

Application of phyto-indication and radiocesium indicative methods for microrelief mapping

E Panidi¹, L Trofimetz² and J Sokolova¹

¹Department of Cartography and Geoinformatics, Saint-Petersburg State University, 33 10-th Line V.O., Saint-Petersburg 199178, Russia

²Department of Geography, Orel State University, 95 Komsomolskaya st., Orel 302026, Russia

E-mail: panidi@ya.ru, e.panidi@spbu.ru

Abstract. Remote sensing technologies are widely used for production of Digital Elevation Models (DEMs), and geomorphometry techniques are valuable tools for DEM analysis. One of the broadly used applications of these technologies and techniques is relief mapping. In the simplest case, we can identify relief structures using DEM analysis, and produce a map or map series to show the relief condition. However, traditional techniques might fail when used for mapping microrelief structures (structures below ten meters in size). In this case high microrelief dynamics lead to technological and conceptual difficulties. Moreover, erosion of microrelief structures cannot be detected at the initial evolution stage using DEM modelling and analysis only.

In our study, we investigate the possibilities and specific techniques for allocation of erosion microrelief structures, and mapping techniques for the microrelief derivatives (e.g. quantitative parameters of microrelief). Our toolset includes the analysis of spatial redistribution of the soil pollutants and phyto-indication analysis, which complement the common DEM modelling and geomorphometric analysis. We use field surveys produced at the test area, which is arable territory with high erosion risks. Our main conclusion at the current stage is that the indicative methods (i.e. radiocesium and phyto-indication methods) are effective for allocation of the erosion microrelief structures. Also, these methods need to be formalized for convenient use.

1. Introduction

The central part of the East European Plain is one of the most interesting regions in the context of modern research on soil state and evolution [1]. However, detailed studies of microrelief influence on soil cover in this area have not been conducted. Particularly, the territory of Orel Region remains unstudied. It is known that within the south part of the chernozem soil zone (in adjacent Bryansk Region) the topsoil structure is determined by ancient microrelief [2]. It is also known that the character of the erosion processes presented in these regions is determined by the existence of different ancient microrelief types [2].

Study and mapping of microrelief impact on the progress of modern erosion processes have high practical significance. These activities make it possible to explain spatial variability of the amount of many soil elements, which determine soil fertility.

The current role of ancient microrelief is complicated by the overlapping influence of modern erosion structures, namely streambeds of the streams that run in the periods of snowmelt and rains. In the context of repeated extreme scenarios of the natural processes development (in particular, frequent intensive rain precipitation in the months when fields aren't protected by vegetation cover), valid



modelling of erosion processes demands that all model components are considered with highest possible detailing and precision.

2. Project context

Our test area is located in the basin of upper Oka River. The area covers some arable slopes with a complex network of ancient ravines (ancient relief structures originating in the late glacial period) and also a modern erosion network (i.e. streambeds of modern-period temporary streams). Existing methods of sediment runoff calculation usually consider only the ancient relief: for example, the method of sediment runoff calculation in the upper parts of hydrographic network that was developed by Bobrovitskaya [3]. This method could be used for streams that flow through the thalwegs of ancient ravines. However, current erosion processes are carried out largely by modern-period temporary streams in the periods of snowmelt and rains. The location of these streams does not always coincide with thalwegs of ancient meso- and microravines. In other words, the development of erosion processes on arable slopes is impacted by a very complex erosion network [4].

Therefore, today it is necessary to estimate the influence of both ancient ravines and modern-period streams in the formation of soil runoff. However, only ancient ravines of meso- and microscale can be identified on topographic maps of 1:10,000 scale, which are used in the tasks of land-use planning and land management. The network of modern streams cannot be detected on these maps.

The role of ancient ravines in the formation of current soil runoff can be considered by various methods, including the method of radiocesium indication (i.e. radiocesium method) [4-7]. As mentioned above, current models of soil runoff take into account relief structures formed by late glacial (and more ancient) processes. Due to this, there is a technique design issue, and we need to produce some correction coefficients for soil runoff and accumulation amounts, to take into account the role of the modern-era erosion network. These coefficients should be calculated for the ancient ravines (detected on maps of 1:10,000 scale) to take into account the erosion activity of modern streams, which run temporarily and often do not coincide with the thalwegs of ravines.

3. The phyto-indication method

The phyto-indication method is quite simple and effective for identification of modern streams during the periods when runoff is absent (in other words, during the periods after spring thaw or rainfall events). The indicator plants have roots reaching the level of subsoil waters. These plants can indicate locations of temporary streams, which are active only during the spring thaw or in the rainy periods.

During field studies of our test area (figure 1) we found that wild perennial plants (as a rule the weed plants) mark thalwegs of modern streams, but not thalwegs of ancient ravines. This indicates either near-surface subsoil water-level in the zone of stream thalwegs, or a high level of capillary action above the level of deep-lying subsoil waters. In connection to this, weed species are clearly confined to streambeds, which is particularly noticeable in dry seasons.

The roots of wild perennial species (e.g. *Artemisia absinthium* L., *Sonchus arvensis* L., *Cirsium arvense* L., *Leonurus quinquelobatus* Gilib., *Calamagrostis epigeios* (L.) Roth, etc.) reach up to 3 meters in this area. Also, stream thalwegs are rectilinear (figure 1) in our test area. These facts lead us to suppose that local cracks (along which stream beds lie) are situated exactly at this depth [6]. The reasons for the origin of these cracks are unknown so far.



Figure 1. Space imagery of the test area (on the left) with relief contours (black lines) and positions of soil samples (black dots) collected along the temporal streams (space imagery © Google Earth, DigitalGlobe); and photo of a temporary stream thalweg (on the right), marked with black arrow.

4. The radiocesium method

The radiocesium method allows us to define locally an amount of soil loss due to runoff [4-8]. The method is based on soil sampling with a regular interval and subsequent analysis of differences in the cesium-137 activity at the sampling point to determine the thalweg position. The method also allows comparative estimation of erosion activity for the ancient ravines and modern temporary streams.

In our study, we estimated soil radioactivity for the post-Chernobyl period (from 1986 until the year of soil sampling). Additionally, we designed a complex algorithm for soil runoff computation, using geomorphometric parameters of the relief (namely catchment area and profile curvature). This algorithm takes into account the combined effects of ancient and modern erosion networks in the erosion processes. In designing the algorithm for soil runoff estimation both in ancient ravine thalwegs and in thalwegs of modern temporary streams, it is important to solve following major issues:

- detection of all factors that impact the lateral distribution of cesium-137 activity in both ancient ravines and in thalwegs of modern streams using the radiocesium method;
- design of an algorithm for estimation of cesium-137 activity based on geomorphometric parameters of the ancient ravine thalwegs, which could allow replacement of time-consuming soil sampling with more productive GIS-based modeling;
- design of an algorithm for modeling dependencies between cesium-137 activity in ancient ravine thalwegs and activity in thalwegs of modern streams.

These algorithms should solve both the problem of automated estimation and mapping of the soil runoff amounts, and the opposite problem of identification and mapping of the microrelief structures.

5. Some results and discussion

The dependencies are shown in figures 2 and 3, which were derived using our field data. Dependencies between cesium-137 activity and catchment area (the DEMON method [9] was used) were derived for ancient ravine thalwegs with catchment areas of ~23,000 square meters (for the cases of slopes of the south and north aspect, figure 2), and catchment areas of ~50,000 square meters (figure 3, left). Additionally, the dependencies between soil runoff amount and profile curvature [10] of the relief were derived.

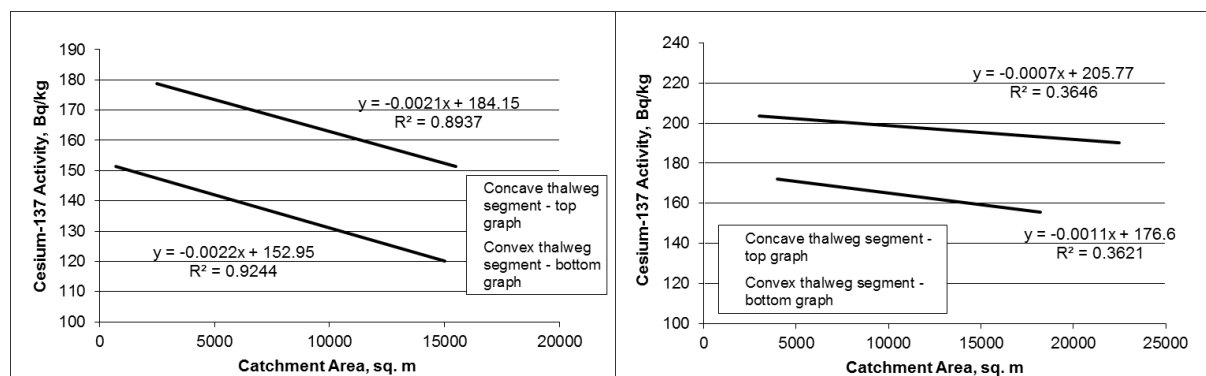


Figure 2. Graphs of dependencies between cesium-137 activity and catchment area values for convex and concave thalweg segments in the case of south aspect (on the left) and north aspect (on the right) of the slope.

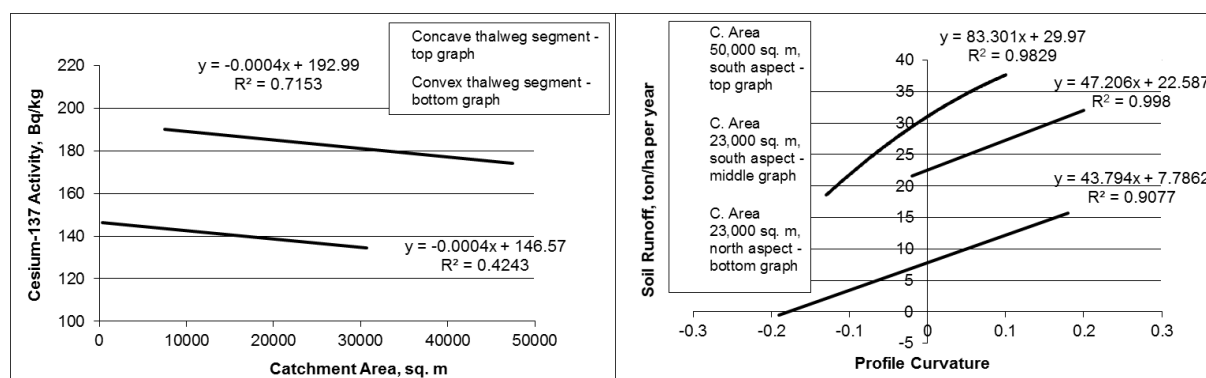


Figure 3. Graphs of dependencies between cesium-137 activity and catchment area values for convex and concave thalweg segments in the case of south aspect of the slope (on the left); and dependencies between soil runoff and profile curvature (on the right).

From the dependency analysis we found that the cesium-137 activity in the concave segments of ancient ravine thalwegs is higher than in the convex segment by 24%, for catchment area of 23,000 sq. m. on the slope of south aspect. The cesium-137 activity in the concave segment of ancient ravine thalwegs is higher than in the convex segment by 19 % on north-aspect slopes. However, values of cesium-137 activity in the concave segment of ancient ravine thalwegs on south-aspect slopes are less (150-180 Bq/kg), than on the north-aspect slopes (180-200 Bq/kg).

Higher values of cesium-137 activity in the soil of north-aspect slopes could be explained by more intensive soil runoff on the south-aspect slopes in the period of snowmelt runoff. For larger ravines (catchment area of 50,000 sq. m.) located on the south-aspect slope, it is typical to have different relationships for cesium-137 activity (figure 3, left). Values of cesium-137 activity in the concave segment of ancient ravine thalwegs are between 170-190 Bq/kg. The excess of cesium-137 activity in the concave thalweg segment above activity in the convex segment is 33%.

The estimations of cesium-137 activity led us to estimate a local soil runoff [5-7]. Also, more accurate estimation of soil runoff can be carried out using dependencies between soil runoff amount and relief profile curvature values (figure 3, right). The graphs show that the soil runoff amount reaches a maximum in the runoff zone (thalweg segment with positive profile curvature values) of thalwegs of ancient ravines with 50,000 sq. m. catchment area. Comparison of runoff amounts in

ancient ravine thalwegs with the same catchment areas (23,000 sq. m.) shows that the soil runoff in the runoff zone on the south-aspect slope is more than two times higher than on the north-aspect slope.

Measurements of cesium-137 activity in thalwegs of modern temporary streams, and comparison with values obtained for cesium-137 activity in thalwegs of nearby ancient ravines located on the same height levels, allow us to establish the empirical correction coefficients [6]. The values of cesium-137 activity, which were obtained for ancient ravines on south-aspect slopes (figures 2 and 3), could be applied to modern streams (with equal length and catchment area) without additional correction. In the north-aspect case, it is necessary to make a correction using coefficients presented in table 1. Cesium-137 activity in the accumulation zone of modern stream thalwegs on the north-aspect slope also can be accepted as equal to cesium-137 activity calculated using dependencies shown on figure 2 (right).

Table 1. Values of coefficients (K), which must be used for multiplication of cesium-137 activity in thalwegs of ancient ravines when estimating the cesium-137 activity in thalwegs of modern temporary streams on the north-aspect slope.

Cesium-137 activity, Bq/kg, ancient ravine	Cesium-137 activity, Bq/kg, modern stream	$K=(2)/(1)$	Runoff and accumulation zones defined by the sign of profile curvature
(1)	(2)	(3)	(4)
164.1	114.7	0.7	Runoff zone
182.0	193.4	1.1	Accumulation zone
173.3	117.3	0.7	Runoff zone
179.1	131.0	0.7	Runoff zone
170.2	129.0	0.8	Runoff zone

In the runoff zone, the cesium-137 activity in modern stream thalwegs on the north-aspect slope can be obtained using values of cesium-137 activity in thalwegs of nearby ancient ravines reduced by 30% (in other words it is necessary to multiply by a coefficient of 0.7). This indicates that modern streams on the north-aspect slope have considerably higher erosion activity than ancient ravine thalwegs on this slope.

The following conclusions were derived as a result of comparison of the runoff values obtained by the radiocesium method in the thalwegs of modern streams and thalwegs of ancient ravines. The soil runoff in ancient ravine thalwegs on the south-aspect slope varies between 9 and 25 tonne/ha per year. Soil runoff in thalwegs of modern streams on the south-aspect slope varies between 11 and 29 tonne/ha per year. In other words, erosion activity and soil runoff of modern streams is similar to that of ancient ravines (for thalwegs with equal catchment areas). Soil runoff in thalwegs of ancient ravines on the north-aspect slope varies between 0 and 3-7 tonne/ha per year (during the period from 1986 until 2014). Soil runoff in thalwegs of modern streams on the north-aspect slope varies between 12 and 29 tonne/ha per year (that is, by three times more than in ancient ravines on the same slope).

Therefore, it can be concluded that the erosion activity of modern temporary streams is broadly similar overall in the case of thalwegs with similar values of catchment area. However, the erosion activity of modern streams is higher in comparison with ancient ravines on north-aspect slopes, and equal to that of ancient ravines on south-aspect slopes.

6. Conclusions

Radiocesium and phyto-indication methods appear to be good instruments for studying modern erosion processes on arable slopes. Chernobyl-origin cesium-137 allows us to identify the positions of modern temporary streams on explored territory, and to estimate values of local soil runoff on arable slopes for the period from 1986 until the date of soil sampling.

Cesium-137 activity in the soil of modern stream thalwegs can be calculated using formulas obtained for thalwegs of ancient ravines, with the help of geomorphometry methods, GIS software, and maps of 1:10,000 scale. The slope aspect must be taken into account, when estimating soil runoff values using cesium-137 activity, because of differences in the snowmelt and rainfall runoff regimes on slopes of different aspects.

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