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INTERPRETATION OF THE MAP OF THE EROSION IN THE CATCHMENT AREA OF ZHELYAVSKA RIVER TORRENT

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Abstract

The map of erosion has been drawn on the basis of black-and-white aerial photographs. Seven categories of terrain were differentiated according to land cover type and the areas subjected to erosion. Map interpretation included an analysis of the impact of the main relief characteristics (inclination, altitude and exposure) together with human activity upon the state of the studied terrains. This state was judged by the index of erosion. The impact of inclination has been found to be multi-aspect, depending on exposure. The latter, compared with the rest of the relief characteristics, predetermined erosion to the greatest extent. We confirmed the decisive impact of anthropogenic activity.

Key words: erosion, mapping, interpretation, and index of erosion.

Introduction

The watershed is situated on the southern inclination of the Balkan Mountain, in the vicinity of Sofia. The object of this study is its upper portion at 756–1295 m altitude. The region is characterized by moderately heavy erosive rainfalls. The annual sum of precipitation is 650–750 mm (Onchev 1983). The maximum amount of precipitation per 24 hours is 70–80 mm. The bedrock is composed of clayey schists. The watershed area amounts to 907 ha. According to land-cover types, it is distributed into:

– Forests – 551.2 ha (60.8 %);
– Clearings – 154.8 ha (17.1 %);
– Barrens – 201.0 ha (22.1 %).

Almost all forests (95 %) are natural. The most common formations are composed of Oriental hornbeam (*Carpinus orientalis* Mill.) and European hornbeam (*Carpinus betulus* L.). These have appeared secondarily, at the places of destroyed oaks (*Quercus* sp.) and Common beech (*Fagus sylvatica* L.) forests (Bondev and Lyubenov 1983). The artificial forests are mainly of Austrian pine (*Pinus nigra* Arn.). As an average, the forests are about 60 years of age.

In 1935, the village of Zhelyava had 1,188 residents, whose livelihood was related to a great extent to animal production. In 2008, the residents diminished down to 449 people, the largest proportion of whom are retired.

The purpose of the present study is to draw a map of erosion using aerial photographs and to interpret this map. In order to achieve the goal, two main tasks were implemented:

– Differentiation, characterization and categorization of the polygons;

Investigation of the impact of relief and anthropogenic activity.

Literature Review

The initial information about the regions of prevailing levels of erosion for the whole territory of this country has been presented as a scheme-based map (Biolchev et al. 1959). On it, two characteristics were reported: inclination and plant cover.

In the recent three decades, mapping has been based on remote-sensing methods, such as aerial photogrammetry. The main diagnostic features have been land-cover type, vegetation cover, and soil erosion (Zakov 1994, 2003, 2005).

Satellite images and geographic information systems (GIS) have also been used for mapping the risk of erosion. The potential risk of erosion was determined on the basis of the maps of inclination, potentially hazardous rainfalls, and the vulnerability of soils to erosion. Plant cover was additionally taken into account for determining the real risk of erosion (Stoev et al. 1997, Malinov at al. 1998, Mårtensson et al. 2001).

For practical needs, the erosion maps must contain information about the eroded areas. Aerial photographs can be used as sources of such information about torrential watersheds of small areas.

Method of Study

Remote sensing of erosion on the basis of aerial photographs is a process of studying homogenous parts of the land surface with different levels of erosion, called further on "polygons" delineated on their photographic images. The present study has been carried out by means of black-and-white aerial photographs in an approximate scale of 1: 15,000 at four stages:

Preliminary study:
– Introduction into the situation;
– Studying the factors of erosion;
Collecting information:
– Mapping the erosion;
– Characterizing the polygons;
Processing the information:
– Categorizing the polygons;
– Categorizing the terrains;
Evaluating the results:
– Verifying the results;
– Interpreting the map of erosion.

The "introduction into the situation" is provided by stereoscopic observation of the watershead, as it visualizes the specificity of each of its different parts. The study of the conditions that determine erosion hazard reveals the reasons for the diversity of the photographic images.

Initially different inclinations of the relief are delineated on of the photographic images, forming large parcels. In each of these parcels polygons are delineated, each of which corresponds to one of the 3 types of land cover: forests, clearings and barrens. The minimum polygon area is 1.0 ha. The characteristics of each polygon are its area, altitude, inclination, exposure, plant cover (of trees and grasses) and the level of erosion. The percentage of each area covered with tree and grassy

vegetation and/or subjected to erosion was determined through photogrammetric methods by means of a transparent plastic sheet with a regular dot-grid.

Polygons are categorized according to two features: land-cover type and erosion level. According to the first one, they are subdivided into forests (I), clearings (II) and barrens (III). On the basis of the ratio of the number of dots falling on erosion-subjected areas to the total number of dots in a polygon or in a representative part of it the following levels of erosion have been differentiated, expressed in percentage as follows:

Slight erosion (a) – up to 10 %;
Moderate erosion (b) – 11 % – 30 %;
Severe erosion (c) – 31 % – 50 %;
Very severe erosion – over 50 %.

Slightly eroded terrains are considered protected against erosion. The first three levels of erosion are found both in the forests and in the clearings, whereas the fourth one - only in the barrens. On the basis of the land cover type and the level of erosion, the delineated polygons have been assigned to the following terrain categories:

Ia (forests with slight erosion) – 293.1 ha (32.3 %);
Ib (forests with moderate erosion) – 161.6 ha (17.8 %);
Ic (forests with severe erosion) – 96.5 ha (10.6 %);
IIa (clearings with slight erosion) – 96.5 ha (10.6 %);
IIb (clearings with moderate erosion) – 16.9 ha (1.9 %);
IIc (clearings with severe erosion) – 41.4 ha (4.6 %);
III (barrens with very severe erosion) – 201.0 ha (22.2 %).

Because of its limited area, Ib category has been united with IIa category.

After careful verification, the final categorization of the polygons has been completed, and the map of erosion has been finalized.

The ratio of the area of the terrains with severe and very severe levels of erosion to the total area of parts that are homogenous features to a particular topographic characteristic class defines the erosion index (E). The following scale has been adopted for determining erosion condition of polygons:

– very bad – $E > 0.5$;
– bad – $0.3 < E < 0.5$;
– good – $0.1 < E < 0.3$;
– very good – $E < 0.1$.

Interpreting of the Erosion Map

Within the studied watershead 161 polygons are differentiated. Interpreting the map of erosion is directed to the analysis of the joint impact of the relief and the human activity.

Inclination. For studying the impact of inclination, terrains have been distributed into five classes:

I_I – (up to 25 %) – oblique – 99.4 ha (11.0 %);
I_{II} – (30 and 35 %) – steep – 83.0 ha (9.2 %);
I_{III} – (40 and 45 %) – very steep – 186.9 ha (20.6 %);
I_{IV} – (50 and 55 %) – abrupt – 227.8 ha (30.6 %);
I_V – (60 and 65 %) – sheer – 259.9 ha (28.6 %).

The distribution of the area of each class according to terrain categories (in the numerator) and of each category according to inclination classes (in the denominator) is presented in Table 1.

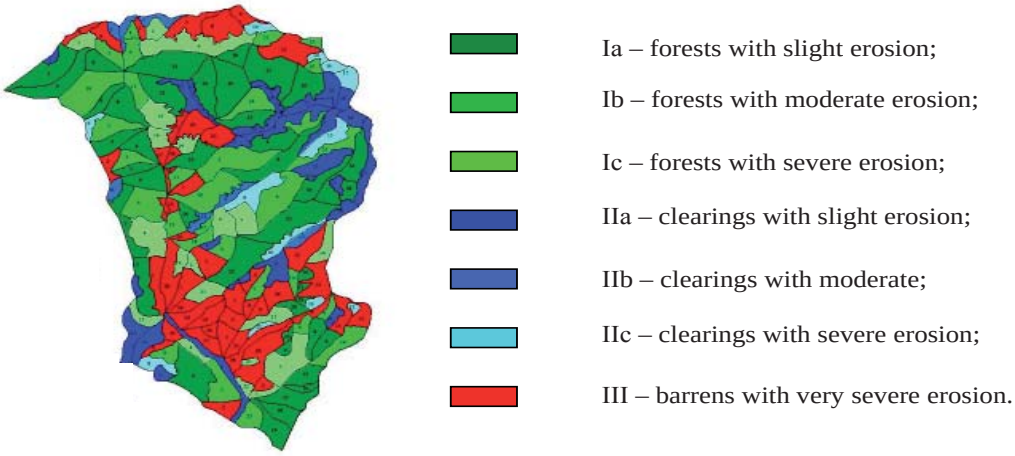

Fig. 1. Map of erosion.

Inclination Class Characteristics

The inclination of I_I class are occupied mainly by clearings, and 94.3 % of these are protected against erosion. The unavailability of forests is a consequence of their destruction of the latter for the purpose of creating highly productive pastures. There are no barrens in this class, which means that on inclinations of up to 25 % the grassy cover successfully regulates the runoff.

In the next class, a drastic aggravation of the situation is observed; it is expressed in the appearance of barrens (18.6 %) and in the multiple increase in the proportion of clearings with severe erosion (34.3 %). The availability of forests (18.2 %) and clearings (22.4 %) protected against erosion is due mainly to their preservation as property of the Bulgarian Orthodox Church.

As inclination increases to 40–50 %, the state of the terrains aggravates even more. With a few exceptions, the clearings have been turned into barrens, which occupy over half (55.0 %) of the area. The

Table 1. The influense of inclination upon the distribution of areas.

Inclination class	Total area of the terrain categories, ha/%						Index of erosion
	Ia	Ib	Ic	IIa	IIc	III	
I_I	–	–	–	94.3/81.4	5.7/13.5	-	0.06
I_{II}	18.2/5.4	3.6/1.9	2.9/2.6	22.4/17.0	34.3/71.5	18.6/8.0	0.56
I_{III}	11.0/7.0	15.7/18	13.9/26.6	1.0/1.6	3.3/15.0	55.0/50.6	0.72
I_{IV}	47.4/44.9	25.0/43	16.7/48.1	–	–	10.9/15.1	0.28
I_V	48.2/42.7	23.1/37.1	8.4/22.7	–	–	20.3/26.3	0.29

proportion of the forests with severe erosion increases up to 13.9 %.

The situation with the last two classes shows a significant improvement: almost half of the forests are protected against erosion. Together with the forests of moderate level of erosion, they occupy over 70 % of the area. However, in these classes, also relatively high percentage of barrens is preserved: 10 % – 20 %.

The values of the erosion index are an indicator for switching trends in the condition of the terrains, parallel with the increase of inclination. These values increase from 0.06, in the I_I class, to over 0.50, in the I_{II} and the I_{III} classes, and then they decrease to lower than 0.30, in the I_{IV} and I_V classes. Based on them, the state of the terrains has been determined as:

– I_I class – very good;
– I_{II} and I_{III} classes – very bad;
– I_{IV} and I_V classes – good.

Characteristics of the categories

The results in Table 1 show that the forests are best represented in the I_{IV} class, where they occupy about 45 % of the category area. In the following, I_V, class, the shares of Ia и Ib Categories do not change substantially, but the share of Ic category decreases to 22.7 %. In the previous, I_{III} class, the smallest proportion belongs to the forests protected against erosion (7.0 %), and the largest one – to the forests with severe erosion (26.6 %). This is due mainly to the stronger anthropogenic impact upon the forests on less steep inclinations: they have easier to access for logging and pasture. In a lot of cases, the state of the terrains in Ic category has been influenced by the water runoff from the clearings and barrens on the higher parts of the inclinations.

In the clearings, there is a well-expressed trend toward an aggravation of their state as inclination increases. The clearings with severe erosion prevail in the I_{II} class (71.5 %), whereas those protected against erosion are best represented in I_I class (81.4 %).

The distribution of barrens by inclination classes shows that the destruction of forests on inclinations with inclination 25 %, followed by intensive pasturing, leads to the appearance of barrens. This hazard is much greater on inclinations of over 35 %, where over 90 % of the barrens are.

Altitude*.* A specific peculiarity of the impact of this feature of the relief in the studied watershed is that this impact coincides to a great extent with the impact of the human activity because the highest terrains are also the farthest from the village. For studying the impact of altitude, the watershed has been subdivided into four hypsometric belts:

H_I – (up to 900 m) – Low mountain – 199.4 ha (22.0 %);

H_{II} (900–1,000 m) – Low mountain – 268.6 ha (29.6 %);

H_{III} – (1,000–1,100 m) – High mountain – 251.4 ha (27.7 %);

H_{IV} – (over 1,100 m) – High mountain – 187.6 ha (20.7 %).

The results of this study are presented in Table 2.

Characteristics of the Hypsometric Belts

In H_I belt, the largest is the share of barrens (45.6 %), followed next by that of forests with severe erosion (21.1 %). The considerable percentage of forests protected against erosion (12.6 %) is due to

Table 2. The influence of altitude upon the distribution of areas.

Hypsometric belts	Total area of the terrain categories, ha/%						Index of erosion
	Ia	Ib	Ic	IIa	IIc	III	
H_I	12.6/8.5	8.4/10.4	21.1/43.5	9.5/16.7	2.8/9.6	45.6/45.3	0.70
H_{II}	36.3/33.3	27.4/45.6	15.6/43.4	2.2/5.2	0.5/6.5	18.0/24.1	0.34
H_{III}	32.4/27.8	20.7/32.2	5.0/13.1	9.7/21.4	7.7/55.1	24.5/30.6	0.37
H_{IV}	47.5/30.4	10.2/11.8	–	34.3/56.7	8.0/28.8	–	0.08

a great extent to the artificial forests there.

The better condition of the terrains in the next hypsometric belt is expressed mainly in the reduced proportions of the barrens (18.0 %) and the forests with severe erosion (15.6 %). Forests protected against erosion (36.3 %) and forests with moderate erosion (27.4 %) occupy most of the area.

In general, the situation in H_{III} type did not change substantially. Despite this, some differences can be noticed: the forest area decreases. Its reduction was the greatest for the class of forests with severe erosion – about 3 times. The clearing area increases to 17.4 %. The increased proportions of the clearing with severe erosion (7.7 %) and the barrens (24.5 %) are related to the influence of another source of anthropogenic impact. The higher parts of the watershed provide the natural linkage of pasture complexes in the higher portions of the mountain. Their more intensive utilization is due also to the circumstance that at these places, Zhelyavska River has permanent water flow and is used as a watering place for the local flocks and herds.

The state of the terrains in the uppermost belt is improving substantially. In this belt, there are neither barrens nor forests with severe erosion. Forests protected against erosion (47.5 %) and clearings (34.3 %) prevail.

The erosion index in the H_{II} and H_{III} belts decreased with certain fluctuations from 0.70, in H_I belt, down to 0.08, in H_{IV} one. Its values show that the state of the terrains is:

– H_I belt – very bad;
– H_{II} and H_{III} belts – bad;
– H_{IV} belt – very good.

Characteristics of the Categories

The forests protected against erosion are comparatively evenly distributed in the last three belts, where they occupy about 30 % of the total area. The forests with moderate erosion are best represented in H_{II} belt (45.6 %) and in H_{III} belt (32.2 %), which is indicative of their transitory location. As altitude decreases, the proportion of forests with severe erosion increases, as 86.9 % of their total area is in the first two belts.

The considerable proportion of the clearings protected against erosion in the lowest belt (16.7 %) is related mainly to the ownership of the lands there. In the other three belts, the proportion of IIa category increases from 5.2 %, in A_{II} belt, up to 21.4 %, in H_{III} belt, and up to 56.7 %, in H_{IV} belt. The distribution of the areas of clearings with severe erosion differs mainly in their largest proportion in H_{III} belt (55.1 %), as well as in their limited proportion in H_{IV} belt (28.8 %).

Table 3. The influence of exposure upon the distribution of the areas.

Exposure groups	Total area of the terrain categories, ha/%						Index of erosion
	Ia	Ib	Ic	IIa	IIc	III	
E_I	4.6/3.8	13.9/21.0	16.0/40.5	12.7/27.3	7.7/45.7	45.1/54.9	0.69
E_{II}	20.5/19.5	24.2/41.8	9.3/26.9	13.5/33.2	4.7/31.6	27.8/38.6	0.42
E_{III}	52.7/44.1	19.9/30.1	11.8/30.0	8.2/17.7	2.1/12.6	5.3/6.5	0.19
E_{IV}	69.1/32.6	8.3/7.1	1.8/2.6	17.8/21.8	3.0/10.1	–	0.05

The distribution of the areas with barrens shows their prevalence in H_I belt and their unavailability in H_{IV} belt. This is related to the influence of the anthropogenic activities there. It decreases with the increase of remoteness from the village.

Exposure*.* Expositions are united in four groups:

E_I – S и SW (of typically sunny exposure) – 244.6 ha (27.0 %);

E_{II} – W и SE (of the transitional sunny expositions) – 278.9 ha (30.7 %);

E_{III} – E и NW (of the transitional shady expositions) – 245.1 ha (27.0 %);

E_{IV} – N и NE (of typical shady expositions) – 138.4 ha (15.3 %).

The distribution of the area of each exposure group is presented in Table 3.

Characteristics of the Exposure Groups

On sites of typically sunny exposure, almost half of the total area (45.1 %) belongs to the coverage class of barrens. Next rank the forests with severe erosion (16.0 %). The share of forests protected against erosion is 10 times smaller than that of barrens. This distribution is due to not only the less favourable hydrothermal regime but also to the longer utilization, during the year, of these lands as pasture grounds.

The improvement of the situation on the transitional sunny expositions is expressed in the less striking difference between the percentage of barrens (27.8 %) and that of forests protected against erosion (20.5 %).

On the transitional shady expositions, over half of the area (52.7 %) is covered by forests protected against erosion. The percentage of forests diminishes, thus reaching its minimum value (11.8 %) with the forests with severe erosion. The barrens in this group occupy an area that is 10 times smaller than that of the forests protected against erosion.

The situation improves in the group with typical shady expositions. The clearly prevailing proportion in it is that of the forests protected against erosion (69.1 %), followed by that of the clearings protected against erosion (17.8 %). There are no barrens in this group.

The trend of a continuous improvement of the state of terrains, as expressed by means of the erosion index, shows the following arrangement:

E_I group – very bad;

E_{II} group – bad;

E_{III} group – good;

E_{IV} group – very good.

Characteristics of the terrain categories

Forests protected against erosion are uncommon on typical sunny expositions.

Their proportion increases up to 19.5 % on the transitional sunny expositions. This category is best represented on the transitional shady expositions (44.1 %) as well as on the typical shady ones (32.6 %). The forests with moderate erosion are the least numbered on the typical shady expositions (7.1 %). A considerable proportion of these forests (21.0 %) are on typical sunny expositions. Forests with severe erosion rarely occur on typical shady expositions. Their proportion in the groups with transitional expositions do not differ substantially. The largest part of the area belonging to this category (40.5 %) is on inclinations of typical sunny expositions.

The area of the clearings protected against erosion is comparatively evenly distributed in all exposure groups, ranging from 17.7 %, in E_{III} group, up to 33.2 %, in E_{II} group. The distribution of the area of the clearings with severe erosion shows a permanently diminishing percentage: from 45.7 %, on typical sunny expositions, down to 10.1 %, on typical shady ones. The differences between the two categories are due mainly to the steeper inclinations in IIc category.

The distribution of the area with barrens shows that over half of it (54.9 %) is on inclinations of typical sunny expositions.

The generalized data about the belonging of over 60 % of the total area of terrain categories to inclination classes, hypsometric belts and exposure groups, as well as their particular proportions within these, are presented in Table 4.

The information in Table 4 allows the following characterization of the terrain categories:

– Forests protected against erosion – very steep inclinations with shady expositions in the Middle and Low Mountain Belts;

– Forests with moderate erosion – very steep inclinations with transitional expositions in the Low and Middle Mountain Belts;

– Forests with severe erosion – very steep inclinations with sunny expositions in the Low Mountain Belt;

– Clearings protected against erosion – inclined inclinations with sunny expositions in the Middle Mountain Belt;

– Clearings of severe erosion – steep inclinations with sunny expositions in the Middle Mountain Belt;

Table 4. Distribution of the main part of the area by relief characteristics.

Category	Inclination		Altitude		Exposure	
	Class	Total area, %	Belt	Total area, %	Group	Total area, %
Ia	I_{IV} and I_V	87.6	H_{II} and H_{III}	61.1	E_{III} and E_{IV}	76.7
Ib	I_{IV} and I_V	80.1	H_{II} and H_{III}	77.8	E_{II} and E_{III}	71.9
Ic	I_{IV} and I_V	70.8	H_I and H_{II}	86.9	E_I and E_{II}	67.4
IIa	I_I	81.4	H_{IV} and H_{III}	78.1	E_{II} and E_I	60.5
IIc	I_{II}	71.5	H_{III} and H_{IV}	83.9	E_I and E_{II}	77.3
III	I_{III} and I_{IV}	65.7	H_I and H_{II}	69.4	E_I and E_{II}	93.5

– Barrens – steep and very steep inclinations with sunny expositions in the Low Mountain Belt.

Conclusion

The great diversity of the states and locations of the different categories of terrains is an expression of the complex combinations of the joint impact of the local relief characteristics and the anthropogenic activity.

The influence of inclination is most closely related to those of exposure and anthropogenic activity. The trend of intensification of erosion parallel with the increase of inclination is valid only for the sunny expositions. As inclination increases, on shady expositions a more favourable hydrothermal regime is established, and this facilitates the development of erosion-limiting vegetation.

Since the main source of impact is the village of Zhelyava, the influence of altitude coincides to a great extent with that of the remoteness from the village, i.e. the anthropogenic activity. With a few exceptions, erosion decreases with the increase in altitude.

Compared with the impact of the rest of the relief characteristics, the influence of exposure reveals the best-expressed trend for limitation of erosion with the transition from typical sunny expositions to typical shady ones. The hydrothermal regime improves in the same direction, and the anthropogenic impact is limited. This means that inclination exposure predetermines the effects of erosion to the greatest extent.

The distribution of the area of terrain categories into inclination classes, hypsometric belts and exposure groups confirms the decisive role of anthropogenic activity for the formation, development or control of erosion.

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