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UNESCO Global Geoparks as useful sceneries to disseminate science and raise awareness of geological risks: the case of Las Loras Geopark (Spain)

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Abstract: Natural and anthropic hazards derived from climate change are endangering heritage and society. Geoheritage is vulnerable. Nowadays we are witnessing the destruction of monuments with high emotional significance due to wars, but climate change is also contributing to the loss of the same cultural heritage. Prevention is often the best way to protect geoheritage from disappearing and society is the best agent to implement preventive measures. Citizens are often unaware of the important treasures they have around them. Geoparks have been a great tool to bring awareness in society, since by involving the public in the whole process of recognition and promotion, they protect the space and the cultural and economic values associated with them. It is important to communicate the initiatives taking place in the geoparks to explain the importance of geology and the risk of losing the cultural value of these areas if natural hazards increase due to climate change, and also the risk to the population living in the area if those hazards reach destructive intensities. This paper is focused on discussing the case of Las Loras Geopark as an example to show the contribution of geoparks to the dissemination of science and the relevance of preserving geoheritage by implementing simple measures based on communication and prevention.

Keywords: geoheritage, UNESCO Global Geoparks, natural hazards, potential consequences of climate change.

1. Introduction

The UNESCO Global Geoparks (UGGp) are unified geographic areas comprising sites and landscapes of international geological importance, managed with a holistic concept of protection, education, research, and sustainable development (UNESCO 2022). Geoparks are delimited territories that host a geological heritage of international relevance, used as the basis for their sustainable socio-economic development. The main objective of a UGGp is, therefore, to promote local sustainable development based on three key strategies: geotourism, geoconservation, and education. These strategies pursue the 17 Sustainable Development Goals defined by the United Nations (Hopwood et al. 2005; Mebratu 1998, UNESCO 2022). The first record of the term geopark that we have been able to find dates back to 2002 (Xun and Milly 2002). Following that first paper, the number of publications on geoparks has increased, as has the number of nominations and designations (Ferreira and Valdati, 2023). To date, the term geopark is mentioned in the title of 609 publications (https://exaly.com/ accessed 24 November 2023). In line with the concept of geoparks, in 2022 the International Commission on Geoheritage, a permanent commission of the International Union of Geological Sciences (IUGS), ratified the First 100 IUGS Geological Heritage Sites as a first step towards a wider program that will give recognition to those geological sites of the greatest scientific importance in the world (https://iugs-geoheritage.org/designations/). Geoparks refer to biodiversity, sustainable use, and exploitation of geological resources (e.g., rocks, minerals, and critical raw materials), as well as to anthropic and natural hazards that endanger the geopark's heritage and the population living in the surrounding area. Anthropic and natural hazards can cause the complete disappearance of a World Heritage site, such as the Qeshm Geopark, a World Heritage site in Iran, in danger due to the negligence of the authorities (https://freedomstarblog.wordpress.com/2020/02/03/destruction-of-irans-world-heritage-site-qeshm-geopark/).

Despite the relevance of UGGp in the protection of the environment, culture, and geoheritage of a region, there is still an imbalance in the recognition of Global Geoparks in the different continents, a situation that should be reversed to consider geoparks of global interest. Currently, most UGGp are concentrated in Asia, South America, and Europe (Herrera-Franco et al. 2021; http://www.globalgeopark.org/GeoparkMap/) and, although Africa has prominent heritage sites (e.g., the monuments of the Fourth Dynasty of the Giza Plateau. Pereira, 2023), only two UGGp are in this continent, corresponding to the M'Goun Global Geopark in Morocco and the Ngorongoro Lengai in Tanzania. Considering that Africa may be subject to a strong influence of climate change and the possible lack of awareness of the African population about the importance of its geoheritage, studies of potential areas for designation as UGGp should be promoted. In fact, some African countries, aware that their natural landscapes may be lost due to natural hazards, have started to implement simple protection measures that we will refer to as best practices. For example, Angola does not host any UGGp or IUGS Geological Heritage Sites but several locations in the country have been categorized as high heritage value areas and have implemented structural measures to channel water during floods. This is the case of Tundavala and Leba in the Huíla Province (Duarte et al., 2014; Henriques et al., 2013; Lopes et al., 2019; Oliveira Tavares et al., 2015). Structural measures are essential to control geohazards, but communication and outreach are of great relevance to raise awareness among the population who otherwise are unaware of their geological heritage and the potential loss if a natural hazard strikes their area.

To shed light on the relevance of geoparks as sceneries for communicating science, we present a case in Spain, Las Loras Geopark (Figure 1), of which one of the authors is a member of the scientific committee (http://geoparquelasloras.es/index.php/gestion-y-participacion-2/). This UGGp can serve as a model to illustrate the importance of such communications, including information on hazards and their prevention, to encourage the designation of geoparks in underrepresented areas, as in Africa, but also to preserve existing geoparks when a risk, even a potential one, threatens their integrity (Fassoulas et al., 2018). Communication is key when dealing with geohazards because it prepares the population for resilience after being hit by one. One of the main goals of geoparks is to disseminate science, as well as geological hazards and their preventive measures, including natural and anthropic hazards and hazards exacerbated by anthropic activities. The potential new environments generated by climate change require the adaptation of measures based on engineering artifacts, but also social approaches related to communication and outreach.

Therefore, the main goals of this paper are to: 1) identify potential geological risks in Las Loras UGGp, 2) propose a science communication plan to raise the local population's awareness of geoheritage and its hazards, and 3) propose simple mitigation measures and infrastructure to prevent risks in a protected area. To reach these objectives, we propose a science communication plan that will provide the appropriate tools to establish and implement communication activities in Las Loras UGGp considering the different possible audiences and their impact and goals. To illustrate preventive measures compatible with the sustainability of a geopark, a case study from Lubango (Angola) is presented, where the implementation of low-cost structural preventive measures has saved lives, geosites, and the territory from destructive floods.

2. Methodology

The methodology used in this work comprised, first, the identification of a high geoheritage value area, Las Loras UGGp, which may be vulnerable to geological hazards resulting from climate change.

Visits to Las Loras UGGp with the scientific coordinator of the geopark and the participation of one of the authors in the scientific committee as a member have allowed us to identify the potential risks and their influence on the population and infrastructure. After identifying potential natural hazards in Las Loras UGGp, we evaluated the potential damage that could be inflicted and proposed mitigation measures that would be sustainable and compatible with the geopark. A risk communication plan was developed to inform and raise awareness among the local population.

To evaluate the risks due to floods, landslides, and rockfall in Las Loras UGGp, we focused on a protected natural area within the UGGp, named Las Tuerces. Using a digital elevation model, a slope map representing the inclination degrees on a color scale, from red to green, was created, including surrounding villages and areas that may be exposed. The result is a map in which the most vulnerable areas are represented as red zones with slopes greater than 50° (Figure 2). The topographic data were downloaded from the OpenTopography data facility (European Space Agency, Sinergise, 2021) and processed using the ESRI ArcMap 10.8 software.

3. Setting

3.1 Las Loras UNESCO Global Geopark

Las Loras UGGp is a territory in the Cantabrian mountain range, located in the north of the provinces of Burgos and Palencia, in the region of Castile and León (Spain) (Figure 1) (Sánchez-Fabián and Salman, 2015).

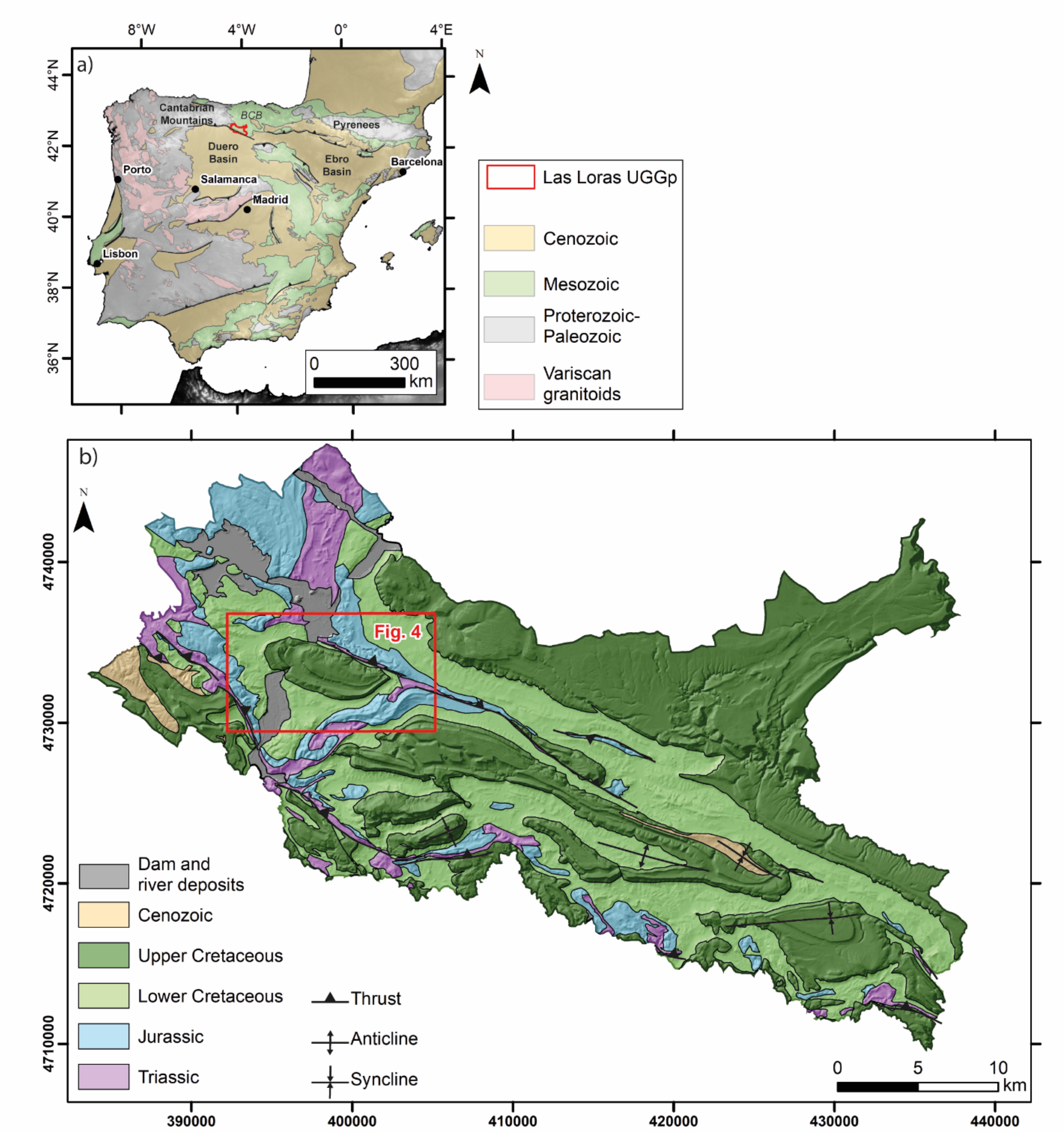

Figure 1: a) simplified geological map of the Iberian Peninsula, and b) digital elevation model and geological map of las Loras UGGp (simplified from IGME GEODE 1:50.000).

This territory was declared a UGGp in 2017, due to the international importance linked to the geological and cultural heritage (Salman and Sánchez, 2021), and revalidated in 2021, after an external evaluation (UNESCO, 2021; International Union of Geological Sciences, 2021). Las Loras UGGp hosts numerous natural structures and landforms of exceptional geoheritage. The attention of visitors to the geopark is immediately drawn to the powerful visual impact and natural beauty of its landscapes. Las Loras UGGp has natural fortresses, with a height of more than 1,000 m, which define the extent of the Castilian Plain and lead us into an ancient territory occupied since the Paleolithic period. Fertile valleys, deep canyons, rock labyrinths, beech and oak forests, and numerous crystalline waterfalls situated between high moorlands, represent one of the most diverse environments in Northern Spain.

The diversity of Las Loras UGGp and its well-preserved geoheritage provided a notorious representation of habitats –some of them unique and rare in Europe– that harbor a wide range of threatened fauna and flora species. The rugged terrain and its strategic biogeographical position in the transition area between the Eurosiberian and Mediterranean regions, along with the outstanding presence of high plateaus, so typical of Las Loras, are the key factors for the remarkable biodiversity of the area (de la Hera et al. 2023).

The cultural heritage of Las Loras Geopark contains the largest concentration of Romanesque buildings in Europe. Well-preserved monasteries, churches, and villages from the 12th and 13th centuries are spread throughout the territory, constituting a network of tiny architectonic treasures of great beauty that take us back to medieval times. The cave hermitages and the extraordinary concentration of megalithic monuments and pre-Roman forts are other highlights of Las Loras Geopark.

Although Las Loras Geopark is currently underpopulated, festivities, dances, and traditional music still survive and enrich its excellent natural and cultural heritage, because people and ethnography are the essential engines of geoparks.

Geoparks have contributed to the development of huge numbers of guides to accompany tourists along the trails and admire the geology and nature. Examples of this are the different hiking sites (e.g., https://es.wikiloc.com/rutas-senderismo/las-tuerces-desde-villaescusa-de-las-torres-y-cueva-de-los-franceses-100359385) or a novelized guide (Pereda, 2021), where the author combines the description of landscapes, the invented story of a mythological being and the walking paths around the area. However, the potential risks or previous natural events are not mentioned.

3.2 Geological background

Las Loras Geopark is located in the southwestern edge of the Basque Cantabrian basin, in the central part of the Pyrenean-Cantabrian mountain range. This area has experienced a complex paleogeographic evolution since the Paleozoic due to successive extensional and compressional tectonic events.

During the Carboniferous, the collision of Laurussia and Gondwana resulted in the formation of the Variscan orogen and the formation of the supercontinent Pangea (Matte, 1991; Martínez Catalán et al., 1997). In the Cantabrian Mountains, the Variscan basement is mainly represented in the west of the Basque-Cantabrian Basin, in the Cantabrian Zone of the Iberian Massif, and in the Basque Massifs (DeFelipe et al., 2017; Figure 1a). In the latest Carboniferous-early Permian, an extensional event led to the collapse of the Variscan orogen (McCann et al., 2006). This extension continued during the late Permian-Early Triassic (Bourquin et al., 2011) and was followed by a generalized transgression in the Early and Middle Jurassic (Salas & Casas, 1993; Aurell et al., 2003). From the Late Jurassic to the mid-Cretaceous, the Pyrenean-Cantabrian realm developed under a new rifting event related to the opening of the North Atlantic Ocean and Bay of Biscay (Ziegler, 1988; García–Mondéjar et al., 1996; Tugend et al., 2014; Pedreira et al., 2015, Abalos, 2016; DeFelipe et al., 2017). The evolution of the Bay of Biscay rifting resulted in the formation of the Basque-Cantabrian basin as a thick Aptian-Albian basin with up to 5 km of sediments, including flysch-like deposits, carbonate banks, and marls on the distant platform (Rat, 1988; García-Mondéjar et al., 1996; Quintana et al., 2015).

From the Late Cretaceous to the Miocene, the Alpine orogeny resulted in a continent-continent collision in the Pyrenean realm and the shortening and uplift of a passive margin in the Cantabrian Mountains (Muñoz, 1992; Teixell et al., 2018; Pedreira et al., 2015). This convergence resulted in the inversion of the sedimentary basins and the exhumation of the Paleozoic basement, giving rise to the Pyrenean-Cantabrian Mountain belt (Fillon et al., 2016; DeFelipe et al., 2018, 2019). South of the Cantabrian Mountains, the Duero and Ebro basins developed as large Cenozoic foreland basins (García-Castellanos et al., 2013; Struth et al., 2019), filled with syn-tectonic sediments until the late Oligocene-early Miocene (de Vicente et al., 2011). Since the Miocene, continental post-tectonic sedimentation sealed the syntectonic deposits, exoreic conditions were established since the Tortonian (9.7-9.1 Ma, Rodríguez- Rodríguez et al., 2020 and references therein) and the current landscape was developed.

Las Loras offers a series of unique landscapes, built thanks to the natural elements such as rain, wind, and sun. The concept of Las Loras comes from the geological formations derived from the compression suffered and subsequent erosion due to the Quaternary fluvial action. The compression led to hanging synclines and, after erosion, Las Loras was formed (Moreno-Peña, 2019; de la Hera et al. 2023a) (Figure 2).

The origins of this basin date back to the Upper Permian and the last processes that affected it took place during the Miocene. The geological formations that outcrop in Las Loras geopark range from the Lower Triassic to the Lower Miocene, so there is a complete record of this sedimentary basin in this geographical area.

The strategic location of the territory within Pangea allowed the most important geological events that affected this European region over the last 250 million years to leave their mark in each of the geological formations of the geopark. The opening of the Atlantic Ocean, the rifting stages of the Bay of Biscay, and the large marine transgression of the Upper Cretaceous can be witnessed on site.

Figure 2. Typical landscape of Las Loras in the Geopark. Source: D. Pereira

At the beginning of the Mesozoic Era, during the Triassic, the terrains that now are part of the geopark were part of the supercontinent Pangea. During this period, the breakup of Pangea took place and great depressions originated by fractures were formed, which gave rise to the Basque-Cantabrian Sedimentary Basin. By that time, the lands of the geopark occupied low areas within Pangea, thus forming part of the Basque-Cantabrian Sedimentary Basin (Ábalos, 2016). The rivers that crossed the territory left a large amount of sediments resulting from the erosion of the great mountain range, which was formed 50 million years earlier, during the Carboniferous period, and was practically swept away by then.

4. Geoheritage and identification of its potential risks

The Global Geosites project, developed by the Spanish Geological Survey in the last years of the 20th century, aimed to design a standard methodology to produce a global inventory of the most prominent geological heritage sites on the planet (IGME https://www.igme.es/patrimonio/globalgeosites.htm). The results of this project helped to develop a national law to preserve natural heritage and biodiversity, considering different geological contexts of international relevance (Law 42/2007, of 13 December, on Natural Heritage and Biodiversity, https://www.boe.es/eli/es/l/2007/12/13/42/con). Las Loras UGGp contains three of the geological heritage sites that need to be preserved, but also several sites of geological interest that represent each of these geological contexts in a particularly relevant way (Sánchez-Fabián and Salman, 2015):

- Carbonate and evaporite karst systems of the Iberian Peninsula and the Balearic Islands.
- The rifting of Pangea.
- Fossils and ichnofossils from the continental Mesozoic of the Iberian Peninsula.

Limestone is the main lithology in the study area, and this rock has been modeled into the present karstic landscape since Cenozoic times (de la Hera et al. 2023b) (Figures 3a and 3b).

Figure 3. Other landscapes of Las Loras Geopark. Some of these elements are known as "tables" (Peña Mesa, above), "molars" (below), and "giant mushrooms". This area of the geopark, which is a protected area, is called "Las Tuerces" (Figure 1b) (Martin-Duque et al. 2012). Source: D. Pereira.

Although a geopark does not imply the status of a protected area, in some cases it may coincide or encompass protected natural areas, as it is the case of Las Tuerces Protected Natural Area (Martin-Duque et al. 2012). In any case, geoheritage sites should be protected by the implementation of local, regional, and/or national laws to preserve the sites for the next generations. Geoparks should assume the defense of their geological elements against destruction, and communicate the risks associated with such potential destruction to the population living in the surroundings. This area is exposed to karst processes that can lead to landslides damaging tourist trails, as is the case of the one that affected the 6 km long Horadada Canyon (Cañón de la Horadada, in Spanish) in the past (Figure 4), one of the most visited sites in the geopark due to the spectacular caves of archaeological interest and outcrops of lignite with amber from the Cretaceous period (Canesin 2017). Due to the high geoheritage value of Las Loras UGGp, a risk management plan is necessary. Figure 4 shows villages and sites that are exposed to potential floods, rockfall, and landslides due to the steepness of the slopes, greater than 50°. Figures 5 and 6 show the geological risks due to landslides in Las Tuerces Protected Natural Area.

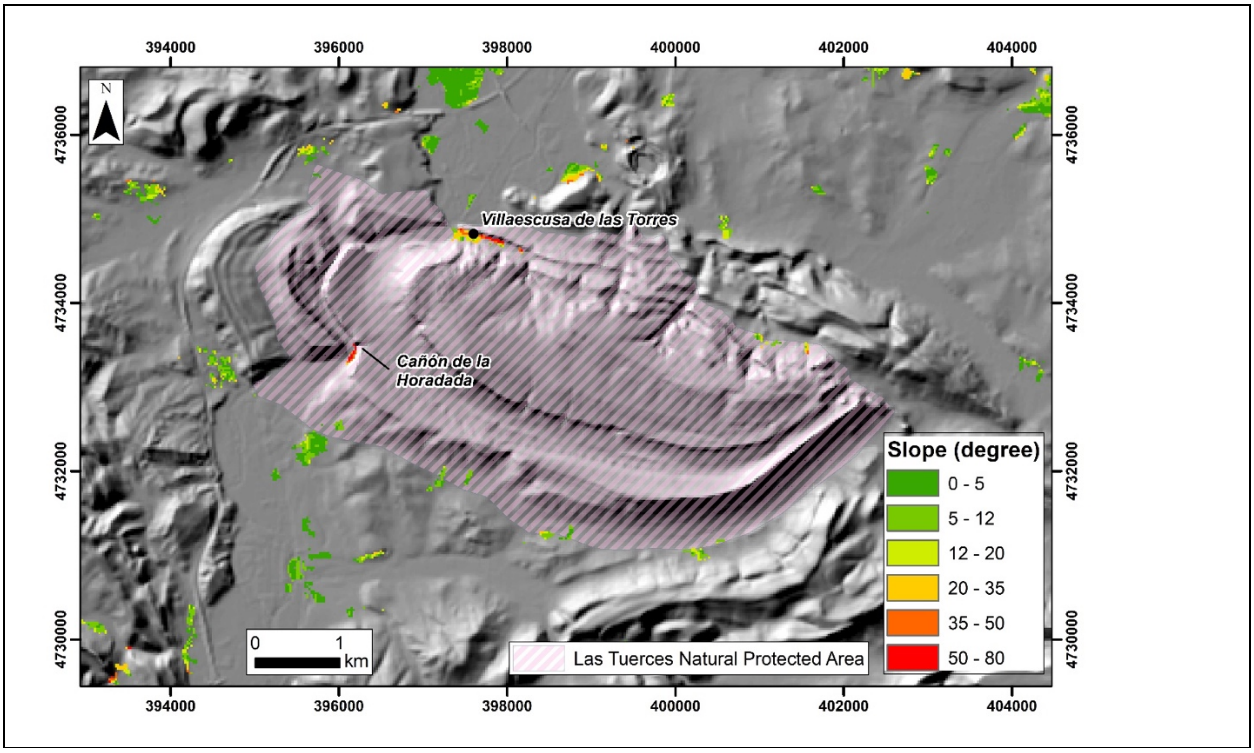

Figure 4: Steepness of the slopes in the villages around the Las Tuerces Protected Natural Area.

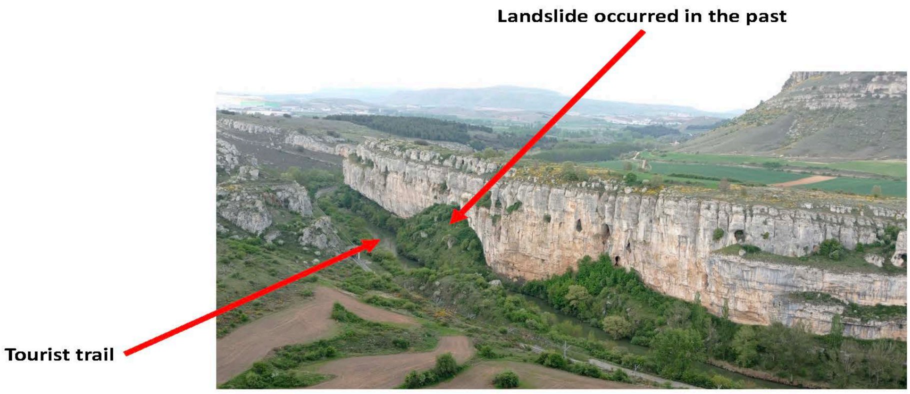

Figure 5. A walking path in Las Tuerces Protected Natural Area (Figure 4) within Las Loras UGGp that was affected by a landslide. No casualties were reported, but the lack of prevention could trigger further landslides, putting the users of this trail in the tourist area at risk. Source: D. Pereira

Figure 6. Image of the village of Villaescusa de las Torres, in Las Loras Geopark, which presents a potential risk of rockfall on it (see location in Figure 2). Source: D. Pereira

5. Science communication plan to raise awareness of risks.

Sharing scientific information with the general public, i.e., communication, is carried out through outreach activities with high social value. Communication must follow specific strategies to involve and captivate the interest of the public, and the language used to transfer knowledge must be simpler, avoiding technical expressions. Science communication plays a key role in improving the relationships between scientists, local decision-makers, representatives from civil society, and residents, and involves the commitment of the scientific community to the local population (Marsili et al., 2017). In the context of geohazards, communication strategies are part of the risk analysis, designed to raise public awareness by providing society with the necessary tools to understand the environmental and geological processes that may affect them directly or indirectly. Knowing the processes that are likely to occur, as accurately as possible, is key to providing an effective warning to the population (Farabollini et al. 2014). Furthermore, a successful communication plan must be tailored to reach people with the necessary information in a way that can be useful if a geohazard occurs (Fischhoff, 2013), but without causing unnecessary alarm. An effective science communication plan can increase the number of visitors, deepening the discovery of the territory and communicating Earth science concepts to nongeologist tourists (Justice, 2018). That plan should address potential risks, even if they are not foreseen in the near future.

Therefore, to promote the understanding of geological issues among non-scientists, we propose a strategic framework for Las Loras Geopark focused on different aspects and goals: 1) to raise awareness of the natural heritage of the geopark, 2) to broaden knowledge of the geological features of the territory, 3) to increase the attractiveness of the area by highlighting its cultural and natural heritage (Patrocínio et al., 2018), 4) to communicate potential geohazards and natural events that could affect recognized geosites, as well as the risk to the population and visitors, and 5) to serve as an example of best practice for other UGGp.

This communication plan is designed to effectively adapt the information to the different target audiences (Gordon, 2022) and is based on six pillars (Figure 7).

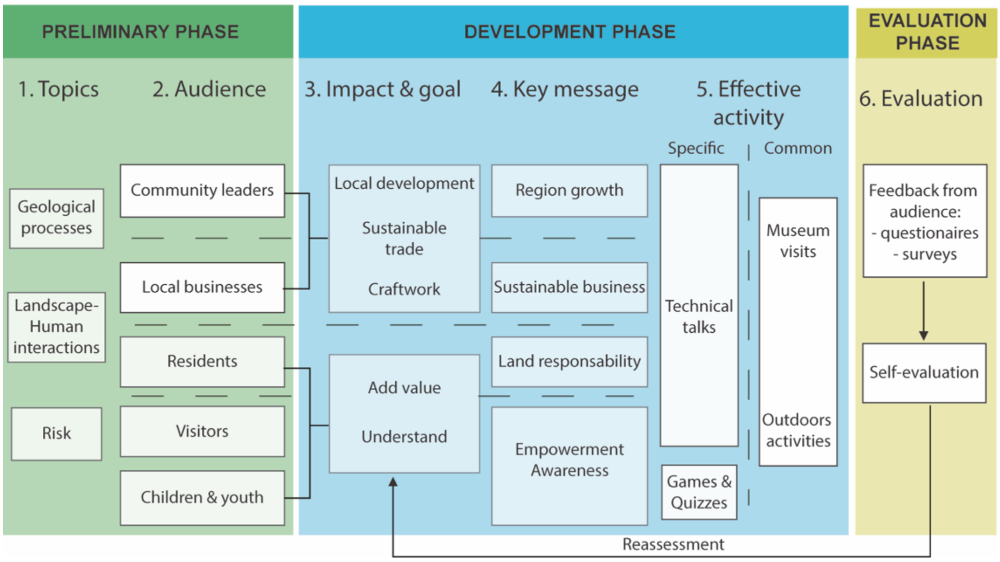

Figure 7. Workflow chart showing the steps to achieve a communication plan in a UNESCO Global Geopark.

5.1 Topics

The first issue to consider when communicating a scientific action is the topic or topics to be communicated. In our study case in Las Loras, we will focus on the geological processes, the interactions between the landscape and natural processes (e.g., wind or water), and the potential risks that could affect the population living in Las Loras UGGp and the numerous visitors.

5.2 Audience

The proper identification of the audience for the communication plan is essential to increase the engagement and effectiveness of the communication, as the message, language used, and best practice guidance will differ according to the listener. The Man and the Biosphere (MAB) UNESCO

Program (UNESCO MAB, 2018; https://www.unesco.org/en/mab) is an intergovernmental scientific program aimed at establishing a scientific basis for enhancing the relationship between people and their environment. It identifies four key audience segments for the communication strategy: community leaders, local businesses, children and youth, and residents in the geopark. We add to these a significant economic segment, which are the visitors to the geopark.

Policy makers such as councils, community leaders, and/or local leaders are influential stakeholders who can shape policies for the management and safeguarding of the geopark, including behavioral changes in communities. Businesses involving farmers, tourism agencies and networks, business owners and entrepreneurs are the most interested in preserving the geopark to enhance its economic development. It should be noted that the person in charge of Las Loras UGGp and its scientific committee have succeeded in engaging some leading companies in the area (e.g., Galletas Gullón, one of the largest cookie manufacturers in Europe based in the geopark area) with the research and communication objectives of the geopark in the form of funded projects that also include the participation of the academic community (http://geoparquelasloras.es/index.php/en/educational-and-scientific-project/, accessed 5 December 2023). Residents and landowners can benefit greatly from the geosphere and biosphere and can take responsibility for the actions taken in the area. Therefore, they need appropriate information and awareness about the nature of the present and future environment, the ecosystem, and the geopark. Children and youth can be fascinated by nature, landscape, and geology if the information is communicated in an appropriate and adapted way, and they can have the enthusiasm to get involved in local activities with the potential to become environmental activists, helping to preserve the natural heritage of Las Loras.

5.3 Impact and goals

When deciding the target audience for the communication plan, the importance of the communicated topic must be adjusted. Personalizing the message to the audience and considering their previous knowledge on the topic will improve the communication process so that they do not receive information that is repetitive or too advanced based on their background.

The proposed aims should consider the SMART goal system, that is, be Specific, Measurable, Attainable, Realistic, and Timely (Doran, 1981), which will prioritize the improvement of the process when trying to reach a specific target audience (Maxwell et al., 2015).

The main impact objectives a UGGp should pursue are: 1) to inspire stakeholders about the impact that geoparks can have on the environment and their relationship with human activities, 2) to create a feeling of belonging to nature and connection with the ecosystem, and 3) to provide the population with the necessary information to build capacity, engaged them in sustainable actions, and involve them in decision-making processes (e.g., UNESCO MAB).

Thus, each audience group will demand a different impact and goal, ranging from highlighting aspects such as local development, sustainable trade, and commerce; local craftwork for community leaders and local businesses; and an added value to nature and understanding of the geological processes for the residents, tourists, and youth.

5.4 Key message

The message to be conveyed should be defined as key points that the target audience can respond to or remember in the medium or long term. Following the SMART principles and considering the main objectives described above, the key message should focus on regional and sustainable growth and business, as well as territorial responsibility, and on empowering and raising awareness of natural events among the younger generation. The impact of climate change on the alteration or even destruction of the current geoheritage should be highlighted, avoiding dramatic language that could cause fear in visitors.

5.5 Effective activities

The activities proposed to communicate the main topics depend mainly on the target audience and have been divided into specific and common activities. All activities should be planned with the support of the local population and businesses.

Information on methods, techniques, the functioning of certain natural processes, and other related topics of interest should be provided in technical conferences for community leaders, local businesses, and residents. The UGGs must have a scientific steering committee with defined roles to identify and promote research related to the geopark, but also to implement projects within the geopark and share the findings with stakeholders and the general public, including information on natural hazards that may affect the area. This committee can help to canalize the main questions the audience may have. The information should be accompanied by pictures and videos of field examples that will attract attention and increase their interest, and thus, more chances to be remembered.

Regarding children and young people, a more effective strategy should be based on play-based learning rather than formal conferences (Cutter-Mackenzie and Edwards, 2013; Rowe et al., 2014), using games, quizzes, gymkhanas, or role-playing (Howes and Cruz, 2009).
In addition, field trips, visits to local museums, and outdoor activities within the UGGp should be included in the communication plan, so the audience can get a practical idea of the current situation of the landscape and natural heritage that we aim to preserve for coming generations.

5.6 Evaluation

The use of surveys and questionnaires to measure the impact and success of the communication plan will provide an overview of the implementation strategy and quality control of the plan.
The implementation of the necessary actions at each stage will contribute to defining the action plan (Figure 7) that will channel efforts to convey a clear message to the target audience. Feedback from the audience will be used to self-evaluate the plan, adjusting and reassessing the implementation during the development phase. As a result, the communication plan could be improved in the long term by reaching a certain number of target audiences, the funding invested by the UGGp in the activity, and the impact caused in relation to the increased awareness of the geopark, the feeling of belonging or local pride and the willingness of the people to get involved (UNESCO MAB).

6. Discussion

The same natural actions that created the spectacular landforms in the geopark could cause their destruction in the event of a catastrophe, such as the natural phenomena observed nowadays as a consequence of climate change. This could lead to the disappearance of a unique geological landscape. Therefore, we propose to use the geopark as a scenery to inform about geology and the risks that can affect the geoheritage and the population. Experts should advise on the potential risks associated with natural and anthropic hazards that may affect the area through seminars, conferences, and meetings taking advantage of geopark activities, as well as all UNESCO activities related to geoparks. Experts should also inform on possible structural flood management measures to protect people, property, and geoheritage in order to reduce the consequences of natural hazards in the form of floods. These measures do not necessarily have to be based on strong engineering interventions. Simple and natural approaches (e.g., wetlands, detention basins, channelization) compatible with the landscape and geosites of the geopark can be considered and ultimately implemented, following some best practices implemented elsewhere, as explained below. Vulnerable sites such as the Horadada Canyon and its escarpments, the natural monuments of Las Tuerces, and also local businesses are subject to be severely affected by these potential hazards.

We have analyzed a case study of the use of simple measures to mitigate the risk of flooding and it seems appropriate to include here as an example of best practices that can be implemented in the geopark as part of the preventive measures. The case study is based on the city of Lubango (Angola). Lubango is located in the southwest of Angola, in the Huíla province. The average altitude is 1700 m. The climate is temperate or temperate-warm, modified by altitude. The rainy season, which is longer than the dry season, coincides with the summer (with a maximum peak of 99 mm water precipitation). Lubango is located on a topographic plateau and in a hydrographic sub-basin of the Caculuvar River with an area of approximately 220 km^2 (Cruz et al., 2017). In February 2016, heavy rains resulted in catastrophic flooding due to the overflowing of the Capitão River (Martins et al., 2019), affecting Lubango and its surroundings (Figure 8). The damage was caused by heavy rains and a chaotic territorial arrangement of the city itself, where no drainage ditches were available to prevent water runoff. Human and infrastructure losses were frequent and flooding caused heavy soil erosion.

Geomorphology is essential to control the extent of flooding. Therefore, a detailed study of the geomorphology would allow the implementation of a specific structural preventive measure. After the heavy rains of February 2016, structural preventive measures were built in Lubango. The measures included the construction of simple ditches to channel water in case of future flooding (Figure 9).

Figure 8: Consequences of floods that affected roads and paths and caused landslides in the surroundings of Lubango. Source: Armanda Cruz, 2011.

Figure 9: Image of four ditches built in Lubango to channel excess water from heavy rains. An example of possible low-impact best practices to be implemented in Las Loras Geopark as preventive measures. Source: Armanda Cruz, 2011.

The simple but effective measures implemented in Lubango showed excellent results and could represent an example of best practice to be followed in the case of Las Loras UGGp, and any other geoheritage site, which could be exposed to destruction due to natural hazards resulting from heavy rains, as we observe more and more frequently. In the case of Las Loras Geopark, the implementation of structural preventive measures must respect the landscape and the sites. Another preventive measure to avoid the loss of geosites, such as the geomorphological sites (e.g., “tables”, “molars”, “giant mushrooms”, etc.), could be based on the strengthening and waterproofing of the soil around the geosites. Rain erosion and structural instability of sites have been the subject of relevant archaeological engineering research projects. In addition to traditional soil stabilizers such as cement and lime, there are many types of non-traditional stabilizers available in engineering, which are generally divided into ions, enzymes, lignosulfonates, salts, petroleum resins, polymers, and resins (Du et al., 2023). The authors of these studies concluded that the addition of stabilizers has the potential to improve the mechanical and waterproof properties of the soil, helping to protect cultural relics. The same technique could be applied to stabilize the area of the important geomorphosites in Las Loras Geopark, to prevent the consequences of catastrophic natural events that climate change could trigger.

7. Conclusions and further work

Geoparks have become a socio-economic driver of the areas where they are recognized. Tourism has increased, as well as the local economy, where small businesses, eco-agriculture, and other previously unknown initiatives are flourishing thanks to the UGGp. UNESCO has promoted geology and geoparks, but the best way to promote them is to maintain close contact with the population who live in them and with stakeholders. It is necessary to support the exchange of ideas, close contact with society, and popular initiatives to preserve geoheritage for the next generations but it is also necessary to prevent the loss of heritage and to inform about potential risks.

Dynamic changes in the hydrogeological system can trigger geohazards such as landslides, rockfalls, mud, and debris flow, as in the case of the Luochuan Loess Geopark (Wang et al. 2019). However, field investigations have indicated that some geosites are threatened by geohazards. That is the case of Las Loras UGGp, in northern Spain, where vertical fissures, studied in depth in the loess, may constitute a pathway for surface water penetration and groundwater erosion. Direct shear tests indicated that rainfall leads to a reduction in the shear strength of the loess (Wang et al. 2019). Freeze-thaw tests showed that the new cracks caused by cold shrinkage destroy the integrated strength of the loess during the freezing process and that water accumulation in the cracks is hampered and the cracks worsen because of thermal expansion during melting.

The protocol to be followed in Las Loras UGGp should not be alarmist, but a communication procedure should be included as part of the activities of the geopark. The aim is to transfer knowledge in the context of a risk society. At present, the scientific committee of the geopark meets periodically to discuss initiatives that involve the scientific community, but also the population that is interested in getting involved in them, and students who are beginning to learn to appreciate their local geoheritage meeting the UNESCO's objectives by engaging in funded projects that take place in the geopark and producing final degree thesis and publications (http://geoparquelasloras.es/index.php/en/educational-and-scientific-project/, accessed 5 December 2023).

The authors advise making an effort to include other preventive measures, such as the implementation of infrastructures to channel the excess water, but also to measure the vertical fissures of the karstic monuments in Las Loras UGGp, as they can provide a path for surface water penetration and groundwater erosion. Different tests, such as freeze-thaw tests, can provide information on the evolution of these fissures in the event of water accumulation in them, resulting in the collapse of the morphosites and the risk for the surrounding population and the visiting tourists, if they are not aware of the potential risks. The case study of low-cost and non-invasive flood mitigation measures implemented in the city of Lubango (Angola) could be a best practice to follow. Similar mitigation measures could be applied to Las Loras UGGp as we consider that the prevention of flooding and loss of geoheritage, and above all human lives, should be a priority for society.

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