Relations between the morphometric characteristics of the relief and the landslides in the Cubolta Hydrographic Basin. Republic of Moldova

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Abstract: Among the processes that predominate on the territory of the Cubolta river basin are the landslides, which affect about 2071.86 ha of the entire surface of the basin. Because landslides occur as a result of factors that contribute to their onset, for example, the morphology and morphometry of the relief, an attempt was made to highlight the relationship between the morphometric elements of the relief and the landslide process. Due to the usefulness of the calculation functions of the ArcGIS software, it was possible to represent graphically the relationship of the morphometric parameters and the landslides existing on the researched territory.

1. Introduction

In addition to surface erosion and devastation (linear erosion), landslides complete the image of geomorphological processes that play a very important role in the morphogenesis of the studied territory.

Landslides occur due to the factors that contribute to their triggering. These include the geological structure, the presence of aquifers, the morphology and morphometry of the relief, climatic conditions and last but not least the anthropogenic pressure.

Taking into account the fact that the morphometric parameters of the relief represent an important factor in the development of geomorphological processes, in the given study of landslides, several thematic layers relevant to the formation of landslides were taken into account. For example, the slope, by the angle value, together with the exposure of the slopes and their altitude play a special role in locating this process and in the possibility of detecting slopes on the surface of which this process could be triggered by new factors in combination with morphometric parameters.

We tend to argue that the vertical fragmentation of the relief also contributes considerably to the onset of this factor and to the formation of favourable conditions for this process.

Next, we will present the information about the categories of landslides detected on the researched territory, according to the criterion of stability, and the spatial distribution of this significant process (Canțir et al., 2022). The relationship between the morphometric parameters and the landslide surface, classified according to the stability criterion, are presented graphically. Thus, we will have a clear picture, which categories of these morphometric parameters are the most favourable for the landslide process. And which will be those land surfaces that require increased attention from those who capitalize the use on these territories.
2. Materials and Methods

To realize this study, it was necessary to create an initial database. In the Republic of Moldova, research in this domain is being carried out per regions with different areas. Often, there are regions with big areas, of that, it leads to incorrect presentation of information, as the analysis of terrain degradation necessitates complex approaches of a wide range of factors that need to be systematically analysed.

Topographic maps at a scale of 1:25 000 were used. This map, allowed us to carry out a detailed analysis of the morphometric parameters of the relief forms and to develop based on them some cartographic models of the parameters of the relief elements (relief steps, the slope, the spatial distribution of landslides and torrential landforms, etc.). The overall analysis of the relief, was also carried out based on the geomorphological maps at the scale of 1:200 000 and 1:600 000 (Belenkii, 1978; Bilinkis et al., 1985).

The mapping of the areas of landslides and torrential formations was carried out with the decoding of orthophotoplans with a resolution of 0.5 m (editions 2007, 2016), (Figure 1). This is a well-known method in the field of remote sensing, a process that also allowed the verification of the correctness of the data obtained on the basis of topographic maps of different scales.

![Figure 1. Contour lines (scale 1:25 000) (a) and orthophotoplans (resolution 40 cm) (b)](image)

GIS technologies includes the development of Geographical Information Systems (based on ArcGIS, MapInfo packages), it is also one of the most innovative and effective means in data analysis and obtaining cartographic representations with the smallest margin of error. The use of GIS technologies includes a widely used method in science, especially in geonomic sciences, cartographic modeling. With the help of numerical models, the parameters of the morphometric indices were calculated with maximum accuracy, as support in the elaboration of special geomorphological maps (slope, exposure, altitude, hydrographic basins, etc.) (Biali and Popovici, 2000; Orlando et al., 2009).

With the help of GIS technologies, the materials were processed, with the Conversion Tools, Spatial Analyst Tool and Data Management. The landslide map was also developed and the morphometric parameters taken into account were analyzed (Cantir and Sirodoev, 2022). Calculations were generated and the results exported to excel to simplify their creation and visualization using graphs.
3. Results and Discussion

For the evaluation of the morphometric indicators, the DEM was created (Figure 2a) (Juc et al., 1995). From a morphometric point of view, the relief, within the limits of the Cubolta river basin, appears as a relatively fragmented relief (Figure 2b).

Altitudes between 85-280 m characterize the relief of the Cubolta river basin.

The average altitude is 221 m. The maximum values of the altitude is 280 m, and the minimum is 85 m.

Using the orthophotoplans from 2016, all the surfaces affected by landslides were mapped (Figure 3), counting a number of 262 landslides (Table 1).

Table 1. The surface occupied by landslides in the Cubolta river basin

<table>
<thead>
<tr>
<th>Landslides</th>
<th>Count</th>
<th>S* (ha)</th>
<th>% Tl**</th>
<th>% TIS***</th>
<th>Smin (ha)</th>
<th>Smax (ha)</th>
<th>Smed (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>active</td>
<td>36</td>
<td>453,46</td>
<td>14,76</td>
<td>0,48</td>
<td>0,53</td>
<td>74,25</td>
<td>12,6</td>
</tr>
<tr>
<td>partially stabilized</td>
<td>63</td>
<td>1005,31</td>
<td>32,73</td>
<td>1.07</td>
<td>0.21</td>
<td>69,5</td>
<td>15.96</td>
</tr>
<tr>
<td>stabilized</td>
<td>163</td>
<td>1613,09</td>
<td>52,518</td>
<td>3,27</td>
<td>0.13</td>
<td>104</td>
<td>9.9</td>
</tr>
<tr>
<td>Total</td>
<td>262</td>
<td>3071,86</td>
<td>100,00</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

*S=surface affected by landslides; **Tl = percent of the total landslides; % ***TIS= percent of the total S of the basin

These were classified into 3 classes: active - 36 landslides (Smed - 12.6 ha); partially stabilized - 63 landslides (Smed - 15.96 ha) and stabilized - 163 landslides (Smed 9.9 ha) (Cantir and Sirodov, 2022).

Figure 2. Hypsometric map of the Cubolta basin (a) and vertical fragmentation of the relief in Cubolta basin (b)
Starting from the map of the landslide distribution (Figure 3), on the one hand, and from a series of thematic maps with relevance on the formation of landslides, on the other hand, we proceeded to their analysis, following the measure in which can be established a direct link between different thematic layers (Gustavsson et al., 2006; Grozavu et al., 2013; Hofer and Frank, 2009; Juc et al., 1995; Niacsu, 2012; Orlando et al., 2005; Rudraiah et al., 2008).

Figure 3. Landslides in the Cubolta river basin

The first thematic layer studied is altitude. According to the hypsometric map (Figure 2a), a little over 40% of the surface of the basin is located on the altitudes between 150 - 200 m. About a third of the surface of the basin is located at altitudes between 200 - 250 m (Figure 4), the altitudinal step between 100-150 m is represented by 17.27%.

The lowest values, which do not reach even 2% of the total surface of the basin are represented by the altitudinal steps with values up to 50 m and 50-100 m, each of them reaching a weight of 0.33% and 1.51% respectively. The surfaces that exceed the altitude of over 250 m occupy a weight of 4.43% and are located in the upper course of the basin (Grozavu et al., 2013; Niacsu, 2012).
On each altitudinal step, the share of the areas occupied by landslides and the area occupied by each type of landslide were calculated (Figure 5, 6).

Following figure 5 it is observed that about 50% of the total landslides occur on the altitudinal level between 150 - 200 m. This may be due to the high weight of these altitudes within the territory, but also to the fact that these altitudes may be the most favorable for the onset and development of the sliding process.

With a weight of 36.8% follow the altitudes between 200 - 250 m, with a triple decrease on the altitudes between 100 - 150 m. The lowest values, up to zero, are recorded at altitudes over 250 m and 50 - 100 m, with no slipping on steps less than 50 m.

Analyzing both figures (Figure 4, 5) we notice that the correlation between altitude, landslide surface and basin surface is maintained at a stable ratio of decrease of both parameters, both the surface of the altitudinal steps to the basin surface and the landslides developed on these surfaces.

**Figure 4.** Share of areas by altitude classes (m)

**Figure 5.** Share of landslides by altitude classes

**Figure 6.** Surfaces affected by landslides by altitude classes
Regarding the distribution of the surfaces of each type of landslide on altitudinal steps, we notice that about 1288 ha of these surfaces of the basin are located on the altitudinal steps between 150 - 250 m. There are no landslides on territories with altitudes below 50 m and only with a few ha of lands with landslides partially stabilized on the altitudinal level of 50 - 100 m. A very interesting moment is the fact that active landslides have an absolute predominance on altitudes higher than 250 m.

The ratio between the partially stabilized and the active ones is practically 1: 1, on the altitudes between 200 - 250 m. An essential gap (1: 6 and 1: 7) of active landslides compared to partially stabilized and stable landslides are recorded on the surfaces covered on the altitudinal step of 150 - 200 m, and on the altitudinal steps up to 150 m, the active landslides are completely missing.

The second thematic layer studied is the slope. Figure 7 shows the share of slope classes in the total basin area.

As a result, practically half of the areas are located on slopes between 2 - 5°, the territories with slopes less than 2° and 7 - 12° have approximately the same values of the total basin area, 13.19% and 13.46 respectively %. With a weight of about 20% are the surfaces with a slope between 5 - 7°, and the surfaces with slopes higher than 12° occupy about 7% of the total surface of the basin.

Figure 7. The share of areas by slope classes

Figure 8 shows that approximately 80% of the total 3071.86 ha occupied by landslides occur at slopes above 7°. Thus, the interval with maximum development is between 7-12°, which even if it occupies only 13.46% of the total surface of the basin comprises over 46% of the total landslides (1416.55 ha).

Figure 8. Surfaces affected by landslides on slope classes

An imposing share of landslides is also developed on territories with a slope of more than 12° (30%), although the share of these areas in the total area of the plain is only 6.93%.

Taking into account the ratio between the areas occupied by landslides and the surface of the river basin, by slope classes, it is observed that the highest values have
the slope classes between 7-12° (0.1116) and those above 12° (0.1388). It means that landslides occupy about 25% of the areas with large slopes (Bunduc, 2021; Codru and Niacsu, 2022).

The next thematic layer (the third) taken into study is represented by the orientation of the slopes (Figure 9). The lands with northeast-southwest and southwest orientation have the largest share and occupy 19.19% and 21.12%, respectively, of the total surface of the territory. The lands with eastern exposure occupy relatively slow slope surfaces with lengths over 1000 m, and the lands with southwest orientation occupy the short and steep surfaces of the slopes.

![Figure 9. Orientation of the slopes within the Cubolta basin](image)

The slopes with western, eastern and southern exposure are represented with relatively equal values. These having a share of 11.46%, 12.14% and 12.85%, respectively. The western ones are mainly located on the left side of the Cubolta river, and the southern ones on its right. The lowest values show the northwestern and northern slopes, which constitute 5.56% and 8.58%, respectively.

According to Figure 10, we notice that the largest areas affected by landslides (>60%) are associated with the slopes with northern, north-eastern and north-western exposure, where the slopes are also high. With a difference of 1.5%, the slopes with an eastern orientation follow, also occupying the surfaces of the territories with a slope of more than 5°.

![Figure 10. The share of landslides by slope orientation classes](image)

Following Figure 11, it is observed that active landslides occupy a larger area on the slopes with a north-eastern orientation than on the slopes with a northern exposure.

This is due not only to the fact that the surface of these slopes is larger, but also because they have slopes of more than 12° and have active landslides associated with collapsing elements.

Taking into account the ratio between the surface area of the landslides on the surface of the basin, by categories of slope orientation, the highest values of the ratio (0.173) and (0.0762) characterize the northern and north-western slopes. It means that landslides affect about 20% of these slopes.
The fourth thematic layer analyzed is the depth of the fragmentation of the relief. The average value of the vertical fragmentation of the relief is 151.0 m. About 36.9% of the surface of the territory is fragmented (<50 m), and the surfaces with the fragmentation of the relief between 50-100 m occupy about the same surface as the previous class and constitute 39.6% of the total surface of the basin. While the average values (150-200 m) occupy only 4.4%. The higher values (200-250 m and > 250 m) have a share of 10.7% and 6.6% of the total territory.

Taking into account the fact that > 75% of the territory of the basin has a vertical fragmentation of up to 100 m (Figure 12 -14), it is also logical that approximately 85% of the total landslides to be located specifically on these territories.

**Figure 11.** Landslides affected areas on slope orientation classes

**Figure 12.** Share of surfaces by vertical fragmentation classes of the relief

**Figure 13.** Share of landslides by vertical fragmentation classes of the relief
In this case, we will have a more relevant picture following the presentation of the ratio between the sliding surface / the basin surface, by vertical fragmentation classes (Figure 15). According to the ratio of landslide / basin surface, by classes of vertical fragmentation of the relief, it is observed that the maximum values of the ratio (0.0587) characterize the surfaces with a fragmentation of the relief comprised between 100 - 150 m. With a ratio of (0.0513) follows the fragmentation class 50 - 100 m, this fragmentation has about 40% of the total surface of the basin. This is most likely the cause of more than 60% of all landslides.

Also, a high ratio (0.0419) shows the lands with a fragmentation of 150 - 200 m, with only 5.61% of the total landslides. The lowest ratio is registered by the lands with a fragmentation of <50 m (0.0199), 200 - 250 m (0.0098) and> 250 m (0.0153).

The most prone to landslides are the surfaces with fragmentation 50 - 100 m, 100 - 150 m and 150 - 200 m, and not the lands with a fragmentation of up to 100 m, as the image was created by analyzing Figures 15 and 16.

4. Conclusions

Based on DEM, were developed morphometric indicators. From morphometric point of view, the relief of the Cubolta basin appears as a relatively fragmented relief. Its altitudes being between 85 - 280 m, the average altitude - 221 m.

With the help of orthophotoplans, were mapped 262 landslides, subsequently, classified into three types of landslides (active, partially stabilized, stabilized).

Most predisposed altitudes to the landslide process are those between 150 and 250 m, and active landslides prevail at altitudes above 250 m.
The interval with a high weight of landslides corresponds to the surfaces with a slope of over 7°, registering a maximum development on the slopes between 7 - 12°. According to the landslide / basin area ratio, by slope classes, landslides occupy about 25% of the surfaces with a slope above 7°.

The largest areas affected by landslides (> 60%) are associated with slopes with a northern, north-eastern and north-western exposure, where the slopes are also high. With a difference of 1.5%, the slopes with an eastern orientation follow, also occupying the surfaces of the territories with a slope of more than 5°.

Following the ratio of landslide area / basin area, by classes of vertical fragmentation of the relief, it results that the most prone to landslides are the surfaces with fragmentation 50 - 100 m, 100 - 150 m and 150 - 200 m, first having the relief with fragmentation of 100 - 150 m.

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