Characterization of the Natural Environment to Support the Construction of the Infrastructures Necessary for the Regeneration of Aldeia da Pena in São Pedro do Sul (Portugal) for Ecotourism Spaces

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Abstract. Portugal is witnessing a phenomenon of depopulation of the rural areas in the interior of the country, with the tendency of almost total abandonment of some small villages. The situation of Aldeia da Pena in the municipality of São Pedro do Sul, embedded in a mountainous area, which has led to this abandonment, already begun many years ago, has preserved its vernacular architecture and is worth recovering and converting to accommodation and leisure spaces in order to support new segments of tourism and in particular Ecotourism and Geotourism, which are emerging in the region. Thus, there is a tendency for these places to be recovered and to change functions since they once served the population that depended on subsistence agriculture. The new function to be viable requires more water than in the past, both for human consumption and for other activities, namely leisure and recreational activities, which currently value and help to make the tourism sector economically viable. Thus, with the intention of an effective recovery of the Aldeia da Pena, in order to contribute to the implementation of the various infrastructures appropriate to the modern society, in the present work, after a brief historical framework, the geomorphological, geological and hydrogeological aspects are presented with emphasis on the lithologies that occur there in order to favor the rehabilitation of the houses essentially in schist stone, and the water potentially available, either underground or of superficial origin. Finally, the main aspects of the proposed infrastructures are presented, and some final considerations are made.

1. Introduction

Aldeia da Pena corresponds to a small village, almost entirely depopulated, with a large part of the houses in complete ruin, which once served a rural community of subsistence agriculture, but due to its isolation, difficult access and several crises over time, it was almost completely abandoned. The vernacular architecture of the existing schist stone houses very well preserved, in harmony with the landscape and nature, make that place unique and with an extraordinary beauty. Taking into account the current trends, in the sense of the region where that village is inserted (Figure 1), serving, essentially, tourism and especially ecotourism and geotourism, makes that village with a high potential to be transformed into a "hotel in horizontal", recovering the various houses essentially for accommodation, but also for basic and other complementary equipment, so that the tourist can have a stay in the place for several days, with "occupation" of tourism and leisure.
Figure 1. Location of Aldeia da Pena in relation to the headquarters of its municipality, S.Pedro do Sul, and also in relation to the surrounding areas integrated into the Magic Mountains Program.

It should be noted that ADRIMAG [1] is a non-profit local development association, responsible for the implementation of community and national programs in the Montemuro, Arada and Gralheira mountains, corresponding to the municipalities of Arouca, Castelo de Paiva, Castro Daire municipalities, Cinfães, S. Pedro do Sul, Sever do Vouga and Vale de Cambra, since August 1991. That association has been developing, promoting and boosting the brand and the tourist destination Magic Mountains, which covers the administrative area presented in Figure 1b. Among many facilities and activities in that vast region, with a geographical area of 1688.6km², deserves a reference the Arouca Geopark [2], recognized as a world heritage site by UNESCO, which is a territory that is distinguished by offering a responsible and sustainable tourism model, focused on ecotourism, geotourism and active tourism. The singularities of the geosites that occur here are remarkable, highlighting the giant trilobites of Canelas and the icnofossils of the Paiva Valley. The places where those singularities occur are of excellent geological interest, whose importance goes beyond the local, regional and national sphere, being even of world reference; fossils occur on the outcropping slates of around 465 million years old (Ordovician Period), with particular emphasis on the collection of trilobites, where, in addition to the scientific exceptionality of the specimens, many of them correspond to the largest specimens in the world for these species [3]. The connection of Aldeia da Pena to the Arouca Geopark can be very large, not only due to its proximity, at just 4km (Figure 1b), but also due to the occurrence of the same geological unit of the Ordovician, which, therefore, was central to the recognition of Geopark worldwide.
In that territory, the "Passadiços do Paiva" [4], which correspond to about 8 km of linear length, of pedestrian paths, with some stretches on the ground, wooden walkways, sometimes with stairs and hanging bridges, among others; together they provide an "untouched" walk, surrounded by landscapes of unique beauty, in an authentic natural sanctuary, next to sudden waterfalls, geosites of the "other world", and endangered plant and animal species in Europe. That equipment further enhances the access of people from all over the world to the region, and who naturally need accommodation. Therefore, the recovery, revitalization, and change of paradigm, of some vernacular architectural villages, such as Aldeia da Pena, urges, in order to give it this new function of accommodation for tourists, in association with dignified and adequate conditions for leisure and well-being, normal in current society.

The detailed characterization of the Aldeia da Pena, from the point of view of its origin, its vernacular architecture, its materials, the state of conservation of the buildings, was carried out by Fernandes [5], where a proposal was also presented for its recovery, not only of the houses themselves, but also in terms of urban design, a set of equipment to support tourism was proposed. In Figure 2, there are presented images of a 3D model, as well as the global plant, with the main aspects of the village and the proposed equipment. A synthesis of the main elements was presented in Fernandes et al. [6].

Figure 2. Main elements of the proposal for regeneration of the Aldeia da Pena: a), b) and c) images of the 3D model, d) design/plant of implementation of the final proposal with record of the main equipment (text in grey corresponds to elements already existing, text in black corresponds to elements proposed (adapted from Fernandes [5]))
2. Geomorphological Aspects
The municipality of São Pedro do Sul has a very varied geomorphology (Figure 3), with lower altitude zones essentially in the southern part of the municipality, particularly in the areas of the Vouga River, and higher, mountainous zones, particularly in the NW zone of the municipality.

Figure 3. Main drainage network and altimetry in the municipality of S. Pedro do Sul (adapted from Santos [7])

Aldeia da Pena is embedded in a global topographical depression, whose surroundings have a “V” shape, in a plan, pointing to East; this "V" being formed by two mountains: i) Ameixiosa mountain – Sequeiros mountain, to the north of the Aldeia da Pena, with global direction NW-SE and with higher altitudes between 750 and 949m asl; and ii) São Macário mountain, south of the Aldeia da Pena, with global direction SW-NE, and with altitudes between 982 and SW, until 946m asl to NE in S. Martinho das Moitas, near Monte Redondo.

The houses in the Aldeia da Pena are located at an altitude between 650 and 680m asl. The village is crossed by a small stream with an order of grade 2 in the Strahler classification [8], with global direction N-S, running from south to north, in a small valley with approximately symmetrical slopes. This water line starts south of the Aldeia da Pena at heights of about 960 m asl and at distances of about 350m from the center of the village, to converge with another water line of the same degree, almost at the base of the village; soon after about 100m, further north, it converges with the Pena stream at a 630m asl. Then, this stream evolves to the north for approximately 2km to the small village Covas do Rio. It goes against the base of Ameixiosa mountain, and evolves to the NW for about 6km, on a course that is already called Deilão stream, to flow in the Paiva River, on its left bank, which is an affluent of the Douro River, which flows into the Atlantic Ocean, in Porto.

3. Geological Aspects
Aldeia da Pena, being a vernacular village with houses almost entirely of schist rock, from the walls to the roof, one can say that it is a direct consequence of the local geology. Therefore, most of its construction materials were collected on site, making the local geology of particular importance. The geological sketch [9] of the Aldeia da Pena area is shown in Figure 4, and it should be noted that the geological unit where the village is based is the schist-greywacke complex (CXG), consisting essentially of grey schists and metagreywacks with blue stripes and/or psamytic beds with intercalations of limestone-silicrated rocks.
Figure 4 presents several photographs, not only of rocky outcrops, but also of some houses or the rest of them, made of stone, based on the schistose rock mass, similar to the material of the walls. It should be noted the rare occurrence of the appearance of yellowish-brown clayey schists, very altered (Figures 5a, 5b), right at the beginning of the village (where one can reach with cars); this very altered schist is infrequent in the area, as the most common are medium alteration schists, greyish-brown in color, from which centimeter and sometimes metric stones are extracted to serve the construction of the walls of houses and sometimes of the rims of doors and windows (Figure 5c to 5e). It emphasizes the fact that the main schistosity of the CXG rock unit is vertical or very close to that spatial position.
Figure 5. Images of lithological elements and houses of the Aldeia da Pena: a) and b) outcrop of very altered clay shale from CXG; c) to e) houses of brownish-grey shale from CXG, with little alteration; f) applications of gray-black-bluish ardosiferous shale, originating from succession of ordovician-carbonic rocks.

The succession of ordovician-carbonic rocks emerges along an extensive structure in synclinal, with a global direction NW-SE, located in the region under study, for north of Aldeia da Pena. It is composed of sequences of quartzite formations intercalated with metagreywacke, overlaid by ardosiferous schists, with fossils, of blue-grey color. The succession, in great detail, of the various lithologies occurring, is presented in the work entitled "Inventory, Characterization and Evaluation of Geological Heritage of the Municipality of the Arouca [10], where it presents, in particular, elements of these geological units in the neighboring municipality of São Pedro do Sul. The excellence of fossils, especially trilobites, found in these units, in an extraordinary state of conservation, were central to the classification of that territory with World Heritage recognized by UNESCO. It should be noted that the territory, for “political-logistical” reasons, included only the administrative areas of the municipality of Arouca, but due to the particularities, these units of the Ordovician, for north of Aldeia da Pena (Figure 5 and Figure 6g and 6h) should include without any doubt that territory of the Geopark, but therefore, already in the municipality of S. Pedro do Sul. For example, the “Livraria da Pena” site is worthy of a true “Geosite”.

4. Climatic and Hydrogeological Elements

The fundamental elements of climate in relation to the present work are temperature (T) and precipitation (P). Records of those data for the Aldeia da Pena do not exist, however, according to a global analysis for the municipality of S. Pedro do Sul, the local climate is classified as being hot and temperate, with some local variations linked to the relief, with clearly two types of climate: of a mountain, more rigorous, and of a valley, milder [7]; at the highest points the average annual temperature is 9.8ºC, and at the lowest points the average annual temperature corresponds to 14.1ºC. It should be noted that in S. Pedro do Sul (low valley area), by records from 1932 to 2010 [11], the minimum daily T reached -8.2 ºC in winter and 27.5 ºC in summer, while the maximum daily T took values between 0ºC and 48.3ºC, in winter and summer, respectively. In the Aldeia da Pena, it is admitted that there are still greater extremes than those recorded in S. Pedro do Sul.
Regarding precipitation, still by records from 1932 to 2010 [11], in S. Pedro do Sul, the annual P oscillated between 523.3 and 1756.9mm, with annual averages of 1061mm, while for S. Martinho das Moitas (mountain site, near Aldeia da Pena), the annual P oscillated between 714.7 and 3130.9mm, with an annual average of 1569.5 mm.

From the point of view of characterization of monthly sequential hydrologic balance, the results presented in Table 1, corresponding to Carvalhal Medical Spa - Castro Daire [12], which are located to the east of the Aldeia da Pena, barely 12.5km from it, are considered representative for the region under study. The results of the hydrological balance show the occurrence of a dry period and a wet period; the first is translated by the hydric deficits (HD), which goes from May to October, reaching the maximum in August; the second, the wet period, translated by the hydric superavit (HS), which goes from November to May of the following year, with the maximum excess of water occurring in January. In the wet period, the HS is divided into two plots: surface runoff (R) and underground runoff (G), i.e.: \( HS = R + G = 1119.79 \ [L/m^2] \).

| Term | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Year |
|------|------|------|------|------|-----|------|------|------|------|------|------|------|------|
| T (ºC) | 6.2  | 7.2  | 9.8  | 11.9 | 14.3 | 18.1 | 20.2 | 20.0 | 17.8 | 13.7 | 9.6  | 6.8  | -    |
| P (L/m²) | 256.3 | 183.9 | 244.4 | 125.4 | 121.1 | 49.5 | 19.7 | 25.0 | 66.9 | 135.1 | 209.4 | 230.3 | 1667.0 |
| HD (L/m²) | -    | -    | -    | -    | -    | 11.8 | 60.2 | 69.6 | 14.5 | -    | -    | -    | 156.1 |
| HS (L/m²) | 240.7 | 162.6 | 208.6 | 73.8 | 49.2 | -    | -    | -    | -    | 0    | 171.7 | 213.1 | 1119.8 |

(*) Temperature (T) and Precipitation (P) correspond to monthly averages of 29 years; in the calculations, the capacity of the soil to be used by the plants, was admitted fully satisfied with 100mm, at the beginning of the dry period, that is, in May; HD and HS are the hydric deficit and the hydric superavit, respectively; (**) Carvalhal Medical Spa, are located east of the Aldeia da Pena, only 12.5km away.

In order to analyze the water potential of the Aldeia da Pena, it should be noted that the territory where it is located and its hydrographic basins: i) schist-greywacke complex formations occur exclusively (Figure 4), with extremely low permeability, which, according to what is common for this type of massifs, clayey schists, the permeability coefficient is less than \( 10^{-9} \) m/s [13]; ii) there are very steep reliefs with steep slopes; and iii) there is little vegetation.

According to the authors' experience, is considered in the present case, "G/HS" ratio of only 10%; considering that HS = R + G, it leads to: G = 112 L/m² and R = 1008 L/m².

It should be noted that there is a tendency for very significant surface runoff, and little water to infiltrate deep, which is not a favorable situation for recharging aquifer systems in the area of influence of the Aldeia da Pena. A careful analysis of the geological map (Figure 4), with a recording of the main springs, shows only one natural spring upstream of the Aldeia da Pena. Perhaps this was the anchor-origin of that village. Currently, besides the same spring, there are two small mines in the area of the village, with very low flow rates, which is enough for the resident population, which is almost zero. In terms of hydrogeological resources, the area of Aldeia da Pena is of very low water potential. On the other hand, there is a lot of water that "falls from the sky", but due to the elements presented, it quickly evolves to the Pena stream, which ends up evolving to the Paiva River and then the Douro River to reach the Atlantic Ocean, in Porto.

5. Elements on infrastructures
In the work carried out by Fernandes [5] a set of actions/works/infrastructures to be developed in order to fit in with the "future regenerated vernacular village" for the main function of ecotourism was presented in some detail; the main elements were summarized in Figure 2. For the whole Aldeia da Pena to function in these new functions, it will need large volumes of water available,
and therefore this item is presented in order to contribute to some solutions and decisions on water abstraction.

As presented in the previous item, from the monthly sequential hydrological balance, the hydric superavit was evaluated in two components: underground runoff, \( G = 112 \text{ L/m}^2 \) and surface runoff, \( R = 1008 \text{ L/m}^2 \). The territory of Aldeia da Pena and its surroundings, taking into account its large runoff (R), and because it tends to flow quickly to the surface, leads to foresee the need to build a small dam, in order to store water in order to meet the needs of the population. In this sense, according to the geomorphological conditions, three possibilities are analyzed, organized from 1 to 3, as shown in Figure 6 and Table 2.

Solution 1 has the advantage of being completely invisible to any citizen in Aldeia da Pena, with excellent storage capacity, and with the possibility of the flow being always by gravity; this solution could also integrate electrical energy production systems, making the village revitalization project even more sustainable.

Solution 2, more modest in size, despite having a smaller storage capacity than the other solutions, is considered to be sufficient in terms of volume of water to be made available, since the stream itself, part of the year has runoff, and part of the consumption to be withdrawn from it, will be replenished; note that the volume to be stored is only 0.01 % of the water that will circulate there for a year (511.7 x 10^6 m^3). This solution could easily be compatible with the natural pool planned for the site, and the wall of the concrete dam could be lined downstream with gabions of schist stone from the site.

Solution 3, would have the particularity of imposing a water plan, which could favor aquatic sports practices, and even river beach spaces; This solution would have the drawbacks, of flooding a considerable area, and there would still have to be pumping water corresponding to the needs of the village.

In relation to the potential over groundwater, it is weak, since the water surplus in the underground flow component, corresponding to \( G = 112 \text{ L/m}^2 \), leads to little groundwater available. That value, extended to the whole basin area considered in solution 3, leads to a total theoretical flow rate of 6.4 L/s, which would be the result of the sum of the flow rates of all the groundwater abstractions that could occur in that area; it should be noted that most of that flow rate resurfaces to the surface in small springs, especially in winter, and that they feed, part of the year, the streams that cross the Aldeia da Pena. Solutions, with strategically well positioned holes to capture groundwater, will have difficulty in obtaining flows above 0.3 L/s. On the other hand, in order to obtain some productive boreholes, in a hydrogeological mechanical prospecting campaign, many will result completely dry, which will correspond to fruitless investments.

Table 2\(^\text{(*)} \). Main elements to optimize the construction of a dam, in 3 options, in order to supply the needs of potable water and aqualudic uses, for the Aldeia da Pena, in the perspective of being revitalized for ecotourism practices.

| Solution | A (m) | H (m) | C (m) | L (m) | V x 10^6 (m^3) | A_R (m^2) | V_P x 10^6 (m^3) | C_R (%) |
|----------|-------|-------|-------|-------|---------------|-----------|----------------|---------|
| 1        | 740   | 60    | 160   | 314   | 0.50          | 364028    | 366.9          | 0.14    |
| 2        | 640   | 40    | 76    | 102   | 0.05          | 507653    | 511.7          | 0.01    |
| 3        | 610   | 40    | 106   | 405   | 0.29          | 1802023   | 1816.4         | 0.02    |

\(^\text{(*)} \) The elements presented are of an approximate character: the volume of the reservoirs is the result of the geometric characteristics, resulting from the imposition of a dam, at altitude A (asl), height H and crest length C; L - reservoir length; V - reservoir volume; \( A_R \) - recharge area; \( V_P \) - potential volume, corresponds to the amount of water that would be obtained in a hydrological year, taking into account the value of R; \( C_R \) - Relative capacity, \( C_R = \frac{V}{V_P} \times 100 \).
Figure 6. Planned implementation of hydraulic structures, in 3 options, with the objective of capturing potable water and supporting aquatic practices for the Aldeia da Pena, in the perspective of its revitalization for accommodation spaces for ecotourism (from military map [14]).

6. Conclusions
This work shows, in particular, the relationship of the Aldeia da Pena with its natural conditions, with regard to geomorphological, geological, climatic and hydrogeological aspects, emphasizing the following: i) the rocky substratum on which the Aldeia da Pena rests, is in its totality schistose rocks, from the schist-greywacke complex, ante-ordovician, and which is often in outcrops (visible at the surface); it should be noted that the regeneration of some walls and structures of some houses can and should be carried out with the local materials, which can even be extracted in some excavations necessary for the street arrangements and other actions to be developed; a detailed study to harmonize this type of situations should be carried out in the future; ii) the geological unit of the ordovician, which is the same that associates the main elements that led to the classification of the territory of the neighboring municipality as a Geopark should be the subject of very detailed studies in the territory of the Aldeia da Pena; that unit is only about 2.5km north of the Aldeia da Pena; it is proposed that particular attention be paid to pedestrian paths, from the village to the Livraria da Pena, which is part of the Ordovician rock mass (Figure 4); iii)
from the point of view of water resources to supply the Aldeia da Pena regenerated as intended, the solution is the construction of a small dam for water storage, which is very abundant in terms of surface runoff resulting from considered rains that occur especially in winter; The present paper advances with three solutions of small dams, which in the long term, among their advantages and disadvantages, will all bring great benefits to the future of the Aldeia da Pena; the decision on them will be up to the local and national authorities, in the context of financial support to disadvantaged regions in the interior of Portugal.

Finally, it is emphasized that the present work is of an academic nature, aiming to show the potential of the place, so that the entities responsible for the territory and populations can have one more support instrument, in order to help recover a place, which the municipality of S. Pedro do Sul deserves, the Portuguese deserve, and even the rest of the world deserve, because Aldeia da Pena will be a place that will receive people from all latitudes to live there its unique characteristics.

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