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VISUALISATION OF HEAVY METAL CONTAMINATION RISK ESTIMATION IN THE COUNTRY AT PODLIPA AND REINER DUMP-FIELDS AT THE ABANDONED ĽUBIETOVÁ Cu-Ag DEPOSIT

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Abstract: From viewpoint of the risk estimation of heavy metal contamination in the mining country has great importance realisation of digital model of the landscape. It is necessary study the terraine inclination and bending, surface water runoff, potential and actual erosion because these characteristics have terminative influence on water percolation through the dump-field technogenous sediments and heavy metal contamination spreding. Modeling of these indicators enable state the risk of the country contamination as well as find the best solutions for the country remediation. The results at the Ľubietová deposit (area of Podlipa and Reiner dump-field) show that the terrain beneath the dumps is endangeret by erosion and heavy metal pollution contamination; much more at Podlipa area and only in limited extent in the surrounding of the Reiner dump-field area.

Key words: country contamination, heavy metals, erosion, water flow, risk GIS-visualisation

1. INTRODUCTION

The area of Ľubietová (Fig. 1) belongs to the historically most significant and great copper ore deposits of Slovakia. According to archaeological findings, copper was mined as far back as the Bronze age (Koděra et al., 1990). Hydrothermal copper mineralisation has been developed in three deposits: Podlipa and Reiner in the vicinity of the village, whereas Svätodušná and Kolba deposits in the Peklo Valley (Fig. 2), approximately 5 km East from the vil-lage where, apart from copper and iron, was formed also Co, Ni and Ag mineralisation.

The most significant deposit Podlipa is situated approximately 1 km East of the village centre, on the southern slope of the Vysoká elevation (995.5m) in Zelená Dolina Valley in the environment of the terrigenous Permian rocks of the Ľubietová crystalline complex which consists of grey-wacke and arkosic shales as well as of puddingstones in contact with Lower Permian granitoid rocks (Fig. 3). The rocks are intensively and dynamically meta-morphosed (Bergfest, 1951; Koděra et al., 1990). The ore mineralisation is represented mainly by chalcopyrite, pyrite, hematite, Ag-tetrahedrite and arsenopyrite, gangue minerals are represented by quartz and carbonates (Bancík & Jeleň, 1999).

Figure 1. Localization of Ľubietová Cu-deposit

Ore bodies were intensively mined in the 15th and 16th centuries but also later in the 17th and 18th centuries. The important mining ended in the second half of 19th century (Ilavský et al., 1994) but some local activities survived until 1915. During a period of 500 years, approximately 25,000 tons of copper was mined from the deposit (Bergfest, 1951).

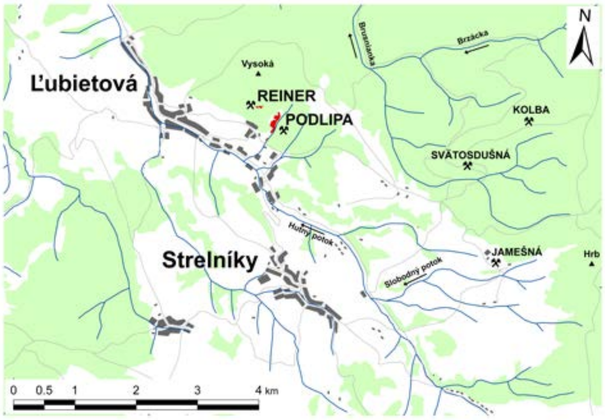

Figure 2. Localization of the Cu-deposits Reiner, Podlipa, Svätodušná and Kolba at Ľubietová

The erosion process of reactive minerals, mainly in acidic environment mobilises the heavy metals and a number of other elements which contaminate the country components (soil, water, biota, air). The pH decrease in soil/technogenic sediments of the dump-fields causes releas of heavy metals from the solid phase (where they are present in the form of barely soluble minerals or in the sorption complex), to the underground and surface water (Andráš et al., 2012). The pH of sediments found in aqueous leachate vary between 4.21 and 7.93. The range of pH values of sediments analysed in a KCl solution leachate is from 4.00 to 7.3 (Andráš et al., 2013).

In supergenic conditions, this is followed by formation of colourful scale of secondary copper minerals. These mineral phases were mainly formed in the process of precipitation from solutions circulating through soil/technogenic sediments, as well as as a result of primary minerals oxidation (Ashley et al., 2003). The increased contents of U (units of $mg.kg^{-1}$) and Th (dozens of $mg.kg^{-1}$) are typical for Permian rocks (Dadová et al., 2014).

Changes of the pH and Eh values in soil/technogenic sediments causes mobilisation of the heavy metals from the solid phase, where they are present in the form of barely soluble primary and secondary minerals or in the sorption complex, to be released into the underground and surface water. Their mobility in solutions and complex compounds is proved also by presence of numerous secondary minerals: carbonates, phosphates, sulphates and oxides.

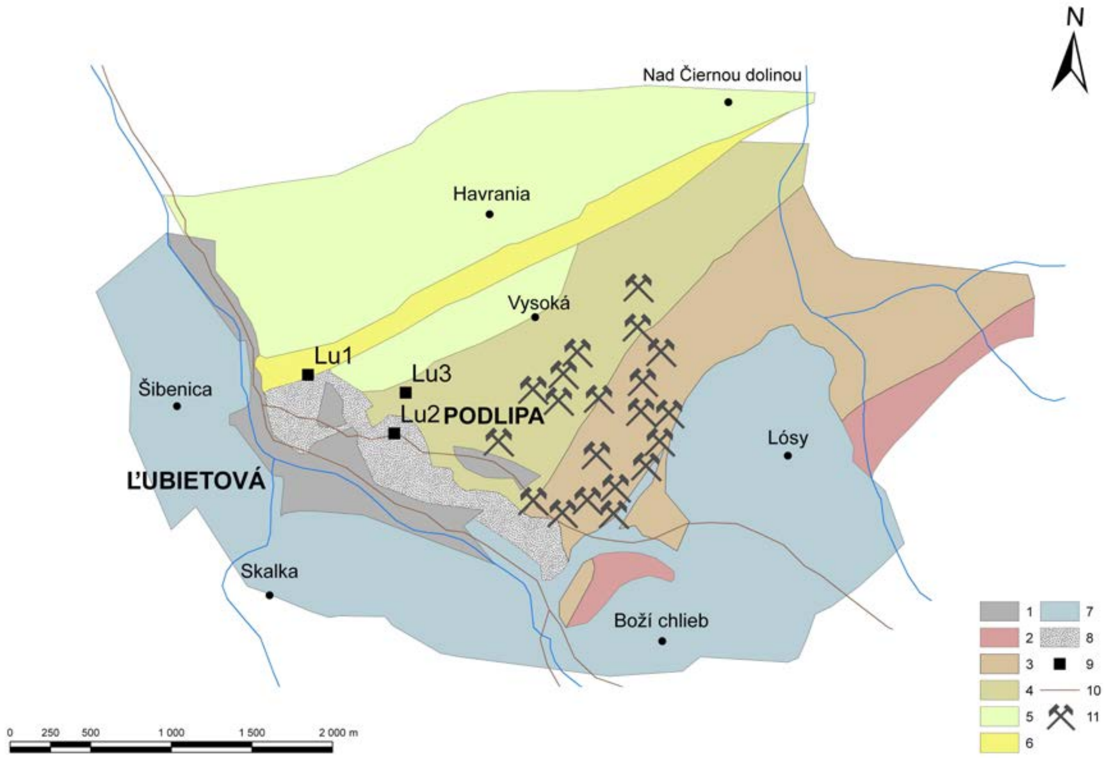

Figure 3. Geological setting of the Ľubietová Cu-deposit

Explanations: 1 - settlement, 2 – crystalline complex, 3 – Permian/Brusno sequence, 4 – Permian/Predajnianske sequence, 5 – Lower Triassic/Donovaly sequence, 6 – Middle Triassic (dolomites, dolomite breccias), 7 - Miocene volcanic rocks/Lvoze complex, 8 – Pliocene gravels, sands and clays, 9 - roads, 10 – streams

The hydrology of the surveyed area is dominated by Hutný brook flowing through Ľubietová village and by an unnamed mountain stream draining the Zelená Valley along the dump-field Podlipa. Both streams are contaminated with heavy metals which are released from the technogenic sediments of the dumps (Lichý et al., 2010).

A visualisation of the results of the above mentioned processes is not only important in terms of informing the public about the possible environmental problems at the selected mining areas, but also for research to describe the possible risk of country contamination with respect to the health and property of citizens in the immediate vicinity of a mining dump-fields.

In terms of determining environmental contamination, it is necessary to model the morphometric characteristics of the relief of the studied area (to generate a digital model of the relief and its analytical indexes such as superelevation, decree of incline and curvature of the relief). These terrain characteristics have a determining effect upon the percolation of water through dump sediments and upon the run-off of drainage and surface water, as well as upon erosion of dump material followed by contamination of landscape components by heavy metals. Modelling the outflow regime is partially carried out by evaluating a model area in terms of the hydric properties of the landscape, its ability to slow and capture atmospheric precipitation and to support their soaking into the lower layers. It defines the influence of the landscape upon water run-off.

2. METHODOLOGY

GIS tools can be applied for analysing of the current status of contaminants in the model-areas and their spread to the wider area. Their use is implementable in various phases and at various levels when preparing a synthesis of the estimated spread of contamination. Limiting factors in their use are only the options for the particular GIS software and the inputted geospatial data. Processing each phase for preparing input factors for a map of contamination has other purposes and, therefore, other requirements for the accuracy and detail of outputs, resulting in requirements for the scale, type and accuracy of input data.

The research was focused on the hydrology and erosion modelling. From existing GIS tools, the GIS GRASS module tool with an open code was used, which is one of the most popular and universal GIS tools used by the groups of experts.

The results of modelling are based directly on data collected in field measurements in the area of the dump-fields, which were segmented into homogenous areas depending upon the visual nature of the given area. Samples from individual dumps were taken in a square 10 m x 10 m network so each sample (weighing approximately 1000 g) in the collection point represented the profile to a depth of 30cm. Only soil/technogenous sediments whose grain size did not exceed 1.5 cm were taken in consideration, because only fine-grained part of soil/technogenic sediments represents represents the highly reactive portion of the dump-field matter (larger fractions of rock and boulders have a small reaction surface and in terms of releasing heavy metals to landscape components, they do not represent a significant risk). Based on laboratory results, rasters of the estimated contamination with heavy elements were generated, with a resolution of the generated raster of 0.5 m. These properties of the generated models together with using the interpolation method (RST allowing complex adjustment of data inputted into the calculation of the model) increases the quality of the results achieved and increases the realism of the final visualisation, approaching the real status of the surveyed area.

The ***digital model of the landscape*** was processed according to the modified isolines supplemented by a point field connected to homogenous lines targeted during field work. The model was generated using the RST interpolation method with a pre-defined structure of balancing in accordance with Neteler & Mitasová (2002).

Modelling the surface run-off of water may be carried out based on characteristics presented by Gerits (1990). It is based on data of the water flow on the relief surface (until it reaches the river (or a channel). Surface run-off of water causes water erosion of the soil and therefore in the same time spreading of the contaminants solved in the water to the country. It is caused by exfiltration and like the Horton overland flow (if the intensity of precipitation exceeds the intensity of infiltration; Moore & Foster, 1990). Depending upon the properties of the soil, vegetation and of the relief (including barriers), overland flow is variable in space and time. In the submitted paper, modelling predicting overland flow using the **„**r.flow" module in a GIS GRASS tool and a „flow" module in the ArcGIS program was realised (Lepeška, 2008).

Generation of a model of potential erosion was realised using GIS tools using empiric models based on identifying statistically significant relationships between variables - WATEM/SEDEM (Van Oost, et al., 2000; Van Rompaey, et al., 2002) and in accordance with Wischmeier & Smith (1965, 1978).

When **modelling the spread of contami-**

nation, knowledge from morphometric relief indexes and some other methodology are used (Bear & Veruijt, 1988, Zachar, 1970, Brown, 2003, Bedrna, 2002, Fojt & Krečmer, 1975, Miklós, 1993, Moore & Foster, 1990, Mitášová & Mitáš, 2000, Kulla, 2006, Heymann et al., 2003, Feranec & Oťaheľ, 2001, 2008, Wischmeier & Smith, 1978, Van Oost et al., 2000, Van Rompaey et al., 2002) and included in the modelling of run-off and erosion processes.

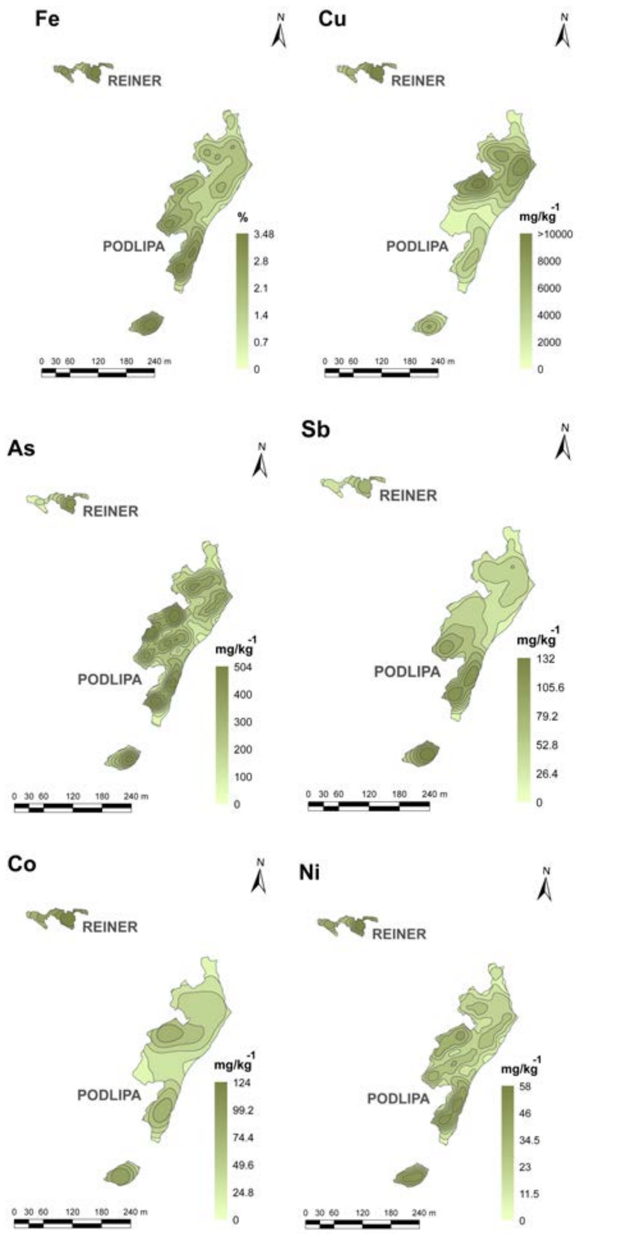

Figure 4. Distribution of Fe, Cu, As, Sb, Co and Ni on dump-fields Reiner and Podlipa

3. RESULTS

The contamination of sediments by trace elements was studied by Andráš et al., (2013). The distribution of individual trace elements reflects their primary concentration in individual parts of the dump-field as well as their geochemical behaviour, mainly their migration ability. A visualisation of the selected heavy metals distribution given on figure 4.

The correlation factor **r** for selected metal pairs is presented in table 1.

Table 1. Correlation factors of selected metal pairs

Metal pair	Correlation factor **r**	Metal pair	Correlation factor **r**
Pb/Cd	0.88	Co/Fe	0.69
Zn/Pb	0.88	Fe/Ni	0.64
Zn/Cd	0.87	Cu/Ni	0.18
Co/Cu	0.81	Co/Ni	0.60
Co/As	0.77	As/Sb	0.30
Ni/As	0.72	U/Th	0.59

A digital model of the country relief (Fig. 3) is calculated using spatial interpolation from inputted geospatial data (elevation points, lines). This represents a set of geo-referenced data characterising the relief's geometric properties (i.e. elevation above sea level and other morphometric indexes - incline, orientation and curvature of the relief) calculated from points whose attributes are their elevation above sea level and a suitable interpolation method. This is the basis for the visualisation of all the other presented results.

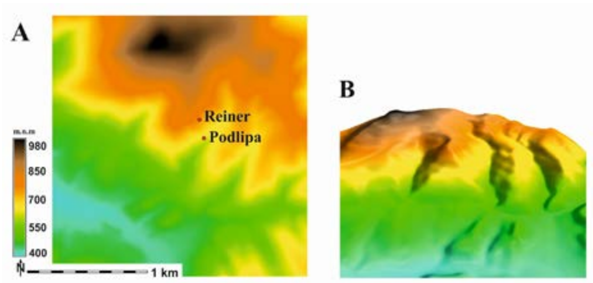

Figure 5. The digital model (A – two dimensional, B – three dimensional) of the country relief in the area of Reiner and Podlipa dump-fields

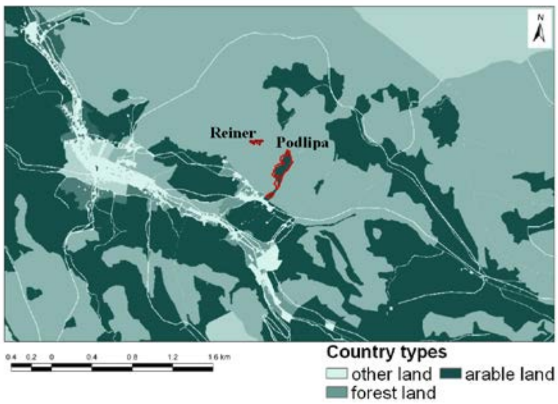

Figure 6. Distribution of the country types necessary for LS (length-slope) calculation.

Distribution of the country types is presented on figure 6.

The ***reference relief flexion*** is a decisive indicator for determining the tendencies for water and material movement down the slope (accelerating, decelerating). The model presen-ted on figure 7 represents the curvature of gradient curves.

The ***inclination of the area*** is the most important indicator for evaluating speed and therefore the amount of run-off water and material on the relief's surface.

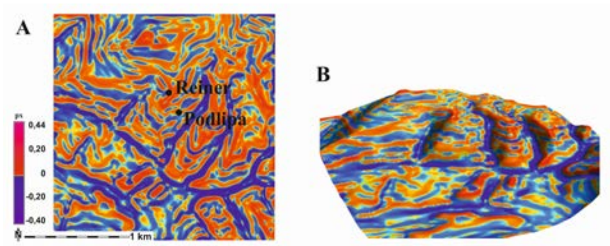

Figure 7. Reference relief flexion (A – two dimensional, B – three dimensional) of model territories at Podlipa and Reiner dump-fields

Horizontal relief flexion is characterised by curved contour lines. The first step of this analysis was to determine the positions of ridges and valleys, peaks and depressions to which, depending upon the curvature of the contour lines, convex slopes were assigned (ridges, forks), concave slopes (valleys, gorges, furrows) or uncurved slopes. The boundaries between individual curvatures (inflection points) were determined visually for each contour line and then connected, resulting in areas with varying curvatures.

It reflects tendencies in the changes of distances between contour lines Δl on gradient curves, however gradually increasing distances mean concave slopes and decreasing Δl mean convex slopes and an even Δl means level slopes. Boundaries between curvatures on each gradient curve represent inflection points on relief-positions where is a occasion for change in tendencies to shift of Δl values. Inflection points are connected in places of change and therefore determine areas with a varying curvature.

Forms of relief (Fig. 8) reflect the potential energy of a georelief - property to accelerate, equalise or slow the flow of substances. Forms of georelief may then be described as couples where their mutual value expresses.

The basic unit for water run-off in the waterway basin is flow - Q, i.e. the amount of water which flows per second through the transverse profile of the waterway. The ***surface flow of water*** can be characterised, as stated in the works of (Gerits et al., 1990), as the flow of water on the surface of the relief until it reaches a channel in the waterway. Surface flow of water causes water erosion to the soil and therefore spreading contaminants in the water and soil. (chemical, radioactive contamination). It is created by two processes - exfiltration and like the Horton overland flow (if the intensity of precipitation exceeds the intensity of infiltration, Moore & Foster, 1990). Depending upon the properties of the soil, vegetation and the relief (including barriers), overland flow is variable in terms of space and time.

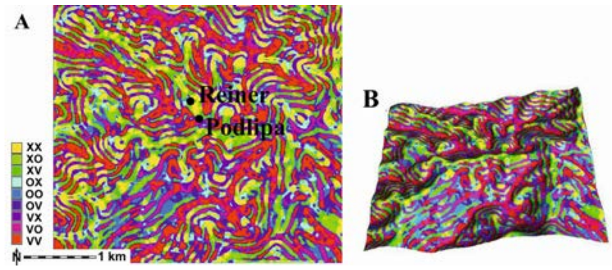

Figure 8. Relief forms of the studied territory

XX - the concentration of the material and the acceleration of its movement, XV - the concentration of the material and the slowing of its movement, X0 - the concentration of the material when not moving, VX - dispersion of the material and the acceleration of its movement down the slope, V0 - dispersion of the material and the slowing of its movement, VV - dispersion of the material when not moving, 0X - acceleration of the movement of the material down the slope, 0V, slowing of the movement of the material down the slope, 00 - the state when there is no movement, concentration or dispersion of the material.

During a precipitation event, the surface flow is an example of a gradually changing, unstable, free surface flow for which the conservation laws of mass and momentum apply (Fig. 9).

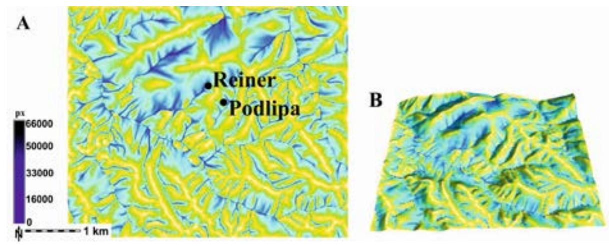

Figure 9. Modelling of potential discharge

In the observed locations, the percentage share of increased (strong) surface run-off is at a level of 83.46% and the remaining 16.54% is medium and slight run-off. This is situated in the part of the relief which we term the crown, the saddle and plateau part of the dump area together with a narrow, slightly incline valley shape of the relief which provides complete run-off from the researched area in Ľubietová – Podlipa (Fig. 9).

Based on the ascertained hydric significance of the environment, it is possible to obtain a suitable basis for designing the most suitable water flow and infiltration strategy for the investigated area. However, such an evaluation based on the used methodology is only feasible at regional and wider level. The creation of such plans and documents for the lower level of villages, or at a level of partial river basins, requires more detailed research of the local landscape characteristics. For the purposes of our research, this methodology gives a view of the researched area in terms of vulnerability related to the possible spread of contamination (Fig. 10).

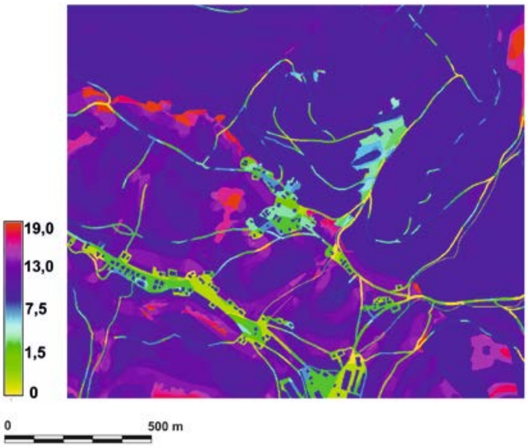

Figure 10. Hydric importance of terraine in surrounding of Ľubietová

For both models, the lowest hydric dependence coefficient of the area is in the old mining dumps and their adjacent areas. The lowest infiltration (Fig. 10) is mainly visible in an area with landscape elements such as a road network, a network of waterways and reservoirs, urban settlements and other residential areas built using non-permeable or barely-permeable materials in which the minimum infiltration of hydrological precipitation in the investigated area can be assumed. Submitted hydric models correspond greatly with models of potential contamination in dump areas in the Ľubietová cadastral area.

The mutual synthesis of factors selected from the stated methodology, inputted in a model generated using GIS tools, allows outlining of the potential area which could be contaminated with heavy metals spread by surface run-off and by erosion from mining waste deposits to their immediate vicinity.

The spread of contaminants is closely linked to run-off conditions and soil erosion. We may distinguish between erodibility as erosion and erodibility as potential for erosion. Erodibility is susceptibility or resistance of soil to erosion - water, wind, etc. This soil property is closely related to some of its properties and, in fact, it means the threat of erosion, threat of soil erosion or its potential (possible) erosion usually expressed by a possible loss of soil from the surface unit per particular time period (which at the same time is the intensity of potential soil erosion) $t.ha^{-1}.year^{-1}$. The general formula (universal equation) for calculation erosion is:

$$\mathbf{A = R * K * L * S * C * P} \qquad [t.ha^{-1}.year^{-1}]$$

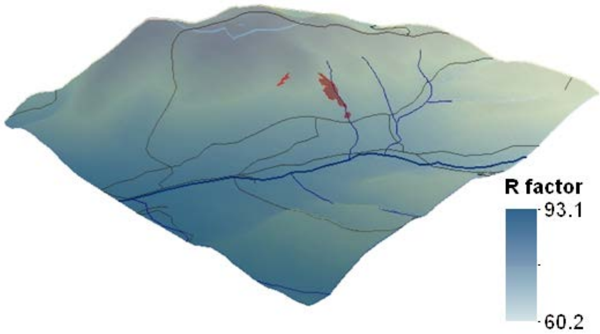

Figure 11. Visualization of the rain factor R, which expresses the intensity, sum and frequency of precipitation, the incidence and kinetic energy of torrential rain

Several factors are taken into account during the calculation. The rain ***factor R*** expresses the intensity, sum and frequency of precipitation, the incidence and kinetic energy of torrential rain (Fig. 11). ***Factor K*** represents the influence of soil quality upon its resistance to falling raindrops and running water, and the influence of the amount of infiltration and amount of surface run-off. The soil susceptibility to erosion factor K is influenced by the basic soil parameters such as granularity, soil structure, content of organic mass and permeability (Fig. 12).

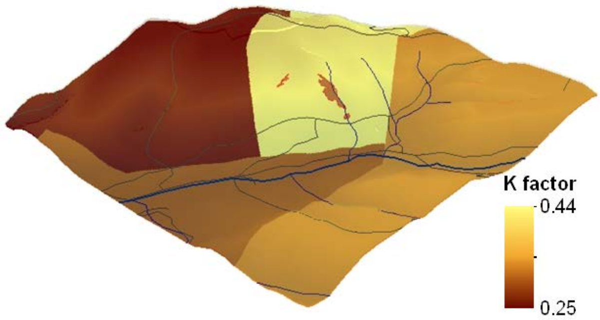

Figure 12. Visualization of the K factor which represents the influence of soil quality upon its resistance to falling raindrops and running water, and the influence of the amount of infiltration and amount of surface run-off.

The ***LS factor*** reflects the run-off conditions in the area (Fig. 13). The LS factor reflects the area's run-off conditions. Vegetation protects the soil against the direct effects of falling raindrops, captures part of the precipitation (interception), decreases the speed of surface run-off and influences soil properties (porosity, permeability, mechanical reinforcement of soil by root systems). The protective influence of vegetation is directly proportionate to stand coverage during period of erosive precipitation - i.e. in our conditions, from April to October, most often in June, July and September.

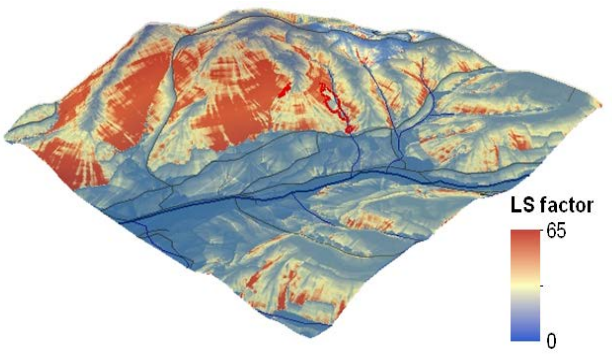

Figure 13. LS factor reflects the run-off conditions in the area

For the needs of simulating scenarios for addressing erosion, we needs knowledge of the landscape properties influencing spatio-temporal changes in surface flow and also therefore the model's input parameters. ***Potential erosion*** (Fig. 14) represents the maximum possible threat to the area by water erosion under the assumption that we did not take into consideration the protective effects of vegetation (the model calculation does not include existing vegetation in the given area and does not assume any anthropogenic anti-erosion barriers or measures). Actual or real erosion (Fig. 15), despite potential erosion, includes existing vegetation in the given area and the implementation of anti-erosion measures in the calculations. The calculations made provisions for the morphometric parameters of the relief, properties of the landscape cover (use of the landscape, vegetation properties), the physical properties of the soil as well as the development of a precipitation event.

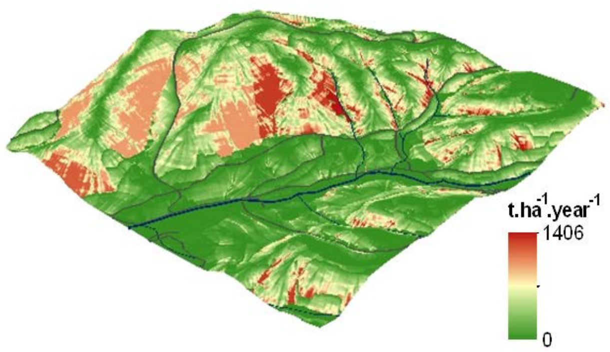

Figure 14. Potential erosion of the studied terraine in t.ha^{-1}year^{-1}

Also anti-erosion ***P factor*** was not used in the calculations.

In terms of calculations, there is a difference between potential erosion and real erosion in ***factor C***, i.e. the factor derived from the real use of the landscape by covering with vegetation (Fig. 16).

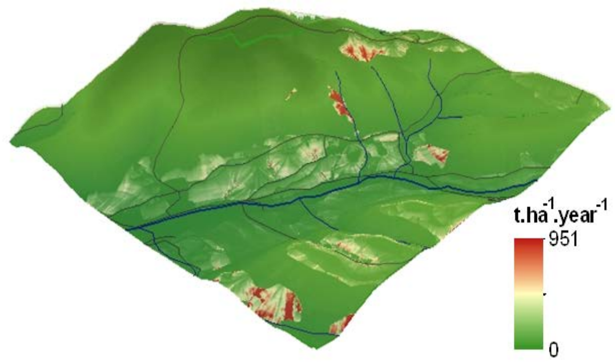

Figure 15. Actual erosion of studied terraine in t.ha^{-1}year^{-1}

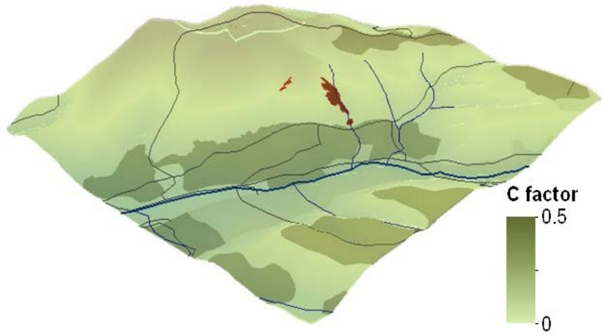

Figure 16. C factor reflect the vegetation cover, which influence the erosion efficienc

Figure 17. Retention reservoir under the Podlipa dump-field

The final rasters (models) presented on figure 14 and 15 indicate increased erodibility which many-times exceeds the limit value of 200 t.ha^{-1}.year^{-1}, mainly for landfills, predominantly caused by insufficient maintenance of the terrain. The situation is also critical due to extreme values of morphometric indexes of the relief and depends greatly upon the practically non-existent hummus part of the soil, causing more difficult anchoring of flora communities which could reinforce problematic locations and decrease the risk of the spread of contaminants via surface flows. The risk of the spread of contaminants from mining dumps is quite high in the urban structure of Ľubietová. Erosion is affecting the residential zone, gardens and orchards where citizens in the researched area cultivate fruit and vegetables for direct consumption.

Based on the discovered facts, were elaborated maps of the potential spread of contaminants in the investigated locations (Figs 6, 7). They reflects data about the inclination of the area, areas contributing to water run-off, actual erosion (Fig. 15), concave shapes, the horizontal curvature and, last but not least, about the micro-waterway in which the investigated area belongs. The calculation was influenced by spatial barriers influencing the spread of contaminants: roads, waterways, water areas, and urban and built-up areas which were subsequently homogenised and modified to their final appearance by filtration.

In the Ľubietová - Podlipa location, the estimated area which could be affected by contaminants is 5.256 ha and from this area, mining dumps cover 3.129 ha. The estimated contamination affects the landscape structure (forest, meadows, pastures, bushes and unused areas), where it not only threatens the health of inhabitants, but also one residential building with an area of 19.61m². The majority of washed away contaminated material is trapped in a retention reservoir (Fig. 17) and by the water flow of a mountain stream draining the valley below the dumps (discharging into Hutný brook).

In the Reiner location, the spread of contaminants to the urban area is limited by a forest stand which, together with the undergrowth, significant limits the erosion process. Contaminants with high migrating ability are deposited on the bottom of the slope on which the mining waste is deposited. The arrangement of forest roads also limits the spread of contamination.

4. DISCUSSION

The main contaminants of environmental components in the studied locations are Fe (as much as 5.85 %), Cu (as much as >10000 mg.kg^{-1}), Pb, As and Sb. Contamination demonstrates geochemical principles which determine the distribution of individual monitored elements in the soil, technogenic sediments and water. Soil reaction (pH) plays a decisive role in the migration of elements. The majority of elements are mobile (and bio-accessible) at lower pH values. The level of acidification therefore determines the risk of contaminating the landscape by mobilised heavy metals from dump sediments (Kiurski et al., 2012; Veerasingam et al., 2012).

The nature of the distribution of individual elements is also controlled by the sorption properties of those elements for absorbing clay minerals and hydrogoethite (“limonite"). These dependencies are shown clearly by the values of correlation coefficients.The most important correlation degree was calculated for following metal pairs: Ag/Ni, Pb/Cd, Zn/Pb, Zn/Cd, Co/Cu, Co/As, Ni/As and a little bit less also Co/Fe and Fe/Ni (Table 1). Amazingly, e.g. the Cu/Ni, Co/Ni, As/Sb and U/Th correlations are beyond all exceptations (in spite of the features of their geochemical relationships) very low. On the other hand, in some cases it is possible relatively simply explain. For example in case of the U/Th pair we can assume that the low correlation degree is caused by different U and Th mobility under the supergene conditions. Whereas U^{4+} is relatively immobile, in water characterised by a high Eh it is oxidised to U^{6+} and is released to solution (Tölgyessy, 2001), Th persists in Th^{4+} form which is only slightly mobile. In consequence of the substantially higher mobility of U, this obtains predominance in solutions over Th (Polański & Smulikowski, 1978) and is able to migrate over great distance.

The main aim was to visualise the above stated and other factors influencing contami-nation of the environment in the studied regions, or to model future development. Individual GIS-images form part of this paper.

The submitted results may be divided into two groups: analysis of the current status of contaminants in the modelled areas and their estimated spread within a wider area. GIS tools may be applied for both. Their use is possible in various phases and at various levels of the model. Limiting factors in their use are only the options for the particular GIS software and the inputted data. Processing each phase of the model has other purposes and, therefore, other requirements for the accuracy and detail of outputs, resulting in requirements for the scale, type and accuracy of input data.

This study addresses spatially small areas as well as processing project documentation and large scale land plans, which requires more detailed data with high resolution and accuracy.

The main part of the paper focuses upon the area of hydrology and erosion modelling with the option to use GIS tools for hydrological calculations. From the number of existing complex GIS tools, the

GIS GRASS module tool with an open code was selected, which is one of the most popular and universal GIS tools used by the groups of experts.

The first part of the results in the submitted paper in the area of GIS modelling and visualisation focused upon processing models of the spatial distribution of contaminants of individual heavy elements in the area of the modelled locations (Fig. 3). The results of modelling and subsequent visualisation arise directly from data collected directly in field measurements in the dump deposit areas.

The second part addresses the modelling of surface run-off (Fig. 12) and erosion affecting the transport of contaminants in the area. The term 'modelling surface run-off' can be understood in two ways. The first option could be modelling the development of surface run-off in terms of seeking the accumulation routes of run-off water, whilst the accuracy of such a model always depends upon the accuracy of the input data which forms the basis of such modelling. Probably the most accurate results would be achieved by finding and demarcating the calculated gutters in the terrain but, in terms of their frequency, it is not feasible. However, models created in the GIS also give sufficiently informative results. The basis for their creation is an analysis of the relief, for which GRASS open software used offers sufficient tools. Morphometric analysis of the relief is closely related to the most important factor which influences the inaccuracy of the model of run-off development, which is a good quality digital model of the relief.

The accuracy of the digital model (Fig. 8) of the relief mainly depends upon the selection of input data and the precision of processing (the use of interpolation methods). The paper used a model created from data obtained from basic topographic maps with a 10m square resolution. It was created by interpolating the altitudes from isolines and border lines supplemented by refining data demarcated directly during the implementation of field works in the modelled locations. The model subsequently allowed calculation of the development of natural run-off and the potential and real erosion together with an option to create a hydric model depending upon other factors. In fact, the run-off of water and spread of material, and therefore also the migration of contaminants in the area, is influenced by built-up areas and the landscape structure which particularly limits its direct run-off. Samples from the Slovak State Series of Maps were also used for creating a digital model of the terrain. However, this step did not bring the required effect since in the majority of anthropogenic barriers, only their position and not their altitude was known. One of the methods for creating a digital model of relief (DRM) and include these objects in the model at the same time, and use their effect without knowing their real altitude is to exclude them from the digital relief model. Using this method, "empty places" were created without the required altitude data, which are not included in further calculations. A disadvantage of this method is discontinuity in the run-off gutters.

The second method was processing the final run-off accumulation lines in such a way that they would circumnavigate impermeable barriers, but this could partially result in losing the statement value of the final model.

The amount of run-off and transported material in the model locations is directly linked to the amount precipitation, it depends upon the soil type and its method of use (whilst in dump areas, it is usually substrate not covered with vegetation showing a high degree of erodibility). These are parameters also entered in models of run-off, real water erosion and hydric models. The volume of resulting indexes of these models also depends upon other factors. When modelling, the "sum of precipitation" over a certain period was used as the precipitation parameter; in our case, it was the average monthly sum and the average annual sum, whilst the output value is then the proportionate part of precipitation decreased by water which soaked and evaporated.

The type of surface where the run-off of water and material in the area takes place also plays a significant role in calculating individual models. The volume of migrated material in the model area must be understood as an estimate in the assumed ideal conditions.

Preparing the digital model of the studied landscape and modelling surface run-off showed that the amount of run-off and transported material contaminated with heavy metals in the modelled locations is directly proportionate to the amount of precipitation and depends upon the type of soil and its method of use.

The risk of erosion in Podlipa and the related possibility of massive drift of dump material to the Zelená Dolina Valley and, from there, further to the retention reservoir situated on the terrace above Ľubietová, enforces the need for increased caution and the need for maintenance measures. Neglecting preventa-tive steps to protect the environment in this region may lead to destruction as seen, for example, after the torrential rain in 2010, when the lower part of the Zelená Dolina Valley eroded to the surface of the rock substratum, and the combe created in technogenic sediments reached a depth of 2m (Fig. 20).

The large retention reservoir below the dump field (fig. 17) was completely clogged with sediments and it was necessary to clear it and remove several dozen cubic metres of sludge.

In Reiner, the spread of contaminants to the urban area is prevented by a forest stand which also protects the slope below the dump against massive demonstrations of erosion. The spread of contamination is also prevented by the spatial position of forest roads which are reinforced and arranged in such a way that they stop water run-off from the dump and allow it to be soaked into the soil in the vicinity of the mining deposits.

Options for retention modifications in the landscape and the potential for technical measures should be compared with data about the probable sum of precipitation and its intensity in the given area. In the conditions of less permeable area, where the main mechanism for creating run-off is surface run-off caused by exceeding soil infiltration capacities, it is necessary to focus upon measures for increasing the infiltration capacity which will not disturb the surface soil cover. Incorrect measures may cause increased erosion and the creation of a denser network of small waterways which will be expressed in faster run-off. Measures in terrains which are close to saturation (e.g. in the vicinity of waterways) must be taken so they do not support quicker saturation of the terrain and do not increase the proportion of surface run-off. Unlike with technical measures, the effects of which we may predict with a certain accuracy, the effects of non-technical measures may vary in varying conditions, even negatively (e.g. increased danger of an incidence of mudslide when the slopes are waterlogged). Measures in smaller waterways therefore require an individual approach evaluated by an expert in the given area.

5. CONCLUSIONS

The distribution of heavy metals in the rocks and ore of the Ľubietová – Podlipa dump field is uneven and corresponds with the original concentration of metals in the technogenic sediment as well as with their migration properties.

Surface water is contaminated with Cu (the values of concentration locally exceed the values determined by the Decree of the Slovak Government No. 296/2005 twofold) and less with As. The pH of the surface (and drainage) water is close to neutral (6.1 - 7.7) and therefore there is low probability of creation of acidic mining (drainage) water. Raw water is contaminated with As in some locations and drinking water exceeds the limits set by the Decree of the Slovak Government No. 354/2006 coll. for Mn and Cd.

Important for the creation of a good quality model of contamination is accurate evaluation of the development of run-off and transported material from the modelled area and, in terms of changed conditions in the landscape, estimation of their impact upon the run-off regime, as well as evaluation of the proportion of individual groups of landscape elements favourably influencing the water regime in cooperation with the maintenance measures taken to date in order to increase the landscape's ability to trap as much water as possible in the dump area.

Knowledge of the principles of the creation of run-off and the analysis of run-off in waterways with varying natural conditions shows in terms of water properties, the greatest influence upon run-off is the geological structure of the area, soil, precipitation activities, morphometric indicators and landscape cover.

GIS modelling showed the differences between the risk of the creation of erosion, the drift of dump materials containing heavy metals and the subsequent contamination of environmental components in the Podlipa and Reiner localities. Whilst in the Podlipa dump field, the risk of the spread of contaminants is markedly higher, the Reiner dump field only shows a limited risk of erosion and the spread of heavy metals to the surrounding landscape.

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