

ASSESSMENT OF THE TILT PHENOMENON AND THE TILT DISTANCE OF THE LAND AS AN EFFECT OF COAL MINING, JIU VALLEY BASIN, ROMANIA

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Abstract: *The aim of the study was to evaluate the phenomenon of land tilting and the tilting distance as a secondary effect of surface coal mining in the Jiu Valley area, Romania. To evaluate the tilting phenomenon, through the two considered elements (inclination – Lt, tilting distance – Td) 16 control points (CP1 to CP16) were used whose coordinates were measured in the Stereographic 1970 projection system, the 1975 Black Sea elevation system at an initial moment (t_0) and at the current moment (t_1). The static method was used by GPS technology to measure the elevations of the control points. Through descriptive statistical analysis, a general characterization of the set of recorded values was obtained, and the ANOVA test confirmed the safety of the data and the presence of variance in the data set. From the analysis of the recorded values, a Spline type model was obtained that described the variation of Lt in relation to Td, under conditions of statistical safety ($\bar{\epsilon} = 0.137302$). Regression analysis facilitated the obtaining of equation-type models, which described the variation of Lt and Td in relation to the X, Y and Z coordinates of the control points (t_0 , t_1), under conditions of statistical certainty ($R^2 = 0.697$, $p = 0.014$ for Td variation according to Z_0 and Z_1 ; $R^2 = 0.722$, $p = 0.0094$ for Td in relation to X_0 and Z_0). According to PCA, PC1 explained 61.303% of variance, and PC2 explained 38.697% of variance. The cluster analysis facilitated the obtaining of a dendrogram based on Euclidean distances, regarding the grouping based on the similarity of the control points in relation to the studied phenomenon, under conditions of statistical safety (Coph. corr.=0.957).*

Keywords: Land tilt, tilt distance, coal mining, Spline model, regression analysis

1. Introduction

The exploitation of different categories of resources from the earth's crust can be done with different technologies, depending on the type of resources and their location in the deposits formed in relation to the surface of the soil, in surface quarries or in underground mines, with major implications on ecosystems and the environment in whole [1], [2], [3].

For a long period of time, coal represented an important energy resource, which facilitated the development of human society, was exploited in different technical and efficient conditions, with socio-economic but also environmental impact, and currently approaches regarding the sustainable exploitation of coal are of interest [4], [5], [6], [7], [8].

Mining greatly affects the morphology of the land surface and soil structure, and the restoration of the vegetation on the affected lands, within a complex of measures, as a post-exploitation process, is an effective way to restore natural balances, to preserve habitats and mitigate the ecological and social impact -economic [9], [10], [11].

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The lands and soil in the areas affected by mining were also studied from pedogenetic, morphological, physical, chemical, biological and microbiological perspectives, as a detectable effect of mining activities, but also from the perspective of the effect on vegetation, agriculture, quality of life, but and by ecological restoration and reconstruction [12], [13], [14], [15].

The reduction of soil fertility and soil degradation were evaluated in relation to land subsidence in the specific conditions of some coal mining areas [16].

The areas affected by coal mining have been studied and evaluated through the prism of specific elements of land surface modification (eg sinking, sliding, tilting, categories of use, economic use, etc.) in order to characterize the extent of the phenomena, to make forecasts, to provide data and information for an adequate management of the affected areas [17], [18], [4], [19].

At the same time, the affected areas were studied for the purpose of their recovery, ecological and socio-economic reintegration by re-vegetating the lands affected and disturbed by mining in order to make hay, pastures or cultivated lands [20], by restoring the landscape post-mining [21], reforestation [22], etc.

For this purpose, the use of germplasm adapted to local or zonal Eco physiological conditions can be considered [23], different methods were used based on genetically modified plants, adapted for such places [24], the promotion of green technologies in the recovery and re-cultivation of affected lands [25], the use of techniques based on mycorrhization of the planted biological material [26].

In the context of the interest for these categories of land, the study proposed to evaluate the phenomenon of tilting and the distance of the tilting of the land as an effect of coal mining, in the area of the Jiu Valley, Romania.

2. Materials and method

In order to evaluate the tilt of the land and the distance from the tilt, as a secondary effect of the mining activities (coal mines), an area in the Jiu Valley, Romania, was considered for the study. 16 control points (CP) were identified, for which the coordinates were measured in the Stereographic projection system 1970, the Black Sea elevation system 1975 at a time t_0 (reference time) and at a time t_1 , in order to capture possible differences between the initial values (t_0) and the final ones (t_1). The area under study, with an area of 95403.89 ha, is located in the Jiu Valley, Romania, with a general presentation of the terrain tilt in figure 1.

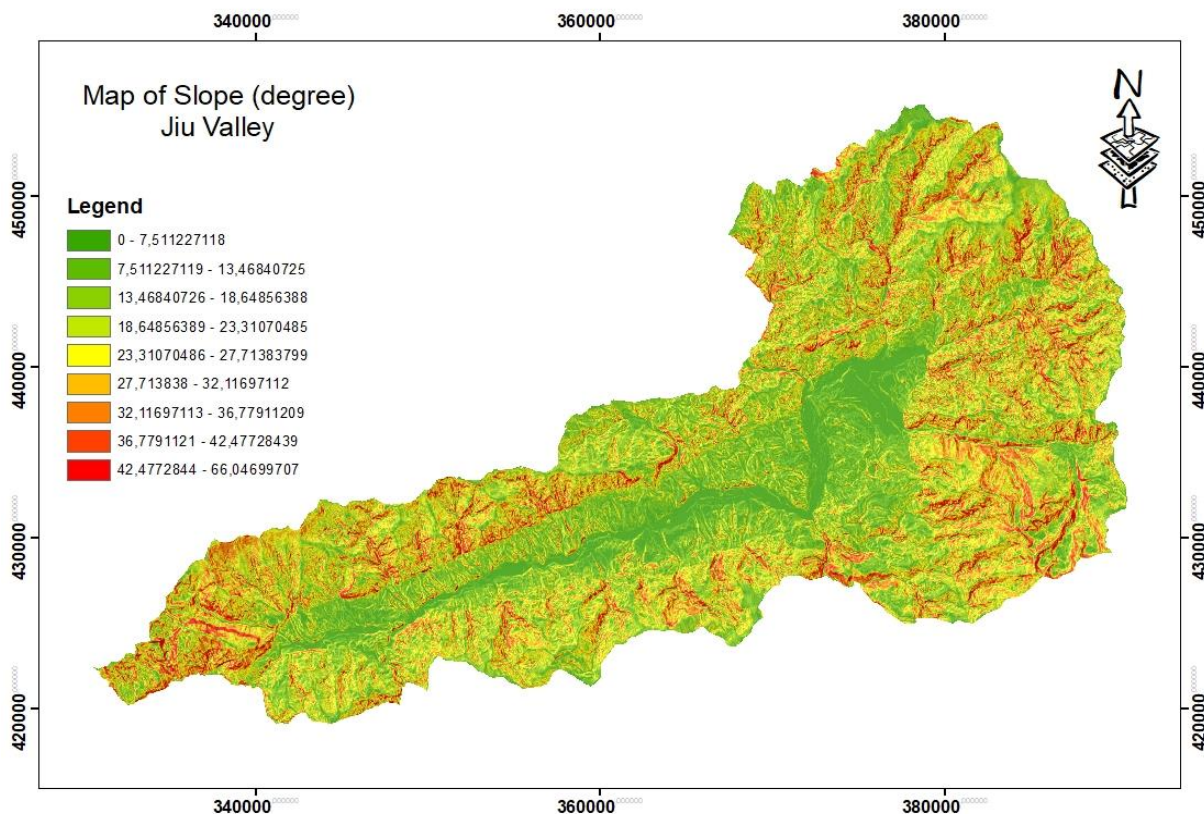


Figure 1. Map of Slope, Jiu Valley, Romania

The tilt of the land and the distance from the tilt were studied, phenomena that appear as consequences of the mining operations in the area under consideration.

Underground mining has the effect of moving and deforming the land following the extraction of useful mineral matter.

These land surfaces, affected by underground exploitations, require monitoring in time and the realization of real-time forecasts for the purpose of integrated management measures to protect the land surface and the existing constructions on it, to mitigate the manifestation of this phenomenon and ensure a sustainable development in the respective areas, these being generally mono-industrial areas and disadvantaged areas.

In the conditions of the present study, the tilt of the land surface and the tilt distance were analyzed.

The tilt of the surface represents the inclination of an area - the segment between two tracking points - on the surface, relative to its initial position. This represents the differential variation of the vertical movement and is determined by the ratio between the differences in the dips of two consecutive observation landmarks and the horizontal distance between them, equation (1). Tilt is a deformation of the surface due to subsidence and has nothing in common with the physical tilt of the land surface.

$$I_i = \frac{S_{i+1} - S_i}{D_{i,i+1}} \quad (1)$$

where: S_i - the sinking of the current landmark; S_{i+1} - sinking the next landmark; $d_{i,i+1}$ - the horizontal distance between the two landmarks.

The tilt distance (Td) represents the horizontal component of the point displacement vectors. It is the horizontal displacement of a point compared to its predecessor, located in the zone of influence of the exploitation. It is determined by the difference between the current distance and the same distance initially measured (before the sinking phenomenon), equation (2).

$$D_i = D_{i,i+1} - D_{0i,i+1} \quad (2)$$

where: $D_{i,i+1}$ - the horizontal distance between the two landmarks at the current measurement; $D_{0i,i+1}$ - the horizontal distance between the same two landmarks at the "zero" measurement.

For the area proposed for tracking the inclination and the distance to the inclination, of the land surface in the Maleia mining area, the stable area and the area that is subject to movement were defined. Two types of landmarks were also considered: some for horizontal and vertical movements and others only for vertical movements. Four pairs of landmarks were placed in the stable area to determine horizontal and vertical movements.

Land surface movement tracking landmarks and topo-geodetic measurements were performed using GPS technology, L1/L2 Topcon dual frequency receivers. The GPS measurement method used for geodetic accuracy is the static method.

PAST software [27], and Wolfram Alpha (2020) [28] were used to process the recorded data.

3. Results and discussion

For the characterization of the land in the study area, respectively the phenomenon of land tilting and the tilting distance, 16 control points were considered for which the elevations were measured.

The data on the elevations at two different moments of measurement (t_0 and t_1), table 1, were useful for evaluating the phenomenon of land tilt and the tilt distance, values that are presented in table 2. The general aspect of the framing area of the study area, regarding the tilt of the land, Jiu Valley, Romania, is presented in figure 1.

The ANOVA test confirmed the safety of the data and the presence of variance in the data set collected in the study ($p < 0.001$, $F > F_{crit}$, for $\alpha = 0.001$), table 3.

The land tilting phenomenon (Lt) in relation to the tilting distance (Td) was described by a spline type model, under statistical safety conditions, table 4, for which the values were calculated with equation (3).

$$\bar{\varepsilon} = \left(\sum_{i=1}^n \varepsilon_i \right) / n = \left(\sum_{i=1}^n \left| \frac{y_{S_i} - y_i}{y_i} \right| \right) / n \quad (3)$$

Table 1. Statistical description of the values recorded at the control points, the study area, Jiu Valley, Romania

Statistical parameter	t_1 (current measurement)			t_0 (reference measurements)		
	X_1	Y_1	Z_1	X_0	Y_0	Z_0
N	16	16	16	16	16	16
Min	373708.6	435197.4	647.994	373708.6	435197.4	648.0599
Max	375838.1	436735.4	830.6045	375838.1	436735.4	830.6333
Mean	375023.5	436133	763.6769	375023.5	436133.1	763.6596
Std. error	178.0901	112.8642	15.27511	178.0889	112.8628	15.27544
Variance	507457.3	203813.2	3733.262	507450.6	203808.1	3733.423
Stand. dev	712.3603	451.4567	61.10043	712.3556	451.4511	61.10175
Median	375150.9	436153.9	774.9239	375150.9	436153.9	774.4535
25 prcntil	374537.5	435992.3	703.3972	374537.5	435992.3	703.4014
75 prcntil	375557.1	436509	824.0965	375557.1	436509	824.1838
Coeff. var	0.189951	0.103514	8.000822	0.18995	0.103512	8.001175

Table 2. Data regarding the tilt of the land in the study area, Jiu Valley, Romania

Control point	Tilt parameters	
	Land tilt (mm/m)	Tilt distance (m)
PC1	0	0
PC2	0.27764	19089.539
PC3	0.09200	635870.481
PC4	4.45942	11526.168
FP5	-4.77032	219985.336
FP6	4.88820	195961.784
FP7	-0.02978	1222115.108
FP8	2.24968	32715.694
PC9	-0.00391	1993147.689
PC10	-0.09710	683839.294
PC11	0.70407	49852.956
PC12	0.04838	1366331.720
PC13	-0.16614	432770.403
PC14	-0.11568	414932.795
PC15	0.03310	1480455.999
PC16	0.03605	809905.344

Table 3. ANOVA test

Source of Variation	SS	df	THX	F	P-values	F crit
Between Groups	6.44E+12	7	9.19E+11	19.08644	5.98E-17	3.766975
Within Groups	5.78E+12	120	4.82E+10			
Total	1.22E+13	127				

Table 4. Statistical values related to the spline model, to describe the tilt phenomenon in relation to the tilt distance

Trials data		Lt in relation to Td			
No	x_i	y_i	ys_i	e_i	$I_{i/1}$
PC1	0	0	0.15635	0	1.00000
PC2	19090	0.27764	0.85167	2.06753	5.44720
PC3	6.36E+05	0.09200	0.09188	-0.00135	0.58763
PC4	11526	4.45940	3.87570	-0.13089	24.78862
FP5	2.20E+05	-4.77030	-4.75790	-0.00260	-30.43108
FP6	1.96E+05	4.88820	4.87470	-0.00276	31.17813
FP7	1.22E+06	-0.02978	-0.02978	-0.00013	-0.19044
FP8	32716	2.24970	2.06230	-0.08330	13.19028
PC9	1.99E+06	-0.00391	-0.00391	0.00000	-0.02501
PC10	6.84E+05	-0.09710	-0.09699	-0.00109	-0.62036
PC11	49853	0.70407	0.74682	0.06072	4.77659
PC12	1.37E+06	0.04838	0.04837	-0.00008	0.30940
PC13	4.33E+05	-0.16614	-0.16271	-0.02065	-1.04068
PC14	4.15E+05	-0.11568	-0.11994	0.03683	-0.76713
PC15	1.48E+06	0.03310	0.03310	0.00006	0.21170
PC16	8.10E+05	0.03605	0.03604	-0.00047	0.23049

$$\bar{\varepsilon} = 0.137302$$

The graphical distribution of the tilt values in relation to the tilt distance, according to the Spline model, is shown in figure 2.

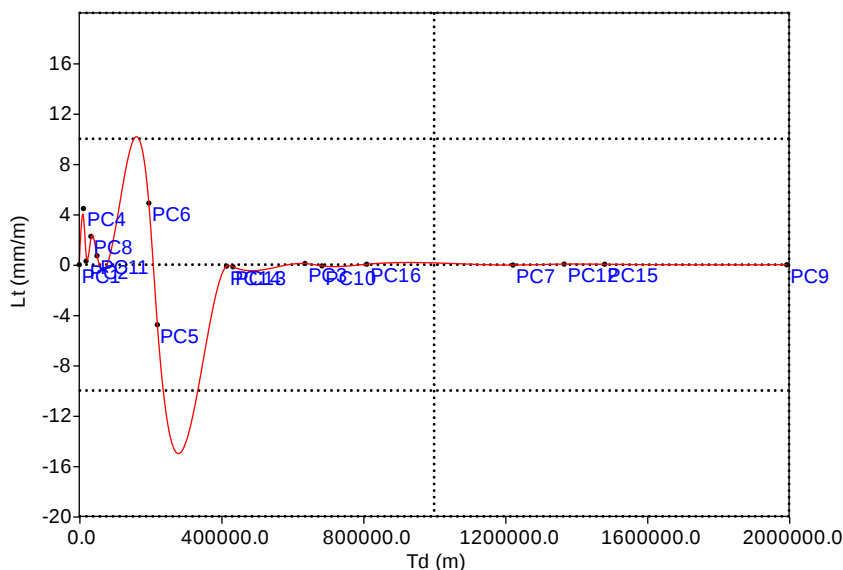


Figure 2. Tilt in relation to tilt distance, spline model, Valea Jiului, Romania

Taking into account the overall aspect of the area under study, and the variation of the values recorded for the inclination and the distance to the inclination of the land in the specific conditions of the Jiu Valley, Romania, an analysis was made of the variance of these elements (Lt, Td) in relation to with the elevation values of the 16 control points (PC1 to PC16).

The multiple regression analysis was used, which analyzed the variation of the studied elements Lt and Td according to the quotas at the reading times t_0 and t_1 . Based on this analysis, models of variation of Lt and Td were found, under statistical safety conditions only in relation to X_0 , Z_0 and Z_1 . The models found were of the form $f(X_0, Z_0)$ and $f(Z_0, Z_1)$.

The variation of the Lt Parameter according to Z_0 and Z_1 was described by equation (4), under general statistical safety conditions ($p=0.056$). The 3D graphical representation is shown in figure 3, and the graphical representation in the form of isoquants is shown in figure 4. For the minimum tilt of the land, the optimal values for x (Z_0) and y (Z_1) were found in the amount of $x_{\text{eight}} = 695.3124464$, and for $y_{\text{eight}} = 695.2819745$.

$$Lt = ax^2 + by^2 + cx + dy + exy + f \quad (4)$$

where: $x - Z_0$; $y - Z_1$; a, b, c, d, e, f – coefficients of the equation (4); $a = 9.42472457$; $b = 9.23983431$; $c = -129.11873162$; $d = 129.12611575$; $e = -18.66456825$; $f = 0$.

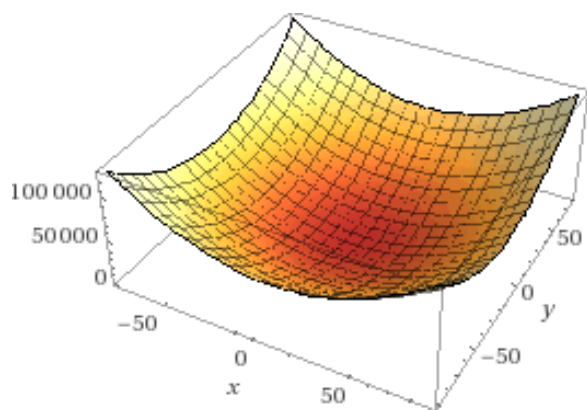


Figure 3. 3D graphic representation of the Tilt variation in relation to the x (Z_0) and y (Z_1) elevations of the land in the study area

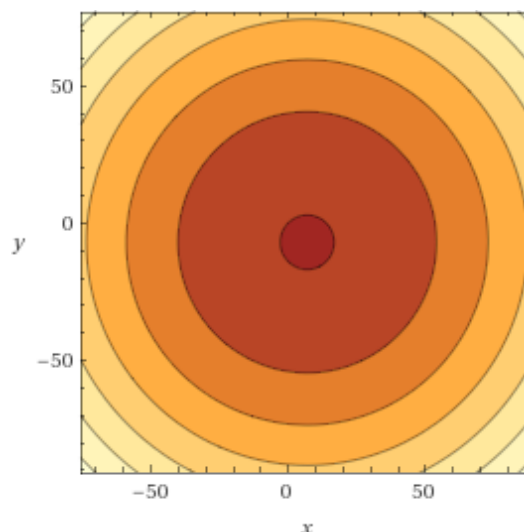


Figure 4. The distribution in the form of isoquants of the Tilt values according to x (Z_0) and y (Z_1) in the study area

Similarly, multiple regression was used to find out the variation of the tilt distance (Td) according to the values of the X_0 , Z_0 and Z_1 elevations. The result was equation (5) which described in statistical safety conditions ($R^2=0.697$, $p=0.014$) the variation of Td according to Z_0 and Z_1 . The 3D graphical distribution is shown in figure 5. The graphical distribution in the form of isoquants is shown in figure 6. For the minimum tilt distance (Td) of the land, the optimal values for x (Z_0) and y (Z_1) were found in the quantum of $x_{\text{eight}}=805.038805$, and for $y_{\text{eight}}=805.0132269$.

$$Td = ax^2 + by^2 + cx + dy + exy + f \quad (5)$$

where: $x - Z_0$; $y - Z_1$; a, b, c, d, e, f – coefficients of the equation (5); $a= 5501184.92280514$; $b= 5681441.05912441$; $c= 144823270.924133$; $d= -144826425.708353$; $e= -11182621.1588526$; $f = 0$.

Looking at the variation of Td according to X_0 and Z_0 , the multiple regression analysis resulted in equation (6) under statistical safety conditions ($R^2=0.722$, $p=0.0094$). The 3D graphical distribution is shown in figure 7, and the distribution in the form of isoquants is shown in figure 9. For the minimum tilt distance (Td) of the land, the optimal values for x (X_0) and y (Z_0) were found in the quantum of $x_{\text{eight}}=375397.8685$, and for $y_{\text{eight}}= 777.1035984$.

From the analysis of the values but also of the 3D graphic distribution, it was found that under the study conditions, the variation of Td in relation to X_0 and Z_0 was very strongly influenced by the elevation Z_0 (y axis, fig. 7) for which the value was found optimal $y_{\text{eight}}= 777.1035984$. Under the same conditions, the ratio of the X_0 rate to the Td variation was negligible.

$$Td = ax^2 + by^2 + cx + dy + exy + f \quad (6)$$

where: $x - X_0$; $y - Z_0$; a, b, c, d, e, f – coefficients of the equation (6); $a= 0.01676537$; $b= 182.73301809$; $c= -5999.10099842$; $d= 2898613.41143636$; $e= -8.47798735$; $f = 0$.

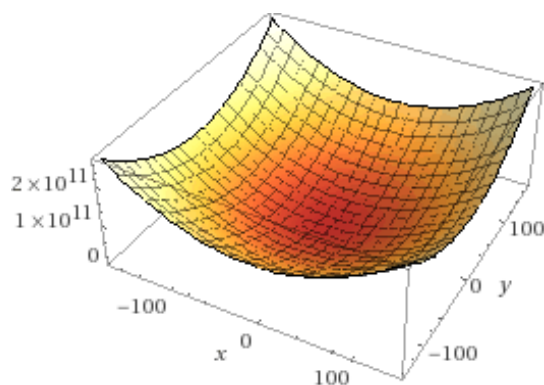


Figure 5. 3D graphic representation of the Td variation in relation to the x (Z_0) and y (Z_1) elevations of the land in the study area.

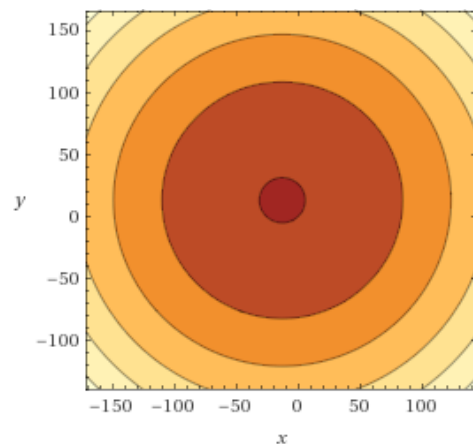


Figure 6. Distribution in the form of isoquants of Td values depending on x (Z_0) and y (Z_1) in the study area

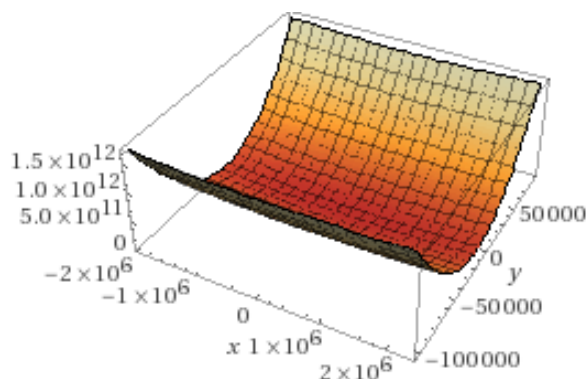


Figure 7. 3D graphic representation of the Td variation in relation to the x (X_0) and y (Z_0) elevations of the land in the study area

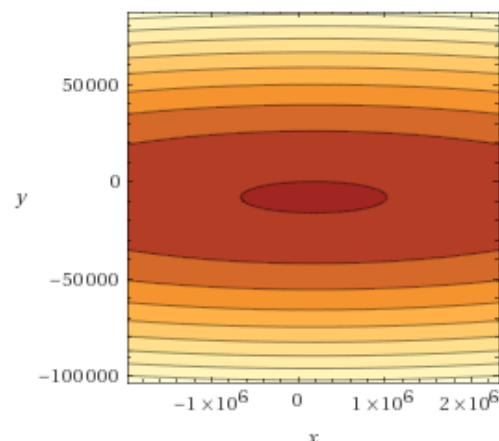


Figure 8. Distribution in the form of isoquants of Td values depending on x (X_0) and y (Z_0) in the study area

According to PCA, the distribution diagram of the control points was obtained in relation to the land tilt phenomenon, through the prism of the two elements considered, Lt and Td, figure 9. PC1 explained 61.303 % of variance, and PC2 explained 38.697 % of variance. From the analysis of the distribution of control points, it was found the orientation and association of some points with Lt (PC4, PC6), the association of some points with Td (PC9, PC15, PC12, PC7), as well as the intermediate or independent positioning (eg PC5) of other points control.

The cluster analysis led to the grouping of the control points, as a trial point, in relation to the tilting phenomenon, under conditions of statistical safety (Coph. corr. =0.957), figure 10. In the case of the obtained dendrogram, based on the Euclidean distances, the independent positioning of the PC5 point and the association of the other points in several clusters and sub-clusters were found, in relation to the degree of similarity for the studied inclination phenomenon.

From the analysis of the dendrogram in figure 10 and the SDI values (table 5), it was found a high level of similarity of the control points in relation to the phenomenon of land tilt, through the prism of the studied elements. High level of similarity was registered at control points PC15 and PC16, PC1 and PC9, PC12 and PC16, PC12 and PC15. The set of SDI values obtained for all control points is presented in table 5.

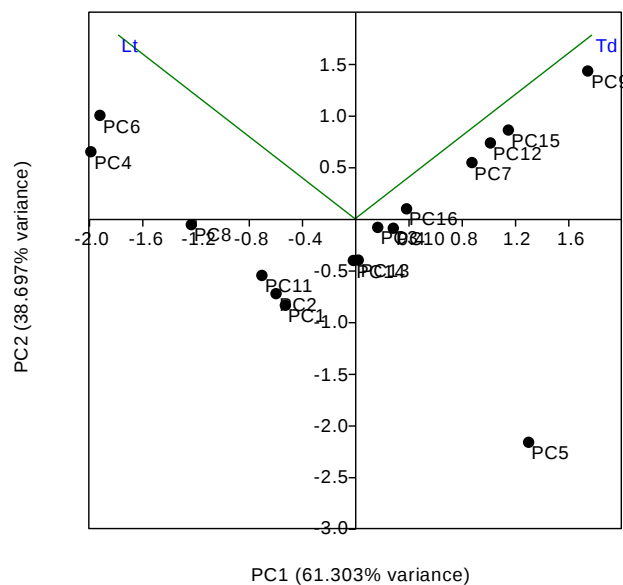


Figure 9. PCA diagram regarding the distribution of control points in relation to the tilting phenomenon and the tilting distance

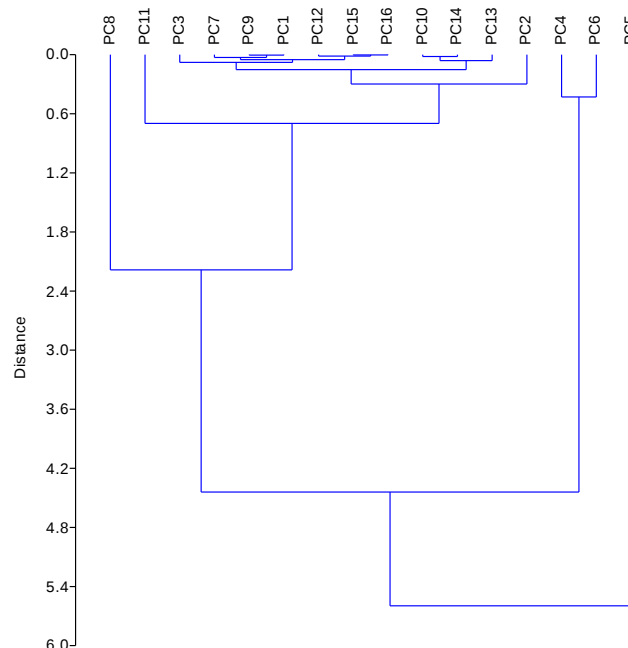


Figure 10. Dendrogram of the grouping of control points (CP) in relation to the phenomenon of land tilt in the studied area, Jiului Valley, Romania

Table 5. SDI values regarding the similarity of control points in relation to the phenomenon of land tilt

	PC1	PC2	PC3	PC4	FP5	FP6	FP7	FP8	PC9	PC10	PC11	PC12	PC13	PC14	PC15	PC16
PC1		0.278	0.092	4.459	4.770	4.888	0.030	2.250	0.004	0.097	0.704	0.048	0.166	0.116	0.033	0.036
PC2	0.278		0.186	4.182	5.048	4.611	0.307	1.972	0.282	0.375	0.426	0.229	0.444	0.393	0.245	0.242
PC3	0.092	0.186		4.367	4.862	4.796	0.122	2.158	0.096	0.189	0.612	0.044	0.258	0.208	0.059	0.056
PC4	4.459	4.182	4.367		9.230	0.429	4.489	2.210	4.463	4.557	3.755	4.411	4.626	4.575	4.426	4.423
FP5	4.770	5.048	4.862	9.230		9.659	4.741	7.020	4.766	4.673	5.474	4.819	4.604	4.655	4.803	4.806
FP6	4.888	4.611	4.796	0.429	9.659		4.918	2.639	4.892	4.985	4.184	4.840	5.054	5.004	4.855	4.852
FP7	0.030	0.307	0.122	4.489	4.741	4.918		2.280	0.026	0.067	0.734	0.078	0.136	0.086	0.063	0.066
FP8	2.250	1.972	2.158	2.210	7.020	2.639	2.280		2.254	2.347	1.546	2.201	2.416	2.365	2.217	2.214
PC9	0.004	0.282	0.096	4.463	4.766	4.892	0.026	2.254		0.093	0.708	0.052	0.162	0.112	0.037	0.040
PC10	0.097	0.375	0.189	4.557	4.673	4.985	0.067	2.347	0.093		0.801	0.145	0.069	0.019	0.130	0.133
PC11	0.704	0.426	0.612	3.755	5.474	4.184	0.734	1.546	0.708	0.801		0.656	0.870	0.820	0.671	0.668
PC12	0.048	0.229	0.044	4.411	4.819	4.840	0.078	2.201	0.052	0.145	0.656		0.215	0.164	0.015	0.012
PC13	0.166	0.444	0.258	4.626	4.604	5.054	0.136	2.416	0.162	0.069	0.870	0.215		0.050	0.199	0.202
PC14	0.116	0.393	0.208	4.575	4.655	5.004	0.086	2.365	0.112	0.019	0.820	0.164	0.050		0.149	0.152
PC15	0.033	0.245	0.059	4.426	4.803	4.855	0.063	2.217	0.037	0.130	0.671	0.015	0.199	0.149		0.003
PC16	0.036	0.242	0.056	4.423	4.806	4.852	0.066	2.214	0.040	0.133	0.668	0.012	0.202	0.152	0.003	

The spatial and temporal interaction between coal extraction in surface quarries, land cover and changes in the use of directly affected or neighboring land surfaces have been taken into account in some studies, with the aim of sustainable mining [29].

In order to optimize the recovery measures of the lands affected by mining, the content and the variation of the content of nutrients in the soil were taken into account and studied in relation to possible categories of land use [30].

Land instability as a result of mining works was studied in relation to different factors (type of rocks, humidity conditions) that generated certain physical and mechanical characteristics and led to land instability [31].

Soil erosion has been studied in relation to agricultural and mining activities, from the perspective of the threat to the balance of ecosystems [32].

The Valea Jiului area, Romania, presented interest for study from different ecological, economic and social perspectives. The water quality was studied from the perspective of the content of heavy metals and some chemical compounds that affect its various uses [33]. Similar research was carried out regarding the quality of water and some sediments in the Cavnic mining area and the Lapus river [34].

Polluting aspects with heavy metals, associated with mining activities in the exploitation of some resources of interest have been evaluated in different mining basins around the world [35], [36].

In the context of the high interests given to the areas and land surfaces affected by coal mining, for the purpose of their monitoring, their ecosystem integration, socio-economic valorization, the present study contributed to an analysis regarding the tilt and tilt distance and provided information and approach models for the purpose of adequate management of these land categories.

4. Conclusions

The approach used in the present study facilitated the analysis and evaluation of the phenomenon of land tilting and the tilting distance, as a secondary effect of coal mining in Jiu Valley, Romania.

Models of the type of mathematical equations were obtained that described the phenomenon of tilting and the tilting distance in relation to 16 control points, whose elevations were measured at different times (t_1 and t_0).

The PCA analysis facilitated obtaining a distribution of control points in relation to the affinity to the two studied elements (inclination and distance to inclination), which confirmed that the approach method facilitates the clear detection of points in the field for the purpose of high-level highlighting fidelity of the analyzed phenomenon.

The cluster analysis facilitated the obtaining of a dendrogram of grouping the control points in relation to the degree of similarity to the manifestation of the studied inclination phenomenon.

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