the area of Hungary is surrounded by the Alps, the Carpathians and the Dinarides mountain ranges. It is characterized by extensive lowlands called the Great Plain and the Little Plain. They include a main hydrological system constituted by Lake Balaton and the Danube River basin with its tributaries: the Rába, Tisza and Dráva. Additionally, the special geological and geographical characteristics of the country surface create exceptional conditions for the groundwater budget. However, its location in such a closed continental basin represents a challenge in the field of environmental management, conservation and protection of the resources [7, 47].

3. GEOLOGICAL AND GEODYNAMIC FRAMEWORK

3.1. Geological features and structural evolution of Ecuador

The Ecuadorian geological features *(Figure 2)* are defined as a set of various tectonic provinces of characteristic rock units oriented north to south and parallel to the regional tectonic strikes [27], where the oceanic terranes were accreted onto the Amazon craton from Early Cretaceous to the Eocene [12], and the onset of the orogenic processes started the Andes Mountain raising. From East to West the following domains are recognized:

The Oriente foreland basin and the Salado marginal basin *(Figure 2)* represent the outer-frontal segment of the fold thrust belt and associated flexural foreland basin. The Cretaceous-Cenozoic sedimentary succession is horizontal, undisturbed to the east and locally deformed to the west. The Cretaceous basin-fill includes sandstone, siltstone, organic-rich shales, and subordinate limestones derived from the craton. The Cenozoic sequence includes sandstones, siltstones, and conglomerates derived from Andean sources. These sequences overlay the Jurassic magmatic arc exposed in the Sub-Andean Zone such as non-metamorphic granites, monzonites, and granodiorites [3, 12, 27].

The Loja terrane, the Guamote terrane, Chaucha terrane, Tahuín terrane (Paleozoic schists and gneisses, Triassic granites and anatexites) and the Alao island arc (Jurassic meta-basalts/andesites) *(Figure 2)* are a set of sublinear metamorphic belts of deformed Upper Paleozoic-Lower Cretaceous sedimentary igneous and volcanic rocks. They are located in the Eastern Cordillera geographic zone. The metamorphism of the rocks is linked to a complex formation of processes such as sedimentary burial, crustal shortening, and terrane collision, complemented with isolated Quaternary volcanic centers [3, 12, 27].

The Macuchi-Piñon island arc and the Cretaceous Piñon oceanic plateaus *(Figure 2)* correspond to the Western Mountain range geographic zone. They are considered as allochthonous mafic and ultramafic Upper Cretaceous rocks overlain by Upper Cretaceous-Paleogene sedimentary rocks and Paleogene-Quaternary magmatic rocks [3, 12, 27].

3.1.1. Structural evolution of Ecuador

The main tectonic evolution stage of the Ecuadorian Andes Mountain is related to the convergent border of the South American Plate and part of the Nazca Plate, located north of the Grijalva Fracture Zone [28]. The most important stages of its tectonic evolution can be summarized in six stages [22, 37].

During the Late Paleozoic, a Pre-Andean Ridge developed and was accompanied by intracontinental basin formation filled with the pre-metamorphic sediments of the Loja, Amotape, Raspas, and Chaucha terranes and the Amazonic craton.

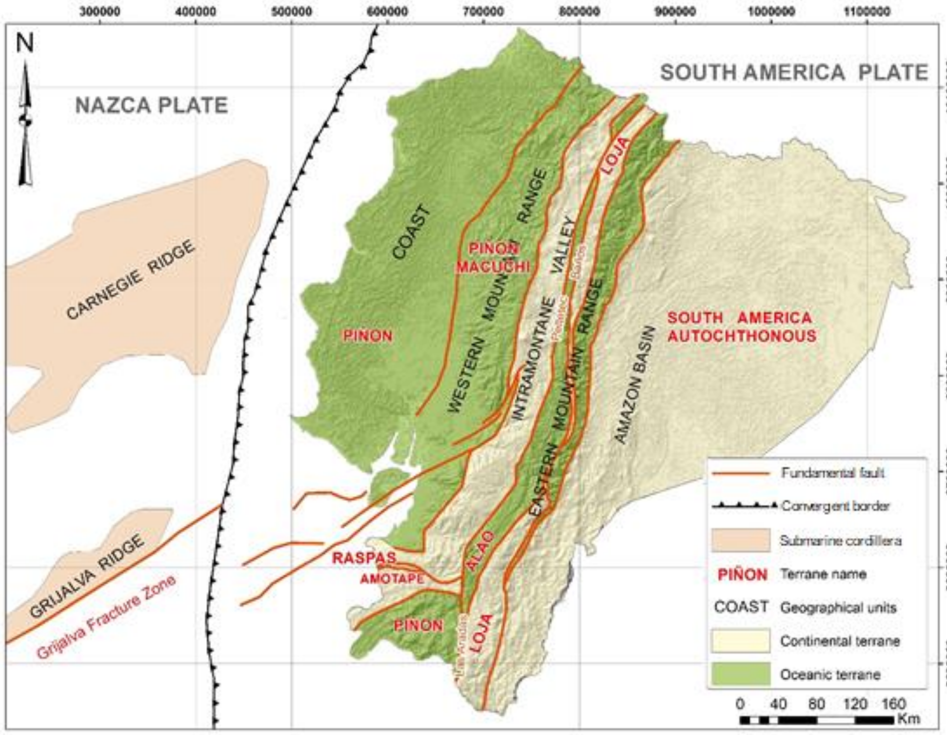

Figure 2
Main structural terrane and geographic units of Ecuador presented in the Geological Map of Ecuador updated by the Geologic and Energetic Institute of Investigation (IIGE) of Ecuador [16, 48, 55]

After the Pre-Andean Ridge suffered a subsidence during the Mesozoic, a new marine transgression took place [51]. The marine calcareous facies became well developed in the Amazon basin. Meanwhile, the Coastal Plain area became covered by thick accumulations of basic volcanic material at a constant rate from the Jurassic to Middle Cretaceous.

The period finished with the tectono-metamorphic accretional event of thrusting and transgression in the fault system Peltetec. Later a new orogenic cycle due to subduction took place during pre-Late Cretaceous. The pyroclastic material intercalated into Maastrichtian sediments occurring in the coastal plain. Meanwhile, in the Andean Range calcareous marine sediments accumulated, and in the Oriente region calcareous marine sediments started to become more detrital *(Figures 2)*.

Then, between the Late Cretaceous and Paleogene time the allochthonous Piñon terrane was accreted and it was thrust east verged on the metamorphic basement of the Real Cordillera [51]. This was followed by the last phase of Andes tectonic uplift originating from the subduction of the Nazca plate during the Neogene.

From the Quaternary until the present time the Andes have maintained their physiography, but the Coastal Plain have been forming marine terraces though out this time, while in the Oriente region intensive fluvial sedimentation has been producing gravel deposits. Additionally, glacial and fluvio-glacial activity has been taking place in the perched mountain range valleys *(Figures 5)*.

3.2. Geological features and structural evolution of Hungary

In case of Hungary, the geological features are determined by its Late Cenozoic evolution, when large basins come into being. With thick sedimentary series from Late Miocene-Pliocene, Pannonian Lake filled up the basins. Subsequently, they became overlain by Quaternary alluvial deposits, loess, and wind-blown sands [23]. Nowadays, the Pannonian Basin is a system composed of numerous basins separated by ranges *(Figure 3)*.

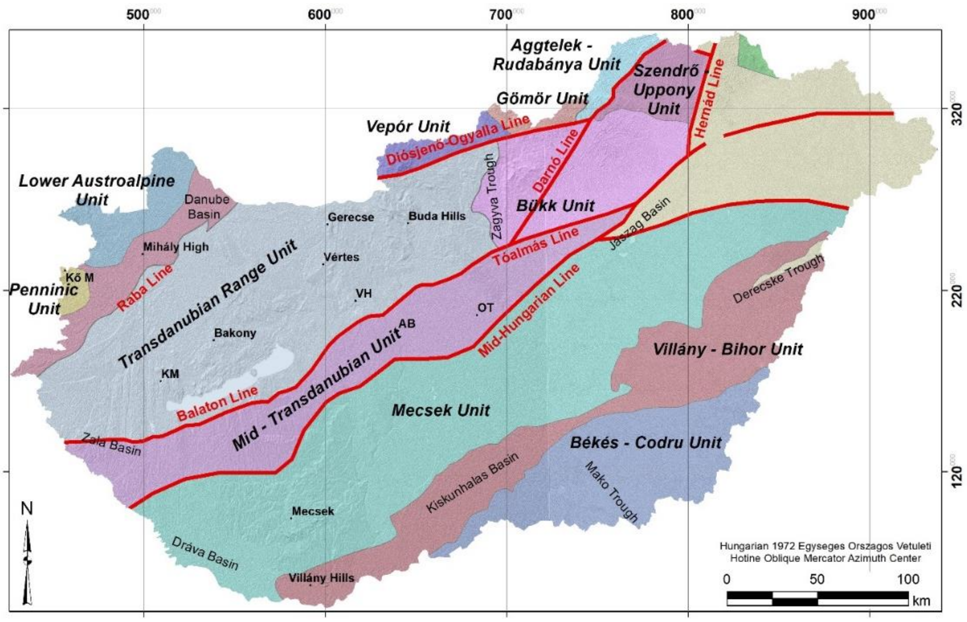

Figure 3

Main structural units of Hungary represented by Haas et al. (2014)

The Mecsek Mountainson the Transdanubia side *(Figure 3)* are constituted by Carboniferous granite, thick Permo-Triassic continental red-beds, Middle Triassic carbonate sequences, extremely thick, marine, siliciclastic Jurassic sediments, and Cretaceous magmatic complexes. Located south of the Mecsek Range, the Villány Hills have an imbricate structure consisting mainly of Mesozoic carbonates [23].

For instance, in the northwestern part of the Hungarian territory, the Sopron and the Kőszeg Mountains crop out *(Figure 3)*. These metamorphosed Paleozoic and Mesozoic complexes represent the sequence of the East Alpine Ranges into Hungary [23].

Also, among the ranges is founded the Transdanubian Range *(Figure 3)*. It extends for 250 km in a NE–SW direction, and it is composed of a great variety of geologic components. For example, Lower Palaeozoic phyllite and carbonates are part of the highland, north of Lake Balaton; while a great part of the Velence Hills northeast of there is made up primarily of Carboniferous granite. As well, the Keszthely, Bakony, Vértes, Gerecse, Pilis and Buda Mountains are mainly made up of Triassic carbonates; and with Jurassic, Cretaceous and Paleogene formations also occurring in the central zone of the Transdanubian Unit [23].

Likewise, the North Hungarian Range *(Figure 3)* forms part of the Pannonian Basin ranges. It shows a very complicated geologic setting. The Szendrő and the Uppony Hills are made up of low grade metamorphic Paleozoic slate and carbonates, while the Bükk Mountains are constituted of a low grade metamorphic Upper Paleozoic–Jurassic series and a similarly metamorphosed Jurassic sedimentary and magmatic complex. Locally, a marine Paleogene sequence covers them. Near the Slovakian border, nappes of Triassic and Jurassic siliciclastic sediments and carbonates crop out as the Aggtelek Mountains and Rudabánya Hills. Other parts of the range, such as the Börzsöny, Cserhát, Mátra, and Tokaj Mountains, are made up mainly of Paleogene and Neogene siliciclastic sequences and Miocene igneous rocks [23].

3.2.1. Structural evolution of Hungary

Four main stages of the tectonic evolution *(Figure 3)* of the Pannonian Basin are described, summarized as follows [15, 23]:

Pre-Alpine, mostly Variscan evolution, determining the geological structure of the plate margins at the beginning of the Alpine plate-tectonic cycle. In the Jurassic, large fragments of the Variscan Belt dismembered from the margins and became incorporated into the Alpine orogenic system.

The Middle Triassic to Early Cretaceous early stage of the Alpine plate-tectonic cycle was characterized by the opening of oceanic basins. Then, the period of the mountain formation took place during the closure of the basins from the Middle Jurassic to the Early Miocene. Meanwhile, the terranes that shape the basement of the Pannonian Basin were emplaced and became a juxtaposed setting by the end of this stage *(Figure 3)*.

Eventually, the subduction of the European Plate in the Neogene produced the development of molasse, and in the Pannonian Basin the subduction-related thinning of the crust was accompanied by intense volcanism. This was followed by an extended, accelerated and unequal subsidence, and infilling of the basin system during the Late Miocene-Pliocene and some sub-basins in the Quaternary.

Finally, during the last few millions of years, a confirmed structural inversion took place in the Pannonian Basin, characterizing its advanced state of evolution [5].

4. KARST WATER BODIES DISTRIBUTION

4.1. Karst hydrogeology in Ecuador

The karst systems are distributed in concordance with their geodynamic evolution. The main karst system shows up in the outcrops of the east border of the Amazon

Basin, but some small caves are registered in the carbonate rocks sedimented into the Piñon terrane and the Western Mountain Range *(Figures 3, 4)*. Also a great number of volcanic caves are registered in the Galapagos Islands [49].

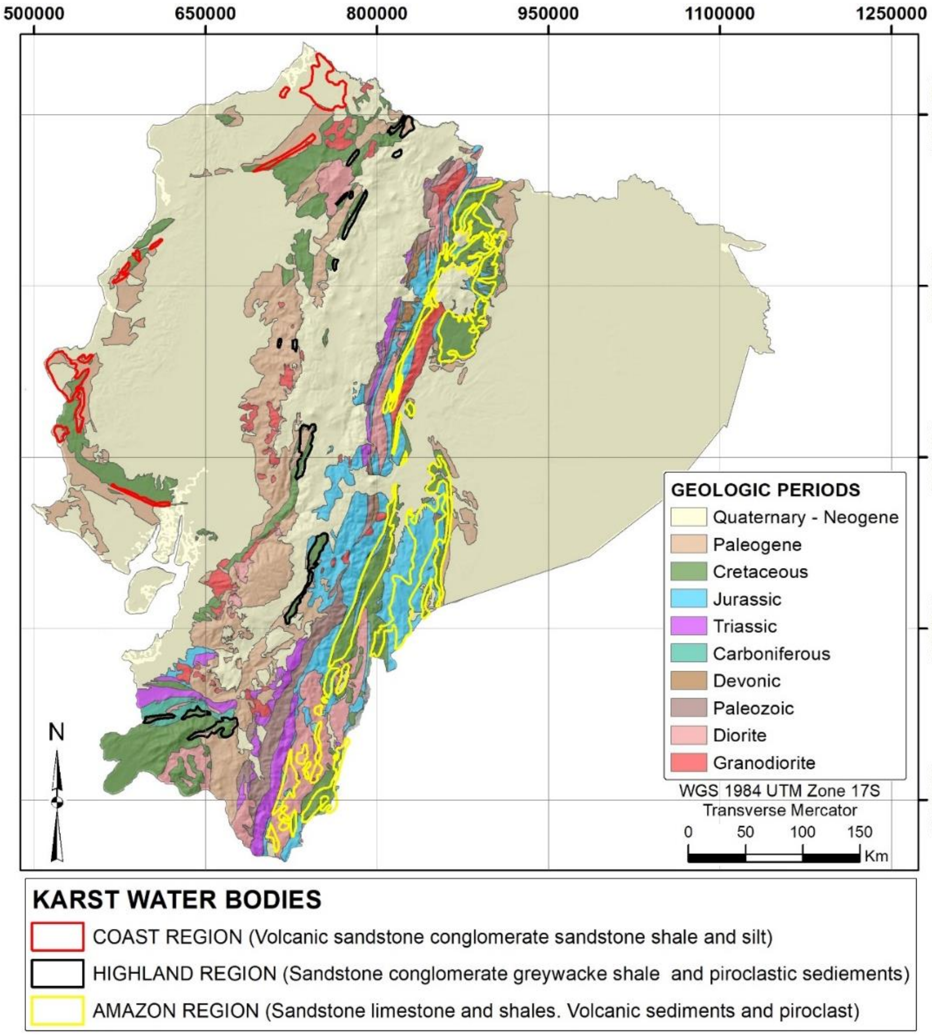

Figure 4

Karst bodies of Ecuador described by Winckell, Zebrowski, Sourdat, 1997, and Constantin et al., 2019 overlaying the Geological Map of the country updated by IIGE, 2019 and reclassified by geologic period age of the formation by the author. The karst bodies in the Coast region are associated with Paleogene formations, meanwhile in the Highland region the karst bodies occur near active volcanic activity and are associated with Cenozoic formations. Finally, in the Amazon region the karst bodies are developed in Cretaceous and Jurassic formations.

The main Ecuadorian cold water karst systems are associated with the outcrops of bituminous carbonate rocks deposited in shallow oceanic environments during the Mesozoic era (Jurassic and Cretaceous periods); these formations are named the Santiago Formation and Napo Formation in the stratigraphic sequence of the Amazon Basin [4, 16] *(Figures 2, 4, 5)*.

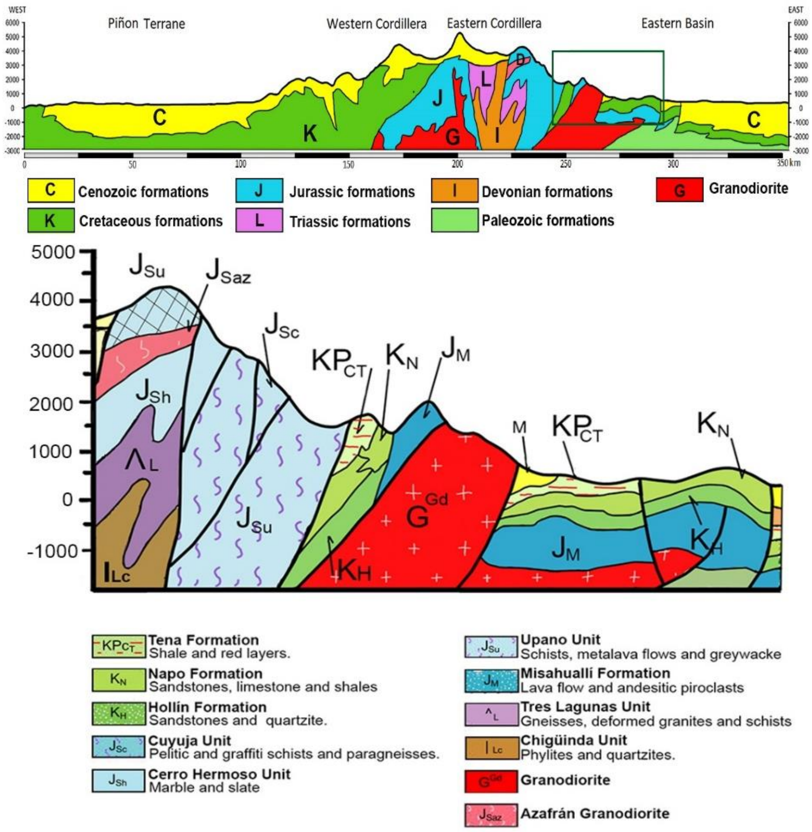

Figure 5

(a) Schematic cross-section of Ecuador at 0° and 1° S latitude included in the Geological Map updated by Eguez, 2019. It was modified by the author to show only the group of formations by age. (b) The second profile zooms the first (green square) in the section of transition between the Eastern Mountain Range and the Amazon Basin. At this location is reported existence of cold-water karst systems developed on Napo Formation (K_N).

The system's geometry is the result of its geological evolution, resulting in elongated carbonate bodies with transversal water flow paths. The limited surface and thickness give a characteristic shallow water table and short transit times [14] into the system, before the outflow on the surface and near streams.

The Ecuadorian Eastern karst bodies are more fascinating for the public perception due to their biodiversity and their history as the site of ancestral cultural practices of the native Amazon people. Nowadays, the investigation goal of the karst systems tends to be focused from a geo-touristic perspective *(Figure 8)* [20, 49], without interest in their hydrodynamic behavior or their potential as freshwater resources. This, combined with the low availability of governmental investment for investigation projects, contributes to making the job of the emergent scientific community of hydrogeologists rather difficult.

For example, the best known and most investigated area is located in Napo county in the northeast of the country *(Figures 4, 5)* [14, 46, 49], where the project of Napo-Sumaco Geopark [20] has documented and described in qualitative aspect the karst cavities employing speleology; however, a complete evolutionary description or hydrogeological datasets are totally non-existent so far.

The empirical observations of tourist guides of the region describe high flow rate into the caves during rainfall days. The reason why may be that the hydraulic systems are likely gravitational flow aquifer systems replenished from infiltration of precipitation over the recharge areas on the exposed surface of permeable rocks, but with no heat flux interchange due to the fast transit time and shallow flow paths, thus limiting the systems to cold karst water bodies *(Figures 4, 5)*.

The thermal water resources in Ecuador [10] are linked to the continental magmatic arc due to the subsidence of the Nazca Plate under the South American Plate, a phenomenon that is part of the Pacific Ring of Fire, which is the most active volcanic complex on Earth. As consequence of these geodynamic facts [38], the geothermal gradient distribution of the Ecuadorian continental territory exhibits high values in the orogenic belt and near the submarine trench, while in the Amazon Basin and middle of the Piñon terrane *(Figure 2)* the geothermal gradient has lower values than the global average of 30 °C/km [8]. For example, in the Gulf of Guayaquil, belonging to the coastal region of Ecuador, the geothermal gradient is between 10.2 and 18.2 °C/km [6], similar to some oil wells in the Ecuadorian Amazon, which show a geothermal gradient of 11 °C/km [2], while between the Western Mountain range and inter-montane valley (Figure 4) the Chachimbiro geothermal project, located in the north central zone of Ecuador, reports a thermal gradient around 100 °C/km [21].

Therefore, based on these characteristics, the existence of thermal karst systems in the Western Cordillera and the Intermontane Valley is explained. The thermal spring has been producing travertine bodies in the outflow point of the hydrothermal fluid by precipitation of carbonates transported by it, but also the system has been going through karstification process while the fluid is flowing within the rock body.

While in the Amazon region the karst bodies have a cold temperature and are generated by the weathering on limestone *(Figure 5)*, in the Highland region the thermal karst bodies are linked with hydrothermal fluids and travertine bodies. Based on the lithological, geographical, and tectonic factors listed above, it is deduced that they are different hydrogeological systems with hydraulic independence from each other.

4.2. Karst hydrogeology in Hungary

In contrast, the karstic water of Hungary is linked with calcareous formations developed during the late Paleozoic and the whole Mesozoic era [15]. They were affected by the karstification process in the Early Cretaceous, Neogene, and Pleistocene [29]. The distribution and properties of the karstic aquifers are influenced by effects of the different events during the geodynamic evolution *(Figure 3)* of the pre-Neogene basement of the Pannonian Basin.

The karst water bodies in the Hungarian area occur under the co-occurrence of two regional flow systems *(Figure 6)*: (1) gravitational flow in carbonate rock aquifer systems and (2) an overpressure driven flow system [25], which are accompanied by a high heat flow controlled by the neotectonic features [13] and are covered by a thick quaternary sediment sequence [32, 45].

The temperature differentiation of the karstic water is a characteristic of the gravitational flow in carbonate rock aquifers system, due to infiltration of cold water into the flow system over the recharge areas on the exposed surface of older permeable rocks [25, 36] in the uplifted nappes of the mountain ranges [23]. The cold water is gravity-driven to the discharge area through the karst system, as well as through joints and faults of the carbonated rocks. Some of the flow paths are able to reach enough depth to contact the heated rocks before ascending, and its heat flow will produce the generation of warmed fluids on the surface *(Figures 6, 7)*.

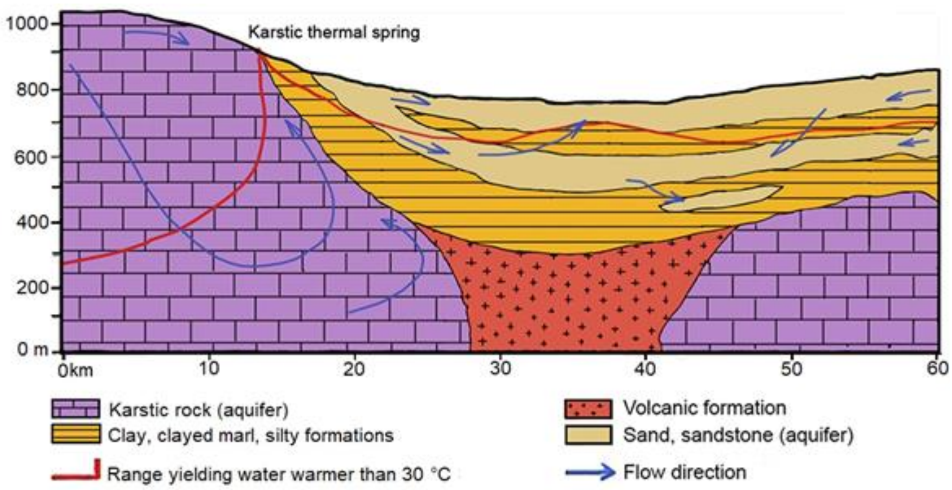

Figure 6

Generalized model of the flow systems in the Pannonian Basin [35]. Blue arrows show the movement paths of the water, and the red lines shows from where the thermal water is available to be yielding.

One example is the Bükk Mountains area (*Figure 9*: 2.1-2.3-2.5); here, the cold karst water of the outcrops is surrounded by a significantly extended thermal karst water area [34, 41].

In the overpressure system, the heat flow works in a different way. A proved disequilibrium of compression mechanism [25] and impact of the neotectonics of the Pannonian Basin [5, 13, 19] affect the buried fractured basement, which is re-covered by a pressure seal, separating the flow system in the porous basin fills from the karstic water systems *(Figure 6)* along the Middle Hungarian Fault Zone *(Figure 7)*. This creates a confined groundwater system with heat convection where the surrounding fault systems have been working as ascending flow paths *(Figures 3, 6)*.

According to the Karstic Water Bodies Map published by the National Office for Research and Technology through the ENFO project, Hungary has 29 karstic water bodies, 14 of which are cold and 15 with thermal waters *(Figure 7, 9)*. It is important to mention that the geodynamic evolution of the Pannonian Basin [23] has made an area of favorable geological conditions for intense heat flux with a thin crust and high geothermal gradient. This special geological fact of the area increases the availability of thermal water resources near the surface. The temperature gradient varies between 40 and 50° C/km. The Great Hungarian Plain is one of the hottest areas of the Pannonian Basin, with heat flow above 100 MW/m^2, while the Transdanubian Central and the Hungarian Mountains in the northeast have low heat flow, between 50 and 60 MW/m^2 [25].

The thermal springs have been known since Roman times, and nowadays bathing facilities are found all around the country. Exploration for thermal water started in the second half of 19th century in Budapest. The most notable well was 970 m deep. It was drilled in Triassic karstified carbonates and produced thermal water at 74 °C [25], giving a guideline for future exploration of new thermal water sources such as the Hajdúszoboszló spa facilities [9] and expansion of knowledge about karst systems of thermal springs such as the Miskolc-Tapolca Cave Bath *(Figure 8b)* [33] or Hévíz thermal lake.

5. Review of Realities

Now that the geographical, geological and geodynamic situation of the karst bodies in Ecuador and Hungary has been introduced, it is possible to contrast the circumstances of the two countries and point out the similarities and differences between them *(Table 1)*.

Hungarian hydrogeological management of karst systems can be taken as an example for Ecuador to develop its own methodology for the hydrogeological characterization of its karst water resources that suit its particular environmental and socioeconomic conditions.

As featured above the report, there are many differences between Hungarian and Ecuadorian karst water bodies. First, Hungary has a high volume of its freshwater supply based on groundwater, including karst water bodies. Meanwhile, in Ecuador, the water supply is fundamentally obtained from surface sources. This is probably the main reason why the social and economic interests of the government in karst bodies are dissimilar, which affects their financial investments in investigation.

The spatial distribution of the carbonate rocks, given by the type of depositional environment, and the geodynamic evolution of these different geographic locations *(Table 1)* explain the variances in the flow dynamics.

Table 1

Summary of the evaluated aspects between Ecuador and Hungary. [26, 43, 52]

Aspect	*Characteristic*	*Country*	
		Ecuador	***Hungary***
Socio-Economic	*Total population 2020*	17,643,054	9,660,351
	GDP	108.4 billion USD	157.9 billion USD
	Surface	283,560 km²	90,530 km²
	Population distribution	63.8% urban	71.7% urban
		36.2% rural	28.3% rural
Geographic	*Continent*	South America	Central Europe
	Annual precipitation	Coast: 100 mm–2000 mm Highland: 760 mm–2000 mm Amazon: 3000 mm–6000 mm	Lowland: 500–600 mm Highland: 600–800mm
	Average Temperature	Coast and Amazon: 20–33 °C	Minimum: –4 °C–0 °C in January
		Highland: depends on altitude, decrease approx. 5-6 °C/1km	Maximum: 18 °C to 23 °C in July
Geology of the cold karst systems	*Rock type*	Intercalation of limestone and sandstones	Limestone and dolomite
	Age of the calcareous formations	Cretaceous and Jurassic	Late Palaeozoic and all Mesozoic
	Depositional environment of the calcareous formations	Shallow marine. Forearc basin	Shallow marine. Open oceanic basin
	Geometry of the karst bodies	Elongated layers	Nappes (inselbergs)
	Thickness of karst bodies	approx. 300 m	> 400 m

Thus, if the parameters for the coexistence of the cold and thermal karstic water are analyzed [31], it is understandable why in Ecuador thermal karst water connected with cold karst water is not documented *(Figure 4)*, meanwhile in Hungary, it commonly occurs around the outcrops of the exposed carbonated nappes *(Figures 7, 9)*.

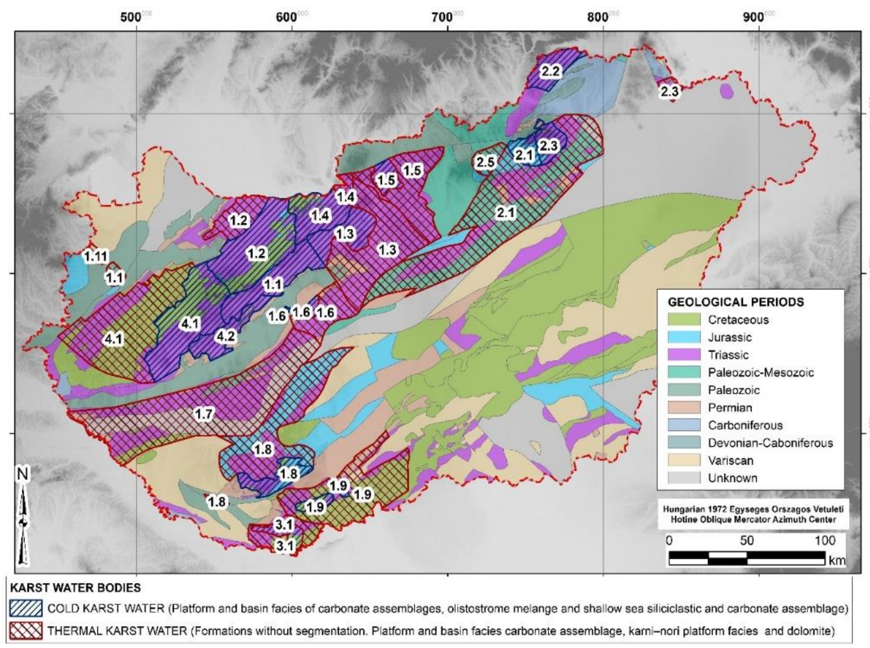

Figure 7

Karstic groundwater bodies mapped by the National Office for Research and Technology, 2009 and presented over the pre-Cenozoic basement geological formations of Hungary reported by the Mining and Geological Survey of Hungary (MBFSZ), 2017. The formations are sorted by geological periods to make it easier to realize the close connection between karst water bodies and carbonate rock of Triassic age. This condition is not exclusive, but it represents the higher likelihood. For more information about the codes check Figure 9.

Figure 8

Postal stamps (a) from Ecuador, presenting a karst system located on the north of the highland on the border with Colombia and (b) from Hungary, presenting the famous cave bath in the northeast of the country in the Bükk karst complex (Figure 8, 2.1 and 2.3).

There are no similarities between Hungarian and Ecuadorian karst water bodies from a geological or geographical point of view, but in a socio-economic context they share the fact of governmental administration of natural resources. Both countries have public institutions in charge of the protection, development and investigation of groundwater resources. Nowadays, Hungary has reached a state of investigation for sustainable and environmental management of the groundwater resources, supported by a long history of failure and successes along the way, and under the umbrella of the Groundwater Directive (GWD) as part of the European Union.

In contrast, Ecuador remains in experimental use of the groundwater even though the second chapter (Articles 117–122) of the Organic Law of Hydraulic Resources, Uses and Exploitation of the Water of 2014 includes a regulation for the use, exploitation, conservation, and obligations concerning the groundwater resources, which is accompanied by a Handbook on Authorization and Employment of Water where the expressed requirements for the evaluation of the aquifers are poor and lacking any sustainable development projection.

As result of the comparison between the two cases, and taking the example of Hungary as the statement for a vision, it appears convenient for Ecuador to first develop a national plan to create a hydrogeological database with the already documented groundwater utilization points. In parallel, the development of spatial delimitation of the karst areas into karst water bodies using a combination of methods like speleology, seismic, and tracers is a first step towards quantification of the available resources.

6. CONCLUSIONS

The human species adapts its lifestyle based on the environment where it is living. This fact is reflected in the different management policies of the karst water bodies in Ecuador and Hungary.

The geographical characteristics of Ecuador reduce the necessity for groundwater resources, because of its high availability of surface water, while Hungary is currently using them, with groundwater making up 95% of the total volume of distributed freshwater. Additionally, social and economic impacts compromise the Ecuadorian government investments in increasing the information about its groundwater sources, while in Hungary it is strongly supported by legislation itself, especially after their integration into the European Union.

Prospecting for and quantification of groundwater resources in order to avoid depletion and ensure the water quality for future human needs is lacking in Ecuador. This circumstance is supported by an obvious lack of necessity, as well as little knowledge of its karst water bodies, particularly from a hydrogeological perspective. In contrast, the example of the Hungarian Management Policies for their karst water is given positive results for the green deal of sustainability of the vulnerable resource of groundwater.

After study the differences between the countries, it became obvious that Ecuador is standing on a stage of poor management policies concerning groundwater characterization, sustainable utilization, and environmental protection. The investigative methodology structure used in Hungary can be adapted to the Ecuadorian perspective and particular necessities, helping to pass from a descriptive characterization to a methodical quantitative description in a shorter way than that taken for Hungary, where the development was evolving with practice, successes, and failures.

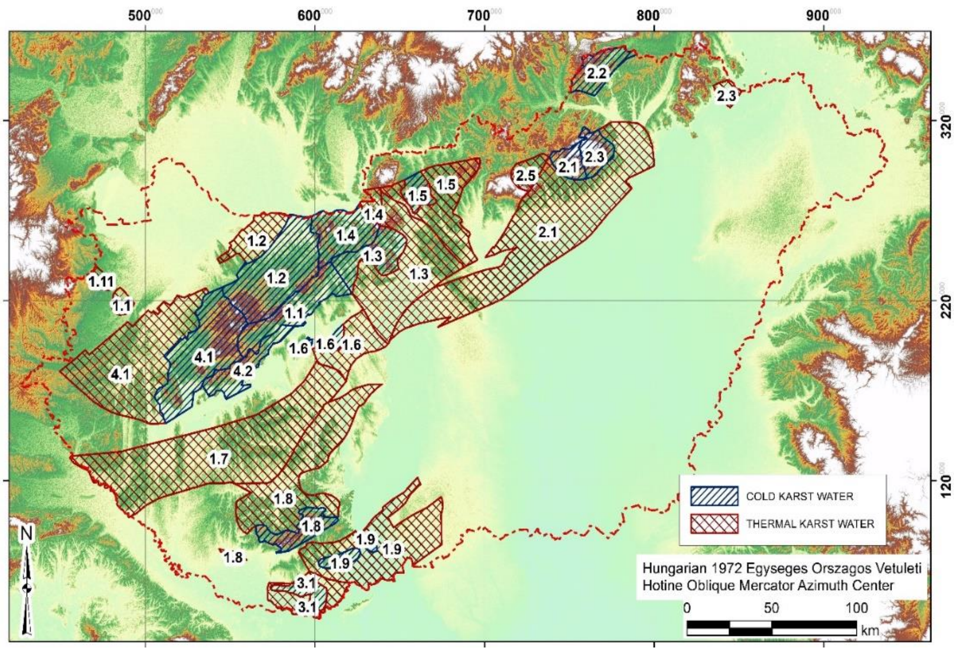

Figure 9

Official nomination (name) of the 31 defined karst water bodies of Hungary reported by the National Office for Research and Technology, 2009. The cold karst groundwater bodies are: (1.1) Water catchment area of the Southern springs of the Transdanubian Central Mountains – Veszprém – Várpalota – Vértes, (1.2) Water catchment area of the Transdanubian Central Mountains – Tatai and Fényes, (1.3) Water catchment area of the Transdanubian Central Mountains – Buda, (1.4) Water catchment area of the Transdanubian Central Mountains – Esztergom, (1.5) Naszály-Nógrádi block, (1.6) Szabadbattyán karst blocks, (1.8) Mecsek karst, (1.9) Mohács blocks, (2.1) Bükk western karst (2.2) Aggtelek Mountains, (2.3) Bükk eastern karst, (3.1) Villány karst mountain, (4.1) Water catchment area of the Transdanubian Central Mountains – Hévíz – Tapolca – Main Tapolca, and (4.2) Balaton karst highlands. The thermal karst bodies are: (1.1) Sárvár Thermal Karst, (1.11) Bükk Thermal Karst, (1.2) Northern Transdanubian Thermal Karst, (1.3) Budapest Wedge Thermal Karst, (1.4) Visegrád – Veresegyház Thermal Karst, (1.5) Nógrád Thermal Karst, (1.6) Szabadbattyán Thermal Karst, (1.7) Middle-Transdanubian Thermal Karst, (1.8) Mecsek Thermal Karst, (1.9) South Baranya- Bácska Thermal Karst, (2.1) Bükk Thermal Karst, (2.3) Sárospatak Thermal Karst, (2.5) Recsk – Bükkszék Thermal Karst, (3.1) Harkány and Wedge Thermal Karst, and (4.1) Western Transdanubian Thermal Karst.

It is an obligation of the Ecuadorian national government to initiate the development of investigation with a perspective to quantify the volume of groundwater resources, and to project their use into a sustainable management plan, in accordance with global efforts in the field of conservation of quality and availability of water. Among the reason why a country chooses the exploitation of groundwater over surface water sources are: (1) a limited volume of surface water, (2) water quality and pollution problems, (3) stable flow rates throughout the year, (4) slower changes for climatic events like intense rains, and (5) lower costs of capturing, treating and distribution systems.

However, to cover the necessity for starting to deal with quantitative hydrogeology at the level of sustainable management national projects and enrich the knowledge about the existing systems, hydrogeological information of large areas will need to be collected. But covering such an area of study is not possible in a short time; in fact, a prioritization of areas is necessary. Focusing first on sections with higher population growing rate and areas of touristic interest like the Napo-Sumaco Geopark project [20] will contribute to water quality protection and risk management issues step by step.

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