GROUND SUBSIDENCE TRIGGERED BY MINING ACTIVITY IN URBAN AND RURAL AREAS OF ALBANIA, ANALYSIS AND GEOENVIRONMENTAL IMPACTS

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ABSTRACT

The impact of mining subsidence on the environment can occasionally be very catastrophic, destroying property and even leading to the loss of life. Usually, however, such subsidence gives rise to varying degrees of structural damage that can range from slight to very severe. The present paper provides some information about geotechnical investigations of the last two decades about ground failures like subsidence, sinkhole and cracking; as well their effects triggered by mining activity in urban and rural areas are here reported. The mining industry has been a very important force in the country's economy since 1950. The extraction process of minerals and raw materials in the mining areas has left a legacy of damage to urban and rural areas surrounding such them. Given the importance of the geo-environmental conditions imposed by mining industry, many field and laboratory works were carried out and the results reported that geo-mechanical properties are affected by the unstable geotechnical conditions. Geotechnical analysis and numerical model were made based on the investigation about the ground failures-subsidence in the mining areas.
Keywords: *land deformation, subsidence, ground cracking, effects and environmental impacts, mining activity, groundwater drainage, settlement, consolidation, GPS surveys, numerical and geotechnical analysis, soils, rocks, physical-mechanical properties*

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1. INTRODUCTION

Albania is very rich in minerals. Exploitation and production of minerals has been an important branch of the country's economy. Traditionally, Albania has produced many minerals and raw materials. The main mineral products of the mining industry exported are chrome, copper, iron-nickel, coals, and construction raw materials. About 42 million/Ton coal, 37 million/Ton chromium and 29.5 million/Ton cupper have been exploited since 1950. 23 chromium and 20 copper deposits which are located in Tropoja, Kukësi, Mirdita, Dibra, Mati, Pogradeci and Korça regions have been exploited. They are related to ultrabasic, volcanic and volcano-sedimentary rocks. In addition, there are 14 main coal deposits, which located in Mborja-Drenova and Gore-Mokër, Tirana, Durrës and Tepelena regions. Coal could be generally found in molasses rocks and less in flysch rocks. Residential homes, industrial areas, schools, road infrastructure, parks have been damaged due to minerals exploitation with serious environmental, economic and social impacts. As damages were mostly caused by land subsidence, engineering geological surveys were made from 2001 to 2019 to investigate the ground failures and the effects caused by mining activity in urban and rural areas (Muceku and Bozo 2002; Tafilaj and Durmishi 2002; Muceku 2005; Muceku *et al*., 2019) are here reported. The geotechnical investigation project area includes all the mine sites where the mining activity caused ground mass movement. In the present paper, the authors shortly describe the geotechnical characteristics and analyze the coal mines of Valiasi and Mëzezi and chromium mine of Bulqiza based on the investigation carried out from 2001 to 2019.

2. MATERIALS AND METHODS

Figure 1 depicts the investigated areas consisting of molasses (Tirana area) and ultrabasic formations (Bulqiza area). The present paper aims to evaluate geotechnical conditions, lithological characteristics, hydro-geological conditions and potential or current mass movements occurred over the present sites.

First, the existing geotechnical data (Tafilaj and Durmishi 2002; Muceku and Bozo 2002; Muceku and Lamaj 2005; Muceku *et al*., 2008; Muceku and Lamaj 2009; Eftimi 2010; Muceku *et al*., 2019) were reviewed and the data reported that three mining areas such as Valiasi, Mëzesi and Bulqiza represent very dangerous sites in terms of land subsidence, sinkholes and ground cracking which were evaluated using the geodesic techniques equipment as the total station and GPS surveys (Muceku 2018).

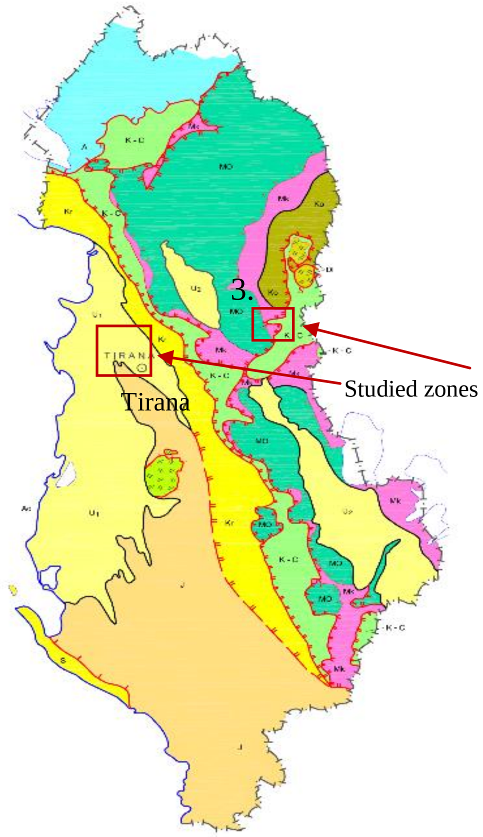


Fig.1: The main geological units of Albania (Xhomo *et al*., 1999) and the investigated areas.

In addition to data review, geotechnical and laboratory investigation were carried out involving engineering geology mapping at the scale 1:500, geotechnical investigations, laboratory tests and SPT-Standard Penetration Test works stabilize these areas (Muceku 2005). The geotechnical works include many boreholes (15.0 up to 30.0 m deep), ground water measurements and collection of many undisturbed and disturbed samples of soils and rocks, which were analyzed in the laboratory for physical and mechanical properties such as grain size, w-natural water content, γo-specific gravity, γ-bulk density, ϕ-internal friction angle, c-cohesion, E-oedometer modulus, Eel-elastic module, υ-poisson ratio and σ-uniaxial compressive strength, etc. Consequently, the lithological profiles and particularly the slide plane depth of the subsidence were obtainable. Once the degree of mass movement is known, the post-mining stabilization techniques as grouting, backfilling etc. could be applied for the stabilization of the mass movement. Numerical model was made for the Mëzesi and Valias coal mine sites to facilitate the intensive investigation process. The model was set up from the theoretical perspective of subsidence in laminated structures. There are several models to describe subsidence, but the present paper uses the model reported in (Yang *et al*., 1993). The theory of soils compressibility (Abbott 1960; Terzaghi and Peck 1967; Crawford and Bozozuk 1990; Crawford *et al*., 1996; Terzaghi *et al*., 1996) was applied for the calculation of subsidence in the Bulqiza mining area. The results and all the available data about the geotechnical characteristics of the sites helps determine the appropriate measures to prevent the area from mass movement which is a real threat for citizens.

2. RESULTS AND DISCUSSIONS

Ground cracking, sinkhole, damage of houses and infrastructure and the widening of floodplain areas (Bulqiza stream) are some of the land subsidence effects with unavoidable economic, civil structures, geo-environmental and social impact. As the data on land subsidence are very important for the sustainable development of urban and rural areas, the evaluation of both risk and impact of land failures in these areas becomes crucial for their planning and developments, in addition to estimation of the characteristics of subsidence and their monitoring. The present paper analyzes the subsidence occurred due to coal extractions and ground water drainage from mining activity in ultrabasic rocks.

Subsidence due to coal mining

Coal production in Albania started in 1926 in the Mborje-Drenova deposits (Korca region) and in 1964 in Mëzezi and Valiasi deposit (Tirana region). Extensive geotechnical works (Muceku and Bozo 2002; Muceku 2005; Muceku *et al*., 2008; Muceku *et al*., 2019) reported that numerous residential areas like Valiasi and Mëzezi, which are located in Tirana district were affected by subsidence phenomenon. The coal mineral was produced applying different mining methods based on the geological planar structures of coal body, coal depth from the surface and geotechnical conditions of the ore deposit site. Based on these geological and geotechnical conditions, *the Longwall mining and Room and the Pillar mining were applied for the* coal extraction in the Valiasi and Mëzezi mines. These mining methods involved the full extraction of coal from a section of the seam, or ‘face’ using in general blasts and rarely mechanical shearers regarding the Valiasi mine. The coal ‘face’ in Valias was from 50 to100m long. Self-advancing, hydraulically-powered supports were used. Once the coal was extracted from the area, the roof of mines collapsed. Over 75% of the coal deposits were extracted from the coil panels, extending through the panel's coal stratum.

Geotechnical characteristic

Figure 1 and 2 depict the Mëzezi and Valiasi mining areas. Geologically, the coal deposits are found in molasses formations that consist of claystone-siltstone layers intercalated with sandstone layer (Fig.2). Most of the studied area is rich in alluvial and proluvial deposits, represented by gravel, sand and clays. The forth coming paragraph reports the results of geotechnical investigations carried out from 2001-2019. Many boreholes (15.0m up to 30.0m deep) were drilled, SPT-Standard Penetration Test and laboratory tests of soils and rocks were made for the physical and mechanical properties such as grain size, w-natural water content, γo-specific gravity, γ-bulk density, ϕ-internal friction angle, c-cohesion, E-deformation module, E_{oed}-oedometer modulus E-elelastic module and σ-uniaxial compressive strength, etc. to: i) determine the geotechnical properties of soils and rocks to be used in the modeling program; ii) estimate and mapping of the surface’s rupture and; iii) propose and recommend the appropriate engineering measures for mitigation and remediation.

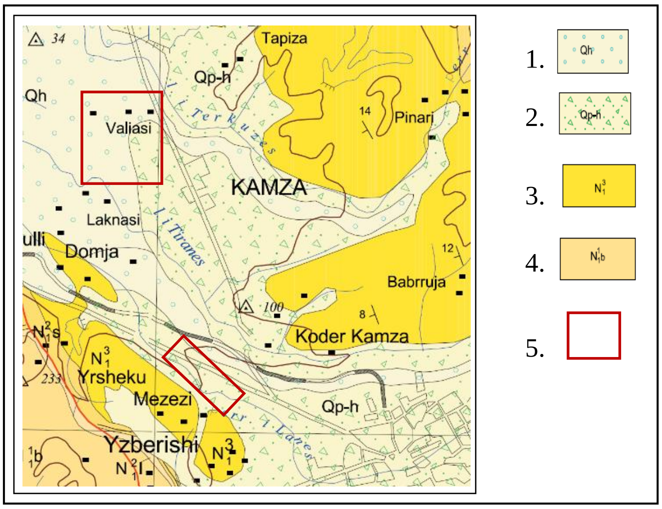


Fig. 2: Geological map of Valias and Mëzezi mining area (Xhomo *et al.*, 2002). **1.** and **2.** Holocene-alluvial and proluvial deposits, gravels, sands, clays, silts; **3.** Messinian-N_1^3m, massive sandstone, gyps, claystone and siltstone; **4.** Burdigalian-N_1^1b, marl claystone, marl, siltstone and sandstone; **5.** Studied area.

The geotechnical properties of typical soils and rocks in these areas are in Table 1- 3 reported. Field's works and laboratories tests identified two geotechnical units: i) Valiasi mine area and; ii) Mëzezi mine area.

Valiasi mine area

Figure 3 depicts the three geotechnical units determined based on laboratory and field works data and the data are in the Table 1 - 3 reported.

The geotechnical unit 1 consists of inorganic silts and clays with fine sands with low to medium plasticity (ML-CL), (ASTM 2011). These soils have stiff to medium consistency, grey and brown color. They are situated in the upper part of lithological profile and are from 10.0-12.0m up to 15.0m thick.

The geotechnical unit 2 is represented by gravel-sand-silts mixtures (GM), (ASTM 2011), saturated, which are from dense to very dense state. It is situated below the geotechnical unit 1, and is from 30.0-35.0m to 40.0m thick.

The geotechnical unit 3 consists of very weak rocks- claystones-siltstones rocks (Brown 1981) e.i., molasses formations making up the lower part of lithological profile.

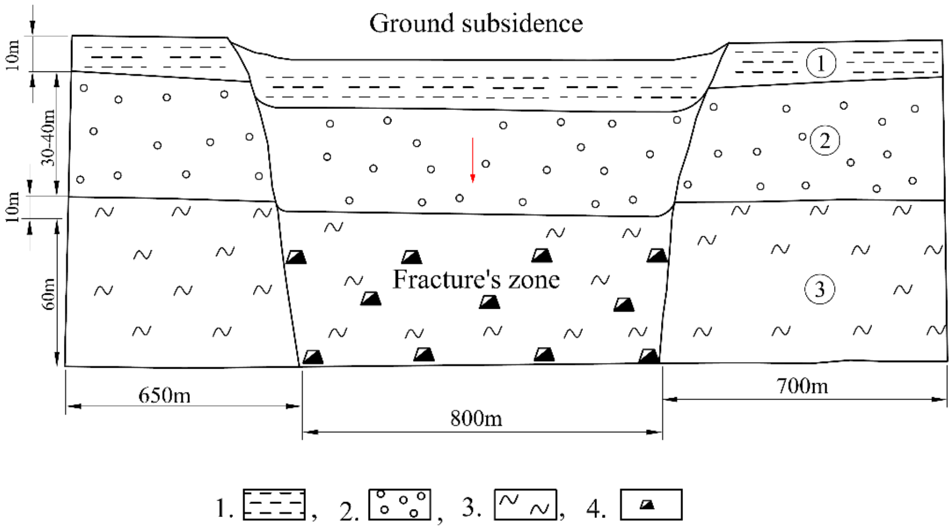


Fig. 3: Lithological profile of Valiasi mining deposit (Muceku *et al.*, 2019). **1**. Inorganic silts and clays (ML-CL); **2.** Gravel-sand-silts mixtures (GM); **3.** Claystones-siltstones rocks; **4.** Mining works.

Table 1. Geotechnical properties of soils, Valiasi site

Symbol	Unit	Geotechnical units nr.1	nr.2
E	Mpa	5.36-7.34	28.0-41.3
γ	kN/m^3	18.7-19.0	19.8-21.0
γ_o	kN/m^3	26.7-27.0	26.-26.5
φ	(o)	16-17	40-43
c	kpa	20-25	0.0
SPT		13-14	33-49
Soils type		ML & CL	GM

E-oedometer modulus, γ-bulk density, γ_o-specific density, φ-internal friction, c-cohesion, SPT-standard penetration test.

Mëzezi mine area
Figure 4 depicts the three geotechnical units distinguished in the Mëzezi Mine area and the geotechnical properties of soil are in the Table 2 and 3 reported.
The geotechnical unit 1 consists of inorganic silts and clays with fine sands with low to medium plasticity (ML-CL), (ASTM 2011) and have the stiff consistency and are beige and brown in color. These soils could be met on the top of the lithological profile and are from 3.5-5.0m to 8.0m thick.
The geotechnical unit 2 is represented by gravel-sand-silts mixtures (GM), (ASTM 2011), which are saturated and in medium to dense state. These soils could be found below geotechnical unit 1, and are from 6.0-10.0m up to 1.0m thick.
The geotechnical unit 3 could be found in the lower part of the lithological profile. It consists of molasses formations rich in clay stones-siltstones rocks that are very weak rocks to weak rocks (Brown 1981).

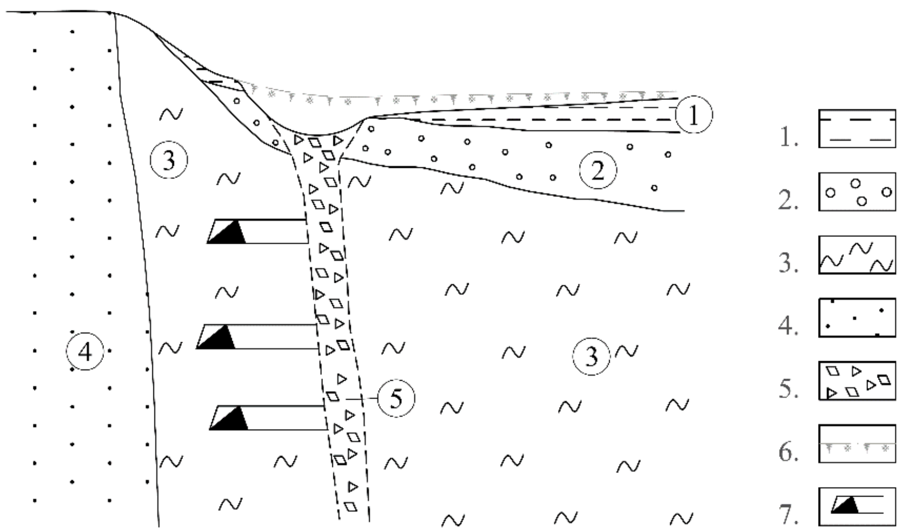


Fig. 4: Lithological profile of Mëzezi mining deposit (Muceku *et al*., 2019) **1**. Inorganic silts and clays (ML-CL); **2.** Gravel-sand-silts mixtures (GM); **3.** Claystones-siltstones rocks; **4.** Sandstones rocks; **5.** Fracture's zone; **6.** Ground surface before the subsidence occurs; **7.** Mining works.

Table 2. Geotechnical properties of soils, Mëzezi site

Symbol	Unit	Geotechnical units nr.1	nr.2
E	Mpa	4.34-6.68	27.1-31.1
γ	kN/m^3	18.3-19.1	19.4-20.0
γ_o	kN/m^3	26.5-26.6	26.2-26.5
φ	(o)	14.0-20.0	39.0-41.0
c	kpa	8.0-13.0	0.0
SPT		7.0-12.0	22.0-37.0
Soils type		ML & CL	GM

E-oedometer modulus, γ-bulk density, γ_o-specific density, φ-internal friction, c-cohesion, SPT-standard penetration test

Table 3. Geotechnical properties of rocks, Mëzezi and Valiasi Coal's deposits sites

Geotechnical properties	Unit	Mëzezi Site	Valiasi Site
σ_c	Mpa	3.44-5.74	2.04-4.59
E_{el}	Mpa	909-1333	836-1263
υ		0.37-0.39	0.38-0.40
λ	m	0.4-0.7	1.0-1.4
γ	kN/m^3	22.90-23.80	22.10-23.70
γ_o	kN/m^3	27.00-28.10	26.30-27.90
Rock's type		very weak-weak	very weak

σc- uniaxial compress strength, Eel-elastics module, υ-poisson ratio, λ-lamination constant, γ-bulk density, γ_o-specific density

Numerical analysis

The subsidence that occurred in the Valiasi mine could be modeled numerically. The model was made based on the theoretical perspective of subsidence in laminated structures. There are several models to describe subsidence, but the present paper uses the model reported in (Yang *et al*., 1993). The key step is to determine the ceiling-to-floor convergence or subsidence magnitude "*s*". The model discussed in (Yang *et al*., 1993) is a two-dimensional model and shows how "*s*" varies over the area of occurrence of the subsidence. The present paper analyzes the variation of this quantity in the transversal plane with respect to the zone that has undergone subsidence. The "*x*" axis lies in this direction. The observations show that the profile of subsidence does not change considerably from one transversal plane to the other reducing the dimensionality of the problem to one. The dynamic equation adapted in 1D reads.

$$\frac{\partial^2 s}{\partial x^2} = \frac{2}{\lambda E}\sigma^{in}, \qquad (1)$$

where "λ" is the lamination constant which basically is the thickness of an individual layer, "*E*" is the Young's modulus for the specific rock and "σ^{in}" is the vertical induced stress at the excavation horizon. The profile of the Valiasi mine illustrates that the cause of subsidence was the rupture of coal pillars at the bottom level. This zone has a linear extension of 800 m. We employ the finite differences method. The whole length of the bottom level of the mine is divided in segments of length h = 1 m. The second order derivative in the framework of finite elements is transformed accordingly:

$$\frac{\partial^2 s}{\partial x^2} \to \frac{s_{i-1} - 2s_i + s_{i+1}}{h^2}. \qquad (2)$$

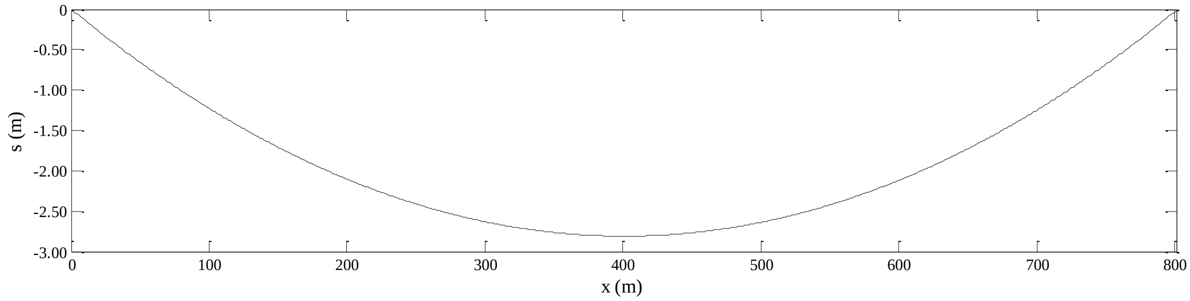
Then equation (1) is transformed into a matrix equation:

$$Ls = \sigma, \qquad (3)$$

where "L" is the three-diagonal matrix of coefficients, σ is the vector of stress and s is the vector of subsidence's magnitude. Inverting the "*L*" matrix yields:

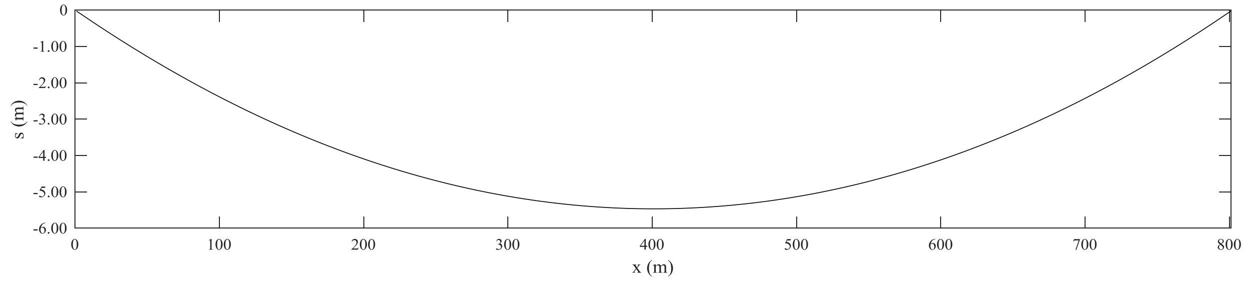
$$s = L^{-1}\sigma. \qquad (4)$$

The other parameters included in (4) are: λ = 1.2 m, is the lamination constant which basically is the thickness of an individual layer, $E = 1\times10^9$ Pa and $\sigma^{in} = -q = 2.096\times10^9$ Pa and "*q*" is the pre-mining vertical stress. The solution is in the Graph.1 plotted.



Graph.1: Subsidence magnitude *s* for Valias mine.

The greatest magnitude of subsidence is in the middle of the whole section and it is approximately 2.81 m which is in good agreement with the measurements. A similar procedure is followed for the Mëzezi mine (Graph. 2). The terrain over the exploited coal deposits has undergone a severe subsidence. The zone is from 8 to 10 m wide. In the sections where the width is 8 m, the length of the segments of the linear mesh is h = 1 cm. The lamination constant is 0.55 m and $E = 1.121\times10^9$ Pa. The induced stress is approximately the same. The calculations show that the maximum subsidence magnitude is 5.5 m. The sections with width 10m suffer a more severe subsidence where the predictions show that the maximum subsidence magnitude is about 8.5 m.



Graph.2: Subsidence magnitude *s* for Mëzezi mine.

In the Valias mine, the coal deposit is almost horizontal. The inclusion of pillars alters slightly the equation 1. The stress vector has to reflect the effect of pillars and becomes:

$$\sigma^{in} = \begin{cases} -q & i^{th} element \in opening \\ \mu_c s & i^{th} element \in pillar \end{cases}. \tag{5}$$

Substitution of (5) into (3) and rearrangements yields

$$L's = \sigma', \tag{6}$$

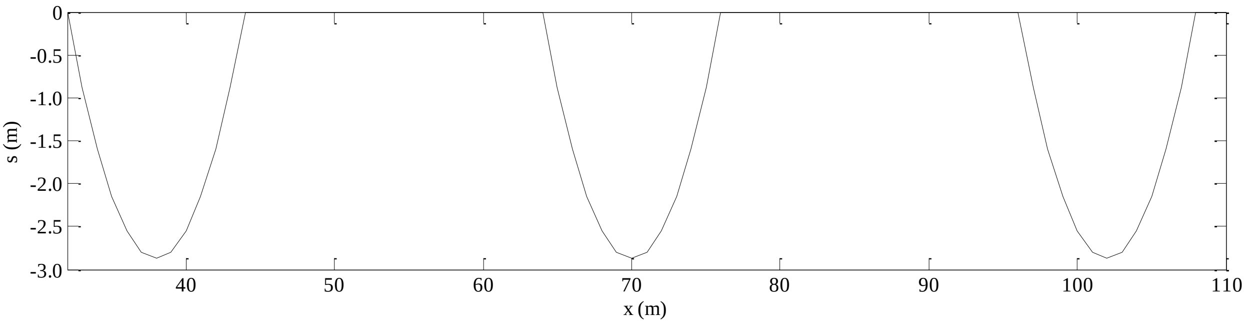
where:

$$L' = \begin{cases} L_{ij} & i \neq j \\ L_{ij} + A_i & i = j \end{cases}, \tag{7}$$

$$A_i = \begin{cases} 0 & i^{th} element \in opening \\ -\mu_c & i^{th} element \in pillar \end{cases}, \tag{8}$$

$$\sigma' = \begin{cases} -q & i^{th} element \in opening \\ 0 & i^{th} element \in pillar \end{cases}. \qquad (9)$$

The Least-Squares inversion of (6) will yield the subsidence magnitude. A part of the subsidence profile for the Valias mine, specifically between 32 and 110 meters, is in Graph 3 plotted.



Graph. 3: Subsidence magnitude *s* for Valias mine when pillars are considered.

There is visible the effect of pillars. In the section where is present a pillar the subsidence magnitude is vanishing. In the parts where there is no pillar the subsidence magnitude reaches a maximum value of 2.9 m. The periodical character of s is extended to the whole horizontal extension. Recall that in this third case study we analyzed the subsidence in the pillars plane. This means that basically the subsidence has occurred not only in the part not supported by pillars, but even in between the pillars.

Subsidence due to ground water drainage

The Bulqiza urban and suburban area was subject of ground subsidence, sinkhole and cracks occurrences from intensive mining activity. The tunnel built for mining purposes below the Bulqiza town, through the Vajkali valley (1985-1995) disrupted the hydrogeological regime of two confined aquifers like the fissured-tectonic ultrabasic rocks and the alluvial-proluvial deposits (rubbles, gravels, pebbles, sands etc.), from which a large amount of the underground water discharged into the Bejni stream (Fig.5). Consequently, a large ground subsidence was triggered followed by many cracks occurrences.

Geomorphologic and geologic setting

The area included in the investigation is located in east of Albania and represents a mountainous valley, with U shape, 3 km long and 1.5 km wide, where the altitudes above sea level range from 744m (plain area of Bulqiza) to 1700-2000m (ultrabasic massif extended around the aforementioned area). A concave-convex profile is developed on the valley sides with slope inclination over 30^{o} and the flat area ranges from 3^{o} to 7^{o}. Geologically, it consists of ultrabasic rocks (Middle-Upper Jurassic) and Quaternary deposits (Fig. 5). Here, alluvial, proluvial and deluvial deposits (Quaternary) overlay. They are up to 180.0m thick. They consist of organic soils, gravel-sand-silts mixtures, cobbles-gravel mixtures and glacial breccia of ultrabasic rocks. The ultrabasic rocks are intensively fissured and fractured by tectonic phenomena.

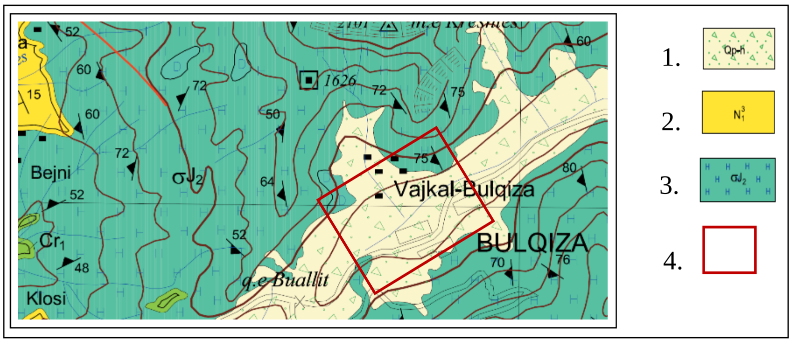


Fig. 5: Geological map of Bulqiza area (Xhomo *et al*., 2002). **1.** Holocene-alluvial and proluvial deposits, gravel, sand, clay, silt; **2.** Messinian-N_1^3m, massive sandstone, gyps, claystone and siltstone**; 3.** Burdigalian-N_1^1b, marl claystone, marl, siltstone and sandstone; **4.** Studied area.

Hydrogeological characteristics

Based on hydrogeological studies (Tafilaj and Durmishi 2002; Eftimi 2010), two aquifers were included in the investigation: i) the porous aquifer of proluvial and deluvial deposits. It is a confined aquifer due to the lithological profile of the upper part which is covered by a potential layer (10.0-15.0m thick) consisting of organic and inorganic silts and clays with fine sands. The porous aquifer consists of gravel-sand-silts mixtures, rock blocks-gravel mixtures and glacial breccia deposits. These formations are 150.0-165.0m thick from the surface. Hydrogeological studies (Tafilaj and Durmishi 2002) made before the opening of the Klosi tunnel (6.5km long), which extends over the Bulqiza ultrabasic massif below the porous aquifer of proluvial and deluvial deposits reported that this aquifer is characterized by the hydrogeological features reported in the Table 4.

Table 4. The hydrogeological features

Symbol	Unit	Value
K	m/day	6
h	m	+3.5over earth surface
q	l/sec/m	0.6-10
T	m^2 /day	180-240

K-permeability coefficient, h-piezometric head, q-specific discharge of wells, T-Transmissivity

The hydrogeological properties in the Table 4 show that it has been an artesian aquifer due to groundwater under pressure, where the piezometric head was +3.5 over earth surface and, ii) the *aquifer of the fissured ultrabasic rocks.* Regarding the water bearing of the ultrabasic rocks many data were collected from the mining works-gallery and prospection-exploration drill-holes carried out by Bulqiza Mining and Tirana Hydrological enterprises in the north and south of the area under investigation. Several hydrogeological observations were made in the fractured ultrabasic rocks of Bulqiza chromium mine. Eftimi (2010) reported that in the Bulqiza chromium mine, at an elevation from 450.0m to 1,200.0m, the ground water drains about 250 l/s. Most of this underground water discharged into a porous aquifer of proluvial and deluvial deposits, and the other quantity was drained out through several water springs, in the Bejn-Klos and Plani Bardhë villages. It means that in these fractures rocks large water quantities are stored. But, since the opening of the Klosi-Bulqiza tunnel, 6.5km long, in ultrabasic rocks below of porous aquifer (Bulqiza depression) in 1995 a large of water amount (450 l/sec) has been discharged through the tunnel, changing the hydrodynamic parameters of the proluvial and deluvial aquifer. Consequently, subsidence occurred.

Geotechnical characteristics and analysis

The Bulqiza depression has different geotechnical units, ranging from fine to coarse grained soils with soft-medium up to very stiff-hard consistency. The area in the north and south of Bulqiza depression is characterized by coarse grained soils, represented by the gravel-sand mixtures with cobbles content (GP) and cobbles-rubbles mixtures with fines (GP). The center area of the Bulqiza depression is characterized by fine grained soils. They are organic and inorganic silts and clays with very fine sands (OL, ML, CL), which are highly compressible soils. These soils could be met below the buildings and roads foundations, and during underground water drainage they were compacted. Figure 6 and 7 depict the geotechnical units analyzed based on field and laboratory works (Brown 1981; ASTM 2011).
The geotechnical unit 1 consists of organic clays of medium to high plasticity (OH) with soft to medium consistency, black in color and saturated.
The geotechnical unit 2 consists of saturated organic clays of low to medium plasticity (OH) and organic silt-clays of low plasticity (OL) with medium to stiff consistency and grey and beige in color.
The geotechnical unit 3 consists of saturated inorganic clays and silts with sands with stiff-very stiff up to hard consistency, grey in color (ML-CL).
The geotechnical unit 4 consists of sand-silt mixtures (SC) with dense to very dense of relative density.
The geotechnical unit 5 consists of gravel-sand-silt mixtures and gravel-sand-clays mixtures with cobbles content (GM-GC). It has very dense of relative density.
The geotechnical unit 6 consists of gravel-sand mixtures with little fines (GP) and with medium to relative density.
The geotechnical unit 7 consists of breccia rocks and medium strong rocks.
The geotechnical unit 8 consists of ultrabasic rock and hard rock.

Table 5. Geotechnical properties of soils, Bulqiza area

Properties	Symbol	Geotechnical units					
		1	2	3	4	5	6
W	%	32.96-38.45	33.3-35.1	27.4-31.8	-	-	-
γ_o	kN/m^3	26.90-27.05	24.61-26.00	26.70-26.92	26.43-26.50	26.10-26.30	26.10-26.24
γ	kN/m^3	17.10-17.40	18.30-18.50	19.40-19.80	19.60-20.0	20.03-21.20	19.60-19.80
E_{oed}	Mpa	3.16-3.74	4.37-5.22	11.56-29.37	16.28-17.64	48.26-56.32	18.94-22.47
Soils type		OH	OH, OL	CL, ML	SC	GM, GC	GP

W-natural water content; γ_o- specific density; γ-bulk density; γ_{sat}-saturate density; E-deformations module

Table 6. Geotechnical properties of rocks of Bulqiza area

Properties	Symbol	Geotechnical units	
		7	8
σ_c	Mpa	34.3-40.5	66.1-86.7
E_{el}	Gpa	10.7-12.5	18.8-21.2
υ		0.27-0.28	0.20-0.22
γ_o	kN/m^3	23.75-25.66	26.87-28.45
γ	kN/m^3	23.18-24.85	25.3-27.1

σ_c- uniaxial compress strength, Eel-elastics module, υ-poisson ratio, γ_o-specific density, γ-bulk density

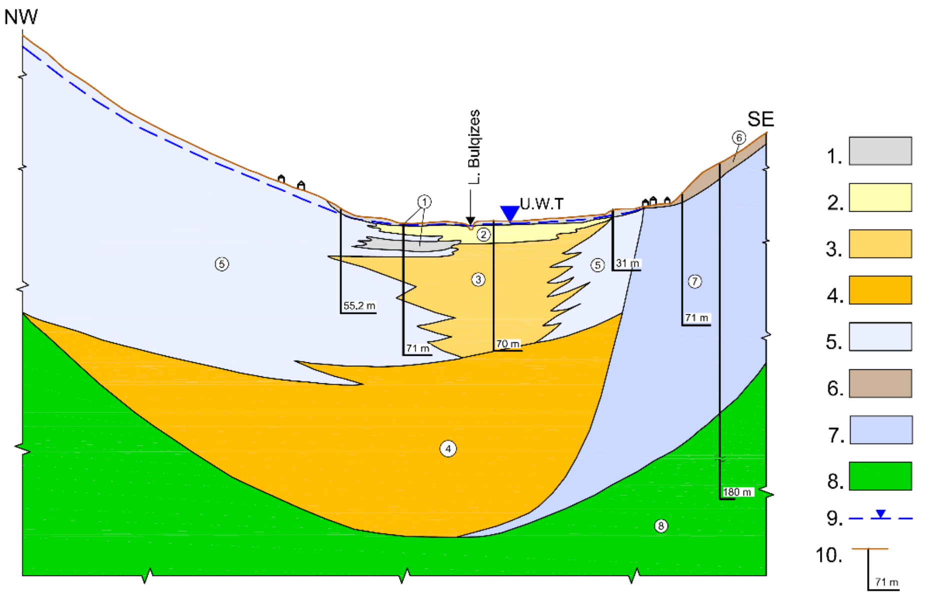


Fig. 6: Lithological profile of Bulqiza area (Muceku *et al.*, 2019). **1.** Organic clays (OH); **2.**Organic clays and silts (OH-(OL); **3.** Inorganic clays (ML-CL); **4.** Sand-silt mixtures (SC); **5.**Gravel-sand-silt mixtures (GM-GC); **6.**Gravel-sand mixtures with little fines (GP); **7.**Breccia rocks, **8.**Ultrabasic rock; **9.**Ground water table; **10.** Borehole.

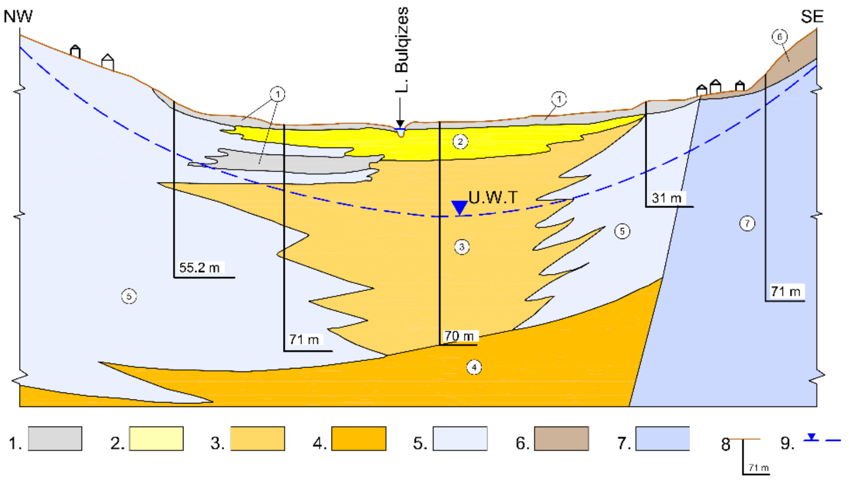


Fig. 7: Lithological profile of Bulqiza area (Muceku *et al.*, 2019). **1.** Organic clays (OH); **2.**Organic clays and silts (OH-(OL); **3.** Inorganic clays (ML-CL); **4.** Sand-silt mixtures (SC); **5.**Gravel-sand-silt mixtures (GM-GC); **6.**Gravel-sand mixtures with little fines (GP); **7.** Breccia rocks, **8.**Ground water table; **9.**Borehole.

Many geotechnical methods were used to determine the compaction effect of soils. For the Bulqiza subsidence we used one of the most common methods of soils compaction (Abbott 1960; Terzaghi and Peck 1967; Crawford and Bozozuk 1990; Crawford *et al.*, 1996; Terzaghi *et al.*, 1996; Bhattacharya and Kuma 2018), where the subsidence is calculated:

$$S_u = (\sigma_{i2} - \sigma_{i1}) * \frac{Z_1}{E} = m_v * Z_1(\sigma_{i2} - \sigma_{i1}) \qquad (1)$$

where:
Su : Subsidence depth
Z_1: Thickness of the soil layer before the subsidence occurs

σ_{i1} : Intergranular pressure of soils before of landslides occurrence, when ground water table was at maximum piezometric level
σ_{i2} : Increased intergranular pressure when the water table is at current piezometric level due to the drainage of the underground water
m_v: Coefficient of volume compressibility of the soil layer before the subsidence occurs
E: The compression modulus of the soil layer before the subsidence occurs.

The Figure 6 and 7 depict the Bulqiza's depression consisting of several soft and highly compressible soils, which are situated in the upper part of the lithological profile. These soils are represented by organic clays of medium to high plasticity (OH) and organic silt-clays of low plasticity (OL). Previous studies have shown that the underground water level in at 1995 has been + 3.5m over ground surface (underground water pressure). In 2000, the groundwater level dropped at 12.0 to 15.0m to 26.0m, below of ground surface. Consequently, land subsidence was triggered about 2.8-3.2m deep from Bulqiza flat area (Muceku and Bozo 2002), due to dewatering of compressible layers. So, the subsidence depth for each compressible layer was calculated based on geotechnical properties and formula (1). Finally, geotechnical data showed that the subsidence is totally 5.26m deep. It should be emphasized that the organic and inorganic clays-silts layers in engineering practice, are considered as problematic soils, because they take a considerable time to end the consolidation process, and it depends on load. In addition, the GPS surveys of 2018 showed that land subsidence in central part of Bulqiza has lowered by 4.2m, or 1.0m lower than in 2001 (Fig. 8). In the peripheral parts, the ground has settled from 0.1-0.2m to 0.4-0.5m since 2001 (Muceku 2002), i.e., active subsidence and ground drop to 5.8m deep in the central part.

LAND SUBSIDENCE IMPACTS

The ground subsidence effects from mining activities are governed by the geotechnical conditions of site deposit, geometry and depth of mineral body and mining methods applied and are a means to address the appropriate engineering measures for the stability of the mine exploitation site. Mining and exploitation of mineral resources generally have a considerable impact on the geo-environment as well as socio-economic settings of the local population. Tirana, Bulqiza, and the Mborja, Drenova, Manza and Krosnishti are characterized by ground subsidence due to the mining activities. The forthcoming paragraph, describes the effects and geo-environmental impact triggered by mining activity in urban and rural areas in Albania.
The subsidence in the *Valiasi mine* area extents over the exploitation area, in a surface area of about 3km^2 and occurred in the form of furrows, 30-50m wide and 1.0-2.5 to 3.0m deep. As a result, some traffics roads and many buildings of 1-2 two stores were damaged (fissured masonry). The geotechnical mapping data of the last two decades reported that the uncontrolled demographic changes and construction (home, roads etc.) represent a high risk for the residents (Muceku 2005; Muceku *et al*., 2008).
The *Mëzezi mine* area is located in the northwest of Tirana, close to Tirana-Durrësi highway and the Tirana-Durrësi railway. Here, many sinkholes (diameter varying from 6.5 to 9.0-11.0.0mand 2.0-3.0m to 5.0-8.0m deep), cracks and settlements sites occurred due to the mining activities carried out near the land surface, from 40.0 to 50.0m deep. The area is about 2.km long, from Mëzezi mine (south) to Yrshek village (north) and 50-80.0m wide (ground cracking). Engineering problems have been reported for the area since 1970. Engineering objects (several residential buildings, mining enterprise offices and some sites along Tirana-Durrës highway and Tirana-Durrës railway) which were built in the mining zone have been continuously been damaged. Consequently, some geotechnical investigations were carried out from 2000 to 2008 to map and evaluate the geotechnical conditions of endangered areas. These studies were carried out to evaluate the geotechnical characteristic of the dangerous area in the framework of urban planning and development of the studied area.
The *Mborje -Drenova mine* area is located in the Korça region. By exploitation coal mineral in Mborje-Drenova mine, were damaged a considerable number of buildings, agricultural areas and electric lines. Furthermore, in some cases in the Mborje Drenova and Krosnishti areas, the mine collapses created some small earthquakes causing some damage of the village buildings.

Muceku and Bozo (2002), Tafilaj and Durmishi (2002), Muceku (2005); Muceku *et al*., (2019) said that the ground failure in the *Bulqiza mine* area occurred in various forms, such as ground and roads cracking, houses and buildings fissure, houses and buildings settlements, and land subsidence and the source is the groundwater drainage from mining activity/work, where the settlement and consolidation of high compressibility soils occurred. Muceku (2018) and Muceku (2005; 2008) used the geodesic techniques equipment as total station and GPS surveys to evaluate subsidence and ground cracking.

Figure 8 depicts the ground subsidence impacts in Bulqiza area found in various forms such as the tilting of building and houses, cracking of roads and buildings, changes of main course of Bulqiza stream, dried and drain the waters spring and aquifers, causing local floods. The damages due to ground subsidence in Bulqiza urban area were quite significant. Ground subsidence of about 1.51 km^2 occurred in the Bulqiza valley from 2000-2001. Both the primary and secondary school which is a two-storey building, a five-storey house and one-storey house were destroyed. The 0.75 km of the permanent national road of the Burreli-Pershkopia national road and the 0.62km between the new and the old Bulqiza town were cracked and settled. A small lake of about 0.14km^2 was created in the center of the Bulqiza flat area, flooding about 14.47 ha agricultures area. 3-4 parallel system cracks, 0.72 km long, 0.2-1.2m wide and 0.5-1.5 to 2.0m deep occurred at northern part of Bulqiza flat area. They extend from west to east in more or less parallel with the Bulqiza valleys and affected its morphology, changing it from flat area in terraced landscape. So, the ground near periphery of Bulqiza valley settled 0.2-0.7m, between first to second, second to third and third-fourth cracks. It settled 0.7-1.3m, 1.3-2.4m and 2.4-3.2m, respectively, damaging about 67 hectares of arable land. Many water springs from Bejni-Klos villages to Bulqiza town were dried due to the mining activities, affecting the landscape and the local economy. The water supply system, sewerage and drainage system of Bulqiza town were deformed and fractured.

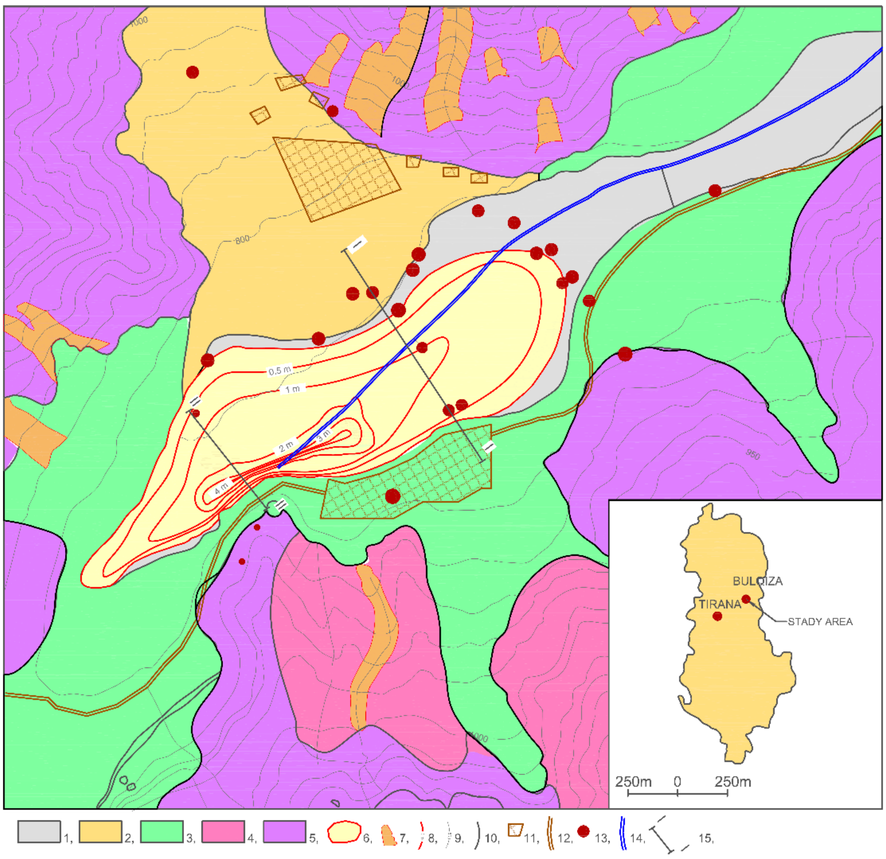


Fig. 8: Geotechnical map of Bulqiza area (Muceku *et al*., 2019). **1.** Organic clays and silts (OH-(OL); **2.** Gravel-sand-silt mixtures (GM); **3.** Gravel-sand-silt mixtures (GM-GC); **4.** Breccia, moderately hard rocks, **5.** Ultrabasic, hard rock; **6.** Subsidence; **7.** Gravel-sand-silt mixtures (GM); 8. isoline of post subsidence in meters; **9.** Topographic isoline in meters; **10.** Lithological boundary; **11.** Bulqiza urban area; **12.** Road; **13.** Boreholes; **14.** Bulqiza stream; **15.** Cross section.

4. CONCLUSIONS AND RECOMMENDATIONS

The present paper provides information about the ground subsidence effects and environmental impacts triggered by mining activity in urban and rural areas of Albania, and the geotechnical investigation carried out in the Valias and Mëzezi and Bulqiza mine areas.

Geotechnical data reported that ground failure in the mining areas could be found in various forms, such as ground and roads cracking, houses and buildings fissure, houses and buildings settlements, sinkhole, land subsidence and widening of floodplain area (Bulqiza stream).

The impact of mining subsidence on the environment can occasionally be very catastrophic, destroying property and even leading to the loss of life. Tirana region (Valias and Mëzezi) and Bulqiza and the Mborje, Drenova, Manza and Krosnishti villages are characterized by ground subsidence due to the mining activities.

The subsidence zone in the Valias area covers the exploitation area, of about 3km^2. It occurred in the form of furrows, 30-50m wide and 1.0-2.5 to 3.0m deep. The traffic roads and many buildings, 1-2 storey building (fissured masonry) were subsequently destroyed.

The *Mëzezi mine* area is located in the northwest of Tirana, close to Tirana-Durrësi highway and the Tirana-Durrësi railway. The area is characterized by sinkholes (diameter 6.5 to 9.0-11.0.0m and 2.0-3.0m to 5.0-8.0m deep), cracks and settlements sites due to the mining activities carried out 40.0-50.0m deep, i.e., very close to the land surface. Consequently, several residential buildings, mining enterprise offices and some sites along the Tirana-Durrësi highway and Tirana-Durrësi railway were damaged.

Agricultural areas, electric lines and a considerable number of buildings were damaged in the Mborje-Drenova mine area (Korça region) during coal exploitation. In addition, here and in the Krosnishti area, the mine collapses created some small earthquakes. Consequently, some houses were damaged.

The urban area of the Bulqiza town was characterized by a 1.51 km^2 subsidence due to anthropogenic activities.

Groundwater drainage by the mining activity/work where a settlement and consolidation of high compressibility soils occurred is the source of ground failure. Land deformation-subsidence and ground cracking were evaluated using the geodesic techniques equipment as total station and GPS surveys. The ground subsidence impacts in Bulqiza area occurred in various forms such as the tilting of building and houses, cracking of roads and buildings, changes of main river course, dried and drain of waters spring and aquifers and causing local floods. The damages due to ground subsidence in Bulqiza urban area were quite significant. Both the primary and secondary school which is a two-storey building, a five-storey house and one-storey house were destroyed. The 0.75 km of the permanent national road of the Burreli-Pershkopia national road and the 0.62km between the new and the old Bulqiza town were cracked and settled. A small lake of about 0.14km^2 was created in the center of the Bulqiza flat area, flooding about 14.47 ha agricultures area. 3-4 parallel system cracks, 0.72 km long, 0.2-1.2m wide and 0.5-1.5 to 2.0m deep occurred at northern part of Bulqiza flat area. They extend from west to east in more or less parallel with the Bulqiza valleys and affected its morphology, changing it from flat area in terraced landscape. So, the ground near periphery of Bulqiza valley settled 0.2-0.7m, between first to second, second to third and third-fourth cracks. It settled 0.7-1.3m, 1.3-2.4m and 2.4-3.2m, respectively, damaging about 67 hectares of arable land. Many water springs from Bejni-Klos villages to Bulqiza town were dried due to the mining activities, affecting the landscape and the local economy. The water supply system, sewerage and drainage system of Bulqiza town were deformed and fractured.

REFERENCES:

Abbott MB. 1960. One-Dimensional Consolidation of Multi-Layered Soils. *Géotechnique*. **10**(**4**)**:**151-165.

ASTM. 2011. American Society for Testing and Materials D2487. *Standard practice for classification of soils for engineering purposes (Unified Soil Classification System). ASTM International*. West Conshohocken, PA. 10. 1520/D2487-11.

Bhattacharya KA, Kumar D. 2018. Land subsidence in east Calcutta. *The Electronic Journal of GeotechnicalEngineering.***23**:365-374. www.ejge.com/2018/Ppr2018.0072ma.pdf.

Brown, E.T. (Ed.). 1981. Rock characterization, testing and monitoring. I*SRM-International Society of Rock Mechanics suggested methods*. Oxford: Pergamon Press.p. 211.

Crawford CB, Bozozuk M. 1990. Thirty years of secondary consolidation in sensitive marine clay. *Canadian Geotechnical Journal.* **27:** 315-319. doi.org/10.1139/t90-042.

Crawford CB, Morrison KI. 1996. Case histories illustrate the importance of secondary-type consolidation settlements in the Fraser River delta". *In: Canadian Geotechnical Journal*. **33**(**6)**: 866–878.

Eftimi R. 2010. Hydrogeological characteristics of Albania Acque Sotterranee. *Italian Journal of Groundwater*. 79-92. DOI 10.4409/Am-007-10-0012.

Muceku Y, Bozo L. 2002. Land Subsidence in the Bulqiza Area, Albania. *3rd Balkan Geophysical Congress and Exhibition.* 24-28 June 2002 Sofia, Bulgaria. 92.

Muceku Y. 2005. The geological hazards. *In Ph. D. thesis. Study of cohesive soils behavior under static and dynamic load for urban development of Tirana-Vora region.* Polytechnic University of Tirana, Albania. 90-105.

Muceku Y, Lamaj M. 2005. Engineering geological mapping for urban development and regional planning in Tirana-Vora area. *Bulletin of Albanian Geosciences*. **2**: 5-16. Tirana.

Muceku Y, Lame M, Gjovreku L, Rudi E, Halili R, Kurti A, Hasanlami R, Torbaj Xh, Kazanxhi L, Ndokaj M, Palko A, Kajaçka A. 2008. Engineering geological zoning mapping of Albanian area at the scale 1: 25000. Center of Civil Geology, Tirana, Albania. 4–183.

Muceku Y, Lamaj M. 2009. Engineering geological mapping a necessary base, on urban planning and Development in Albania. *Bulletin of Albanian Geosciences*. 99-118. Tirana.

Muceku Y, Lamaj M, Milushi K, Onuzi K, Avxhiu A. 2019. Preliminary results of the Albanian geotechnical map at the scale 1:200 000: a case study. *Journal of Natural and Technical Sciences*. **1**: 7-25.

T**afilaj I, Durmishi Ç. 2001.** Land subsidence in Vajkali Valley (in Albania) – A typical example of groundwater pressure lowering influence. In: *"Expert Assessment of Land Subsidence Related to Hydrogeological and Engineering geological Conditions in the Regions of Sofia, Skopje and Tirana",* Proceedings, Sofia. 35-44.

Terzaghi K, Peck RB. 1967. Soil Mechanics in Engineering Practice. *John Wiley & Sons, Inc.*, New York, 46-154, 269-281.

Terzaghi K, Peck RB, Mesri G. 1996. Soil mechanics in engineering practice, 3rd Edition. *John Wiley & Sons, Inc.* New York. 223-236.

Xhomo A, Kodra A, Dimo Ll, Xhafa Z, Nazaj Sh, Nakuçi V, Yzeiraj D, Shallo M, Vranaj A, Melo V. 2002. Geological map of Albania at the scale 1:200 000. Geological Survey of Albania, Tirana.

Xhomo A, Kodra A, Gjata K, Xhafa Z. 1999. Geotectonic map of Albania. Geological Survey of Albania, Tirana.

Yang G, Chugh YP, Yu Z, Salamon MDG. 1993. A numerical approach to subsidence prediction and stress analysis in coal mining using a Laminated Model. *International Journal of Rock Mechanics and Mining Sciences and Geomechanics.* Abstracts. **30** (**7**): 1419-1422.