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SIMULATING ENVIRONMENTAL IMPACTS BASED ON THE EXAMPLE OF ROŞIA MONTANĂ

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Abstract

One of the challenges of modern terrain modelling methods is to incorporate non-existing, planned features in the output. Remote sensing based solutions can only detect structures and shapes that are already present in the environment. In order to assess the impacts of a planned development on the surrounding landscape properly it is inevitable to solve this issue. In addition to the environmental, social and economic consequences, mining activities, especially open cast mining will also leave significant scars on the landscape. These can not only have a visual effect but also impact local weather conditions by changing winds, precipitation patterns. The current paper demonstrates a collection of methods and techniques able to cope with the various challenges that arise when modelling the landscape impacts of such developments. The experiments were performed in the area of Roşia Montană, where a Canadian company plans to create the largest open cast gold mine in Europe. The results of the terrain modelling process allow for the quantification of the estimated impacts on the terrain and the land cover of the area caused by the mining project. The presented methodology and visualisation tools can also facilitate the decision support mechanisms making the communication 'more understandable' amongst stakeholders; information meetings and public hearings involving organizing groups at any level. Obtaining the results required the development of several unconventional techniques especially in terrain modelling and visual landscape simulation, involving the combination of sometimes very different base methods.

Keywords: digital terrain modelling, visual impact assessment, landscape modelling, decision support, Roşia Montană

INTRODUCTION

Spatial decision support systems (SDSS) contain different components and can be used for planning, management and public communication purposes. Integrated structures of spatial data, numerical models and formulated expert knowledge are widely applied in environmental studies since computing, geodata collecting and processing technologies, such as database management tools, geographic information system (GIS) and remote sensing (RS), are available for researchers, analysts and policy makers (Goodchild et al., 1996; Bareth, 2009; Laudien et al., 2010).

The growing official and public demand of access to modern, realistic and user-friendly computer visualisation technologies suggests the new potentials of geo-visualization and navigable virtual landscape in decision and policy support and public relation, beyond digital cartography (Sheppard and Cizek, 2009; Pettit et al., 2011). The development of SDSS requires a harmonized dataset of spatial information. However, the necessary sources are not always available. Difficulties and elaborated solutions are also presented in the paper, in the case of the planned environmental intervention of the largest open cast gold mine in Europe.

Roşia Montană (Verespatak, Goldbach) and the surrounding region is known for its extensive resources of gold, silver and other minerals. The town has rich mining traditions dating back more than 2000 years (Téglás, 1888; Sîntimbrean and Bedelean, 2002; Géczi and Bódis, 2003; Paşca, 2010). The most significant remnants of the mining activities is the extensive network of shafts and tunnels built in the Roman era, some of which are open for visitors in the mining museum. The activities have been present almost constantly until 1996 when the Romanian State Mining Company decided to stop the extraction due to unsatisfactory yields (Géczi, 2011).

Canadian company Gabriel Resources formed a new business called Roşia Montană Gold Corporation (RMGC) in 1999, which planned to create the largest open, cast gold and silver mine in Europe. Their estimates say that 300 metric tons of gold and 1600 metric tons of silver can be extracted in a period of 20 years (Haiduc, 2003; Géczi et al., 2005; Paşca, 2010; RMGC, 2015). The project has raised vocal opposition from civil organisations (Buzoianu and Țoc, 2013; MTI, 2013) because of the environmental risks posed by the cyanide-based technology that is planned to be used for ore processing (Földessy and Bőhm, 2012; Parasca and Butnaru, 2014). This will require the creation of a 2.7 km long tailings reservoir, covering 304 hectares while flooding a village. The pond will be held in place by a 180-metre-high dam (Bara, 2002, Haiduc, 2003).

In spite of the company's plans to start the project in 2006, the impacts of the Tisza cyanide pollution in 2000 (Prommer and Skwarek, 2001; WWF, 2002) and the breach of the alumina tailings dam near Kolontár in 2010 2010 (BBC, 2010, ICPDR, 2011) among other similar environmental disasters succeeded in thwarting the commencement of mining activities thus far.

The controversy surrounding the project does not stop at potential environmental risks though. According to the yield-estimates performed on behalf of RMGC, the actual gold and silver content of the rocks is so low that it borders on being economically unviable to extract. This means that the amount of profits and subsequent taxes toward the Romanian budget is highly unstable and difficult to estimate with high accuracy, especially when the fluctuation of gold prices is also taken into account. The low grade of ore content also requires enormous amounts of rocks to be processed and results in a very large volume of unusable waste material, some of which will be deliberately contaminated with cyanide and other dangerous chemicals (Haiduc, 2003). The subsequent storage, management and maintenance of these materials will invoke further costs as well as environmental risks for several years after the project is deemed complete.

The objective of the current study is to estimate the environmental impacts of the project as proposed by RMGC. The research focus is the terrain and the visual impacts on the landscape, as well as determining the changes in land cover. I will also demonstrate the results of a simulation about a dam failure on the planned tailings reservoir.

STUDY AREA

Roşia Montană is located in the NW part of Alba County in Romania. The actual township is made up of several smaller settlements in the Roşia valley with the centre being in the top half of the valley (Fig. 1). The population of the settlement cluster was 2656 in 2013, according to the Romanian Office of Statistics. The largest settlement in the study area is Abrud, in the SW corner with 5072 inhabitants in 2013.

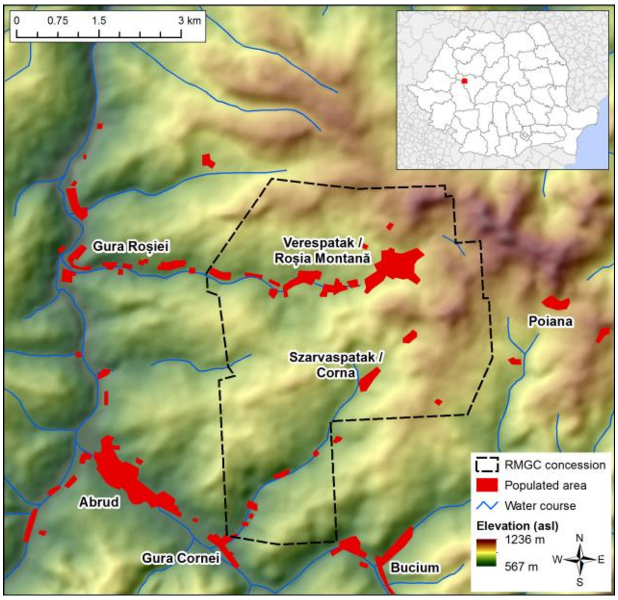

Fig. 1 Location of the study area

The concession zone is about 24 square kilometres, but for better context the full study area contains a 10 by 10 kilometre square. In terms of hydrology, the main watercourse in the study area is the River Abrud flowing to the North into River Arieş, a tributary of River Mureş (Maros) which in the end flows into River Tisza near Szeged, Hungary.

Since the main economic activity in the area is mining and associated processing industries, the waters have been heavily polluted, most significantly in the communist era, when little (if any) attention was paid toward the environment. The Roşia stream still contains relatively high levels of heavy metals and other pollutants, although the concentrations are decreasing since the cessation of active mining and processing activities.

The project plan proposed by RMGC intends to spend a considerable effort on improving the existing pollution sources as well as preventing future contaminations by diverting the natural water flows in the area. They also promise to respect the historical treasures of the area by avoiding the designated protection zones. Nevertheless, it is difficult to imagine that the high capacity vehicles, trucks and the explosions used in blasting out the mining pits will leave the surrounding buildings and historical landmarks unscathed.

The biggest environmental risk of the planned project would be the tailings reservoir located in the Corna valley (Géczi et al., 2006). This pond, in its final stage will be filled with 213 million m^3-s of waste material left behind from the ore processing. The sludge will contain high concentrations of cyanide and other harmful or toxic compounds (Haiduc, 2003). By comparison, the Tisza cyanide disaster in 2000 was caused by “only” 100,000 m^3 of water containing cyanide and heavy metals. Another significant risk factor is the location of the tailings pond, being just 1.78 km-s from the town of Abrud.

METHODS

In order to perform the necessary modelling and simulation tasks extensive preparations had to be done as well. These involved obtaining the source data and maps from various sources and collating them into a common database. The majority of the process used various GIS techniques, some of which have been developed and enhanced by the author.

The most difficult challenge was to incorporate the planned mining facilities and landforms into the existing surface in a seamless way. Artificial terrain elements tend to be more angular and to consist of more straight edges than those found in undisturbed areas. The main task was to resolve this conflict in a combined elevation model. To this end, it was decided to take advantage of the best characteristics of the two major surface modelling methodologies: vector and raster based algorithms.

Both approaches are using points of fixed elevation as base, but they estimate the elevation of in-between locations in different ways. The TIN (Triangulated Irregular Network) method in the first group generates triangles among the points with known elevation (Peucker et al., 1979; ESRI, 1994). This results in a surface with an angular, edgy appearance. One of the advantages of the TIN method is that it is computationally cheap, compared to the raster methods, delivering quicker results. However, the generated surface is visually quite different from the appearance of the most natural terrains, usually having much less edges and sharp breaks in them.

The majority of natural terrains can be modelled better using a raster approach. While there are many mathematical models to interpolate the unknown elevation value of the points based on the input data, most of these are aimed to generate statistical surfaces. Terrains have very specific features and characteristics, most of them formed by flowing water, which are beyond the capabilities of the generic interpolation methods like IDW (Inverse Distance Weighting), Kriging or spline based solutions. A more advanced algorithm was developed at the Australian National University (Hutchinson, 1988) which was able to respect the special requirements set by the effects of natural processes on the surface. The ANUDEM algorithm is now being used in ESRI's ArcGIS Spatial Analyst behind the '*Topo to Raster*' geoprocessing tool (Hutchinson and Dowling, 1991; Hutchinson, 1996; Hutchinson, 1997).

The tool is able to take advantage of the input data types commonly used to describe terrains, such as contour lines, elevation points. Water is the primary erosive force determining the general shape of most landscapes. For this reason, most landscapes have many hilltops (local maximums) and few sinks (local minimums), resulting in a connected drainage pattern. '*Topo to Raster*' uses this knowledge of surfaces and imposes constraints on the interpolation process that results in a connected drainage structure and correct representation of ridges and streams.

Using any of the two approaches above on their own would still not be able to produce an output surface that is sufficiently "smoothed" in the undisturbed areas while keeping the angular quality of the artificial structures. To achieve this, a combination of techniques had to be used. This means that a base surface was created using '*Topo to Raster*', and the rasterised TIN models of the artificial structures were merged into it later using raster arithmetics.

In the present study, the elevation data was based on the EU-DEM database available as a free download from the European Environment Agency (EEA) website. This was created using the latest versions of the ASTER-GDEM and SRTM (Shuttle Radar Topography Mission) surface models (Hensley et al., 2000; Hennig et al., 2001; Farr et al., 2007) with additional edits to improve the water surfaces. The final model is a 30-metre-resolution, medium scale raster surface, which is very usable for researches based on watershed basins (Tøttrup, 2014). The special requirements set by the modelling of artificial features required further processing of the raw EU-DEM data in order to improve its resolution and hydrological accuracy. Contours were derived from the surface at 10-metre intervals to serve as the base input for the new elevation model, which would be capable of storing the planned features as well. For better hydrological accuracy we used the water network layer in the Romanian National Cadastre Agency's INSPIRE View Service (ANCPI, 2014), which was digitised manually for the extent of the study area. Since '*Topo to Raster*' is using the stream network to build valleys and ridges into the resulting surface, the existing streams and rivers had to be extended upstream, until the shape of the contour lines made it necessary. This ensured that the valley's baseline was without obstructions and the water could flow freely as close to the natural conditions as possible. In the paper, this will be referred to as refined EU-DEM.

RMGC has published its Environmental Impact Assessment (EIA) reports as PDF documents in several versions. For this study the 2006 version was used (RMGC, 2015), which contained detailed maps of the planned mining facilities and other structures in the following time series:

- initial stage (year 0);
- operational stage (year 7);
- operational stage (year 14);
- operational stage (year 16);
- reclamation stage (year 19).

The PDF documents were converted into GIS compatible format and georeferenced into UTM34N projection to match the rest of the input datasets. The planned shapes were grouped into two categories, each requiring its own approach in modelling.

One group contained the planned quarries, mining pits and waste dumps. The most important part of modelling these structures was the creation of 3D line elements around them to define the boundary of the shapes. These 3D lines received their elevation values from the unaltered terrain (refined EU-DEM), while being digitised to follow the edges of the mining structure.

The planned structures also contained flat surfaces, which were modelled as simple polygon features with the elevation value read from the map labels stored as an attribute. In order to improve the accuracy of the TIN surface some additional contour lines and 3D lines were required in places where the algorithm would have otherwise produced incorrect results.

The digitised lines and polygons were then used to create TIN surfaces. To ensure that the resulting surface only covers the area of the artificial features, a boundary polygon was also added as the input data. This TIN model was then ready to be converted into a raster surface and to be mosaicked into the base refined EU-DEM. The 3D lines around them ensured the seamless integration, with the boundary polygon made sure that triangles were only formed within the structure.

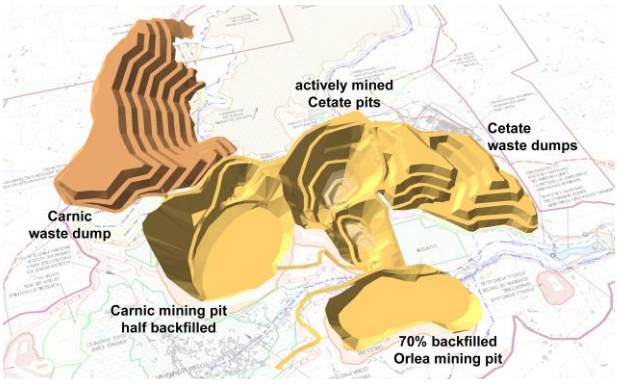

Fig. 2 TIN components of mining related features

The other main group consisted of the lakes and reservoirs planned in the project. These were digitised as polygon features, but it turned out that additional concerns had to be taken into account. The maps in the EIA were based on a terrain of unknown origins, as the map did not contain any information about the source of the used data. Therefore, it was possible (quite likely) that the refined EU-DEM would not match exactly to the shapes in the map which were based on a different elevation model. To overcome this problem the polygons representing the water (and similar) surfaces were digitised extending beyond the shapes in the map.

The TIN surface generated from the extended polygons was then converted into a raster surface based on the cell configuration of the base DEM (refined EU-DEM). The raster surface in its original state extended "below" the cells of the original DEM, i.e. where it was higher than the level of the tailings pond or lake. These cells had to be eliminated before mosaicking using simple raster comparison and arithmetic operations. The same approach was used in the case of modelling the dam structures as shown in Fig. 3.

Once the raster model only contained the cell that were higher than or equal to the corresponding cells in the original terrain, it could be merged into the surface. Using this method ensured that no gaps are formed and the "water" completely fills up the available space in the model. Taking the polygon digitised directly from the RMGC map may have caused such gaps, but this way the integration was seamless.

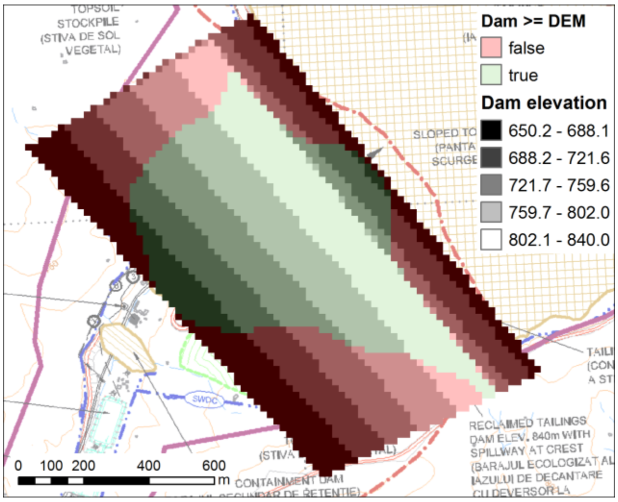

Fig. 3 Determining the cells to be discarded based on their elevation values

The modelling steps described above were performed for each of the project stages mapped in the EIA report, so in the end, five simulated terrains were created. Fig. 4 shows one of the maps draped on the built surface.

An additional, but very important part of the process was to simulate impact of the planned changes on the visual appearance of the landscape. This involved modifying SPOT satellite images of the area using standard graphics editing tools. The modifications were performed in the GiMP Open Source graphics software capable of every bit of functionality required in the editing.

The baseline SPOT image was captured in 2006, showing the existing Cetate mining pit and the surrounding area. Using texture and colour samples taken from

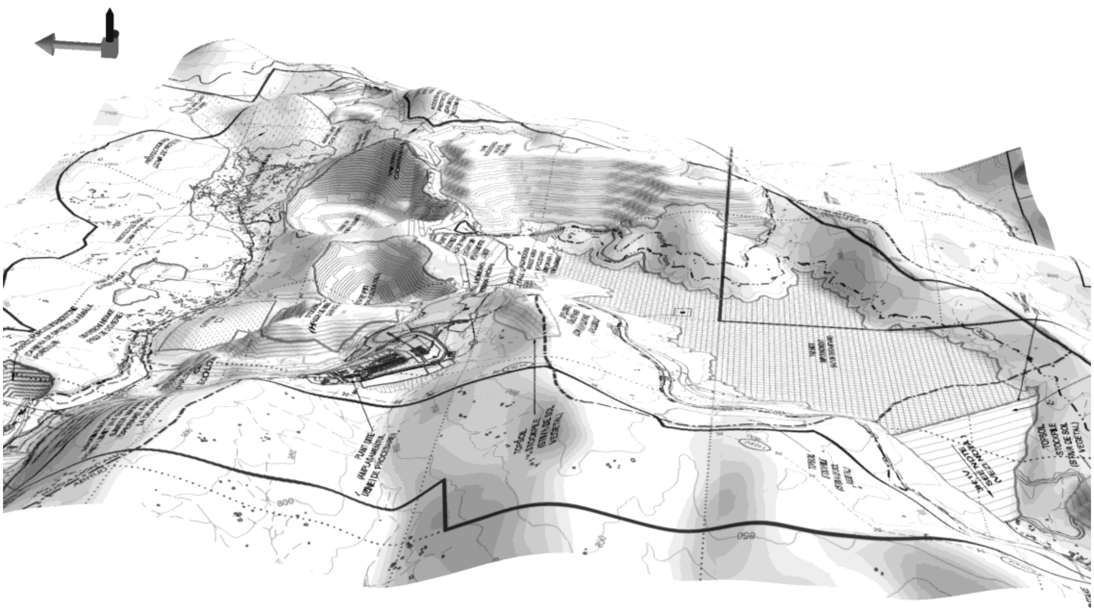

Fig. 4 RMGC map of year 14 draped over simulated terrain model

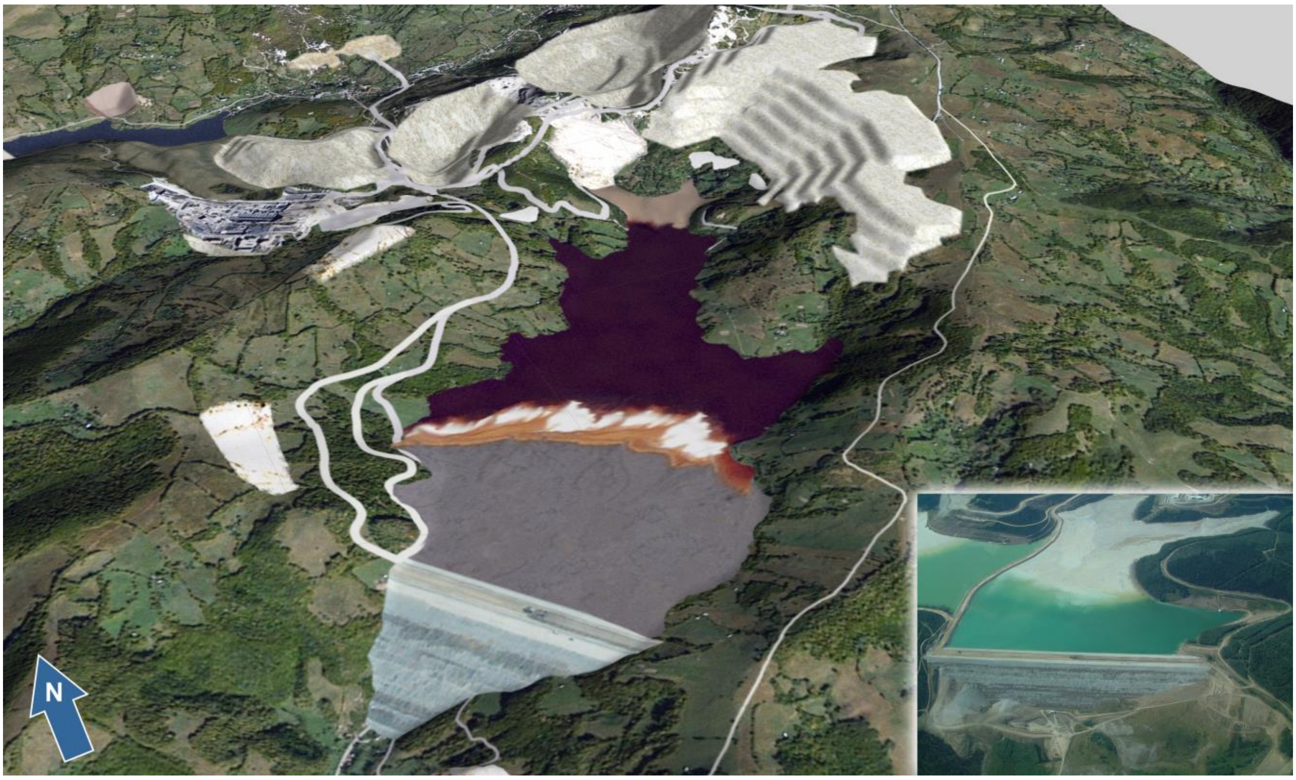

Fig.5 Simulated SPOT image of year 7 (photo in bottom right contains the texture sample for the tailings dam)

existing tailings ponds, mining pits, quarries and other features in the surrounding region (most notably the copper mine near Roşia Poieni) it was possible to generate hypothetical images of the planned changes. Textures could be obtained from other sources as well, for example, Fig. 5 shows the tailings pond in year 7 of the project, with the dam's texture copied from the photo in the bottom right corner.

Creating the visual appearance of roads was done by using the simple paintbrush tools and taking a colour similar to that found on the majority of existing roads in the image. The modifications were then subjected to various colouring and artistic effects to increase the level of similarity to the original satellite image. As with the terrains, the satellite images were also produced in five versions, which were later used in animations and time-series composite images.

RESULTS

The simulated terrain models are shown in Fig 6. Another aspect of the results was the estimation of land cover changes in the area. Based on the simulated SPOT satellite images and the original CORINE (EEA 2000) land cover 2006 (CLC2006) map of the study area it was possible to create a time series of the planned changes. The process involved removing any CLC2006 polygons from within the affected areas and repopulating these blanks with new polygons according to the modified SPOT image data. Analysing the relationship between current conditions on SPOT and CLC2006 it was quite possible to determine the changed land cover category. The simulated land cover of the reclaimed waste dumps takes into account the passage of time as well. This means that in project years 14 and 16 they are classified as scrub, while in year 20 they change into mixed forest, assuming the areas would be planted with fast growing trees. The time series maps of the simulated CLC data are shown in Fig. 7.

Using the source CLC2006 data and the boundary polygon encompassing all the planned mining features it was also possible to calculate the ratio of land cover types that will be impacted by the project. The boundary polygon was created by merging all the clipping polygons used in the TIN generation stage. Table 1 shows the results of this analysis. The percentage should be interpreted as the ratio of the land cover class within the area affected by mining.

Table 1 Distribution of different land cover types based on the CORINE land cover data for the year 2006

CLC2006 code	Land cover class	Area (%)	Area (ha)
311	Broad-leaved forest	40.56	379.22
231	Pasture	25.87	241.87
131	Mineral extraction site	11.54	107.92
112	Discontinuous urban fabric	9.91	92.63
242	Complex cultivation pattern	8.72	81.48
313	Mixed forest	2.89	27.02
324	Transitional forest-shrub	0.51	4.74
Total		100	934.88

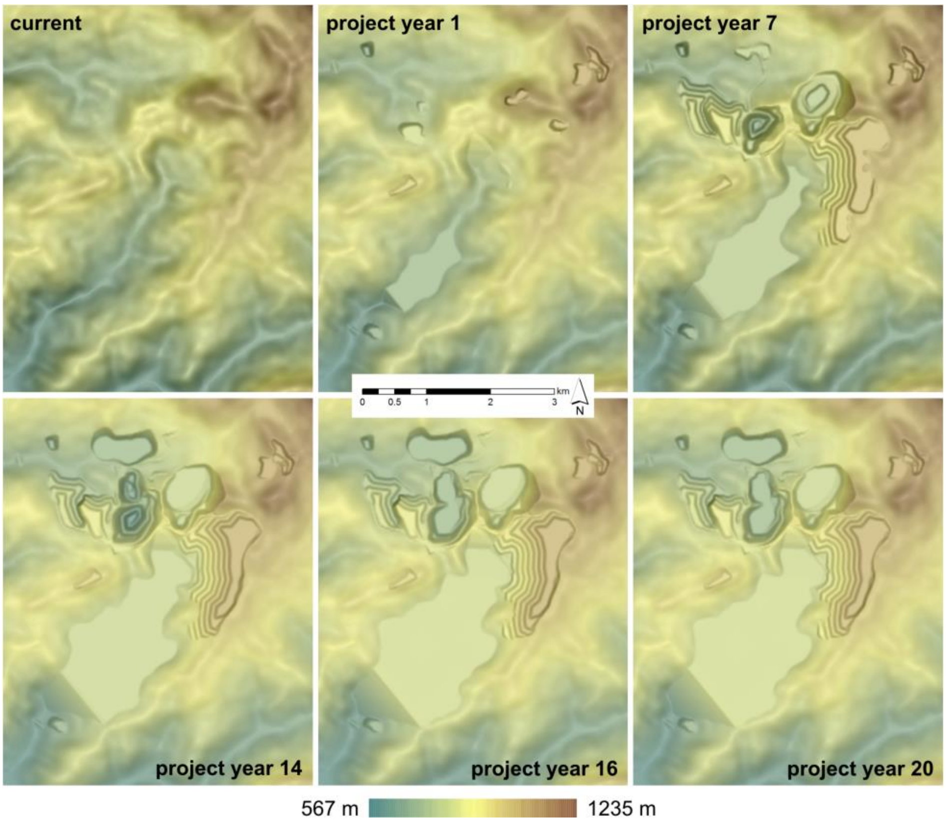

Fig. 6 Time-series maps of the simulated terrain changes

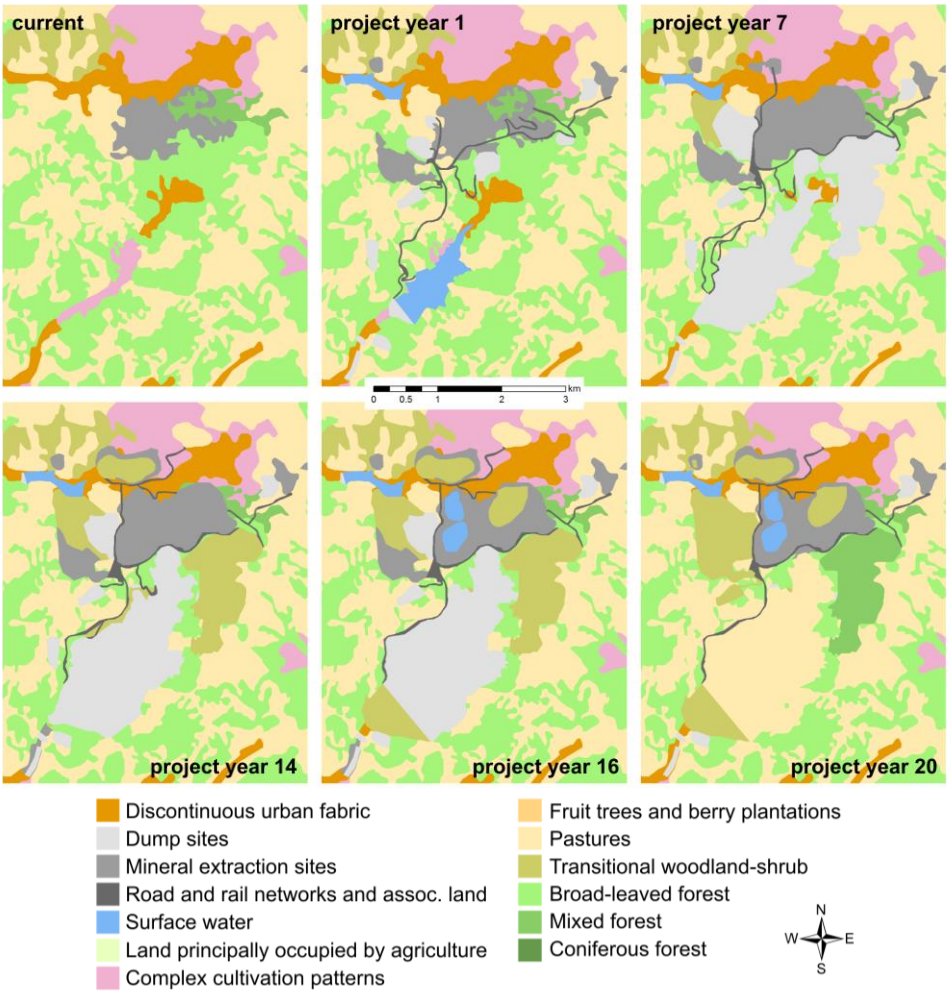

Fig. 7 Results of simulated CLC maps for each mapped project stage

One of the derivatives of the generated terrains was a time-series with the changes in elevation values during the project, shown in Fig. 8.

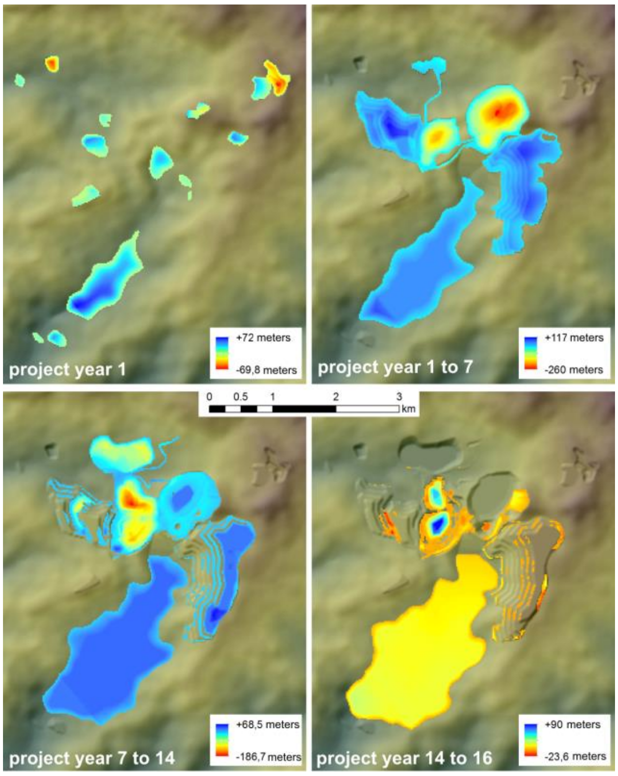

Fig. 8 Elevation changes in the study area

The generated terrain models allowed for the calculation of the volume of the relocated materials between each stage. The resulting figures are only estimates; their accuracy depended on the spatial resolution of the input surface models (20 metres) and the accuracy of the baseline, refined EU-DEM data.

One additional issue regarding the volume changes was that one of the four main mining pits (called Jig) did not appear in the RMGC maps in its excavated state. The plan for year 7 showed nothing in its area, while the one for year 14 showed that the pit has already been completely filled back with material. This meant that the volume of rock moved from and to Jig was left unknown. Table 2 lists the calculated amounts, with the limitations described above.

The calculations reveal that 529 million cubic metres of rocks and other materials are going to be relocated during the 16 years of active mining. The RMGC map after year 16 showed no changes in the terrain, mostly because the focus during those years is on reclamation of the disturbed areas. The two pit lakes in the Cetate pit and the extraction surfaces in neighbouring Carnic and Orlea pits will remain untreated as mining exhibits. The tailings pond is planned to be reclaimed as low value grazing land or managed grassland. The toxic compounds within the tailings material will require several decades to decompose properly into less dangerous chemicals, but the topsoil would be transported from stockpiles collected from other areas beforehand. The relocated materials were also visualised in a series of maps. The blue areas are those where material has been removed, the red patches cover the areas where material has been deposited (Fig. 9).

Table 2 Results of volume change calculations for each stage and the full project duration (thousand cubic metres)

Mining feature	Present – yr. 0	Year 0 – 7	Year 7 – 14	Year 14 – 16	Total
dump North of tailings pond	2,216.80	0	0	0	2,216.80
sandstone quarry	-1,256.82	0	0	0	1,256.82
andesite quarry	-3,313.85	0	0	0	3,313.85
andesite quarry waste dump	1,334.66	0	0	0	1,334.66
topsoil pile south of tailings dam	1,005.98	0	0	0	1,005.98
Carnic waste dump	1,029.49	45,551.14	14,778.60	0	61,359.23
Carnic pit	-127.53	-71,514.01	-47,862.92	-91.77	-119,596.23
Cetate pit	0	-23,955.94	-45,190.33	0	-69,146.27
Cetate waste dump	2,420.90	26,951.20	0	-297.72	29,074.38
Orlea pit	0	-274.69	-18,482.88	0	-18,757.57
Cetate lakes (water)	0	0	0	9,193.02	9,193.02
tailings reservoir	20,549.74	59,741.77	81,059.31	52,385.16	213,735.98
Total volume of relocated material (absolute value)					529,990.79

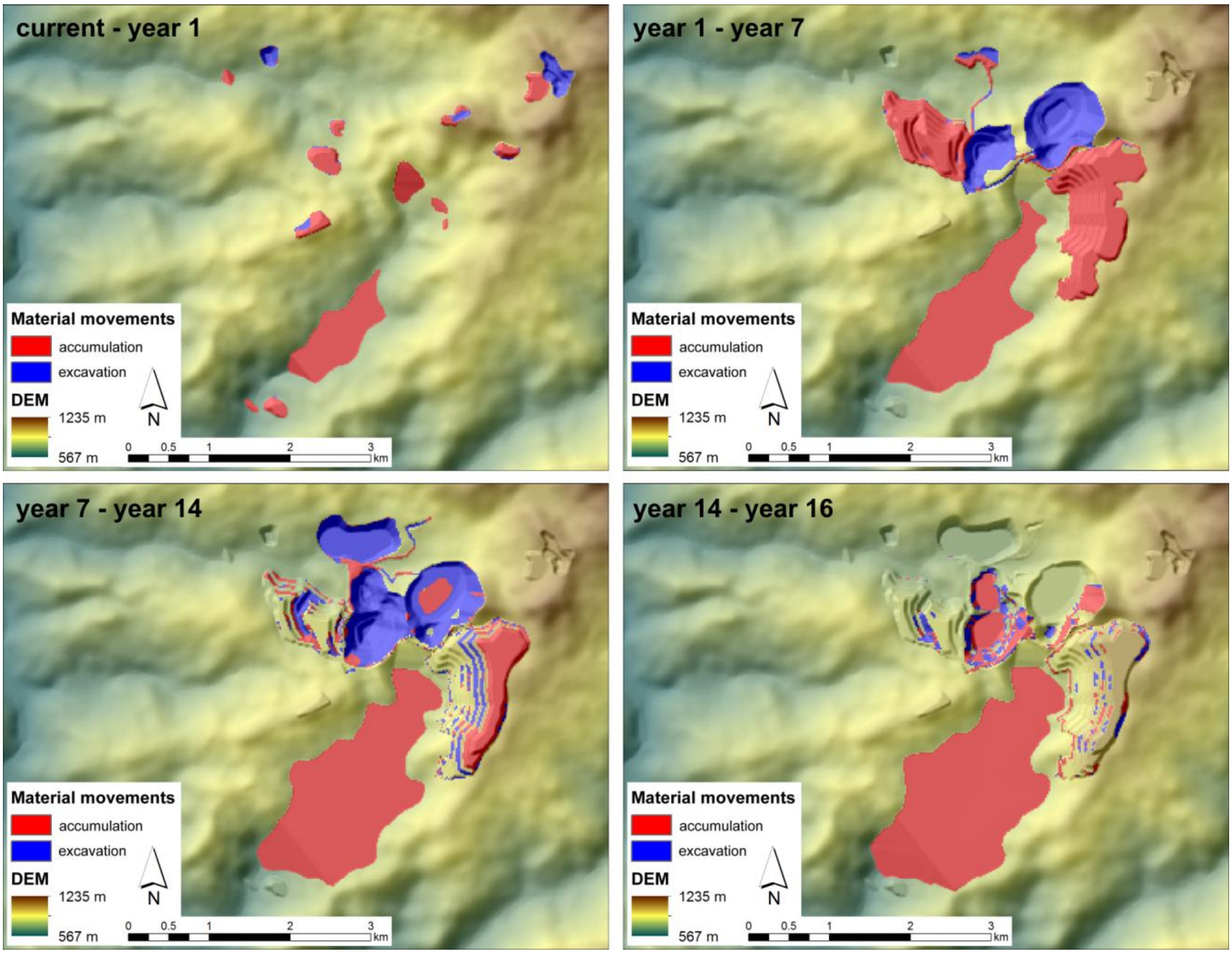

Fig. 9 Areas of material relocation during the stages of the project

DISCUSSION AND CONCLUSIONS

Environmental or infrastructural investments triggering significant changes require comprehensive impact assessment. Spatial decision support systems include tools enabling the creation of alternative scenarios. They also offer access to visual information and visual analytics functionality. These capabilities made such systems widely applied and an essential part of analyses of possible future geo-scenarios (Sheppard and Cizek, 2009; Pettit et al., 2011; Sheppard, 2012). The NIMBY syndrome ("not in my backyard" attitude expressing low public acceptance or opposition by residents to new proposals) is a frequently experienced situation (Wolsink, 2007). Landscape modelling extended by advanced visualisation methods for communication of landscape futures scenarios to stakeholders can enlighten hidden aspects of projects facilitating better understanding of pros and cons (Pettit et al., 2011).

The analyses performed on the simulated terrain data covering the area of the largest open cast gold mine in Europe have also revealed several results unforeseen without the presented unconventional, combined environmental and digital elevation modelling techniques (Barton et al., 2015). Some of these offer deeper insight into information already known from the RMGC EIA reports and studies (Haiduc, 2003; Paşca, 2010; RMGC, 2015), but some shed light on previously unknown consequences or details.

The terrain modelling processes developed during the research offer much more usable surfaces by combining the best characteristics of raster and vector methods, as the planned surface requires them. They allow the analyst to simulate terrain changes based on nothing more than the maps of the planned developments. The visual impact simulation process (performed by editing satellite images using standard graphics software) offers an inexpensive, efficient and creative way to visualise the changes in the landscape. The resulting terrain and image data can be displayed in 3D images and animations for better explaining the results to the community.

Area and volume calculations show that approximately 0.5 cubic kilometres of rock and other materials would be relocated during the planned mining project. When this amount is compared to the 300 metric tons of gold and 1600 tons of silver RMGC is expecting to extract we can see how disproportionate it is. The relatively low grade of the deposits in the area results in a very large impacted zone (934 hectares), 1/3 of which is taken up by the tailings pond in Corna Valley. This will contain more than 200 million cubic metres of waste material left behind from the cyanide leeching processes and will require close monitoring and management for several years after the project is closed.

The toxic compounds will make any meaningful land use very difficult in the future while it poses a potential threat to both the environment and the health and safety of the population downstream. Having a 180-metre high dam just 1700 metres from a town of 5000 people (Géczi et al., 2005), which is holding back thousands of tons of toxic sludge can easily be called irresponsible. Unless all the safety and building material requirements are strictly enforced, the dam will be liable to failure and this disaster would certainly have a severe impact on the River Maros. The river flows through densely populated regions of Central Western Romania, much of which relies on the river for irrigation and drinking water. Since there are already numerous mining operations in the region acting as additional pollution sources, it is very difficult to rationalise the introduction of such a high risk factor into the system. Thinking back on ecological and subsequent economic consequences of the Tisza cyanide disaster in 2000 (caused by a fraction of tailings material than what is planned in Roşia Montană) it is easy to imagine how severe an impact a dam breach would cause.

The modelling shows that the project would irrevocably turn the area into a highly industrial landscape. While it is true (if the company can live up to its word) that many of the currently observable pollution sources would be eliminated, we cannot forget about the new potential risks that would be introduced, especially the tailings reservoir. It is also very flexible whether the company can actually offer the amount of employment opportunities it is advocating in it campaign for the mine. Moreover, this amount will inevitably decrease with time as new and more efficient technologies are constantly being developed.

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