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Assessment of soil erosion trough the use of ^{137}Cs at Jaslovske Bohunice , Western Slo vakia

E. FULAJTAR

Soil Science and Conservation Research Institute. Gagarinova 10, 827 13 Bratislava. Slovakia

ABSTRACT

The intention of this study is to provide a well-representative set of data on long term erosion rate in pilot area representing the loess hillylands of Slovakia. For this purpose, the ^{137}Cs-method is most appropriate.

Pilot area was chosen nearby the Jaslovske Bohunice village, Western Slovakia. The sampling strategy was based on a multiple transect approach. The analyzing was performed at Nuclear Power Plant Research Institute, Jaslovske Bohunice. The obtained data were interpreted using several calibration models expressing the relation of ^{137}Cs activity to soil erosion-accumulation rate. The proportional model, the simplified mass balance model and the standard mass balance model developed at Exeter University, Great Britain, were tested.

The highest values are provided by simplified mass balance model. The proportional model gives somewhat lower values. Considerably lower values were calculated by standard mass balance model. The most realistic are the values given by the last model, as this model uses the most comprehensive set of input parameters. The erosion rates calculated by this model range up to 34 t ha^{-2} $year^{-1}$ and accumulation rates reach the maximum at 37 t ha^{-2} $year^{-1}$.

Key words: Soil erosion. Erosion rate. Erosion mapping. Radionuclide tracers. ^{137}Cs-method.

INTRODUCTION

The data on soil erosion intensity are an important part of theoretical background necessary for soil conservation programs. Despite that, the data on this topic are very limited in Slovakia. Stasik et al. (1983) and Chomanicova (1988), who performed soil erosion measurements on small sized monitoring plots, provided some information.

Since the beginning of 1990's the erosion intensity attracts more attention. In 1993, the field measurements on small monitoring plots similar to the approach used in 1980s began (Fulajtar, 1997) and, since 1996, the measurements in elementary watersheds have been performed (Fulajtar, 1999). All data gained by these measurements represent short term erosion rates (2 - 5 years of observations).

The ^{137}Cs technique can make an important contribution to the knowledge on soil erosion as it provides an information on long term mean erosion rates. At the beginning of 1990s the first studies using the ^{137}Cs-method for erosion detection were accomplished

(Linkes et al. 1992, Lehotsky and Stankoviansky 1992, Lehotsky et al. 1993). At several studied sites (such as Voderady, Pata, Luborca, Horne Srnie and Bzince) individual transects were sampled. Later Lehotsky (1999) provided a geomorphological study evaluating erosion-deposition dynamics in Jablonka pilot catchment representing the flysh hillylands of Northern Slovakia. This investigation was based on 10 profiles with ^{137}Cs measurements situated at key topographical positions of the catchment.

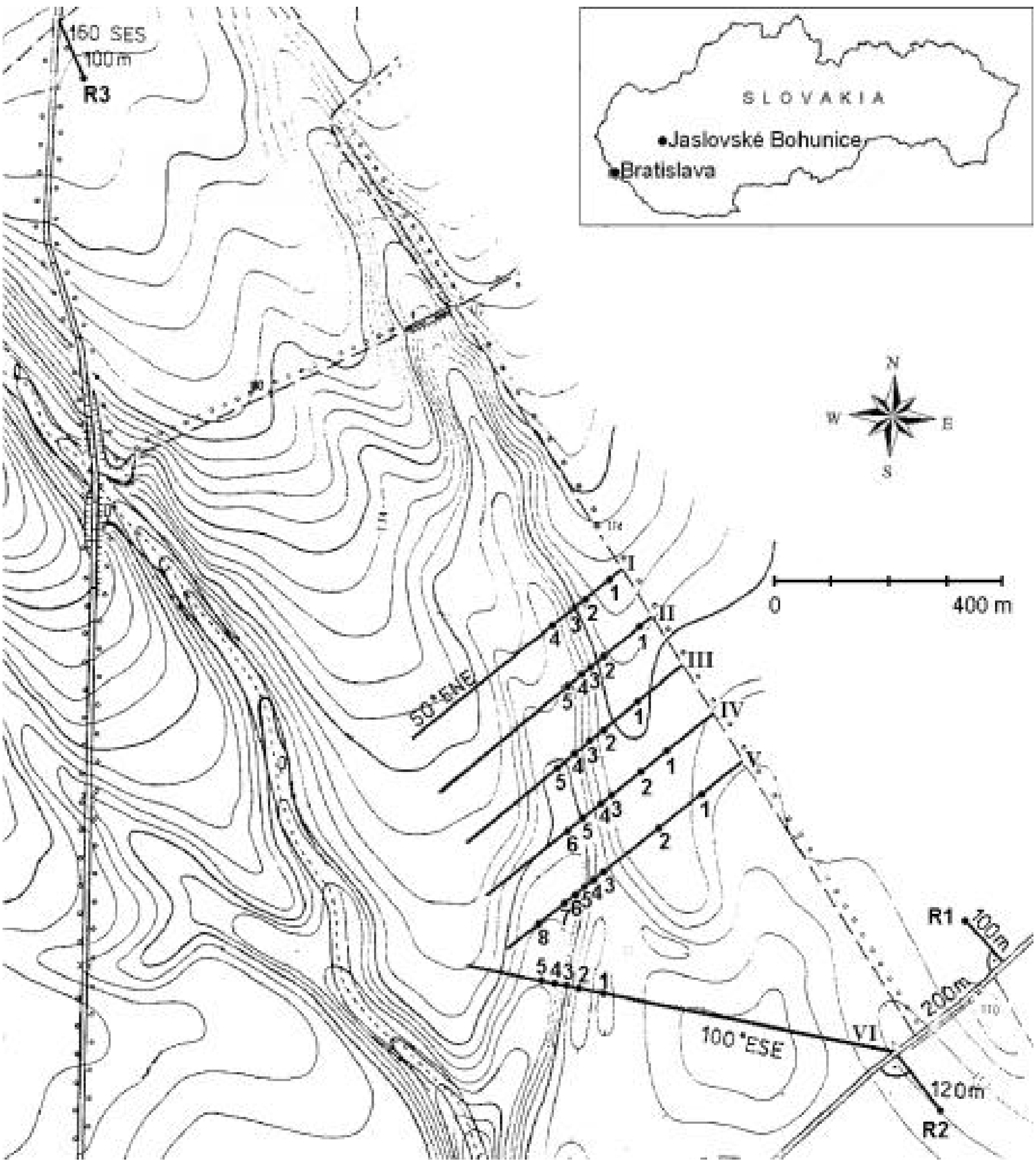

Figure 1. Location of transects at Jaslovske Bohunice Site.

All investigated sites represent the arable land and all of them were sampled incrementally by the depth. The results show a typical ^{137}Cs distribution on slopes under the arable land. The ^{137}Cs concentration in the soil and its depth distribution in the sampled profiles show evident differences between the plateau positions, the slope positions and the valley bottoms related to erosion and deposition.

Unfortunately the quantitative evaluation of erosion-deposition rate was not provided. The question how to relate the ^{137}Cs loss with the soil loss is a fundamental problem of ^{137}Cs-method. However, since the first ^{137}Cs studies have been published in Slovakia, a great advance in methodology was achieved (especially in Great Britain). Several models for calibration the soil loss according to ^{137}Cs loss were developed (Walling and He, 1997).

Another limitation of the first ^{137}Cs studies in Slovakia is the small number of sampled profiles. As the ^{137}Cs contamination of soils is affected by many factors and it shows a natural microvariability (Owens and Walling, 1996), the representativeness of individual transects is rather limited. To reach an acceptable representativeness, much more sampling points would be needed at each studied site.

To overcome these limitations in erosion assessment by ^{137}Cs-method, a research project "Assessment of soil erosion through the use of ^{137}Cs-method" was started at Soil Fertility Research Institute, Bratislava, in 1996. The intention of this project is to collect a large data set from well representative site, and to test the possibility of quantitative estimation of long term mean soil erosion and deposition rates with the aid of chosen calibration models. This project was done with a financial support provided by International Atomic Energy Agency, Vienna, and under a methodological supervision of Exeter University, Great Britain. This paper summarizes the results from first study site.

MATERIAL AND METHODS

Choice of area

The study site was chosen nearby Jaslovske Bohunice village in typical loess hillyland belonging to most important agricultural area of Slovakia that is strongly affected by soil erosion. Chernobyl-derived ^{137}Cs contamination is rather limited in this area and the total ^{137}Cs contamination is dominated by bomb-derived ^{137}Cs. The chosen valley is surrounded by flat plateau suitable for taking the reference samples and the valley slopes are more or less regular enabling an easy extrapolation of the point data.

Characterization of Jaslovske Bohunice Site

The Study Site is situated in the northern part of the Trnavska Pahorkatina, 12 km north-east of Trnava town, West Slovakia. The whole area is built of typical calcareous loess deposits. The altitude of surrounding slightly inclined plateau decrease from 190 to 165 m above the sea. The relative elevation of plateau over the valley bottom is about 10 m. The inclination of the valley slopes is 4 - 8º. Mean annual temperature is 9,4ºC, mean monthly temperature is 19,6 ºC for warmest month (July) and -1,8 ºC for coldest month (January), annual sum of precipitation is 586 mm and maximum monthly precipitation is 64 mm (June). Soils are loamy (approx. 15 - 25 % of clay, 60 - 65% silt and 10 - 15% sand) and rich in organic matter. Luvi-Haplic Chernozems (WRB, 1994) prevails. At steep slopes they were transformed by erosion to Haplic Calcisols poor in organic matter. In the valley the colluvial soils having a very thick A horizon (over 2 m) occur.

The land use is very uniform since the beginning of 1950's, when all land underwent the process of so called "collectivization" and the entire studied valley became a part of Jaslovske Bohunice Co-operative Farm. Since that time the large scale land management is applied. The crop rotation is dominated by winter wheat, maize, spring barley, sunflower, rape, alfalfa, sugar beet and green pea.

The ^{137}Cs contamination of soils in Trnavska Pahorkatina was investigated by Moravek et al. (1993). In ploughed horizon it is approximately 15 Bq kg^{-1}. Approximately one third of this value (5 Bq kg^{-1}) should be attributed to Chernobyl fallout, remaining portion represents the bomb-derived contamination.

Sampling strategy

The basic methodological concept of ^{137}Cs method was adopted from Walling and Quine (1993). The reference sites were chosen on flat plateau surrounding the investigated valley. The distance from the valley does not exceed 1 km. The sampling strategy was based on a multiple transect approach. The regular grid was inappropriate. The simple and rather symmetrical shape of the narrow valley surrounded by flat plateau requires much smaller sample density along the valley, than across the valley. The distances between the sampling points on transects were adjusted according to the topography in each transect to express the key slope positions. To follow the preferential directions of runoff, all transects follow either the slope lines, or the usual direction of crop lines if they are only slightly declining from the slope lines (not more than 20º).

The sampling was done by metal tube of 49 mm internal diameter which was hammered into soil. One reference point and two transects were sampled incrementally by the depth. Remaining samples were bulked. The reference points and incremental transects were sampled in 6 replicas, remaining transects in 3 replicas. The first depth interval of incremental samples was 25 cm as it corresponds to ploughed horizon, the remaining depth intervals were 5 cm thick. The depth of samples was adjusted to the topographical positions in such a way, that the sample involved all the depth in which ^{137}Cs activity was detectable. It means, that at plateau the sample depth was 40 cm, at slopes it was 35 cm and in valley bottom 50 or 60 cm.

Analyzing

The air dried samples were weighted, sieved through 2 mm sieve and homogenized. The analyzing was performed at Nuclear Power Plant Research Institute at Jaslovske Bohunice. The ^{137}Cs activity was determined by semiconductor gammaspectrometer SILENA working in 4096 regime channel spectra. Assessment of the results was done using gamma spectrum SILENA-M software.

Calibr ation models

To relate the measured variability of ^{137}Cs inventory with soil erosion and deposition, three calibration models - *the proportional model (PM), the simplified mass balance model (MBM1) and the standard mass balance model (MBM2)* developed at Exeter University in Great Britain were used. The mathematical background of these models is provided by Walling and He (1997). These calibration models are available as user friendly PC software that enables to perform the calculations in routine way.

Proportional model is based on the premise, that ^{137}Cs is mixed homogeneously in ploughed horizon and the soil loss is directly proportional to loss of ^{137}Cs. The relation is very simple, considering only the time since ^{137}Cs deposition, soil bulk density, the depth of ploughed horizon and particle size correction factor. The expression of time since ^{137}Cs deposition is simplified. The gradual fallout lasting from mid 1950's to mid 1970's is replaced by

Table 1. The ^{137}Cs activity at Jaslovske Bohunice Site (Bq m^{-2}).

Individual Reference Profiles								
R1	2362.4							
R2	2860.8							
R3	4564.0							
				Slope positions				
	P	CvPP	CvS	SS		CcS	VB	
Transect I	2390.8		2592.6	2292.0				4531.6
Transect II	2381.5		2436.4	2281.4		4036.3		3607.8
Transect III	3116.9		3019.9	2258.7		2864.2		5304.0
Transect IV	3031.1	2945.2	2440.1	2402.4		3835.2		4000.5
Transect V	2812.1	2822.6	1481.3	1848.5	2852.7	3379.9	3416.1	3953.9
Transect VI	2786.4		2310.2	2010.7		3922.1		4852.5

P - Plateau, CvPP - Convex plateau position, CvC - Convex slope, SS - straight slope, CcS - Concave slope, VB - Valley bottom theoretical abrupt fallout in 1963, when the fallout reached the maximum intensity. The particle size correction factor was introduced to take account of the selective removal of the fine particles by erosion, because the ^{137}Cs is preferentially associated to fine particles.

Simplified mass balance model involves into the calculation also the radioactive decay of ^{137}Cs since its deposition and the gradual "dilution" of ^{137}Cs concentration in ploughed horizon. This dilution is caused because when some surface soil material is removed by erosion, an adequate subsoil material is admixed to ploughed horizon by ploughing. By this way the ^{137}Cs concentration in ploughed horizon is decreasing with time, and each year the constant soil loss would correspond to lower loss of ^{137}Cs.

Standard mass balance model incorporates the concept of time-variant ^{137}Cs fallout and the seasonal aspect of soil loss. The concept of time-variant ^{137}Cs fallout expresses the gradual fallout lasting from mid 1950's to mid 1970's. If local data on ^{137}Cs fallout are not available, it is possible to use a mean fallout dynamic for northern hemisphere. The concept of seasonal dynamics of soil loss expresses the wash of freshly deposited ^{137}Cs. Part of the fresh ^{137}Cs fallout lying on the soil surface is washed away before it is bounded to soil colloids and mixed to the ploughed horizon by ploughing.

RESULTS AND DISCUSSION

Soil contamination by ^{137}Cs and its horizontal and vertical distribution

The location of sampled transects is drawn on Fig. 1. The obtained values of ^{137}Cs activity expressed as total inventories per surface unit are in Table 1.

The reference profiles are situated at broad flat plateaus east and north of the valley. The reference sample set comprises of 3 individual profiles (R1, R2, R3) and 5 plateau profiles of the transects (IV-1, IV-2, V-1, V-2, VI-1). The mean reference value calculated as an average of these 8 profiles is 3 023 Bq m^{-2}.

The total ^{137}Cs inventories of transect profiles show an evident variability related to the topography. Fig. 2 shows, that along the transects usually the values decrease from plateau to upper and middle slope, they rise again at the footslope and finally they reach their maximum in the valley bottom. These differences express the soil loss at slopes and its deposition in the valley.

The depth distribution of ^{137}Cs contamination sampled at Transect III and VI is shown at Fig. 3. The usual thickness of ^{137}Cs contaminated layer at arable land, if not affected by erosion, should correspond to the ploughed horizon (which is 30 cm thick) as the ^{137}Cs fallout is mixed into soil by ploughing. In reality it slightly exceeds the ploughing depth, because the bioturbation exchange some soil material between the ploughing horizon and the upper part of subsoil. Thus the usual thickness of ^{137}Cs contaminated layer is approximately 35 cm. In profiles, where the thickness is greater, the difference should be attributed to deposition. According to this assumption the thickness of the deposition in the valley is 15 cm at Profile III-5 and 10 cm at Profile IV-5. Small local accumulation (5 cm) is also at Profile III-1 on the plateau. It is a result of local redistribution of soil material related to microrelief. These results show that the accumulation in Jaslovske Bohunice is similar to earlier investigated sites (Linkes et al. 1992, Lehotsky and Stankoviansky 1992, Lehotsky et al. 1993, Lehotsky, 1999).

The eroded profiles show usually only little or no reduction in the thickness as the ^{137}Cs contaminated layer can be never thinner than the ploughing depth. However, eroded profiles are characterized by considerable reduction in ^{137}Cs concentration.

The depth distribution of ^{137}Cs contamination indicates that the dominant sediment transport is from the slopes to the valley bottom, but not further down by the valley. If the transport down by the valley would be significant, the depth of deposition would be increasing from the Profile III-5 situated in upper part of the valley towards the Profile IV-5 situated in its lower part.

Soil loss estimation

The soil loss calculated by three chosen calibration models is presented in Tab. 2. The calculation by mass balance models can be done only if the first point of the transect is eroded, it means only if its ^{137}Cs inventory is lower than the mean reference value. However, the ^{137}Cs inventories of plateau profiles are fluctuating in certain range and commonly they slightly exceed the mean reference value. This limitation can be overcome by starting the calculation from second point of the transect, which has ^{137}Cs inventory always lower than the mean reference value. The other way to avoid this problem is to calculate erosion-accumulation rates not for each transect separately, but for the whole site. In such a case all ^{137}Cs inventories are sorted according to magnitude and the calculation is done in

Table 2. Soil erosion-deposition rates calculated by calibration models.

Soil erosion - accumulation ($t.ha^{-1}.year^{-1}$)				
Sampling point	^{137}Cs activity ($Bq.m^{-2}$)	Proportional Model	Mass Balance Model I	Mass Balance Model II
Transect I				
I-1	2390.8	- 23.05	- 32.59	- 10.21
I-2	2592.6	- 22.99	- 26.80	- 10.18
I-3	2292.0	- 26.66	- 38.44	- 12.12
I-4	4531.6	55.16	78.28	24.10
Transect II				
II-1	2381.5	- 23.39	- 33.14	- 10.39
II-2	2436.4	- 21.39	- 29.98	- 9.37
II-3	2281.4	- 27.04	- 39.08	- 12.33
II-4	4036.3	36.95	52.93	20.14
II-5	3607.8	21.32	30.54	11.62
Transect III				
III-1	3116.9	3.53	*	*
III-2	3019.9	- 0.11	- 0.14	- 0.06
III-3	2258.7	- 27.80	- 40.46	- 13.27
III-4	2864.2	- 5.79	- 7.52	- 2.30
III-5	5304.0	83.18	119.32	36.85
Transect IV				
IV-1	3031.1	0.29	*	*
IV-2	2945.2	- 2.84	- 3.63	- 1.12
IV-3	2440.1	- 21.26	- 29.77	- 9.30
IV-4	2402.4	- 22.63	- 31.93	- 10.00
IV-5	3835.2	29.62	41.65	12.78
IV-6	4000.5	35.78	50.13	15.38
Transect V				
V-1	2812.1	- 7.69	- 10.07	- 3.09
V-2	2822.6	- 7.31	- 9.55	- 2.93
V-3	1481.3	- 56.22	- 98.41	- 33.66
V-4	1848.5	- 42.83	- 68.08	- 22.29
V-5	2852.7	- 6.21	- 8.08	- 2.47
V-6	3379.9	13.01	21.29	6.89
V-7	3416.1	14.33	23.45	7.59
V-8	3953.9	33.96	55.54	16.09
Transect VI				
VI-1	2786.4	- 8.63	- 11.35	- 3.48
VI-2	2310.2	- 25.99	- 37.34	- 11.76
IV-3	2010.7	- 36.91	- 56.58	- 18.22
VI-4	3922.1	32.92	48.90	15.67
VI-5	4852.5	66.71	98.95	30.88

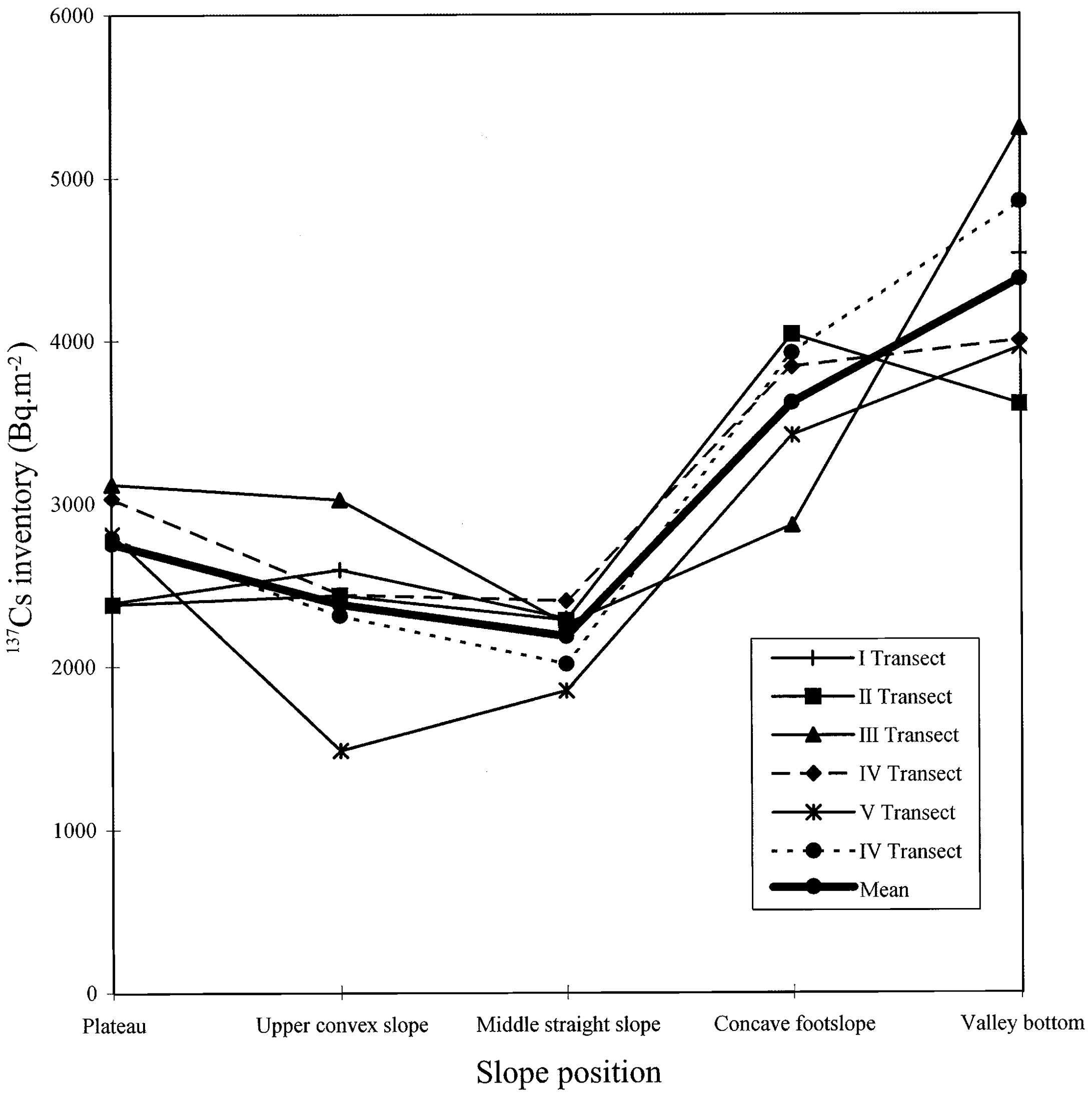

Figure 2. ^{137}Cs inventory distribution along the transects.

this order. As the calculation is more accurate per transects, this approach was used.

The local data on time variant ^{137}Cs fallout required for MBM2 were not available for Slovakia. Therefore the mean fallout dynamic for Northern hemisphere was used. The portion of freshly deposited ^{137}Cs that was washed before being incorporated to ploughed horizon was estimated using the usual time of ploughing (from August 15 to October 30) and the time of main rainy season during the year (June - July).

Comparing the values given by used models (Tab. 2) it is evident, that the highest values are given by MBM1 and the lowest by MBM2. The values from PM are in the middle of this range. PM is the most simple model and resulting values express only the influence of most basic parameters. The values from MBM1 are higher, because the additional parameters which are incorporated into this model (corrections for radioactive decay of ^{137}Cs and for successive dilution of the ^{137}Cs concentration by incorporating the subsoil material to ploughed horizon) cause, that more soil loss should be attributed to certain loss of ^{137}Cs than in PM. On the contrary, the MBM2 values are lower, because taking into account the wash of freshly deposited ^{137}Cs before it is incorporated into soil lowers considerably the amount of soil loss that should be attributed to certain ^{137}Cs loss.

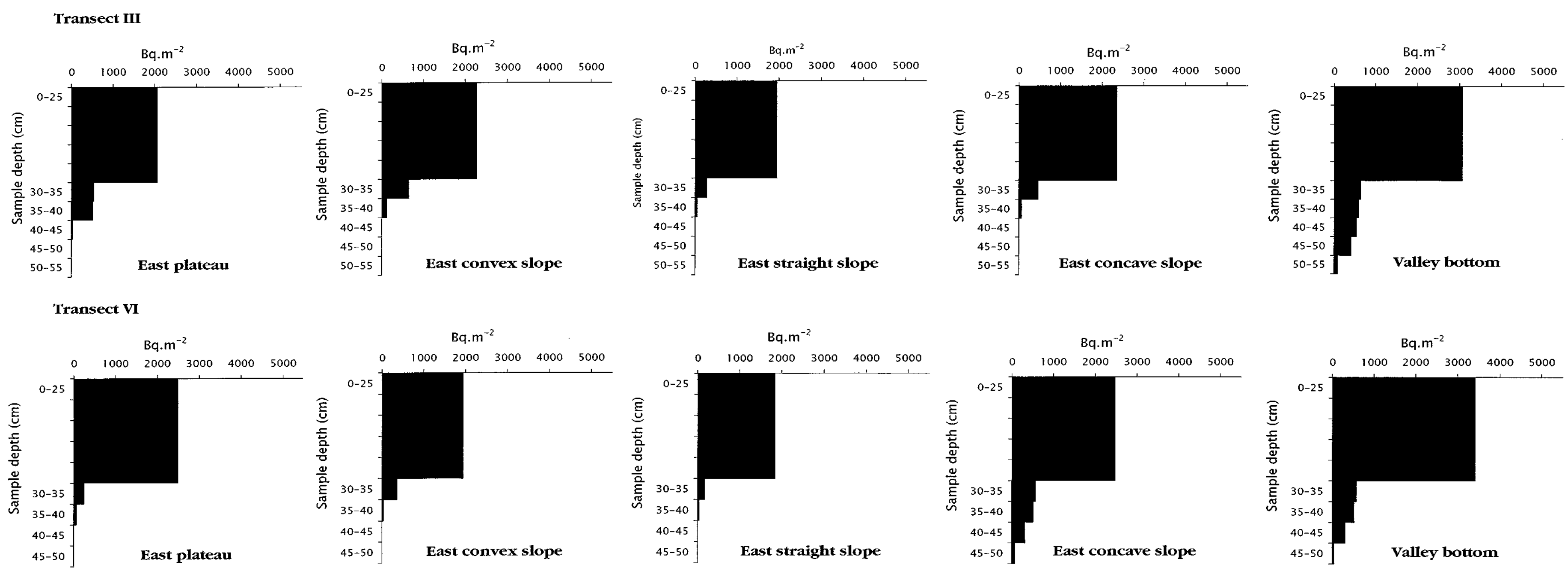

Figure 3. Depth distribution of ^{137}Cs in incremental transects.

The results of MBM2 seem to be most realistic, because this model uses a most comprehensive set of parameters. Moreover, the erosion rates calculated by this model (ranging up to 34 t ha^{-2} $year^{-1}$ for erosion and up to 37 t ha^{-2} $year^{-1}$ for accumulation) are not far from some mean annual values calculated from data measured on small sized plots (Fulajtar, 1997). However, MBM2 brings a possibility of misestimation, because it is difficult to express what portion of the freshly deposited ^{137}Cs is washed by rains before it is mixed to soil and bounded to colloids. Too little is known about important parameters influencing this process, for example about soil surface roughness, soil permeability, rain intensity. Therefore the use of PM, although it is simple is reasonable. This simplicity is a great advantage of PM, as all the input parameters can be easily maintained. This would be important especially if the model would be used by routine way or by less skilled personnel.

Spatial distribution of ^{137}Cs contamination and soil erosion

The resulting maps of ^{137}Cs spatial distribution and soil erosion - deposition are at Fig. 4, 5. Soil erosion-deposition map was done using the values calculated by PM. The accuracy of spatial extrapolation of point data is determined by the sample density, spatial distribution of samples and the capability of the GIS software applied. The sampling density is approximately 2 sampled points per hectare. This is not too little, but the sample distribution is not uniform. The distances between the points

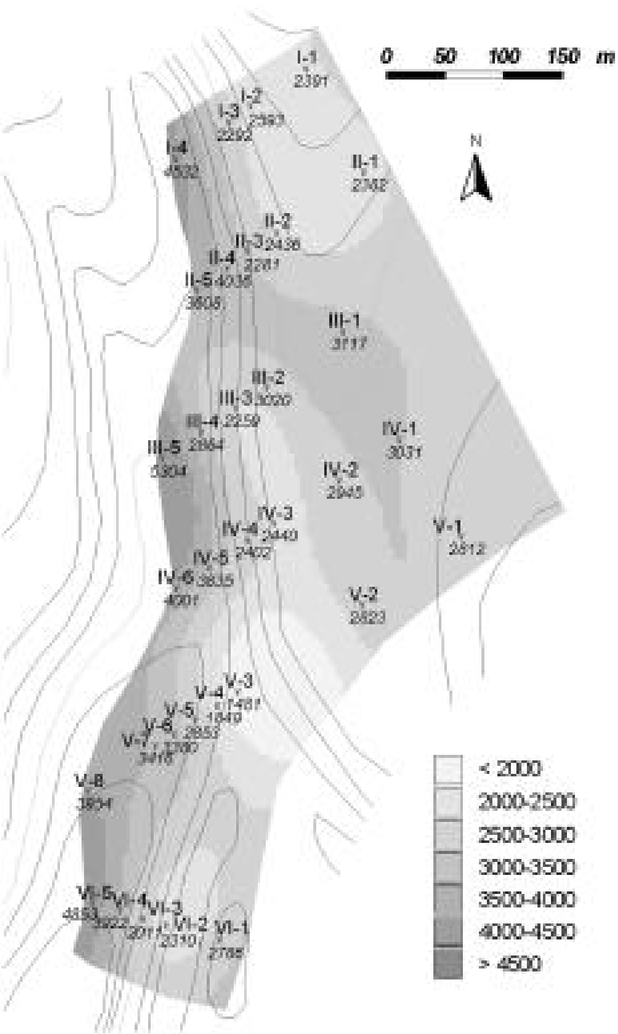

Figure 4. Spatial distribution of ^{137}Cs (Bq m^{-2}).

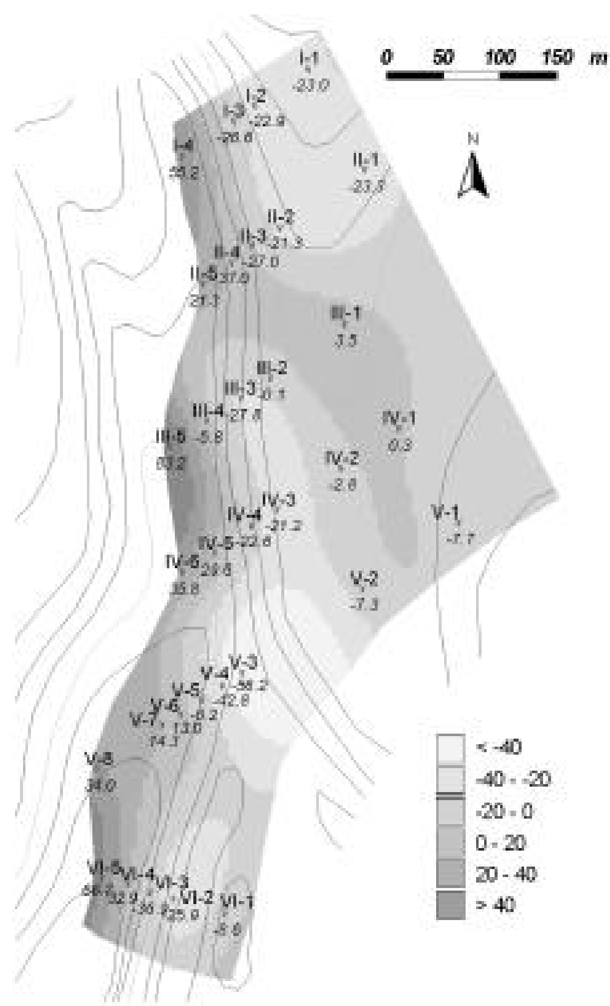

Figure 5. Spatial pattern of soil erosion and deposition (t ha^{-1} $year^{-1}$).

within the transects vary from 15 - 30 m on the slopes up to 50 - 100 m on the plateau and the distances between the transects are 100 m. This influence to some extent the shape of obtained isolines. However, the obtained maps show clearly the removal of ^{137}Cs and soil from the slopes and their deposition in the valley bottom. The large plateau surrounding the upper parts of the Transects III, IV and V is close to erosion-deposition equilibrium.

CONCLUSION

The spatial distribution of ^{137}Cs inventories at Jaslovske Bohunice Site reflects clearly the erosion-deposition pattern. The ^{137}Cs inventories are considerably lower at the slopes than at the plateau and they are highest in the valley. These differences indicate erosion on the slopes and deposition in the valley.

The soil erosion and deposition rates were calculated by three chosen calibration models. The simplified mass balance model gives the highest erosion rates. The proportional model is in the middle of the range and standard mass balance model gives the lowest values. The last model seems to be most realistic. However, the use of proportional model is also reasonable, for its simplicity and easy availability of the input parameters.

The ^{137}Cs inventories and the erosion rates from the proportional model were extrapolated and maps of ^{137}Cs contamination and Soil erosion-deposition were created.

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REFERENCES

Fulajtar, E., 1997. Monitoring of erosion intensity at small sized plots, (In Slovak: Meranie intenzity erozie na malorozmernych pozorovacich parcelach), Research report, VUPU, Bratislava, 137 p.

Fulajtar, E., 1999. The influence of soil erosion in agricultural country on quality of water in rivers (In Slovak: Vplyv eroznych procesov v polnohospodarsky vyuzivanej krajine na kvalitu vodnych tokov), Research report, VUPU, Bratislava, 60 p.

Chomanicova, A., 1988. The reasons of erosion and most appropriate soil conserving approaches for soils of flysh areas, (In Slovak: Pricina erozie a najvhodnejsie sposoby protieroznej ochrany pod na flysovych substratoch), Research report, SFRI, Bratislava, 54 p.

Lehotsky, M., 1999. Soil erosion investigation using Caesium-137 and dendrogeomorphic methods (case studies in Jablonka catchment), Soil conservation in large-scale land use, ESSC Int. Conference, Bratislava, p. 81-87.

Lehotsky, M., Stankoviansky, M., 1992. Detection of water erosion-accumulation processes with use of ^{137}Cs-method, (In Slovak. Detekcia priebehu zrazkovych erozno-akumulacnych procesov na zaklade stanovenia obsahu izotopu ^{137}Cs v pode), Geograficky casopis, 3, p. 273-287.

Lehotsky, M., Stankoviansky, M., Linkes, V., 1993. Use of Caesium-137 in study of pedogenetic processes, In Farm land Erosion, Proceedings of the International Symposium on Farm Land Erosion, Paris, 1992, S. Wicherek, Elsevier, Amsterdam, p. 339-346.

Linkes, V., Lehotsky, M., Stankoviansky, M., 1992. Contribution to the knowledge on development of water erosion in Danube Hilly land with use of Caesium-137, (In Slovak: Prispevok k poznaniu vyvoja vodnej erozie pod na pahorkatinach Podunajskej niziny s vyuzitim Cezia-137), Vedecke prace VUPU 17, VUPU, Bratislava, p. 113-119.

Owens, P.N., Walling, D.E., 1996. Spatial variability of Caesium-137 Inventories at Reference Sites: an Example from two Contrasting Sites in England and Zimbabwe, Appl. Radiat. Isot., 47(7), 699-707.

Stasik, V., Karnis, J., Mocik A., 1983. Quantitative assessment of the loss of nutrients by erosion (In Slovak: Kvantifikacia uniku zivin najma eroznymi procesmi), Research report, SFRI, Bratislava, 38 p.

Walling, D.E., He, Q., 1997. Models for Converting ^{137}Cs measurements to estimates of Soil Redistribution Rates on Cultivated and Uncultivated Soils (Including Software for Model Implementation), A contribution to the IAEA Co-ordinated Research Programs on Soil Erosion and Sedimentation, Exeter University, Exeter, 29 p.

Walling, D.E., Quine, T.A., 1993. Use of Caesium-137 as a tracer of erosion an sedimentation: handbook for the application of the Caesium-137 technique, UK Overseas Development Administration Research Scheme R4579, Department of Geography, University of Exeter, 196 p.

World Reference Base for Soil Resources, ISSS-ISRIC-FAO, Wageningen/Rome, 1994.