Ylber MUCEKU[*], Sami NENAJ[**], Llesh PRENGA[**]

ENGINEERING GEOLOGY AND GEOPHYSICS STUDIES FOR URBAN PLANNING AND DEVELOPMENT IN SHKODRA AREA, ALBANIA

Përmbledhje: Artikulli trajton në mënyrë të përmledhur rezultatet shkencore të studimeve komplekse gjeologo-inxhinierike dhe gjeofizike të kryera gjatë viteve 2000–2006 në rajonin e Shkodrës, Shqipëri. Zona e studiuar shtrihet në pjesën veriperëndimore të Shqipërisë në lindje dhe perëndim të Liqenit të Shkodrës. Qëllimi i këtyre studimeve ka qenë përcaktimi i zonave gjeologo-inxhinierike me karakteristika të njëjta në lidhje me vetitë gjeoteknike të dherave dhe shkëmbinjëve që ndërtojnë zonën e marrë për studim, vlerësimi dhe përcaktimi i sektorëve dhe zonave ku zhvillohen rrëshqitjet e tokave, vlerësimi dhe përcaktimi i sektorëve dhe zonave që përmbyten dhe që rrezikohen nga përmbytjet e ujërave të Liqenit të Shkodrës, si dhe vlerësimi dhe përcaktimi i masave inxhinierike që duhet të merren në lidhje me mbrojtjen e tyre nga rrëshqitjet dhe përmbytjet. Përveç studimeve të përmendur më sipër, në këtë zonë, janë kryer studime hidrogjeologjike për furnizimin me ujë të pijshëm të zonave suburbane qe shtrihen në të dy anët e Liqenit të Shkodrës, si dhe studime të detajuara litologjike e gjeomorfologjike. Gjithashtu, në këtë artikull janë dhënë sektorët dhe zonat më të përshtatshme në lidhje me planifikimet dhe zhvillimet urbane të rajonit Shkodër. Në fund janë dhënë konkluzionet dhe rekomandimet.

Fjalë kyçe: *zonë gjeologo-inxhinierike, vrojtime gjeofizike, gjeofaktorë, vrojtime hidrogjeologjike, ujëra nëntokësorë, manaxhimi i rrezikut të përmbytjeve, vetitë fiziko-mekanike, dhera, shkëmbinj*

Abstract: This paper presents the results of the multidisciplinary researches-engineering geology and geophysics studies carried out during 2000–2006 in the Shkodra area, Albania. The studied area is located in north-western part of Albania along of Shkodra lakes banks, Albania. The purpose of these studies were to define the geo-engineering zones with homogenous characteristics related to geotechnical properties of soils and rocks of the zone around of the Shkodra Lake and engineering measures according to risk management of the flooding from lake waters, as well as hydrogeological investigation related to water supply of villages, which extend in east of Shkodra Lake. Moreover, detailed lithological and geomorphological observations have been carried out. Also, in this study are given geodynam-

[*] Ylber Muceku, Institute of Geosciences, Polytechnic University of Tirana, Albania
[**] Sami Nenaj, Llesh Prenga, Geological Survey of Albania

ics phenomena are floods and landslides. In the end are given the conclusion and recommendations.

Key words: *engineering geology zone, geophysics investigation, geofactors, hydrogeological investigation, underground waters, risk management of flooding, physical mechanical properties, soils, rocks*

INTRODUCTION

The studied area is located in western part of Shkodra flat on both side of Shkodra Lake, Albania. In east, close to Shkodra Lake extends one the main towns of Albania, the Shkodra town and north east Kopliku town. Also, around the lake are developed several very beautiful villages as Shiroka and Zogaj villages, which are located in west, whereas in northeast and eastern side are Vuk Palaj, Buza-Flaka, Buze Uji, Grud Fusha, Omaraj, Boriçi and Fushë Grilli villages. Based on request of the government & privates institutions and companies during since 1987 up to nowadays years are carried out many engineering geology, hydrogeology and geology studies on this area. So, in 1985–1986 year from Seismological Institute of Tirana and Tirana Engineering Geology Enterprise is completed an microzoning seismological map on scale 1:10.000 for Shkodra town, 1998–99 year is carried out the study of engineering geology condition of the lakes bank from Buna bridge up to 20 km in north for the taking of the protected engineering measurements of the western part of Shkodra flat from flood phenomenon, 2000–2008 years was worked to engineering geology mapping on scale 1: 25.000 for whole area of Shkodra district. In 2002–2007 by Geophysical Center of Tirana are carried out geophysical investigations for underground waters in Shkodra flat for water supply of many villages in this area. Also, in 2007–2008 years in the Buna River from Shkodra Lake up to conflux Buna and Drini Rivers. This paper is a summary of all these studies. The purpose of these studies was to give base information according to characteristics of the territory for planning, land use and engineering structures. In this time the data related to sites conditions of urban environment, has assumed increasing importance, confirmed by problems resulting from unfavorable engineering geological conditions (landslides, collapsible soils, etc). This paper is a summary of all these studies.

METHODOLOGY

The main product for the Shkodra Lake Basin project carried out on 2000–2008 year was the compilation of the detailed engineering geology map on scale 1: 25000, which contents the geo-engineering zones with homogenous characteristics related to geotechnical properties of soils and rocks, stable and stable zone according to landslides and floods phenomenon and the perspective area according to urban development, geological setting, underground waters and geomorphology. The woks of this study include the database compilation, after that the field investigations-laboratory analysis and the end the interpretation-correlation of the date taken from field-laboratories works, as well as the preparation of the engineering geological map

together with text. According to database compilation are taken under consideration all studies carried in this area (Koçiaj *et al*., 1986, 1987; Xhomo *et al.,* 2002; Bicaj & Prenga, 2002; Muceku *et al*., 2002–2008). Whereas, the field investigations represent by superficial deposits observation in oriented profile on scale 1:25.000, 120 drillings done in studied area range from 10.0 m up to 20.0 m deep, in situ measurements as geophysical investigations-electrical methods (vertical electrical soundings – VES). The solutions of litological and underground waters problems from geophysical investigations are closely related to the fact that there is a difference in the values of resistivity of different types of soils (clays to gravel) and basements formations. Based on this property are determined several lithotogical unit. Also, from field works are taken and analysis 165 soils samples (100 undisturbed and 65 disturbed samples) and 33 rocks undisturbed-disturbed samples, which are analyzed laboratory for determination of mechanical and physical properties, as soils grain size distribution, bulk density, Atterberg's limits, moisture content, specific density, dry density, porosity, porosity coefficient, shear strength, oedometer modules and uniaxial compressive strength test etc. From analysis and interpretation all these results is capacitated the compilation of the engineering geological map on scale 1: 25 000. It is build basing on geofactors as lithological, geomorphological, hydrogeological, geodynamics phenomena and physical-mechanical properties. The map is divided on several engineering geological zone and sites with homogeneous characteristics related to above mentioned geofactors.

RESULTS

The engineering geology and geophysics studies in Shkodra area were done for urban planning and development purpose. For that are used the geofactors as lithology, morphology, hydrogeology, geodynamics phenomena and physical and mechanical properties of rocks and soils, which are wrote as followings:

Geology setting

The Shkodra Lake is 25 km long and 14 km wide. It was filled by the marine Pliocene, forming a gulf in the Adriatic Sea (Fig. 1). Many tectonic events occurred during the geological history of the studied region, such as continuous settlement which occurred many time during this history with accompaniment of land depression. So, in the end of Pliocene period has occurred uplift movement of this area doing the creation of a new land. In the Quaternary period this region pass a tectonic tension and extension phase accompanies by landslides, creating the graben (Fig. 2) structure of Shkodra Lake (Xhomo *et al*., 2002). It filled by the alluvium deposits of the Kiri River and many streams. The alluvium deposit composed by gravel, sand and pebbles which are limestones. In the studied area are determined five geological deposits as alluvial deposits-gravel, sands and silts-clays, deluvial deposits mixtures of rubles with silts, flyschs and limestones rocks (Fig. 1).

Alluvial deposits extend on mostly of the studied area and construct the delta of the Kiri River. These are represented by gravel, sands and silts-clays with thickness

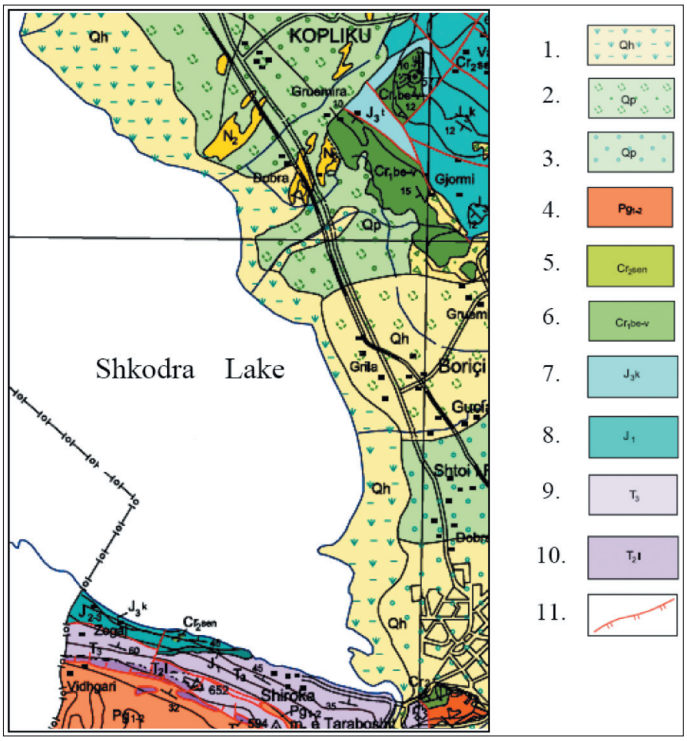

Figure 1. Geological map of Shkodra Lake region (after Xhomo et al., 2002)
1. Swamp deposits, loams intercalated with peat layers; 2, 3. Alluvial and prolluvial deposits, gravel, sands and silts-clays; 4. Flysch rocks-combinations of sandstones, claystones and siltstones layers; 5, 6, 7, 8, 9. limestone's rocks; 10. tectonics line.

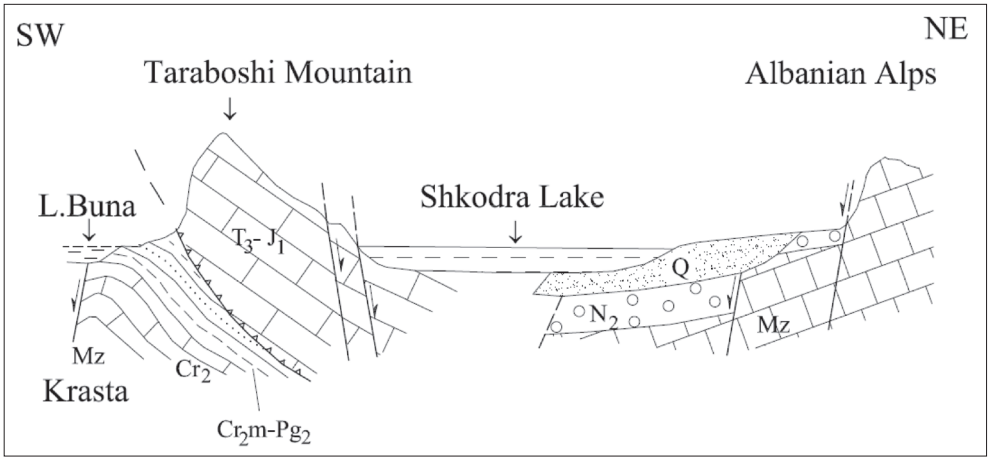

Figure 2. Geological profile of Shkodra Lake (after Melo et. al., 2002)

60–75.0 m up to 100.0–125.0 m. They are situated on the molasses and limestones deposits.

Swamp deposits extend on east of Shkodra Lake. These formations consist of mixture of peat and loams. They are 5.0–7.0 m up to 15.0–20.0 m thick.

Diluvium deposits are found along the lower part of the Taraboshi mountains slopes and in the major part of the torrent joining, which are developed on mountains slopes. They are composed by mixture of rubbles-stones of limestones rocks with irregular shape with sands-silts. These deposit formed a thickness range from 1.0–2.0 m up to 3.0–3.5 m. Generally they are of heterogeneous character.

Flysch formations are included in Paleocene-Eocene Pg_{1-2} and Oligocene-Pg^{1}_{3} age. They extend in south and west of the studied are. The flysch rocks are combinations of sandstones, claystones and siltstones layers. Relationships between the flysch and limestones formations are tectonic (Fig 2).

The Limestone's rocks belong from Middle Triassic (T_2) to Upper Cretaceous-Senomanian (Cr_2 sen) age. They are located in south, west and east of the studied are. These rocks consist of thin-middle strata and situates over flysch with tectonics zone (Fig. 2).

Morphology

The morphology of the studied area is closely related to the geology. Mostly of that it represents a flat zone, which is built by soils (Quaternary). The west, north and northeast bank of the lake are surrounded by mountain, whereas the east lake bank represent by a flat plain. The Taraboshi Mountain on the east shore are built from limestones rocks, which is a stable bank make up a favored zone to tourisms development. Contrary, the east bank is a flat plain area and several times as result of rainstorm is flooded. This bank is built by alluvium deposits, which are a combination of silts and sands layers (upper part of profile) and gravels soils (lower-middle part of profile). Based on morphology features the studied area is divided in morphological unit as flat morphological unit and hills morphological unit.

Flat morphological unit

The flat morphological unit has an inclination angel smaller than 5 ° (very gently). The elevation of the flat area varies from 6.5–20 m (Shkodra town) to 200.0–230.0 m (north of Kopliku town), but in west and east of Shkodra Lake is extend the Taraboshi mountain. Along of this zone from north-east to south-west direction has established their valleys the Kiri river and from east to west direction Drini river. They have a valley like „U" shape. Based on morphological features it is divided in two morphological subunits, which are first terrace of Kiri River, first terrace of Drini Buna.

First terrace of Kiri River extends from eastern part of Shkodra town up to Shkodra Lake. It represents a flat area with inclination angle 2–3 ° toward southwest. They are constructed by alluvial deposits, which are composed of silts, clays and gravel soils, which built mostly of litological profile. On this terrace are built Shkodra, Ko-

pliku towns and many villages. They are situated on molasses and limestone rocks. The thickness of these deposit are 70.0–10.0 up to 150.0 m.

First terrace of Buna River extend in southern part of studied area between of Taraboshi mountain and Rozafa castle hill, forming a flat area, which dip to south with angle 2–4 °. It's built by silts, silty sands, sands, gravels and pebbles-blocks deposits, which are thick, ranging from[2]0.0–25.0 m up to 35.0–40.0 m. In the studied area along of this terrace on both side of the Buna River are constructed many engineering object as roads, bridges and buildings.

Hills morphological unit

It is located in west and south of studied area. It is represented by Taraboshi Mountain and hills chain of Tepe-Rozafa castle hill. The elevation of this morphological unit ranges from 130.4 m (Rozafa castle hill) up to 491.7–650.9 m (m. Sukes-m. Golishtit, Taraboshi Mountain). The morphological unit is composed by limestones, dolomite and flyschs rocks. The hills slopes have inclination range from 7 °–10 ° up to 15 °–30 ° and some place more.

Hydrogeological condition

The observed site related to hydrogeology is composed by two complexes of rocks, which are the Quaternary deposits and limestons rocks. From north to south of the studied are is built by the Quaternary deposits, which are part of the first terrace of Kiri and Buna River. From hydrogeological point of view, the mostly of lithological profile of these terraces form the rich aquifers, because of they consist of gravels, which are supplied by Kiri and Buna River and karstic waters originated from limestones. So, from field works in the investigations area, which extend from north of Kopliku town to Drini bridge, where are carried out more than 100 hydrogeological boreholes results the Quaternary deposits built from a very aquifer, gravel. This aquifer extend from northern part of Kopliku town to south of Shkodra town. Beside of the hydrogeological works (boreholes), this aquifer is determined by many geophysics measurements profile-electrical methods, such as resistivity profiles and the vertical electrical soundings carried out in the studied area. It should be emphases that in northern part of Shkodra town are used the combination of electrical profiles with vertical electrical soundings (VES) leads to separation of karstic formations that present water collectors and circulation of the water. In the case where the electrical profiles with the Schlumberger array were used the grid of survey is 250 x 20 m, whereas for vertical electrical soundings the grid is 250 x 100 m. In the case of solving the problem of separation of karstic regions filled with water or with clays, the spontaneous polarization (SP) and sometimes the induced polarization (IP) methods have been used. With the application of Schlumberger array in electrical profiles we concluded that the icon resistivity values are complicated, but we can distinguish some anomalies with low values of resistivity. For explanation of that we are given a case study done in Koplik region related to underground water investigates for water supply of many villages in this area.

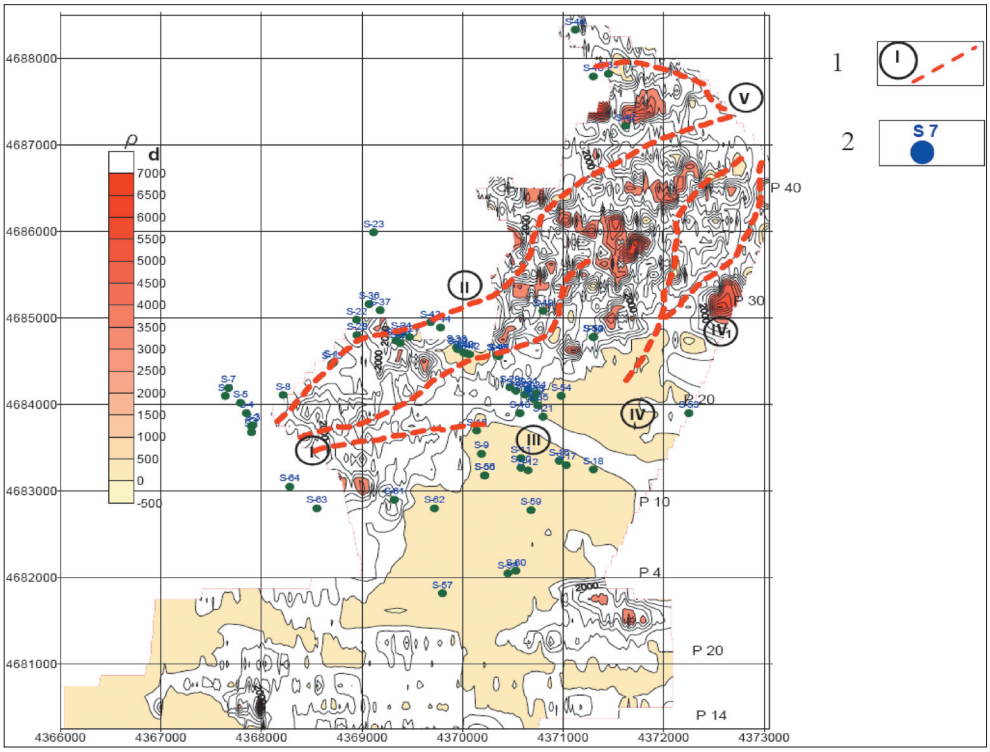

Figure 3. Izoline map of ρa in Bajza-Koplik area (after Prenga & Nenaj, 2002)
1. Anomaly axis and its number, 2. hydrogeological borehole

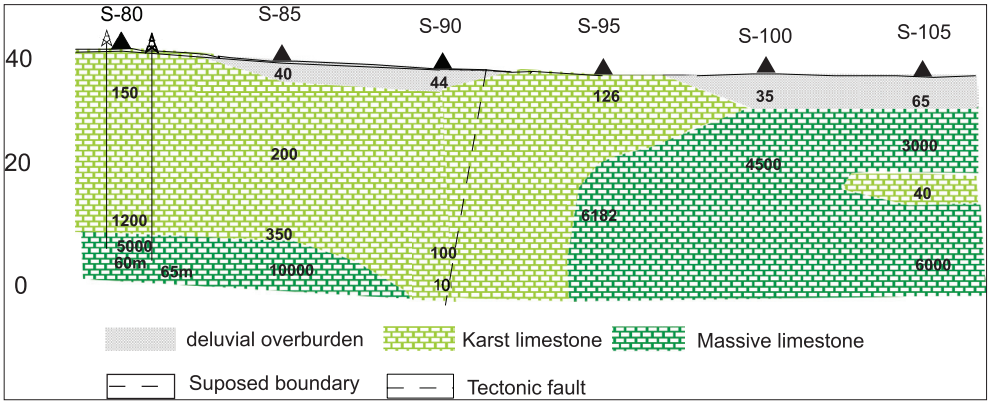

Figure 4. Geolectric-VES cross section in Bajza-Koplik area

The length and the width of these anomalies are from 1.5 km up to 5.0 km and 0.4 km up to 1.0 km respectively. The values of resistivity where the karstic process is present vary from 200 ohm up to 1500 ohm, whereas in compact formations the val-

ues of this parameter vary from 5000 ohm up to 8000 ohm (Fig. 3). The quantitive interpretation of vertical electrical soundings represents a much more complicated icon of the apparent resistivity values. This phenomenon is related to an intensive karstic process in carbonatic formations. In the geoelectrical section, are clearly depicted regions where karstic procces is present? From the Vertical electrical soundings the karstic procces in carbonatic formations is estimated in a depth of about 70–80 m and they are near surface sources (Fig. 4). The regions with developed karstic process are located in parts of tectonic ruptures in which the subsurface water circulates. Whereas, in the quaternary deposits are composed from silts, sands and gravels for underground water explorations are used the SE method. So, from geological-geophysical sections, the true resistivity values of these formations differ essentially from the surface toward the depth reflecting in this way, lithological variation of geological section. From ES data is distinguished the sand layers and gravel ones, where the resistivity values of them are from200–300 ohm up to 1000 ohm. In the case of clays and sand-clays layers the resistivity values are from some ohm till tens ohm. In the geological-geophysical section is clearly shown also that, generally the depth of gravel layers deposits goes until 100–150 m. From hydrogeological investigations carried out in those regions has proved the presence of very big water resources. From field works results that permeability coefficient „k" in gravel is k=60.0–70.0 m/day (south of Shkodra town) up to k=104.0–129.0 m/day (center to north of Shkodra town), whereas, the specific discharge „Q" is 6.9–7.8 lit/sec (south of Shkodra town) up to Q= 53.0–62.0 lit/sec (center to north of Shkodra town). The underground water table is 1.5–5.0 m below surface in Shkodra town, 10.0–16.5 m in northern part of Shkodra town and more 16.5 m in Koplik region. In the sectors around Shkodra Lake 1.5–2.5 km wide is 1.0–2.5 m deep. The chemical composition of the underground of quaternary complex in Shkodra flat are Ca = 54.9–93.3 g/liter, Na + K = 6.2–30.6 g/liter, Mg =9.2–15.5 g/liter, HCO_3 =186.7–256.2 g/liter, SO_4 = 7.7–13.6, g/liter, Cl = 7.1–10.7 g/liter, Ph = 6.9–7.2.

Geodynamics phenomena

From field works results the in studied area from intense rainfall on both side of the Shkodra Lake and Buna River occurred the floods phenomenon. The lake is fed by several streams and many karstic springs. It drains directly into Adriatic Sea through the Buna River. The precipitation influences directly in the distribution and the amount of water-flow the Shkodra Lake and Buna River. Floods in this area are caused by the rainfalls. This is why floods are registered in many times from January to February, 1963 up to 2010 year, the period when the rainfalls are abundant. Urban areas situated on the low-lying areas in south-western part of Shkodra town and Bahçalleku square are particularly exposed to extensive floods phenomena from Shkodra Lake and Buna River, where in some cases from this phenomenon these parts are flooded, doing a large impacts particularly in terms of economic losses. Thus flood hazards in built environments have to be seen as the consequence of natural factor. Now days, the Shkodra urban growth expands over some sectors of the floodplains, reducing the area into

which floods can naturally overflow. As is seen it, these parts of the urban area are under floods threatening. Therefore, these sectors need to take the protected engineering measurements as artificial levees. As a result of the floods, the water spread and occupied many engineering objects as building and roads doing a lot of damages.

Engineering geology map

The purpose of this study was to define the geo-engineering zones with homogenous characteristics related to geotechnical properties of soils and rocks construct the area around Shkodra Lakes and engineering measures according to risk management of the flooding from lake and Buna River waters. Also, a special attention is dedicated the hydrogeological investigations related to water supply of residences centers, which extend in east of Shkodra Lake. Moreover, detailed litological and geomorphological observations have been carried out. For that the engineering geology investigations (Muceku, Y., 2002–2008) are carried out on this area include the field works-engineering geology mapping on a scale 1: 25000 done in whole area and a lot of drillings and laboratory tests completed along east lake bank from Buna bridge up to 20.0 km in north closed to Buze uji village, for constructions purpose of any engineering objects in western part of the Shkodra plain. Also, on east of lake or north Shkodra town are carried out hydrogeological boreholes and many geophysical measurements-apparent resistivity method with vertical electrical sounding (VES) for determination of the underground water and litological situation, as well as bedrocks depth. Based on these works we successfully completed the engineering geology study for this area. The results obtained from these studies have allowed estimating of the litology, morphological features, hydrogeological condition and geotechnical characteristics, as well as the floods plain area. Based on geofactors is arrived to compile the engineering geology map with scale 1: 25000 (Fig. 5 and 6), which will serve the government and privates companies for urban planning and development. The engineering geology map is divided in several engineering geology zones as:

1. Engineering geology zone of gravel-sand-silts mixtures-GM.

2. Engineering geology zone of inorganic silts and clay with very fine sands soils type-ML and CL.

3. Engineering geology zone of inorganic clay and silts with very fine sands soils type-CL and ML.

4. Engineering geology zone of organic silts and organic clay -peat mixtures OH and Pt.

5. Engineering geology zone of soft rocks-Fl_S.

6. Engineering geology zone of medium strength rocks-Fl_M.

7. Engineering geology zone of hard rock-L.

1. Engineering geology zone of gravel-sand-silts mixtures-GM type.

This zone is built by soils are the gravel-sand-silts mixtures, saturated, grey color, which are in medium to dense state. This zone extends from north to south (Kopliku-Shkodra town). It has a thickness 15.0–25.0 m up to 65.0–95.0 m. The geotechnical properties of this zone are given in Table nr. 1.

2. Engineering geology zone of inorganic silts and clay with very fine sands soils type-ML and CL.

Represents by the inorganic silts and clay with very fine sands soils type (layer 1), low plasticity, which have the medium to very stiff consistency, light beige color with grey and black spots. The soils thickness of this zone is 4.5–6.5 m. Below superficial layer nr. 1 (Table 1) is situated the inorganic clays and very fine sands soils with low plasticity, medium to stiff consistency, grey colors, which range from 6.0–6.5 m up to 30.0–35.0 m (layer nr. 2, Table 1).

3. Engineering geology zone of inorganic clay and silts with very fine sands soils type-CL and ML.

It's built by the gravelly clays, sandy clays and silty of clayey fine sands. This zone extend in the Drini River terrace and stream teraces of Rrjodhi and Thate. The soils of this zone are 4.0 5.0 to 7.0–8.0 m thick.

4. Engineering geology zone of organic silts and organic clay -peat mixtures OH and Pt.

This layer is organic silts and organic clays of medium to high plasticity – OH with grey color intercalates with peat soils layers. These soils have a thickness range 5.0–6.0 m up to 10.0–15.0 m. The physical-mechanical properties of these soils are given in Table 1.

5. Engineering geology zone of soft rocks-Fl_S.

It is represented by soft rocks-flysch rocks, which are claystones and siltstones intercalated with sandstones. This zone is located in south of the studied area.

Engineering geology zone of medium strength rocks-Fl_M.

It is represented by medium strength rocks-flysch rocks, which are sandstones and siltstones intercalated with claystones. This zone is located in south and north of the studied area.

Table 1. Physical properties of soils in engineering geology zone nr. 1, 2, 3, 4 and 5

Zone nr.	Layer nr.	Physical mechanical properties												
		Gravel	Sand	Silt	Clay	WL	Wp	Wn	γ	γo	φ	c	E	USCS
		%	%	%	%	%	%	%	kN/m^3	kN/m^3	(o)	kPa	KPa x 10^4	
1	1	50.2–62.1	28.2–41.6	4.4–12.8	1.12.5	–	–	–	19.9–22.0	26.5	43–44	–	3.50–4.50	GM
2	1	–	16.8–39.6	49.4–74.2	8.6–18.4	38.3–42.6	19.9–24.6	25.9–32.5	18.5–18.8	26.7–26.9	16–18	15–25	0.375–0.70	ML-Cl
3	2	–	16.9–37.7	51.1–64.3	19.8–25.6	40.1–42.5	22.6–25.8	27.6–34.9	18.6–19.0	26.8–27.0	14–17	15–30	0.32–0.75	
3	1	4.9–23.7	16.4–28.7	51.7–59.5	11.8–14.4	38.6–43.40	22.8–25.10	24.48–29.34	19.1–19.2	26.8–27.0	17–19	20–30	0.685–11	CL-ML
4	1	–	18.5–32.9	39.8–78.0	17.5–29.8	46.7–53.5	29.7–30.4	30.9–48.6	17.4–18.3	27.0–27.2	9.0–15.0	5–10	0.07–0.22	OH-Pt

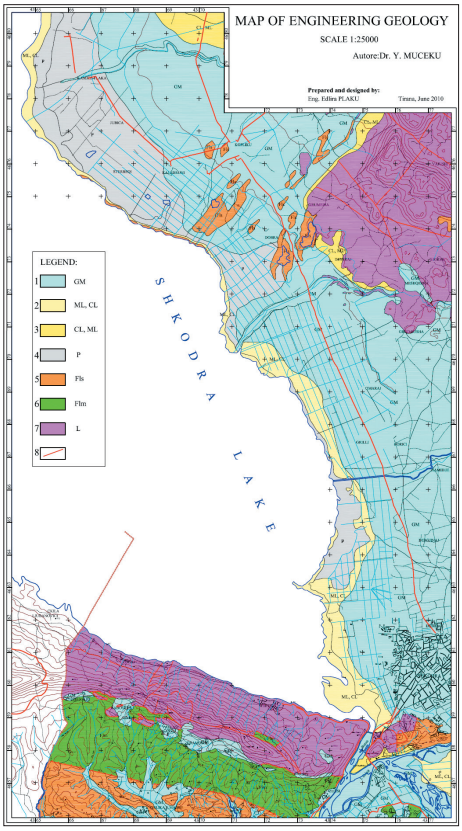

Figure 5. Map engineering geology on scale 1: 25 000 of Shkodra region (after Muceku, 2008)
1. Zone of engineering geology GM, 2. Zone of engineering geology ML and CL, 3. Zone of engineering geology CL and ML, 4. Zone of engineering geology OH and Pt, 5. Zone of engineering geology FlS, 6. Zone of engineering geology FlM, 7. Zone of engineering geology L.

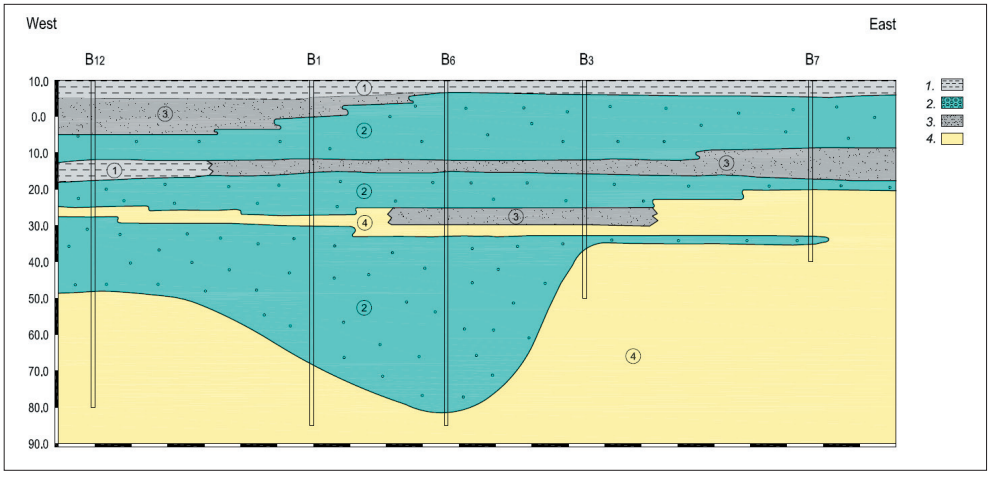

Figure 6. Lithological profile in Shkodra urban area (after Muceku, 2008)
1. Inorganic silts and sands, 2. gravel-sand mixtures, 3. silts-clays-sand-gravels mixtures, 4. inorganic clays and silts and very fine sands

Engineering geology zone of hard rock-L.

This zone consists of limestones with thin-medium strata range from 0.2–0.3 m to 1.0–1.5 m, light gray in color. They are including in the hard rock's group.

Table 2. Physical properties of rock in engineering geology zone nr. 5, 6 and 7

Engineering geology zone	Physical mechanical properties				
	γ	γd	γo	τc	Rock type
	kN/m^3	kN/m^3	kN/m^3	KPa x 10^4	
5	24.5–24.9	23.9–24.5	25.85–26.15	0.636–0.691	F_s
6	24.7–25.3	24.2–24.8	25.4–26.5	0.689–0.95	F_M
7	26.0–27.4	25.5–26.8	26.9–28.3	7.5–8.9	LM

CONCLUSIONS AND RECOMMENDATIONS

From the engineering geology and geophysics studies carried out around of Shkodra area results:

The perspective zones for urban development of Shkodra town are north of Shkodra town and in west of Shkodra Lake, along of Taraboshi mountain slope from Zogaj village to Buna Bridge.

The floods phenomena have occurred for several times in south-western part of Shkodra town from which these parts incurred a large impact particularly in terms of economic losses.

Municipalities are well advised to spend adequate resources for comprehensive flood risk assessments. Only if there is data which clearly indicates which neighborhoods are most at risk, successful measures can be planned to take the protected engineering measurements.

From geophysical and hydrogeological measurements results that region is very rich according to underground waters.

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