

## **THE CURRENT SITUATION OF PROTECTION AND CONSERVATION OF THE COLÔNIA IMPACT CRATER, SÃO PAULO, BRAZIL**

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**Abstract:** Nature conservation, sustainable development and the consequences of environmental degradation are central themes in debates about the future of humanity. From a sustainability perspective, reconciling the tense relationship

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between economic growth, quality of life and ecosystem preservation is becoming increasingly difficult. This paper presents a holistic approach to the socio-environmental problems of the Colônia impact crater. The efficiency of environmental protection measures, the feasibility of management programs and the political platform for sustainable development are the main issues discussed. The data reveal a high risk of increasing environmental degradation and worsening regional disparities. The implementation of geotourism, mainly via educational trails, landscape photography and agro-tourism, is one of the most favourable alternatives for social and economic development in the region. Such a project should be developed with broad participation from the local community and with an active and permanent policy management.

**Key words:** Colônia impact crater, Nature preservation, Sustainable development

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## INTRODUCTION

The Colônia impact crater lies in the southern zone of the São Paulo Metropolitan Region and covers an area with a large number of water catchments at the south-western edge of the Billings hydrographic basin (Figure 1). This prominent ring-like structure has attracted the attention of many researchers over the last several decades (Kollert et al., 1961; Riccomini et al., 1989; Neves, 1989).



**Figure 1.** The Colônia impact crater within the Billings hydrographic basin. Inset: the South American illustration of the Arid Ocean Map (source: adapted from Velázquez et al., 2014a)

Apart from its extraordinary scientific relevance for geological, biological, palaeoclimatic and palaeoecological research, the natural elements of the crater provide

favourable conditions for a wide range of educational activities that could be developed with students of different academic levels (Velázquez et al., 2006; 2008). The crater is also a stunning site for the practice of geotourism, and the community may undertake diverse outdoor leisure activities in a pleasant tropical climate provided by the remaining Atlantic Forest (Souza & Velázquez, 2008; Valderrama, 2010).

It is worth mentioning that Ries, in Germany, and Colônia, in Brazil, are the only two peopled craters of 188 impact structures catalogued in the Earth Impact Database (PAASC, 2015). The Ries crater is the site of the first geopark in Bavaria; the geopark covers 1800 km<sup>2</sup> and includes five different counties with 53 communities, making it the world's most populous geopark (Stöffler et al., 2008). The Colônia crater occupies an area of approximately 10.2 km<sup>2</sup> and was declared a Geological Monument by the Council of Geological Monuments of the São Paulo State (CoMGeo-SP) in 2009. The crater currently has approximately 45,000 residents, including besiegers, smallholders and an extensive, irregular urban settlement. The accelerated growth of urbanization and the expansion of agriculture in the region have led to a considerable reduction in vegetation.

Given the need to put an effective preservation program into practice in the crater region, conducting a detailed analysis of the current environmental situation to produce a document that provides simple, useful measures to reduce the risks of degradation was considered appropriate.

The scope of this process also included encouraging the local community to be an active participant in programs that prioritize economic growth and social equality without endangering local geological and biological diversity. Conservation of this region's NATURAL HERITAGE is strongly recommended to ensure the continuity of several studies and optimize its use in education and tourism (Velázquez et al., 2014a).

### **CONCEPTUAL FRAMEWORK AND PRACTICAL IMPLICATIONS**

In the traditional approach of nature conservation, the biological diversity has usually received more attention to the importance of sustainable management. The geological records, however, are indispensable elements that should also be brought into account where the theme includes environmental planning and sustainable development (Brilha, 2005). In this context, since the early 90s, the International Union of Geological Sciences (IUGS) and UNESCO have been promoting a systematic cataloguing of geological with particular interest. This initiative has as main objective to promote an exceptionally broad disclosure of the geological features, which bring together a high potentiality for science, teaching activity and leisure time (ProGEO, 2011). In recent times, it is remarkable the significant increase in the number of research groups that devote their activities to this new investigation segment in Brazil.

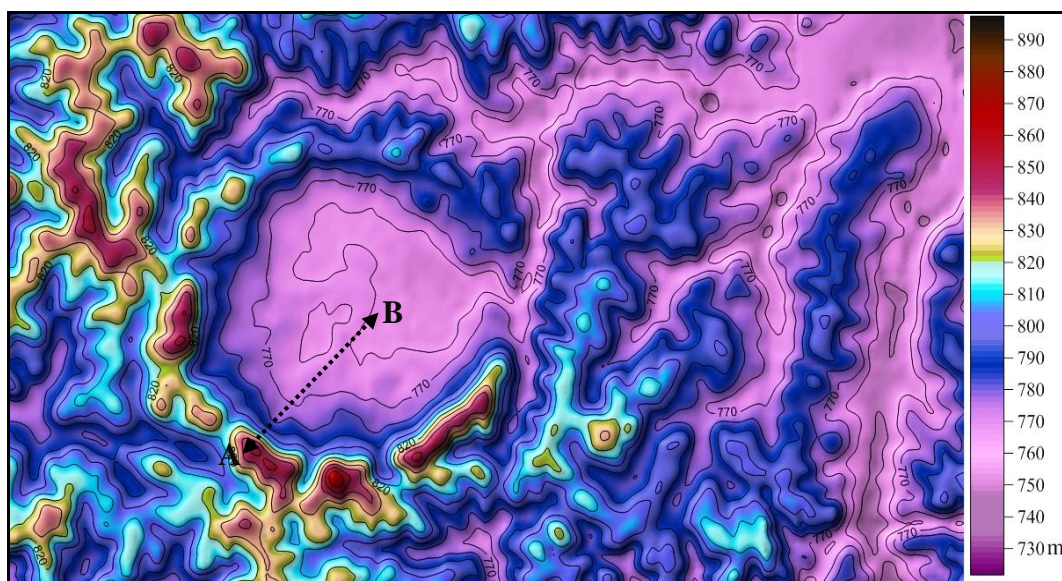
Nevertheless, terms such as geodiversity, geological heritage, geoconservation, geopark and geotourism, highly widespread in northern hemisphere countries (Newsome & Dowling, 2010; Farsani et al., 2012, Adriansyah et al., 2015), have not been fully integrated into the national academic literature. Likewise, the factual benefits of conservation programmes are still very isolated and, sometimes, geological sites that have been duly recognized not receive the deserved care (Barroso, 2013). As previously pointed out by some authors, geological elements are natural heritage and should also be capitalized as the archaeological and cultural patrimonies, considering that these records are the lasting memory of the long evolutionary story of our planet (Sharples, 2002; Brilha, 2005; Brocx & Semeniuk, 2007; ProGeo, 2011). In this sense, geotourism has often been cited as a possible option to improve the usage of geological sites and encourage the practice of environmental preservation (Hose, 1995). Although the term "geotourism" has provoked controversy regarding to the definition (c.f. Arouca

Declaration in [https://dl.dropboxusercontent.com/u/36358978/News/Declaration\\_Arouca\\_%5BEN%5D.pdf](https://dl.dropboxusercontent.com/u/36358978/News/Declaration_Arouca_%5BEN%5D.pdf)), the environmental and social benefits arising from this new modality of tourism for the local community are unquestionable. As empathised by Lazzari & Alloia (2014), this tourist activity, when it is well-planned and organised, can “to facilitate public interest in geotourism, geoscientists, government agencies, communities, and other stakeholders must collaborate to sensitize the public, develop, and preserve these national patrimony/heritage sites for teaching, training, research, sustainable development, job creation, environmental conservation, and exploration of alternatives to traditional exploitation/uses”.

This innovative way of tourism able of harnessing the geological peculiarities of a region, promoting sustainable development through actions that encourage the practice of environmental and social responsibility, it was the main reason to perform the research in the Colônia impact crater region. On the basis of the proposals suggested by Dowling, 2011 and Crawfo & Black, 2012, this article provides a holistic evaluation considering the following aspects: a) geological and geomorphological features, b) vegetal cover distribution, c) environmental protection laws, d) dynamics of urbanisation and e) strategic plan for preservation.

### PHYSICAL CHARACTERISTICS OF THE REGION

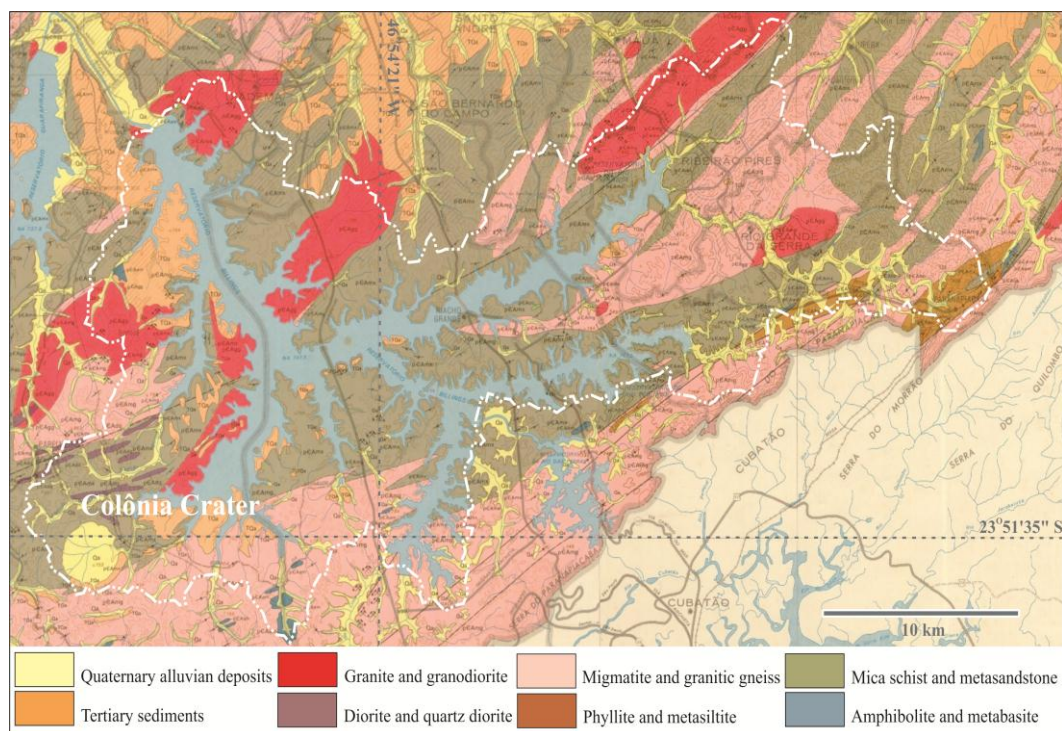
A careful examination of the physical environmental components of the Colônia impact crater is indispensable to understanding the natural processes that could potentially increase the risk and vulnerability of the region. Although several elements should be taken into account in the evaluation of a substrate's physical properties, according to Gissoti & Zarlenga (2004), two are often quoted as essential: a) a comprehensive understanding of the landscape particularities from a morphological viewpoint and b) a general summary focusing on the regional and local distribution of the main lithological units.



**Figure 2.** Circular topographical feature of the Colônia impact crater showing a clear altitude difference between rim and floor. Digital elevation model from SRTM data. The A-B transect indicates the position of the sketch shown in Figure 4

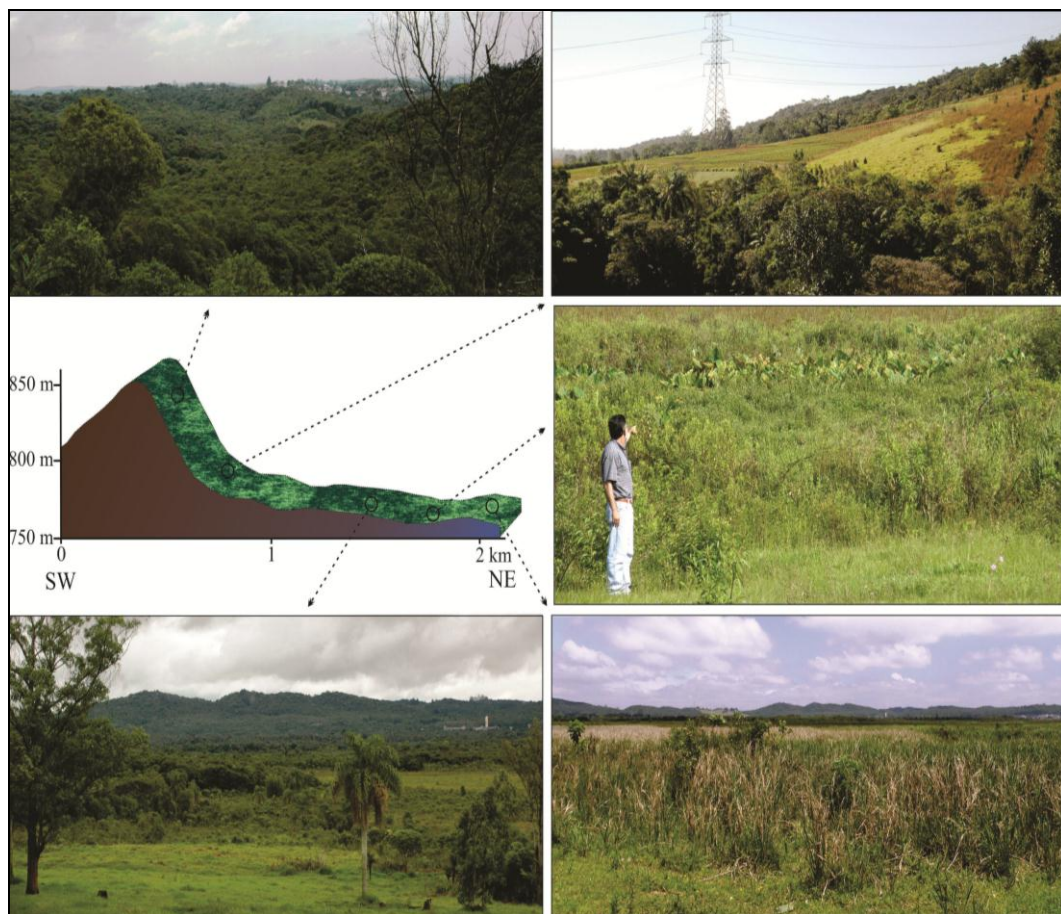
The crater has an area of approximately 10.2 km<sup>2</sup> and possesses distinct geological and geomorphological characteristics. With a 3.6 km rim-to-rim diameter, the Colônia crater can be easily identified on a satellite image. The uplifted rim is composed of several flat-topped hills arranged in a ring, a typical residual landform that is markedly different from the central area. This topographical feature was generated through a multistage cratering process, resulting in a significant contrast in the altitudes of the rim and floor of the crater (Figure 2). This contrast reaches 120 m in some places. Unlike the ring, which displays steep hillsides, the internal area is an extensive, flat surface with minor local variation. The surface drainage pattern is similar to a bowl-shaped basin, in which most watercourses drain toward the centre. The Ribeirão Vermelho River is the only runoff channel flowing in an easterly direction to discharge its waters in the Billings hydrographic basin.

The most common rock-stratigraphic units in the region are those from the crystalline basement, Embu Domain (Sadowski, 1974), which are part of an orogenic zone complex of the Neoproterozoic Era named the Ribeira Fold Belt by Hasui et al., 1975. An exhaustive geological survey was carried out by Coutinho (1972). The region of Colônia was as a terrain composed essentially of Precambrian metamorphic and igneous rocks, Tertiary sediments and Quaternary deposits. Mica schist, gneiss, quartzite, migmatite and quartz diorite are the oldest rocks sustaining the crater rim (Coutinho, 1980) (Figure 3). The outcrops are not exposed continuously and are often covered by an extensive layer of deeply weathered rock and dense vegetation. A long, narrow strip of remaining Paleogene deposits from the São Paulo Basin, correlated with the Resende Formation (Riccomini et al., 1992), occurs in the southern and south-eastern segments of the crater's inner rim.



**Figure 3.** Main lithological associations of the outcropping in the Colônia impact crater region. The Billings hydrographic basin is indicated by the white dotted line (source: Coutinho, 1980)

Climate, relief, soil permeability and soil types are all natural conditions that strongly influence plant species distribution throughout the crater. Although the region does not present significant variations in terms of altitude, field observations suggest that the effects of slope gradient and the saturation zone of groundwater are the principal factors controlling the spatial distribution of vegetation on the site (Figure 4). In general, it is possible to note a clear difference between the vegetation in the most erosive zone, the crater rim, which is composed of large trees serving as habitat for a rich array of fauna including birds, mammals and reptiles (Marçon, 2009), and the sedimentation zone, the crater centre, where a mosaic of marshy vegetation and other types of herbaceous plant species gradually begin to prevail (Velázquez et al., 2006; Marçon, 2009).



**Figure 4.** Schematic illustration of the slope gradient effect and the saturation zone of groundwater on the spatial distribution of vegetation

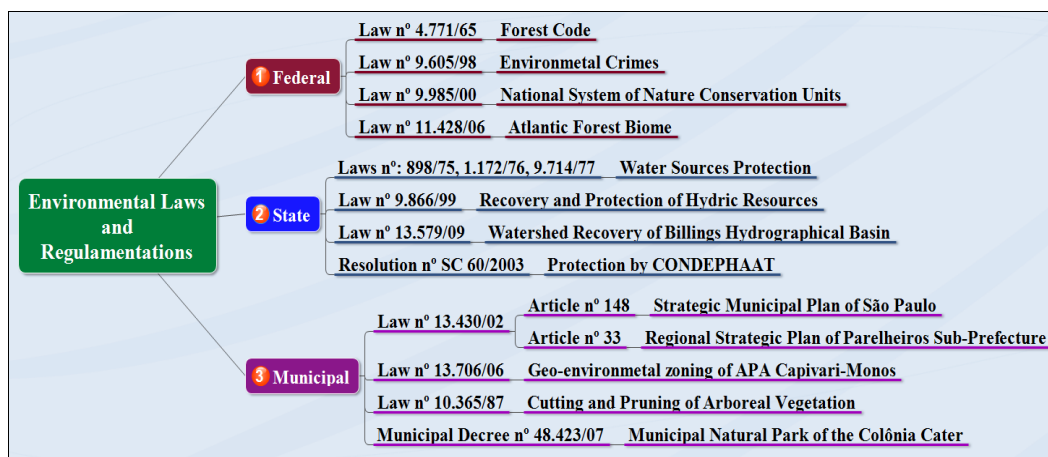
The sediments that fill the crater are still undergoing compaction and consolidation processes. As a result of this very particular situation, the layers are highly permeable and exhibit behaviour similar to an unconfined aquifer. In this type of aquifer, the water table is extremely close to the surface, and the downward movement of contaminants becomes an imminent danger, particularly during periods of intense rain, when groundwater recharge occurs across the entire surface. This area is particularly susceptible to pollution

and requires stronger environmental protection measures. Therefore, all potentially polluting activities should be rigorously forbidden.

The risks of landslides and flooding are also severe problems in the crater, and both processes are markedly worsened by unplanned urbanization. In areas with steep slopes and little or no vegetation, rainwater penetrates to deeper layers. In such circumstances, erosion operates efficiently, removing the weathered rock materials without major impediments. This is the main mechanism responsible for structural failures in civil engineering works, generating instability in buildings along hillsides and increasing the possibility of a general collapse. Residences situated in topographically low regions, and, in particular, very close to the Ribeirão Vermelho River, have also been subject to frequent, episodic flooding, which has endangered the physical integrity of many families.

### LEGAL PROTECTION MEASURES

A large number of environmental rules have been established to preserve the Colônia crater region (Figure 5). The first concerns State Legislation around the Watershed Protection Area of the São Paulo Metropolitan Region. Since its promulgation in 1975, this law has organized and guaranteed the supply of drinking water to the population. To further ensure the watershed protection and to reinforce local preservation, the Environmental Protection Area of Capivari-Monos was created in 2001. This resolution was issued by the municipal government to safeguard an area of 251 km<sup>2</sup> that, until then, had received little to no attention. The region contains important native vegetation of the Atlantic Forest, several wildlife and flora species, and numerous waterfalls (SMVA, 2011). Similar to other areas of large size, the main problems faced in this region relate to management and efficient supervision.



**Figure 5.** This chart summarizes the main environmental measures that have been instituted to protect the Colônia impact crater region (sources: data from SMVA, 2012; SMA, 2013)

A few years after the formation of the Environmental Protection Area, the Defence Council of Historical, Archaeological, Artistic and Tourism of the State of São Paulo (CONDEPHAAT), after a comprehensive analysis and through the application of specific legislation, declared dominion of public power and natural heritage over the region occupied by crater. With the advancement of research, the relevance of the crater became widely accepted by the scientific community. Based on an exhaustive bibliographical review conducted by Riccomini et al., (2005), the Brazilian Commission of Geological and

Palaeobiological Sites took the initiative to add Colônia in its database. Two years after the addition, a small area located further to the south of the crater was officially decreed Municipal Natural Park of the Colônia Crater. A total area of 52.8 hectares was slated for the development of research activities, environmental education, ecotourism, maintenance and integral protection of the area's ecosystems (SMVA, 2012). The most recent decision made by the Secretary of State of the Environment, through the Council of Geological Monuments of the São Paulo State (CoMGeo-SP) conceded the title of Geological Monument to the Colônia impact crater (SMA, 2013).

Despite preventive measures and the efforts of various social and institutional actors (community leaders, environmental NGOs, local entrepreneurs and governmental authorities) to prevent abuse, the practices of deforestation and burning; hunt, capture and unlawful sale of wildlife; and the predatory extraction of palmettos, bromeliads and orchids are still common in the region. In view of this unsatisfactory situation, adoption of a strategy to conserve the crater should be a priority, not only for its direct impact on the life quality of the local community, but because of the intrinsic value of its natural diversity.

### **HISTORICAL PERSPECTIVE OF HUMAN OCCUPATION**

There is very little information available on human settlement of the region prior to the arrival of German immigrants in 1827. An analysis of historical data indicates to a sporadic presence of Indians and mestizos scattered throughout the region. According to Ribeiro (1997), the "Colônia Alemã" neighbourhood, later referred to as "Colônia Paulista", is one of the oldest settlements formed by foreign residents. Since the time of its establishment in 1827, "Colônia Paulista" has been a neighbourhood with little inclination toward development. In spite of being an economically disadvantaged region, the trajectory of German immigrants in the area has been documented by historical sites such as a meeting house and cemetery (ACEMPRO, 2008). After the Second World War, several Japanese families occupied the area. With a firm and determined attitude toward cultivating the land, these immigrants concentrated their activities on floriculture and horticulture. Although agricultural activities can negatively affect the environment, the boundary of the cultivated land area has remained relatively steady (SMVA, 2012).

The most significant transformation occurred with the foundation of the Vargem Grande neighbourhood in 1989. Encroachment was promoted by the Union of the Slum Dwellers of Grajaú (UNIFAG). With approximately 1,200 families, the occupation started on the northern rim and spread there after towards the centre of the crater, until it neared the floodplain of the Ribeirão Vermelho River (SMVA, 2012). According to the Community Housing Association of Vargem Grande, there are currently almost 45,000 residents in the neighbourhood, and over half of the population lives without access to basic sanitation systems (Figure 6). Another cause for concern is the Penal Establishment Agent of Security Penitentiary Joaquim Fonseca Lopes. Inaugurated in 1987, this prison operates at over two times the maximum capacity, maintaining a population of 1,392 detainees (SAP, 2013).

The natural conditions of the crater —steep slopes, active floodplain and large areas with loose soils— are usually considered unfavourable for urbanization. Unfortunately, the adverse conditions of this site have not been sufficient to impede the obstinate determination of foreign immigrants in exploring unknown lands, on the one hand, and the legitimate necessity of a disadvantaged social class with no other options to establish a place to live on the other hand. With a little technical knowledge, a minimum of infrastructure (drinking water and electric power), and without appropriate planning, the crater region was transformed into a typical example of illegal



land ownership. Today, the landscape of the crater is a mosaic comprising fragment of Atlantic forest, floodplains, agricultural lands and homesteads, a natural park, a penitentiary and the Vargem Grande neighbourhood.

The chaotic pattern of urban growth inside the crater, as well as the expansion of agricultural areas, has severely impacted the environment (Figure 6), directly directly resulting in significant loss of vegetation cover, reduction in the permeability of the upper sedimentary layer, increases in soil erosion processes and the silting up of superficial drainage networks.



**Figure 6.** Panoramic views of the Vargem Grande neighbourhood located at the northern rim of the Colônia impact crater. In the background can be seen the southern rim partly occupied by besiegers and smallholders

### **STRATEGIC ACTION PLANS FOR ENVIRONMENTAL PROTECTION**

The Parelheiros district has the most extensive vegetation cover of the Metropolitan Region of São Paulo, is one of ten districts with better environmental quality, and it also possesses the second largest rural area in the Region. However, this promising scenery is under continuous anthropogenic pressure, which represents a risk for environmental protection. Such a threat confirms the need for an integral action program that takes into consideration all aspect of the current problem (Colonna & Velázquez, 2012).

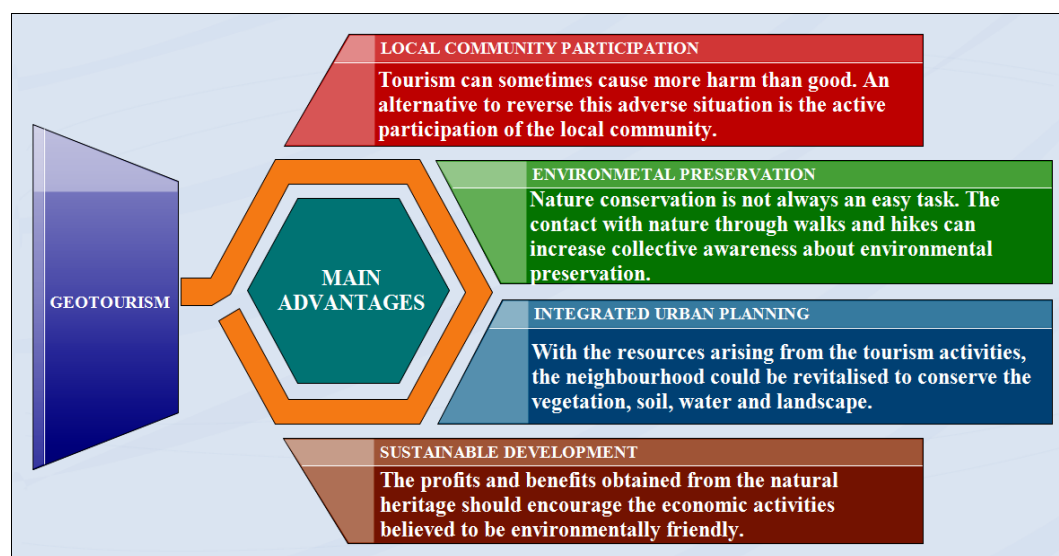
The first proposal for territorial planning in and around the Colônia impact crater was included in the Regional Strategic Plan of the Parelheiros Subprefecture, launched in August 2004, in which were summarized the main guidelines for the use and occupation of the land and the measures for environmental preservation. As pointed out by Alcarde (2010), the recommendations are only an incentive for the elaboration of a local management plan, because legal actions that should have put into practice the programs were seriously compromised. Research driven by Paiva Junior (2012) also shows the importance of incorporating alternative parameters that, in certain situations, could prove advantageous for the process of preservation and sustainable development.

For this author, the most relevant aspects of successful program planning are: a) the selection of appropriate indicators at different strategic levels, b) an efficient method

for the collection and interpretation of data and c) the active participation of the local community to be benefited. Obviously, this type of approach involves a series of changes to the traditional urban planning model. The first step requires the acquisition of new data to develop an accurate diagnosis of the current situation and provide appropriate guidance for participatory decision making.

The Municipal Natural Park of the Colônia Crater Management Plan is another document that focuses on the crater region (SMVA, 2012). After being approved by the Management Council of the Environmental Protection Area—Capivari-Monos and the Municipal Council of the Environment and Sustainable Development, the plan was officially released in 2012.

With the purpose of protecting an area of 52.8 hectares located on the extreme southern edge of the crater, the management plan aims to establish guidelines and define the actions that should be performed to ensure the execution of environmental preservation, monitored visits, research and leisure activities on site. Furthermore, it provides a legal framework outlining the main laws and processes that govern the enforcement of management programs and the protection of the park. Although it is still in the implementation stage, this document offers the tools required to overcome the challenges of planning, management and conservation.



**Figure 7.** The main environmental, social and economic benefits arising from the implementation of a geotourism program

The action plans proposed by the public authorities are clearly intended to preserve the crater region. However, transformational processes demand rigorous attention and periodic assessment through the use of accurate technical studies. The execution of programs and activities that motivate the participation of the local community are also extremely important. Aside from ensuring the means of implementation, infrastructure and human and financial resources, programs should give higher priority to the more ambitious proposals, those that take into account the possibility of broad societal involvement (Figure 7). An initiative of this nature should not be limited only to the interests of the best organized social groups. It should create opportunities to involve as many people from the local community as possible.

## FINAL CONSIDERATIONS

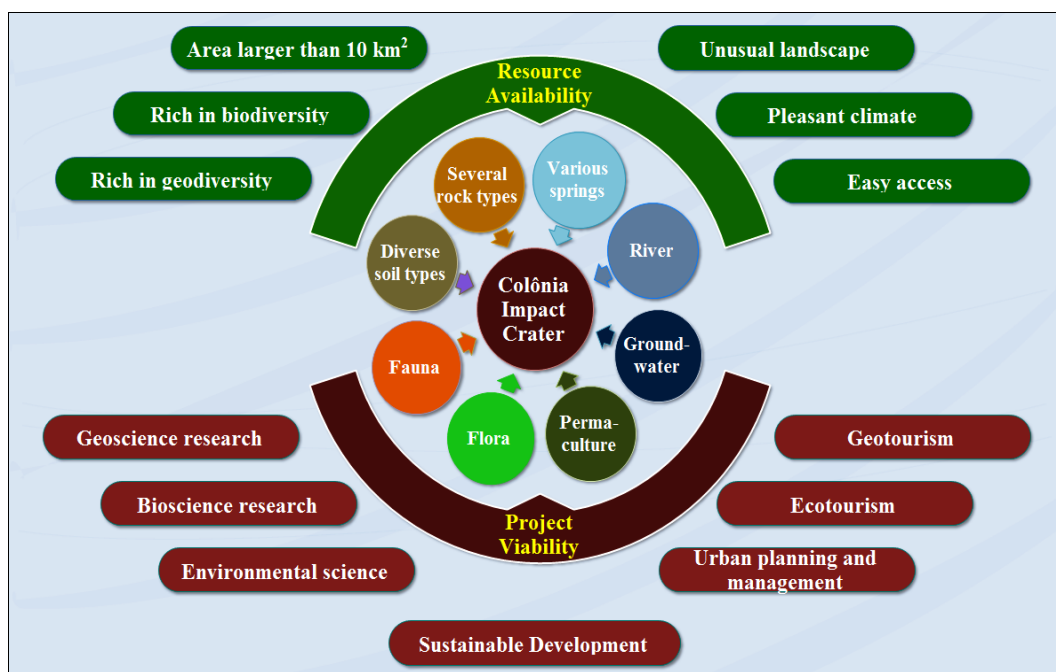
The natural elements that comprise the Colônia impact crater can be used in education to illustrate diverse aspects of the geological and biological sciences. The mineralogical and textural features of the metamorphic, magmatic and sedimentary rocks present several types of transformational processes that have occurred from the earliest times to the present in the Earth's crust. Important information about the region's palaeoclimatical evolution can be obtained from sediments within the crater. In a similar way, palaeoweathering of the surface provides essential information about the process of soil formation and allows scientists to diagnose areas at greater risk of landslide. The crater also has a rich biota that includes a wide variety of animals and plants. Due to its privileged geographical position and easy access, the crater region provides favourable conditions for geotourism, where students of various educational institutions, with different levels of schooling, could have the opportunity to develop integrated activities using the scientific method and pedagogical techniques. It is also an important recreational area with several trails and an extensive space for sports, walking and cycling (Velázquez et al., 2014a).

The accelerated process of urbanization is certainly one of the major factors responsible for the transformation of the natural landscape and its consequent environmental degradation. For this reason, nature preservation and the planning and territorial management of natural areas continue to be very difficult tasks for local authorities. However, the municipal government and the local community have already entered into negotiations to address some specific needs. The dialogue focuses on two priorities: a) accommodating the families that live in at-risk areas elsewhere and b) establishing a landscape project for the remodelling of the Vargem Grande neighbourhood and the recovery of degraded areas. Current decisions fall far below expectations. The lack of consensus between the parties involved concerning the redefinition and reformulation of the primary objectives has caused a certain tension in the negotiations of the agreements and, in some cases, has jeopardized the execution of the projects. Nevertheless, the management program to be implemented in the region requires an integrated strategy that incorporates environmental preservation principles, economic growth and sustainable urban development.

In light of the points outlined above, it is possible to verify that the programs and negotiations in progress, although very well formulated in technical and political terms, are as yet insufficient to address the problems of urbanization, agricultural expansion and nature preservation. For an adverse situation such as this, sustainable tourism is an excellent alternative. Such a program should take into account the totality of the resources available: (i) landscape tourism, which provides opportunities for the appreciation of the amazing feature of a hypervelocity impact, (ii) nature tourism, where people observe the diversity of flora and fauna via trails and (iii) permaculture tourism, which allows tourists to learn about a system of family farming adapted to the local conditions without agrochemicals (Velázquez et al., 2014b). Ecotourism as a tool for socioeconomic development in environmental protection areas is doubly advantageous. The activities can be diversified into several segments, generating new employment opportunities for the local community. Another benefit derived from this experience is the possibility to show the potentiality and value of the region's natural resources, encouraging the community in general to develop actions that involve environmental preservation.

The Colônia impact crater region has all of the attributes to become an attractive place for tourism (Figure 8). However, a detailed study should be conducted on the social and environmental problems surrounding the crater to ensure a promising future. As

mentioned by Ruiz de León (2010), the transformation of natural resources into quality tourism services for a region will only be possible with the active participation of the local community. From this principle, the geotourism is proposed as a feasible opportunity to promote the valorization of the region's natural resources while encouraging the participation of the community in environmentally sound tourism programs.



**Figure 8.** Contextualisation of the resources available and the main activities that can be performed to ensure the preservation, sustainable development, continuity of research, teaching practice and leisure for the population

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