DOI: http://dx.doi.org/10.6035/Kult-ur.2020.7.13.5 - ISSN: 2386-5458 - VOL. 7, N°13, 2020 - pp. 139-162

Received: 2019-07-16 | Reviewed: 2019-11-28 | Accepted: 2020-04-23 | Published: 2020-08-07

Citation / Cómo citar este artículo / Com citar aquest article:
Fraga de Araújo Pereira, R. G., Flores Urushima, A., & Alexandre Yamashiki, Y. (2020). Cities and geodiversity: coexistence of humans and abiotic nature in urban territories. *Kult-Ur*, 7(13), 139-162. https://doi.org/10.6035/Kult-ur.2020.7.13.5

Cities and geodiversity: human coexistence with abiotic nature in urban territories

Ciudades y geodiversidad:
coexistencia humana con naturaleza abiótica en territories urbanos

Ricardo Galeno Fraga de Araújo Pereira
Universidade Federal da Bahia - UFBA, Brasil
fraga.pereira@ufba.br
https://orcid.org/0000-0003-3913-3735

Andrea Flores Urushima
Kyoto University, Japan — andurush@cseas.kyoto-u.ac.jp
https://orcid.org/0000-0002-9597-7046

Yosuke Alexandre Yamashiki
Kyoto University, Japan
yamashiki.yosuke.3u@kyoto-u.ac.jp

ABSTRACT: Urbanization is an irreversible global process. Natural elements and systems present in city territories or at non-city sites attend to the demands for natural assets from urbanization processes. Renewed attention to the impacts of the urban organization of societies is essential to promote the harmonious survival of urbanization with natural processes. Although the presence of humans on the planet represents just a small fraction of the Earth's history, human agglomeration in cities has caused impacts on a global scale. Cities demand services and products from natural areas that are sometimes located in faraway rural areas, affecting geological environments such as beaches, rivers and aquifers, and other processes such as hydrological cycles or atmospheric circulation. The anthropogenic impact on urban catchment areas may induce unexpected environmental degradation in urban areas that affects the hydrological cycle. Although relative newcomers in terms of the Earth's lifetime, cities are a privileged human habitat, with intrinsic maintenance mechanisms that form the basis of the modern organization of the world's societies and economies. The present article adopts a geological perspective and a land ethic paradigm to discuss alternatives for a harmonious existence between cities and abiotic nature.

Keywords: Cities, Geodiversity, Geoconservation.

—

RESUMEN: La urbanización es un proceso global irreversible. Los elementos y sistemas naturales presentes en los territorios de la ciudad o en lugares no urbanos atienden las demandas de activos naturales de los procesos de urbanización. La atención renovada a los impactos de la organización urbana de las sociedades es esencial para promover la supervivencia armoniosa de la urbanización con procesos naturales. Aunque la presencia de humanos en el planeta representa solo una pequeña fracción de la historia de la Tierra, la aglomeración humana en las ciudades ha causado impactos a escala mundial. Las ciudades demandan servicios y productos de áreas naturales en ocasiones ubicadas en áreas rurales lejanas, que afectan los entornos geológicos como playas, ríos y acuíferos, y otros procesos como los ciclos hidrológicos o la circulación atmosférica. El impacto antropogénico en las áreas de captación urbanas puede inducir una degradación ambiental inesperada en las áreas urbanas que afecta el ciclo hidrológico. Aunque relativamente nuevas por lo que respecta al tiempo de vida de la Tierra, las ciudades son un hábitat humano privilegiado, con mecanismos de mantenimiento intrínsecos que forman la base de la organización moderna de las sociedades y economías del mundo. El presente artículo adopta una perspectiva geológica y un paradigma de ética de la tierra para discutir alternativas para una existencia armoniosa entre las ciudades y la naturaleza abiótica.

Palabras clave: ciudades, geodiversidad, geoconservación.

—

RESUM: La urbanització és un procés global irreversible. Els elements i sistemes naturals presents en els territoris de la ciutat o en llocs no urbans atenen les demandes d'actius naturals dels processos d'urbanització. L'atenció renovada als impactes de l'organització urbana de les societats és essencial per a promoure la supervivència harmoniosa de la urbanització amb processos naturals. Encara que la presència d'humans en el planeta representa només una xicoteta fracció de la història de la Terra, l'aglomeració humana a les ciutats ha causat impactes a escala mundial. Les ciutats demanden serveis i productes d'àrees naturals a vegades situades en àrees rurals llunyanes, que afecten els entorns geològics com a platges, rius i aqüífers, i altres processos com els cicles hidrològics o la circulació atmosfèrica. L'impacte antropogènic en les àrees de captació urbanes pot induir una degradació ambiental inesperada en les àrees urbanes que afecta el cicle hidrològic. Encara que relativament noves pel que respecta al temps de vida de la Terra, les ciutats són un hàbitat humà privilegiat, amb mecanismes de manteniment intrínsecs que formen la base de l'organització moderna de les societats i economies del món. El present article adopta una perspectiva geològica i un paradigma d'ètica de la terra per a discutir alternatives per a una existència harmoniosa entre les ciutats i la naturalesa abiòtica.

Paraules clau: ciutats, geodiversitat, geoconservació.

1. Introduction

The geological features of a territory heavily influence the socio-spatial patterns that will subsequently develop in an area. However fundamental site-specific geological features are to where cities develop, they are often overlooked in the discussion about the emergence and maintenance of cities. The physical features of nature have often been the object of study in geography, and links between geographers and city researchers are abundant. In contrast, a focus on the geological aspects of cities is important for reframing the understanding of what cities are and how they will change in the future in two relevant ways. First, geology, in general, and the more specific discussion around geoheritage and geodiversity – in contrast to biodiversity – highlights the structural relevance of abiotic nature to the development of cities and to urban histories. Second, a geological approach to the urban environment debate nurtures an integrated approach to the environmental history of cities. This in turn provides evidence on the linkage between abiotic nature and urban problems, which can then support urban renewal processes that may change the way people live in cities and their culture.

Urban ecologists have demonstrated that cities are functioning ecosystems (Colin and Max 2015) embedded in the material and ecological history of particular regions. The memory and culture of places are closely connected to a natural environment that supported the establishment of human habitats (see Cevasco and Hearn, 2015, for further detail). Since the advent of the industrial city, the global dominance of urban society (Lefebvre, 1970) has spurred an ecological thinking that aims to protect nature against human, and ultimately, urban dominance. While biodiversity conservation discourses gained attention in cities, for example with the creation of parks, there has been little discussion of the geodiversity aspects of cities, their influence on how local ways of living are shaped, and their relevance for the future maintenance of cities. This article aims to evidence the relevance of geodiversity, geoheritage and geoconservation in cities, and the need to rethink policies oriented towards their maintenance. This new approach to the discussion of urban environments is useful to expand understanding on the ways cities function, their physical structures and the definition of natural heritage in cities.

2. Cities and geodiversity assets: the value and services of abiotic nature

The natural materials of the Earth's crust (e.g., minerals, rocks, Fig**.** 1A; soil and sediments, Fig. 1B) are the elements of its geodiversity. Dynamic processes occurring in the planet's interior can sometimes affect the substrate (e.g., convection currents, magmatism, Fig**.** 1C, and metamorphism) or its surface (e.g., weathering, erosion, hydrological cycle and glaciers, Fig**.** 1D) resulting in hazardous processes for human settlements, which are also comprised of geodiversity assets. The Earth's materials are a result of events that have continuously occurred within a geological timeframe spanning 4.5 billion years. Some materials resulted from processes within the Earth's dynamic system that occurred in the past and are no longer active, but have deeply influenced socio-spatial patterns of human settlements. These elements and processes shape the rich and structural geodiversity of human settlements.

DOI: http://dx.doi.org/10.6035/Kult-ur.2020.7.13.5 - ISSN: 2386-5458 - VOL. 7, N°13, 2020 - pp. 139-162

Gray (2018) states that the term 'geodiversity' was first introduced and defined in 1993, after the Convention on Biological Diversity was opened for signature in 1992. According to this author, geodiversity is "the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landform, topography, physical processes), soil and hydrological features. It includes their assemblages, structures, systems and contributions to landscapes".

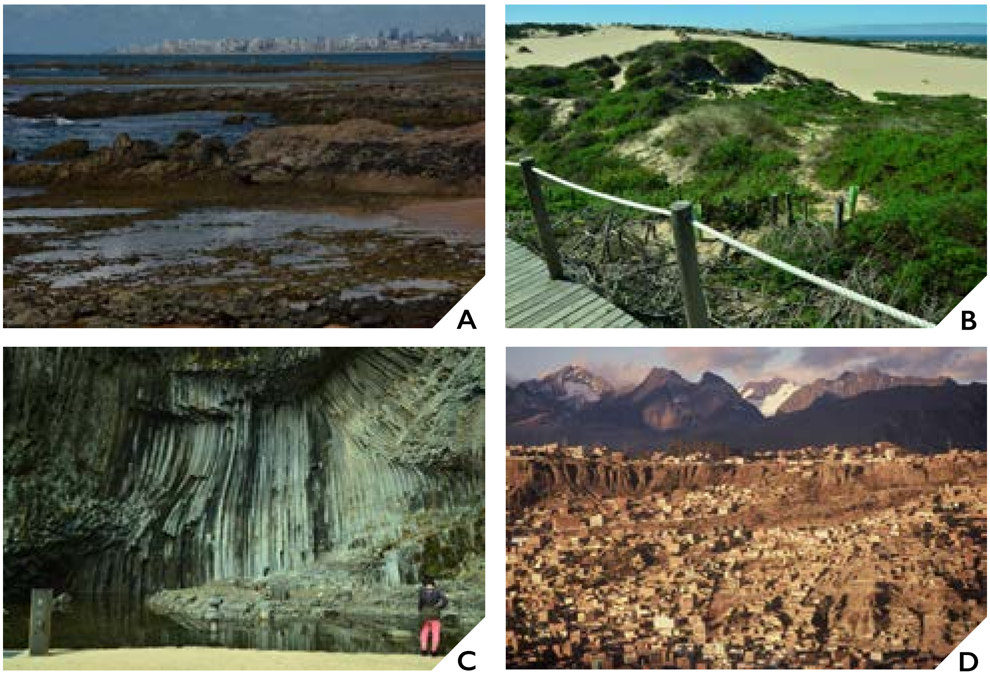

Figure 1: Elements of geodiversity: A. Rock outcrops at the Praia de Itapuã beach in Salvador, Bahia (Brazil, March, 2017). B. Sediments at the Guincho Cresmina sand dunes in Cascais (Portugal, March, 2018). C. Columnar basalts, formed by the crystallization of volcanic lava flows at the Genbudo Cave Park, Toyooka (Japan, March, 2018). D. Andes mountains with glaciers at La Paz (Bolivia, September, 1998). Photos by Ricardo G. Fraga de A. Pereira.

Many cities around the world developed in close association with landforms that served to provide protection, supported the fulfillment of sacred rituals and beliefs, or supplied water for human needs from rivers. The functional value of the geodiversity has attended to the needs of human settlements since prehistoric times, when rocks were used to make tools (Fig. 2A) and human groups used cave landforms as shelters and as a platform to leave messages (Fig. 2B). Modern societies have investigated and interpreted these to better understand human presence on the planet.

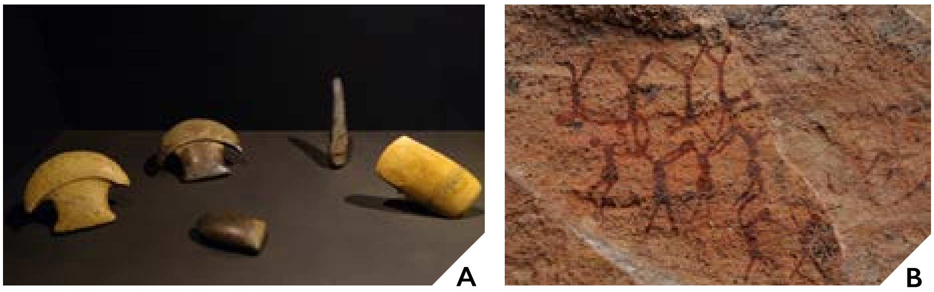

Figure 2: Evidence of use made of geodiversity by Brazilian indigenous populations: A. Stone tools exhibited in the FUMDHAM Museum, São Raimundo Nonato, Piauí (Brazil); B. Paintings on walls of rock shelters in the Boqueirão da Pedra Furada, Serra da Capivara National Park, Piauí (Brazil). Photos by Ricardo G. Fraga de A. Pereira, December, 2017.

Moreover, abiotic nature provides significant 'ecosystem services' from elements of geodiversity that are frequently ignored in cities. Ecosystem services are contributions that ecosystems make to human well-being; the Common International Classification of Ecosystem Services (CICES) around human needs was framed by Haines-Young and Potschin (2013). The CICES can be easily applied to classify the services provided by the elements of geodiversity in cities, although they are often neglected in contemporary urban societies. Assuming this concept, Gray (2018) refers to the 'abiotic ecosystem services' or 'geosystem services' and establishes the services of geodiversity elements as follows:

- Regulating services: include many terrestrial cycles such as carbon, nitrogen, phosphorus and sulphur cycles, as well as rock and hydrological cycles (Fig. 3A). Also included here are geomorphological processes, which help us to understand the environmental regulating role of natural hazards and mitigate their impact on society.
- Supporting services: include soil-forming processes, habitat provision (Fig. 3B), the land as a platform for human activities, for human burial and disposal of waste, for storage of resources including water, oil and gas, and for potential carbon capture and storage.

- Provisioning services: involve freshwater, mineral and renewable energy sources, a wide range of construction materials, as well as industrial and metallic minerals including gold and silver (Fig. 3C), geological resources that underlie the existence of modern society.
- Cultural services: include the mental and physical benefits of being in natural environments, geotourism and leisure pursuits (Fig. 3D), as well as the artistic, symbolic and spiritual association with geological environments.
- Knowledge services: include the potential to reconstruct past environments and the evolution of life using geological evidence, environmental monitoring, education (Fig. 3E) and geoforensics based on the verification of diverse characteristics of soils and sediments to link suspects to crime scenes.

As shown above, the regulating, supporting and provisioning services are measurable objective services that directly affect cities' inhabitants. In contrast, the cultural and knowledge services are subjective or intangible, difficult to measure, and not necessarily recognized at present. In the twenty-first century, most of the world's population lives in cities and depends on the objective geosystem services. However, the subjective services are constantly disregarded, and natural heritage can be often regarded as an obstacle to cities' development, and as something that must be controlled with high-cost engineering solutions. The economic value of land frequently overrides the cultural, educational or even leisure values of geodiversity elements.

However, in order to predict natural hazards such as floods or droughts, planners and policy makers must take into consideration the geodiversity knowledge services present in a city's substrate, observing the broad geological perspective of time. Identifying and promoting geoconservation is an important way to pass on this knowledge to future generations and to preserve the memory of an urban space.

Figure 3: A. Hydrological cycles involve the circulation of water underground, on the surface and in the atmosphere. Urban surface coverings obstruct water infiltration, preventing aquifers from recharging and causing floods, such as the ones that affect the main avenues in São Paulo, Brazil's largest city. These roads were built on floodplains after rivers had been diverted (October, 2004). B. The geodiversity role of land as a platform for human activities, including habitat provision. In Rio de Janeiro, the hilly relief provided protection for the ancient Brazilian capital (December, 2015). C. The silver mines at Cerro Rico in Potosi (Bolivia), were formed as a result of volcanic activity and have been exploited since the sixteenth century (July, 1998). D. Canoeing on the Elbe in Hamburg (Germany). In developed countries, the geodiversity secures good water quality in urban rivers to promote citizens' well-being (June, 2009). E. The rocks around the Barra lighthouse in Salvador (Bahia/Brazil) hold the history of the origin of the city's geological substrate. Some of these rock structures provide information about the continental break up between South America and Africa (March, 2016). Photos by Ricardo G. Fraga de A. Pereira.

Besides geodiversity knowledge services, its cultural services have also relevance and direct implications for city dwellers' health and quality of life. The conservation of geodiversity through cultural services helps reinforce local identities, civility and citizenship. In many cities around the world, sacred places associated with geodiversity elements can be either a reason for pilgrimage or for acts of intolerance (Fig. 4). In both cases, these sites need management and specific policies for their use, conservation and protection that can prevent their suppression or damage.

Figure 4: Pedra de Xangô (A) is a sacred site for Afro-Brazilian religions in Salvador, Bahia (Brazil). Practitioners of these religions leave offerings there for Xangô (B), the god of justice. Acts of religious intolerance are frequently observed at the site, in the form of graffiti and other degradation (C). Photos by Ricardo G. Fraga de A. Pereira, November, 2017.

Gordon *et al.* (2012) encourage the geoscience community to "demonstrate convincingly the economic, social, cultural and environmental values and benefits of geodiversity" in order to provide easily accessible knowledge for conservation practitioners and policy makers. The authors then urge conservation agencies to use this knowledge "to develop more integrated approaches to geodiversity, biodiversity and landscape conservation management".

In the last century, despite the global recognition of the cultural, educational or scientific values of geodiversity elements for human societies around the world (Larwood *et al*., 2013), in some countries, such as Brazil, they still play a minor role in the nature conservancy debate. International agreements and national level environmental policies could drive local initiatives at the municipal level, and can be used for the conservation of geodiversity elements in urban areas. However, these are rarely taken into consideration by local stakeholders in land management or in urban infrastructure construction. On the global scale, the focus on engineering solutions takes precedence over restoration, conservation and promotion of natural diversity, including geodiversity assets. As a result, water quality in urban beaches, rivers or aquifers has deteriorated in many major cities across the world, which limits the use of these natural resources. The suppression of abiotic diversity, viewed mostly as resources for urban development or often replaced by anthropogenic structures, leads certain aspects of local environmental history to be neglected; this history could provide explanations or solutions for present or future hazards such as floods, landslides or droughts.

Traditionally, most nature conservation efforts across the world focus on living organisms. However, since the late twentieth century new approaches focusing on abiotic elements have started to gain attention on a global scale (Pereira, 2010). Taking into account that geodiversity comprises the natural raw materials used in daily life, together with the space where human activities take place, these abiotic elements can be said to possess a variety of values, far beyond their economic value, including cultural, functional, aesthetical, scientific, ecological and even intrinsic values. Sharples (2002) notes that the direct values of geological, landform and soil systems to humans are the most frequently cited reasons to justify the conservation of some geodiversity elements, although they also play important roles in the maintenance of natural environments.

3. Geoconservation in urban areas

Several cities across the world emerged as a result of the supporting, provisioning and/or cultural services of geodiversity within specific physical spaces of the globe. River plains, natural reservoirs of water, singularly shaped mountains or hills that are regional reference points, among others, at times triggered the formation of settlements. These later became well-known cities whose origins are deeply connected to a specific local environmental history. Clarifying the specificity of the environmental history and of the substrate features of each urban space would allow us to envisage better solutions for their occupation; provide support in dealing with processes that could combine to form a hazard scenario; and allow for the use and conservation of urban environmental assets that support the promotion of a better quality of life for cities' inhabitants.

According to Flores Urushima (2016), the global impact of urbanization is now recognized as an irreversible process. The United Nations Department of Economic and Social Affairs (UNDESA, 2012) shows that in 2008, for the first time in history, 50 percent of the world's population lives in cities, a figure that is predicted to reach 72 percent in 2030. From this perspective, cities' environmental policies must take into account the multiple services and benefits of geodiversity elements for our society. These policies should also include the use of geodiversity for leisure or as an environmental memory of the urban space as a legacy for future generations. This in turn can contribute to local quality of life and deliver public value to the natural geological substrates. Thus, geodiversity elements represent essential assets for day-to-day societal needs, and restrictions on their use affect our quality of life in different ways.

Geoconservation focuses on the identification, protection, and management of valuable elements of geodiversity. According to Brilha's (2016) definition, when these elements are of scientific value, they are known as geological heritage, which he defines as "(i) in situ occurrences of geodiversity elements with high scientific value—geosites and (ii) ex situ geodiversity elements that, in spite of being displaced from their natural location of occurrence, maintain a high scientific value (for instance, minerals, fossils, and rocks available for research in museum collections)—geoheritage elements". On the other hand, if these elements do not have a particular scientific value but are still important resources for education, tourism, or the cultural identity of communities, they are considered to possess other values, such as educational, touristic and/or cultural values, and are known as (iii) geodiversity sites if they are in situ occurrences, or (iv) geodiversity elements, if they are ex situ occurrences. The conservation of these assets allows society to use them in activities such as, teaching/learning, tourism, and leisure.

Geoconservation practices include compiling geodiversity inventories. These inventories are necessary to identify sites of high scientific interest or superlative value, which are then assessed, interpreted, managed or protected.

Until the mid-twentieth century most conservation policies around the world had no direct focus on the conservation of geodiversity, even though many national environmental policies include instruments to protect abiotic nature aimed at preventing hazards (Fig. 5) related to floods, landslides, earthquakes or volcanism, very often focusing on conservation of mountainous regions. However, these instruments lack systematic approaches, and may not be considered as geoconservation with its own paradigms and with a focus on the conservation of geological heritage.

Figure 5: In Japan, due to natural hazards land use policies were historically designed to prevent damage from phenomena such as earthquakes and landslides on a regional scale. As a result, densely occupied cities developed along rivers or coastal plains, as opposed to the more mountainous forested countryside depicted in this photograph in the surroundings of Kyoto. Photo by Ricardo G. Fraga de A. Pereira, Mar/2018.

Given this reality, as geoconservation manages the valuable elements of geodiversity and is not necessarily based on governmental policies, it is rarely practiced in urban areas. But the sensitivity and uniqueness of geodiversity elements can also serve to promote the creation of areas with specific land management policies oriented towards protecting geodiversity elements and adding value to abiotic elements to improve quality of life in urban areas. As an example, Figure 6 shows situations where the conservation, or, in some cases, the restoration of geodiversity elements created an opportunity to improve human well-being in urban territory.

Portal and Kerguillec (2018) point out that since the first cities were built, abiotic nature and human built environments have constituted essential components of urban landscapes. According to these authors, "recognition of geodiversity and of its heritage aspects has resulted in new perceptions of abiotic forms and landscapes. While protected natural areas are often the preferred sites for the study of these new forms of heritage, the urban environment appears to be less subject to scientific study, protection, and geoheritage enhancement".

These authors draw attention to the Global Geoparks Network, a worldwide geoconservation strategy with support from UNESCO. The network currently has about 147 labeled areas, although only two of them are found in urban areas: the Hong Kong geopark, created in 2011 (on the outskirts of a city of more than 6 million inhabitants) on hilly terrain which obstructs further urban expansion; and the English Riviera geopark, recognized in 2007 for its geological, historic, and cultural heritage, which includes mostly small touristic towns.

According to Ilić *et al.* (2016), urbanization is one of the most serious threats to geodiversity. Consequently, the management of georesources in urban areas can hardly exclude geodiversity from spatial development plans and strategies. These authors used various scales to assess geodiversity in the city of Belgrade, finding that the areas with a low geodiversity index have great significance for the development of the city. In contrast, the areas with the richest geodiversity, which are less densely populated, have the best potential for geoconservation.

Figure 6: A. The River Douro in Oporto (Portugal) is a symbol of one of the oldest demarcated wine regions in the world. Nowadays citizens used the river for fishing, swimming or canoeing. Recently, during the 20th century, it was seriously contaminated by sewage (September, 2007). B. The River Kamo in Kyoto (Japan). The conservation of the river banks through specific land use policies opened up a leisure area for citizens (March, 2018). C. Although the River Seine in Paris (France) is contaminated by heavy metals, nutrients, sediment, and bacteria, boat tours are one of the city's tourist highlights (March, 2018). D. The River Thames in London (England) was declared to be dead at the end of the 1950s. After many government efforts and a general increase in environmental awareness, the water quality was restored during the 1970s and the river is now an iconic reference of the city's daily life (November, 2009). Photos by Ricardo G. Fraga de A. Pereira.

4. Nature conservation policies in Brazil and their application for urban geodiversity elements

At the national level there are two main nature protection policies in Brazil that can be applied in the conservation of geodiversity elements, namely the National System of Conservation Units (SNUC, Federal Law 9985 of July, 2000) and the Forest Code (Federal Law 12651 of May, 2012). The first one establishes the criteria and standards for the creation, implementation and management of protected areas in the country, while the second governs the protection of native vegetation and defines the creation of the Areas of Permanent Preservation (APP), which are related to water bodies and some specific relief areas.

The SNUC defines two main groups of protected areas: a) integral protection areas, where human presence and interference are avoided, and the preservation of nature is the main aim (Fig. 7); and b) sustainable use areas, where the main focus is on conservation of the natural elements, through management and sustainable human use. The first group encompasses five categories of protected areas, with more restricted paradigms for land use, while the second group encompasses seven categories, where land management is more flexible and many kinds of land use are allowed. Pereira *et al.* (2008) discuss the application of this policy to geological heritage conservation in Brazil.

Figure 7: The forested and protected mountains in the Tijuca National Park and the buildings of the Botafogo neighborhood of Rio de Janeiro (Brazil). Tijuca is the most visited park in Brazil and is an emblematic SNUC protection area, surrounded by urban occupation in the country's second largest city. In the seventeenth and eighteenth centuries, the Tijuca Massif was, for the most part, devastated by timber extraction and occupied by monoculture plantations, generating serious environmental problems. In consequence, the forest was created in the nineteenth century and the national park was established in 1961. Nowadays it is recognized worldwide as a successful urban protected area. Photo by Ricardo G. Fraga de A. Pereira (Dec/2015).

The creation of a protected area in itself cannot ensure the conservation of its geodiversity elements. As established in the SNUC, it must also have a management plan and an advisory board. The advisory board is headed by a member of the institution responsible for the area administration, who invites other institutions and stakeholders onto its board. The management plan defines the zoning of the area and the use of its assets. Periodically the advisory board members meet to debate and assess whether the zone plan is being respected, and decide on any necessary actions to regulate non-compliance. Pereira (2010) estimates from data available until 2005 that 13% of the Brazilian territory was under protection of a SNUC category, and should be managed by a governmental body. The author also drew attention to the fact that, unfortunately, most of these protected areas do not meet all the requirements for their full implementation, as some lack a management plan or an advisory board, and in some cases, both.

The Forest Code defines buffers at the marginal areas of springs, drainages and water reservoirs, hills with slopes above 45°, highlands, floodplains, vegetation on sand dunes and a few other relief areas defined as Areas of Permanent Protection. It aims to protect the land, regardless of whether or not it is covered with vegetation, as these areas have the environmental function of preserving water resources, the landscape, biodiversity, geological stability and soils, and ensuring the well-being of the human population.

The consequence of these policies for environmental management in cities is that if an area has any relevant regulating, provisioning, cultural or knowledge services, governmental action must be taken to create a protected area under one of the SNUC categories. On the other hand, specific portions of the land, which present characteristics described in the second chapter of the Forest Code, are automatically protected by this policy and some use is restricted. Both policies would cover the protection of geodiversity assets in Brazilian cities if they were appropriately applied and respected by all the stakeholders.

According to Brazil's Federal policies, geodiversity elements that are located within the borders of a city's protected areas, created after considering the SNUC's conservation units, must be protected by the institutions responsible for managing each of these units. Most of them are delegated to the state's environmental bodies or city halls. Beside this policy statement, these elements hold relevant knowledge services and sometimes important cultural services for the city's inhabitants. But policy makers often neglect these services due to the demand for urban growth, and consider only the supporting service of geodiversity elements when validating their decisions and city planning actions.

One way to promote the conservation of geodiversity in Brazilian cities would be through APP compliance, as established in the Forest Code, and the reinforcement of already existing SNUC protected areas, by promoting the identification and valorization of the abiotic elements inside these areas. Considering that APPs can easily be found in many parts of the Earth's surface, such as water body margins or hilly areas, in cases where SNUC's protected areas do not exist a relevant option would be to create one, based on the cultural, knowledge or even regulating services of geodiversity.

5. Facing future climate change scenarios and the need for worldwide conservation of abiotic nature

One unquestionable fact is that throughout the 4.5 billion years of the Earth's existence, it has undergone numerous transformations, which makes it a dynamic system. Such transformations include substantial temperature variations, changes to the shape and size of the continents and fluctuating sea levels. During the Cenozoic era—the last 66 million years of the Earth's history—concentrations of greenhouse gases, especially CO_2 in the atmosphere, its climate and sea levels have undergone many natural changes.

The genus homo, the origin of our species, only appeared in the last 2.5 million years of the planet's history, and archaeological evidence shows that only in the last 12,000 years did homo sapiens manage to occupy the entire planet. The Anthropocene still lacks a formal definition as a geological unit within the Geological Time Scale. Officially we are still in the Meghalayan Age of the Holocene Epoch. A proposal to formalize the Anthropocene is being developed by the Anthropocene Working Group (AWG) of the International Commission on Stratigraphy (http://quaternary.stratigraphy.org/working-groups/anthropocene/). And despite such a short existence and interaction of homo sapiens with geodiversity, the Intergovernmental Panel on Climate Change (IPCC, a body of experts and government representatives) accepts anthropogenic responsibility for the recent changes of the Earth's climate (IPCC, 2014). The scientific community has still to reach a consensus on whether the causes of climate change are mainly anthropogenic. However, our way of living and dealing with natural resources undoubtedly contributes to the increasing amounts of CO_2 and other greenhouse gases that are emitted to the atmosphere, where they change the balance of the natural carbon cycle. A current crucial debate concerns the extent to which humans are affecting climate changes in the Cenozoic era, and how our societies will be affected in the future by climate change and the fluctuations in mean sea levels.

As an example of the natural changes of the planet during the Cenozoic era, Fig. 8 shows the variations in the relative sea level on the coast of the city of Salvador (Bahia, Brazil) during the last 8,000 years (data from Martin *et al*., 1987), comparing these variations with historical subdivisions and events that occurred in other cities around the world. This figure shows that by the time of the foundation of Constantinople (now Istanbul, Turkey), the sea level at the site where Salvador was established had fallen by about 2.5 meters.

Based on geological evidence, Martin *et al*. (1987) demonstrate that the relative sea level variations of the Salvador shoreline reached a magnitude of 5 meters higher than the present day on a historical scale, in less than 8,000 years. This variation led to flooding of the city's coastal plain a long time ago. Since most of the world's population lives on shorelines, changes of such a magnitude can create hazardous scenarios that destroy most of cities' coastal infrastructure. Whether or not climate and sea level changes are due to human activity, they must be taken into account in the future planning and management of cities.

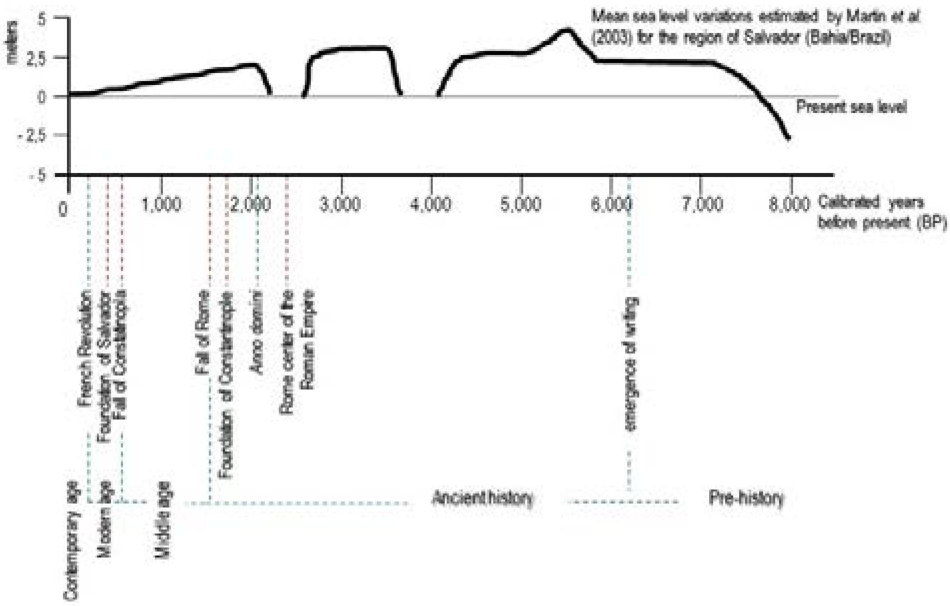

Figure 8: Relative sea level changes at the coast of Salvador (Bahia/ Brazil), using data provided by Martin *et al.* (1987), compared to historical subdivisions and events in ancient cities.

City planners must assume that city infrastructure is a legacy for generations to come and for biodiversity. Geodiversity elements that provide raw material for our societies also provide ecosystem services and provide habitats for other living organisms, ensuring the biodiversity of the planet. City rivers are not only drainage systems; they are also part of the sedimentary cycle, and ensure the flux of particles, such as sand and mud, that prevents coastal erosion.

Geoconservation supports the preservation of Earth element knowledge services, and may allow future generations to understand the planet's evolution in detail, recognize the risks of building infrastructure in certain territories, and also identify areas where occupation should be avoided. In many cases unoccupied areas can be designated as protected areas under specific local or national codes and used for leisure activities, which would also improve the quality of life for city dwellers or a space for promoting biodiversity in urban areas.

The planning of cities today and in the future should incorporate a wider time analysis on a geological scale of time and space, where geodiversity elements and geoheritage can be finite or renewable. Policies are needed that consider engineering projects to promote minimal interference in relief areas, reuse raw materials, minimize waste, and prevent the destruction of natural areas around the metropolises due to waste disposal. Local policies should prevent the occupation of river and coastal plains, and also river tunneling, in order to maximize water provision and the hydrological cycle, promote natural diversity in urban spaces, and thereby mitigate risks from drought, floods or the long-term effects of sea level changes.

In general, natural diversity must be evaluated as an asset rather than an obstacle to human occupation. This needs to be a new worldwide paradigm for the coexistence of humans and abiotic nature in urban territories in climate change scenarios. It is especially relevant in cases where the anthropogenic impact on the urban catchment zone may provoke serious unexpected issues in urban environments when facing extreme hydrological events. Until recently, industrial, urban, and mineral waste was discarded in remote areas away from human habitation. But recent cases in Brazil—such as the water crisis in the city of São Paulo and the pollution of its water reservoirs by untreated wastewater in rivers basins or the collapse of mining dams in the state of Minas Gerais—show that these are not the solution for the future of cities. Both cases illustrate how a potentially catastrophic scenario can cause serious damage to strategic sectors affecting human survival. Looking to the future, we must acknowledge that unexpected hydrological phenomena will be the real consequence of new extreme and chronic events (flood, dam breaks, overflow, river sedimentation, etc.) related to climate change and to human action in natural cycles.

Leopold (1970) argued that: "all ethics so far evolved rest upon a single premise: that the individual is a member of a community of interdependent parts". His concept of the land ethic is that it "enlarges the boundaries of the community to include soils, waters, plants, and animals, or collectively: the land". In short, Leopold advocated "a land ethic [that] changes the role of Homo sapiens from conqueror of the land-community into plain member and citizens of it. It implies respect for his fellow-members, and also respect for the community as such.

In an urban area, geodiversity elements are part of this land community, and should not be considered simply as raw materials or a landscape where humans build cities and infrastructure. Stakeholders must understand the geological processes and their role in the natural environment where urban interventions take place.

When thinking about the future, citizens and city planners must reframe their decisions within an ethical land use basis, and take on board other ethical paradigms that go far beyond the sustainable (and anthropocentric) point of view. This will ultimately lead to new cities full of natural diversity, and quality of life for all members of their communities. Although regarded as utopian, Leopold reminds us that the land use ethic is still mainly governed by the economic self interest that emerged a century ago. A paradigm shift in city management and local urban land use policies is vital to our survival in the Earth's dynamic system, with its rapidly changing physical and chemical conditions. If we remain entrenched in old paradigms, human existence on the planet will go down as just a brief event in Earth's long history.

Considering that since the earliest first cities were built, abiotic nature has constituted an essential component of urban landscapes, geological inventories and geodiversity assessments should be included in cities' master plans. The widespread recognition of geodiversity values must underpin new legal codes that ensure the management and protection of sites, guided by their regulating, provisioning, and cultural services, taking full account of climate change scenarios and the geological timescale in the Earth's processes. Although this may be an emerging reality in some cities in developed countries, it is far from the reality in the most populated cities of the world, particularly in developing or less developed countries.

6. References

BRILHA, J. (2016). Inventory and quantitative assessment of geosites and geodiversity sites: A review. *Geoheritage, 8*(2), 119-134. doi:10.1007/s12371-014-0139-3

CEVASCO, R., MORENO, D., & HEARN, R. (2015). Biodiversification as an historical process: An appeal for the application of historical ecology to bio-cultural diversity research. *Biodiversity and Conservation, 24*(13), 3167-3183. doi:10.1007/s10531-015-0943-3

FLORES URUSHIMA, A. (2015). Territorial prospective visions for Japan's high growth: The role of local urban development. *Nature and Culture, 10*(1), 12-35.

GORDON, J. E., BARRON, H. F., HANSOM, J. D., & THOMAS, M. F. (2012). Engaging with geodiversity—why it matters. *Proceedings of the Geologists' Association, 123*(1), 1-6. doi:10.1016/j.pgeola.2011.08.002

GRAY, M. (2017). Geodiversity: The backbone of geoheritage and geoconservation. In: Reynard, E. & Brilha, J.: Geoheritage – Assessment, Protection and Mangement. Elsevier doi:10.1016/B978-0-12-809531-7.00001-0

HAINES-YOUNG, R. & POTSCHIN, M. (2013) CICES v4.3 – Revised report prepared following consultation on CICES Version 4, August – December 2012. EEA Framework Contract No EEA/IEA/09/003.

ILIĆ, M. M., STOJKOVIĆ, S., RUNDIĆ, L., ĆALIĆ, J., & SANDIĆ, D. (2016). Application of the geodiversity index for the assessment of geodiversity in urban areas: An example of the Belgrade city area, Serbia. *Geologia Croatica, 69*(3), 325-336. doi:10.4154/gc.2016.27

IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.). IPCC, Geneva, Switzerland, 151 pp.

LARWOOD, J. G., BADMAN, T., & MCKEEVER, P. J. (2013). The progress and future of geoconservation at a global level. *Proceedings of the Geologists Association, 124*(4), 720-730. doi:10.1016/j.pgeola.2013.04.001

LEFÈBVRE, H. (1970). La révolution urbaine. Paris: Gallimard

LEOPOLD, A. (1970) A Sand County Almanac, With Essays on Conservation from Round River. Ballantine Books. New York - USA.

Martin, l.; Suguio, K.; Flexor, J-M; Dominguez, J.M.L. and Bittencourt, A.C.S.P. (1987) Quaternary evolution of the central part of the Brazilian coast. The role of relative sea-level variation and of a shoreline drift. In: Quaternary Coastal Geology of West Africa and South America, UNESCO Report in Marine Science, 43, 97-145.

Pereira, R. F., Brilha, J. & Martinez, J. E. (2008) Proposta de enquadramento da geoconservação na legislação ambiental brasileira. Memórias e Notícias- Revista Cient. do Dept. de Ciências da Terra e do Museu Mineralógico e Geológico da Universidade de Coimbra. No.- 3 (Nova Série). Coimbra-PT, p- 491- 499. Available at: http://sigep.cprm.gov.br/destaques/Pereira_Brilha_Martinez_GDCL_2008.pdf, downloaded at June 24th, 2019.

Pereira, R. F. (2010) Geoconservação e desenvolvimento sustentável na Chapada Diamantina (Bahia – Brasil). Tese de doutoramento, Escola de Ciências da Universidade do Minho (Braga/Potugal). 295 p. Available at: http://hdl.handle.net/1822/10879, downloaded at June 24th, 2019.

Portal, C., & Kerguillec, R. (2018). The shape of a city: Geomorphological landscapes, abiotic urban environment, and geoheritage in the western world: The example of parks and gardens. *Geoheritage, 10*(1), 67-78. doi:10.1007/s12371-017-0220-9

Sharples, C. (2002) Concepts and Principles of Geoconservation. Published electronically on the Tasmanian Parks & Wildlife Service website (Version 3). Available at: http://dpipwe.tas.gov.au/Documents/geoconservation.pdf, downloaded at June 24th, 2019.

Sivakumar, B. (2011). Water crisis: From conflict to cooperation-an overview. *Hydrological Sciences Journal, 56*(4), 531-552. doi:10.1080/02626667.2011.580747

United Nations Department of Economic and Social Affairs UNDESA (2012) World Urbanization Prospects: The 2011 Revision. New York: United Nations.