

Assessing ecosystem services provided by geodiversity in the Sertão Central, Ceará, Brazilian Northeastern

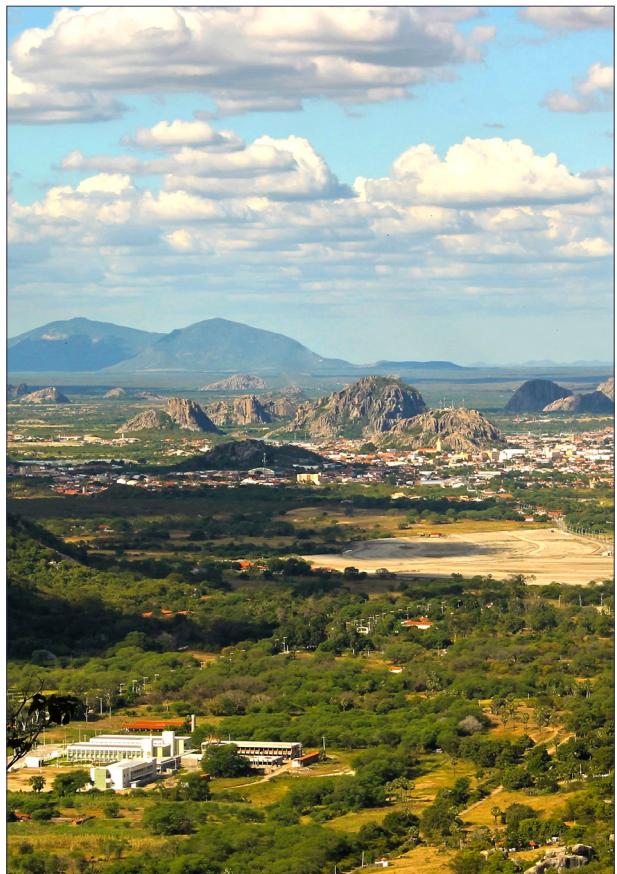
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Introduction

Ecosystem Services (ES) are the goods and services provided by nature that benefit society and future generations (MEA 2005). As an essential element for human sustainability, geodiversity plays an important role in maintenance of ecosystems (Gray 2013, Brilha et al. 2018). In order to contribute to territorial planning and improvement of the sustainable use of geodiversity, the aim of this work is a preliminary qualitative assessment of the ecosystem services provided by geodiversity in the Sertão Central, hinterland of the state of Ceará, north-eastern Brazil, a semiarid region characterised by fragile socioeconomic and socioenvironmental conditions. The study area comprises about 9700 km² distributed in five municipalities. The geology consists of crystalline rock assemblages mostly affected by the West Gondwana amalgamation and collage during the Neoproterozoic, and by large peripheral depressions, residual massifs and inselbergs that are dominant in the landscape (Figure 1).



Methods and results

The geological-environmental domains approach suggested by Brandão et al. (2013) was used to assess the ES. Following the Essential Geodiversity Variables (EGVs) described by Schrodt et al. (2019), detailed variables to guide the geodiversity analysis were proposed for the study area and, based on Brilha (2018), the main ecosystem services provided by geodiversity were identified.

Eight geological-environmental domains were defined: (i) Folded Proterozoic Sedimentary Sequences, (ii) Folded Proterozoic Volcano-Sedimentary Sequences, (iii) Gneiss-Migmatite and Granulite Complexes, (iv) Deformed Granitoid Complexes, (v) Strongly-Deformed Granitoid Complexes, (vi) Non-Deformed Granitoid Complexes, (vii) Mafic-Ultramafic Bodies, and (viii) Unconsolidated Cenozoic Sediments. Qualitative analysis allowed the definition of local EGVs (Table 1), and the identification of 27 goods and benefits provided by geodiversity in the study area (Table 2).

Figure 1 - Features of geodiversity in the study area: a large flat depression, inselbergs, and residual massifs composed by igneous and metamorphic rocks, and aligned following tectonic structures (photo taken during the rainy season).

Table 1 - Examples of the EGVs in the working area (adapted from Schrodt et al., 2019).

EGV Class	General EGVs	EGVs in Sertão Central
Geology	Hardrock, fossil and mineral distribution	Stones, gemstones, and metallic minerals
	Unconsolidated deposits	Aggregates (sand and gravel)
	Geophysical processes	Mass movement and micro to minor earthquakes
Geomorphology	Landform distribution	Flat surfaces, mountains, and hills
	Chemistry	Dominance of natural, low-to-moderate fertility soils
Soil	Physical state	Dominance of poor-drained, shallow to moderate depth soils
	Surface water	Intermittent rivers with dendritic patterns
Hydrology	Groundwater	Fractured-rock and porous-rock aquifers, both with irregular hydrogeological potential

Discussion and conclusions

Our preliminary assessment elucidated the importance of geodiversity for the local economy, providing resources for industry, civil engineering, jewelry and tourism. The results also demonstrate the role of geodiversity in the mitigation of the effects of the local semiarid climate, like softening temperatures close to the mountains and regulating the groundwater reservoirs during dry seasons, for instance. On the other hand, the fragile soils and hydrological features highlight the vulnerability of the region, considering land and occupation misuses and climate changes. Additionally, it is also clear the influence and benefits of geodiversity in the local culture, such as in science, education, and cultural production (Figure 2).



Figure 2 - The most representative example for cultural services provided by geodiversity in the study area: the Pedra da Galinha Choca (Broody Hen Stone) represents a sense of place and a symbol to the local community, encompassing scientific values, and goods and benefits for recreation and tourism. The same place is also an example for supporting services, i.e., as a water reservoir for domestic and agriculture supply, habitat for both plant and animal species, and supporting for fish-farming.

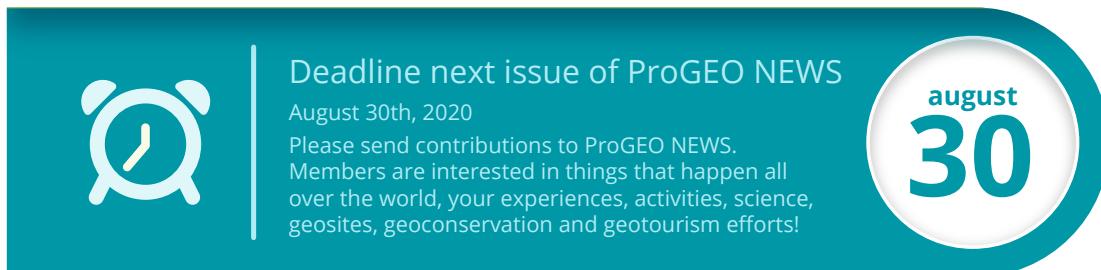
Table 2 - Main goods and benefits provided by the geodiversity identified in the working area.

Regulation	Supporting	Provisioning	Cultural
Regulation of the water quality due to the circulation through rocks and sediments	Habitat for both vegetal and animal species	Building and ornamental stones (granites, gneiss, quartzites, marbles and conglomerates)	Scientific research into several branches of geosciences
Local climate regulation by ranges and hills	Platform for infrastructure and urban development, highlighting water reservoirs	Gemstones for jewellery and handcrafts (pegmatite minerals)	Sites of geoheritage and historical evolution of the Earth
Participation on water cycling (evapotranspiration)	Platform for agriculture development (subsistence and small farms)	Aggregates to construction industry (bricks, clay, sand, and gravel)	Educational value as field resources for geoscience students
Regulation of soil erosion and desertification processes	Platform for waste storage and cemeteries	Metallic minerals for industry (manganese, chromite, and EPG)	Sense of place, symbols, toponymies and spiritual values, mainly religious meanings
-	Life supporting for fish-farming	Inorganic nutrients essential to live and agriculture production	Physical and mental health promoted by contact with nature landscapes
-	-	Surface freshwater for domestic supply	Tourist attractions (water reservoirs, viewpoints, mountains)
-	-	Surface water for agriculture and industrial use	Inspiration for cultural production (books, paintings, movies, legends etc.)
-	-	Groundwater for domestic use	Recreation and sport activities (hiking, trails, cycling, rock climbing, air sports)
-	-	Groundwater for agriculture use	Use of local stones in historical monuments

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