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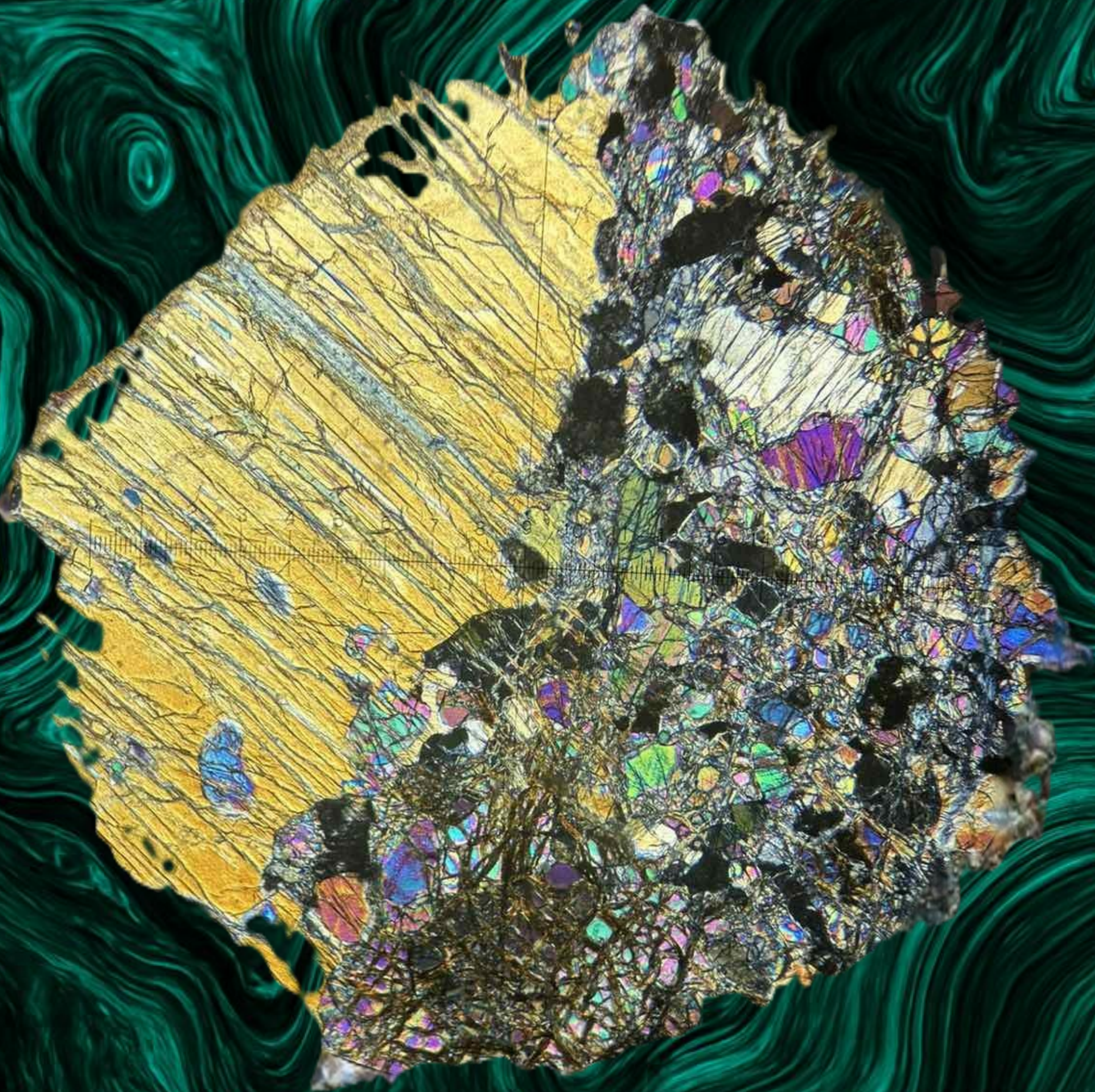

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DOI 10.51558/2303-5161.2025.13.13.1 Scientific paper

MICROPHYSIOGRAPHY OF SPILITES AND ASSOCIATED ROCKS IN THE SURROUNDINGS OF VAREŠ

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Summary

Twelve samples of spilites and associated rocks from the surroundings of Vareš were processed microphysiographically. Based on optical examinations of rocks, structural-textural characteristics, rock color, type and intensity of alteration processes, and respecting the existing classification schemes, different lithotypes were defined. Spilites are the dominant rock type. Taking into consideration textural varieties, ophitic and porphyritic spilites were distinguished. These two varieties are mineralogically similar. The main petrogenic minerals are albite and augite, with a dominating amygdaloidal structure, while the vesicular and fluidal structures are subordinate.

The rocks associated with the spilites are ophitic basalts, rocks of spheroidal jointing, with amygdaloidal and vesicular structure. Both structure and jointing are parameters that distinguish them from similar diabases.

Keywords: ophitic spilites, porphyritic spilites, ophitic basalts, Vareš.

1. INTRODUCTION

The term spilite refers to altered aphyric basaltic rocks that are poor in phenocrysts or to albitized basaltic lavas (*Le Maitre et al. 2002*). Spilites are the most widespread Triassic volcanic rocks in the Dinarides. Initially, they were identified in the vicinity of Sarajevo. Spilites are most widely distributed in the Triassic volcanic area of Zelengora - Treskavica - Igman and along the belt Čevljanovići - Vareš - Borovica. They were also discovered at Krstac near Prozor, in the Vrbas valley and near Čajniče. Spilites near Čajniče are subordinated to the more felsic differentiates (*Pamić, 1957*).

Significative approach to the microphysiography of spilites and associated rocks around Vareš was realized in the 70s of the last century. The results of a modest scope were published more than half a century ago. During the year 2024, as a part of the scientific-research project *Petrological and geochemical characterization of the upper part of the ancient oceanic crust – Vareš surroundings"*, the rocks in question were systematically sampled and petrographically defined. A total number of twelve rock samples were examined. Their nomenclature and classification, according to the standard classification schemes, are based on optical tests of rocks and their structural-textural characteristics, as well as the way they appear in the field.

2. GEOLOGICAL STRUCTURE

Vareš is a town located in Central Bosnia, in the upper course of the river Stavnja. Distance from Sarajevo (north) and Zenica (east) is about 35 km of airline.

In geotectonic terms, the wider area of Vareš belongs to the contact of the central ophiolite zone (northern wing of the Vareš structure) and the zone of Paleozoic schists and Mesozoic limestones (southern wing of the Vareš structure). This structure extends approximately in direction WNW-SE along the Borovica - Ravne section, from where it bends south towards Čevljanovići and Srednje.

This unit also includes elongated volcanic bodies that follow the aforementioned orientation. The most notable in size are the bodies in the immediate vicinity of Vareš (0.4 x 4.2 km, area of about 135 ha) and in the Zubeta - Ravne section (0.3 x 4.4 km, area of about 113 ha).

At the beginning of the Alpine magmatic-tectonic cycle, Vareš area was covered by the sea, and it is assumed that the sedimentary basin was differentiated into a southern and northern part.

The northern development of the Lower Triassic (Scythian - T_1) is represented by quartz sandstones (so-called "Sarajevo sandstones") and sandy clays, while carbonate sediments are completely absent. The southern development of the Lower Triassic is characterized by fine-grained sandstones with a carbonate binder, followed by sandy clays, marls and sandy limestones. The final members of this development are clayey dolomites and tufa limestones (Zellenkalk), which are particularly widespread east of Vareš, in the wider area of Pržići and Dahštansko (Figure 1).

Anisian formations (T_2^1) have been analysed in detail in several localities and well documented paleontologically, which made it possible to separate two Anisian developments. The northern Anisian development (T_2^1) is simple. There usually dark gray crinoid limestones about 60 m thick lie above the white coarse-grained quartz sandstones. Quartz sandstones are conglomeratic in places. Above them are massive and lumpy Han-Bulog limestones, and over them are massive gray dolomitic limestones (Mountain Zvijezda). Limestones are most often recrystallized biosparites and intrasparites, and less frequently microsparites and calclutites. Often, however, Anisian is represented only by massive dolomitic limestones.

In the southern development of Anisian (T_2^1) there is a gradual transition from Scythian to Anisian. Transitional horizon is characterized by clayey dolomites or porous dolomitic limestones, overlain by gray layered dolomites.

Ladinian formations (T_2^2) are widespread in both the northern and southern wings of the Vareš Triassic structure, but with significant lithofacial differences. In many cross-sections, a gradual transition from Anisian to Ladinian is observed. Transitional horizon is characterized by hematite and manganese claystones (Vareš area), or dolomites and dolomitic limestones (Borovica area). The northern development of Ladinian is represented by limestones and dolomitic limestones, while the southern development is characterized by spilites, tuffs, clays, cherts and limestones. Ladinian is paleontologically documented in both developments.

In the northern development Ladinian is developed only in carbonate facies: limestones and dolomitic limestones predominate (mainly pseudosparites and recrystallized biosparites, less frequently recrystallized biomicrites, or dismicrites). In some places, these limestones contain nodules and lenses of cherts. The limestones are massive and most often cannot be separated from the identical Anisian limestones.

Magmatic members of the Ladinian are represented by spilites and tuffs. It is a discontinuous zone of volcanic rocks that occurs from Vareš to Čevljanovići. Spilites appear in the pillow forms or brecciated pillow forms (diameter of pillows 20-70 cm) with enclaves of Anisian limestones, which was one of the reasons for their inclusion in the Ladinian. Pyroclastic rocks, as companions of volcanism, are found only in Ladinian sediments. The lowest position of extrusive rocks is over the limestones of the Anisian zone *Ceratites trinodosus*.

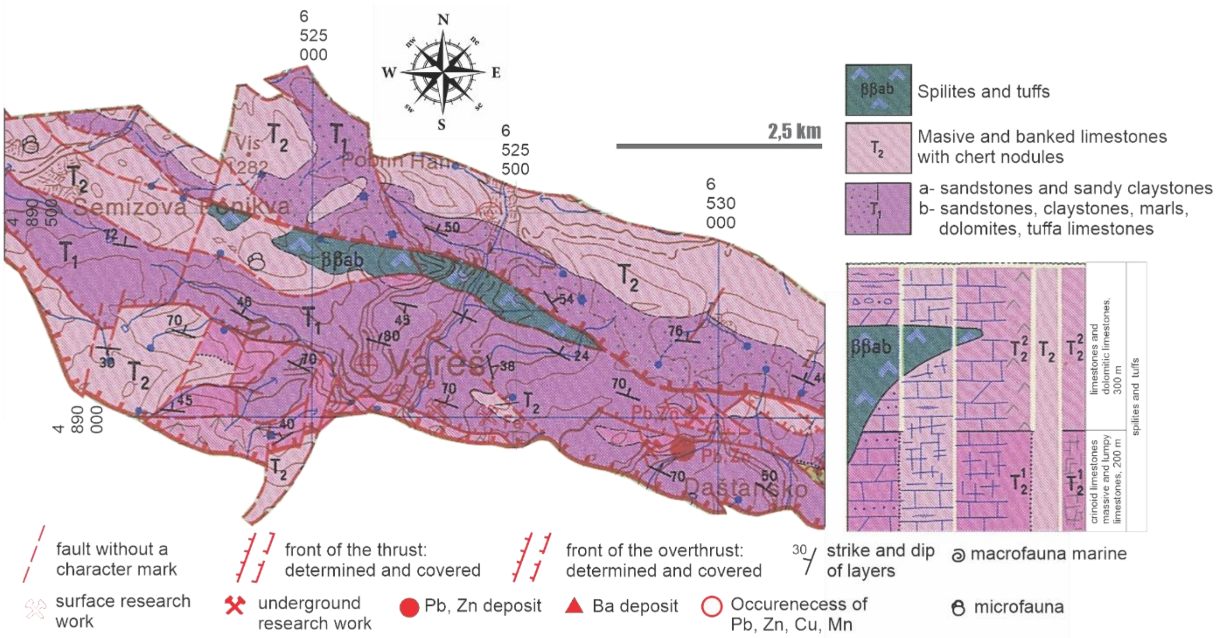

Figure 1 – Geological map of the wider Vareš area (Olujić et al., 1970).

In the southern development, Ladinian is represented by coloured clays and cherts, and plate limestones (siliceous micrites, less often microsparites and pseudosparites). Mentioned sediments usually alternate and can be layered with tuffs and tuffitic sandstones. Among the igneous rocks, the already shown spilites are the most common. Entire complex is finely folded and meters-long folds are very common. Mentioned folds are often intersected by faults (*Olujić et al., 1970; Pamić et al., 1970*).

3. RESEARCH AND TESTING METHODS

During field activities in the surroundings of Vareš (February - March 2024), 25 rock samples were collected on several occasions. After macroscopic determination, the number of samples was reduced to 12 (table 1).

Table 1. Labels and geographical positions of taken rock samples.

sample	N	E	sample	N	E
2	44°10'11.51"	18°19'59.42"	**8**	44°10'7.56"	18°19'57.14"
3	44°10'13.48"	18°19'55.42"	**9**	44°10'1.73"	18°19'57.38"
4	44°10'7.36"	18°19'25.47"	**10**	44°10'2.60"	18°19'58.19"
5	44°10'18.58"	18°19'27.05"	**11**	44°10'7.74"	18°19'57.21"
6	44°10'19.60"	18°18'47.36"	**12**	44°10'3.19"	18°19'59.29"
7	44°10'18.10"	18°19'29.32"	**13**	44°10'7.85"	18°19'57.03"

Samples for petrographic examinations were taken directly from the outcrops discovered in the cuttings and also from the streams. The number of field samples was determined depending on the geological structure of the terrain, its exposure, access, observed mineralogical and structural-textural varieties, and the freshness of the rocks (Figure 2). Thin sections for rock microphysiography were made at the Croatian Geological Institute in Zagreb.

Optical tests were performed on a Leica DM 2500P polarizing microscope at the Faculty of Mining, Geology and Civil Engineering of the University of Tuzla. Microphotographs were taken under orthoscopic conditions, with and without the analyzer on. In order to obtain realistic colors on the microphotographs, with regard to the used light source, a software correction of the white color balance was performed.

Figure 2 – Geographic positions of taken rock samples.

4. TEST RESULTS

4.1. Macroscopic determination

Textural types are diverse, and among structural types amygdaloidal, vesicular, brecciated and homogeneous structures were found (Figure 3).

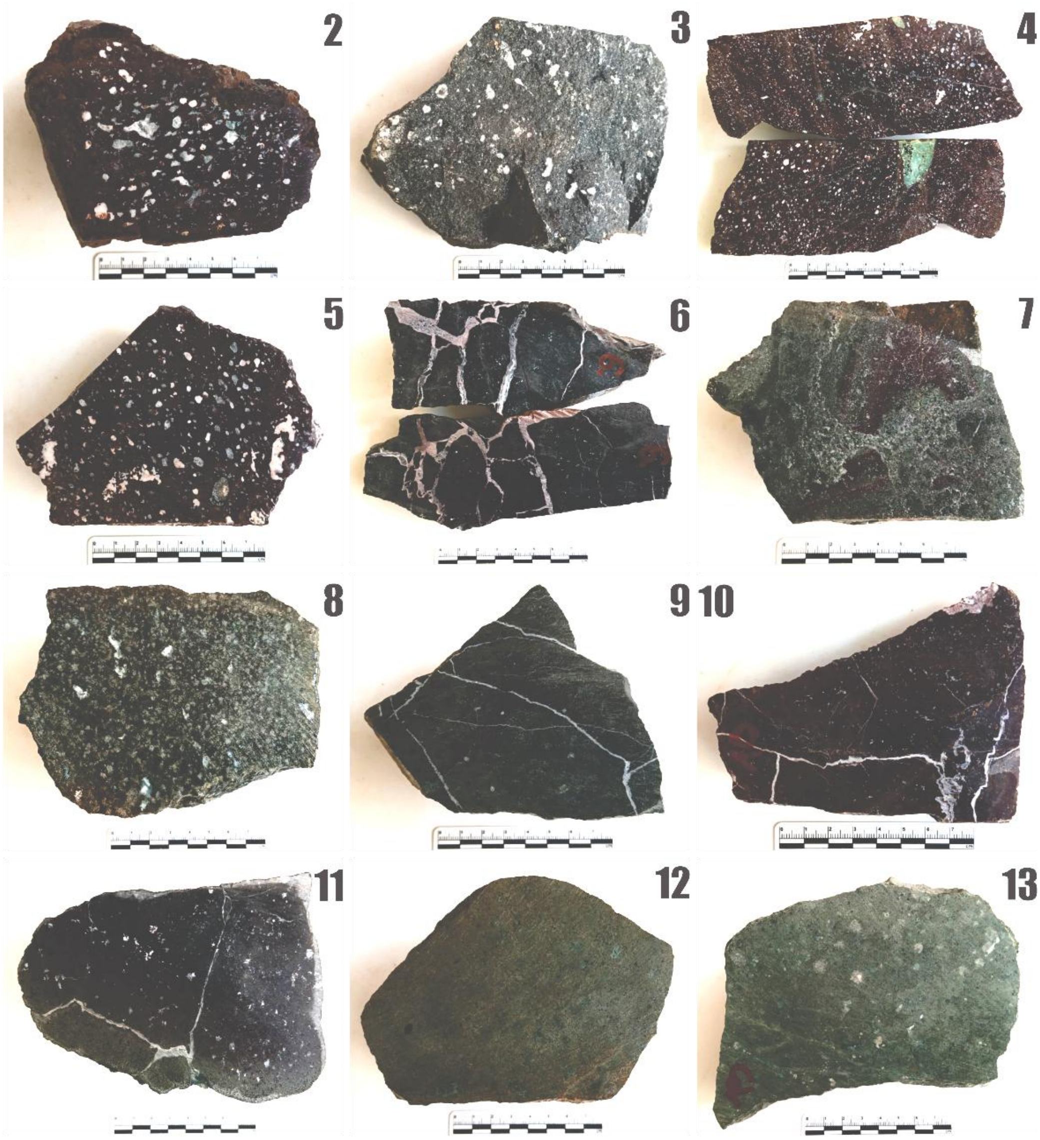

Figure 3 – Macrophotographs of sampled rocks.

Based on the color, presence/absence of amygdales and cracks, the following groups of rocks are distinguished:

- purple rocks with amygdales, vesicles and cracks. Amygdales occupy up to 30% of the rock, and are up to 0.5 cm in diameter. Their filling is white (calcite) and greenish (samples 2, 4 and 5). In samples 6, 9, 10 and 11, cracks dominate over the amygdales. The cracks are irregularly oriented, filled with white colored minerals, up to 3 mm in diameter. Amygdales appear sporadically, white and greenish in color, up to 1 mm in diameter.
- gray rocks with amygdales and cracks. Amygdales occupy up to 15% of the rock, and are up to 0.3 cm in diameter. Their filling is white (calcite) and greenish (samples 3 and 8). Along with the amygdales, there are irregular piles of pyrite (diameter 2-3 mm), mostly around the edges of the amygdales (sample 3).
- greenish colored rocks, with cracks that dominate over sporadic amygdales (samples 12 and 13).

According to structural characteristics, sample number 7 stands out. This sample is characterized by brecciated appearance, and is defined as spilitic conglo-breccia. It is built of

polygonal to semi-rounded fragments of ophitic spilites, and the space between the lithoclasts is composed of "glass".
During the field observations, characteristic phenomena of jointing of the rocks in question were observed. The predominant jointing is spherical/pillow-like. The diameters of the pillows range from 20 to 70 cm. Less common is plate-like rock jointing (Figure 4).

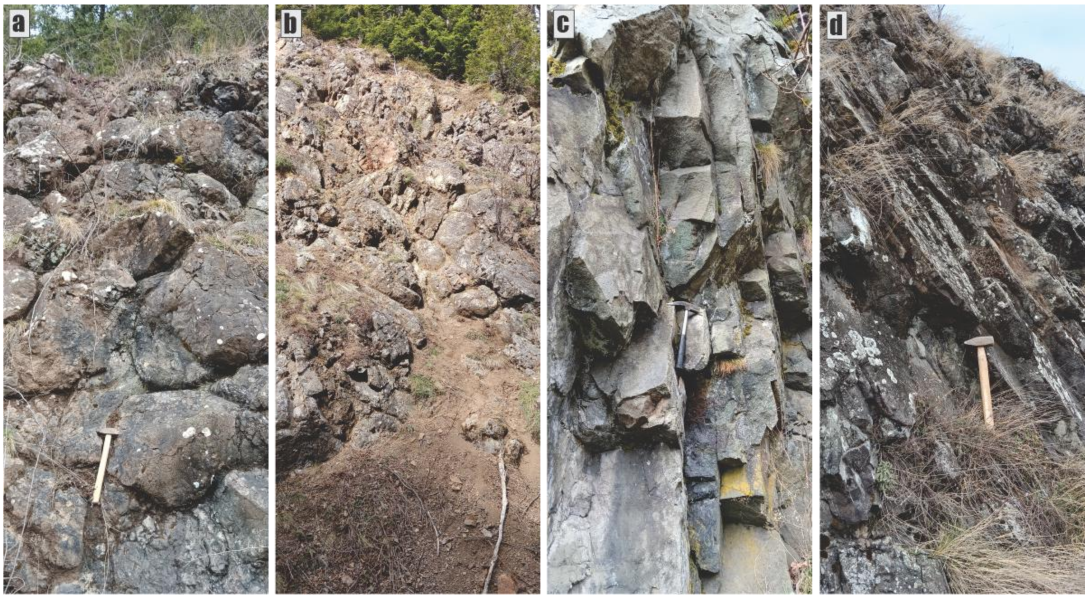

Figure 4 – Jointing of spilites and associated rocks in the Vareš surroundings: a, b) spherical/pillow-like; c, d) plate-like.

4.2 Rocks microphysiography

Spilites

Mineral composition of both structural varieties of spilite (ophitic and porphyritic) is quite uniform (tables 2 and 3). Albite is the most common mineral. It appears as idiomorphic, prismatic or needle-like. The grain length ranges from 0.2 - 0.4 mm. Albite in spilites is rarely fresh, more often it is altered, i.e. suppressed by small secondary minerals: calcite, greenish celadonite, pumpellyite and chlorite (?). According to data from theodolite-microscopic measurements, they usually contain 3-5% of the anorthite component (*Pamić, 1963*).
Plagioclases occur in prismatic forms up to 0.5 mm long. They are irregularly arranged in the rock mass; in some places they form piles, which create the impression of a glomeroporphyric texture. Plagioclases are albitized, blurred and "eroded" by magmatic resorption.
Characteristic femic mineral of spilite is augite, which appears in separate grains of allotriomorphic and hypidiomorphic habit (phenocrysts up to 0.7 mm), then may be branch-like and divergent-rayed. It is rarely fresh, mostly is disintegrated, chloritized and to a lesser extent epidotized. In spilites, which in a ground mass have an elevated content of brown-black isotropic matter, augite may be absent.
Among secondary minerals, celadonite, pumpellyite, chlorite, and accessory ilmenite and magnetite were also detected in the spilites. Pumpellyite appears in the form of fine-grained greenish-brown pleochroitic and dendritic aggregates. It appears in the marginal parts of the

pillows, probably as a result of volcanic glass devitrification during submarine hydrothermal activity, what is indicated by relics of glass around amygdales. Celadonite was created by the alteration of femic minerals. Crystals and fine-grained aggregates are green-blue in color. It appears in amygdales, cracks and in the ground mass of the rock (*Babajić A. et al. 2013; Babajić A. et al. 2017; Babajić A. and Babajić E., 2023*).

Table 2. Mineral composition, texture and structure of ophitic spilites.

sample	mineral composition	texture / structure
2	Ab, Aug, Cal, Cel, G, Ilm	hyalo-ophitic / amygdaloidal, vesicular
3	Pl, Aug, Ab, Cel, Cal, G, Py, Ilm	ophitic / amygdaloidal
4	Ab, Cal, Cel, Chl, Ilm	hyalo-ophitic / amygdaloidal
5	Ab, Aug, Cal, Cel, G, Ilm, Mag	hyalo-ophitic / amygdaloidal
6	Aug, Ab, Cel/Chl	hyalo-ophitic / amygdaloidal
7	Ab, Cal, Cel, Chl, Pmp, G, Ilm	ophitic / brecciated
9	Aug, Ab, Cel/Chl	ophitic / amygdaloidal, fluidal
10	Ab, Cal, Cel, Chl, Pmp, G, Ilm	ophitic / amygdaloidal

(Ab - albite, Aug - augite, Pl - plagioclase, Chl - chlorite, Cal - calcite, Pmp - pumpellyite, Cel - celadonite, Py - pyrite, Ilm - ilmenite, Mag - magnetite, (Warr, 2021)), G –glass (internal mark).

Among the secondary minerals, presence of greenish chlorite was very often emphasized (*Pamić, 1963, Pamić and Đorđević, 1966*). Subsequent research indicated that it is celadonite and pumpellyite (*Trubelja et al., 1976*), which was also confirmed in this case. In some of the samples, it was not possible to determine with certainty whether it was chlorite or celadonite, and both of these minerals were taken into account (Cel/Chl).

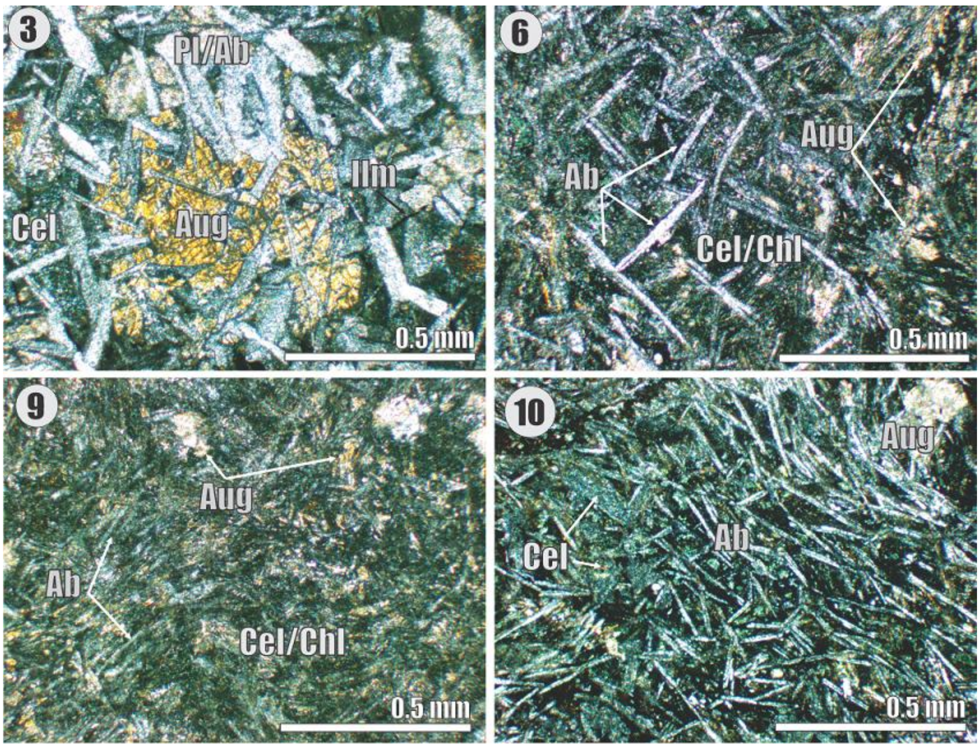

Figure 5 – Microphotographs of ophitic spilites samples. (*Ab - albite, Aug - augite, Pl - plagioclase, Chl - chlorite, Cal - calcite, Cel - celadonite, Ilm – ilmenite (Warr, 2021)).*

Table 3. Mineral composition, texture and structure of porphyritic spilites

sample	mineral composition	texture / structure
8	Pl, Aug, Ab, Cal, Cel/Chl, Ilm	porphyritic / homogenous
11	Pl, Aug, Ab, Cal, Cel/Chl, Qz, Ilm	porphyritic / amygdaloidal

Pl – plagioclase, Aug - augite, Ab - albite, Cel - celadonite, Chl - chlorite, Cal - calcite, Ep – Epidote, Ilm - ilmenite, Qz - quartz (Warr, 2021). G –glass (internal mark).

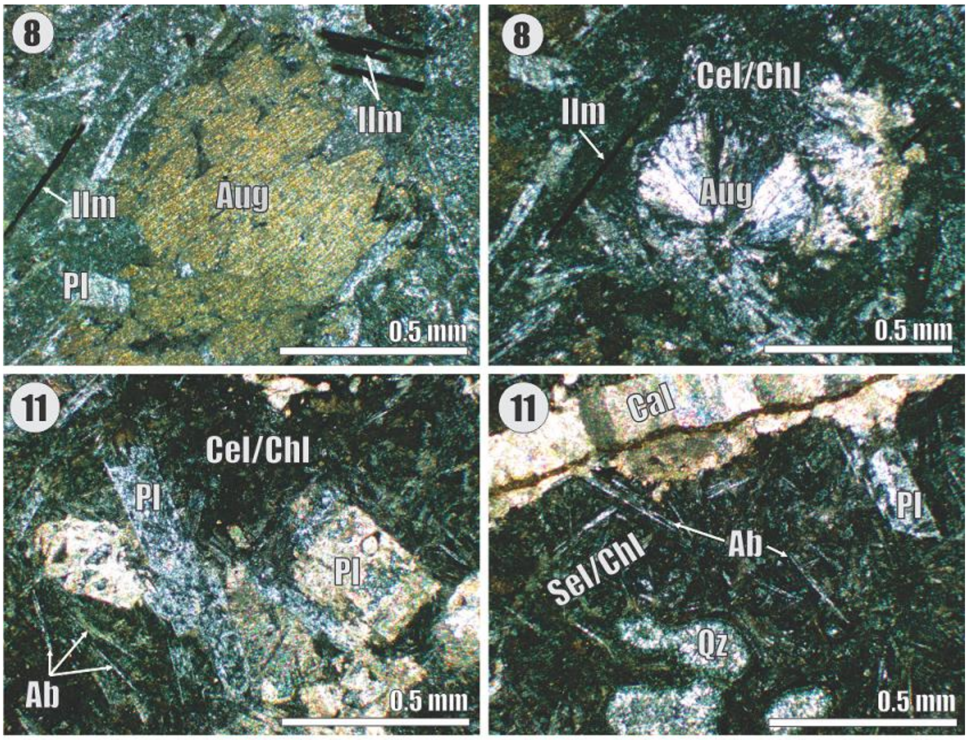

Figure 6 – Microphotographs of porphyritic spilites samples *(Ab - albite, Aug - augite, Pl - plagioclase, Chl - chlorite, Cal - calcite, Cel - celadonite, Prh - prehnite, Ilm - ilmenite, Qz - quartz (Warr, 2021)).*

Amygdales

Amygdales are a very common occurrence in the subjected rocks. Their presence ranges up to 30% of the rock. Their diameters vary widely, up to 2 cm, most often 0.2-0.5 cm.
Amygdales are most often filled with calcite, chlorite, celadonite, pumpellyite, less often with quartz and chalcedony. In the calcite amygdales, rhombohedral cleavage tracks and radial-divergent aggregates were found. Amygdales with celadonite have a characteristic quartz rim.In the ophitic varieties of spilite around the amygdales, but also in the ground mass of the rock, an isotropic black-brown substance called "glass" is determined (Figure 7).
Previous examinations of "glass" using the X-ray diffraction method indicated the presence of leucoxene and montmorillonite (Pamić, 1982).

Ophitic basalts

Ophitic basalts are often called diabases, because of the ophitic structure. However, ophitic basalts differ from hypabyssal diabases in the geological manner of occurrence (volcanic masses in the form of pillow textures that often appear in association with more felsic differentials, eg andesites). Another criterion is the presence of amygdaloidal and vesicular structure, which is absent in diabases. Also, ophitic basalts are often interbedded with pyroclastic rocks.

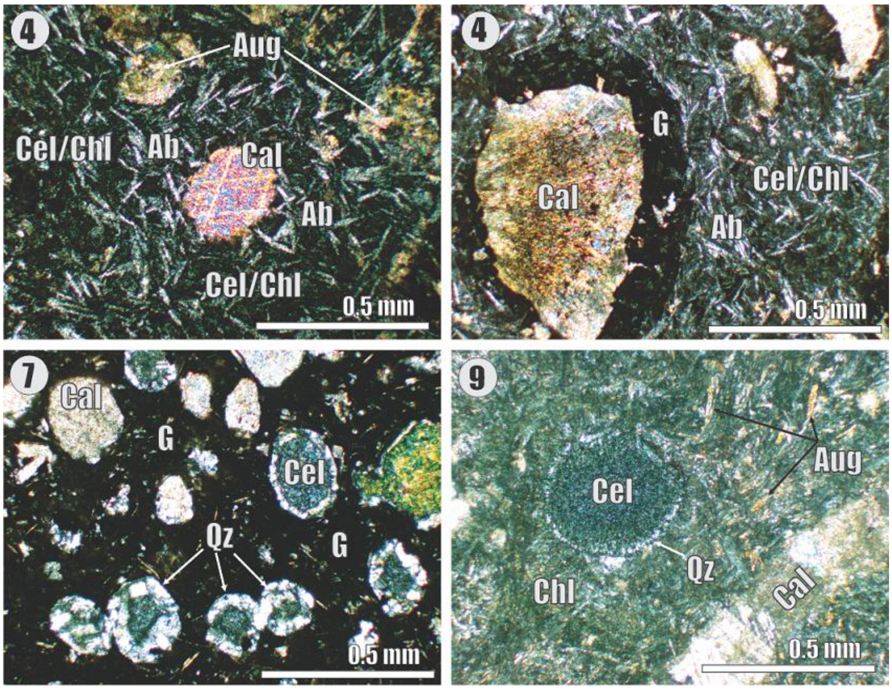

Figure 7 – Amygdales in the ophitic spilites (4 and 9) and spilitic breccias (7) of Vareš *(Ab - albite, Aug - augite, Pl - plagioclase, Cel - celadonite, Chl - chlorite, Cal - calcite, Qz - quartz (Warr, 2021)), G – glass (internal mark).*

Extrusive rocks with basic plagioclase and ophitic texture are defined as ophitic basalts, emphasizing the structural variety in accordance with the classification of Streckeisen (1978). The main petrogenic minerals are plagioclase and clinopyroxene. Plagioclase is mainly labrador or bytownite, and the microliths in the ground mass of the rock are more felsic - andenzine, less often oligoclase. Clinopyroxene is represented by augite filling the space between plagioclase. Alterations are related to plagioclase, which is suppressed by small secondary minerals, with the separation of albite. Augite is usually fresh, and in this case they are difficult to distinguish from ophitic spilites.

Epidote occurs in prismatic crystals as well as massive to earthy aggregates. It has a characteristic yellow-green to green color. It is a alteration product of the basic plagioclase with the yield of the Fe component (*Babajić A. et al. 2017*) (table 4).

Table 4. Mineral composition, textute and structure of ophitic basalts.

sample	mineral composition	texture / structure
12	Pl, Aug, Ab, Ep, Cel, Chl, Cal, Ilm	ophitic, homogenous
13	Pl, Aug, Ab, Cel, Chl, Cal, Mag, Ilm	ophitic, amygdaloidal

(Ab - albite, Aug - augite, Pl - plagioclase, Chl - chlorite, Cal - calcite, Cel - celadonite, Ep – epidote, Ilm - ilmenite, Mag - magnetite, (Warr, 2021)).

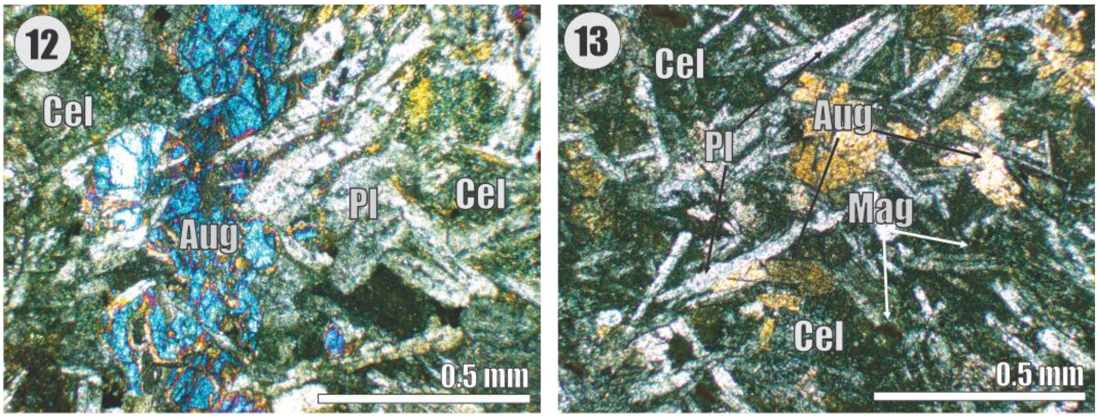

Figure 8 – Ophitic basalts composed of plagioclase (albitized) i clinopyroxene (augite).
(Aug - augite, Pl - plagioclase, Chl - chlorite, Cel - celadonite, Mag – magnetite (Warr, 2021)).

5. CONCLUSION

Spilites are the dominant rock type in the surroundings of Vareš. They most often appear in the pillow forms, which are the result of submarine volcanism. Plate-like type of appearance is more subordinate. Dimensions of the spherical (pillow-shaped) forms of spilite from Vareš range from 20 to 70 cm, rarely larger. Eastern part of the magmatic body (left bank of the river Stavnja) is intensively tectonized and altered, which makes the primary structures poorly visible in the field.

Based on textural characteristics, ophitic and porphyritic spilites are distinguished. Both textural varieties contain a variable amount of amygdales, which are most often filled with calcite, celadonite and pumpellyite, less often with quartz. In the ophitic varieties of spilite around the amygdales, but also in the ground mass of the rock, an isotropic black-brown substance called "glass" is determined. This mass needs to be further investigated.

Optical tests revealed that the ophitic spilites have an ophitic to hyaloophytic texture, amygdaloidal and less often vesicular or fluidal texture. Petrogenic constituents are plagioclase, augite, albite, celadonite, chlorite, pumpellyite, calcite, ilmenite, magnetite and pyrite.

Porphyritic spilites are amygdaloidal to homogeneous in structure, with the minerals plagioclase, augite, albite, calcite, celadonite, chlorite, quartz and ilmenite.

Associated ophitic basalts have an amygdaloidal and homogeneous structure. The primary minerals are plagioclase (basic) and clinopyroxene augite. A series of secondary minerals consists of albite, calcite, celadonite, chlorite, epidote, along with ilmenite and magnetite.

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QUANTITATIVE AND QUALITATIVE SITUATION IN THE WATER SUPPLY SECTOR

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Summary

Water is a vulnerable natural resource unevenly distributed on plant Earth, which must be preserved, adequately protected, and rationally disposed of in available quantities. Water is good for general use and should be treated in accordance with the Water Charter, and provide users with access in the sense that no one deny another person the use of water. Proceedingfrom the fact that the improvement of water requires the attention of the public at the local, national, regional and world level, it follows that activities of new amounts of water, as well as their protection and distribution to all those who need it, must be given special attention with cocrete measures and activities. Article 18 of UN Agende 21 refers to the protection and preservation of sources of drinking water, while at the same time providing a sufficient amount of fresh water. Therefore, there is a warning aboutthe misuse and continuous of water resaurces which disrupts the quality and quantitiy of water. In the Europeon Charter of water, it is said that water is a general hereditary good, the value of which must be known by everyone, and it must be ecconomized and used carafelly. However, the human population, in its excessive desire to manage water resources, has also had a counter-effect, although it is a well-known fact that it is imposible to find a substitude for water.

INTRODUCTION

The most important document on which the regulations and strategy for managing water resources, especially groundwater bodies, are based is the Framework Directive on Water of the European Union, the basic concept of which is aimed at preserving, protecting and improving the quality of the environment in which water bodies exist. There are numerous problems in the water sector, but in addition to recording the problems, it is necessary to carry out concrete activities to improve the condition of water bodies both quantitatively and qualitatively. It is a set of processes for which it is necessary to organize expert teams, secure financial resources, formulate legal regulations and continuous monitoring. As an example of the complexity of water supply for a number of municipalities in the Tuzla Canton, we can take the hydrogeological research in Srebrenik, which for a long time has lacked the necessary quantities of water for proper water supply to the population.

1. THE IMPORTANCE OF PLANNING AND EFFECTIVE ACTION TO PROTECT WATER RESOURCES

In the modern world, water is becoming an increasingly important resource, and the dynamic development of society and the increasing threat to the three geological environments (water, air and soil) is becoming a key issue of sustainable development. Water knows neither administrative nor territorial boundaries, but is a medium that is in constant motion, in the dynamics of which it is often exposed to different pressures of polluting substances. At the same time, the occurrences of increasing hydrological unevenness and extreme hydrological events are especially pronounced nowadays. Bosnia and Herzegovina is a country with significant amounts of underground and surface water, but these resources are not inexhaustible and are directly related to hydrological conditions. At most hydrological stations in the water area of the Sava River in FBiH from August 2021 to August 2022, water level and flow values were recorded that are close to historical minimums or even record low, while 2024 was the leading year. Rivers, lakes, underground water bodies are polluted with different forms of pollutants from a very wide spectrum of pollutants, without any remediation treatment. River flows that are polluted to a greater or lesser extent in the entire river basin (flows of the Sava river basin - the area of the rivers Una, Vrbas, Bosna and Drina) are particularly under attack. They are increasingly becoming recipients of sewage waste and industrial waste water. Ensuring sufficient quantities of physical-chemical and bacteriologically correct drinking water is becoming more and more a problem in the territory of the Federation of Bosnia and Herzegovina, where, according to estimates, about 50% of the population is connected to the public water supply system, and even less to the sewage system. Most of the local water catchment facilities do not have sanitary protection zones, and therefore there is no adequate insight into the correctness of drinking water, nor its protection. The water resources of Bosnia and Herzegovina consist of river basins, natural lakes, artificial accumulations and underground waters. Due to the discharge of untreated waste water from the population and industry, most of the river courses in Bosnia and Herzegovina are polluted or contaminated with various pollutants, which make some water courses out of class IV (especially the Bosna and Vrbas rivers). The main polluters as sources or foci of pollution from which different spectra of contaminants are emitted are: population, thermal energy plants, exploitation of mineral raw materials, food industry, crafts, garbage dumps and wild disposal of municipal and industrial waste, uncontrolled disposal of hazardous (toxic) waste, soil erosion conditioned by the stripping of the forest cover, i.e. cutting down the forest. On the basis of the above, problems arise in the water sector, which are manifested through:

1. Inadequate (even questionable) water supply to the population and industry,
2. Water quality that, by sampling water samples from the source, shows physical-chemical and bacteriological defects,
3. More and more frequent incident pollution of the source and the spread of infectious diseases through the consumption of defective water,
4. Insufficient, inadequate or no protection of water quality (designed zones of sanitary protection), and inadequate protection against the harmful effects of water due to unregulated water flows, flood waves and non-maintenance of embankments,

5. Occurrences of soil erosion due to excessive and uncontrolled cutting of forests, erosion within unorganized and unmaintained riverbeds, and the occurrence of landslides.

The causes of this state are different both in terms of extent and diversity. First of all, one of the causes is the absence of integral water management, as well as the absence of clear strategies in this sense that would be legally conceived and based on the actual situation on the ground. The lack of development plans that would harmonize the needs of urban and rural areas is something that must be systematically worked on and legislated. Another problem, no less, is the damaged or destroyed infrastructure of the water supply and sewerage network, which cause large losses of water, especially drinking water, for the rehabilitation and construction of new infrastructure, it is necessary to allocate significant financial resources, which can be ensured from the good chargeability of its services if the users are satisfied, so without restrictions and with an orderly supply of hygienically correct water, and with mandatory water monitoring with an information system (database). The third and perhaps the biggest problem is the inadequate or complete lack of protection of water resources, that is, the source, which makes the water exposed to various pollutants, and thereby physical-chemically and bacteriologically endangered. A special segment is protection against the harmful effects of water, such as unregulated water flows, floods and erosion of surface land, and landslides, which also leave unfathomable consequences for drinking water. The causes of such problems are most often the lack of financial resources (lack of funds and favorable financing mechanisms), equipment, but also adequate personnel, and from this result poor or no plans and programs and development strategies. When it comes to drinking water, it is necessary to establish an integral management of water, as well as an adequate strategy for hydrogeological research and the discovery of new amounts of drinking water, as well as the coordination of several disciplines that deal with water. the water directive is sporadically applied to solve the problem of water resources in the territory of Bosnia and Herzegovina). In order to extend the life of water bodies, we need to establish a purification system, i.e. different types of remediation of waste water that threaten the quality of the source, and to replace and introduce new methods of remediation treatments (replacement of dirty technologies), along with water monitoring and the introduction of an information system for early detection of incident situations and creating database. Special and primary attention must be given to the purification of waste water (and not only in liquid, but also in solid and gaseous state, they all affect the three geological environments), because due to waste water with a different spectrum of pollutants, most river courses are polluted, and indirectly and underground water bodies. As an example of the complexity of water supply for a number of municipalities in the Tuzla Canton, the example of hydrogeological research carried out in Srebrenik, which for a long time has lacked the necessary quantities of water for proper water supply of the population, will serve.

For a long time, the city of Srebrenik has had problems with an insufficient amount of water for the water supply needs of the population, but also with the increasingly developed industry, which affects the quality of the water. This problem is particularly reflected in the local communities of the eastern part of the Municipality, given that there are no significant water bodies of underground water, from which drinking water needs could be met through wells. The urban area of Srebrenik lacks 10 l/s of drinking water in a period of two to three months in one year. For this reason, construction of a replacement well at the source of Vlahulje (well B-5A), in the immediate vicinity of well B-5 built in 1987, was started.

Well B-5A was constructed in 2018 by the company "Geoservis" d.o.o. Livestock. In 2023, work began on the introduction of well B-5A into the water supply system of the municipality of Srebrenik - pressure line from facility 1 and 2 of well B-5A to the facility for the connection with wells B-6 and B-7 (PHASE II).

It was necessary to record and inspect the state of the well, its possible cleaning and conquest, as well as defining the hydrogeological parameters, i.e. determining the capacity of the well and the conditions of exploitation (optimal capacity of the well), as well as the water quality.

Given that more than five years have passed since the construction of the well, and that it was not in operation, we were of the opinion that it is necessary to carry out certain works in the B-5A well itself before putting the well into operation. A program of works was carried out, which included recording the condition of the well with an underwater camera, cleaning with the air-lift method, during which constant control of the sand content (impurity) in the water would be carried out. After the full depth of the well structure is reached, as well as the purity of the water, it is planned to proceed with further cleaning of the aquifer and increasing the porosity of the environment in which the well was built, with constant pumping using a pump with a set capacity 50% higher than the designed capacity of the well, if that allows dynamic lowering of groundwater. Pumping would last a minimum of 15 days, with constant monitoring of the groundwater level at well B-5A and well B-5. After that, it is necessary to perform well testing using the "Constant-test" method, with three (3) pumping capacities and three (3) established reductions in the groundwater level.

Before the start and after the preliminary works were carried out, it was necessary to perform a complete biological-physical-chemical analysis of the water, that is, water sampling at the beginning and end of the activity, for: two samples for extended analysis of the physical-chemical composition of the water at the beginning and end of the work , two samples for bacteriological analysis of water at the beginning and end of the works and one sample for testing the α and β activity of the water (at the end of the work testing). After all the necessary work that was carried out according to the stages of preparation and organization of the work site, taking water samples for microbiological and chemical tests, and recording the well structure with a video camera, the II phase - cleaning and flushing of the well for a minimum of 72 hours was started, then the III phase - pumping the well pump for 15 days with monitoring of the water level in wells B-5A and B-5, and IV phase - testing of the well for a minimum of 72 hours with three pumping capacities and with three stabilizations of lowering the groundwater level and taking samples for microbiological, chemical and testing α and β water activity.

CONCLUSION

From the above, it is clear that due to the necessity of providing sufficient quantities of water for the needs of the residents of the city of Srebrenik, the construction of a replacement well B-5A was carried out, with a program of works that would ensure the functionality of the well. The works were carried out in accordance with the previously completed Work Program, which was completed in its entirety. During pumping at well B-5A, with a pump with a capacity of 18 l/sec, a drop in the level was also recorded at well B-6, which is used for the City's water supply (17 l/sec), because a hydraulic connection was established between these two wells, which is why a pump tripped on B-6. The actual capacity of the B-5A well is at least 25 l/sec (25-30 l/sec), which was determined during the construction of this well in 2018, as well as the testing carried out in 2023 with the previously described works.

However, this capacity seriously impairs the existing pumping capacity at well B-6, so with further exploitation of the existing capacity at well B-6, the optimal pumping capacity at B-5A would be 10-12 l/sec. By recording in the well, it was established that the well was cleaned, as well as that the built-in filters were fully functional.

The results of the physical and chemical tests of the water sample taken before the cleaning works of well B-5A show that the water does not meet the regulations of the Rulebook on natural mineral and natural spring waters "Official Gazette of BiH" No. 26/10 and 32/12, due to turbidity, the presence suspended particles and a higher manganese content of 0.253 mg/l (allowed less than 0.05 mg/l). Also, according to the microbiological analysis, the water does not meet the requirements of the "Regulation on natural mineral and natural spring waters" Official Gazette of BiH No. 26/10 and 32/12. (increased presence of illegal microorganisms-bacteria). This example of water supply in the city of Srebrenik is only one in a series of similar problems of all the municipalities of TK, and it is necessary to solve them systematically with an expert team, sufficient financial resources and the implementation of legal regulation.

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HYDROGEOLOGICAL TESTING OF WELLS IN GROUP OPERATION AT THE BARICE WATER SOURCE; ŽIVINICE MUNICIPALITY

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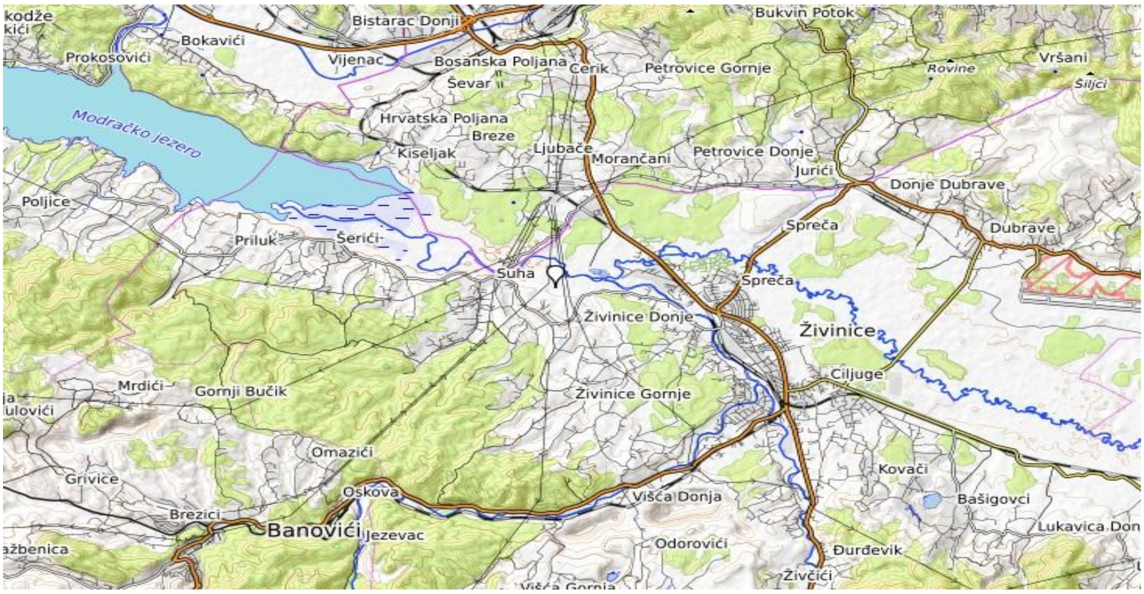
Abstract

For a long period, the drinking water supply for the population of the city of Živinice has not been at a satisfactory level. Larger settlements have local water supply systems, while the city of Živinice, along with suburban settlements and the Dubrave settlement, is supplied with drinking water from the joint water supply system of Tuzla and Lukavac, originating from the "Spreča" pumping station (Toplica water source).
The main issues in the drinking water supply relate to insufficient water quantities, limited reservoir capacity, and low network pressure, all of which result in frequent water supply restrictions. To improve the drinking water supply in this area, hydrogeological investigations were conducted to capture new water quantities from the "Barice" water source, located in the Živinice Municipality.
Hydrogeological and geological mapping of the research area was carried out, along with the drilling of piezometric boreholes and wells. Considering that both piezometers and wells are replenished from the same aquifers, measurements of groundwater levels during the construction of new wells indicated a decrease in water levels in surrounding hydrogeological structures during test pumping. Consequently, well testing in group operation was conducted.
Keywords: hydrogeological testing, water intake structures, test pumping of wells, source capacity, water supply

INTRODUCTION

The research area covers a surface of 15 km² and is located approximately 2 km from the city of Živinice. The terrain is predominantly flat and includes a part of the Spreča field, with absolute elevations ranging from 203 to 209 meters above sea level. This type of relief, characterized by steep slopes in the southern part, has resulted in a well-developed hydrographic network of intermittent or permanent watercourses, mostly oriented in a south–north direction. In the central part of the area, within Pliocene-Quaternary deposits, where the terrain transitions from steep to gently undulating, several parallel river valleys have formed, cutting almost down to Jurassic deposits. The research area belongs to the watershed of the Spreča River, which is the main recipient of the Tuzla Canton.
According to measurements taken downstream from the research area (Modrac), the lowest average monthly flow of the Spreča River occurs in September (6.69 m³/s), while the highest is in February (30.5 m³/s), with an average annual flow of 16.3 m³/s. Short-term groundwater level

observations conducted on installed piezometers during investigations between 1989 and 2019 indicate the presence of four distinct aquifer layers.



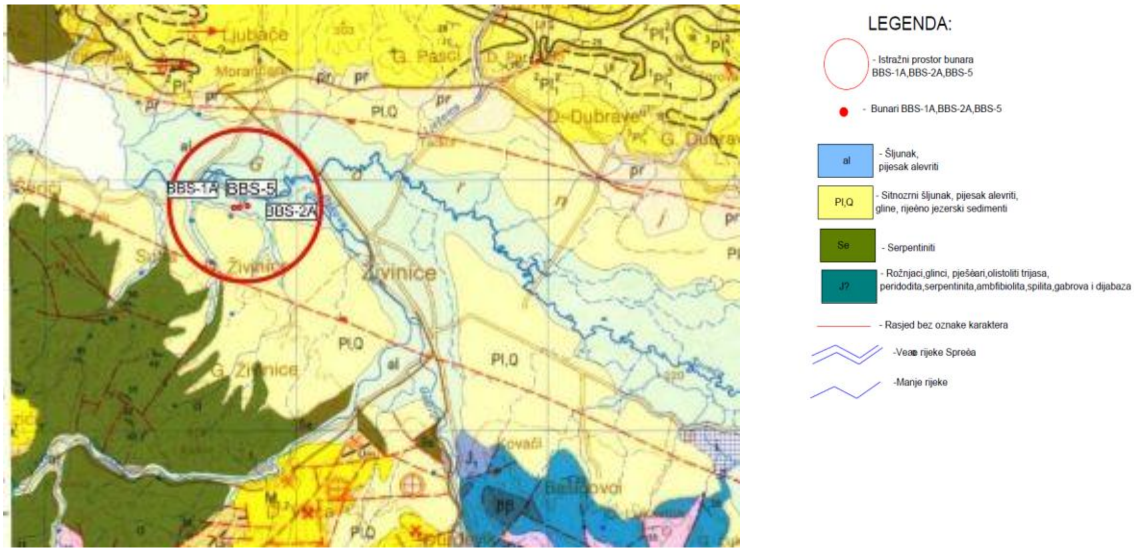
Picture 1. Geographical location of BBS-1A, BBS-2A, BBS-5

The constructed wells are replenished from the same aquifer layers, and during test pumping, mutual influence and a decrease in water levels were observed. When pumping at higher capacities exceeding 24.00 l/s, the dynamic water level dropped and was unable to reach a stable condition. During the same time period, water levels were monitored in other available hydrogeological structures.

A dug well by the road, located near the wells supplying the Barice local community, was identified as an artesian aquifer with a capacity of 2.48 l/s. However, during group well pumping at capacities exceeding 15 l/s, this well completely dried up. Wells operating under unfavorable conditions suffer damage to the near-well zone, as well as to the well pumps, which function at full power and capacity. Given the described well operation regime, well clogging and damage to the near-well zone can occur rapidly. Additionally, exceeding the permissible inflow velocities can lead to a turbulent flow regime, resulting in reduced yield and accelerated "aging" of the wells.

GENERAL GEOLOGICAL CHARACTERISTICS OF THE AREA

The Barice research area belongs to the central ophiolitic zone geotectonic unit, characterized by diverse ultrabasic rocks of the Konjuh massif, dating back to the Jurassic period. These formations are predominantly covered by Pliocene-Quaternary and alluvial deposits.



Picture 2. Geological map on a wider scale 1: 100,000 made on the basis of OGK list Tuzla.

JURASSIC PERIOD

A portion of the Lower Jurassic and the diabase–hornstone formation, likely corresponding to the Middle and Upper Jurassic, are developed in this area. The research area belongs to the central ophiolitic zone, which includes various ultrabasic rocks of the Konjuh and Ozren massifs (in the wider Banovići area) at its southwesternmost part. Within the Jurassic formations in this study area, the dominant rocks are peridotites, with a minor presence of serpentinites.

Peridotites (P)

Peridotites appear south of Banovići as the northwestern ultramafic Konjuh massif. The relationship between peridotites and other magmatic members and sediments is tectonic, with cataclastic and more or less mylonitized zones. According to J. Pamić (1964), peridotites and other ultramafic rocks were intruded as solid and cold bodies into Jurassic sediments, which explains the lack of structural conformity with the surrounding rocks and the absence of contact metamorphism effects.

Serpentinites (Se)

Serpentinites consist mainly of serpentine minerals, along with numerous secondary minerals such as chlorite, talc, limonite, and occasionally carbonates, quartz, opal, and chalcedony. Relict primary minerals, such as olivine and pyroxenes, are also frequently present. In the study area, serpentinites are found only in the Upper Živinice region, specifically in the settlements of Šabanovići and Rahmanovići.

PLIOCENE–QUATERNARY (Pl,Q)

Pliocene deposits in the Tuzla–Živinice area are represented by the Pontian stage, which is further divided into the Lower Pontian (Novorossian stage) and the Upper Pontian (Portoferian stage). Significant sedimentation occurs only in the Spreča tectonic depression. The edge of this tectonic trench, uplifted by neotectonic movements, has become a distribution area for terrigenous material, which has formed thick layers of clastic rocks of aquatic–fluvial–lacustrine origin. The composition is dominated by clayey–sandy sediments, siltstones, marl and marl–sandy clays, sand, and gravel.

QUATERNARY PERIOD

River Sediments (al)

These deposits are found in the valley of the Spreča River and its tributaries. Along the course of the Spreča River in the Spreča field, river deposits are differentiated at a single level as channel-proximal alluvium (floodplain terrace). Due to the geological structure of the river basin and the energy of the flow, these deposits are dominated by fine-grained sediments of floodplain facies, consisting of silt–clay and sandy material, overlying gravelly–sandy channel facies. A significant presence of gravel and sand is observed at the confluences of larger left-bank tributaries such as the Oskova River. Compared to river deposits from other streams, the Oskova's deposits differ significantly in granulometric and mineralogical–petrological composition due to differences in the geological background of its basin and a steeper flow gradient.

HYDROGEOLOGICAL CHARACTERISTICS

The Spreča field is a vast enclosed depression, approximately 40 km long and with an average width of five kilometers, located in the southern part of the Tuzla Neogene Basin. This depression is conditioned by the well-known Spreča fault, which extends in a northwest–southeast direction between the Eocene horsts of Majevica and Trebovac in the north and the ophiolitic zone in the south.

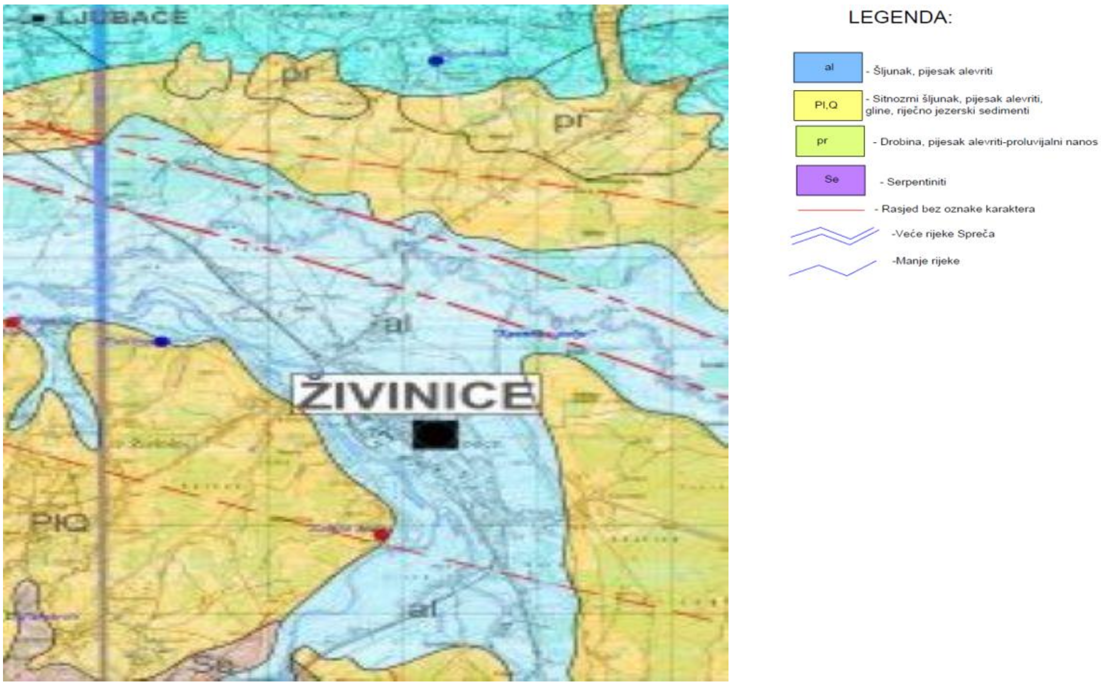
The narrower area of the Spreča field, designated as a water supply source for Tuzla, is limited to the section from the confluence of the Spreča River into Modrac Lake (Maline) to the confluence of the Gribaja River into the Spreča, spanning approximately 10 km. The deep depression has resulted in thick accumulations of alluvial deposits from the Spreča River, whose composition reflects fluctuations in sedimentation intensity, deposition characteristics, and material transport directions.

In the gravel-rich sections, material of hornstone origin (diabase–hornstone formation from the ophiolitic complex in the south) is predominant, while in the sandy–clayey sections, quartz-rich materials and clay minerals are more common, originating from the Neogene basin clastics in the north.

The "Barice" water source is located along the left bank of the Spreča River, downstream from the Oskova confluence, and forms part of the southern boundary of the alluvial hydrogeological complex of the Spreča field. It is bordered to the north by the meandering Spreča riverbed and to the south by a Pliocene–Quaternary terrace.

According to previous research, the core area of "Barice–Maline" is primarily composed of:

- Pliocene–Quaternary terrace deposits of clayey–sandy–gravelly composition, and
- Gravelly–sandy–clayey alluvial deposits of the Spreča and Oskova River valleys.



Picture 3. Hydrogeological map with the legend of the source of Barica

Filtration Characteristics

Previous research has primarily determined filtration characteristics based on pumping tests conducted on piezometric boreholes. These boreholes were constructed at different times, with varying structural and technical characteristics, and pumped using different methods, contributing to inconsistencies in the results.

The following average values of filtration parameters have been obtained from these studies: transmissivity (T), filtration coefficient (k), specific yield (μ), and piezoconductivity coefficient (a).

$$T = 2.8 \times 10^{-3}\ m^2/s$$
$$k = 1.7 \times 10^{-4}\ m/s$$
$$\mu = 0.044$$
$$a = 3.11 \times 10^{-1}$$

It is observed that the filtration parameter values obtained for the Barice area fall within the range of values for the broader region (except for the Maline area). Therefore, their average values can be used for orientation calculations.

Hydrodynamic Characteristics

In the narrower "Barice" area, the hydrodynamic conditions are likely still undisturbed due to both the distance (approximately 5 km) and the probable hydraulic separation by the Spreča River, which acts as a hydrogeological boundary with a constant water level.

Short-term observations of groundwater levels in the piezometers during the research period from 1989 to 2019 indicate four distinct aquifer layers:

- First aquifer layer (shallow phreatic aquifer with a free water level) down to a depth of 6.0 meters

- Second aquifer layer (first artesian aquifer under pressure) at depths from 8.0 m to 21.5 meters
- Third aquifer layer (second artesian aquifer under pressure) at depths from 15.0 to 30.0 meters
- Fourth aquifer layer (third artesian aquifer under pressure) at depths exceeding 53.0 meters

This indicates complex recharge and drainage conditions. Recharge occurs through underground inflow from the broader surroundings and from older Pliocene-Quaternary sediments laterally and at depth. The weak artesian level suggests a lower hypsometric position of the recharge area. The higher artesian pressure in the elevated area (at an elevation of 207 meters) and lower pressure in the Spreča riverbed area (approximately 203 meters) indicate indirect drainage into the Spreča and Oskova rivers. The lack of continuous groundwater level monitoring for these aquifers prevents a more detailed interpretation of hydrodynamic relationships.

Drilling of Piezometric Boreholes

Following the interpretation of previous research results and detailed hydrogeological mapping, the locations for exploratory boreholes PBBS-3, PBBS-5, PBBS-1A, and PBBS-2A were determined.
When selecting borehole locations, consideration was given to the existing water supply infrastructure in the Barice water source area. Two wells were already present in the study area: one at the Mišići site, constructed in 1989, and another (marked as PB-3) at the Ravan site, used for the water supply of the Suha settlement. In addition, the locations were chosen considering three existing wells within the Barice water source area, which already had an established water supply infrastructure. After agreement, the most favorable locations for drilling exploratory boreholes were defined as parcels in K.O. Živinice Donje (PBBS-5, PBBS-1A, PBBS-2A).

Construction of Wells BBS-4, BBS-5, BBS-1A, BBS-2A

After drilling the piezometers and conducting the aforementioned works, a Preliminary Report was prepared, recommending the construction of three wells, each with a depth of 35 meters.
The wells were constructed as exploratory wells with standard profiles, but they were also designed for permanent exploitation. The concept was based on tapping the third aquifer layer. The well depth was uniform, at 35 meters. The wells were drilled using the rotary method with direct flushing using clean water. Drilling began with a Φ 600 mm diameter down to a depth of 10.0 meters, after which a protective casing Φ 508/495 mm (standard steel pipe) was installed. The casing was sealed with clay along the entire annular space of the borehole to isolate the upper aquifer layers. After installing the protective casing, drilling continued with a Φ 400 mm diameter bit down to a depth of 35 meters.
Upon reaching the depth of 35.00 meters:

- For wells BBS-4 and BBS-1A, a well structure was installed consisting of a Φ 273/260 mm protective-exploitation casing with inline Φ 250/202 mm wound-wire filters and a sediment trap. The filter slot width was approximately 1.0 mm, and the pipes were joined using standard welded rings.

- For wells BBS-5 and BBS-2A, a well structure was installed consisting of a PVC exploitation casing Φ 225/200 mm with inline Φ 225/200 mm slotted filters and a sediment trap. The filter slot width was approximately 2.0 mm, and the pipes were connected with threaded joints. After installing the protective-exploitation and filter structures, the annular space of the borehole was backfilled with granulated filter material (grain size Φ 4-8 mm) down to a depth of about 10 meters, while the remaining annular space up to the top was sealed with clay.

Well development and stabilization were carried out using the airlift method, ensuring the necessary flushing time to achieve water clarity and remove unwanted particles.

Well Testing

Well testing was conducted through experimental pumping using the STEP TEST method with three pumping rates, a Test Constant, and Recovery Test measurements with short interruptions. The preliminary testing established the following well capacities:

- Well BBS-4 – Q = 1.20 l/s
- Well BBS-1A – Q = 6.20 l/s
- Well BBS-5 – Q = 6.80 l/s
- Well BBS-2A – Q = 6.50 l/s

PRELIMINARY INDIVIDUAL PUMPING TESTS AT WELLS BBS-5, BBS-1A, BBS-2A

Pumping Test at Well BBS-5

Due to the specific location characteristics, which include a subartesian water pressure, the pumping test was conducted using a combined method with a submersible pump of 5.5 kW power, installed on galvanized pipes with a diameter of Ø 2 inches, at a depth of 10 meters. As part of the pumping test, the step-drawdown method (STEP-TEST) was applied with three pumping rates:

- Q1 = 4.00 l/s
- Q2 = 6.00 l/s
- Q3 = 6.80 l/s

The following parameters were obtained:

- Static water level before pumping: 0.2 meters
- Pumping capacity: 6.80 l/s
- Dynamic water level in the well: 4.50 meters
- Drawdown in the well: 4.30 meters
- Specific capacity: 1.58 l/s/m

After the step test, a recovery test was conducted to observe the return to the static water level over the required time period.
Following the recovery observation, a Constant-rate test was performed with Qmax = 6.80 l/s,

as well as recovery monitoring after completing the constant-rate test.

Pumping Test at Well BBS-1A

Due to the subartesian water pressure, the pumping test was conducted using a combined method with a submersible pump of 5.5 kW power, installed on galvanized pipes with a diameter of Ø 2 inches, at a depth of 10 meters.
As part of the pumping test, the step-drawdown method (STEP-TEST) was applied with three pumping rates:

- Q1 = 4.00 l/s
- Q2 = 6.00 l/s
- Q3 = 6.20 l/s

The following parameters were obtained:

- Static water level before pumping: 0.2 meters
- Pumping capacity: 6.20 l/s
- Dynamic water level in the well: 7.80 meters
- Drawdown in the well: 7.60 meters
- Specific capacity: 0.81 l/s/m

After the step test, a recovery test was conducted to observe the return to the static water level over the required time period.
Following the recovery observation, a Constant-rate test was performed with Qmax = 6.20 l/s, as well as recovery monitoring after completing the constant-rate test.

Pumping Test at Well BBS-2A

The subartesian water pressure required the pumping test to be conducted using a combined method with a submersible pump of 5.5 kW power, installed on galvanized pipes with a diameter of Ø 2 inches, at a depth of 17 meters.
As part of the pumping test, the step-drawdown method (STEP-TEST) was applied with three pumping rates:

- Q1 = 4.00 l/s
- Q2 = 6.00 l/s
- Q3 = 6.50 l/s

The following parameters were obtained:

- Static water level before pumping: 0.2 meters
- Pumping capacity: 6.50 l/s
- Dynamic water level in the well: 9.00 meters
- Drawdown in the well: 8.80 meters
- Specific capacity: 0.73 l/s/m

After the step test, a recovery test was conducted to observe the return to the static water level over the required time period.

Following the recovery observation, a Constant-rate test was performed with Qmax = 6.50 **l/s**, as well as recovery monitoring after completing the constant-rate test.

PUMPING TEST OF WELLS IN GROUP OPERATION

The objective of the group pumping test was to determine the hydraulic characteristics and operational parameters of the wells through their mutual influence (capacity, drawdown, hydraulic losses) using standard methods. Since these wells are designed for long-term operation and are all recharged from the same aquifers, the test was conducted in two phases.
The first phase, using a single pumping rate, lasted until the water levels in the wells approximately stabilized (±3 cm). The test began with the initial pumping rate **Q1**, followed by a second rate **Q2** = 1.5 to 2 times **Q1**, and finally, the third rate **Q3**, which ensured the maximum allowable drawdown—2.0 meters above the pump intake level in the wells. Once stabilization was achieved at the third pumping rate, the pumping was stopped, and the recovery of groundwater levels to the static level was observed.
After obtaining preliminary results from this test, an extended pumping test was conducted with a constant discharge rate. The individual well pumping capacities were:

- Q1 = 5.0 l/s
- Q2 = 6.50 l/s
- Q3 = 8.00 l/s

During the pumping test, continuous monitoring of groundwater levels was carried out in both the pumping wells and nearby piezometers. The observation of groundwater level recovery to the static level was performed only after the final pumping rate. Existing wells (at least two) were used as observation points.
Following the step-drawdown test lasting 36 hours, a discharge rate was determined for the extended pumping test with a constant flow. During this phase, continuous groundwater level measurements were taken at the pumping well and observation points.
Throughout the pumping test, all relevant data were recorded, particularly:

- Pumping capacity at the well (measured with a flow meter or calibrated orifice plate)
- Static groundwater level before pumping at both the pumping well and observation points
- Dynamic groundwater level during pumping, along with the time of data collection
- Operational condition of the pumping system (pump, power supply controls, etc.)

During the group pumping test, water levels in surrounding piezometers and wells were measured. When all three wells were pumped at a rate of 5 l/s, the water levels failed to stabilize, and a continuous decline was observed in both the wells and piezometers. Over a three-hour measurement period, the water level dropped by approximately 20 cm per hour.
Due to this, the pumping rate at Well BBS-2A was reduced to 4.50 l/s, as this well exhibited the highest drawdown, reaching -7.70 meters.
After reducing the pumping rate at Well BBS-2A to 4.50 l/s, the group pumping test continued with pumping rates of 5.0 l/s at Wells BBS-5 and BBS-1A.

ASSESSMENT OF THE WELL CAPACITY

Following the group pumping test at the Barice-Maline wellfield, it is necessary to apply an appropriate hydrogeological schematization and make certain assumptions common to analytical solutions for groundwater filtration processes.

Based on the hydrogeological conditions in the wellfield area and the adopted concept of abstraction structures, the wellfield can be considered a two-layer homogeneous and isotropic porous medium, operating under confined conditions, with two conditionally parallel boundaries (strip layer model).

The southern boundary consists of low-permeability Pliocene-Quaternary gravel-sand terraces, which, for simplification, is assumed to be an impermeable boundary with the condition Q = 0.

The northern boundary can be treated in two ways:

- If the Spreča and Oskova riverbeds are hydraulically connected to the aquifer, the boundary condition is h = constant.
- If this hydraulic connection is absent (due to a clay isolation layer), the filtration field is considered unbounded.

This uncertainty requires further investigation, but for now, the second boundary condition (h = ∞) has been applied for the calculation.

Capacity Calculation

The capacity estimation was conducted under non-steady-state filtration conditions over a period of t = 4 days.

Since this involves an extended pumping period (i.e., continuous operation), where the parameter:

$$\mu = r^2/4at \leq 0{,}05$$

The exponential form of the "well function" W(u) can be approximated logarithmically with sufficient accuracy (error <10%):

$$W(u) = Ei\left(-\frac{r^2}{4\,a\,t}\right) \cong \ln\frac{2{,}25\,T\,t}{r^2\,\mu}$$

Thus, for the capacity of a single fully penetrating well under the given hydrogeological conditions and for the specified drawdown, the following formula is applied:

$$Q = \frac{4\,\pi\,T}{S}\left[\frac{2{,}25\,T\,t}{r^2\,\mu} - \ln\frac{2{,}25\,T\,t}{4a^2\mu} + \ln\frac{2{,}25\,T\,t}{4b^2\mu}\right]$$

Applying the boundary condition h = ∞, the simplified formula for calculation is:

$$Q = \frac{4\,\pi\,T}{S}\left[\ln\frac{2{,}25\,T\,t}{r^2\,\mu} + \ln\frac{2{,}25\,T\,t}{4\,b^2\,\mu}\right]$$

Input Parameter Values:

Ssr= 5,88 m, $T = 2{,}8 \times 10^{-3}\ m^2/s = 241{,}9\ m^2/day$, r = 0,10 meters

μ = 0,044, t = 4 days, b = 300 meters

Where:

- Q – Well capacity (m^3/s)
- T – Transmissivity coefficient (m^2/s)
- S – Drawdown in the well (given)
- r – Well radius
- μ – Specific yield
- b – Distance from the well to the impermeable boundary (Q = 0)
- t – Pumping duration

The filtration parameters T and μ were taken as average values for the filtration area, resulting in:

$$Q = 15{,}07 \ l/s$$

The calculation was performed based on test pumping; however, it is important to consider that there are already seven wells at the source, which influence each other. The fact remains that the wells cannot pump more than 5 l/s per well, as they were designed and adapted to the conditions prevailing in the Barice area.

Based on an assessment, the Barice source can provide 30-40 l/s of water across all wells. Therefore, the adopted source capacity is:

$$Q_{izv.} = 30 \ l/s$$

The obtained data indicate that further investigative work is necessary to confirm the adopted assumptions, more precisely define the spatial and filtration parameters of the filtration area, and ensure that new water intake wells are technically and hydraulically correctly constructed.

CONCLUSION

The "Barice" water source is located along the left bank of the Spreča River, downstream from the confluence of the Oskova River, and is part of the southern boundary of the alluvial hydrogeological complex of the Spreča field. It is bordered to the north by the meandering riverbed of the Spreča and to the south by a Pliocene-Quaternary terrace.

Based on the results of previous hydrogeological research, the "Barice" area is primarily composed of:

- Pliocene-Quaternary terrace deposits of clayey-sandy-gravelly composition, and
- Gravelly-sandy-clayey alluvial deposits of the Spreča and Oskova river valleys.

The groundwater at the "Barice" source is of the calcium-magnesium type, and physicochemical and bacteriological water analyses confirm its compliance with the Regulation on the Health Safety of Drinking Water (Official Gazette of BiH 40/10).

From a hydrogeological perspective, the source has favorable natural protection conditions. However, despite this, it is necessary to establish a special water quality control regime and to design new sanitary protection zones or redesign the existing ones, as defined in the 2011 study.

Since the constructed wells are recharged from the same aquifer layers, test pumping of the wells revealed a mutual influence in terms of water level reduction. When pumping at capacities exceeding 24.00 l/s, the dynamic water level dropped significantly and could not reach a stable state. At the same time, water levels in other available hydrogeological structures were monitored.

A dug well near the road, located next to the wells supplying water to the residents of the Barice local community, is characterized as an artesian source with a capacity of 2.48 l/s. However, when the wells were pumped in group operation at capacities exceeding 15 l/s, this artesian well completely dried up.

Under such conditions, the operational wells function under an unfavorable regime, which is harmful to both the wells and the surrounding well zones, as well as to the well pumps operating at full capacity.

This described operational regime can rapidly lead to well clogging and deterioration of the surrounding well zone due to exceeding the allowable inflow velocities and the resulting turbulent flow conditions. This, in turn, causes a decrease in well yield and accelerates the "aging" of the wells.

For this reason, it is recommended that the maximum pumping capacity (Qmax) for all three wells be set at 15.00 l/s.

Based on the conclusions drawn regarding the hydrogeological relationships in the water intake area and the adopted concept of water intake structures, it can be concluded that the study area represents a two-layered homogeneous and isotropic porous medium, with a confined flow regime and two conditionally parallel boundaries.

The southern boundary consists of a low-permeability Pliocene-Quaternary gravelly-sandy terrace, which, for the sake of simplifying calculations, is considered an impermeable boundary with a condition of Q=0. The northern boundary can be treated in two ways. In the first case, if the riverbeds of the Spreča and Oskova rivers are hydraulically connected to the aquifer layers, the boundary condition is h=const. If this hydraulic connection does not exist due to the presence of a clay layer acting as an insulator, then the filtration field is conditionally unlimited.

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THE POSSIBILITY OF FINDING NEW DEPOSITS OF CONSTRUCTION AGGREGATES IN TUZLA CANTON FOR THE NEEDS OF BUILDING ROAD INFRASTRUCTURE

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Summary

Construction aggregates (crushed stone) is a mineral raw material that is practically irreplaceable in construction, both in low-rise construction and in high-rise construction [9]. Although in recent times more and more stone aggregates are obtained by recycling construction waste, still by far the largest part of these useful raw materials is obtained by exploitation from quarries and gravel pits [14]. Tuzla Canton has significant resources of this valuable mineral raw material. Currently, ten construction aggregates quarries have been opened in this canton, of which one is a diabase quarry, and the rest are limestone quarries.
The construction of several highways and expressways is planned in the area of Tuzla Canton, with the aim of better traffic connections with the rest of the country and with the world. In the near future, the construction of two highways is planned: "Border with the Republic of Croatia-Orašje-Brčko-Tuzla" and the so-called y arm of the highway that will connect Corridor Vc with Tuzla [8]. In order to meet the increased needs of the Tuzla Canton for construction aggregates during the period of intensive road infrastructure construction that follows, it will be necessary to open new quarries. In particular, an increase in demand for construction aggregates with a carbonate composition is expected. The authors of this paper, based on previous experiences, as well as their own knowledge, proposed several locations where geological formations of different ages and with high-quality limestone masses suitable for finding economically profitable deposits of Construction aggregates in the relative proximity of the route of the future highway in the territory of Tuzla Canton have been identified.
Key words: construction aggregates, Tuzla Canton, geological exploration, exploitation, quarry, limestone, diabase.

1. INTRODUCTION

Rocks are natural formations consisting of one or more minerals of a certain chemical composition and structure. Building stone is obtained from rocks. Stone is a non-metallic mineral raw material that is extremely important in construction. It is practically irreplaceable, both in low-rise construction and in high-rise construction. The largest part of its production falls on crushed stone, or as they call it construction aggregates, the production of which at the world level is growing year by year. Although not all countries keep accurate statistics regarding the production of stone aggregates [12], it is assumed that the annual production of these materials in the world is close to 20 billion cubic meters. Although in recent times more and more stone aggregates are obtained by recycling construction waste, still by far the largest part of these useful raw materials is obtained by exploitation from quarries and gravel pits.

The communication connectivity of an area is a basic prerequisite for its further development. At hree Pan-European transport conferences held in Prague in 1991, in Crete in 1994 and in Helsinki in 1997, Europe defined a total of ten new transport corridors in Central and Eastern Europe. It is planned to build roads and railways on these corridors. Corridor Vc, which connects Eastern and Central Europe with the Mediterranean coast, as part of this European project, passes through our country. A part of the international highway is under construction on it, which represents the largest post-war infrastructure project in Bosnia and Herzegovina.

In addition to the highway on Corridor Vc, several more highways and expressways are planned to be built in Bosnia and Herzegovina. It is planned that some of them will pass through the Tuzla Canton, which will greatly contribute to the better traffic connection of this industrial region with the rest of the country (Fig. 1.). First, the plan is to build the highway "The border with the Republic of Croatia-Orašje-Brčko-Tuzla", the total length of which is 61 kilometers. This highway is divided into two parts. The first unit is the section "Orašje-Brčko-Maoča" with a length of approximately 30 kilometers, while the second unit is the section "Maoča-Tuzla" with a length of approximately 31 kilometers. The implementation of this project should begin with the construction of the Čanići-Tuzla subdivision (Šićki Brod), which is included in the FBiH Public Investment Program 2022 - 2024. The connection of the Tuzla Canton with the highway on Corridor Vc was also planned. The so-called y branch will depart from Corridor Vc in the region of Žepča and Zavidovići, and will continue along the Krivaja valley, then turn towards Seona in the municipality of Banovići and further towards the municipality of Lukavac. It will bypass Modračko Lake on its western side, and south of the town of Lukavac will turn east towards Šićki Brod, where it will join the Tuzla-Orašje highway [8]. The construction of the Tuzla-Zvornik expressway is also planned.

The planned works on the road infrastructure will require an increased demand for stone aggregates, above all for those of carbonate origin. This work is, among other things, a modest attempt by the authors to point out the existence of promising locations for finding deposits of technical and construction stone, primarily limestone, near the route of the future highway that will be built in the coming years in the Tuzla Canton.

2. INCREASING NEEDS FOR CONSTRUCTION AGGREGATES IN TUZLA CANTON DUE TO THE CONSTRUCTION OF NEW ROAD INFRASTRUCTURE

The question arises, how to supply the Tuzla Canton market with the necessary quantities of stone aggregates in the coming period when the plan is to significantly increase the construction of road infrastructure, primarily highways? Due to the cost of transportation, construction aggregates quarries should not be more than 30 kilometers away from the route being built [14]. This narrows the choice of existing quarries from which stone could be used for these needs, as well as the selection of new locations for opening quarries. Currently, there are ten limestone quarries in continuous exploitation in the Tuzla Canton, seven of which are located in a zone closer than 30 kilometers from the planned highway route. At several other locations, the process of obtaining permits for the opening of quarries is underway.

It should be noted that the existing construction aggregates quarries currently manage to meet the needs of the market for crushed stone. It is expected that in the coming period, with the beginning of the construction of certain sections of the highway, if no new quarries are opened, there will be a shortage of aggregates of carbonate origin. This is because the existing quarries do not have enough capacity to meet the growing needs of the market. In addition, it should be noted that some of the largest quarries produce almost exclusively for the needs of the industry for which they were opened. Primarily the Vijenac limestone quarry, which markets almost 90% of its production for industrial needs. Also, the Duboki Potok-Bijela Rijeka and Drenik limestone quarries use a significant part of their production to meet the needs of their own lime factory and concrete element factory.

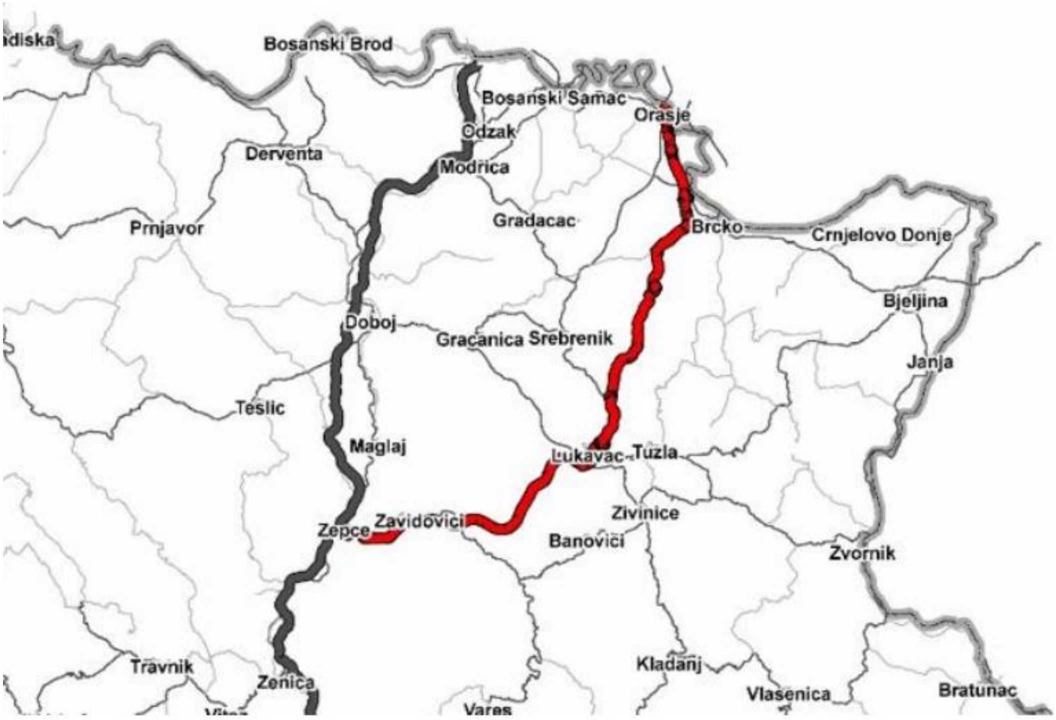

Figure 1. Highway Border with the Republic of Croatia-Orašje-Brčko-Tuzla and Highway Žepče-Tuzla (source - Public Company Autoceste FBiH d.o.o. Mostar)

3. OVERVIEW OF THE EXPLOITATION OF CONSTRUCTION AGGREGATES IN THE AREA OF TUZLA CANTON

Seven limestone quarries and one diabase quarry in the Tuzla Canton are located in a zone closer than thirty kilometers from the route of the future highway [1]. We give a brief overview of these construction aggregates quarries, as well as the basic physical and mechanical characteristics of the stone exploited in them.

Vijenac limestone quarry

The Vijenac limestone quarry is located on the hill of the same name, about 8 kilometers northeast of Banovići (Fig. 2.). An asphalt road leads to the quarry via Prokosovići and Poljica. It is connected by an asphalt road to Banovići via the villages of Čubrić and Treštenica. A quarry was opened at this location as early as 1957. These are Tithonian-Valendian (Jurassic-Cretaceous) coral-reef limestones. The open profile shows stratification, and the thickness of the layers is from 1.5 to about 10 meters. The strata extend in the direction NE - SW, and fall in the direction southeast and east at an angle of 52 - 75°. At this quarry, three exploitation floors were opened at elevations of 500, 525 and 550 meters.

The Vijenac limestone quarry was opened for the needs of the industry in Lukavac and today it works for the needs of the Soda Factory and the Cement Factory. The total annual production of the quarry is about 580,000 m^3 of solid mass, of which about 515,000 m^3 is used for the aforementioned factories, and the rest is marketed. Limestone is transported from the quarry to the soda factory in Lukavac by cable car with a capacity of 150 t/h and a straight line length of 12 km. Since transportation by cable car cannot meet the needs of the industry in Lukavac, the rest is transported by trucks.

Figure 2. Vijenac limestone quarry (Photo „Rudnik krečnjaka Vijenac d.o.o. Lukavac“)

According to the results of the analysis (Tab. 1.), stone from the Vijenac limestone deposit can be used: for the production of calcined and caustic soda, for the production of nitrogen fertilizers, in the cement industry, for the production of filler flour for asphalt, for the lower part of roads and for most of the upper parts of roads in road construction, for the production of various types of concrete mixtures, as well as crushed stone for masonry in construction, etc. [1]

There is a possibility of increasing the production capacity of limestone from the Vijenac quarry, for the purposes of building future highways, but on a limited scale, due to the advantage of supplying industrial plants in Lukavac. The advantage of this quarry is its location near the route of the future highway (about 3 kilometers away from the nearest planned route). Considering the distance from the route, stone aggregates from this quarry could be used on almost the entire section of the future Žepče-Tuzla highway, as well as on the Šićki Brod-Čanići subsection of the Tuzla-Orašje highway.

Table 1. Physical and mechanical characteristics of limestone from the Vijenac quarry

No.	Type of determination	Value
1.1.	Compressive strength (dry specimens)	mean = 140,5 MPa
1.2.	Compressive strength (saturated specimens)	mean = 127,6 Mpa
1.3.	Compressive strength (sp. after 25 freeze-thaw cycles)	mean = 124,02 Mpa
2.	Absorption of water at atmospheric pressure	= 0,199%
3.	Bulk density	= 2674 kg/m^3
4.	Density	= 2715 kg/m^3
5.	Coefficient of Density	= 0,984
6.	Absolute porosity	= 1,56% (vol.)
7.	Frost resistance (after 5 cycles of immersion in Na_2SO_4)	= 0,113% - resistant
8.	Abrasion resistance (Böhme test)	mean =15,44 $cm^3/50\ cm^2$
9.	Impact resistance	= 21,2%
10.	Abrasion according to the LA method: gradation "B"	= 25,9%
11.	Abrasion according to the LA method: gradetion "C"	= 21,0%

Stupari limestone quarry

The limestone quarry "Stupari" is located on the right bank of the river Gostelja, 2 km downstream from the settlement of Stupari (Fig. 3.). This deposit is made up of gray, bluish and greenish massive limestones of the Anisian ages [17], which, going upwards, pass into plate-like, marly limestones (thickness of the layers is 10-20 cm) of yellow, gray and reddish colors. The main mass of the rock is composed of microcrystalline calcite mud. Its structure is microcrystalline, and its texture is homogeneous. It is limestone (biomicrite), without the presence of organic matter in it. In the middle part of the deposit, a lens of reddish breccia limestone occurs, 12 - 15 m wide. The quarry is divided by height into four levels: 365, 390, 405 and 425 m. The main plateau is located at an altitude of 345 [1] .

Figure 3. Orthophoto shot of Stupari Limestone Quarry

The main road Tuzla - Sarajevo passes right next to the quarry, through which there is a connection with the road network of the wider region and the country. Products from this deposit can also be transported by rail via the Đurđevik Coal Mine terminal, located about 8 km from the quarry. Therefore, we can say that from the aspect of communications, this quarry has a very good position.

Table 2. Physical and mechanical characteristics of limestone from the Stupari quarry

Broj	Type of determination	Value
1.1.	Compressive strength (Dry specimens)	mean = 124,0 MPa
1.2.	Compressive strength (saturated specimens)	mean = 106,2 Mpa
1.3.	Compressive strength (sp. after 25 freeze-thaw cycles)	mean = 96,8 Mpa
2.	Absorption of water at atmospheric pressure	= 0,104%
3.	Bulk density	= 2690 kg/m^3
4.	Density	= 2780 kg/m^3
5.	Coefficient of Density	= 0,968
6.	Absolute porosity	= 3,24% (vol.)
7.	Frost resistance (after 5 cycles of immersion in Na_2SO_4)	= 0,11% - resistant
8.	Abrasion resistance (Böhme test)	mean =24,76 cm^3/50 cm^2
9.	Impact resistance of edges (Deval coefficient (k_D))	= 1,10
10.	Abrasion according to the LA method: gradation "B"	= 28,16

According to certificates, it can be used for the production of load-bearing bases (pads) in road construction, then for the production of crushed aggregates for concrete, as crushed stone in civil engineering, as processed and untreated stone for masonry, etc.(Tab. 2.) [1]

Regarding the possibility of using stone from this quarry for the construction of the planned highways Tuzla-Orašje, that is, Žepče-Tuzla, we can state that the quarry is about 29 kilometers away from the nearest part of the route, which is Šićki Brod. That is approximately the ultimate limit of economic profitability from the aspect of distance.

Oštro Brdo limestone quarry

The Oštro Brdo limestone deposit is located in the far north-eastern part of the municipality of Kladanj, near the border with the municipality of Živinice. The quarry is located about 3.5 km south of the village of Gračanica, on the left bank of the Zaboj stream, which flows into the river Suvaja. The deposit is represented by gray, layered, banked and massive limestones, which are breccia and tectonized, especially in its northern parts. The tectonized limestones are partially recrystallized and intersected by millimeter calcite veins. The thickness of the layers ranges from 20 to 60 cm, and banks up to 1 m thick are also encountered. The general dip of the layers is in the NE direction with relatively steep dip angles of 40 - 65^0.

Figure 4. Oštro Brdo limestone quarry (Photo Hajdarević I.)

Limestone from the Oštro Brdo quarry can be used: for the lower part of road constructions, and for most of the upper part of road constructions, for the production of various types of concrete mixes, as well as crushed stone for masonry in construction, etc. (tab. 3.) [1]
The Oštro Brdo quarry (Fig. 4.) from Šićki Brod, as the closest point on the future highway, is about 30 kilometers away, which represents the limit of the economic viability of using fractions from this quarry in road construction.

Table 3. Physical and mechanical characteristics of limestone from the Oštro Brdo quarry

Broj	Type of determination	Value
1.1.	Compressive strength (Dry specimens)	mean = 124,3 MPa
1.2.	Compressive strength (saturated specimens)	mean = 119,0 Mpa
1.3.	Compressive strength (sp. after 25 freeze-thaw cycles)	mean = 105,04 Mpa
2.	Absorption of water at atmospheric pressure	= 0,11%
3.	Bulk density	= 2672 kg/m^3
4.	Density	= 2778 kg/m^3
5.	Coefficient of Density	= 0,96
6.	Absolute porosity	= 0,78% (vol.)
7.	Frost resistance	- resistant
8.	Abrasion resistance (Böhme test)	mean =23,21 cm^3/50 cm^2

Duboki Potok-Bijela Rijeka limestone quarry

The Duboki Potok-Bijela Rijeka limestone quarry (Fig. 5.) is located about 6.5 km southeast of Srebrenik. The river Tinja limits the deposit from the north, the river Bijela from the west, and the nameless stream from the east side of the deposit. The deposit is located along the asphalt road Tuzla-Srebrenik-Orašje, which connects the deposit with all important centers. There is a railway station in Duboki Potok settlement, and the stone can be transported by railway for the needs of customers in the country and abroad.

Figure 5. Duboki Potok-Bijela Rijeka limestone quarry (Photo INGRAM d.o.o. Srebrenik)

The layers of lithotamnian limestones in the Duboki Potok-Bijela Rijeka quarry have a NW-SE direction, and lie about 250 to the north. In the lower parts, light gray limestones with foraminifera prevail. In the higher levels, there are banked and massive limestones with large nummulites [3]. On the deposit itself, all the wells were completed in limestone, which means that the power of the productive series, i.e. its floor, has not been defined. The basic plateau at the quarry is at 260 m.a.s.l. The height of each floor is 20 m and there are five of them (at elevations of 280, 320, 360 m), and the tailings floor is designed at an elevation of 380 m [1]. The annual production of limestone of different fractions amounts to about 300,000 m3 of solid mass. Part of the production of over 50,000 m3 is currently used in our own factories (a factory for the production of hydrated lime and a factory of concrete elements), while the rest is sold on the domestic and Croatian markets.

Table 4. Physical and mech. characteristics of limestone from the Duboki P.-Bijela R. quarry

Broj	Type of determination	Value
1.1.	Compressive strength (dry specimens)	mean = 137,4 MPa
1.2.	Compressive strength (saturated specimens)	mean = 125,6 Mpa
1.3.	Compressive strength (sp. after 25 freeze-thaw cycles)	mean = 115,6 Mpa
2.	Absorption of water at atmospheric pressure	= 0,52%
3.	Bulk density	= 2660 kg/m^3
4.	Density	= 2730 kg/m^3
5.	Coefficient of Density	= 0,974
6.	Absolute porosity	= 2,76% (vol.)
7.	Frost resistance (after 5 cycles of immersion in Na_2SO_4)	= 0,116% - resistant
8.	Abrasion resistance (Böhme test)	mean = 18,1 cm^3/50 cm^2
9.	Impact resistance (Trenton)	= 8,32%

Since the maximum planned capacity of the quarry is over 350,000 m3 of solid mass, it is evident that this quarry, in addition to the current market, could market over 50,000 m^3 of solid limestone annually for the construction of the future highway (Tab. 4.) [1]. With an additional increase in capacity and significantly more.

Drenik limestone quarry

The Drenik limestone quarry (Fig. 6.) is located about 1.5 km southeast of Srebrenik, on the left bank of the Tinja River. The deposit is located next to the asphalt road Tuzla-Srebrenik-Orašje, which connects the deposit with all important centers. The Drenik quarry was opened in lithotamnian bank-like and massive limestones of Paleocene-Eocene age [2].

After a break of several years, production in the Drenik quarry has been reactivated and currently amounts to about 70,000 m^3 of solid mass per year. The production is marketed on the domestic market and the market of the Republic of Croatia. The maximum projected capacity of the quarry is about 185,000 m^3 of solid mass, so it is evident that this quarry can produce significant quantities of different stone fractions (Tab. 5.) [1], as well as ready-made concrete for the construction of future highways in the area of Tuzla Canton.

Figure 6. Drenik limestone quarry (Photo Hajdarević I.)

Table 5. Physical and mechanical characteristics of limestone from the Drenik quarry

Broj	Type of determination	Value
1.1.	Compressive strength (dry specimens)	mean = 178,0 MPa
1.2.	Compressive strength (saturated specimens)	mean = 142,6 Mpa
2.	Absorption of water at atmospheric pressure	= 0,403%
3.	Bulk density	= 2670 kg/m^3
4.	Frost resistance (after 5 cycles of immersion in Na_2SO_4)	= 0,116% - resistant
5.	Abrasion resistance (Böhme test)	mean = 18,1 cm^3/50 cm^2
6.	Sulfur content (as SO_3)	= 0,05%
7.	Chloride content	= 0,01%

Orlova Klisura limestone quarry

Orlova Klisura limestone quarry is located on the right bank of the Tinja in the gorge of the same name, between the villages of Gornji Potpeć and Lisovići, about 10 kilometers southeast of Srebrenik and about 20 kilometers northwest of Tuzla. Towards the Tinja river, it is characterized by steep sections up to 60 m high (Fig. 7.).

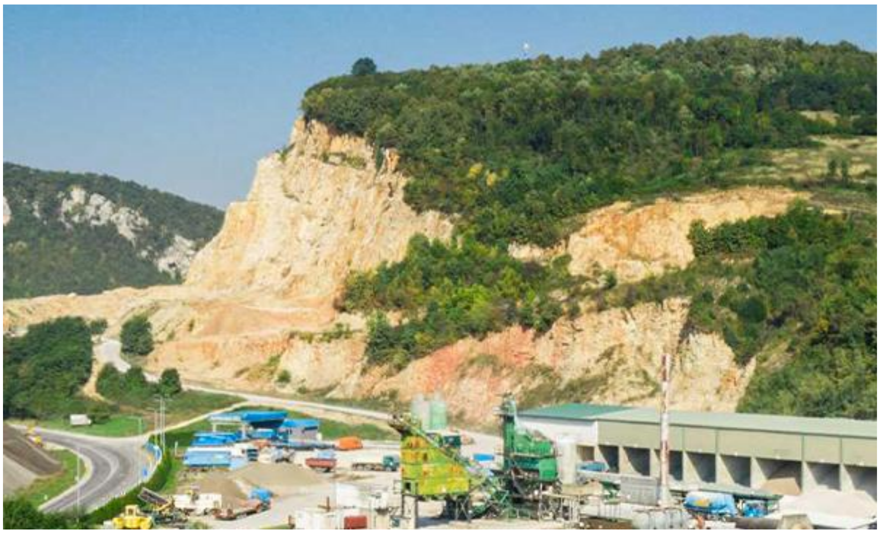

Figure 7. Orlova Klisura limestone quarry (Photo Jata Group)

Table 6. Physical and mechanical characteristics of limestone from the Orlova Klisura quarry

Broj	Type of determination	Value
1.1.	Compressive strength (dry specimens)	mean = 109,9 MPa
1.2.	Compressive strength (saturated specimens)	mean = 105,5 Mpa
1.3.	Compressive strength (sp. after 25 freeze-thaw cycles)	mean. = 92,7 Mpa
2.	Absorption of water at atmospheric pressure	= 0,20%
3.	Bulk density	= 2794 kg/m^3
4.	Density	= 2845 kg/m^3
5.	Resistance to crushing (LA method)	= 22,4
6.	Absolute porosity	= % (vol.)
7.	Frost resistance (after 5 cycles of immersion in Na_2SO_4)	= 0,24% - resistant
8.	Abrasion resistance (Böhme test)	mean = 15,2 cm^3/50 cm^2

Flysch sediments of Upper Cretaceous age and limestones of Paleocene-Eocene age are present in this deposit. The Upper Cretaceous flysch was developed from the basic plateau (290 m.a.s.l.) to an elevation of 340 m.a.s.l. and is represented by limestones (calcarenites) and, to a lesser extent, marls. Further, above the elevation of 340 m.a.s.l., all the way to the end of the outcrop, Paleocene-Eocene bank limestones lie discordantly over the flysch.The main road Tuzla-Srebrenik-Orašje passes right next to the quarry, as well as the Brčko-Banovići railway, so it can be said that from the point of view of communications, this deposit has a very favorable position.

According to certificates (Tab. 6.) [1], it can be used as a technical-building stone for obtaining fractions of stone aggregate intended for concrete mixtures, then for the production of the lower load-bearing layers of road constructions - buffers, as a material for the production of asphalt concrete for class III and IV traffic loads, for the production of bituminous and tar macadam, and as building stone for masonry and other similar purposes.

Due to the proximity of the route of the future Tuzla-Orašje highway (about 8 km in the closest part) and due to the increase in reserves by taking under concession the additional exploration space located in the existing quarry, this limestone deposit will be able to significantly contribute to the construction of this important infrastructure project.

Gradina-Potpeć limestone quarry

Construction aggregate quarry Gradina-Potpeć was opened in Paleocene-Eocene banked and massive limestones (Fig. 8.). It is located on the right bank of the Tinja River, about 5 kilometers southeast of Srebrenik. The deposit is located in the immediate vicinity of the Tuzla-Srebrenik-Orašje asphalt road, which is connected to the domestic and foreign markets. The railway station located in Srebrenik also increases the possibilities of placing stone fractions from this quarry on the market.

Figure 8. Gradina-Potpeć limestone quarry (Photo Hajdarević I.)

Table 7. Physical and mechan. characteristics of limestone from the Gradina-Potpeć quarry

Broj	Type of determination	Value
1.1.	Compressive strength (dry specimens)	mean. = 91,0 MPa
1.2.	Compressive strength (saturated specimens)	mean = 90,0 Mpa
1.3.	Compressive strength (sp. after 25 freeze-thaw cycles)	mean = 86,0 MPa
2.	Absorption of water at atmospheric pressure	= 0,30%
3.	Bulk density	= 2750 kg/m^3
4.	Density	= 2666 kg/m^3
5.	Absolute porosity	= 0,2% (vol.)
6.	Frost resistance (after 5 cycles of immersion in Na_2SO_4)	= % - resistant
7.	Abrasion resistance (Böhme test)	mean = 11,0 cm^3/50 cm^2
8.	Edge resistance to impact (drum)	A_u = 12,0 (L.A)

The Gradina-Potpeć quarry with satisfactory stone quality (Tab. 7.) [1], less than 10 kilometers from the route of the future Tuzla-Orašje highway, represents a potentially serious supplier of stone fractions of various assortments.

Ribnica diabase quarry

The "Ribnica" diabase deposit is located about 10 kilometers southwest of Banovići, near the town of Ribnica (Fig. 9.). It is located next to the Banovići-Zavidovići asphalt road (it is 12 km from Banovići and 20 km from Zavidovići), so it can be said that its position in terms of communication is the Dijabaz-dolerite massif. Ribnica has an area of about 20 km^2 and is located on the northern edge of the Krivajsko-Konjuška ultramafic massif, which is an integral part of the Dinaric ophiolitic zone [18]. Masses of diabases are found as smaller, broken fragments, like this one in the Ribnica locality, where geological research has determined economically significant reserves of stone with satisfactory physical and mechanical properties (tab. 8.) [1]. Here, diabases are in contact with dolerites, which are more subordinate. They have the same mineral composition as diabases, the same ophitic structure, but they are somewhat coarser-grained than them. In addition to the fault zones, there are metadiabases that do not exceed the amount of 10% in the deposit.

Figure 9. Ribnica diabase quarry (Photo Hajdarević I.)

Table 8. Physical and mechanical characteristics of diabase from the Ribnica quarry

Broj	Type of determination	Value
1.1.	Compressive strength (dry specimens)	mean = 141,62 MPa
1.2.	Compressive strength (saturated specimens)	mean = 124,37 Mpa
1.3.	Compressive strength (sp. after 25 freeze-thaw cycles)	mean = 108,94 Mpa
2.	Absorption of water at atmospheric pressure	= 0,28186%
3.	Bulk density	= 2890,7 kg/m^3
4.	Density	= 2923,3 kg/m^3
5.	Coefficient of Density	= 0,98892
6.	Absolute porosity	= 1,1258% (vol.)
7.	Frost resistance (after 5 cycles of immersion in Na_2SO_4)	= 0,14562% - resistant
8.	Abrasion resistance (Böhme test)	mean =14,84 cm^3/50 cm^2
9.	Impact resistance of edges (Deval coefficient (K_D)	= 3,9828%
10.	Abrasion according to the LA method: gradation "B"	= 15,7996%
11.	Sulfur content (as SO_3)	= 0,17733%

Diabase stone fractions from the Ribnica quarry could satisfy all, or almost all, material needs for the wear layers of the planned highways in the territory of the Tuzla Canton.
Due to the higher price of diabase fractions compared to carbonate fractions, the use of this material is not to such an extent conditioned by the immediate proximity of the quarry to the route of the road being built.
This allows a greater distance of the quarry from the installation site.

4. PERSPECTIVE GEOLOGICAL FORMATIONS FOR FINDING DEPOSITS OF CONSTRUCTION AGGREGATE IN THE TERRITORY OF TUZLA CANTON

The first geological surveys of the area of today's Tuzla Canton began during the time of the Austro-Hungarian Monarchy and are part of the regional surveys carried out by the Geological Survey from Vienna. At that time, these regions were explored by famous geologists: Hauer [5], Bittner [13], Tietze [13], Mojsisovitz [13], Grimer [4].

In the second half of the 20th century, the Basic Geological Map (OGK) was started on a scale of 1:100,000 for the purposes of creating maps: Zavidovići, Doboj, Vlasenica, Zvornik, Brčko and Tuzla. These Basic Geological Map sheets provided basic data on the geological structure of the terrain, structural-tectonic composition of the terrain, rock types, etc. They were made by the Geological Institute Sarajevo.

At the same time, in addition to the creation of OGK, research was carried out in several directions: research to prove reserves of hard and brown coal, lignite, oil and gas, research to find new deposits of rock salt, hydrogeological and hydrological research of waters for industrial purposes (lake Modrac), research underground water (drinking, mineral and thermal mineral), as well as for the christening of various deposits of non-metallic raw materials for the cement industry, production of gas concrete, and more recently, research to prove stocks of technical-building stone. Those investigations were carried out by geologists: M. Luković [11], I. Soklić [15], P. Stevanović [16], M. Eremija [16], Č. Jovanović [7] and numerous others.

From a geological point of view, the territory of Tuzla Canton is an interesting area for research into the existence of possible deposits of quality construction aggregate. From the research that was done during the creation of OGK, it is clearly visible which geological formations can contain quality masses of stone that can be used as aggregate in construction techniques.

As for the perspective of finding rock masses suitable for obtaining aggregates that can be used in pavement constructions, it should be pointed out that they must meet certain conditions. Primarily, they should have satisfactory physical and mechanical characteristics in accordance with technical regulations and applicable standards. Also, they should have favorable mineralogical-petrographic characteristics, as well as an appropriate chemical composition.

Geological factors that influence the evaluation of the value of a deposit of construction aggregate are: the size of the deposit, the type of mineral raw material, the quality of the mineral raw material, the possibility of exploitation, the geomorphological characteristics of the terrain, the degree of geological exploration of the deposit and the proximity of the market.

All rocks are not suitable for use as construction aggregate. We distinguish rocks of magmatic origin, which are often called by the not very precise name "eruptives", and rocks of carbonate origin, limestone and dolostone.

Rocks of magmatic origin, due to their favorable physical and mechanical properties and high resistance to the action of external factors, are mainly used to obtain aggregates that are used to make asphalt-concrete for wearing layers of roads. Of the igneous rocks in our region, basic rocks (diabases, spilites, dolerites) are mostly used, and neutral igneous rocks (andesites and dacites) are less common.

Rocks of carbonate origin are used in the largest percentage when making road constructions. They are used to build the lower part of the road (buffer including the bedding), and the largest part of the upper part of the road, which includes the mechanically compacted bearing layer, a layer of stabilizing aggregate bound with bitumen or cement, as well as parts of the asphalt pavement (asphalt bearing and asphalt binding layer). Of course, rock aggregates used for these purposes must meet all prescribed standards.

Currently, the only quarry of construction aggregate of magmatic origin in the area of Tuzla Canton is the Ribnica diabase quarry. Considering the balance reserves of stone at this quarry, it could meet most of the aggregate needs for the wearing layer of the future highway.

In the Table 9. we provide an overview of balance reserves (A+B+C1 category) at existing quarries that could supply the routes of the future highways Tuzla-Brčko and Žepče-Tuzla with stone aggregates [1]:

Table 9. Overview of balance stone reserves by quarries

Quarries of stone of magmatic origin - diabase (for Asphalt wearing course)			
Red. br.	Quarry	Municipality	Balance reserves (A+B+C1 cat.) (m^3)
1.	Ribnica	Banovići	14 632 000
In total			**14 632 000**
Quarries of stone of carbonate origin - limestone			
1.	Vijenac[1]	Lukavac	20 297 000
2.	Stupari	Kladanj	707 000
3.	Oštro Brdo	Kladanj	4 632 000
4.	Duboki Potok-Bijela Rijeka[2]	Srebrenik	14 163 000
5.	Drenik	Srebrenik	3 842 000
6.	Orlova Klisura	Srebrenik	3 227 000
7.	Gradina-Potpeć	Srebrenik	1 650 000
In total			**48 518 000**

[1] - *by far the largest part of the reserves from the Vijenac quarry is intended for industrial use in cement and bicarbonate factories*

[2] - *part of the production from the Duboki Potok-Bijela Rijeka quarry is reserved for the production of lime and concrete elements in our own factories*

It should be emphasized that most of the current production capacities in these quarries are used to meet the current needs of the economy and the population of the Tuzla Canton and its surroundings, which means that in order to meet the demand for new quantities in the scale necessary for the smooth construction of the planned highways, a significant expansion of the production capacities in current quarries, as well as the opening of new quarries of construction aggregates.

From all areas with rock masses suitable for opening a quarry of construction aggregates in the area of Tuzla Canton, primarily intended for obtaining stone aggregates for the construction of future highways, we have singled out the following:

Area no. 1 (Vijenac-Jaruške Gornje-Oštrić)

Limestone masses that meet the criteria for opening a quarry of construction aggregates, and which are closest to the planned route of the future Žepče-Tuzla highway, are located in the territory of the municipality of Banovići, east of the town of Seona, and south and southeast of the village of Jaruška. It is a geological formation made of massive limestone beds of Jurassic-Cretaceous age. These rocks are very suitable for use as construction aggregates, which is proven by the fact that in 1957 one of the largest limestone quarries was opened in them, not only in the area of Tuzla Canton, but also in the whole of Bosnia and Herzegovina. It is the Vijenac quarry, where exploitation is still carried out. This quarry is located on the northeastern edge of this limestone massif.

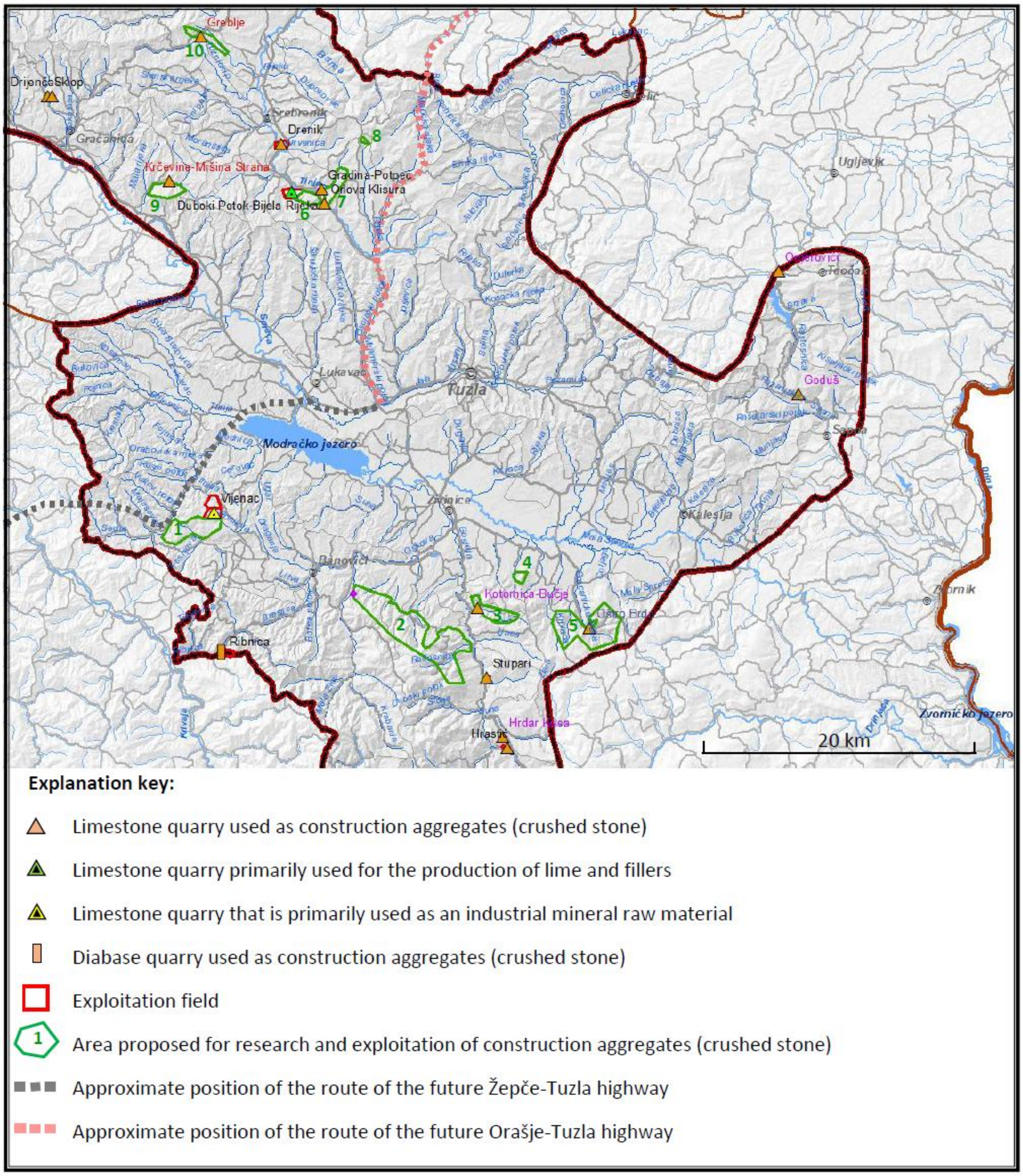

Figure 10. Map showing quarries and potential areas for exploration and exploitation of technical and construction aggregates (crushed stone) in the Tuzla Canton

The planned route of the Žepče-Tuzla highway passes right next to the border of these rock masses, so we can say that this is one of the most favorable terrains for finding deposits of quality construction aggregates for the construction of this road communication. This rock mass is 25 to 28 kilometers from Šićki Brod, so the stone fractions from a future quarry that would be opened here could also be used in the construction of the route on the Šićki Brod-Čanići subsection of the Tuzla-Orašje highway. All of the above speaks in favor of the fact that this is a very promising area for accessing geological research on the selection of a suitable location for the opening of a limestone quarry as construction aggregate (Fig. 10.) [1].

Area no. 2 (Ravni Bor-Djedinska planina)

Another interesting area in the Tuzla Canton for geological research with the aim of finding suitable locations for the opening of quarries of construction aggregates in carbonate rock masses is located on the northern and northeastern slopes of Djedinska mountain (Fig. 10.). From the Oskova river in the west, over the entire Djedinska mountain, all the way to the Gostilje River in the east, there is a belt of massive and banked limestones of the Middle and Upper Triassic [6]. This terrain is located for the most part in the municipality of Živinice, and only the extreme southeastern part in the municipality of Kladanj. Due to the complex tectonic structure, these formations are not broken down on the Basic Geological Map, although in some localities they can be broken down based on the found micro and macro fauna, as well as lithological features and stratigraphic position. The lowest horizons are represented by gray and light gray limestones with lenses of reddish limestones in the upper part. Hanbulo fauna was found in these limestones, which proves their Anisian age. Layered limestones, rarely dolomites, lie over these limestones in some places. In some places, marly limestones with chert nodules and fauna of Daonel and Halobia occur. This indicates the Ladinian age of these deposits. This series does not have a continuous horizontal extension and passes laterally into coral-reef limestones, which pass upwards into the Upper Triassic. Upper Triassic sediments are represented by limestones similar to Anisian, and less often by dolostones. Their age is proven by findings of the Upper Triassic microfauna.

The northern and northeastern parts of these carbonate masses are interesting for geological research with the aim of finding locations for quarries from which stone fractions could be used in the construction of planned highways. The reason for this is primarily due to the acceptable distance of these terrains from the highway routes. This zone includes the locality Ravni bor in the northwest, and further extends through Gravić kosa and Borovac to Ruj, Igrište and the village of Lupoglavo in the far southeast. This entire zone is 25-30 kilometers from Šićki Brod, which represents a tolerable distance from the aspect of transport costs. Geological surveys have already been carried out at the Ravni bor site and limestone reserves as a construction aggregate of more than 3 million cubic meters of solid mass have been proven, but due to certain administrative difficulties, the quarry has not yet received all the necessary permits for work.

Area no. 3 (Kotornica-Jasik)

The third interesting area is located east of the river Gostilje in the area of Kotornica-Jasik in the municipality of Živinice (Fig. 10.). It is part of the carbonate, predominantly limestone rock masses that represent the continuation of those from the Djedinska mountain area. There was already a limestone quarry in the Kotornica-Bučje location, which was closed a few years ago. In the same locality, the reopening of the limestone quarry is in the process.

The area that is interesting includes the Jasik hill, as well as both banks of the Kotornica stream, where it would be worth starting geological research with the aim of finding more locations with quality stone suitable for opening a quarry of construction aggregates. In addition to high-quality limestone masses, this area is also interesting due to its proximity to the Sarajevo-Tuzla main road, which greatly facilitates the possibility of transporting stone aggregates to the market. This area is about 25 kilometers from the route of the future highway near Šićki Brod, which is a satisfactory distance, given the good communication connections.

Area no. 4 (Berbenjak)

The mass of undecomposed limestones of the Middle and Upper Triassic, which is located about 5 to 6 kilometers northeast of the Jasik-Kotornica area in the Berbenjak hill area between Donja and Gornja Lukavica (Fig. 10.), on the southern edge of Sprečko polje, is also interesting in terms of the possibility of finding a suitable location for opening a quarry of construction aggregates. this limestone mass also belongs to a belt of carbonate deposits that can be followed from the Oskova river in the west, through Djedinska mountain Stupari and Kotornica to the Gračanica village on the southern edge of the Sprečko polje. It is located in the territory of the municipality of Živinice.

This area is about 26 kilometers away from Šićki Brod, as the closest point on the route of the future highway.

Area no. 5 (Obli vrh-Veliko brdo)

The next in the series of carbonate masses of Middle Triassic to Upper Triassic age, going from west to east, is in the area that includes the sites Obli vrh and Veliko brdo on the border of the municipalities of Živinice and Kladanj (Fig. 10.). A construction aggregates quarry has already been opened within this rock mass and has been operating for many years. It is the Oštro Brdo quarry. In the limestone masses within the proposed area, detailed geological research could undoubtedly find more suitable locations for the opening of quarries that would meet the necessary standards in terms of quality and quantity.

This area is from the nearest point on the future highway, which is Šićki Brod, about 30 kilometers away, which is approximately the ultimate limit of profitability from the point of view of transportation costs.

Area no. 6 (Drenovac-Orlova klisura)

The Paleocene-Eocene limestone massif in the Drenovac-Orlova Klisura region is located on the left bank of the Tinja River in the municipality of Srebrenik (Fig. 10.). These lithotamnian limestones occur in the form of lenses over 3 km long and 700-800 m wide. In the lower parts, light gray limestones with foraminifera prevail. In the higher levels, there are banked and massive limestones with large nummulites. Massive limestone is a rock of monomineralic composition, of organic origin, formed from zoogenic and phytosediments with a high $CaCO_3$ content. Layered gray marls are found in the limestone floor in the wider area of the deposit.

In the northwestern part of this limestone mass, there is already an old active quarry Duboki Potok-Bijela Rijeka. In the extreme southeastern part of this area, the necessary permits for the opening of another quarry are in the process of being obtained. Due to the proven quality of these limestones, as well as the proximity of the future Tuzla-Orašje highway (8 to 10 kilometers), this is a very attractive area for opening a construction aggregates quarry.

Area no. 7 (Kameničak-Kovačevo brdo)

Northeast of the Orlova Klisura and Gradina-Potpeć quarries in the Kameničak-Kovačevo brdo area continues the area with massive Paleocene-Eocene limestones (Fig. 10.). This area, excluding populated areas, is suitable for expanding the two mentioned quarries, as well as for possibly opening new quarries. Good road communications, as well as the proximity of the Tuzla-Orašje highway route, give importance to this area in terms of the possibility of conducting geological research with the aim of finding favorable locations for opening a quarry. The route of the future highway is about 7 to 8 kilometers from this area.

Area no. 8 (Grabovik-Zaketuša)

In the area of Grabovik-Zaketuša (Fig. 10), there are limestone rock masses, also of Paleocene-Eocene age [2]. It is located on the territory of the municipality of Srebrenik. The favorable position of this area is reflected in the fact that it is the closest of the existing quarries, as well as of all the rock masses proposed so far, to the Čanići-Maoča subsection of the Tuzla-Orašje highway. Such a position of the quarry that would be opened in this area would enable the lowest transport costs of stone aggregates for the part of the highway that leads further towards Maoča and Brčko.

Area no. 9 (Hotilj-Krčevine)

The area of Hotilj-Krčevina is located on the territory of the municipality of Gračanica, in the region of Orahovica Donje. It covers a large part of the Hotilj hill, as well as the area of Krčevina northeast of it (Fig. 10.). Limestones with rudites and globotruncas [10] that make up this terrain could be suitable for use as construction aggregates. One quarry within this area at the location of Krčevine-Mršina strana was already in the opening phase, but the process of obtaining permits has been suspended in the meantime.

Before the final decision to open a quarry in these limestones, it would be necessary to carry out a detailed geological prospecting of the terrain, in order to determine the most promising locations for geological research in order to open a quarry. This terrain is located between 22 and 30 kilometers from the Šićki Brod-Čanići subsection of the Tuzla-Orašje highway. From the route Žepče-Tuzla, the closest part in Lukavac is 22 kilometers away.

Area no. 10 (Krešnice-Ćerimovo)

Between Doborovci and Srnice Gornje, in the municipality of Gračanica, there is a belt of massive limestone beds that stretches from west to east. From the region of the Vranjevac hill, this belt stretches to the southeast in the direction of the localities of Krešnice and Ćerimovo (Fig. 10.). The length of the zone with massive limestone is about 3 kilometers, while its width varies from 200 to 800 meters. The Greblje quarry is located in that area. The company that opened the quarry was granted the right to explore, but did not obtain all the permits necessary to start legal exploitation. These limestones should be geologically investigated in more detail, because there is a real possibility that the quality and quantity of stone can meet the requirements for use in highway construction.

This area is particularly interesting because it is not too far from the Tuzla-Orašje highway route that leads through the territory of Brčko District. It is about 28 kilometers from Maoča, and about 30 kilometers from Brka.

5. CONCLUSION

If the Tuzla canton wants to use its raw material base, which it undoubtedly possesses, and thus reduce the costs of building the highway, which is so necessary for this canton, it is necessary to introduce changes and additions to the spatial plan, which would clearly indicate the additional areas intended for the exploration and exploitation of construction aggregates (crushed stone). We should take advantage of the increasing demand for construction aggregates as a natural material and enable businessmen who are engaged in the exploitation of these mineral raw materials to use at least part of the potential we have in this area. The Tuzla Canton has significant resources of this sought-after material that have not been used to a sufficient extent. It is necessary to attract potential concessionaires and stimulate them in appropriate ways, or at least enable them to obtain the necessary permits within the deadlines prescribed by law. All these activities require the joint work of competent municipal, cantonal and, if necessary, federal institutions. Of course, it should be insisted that concessionaires must comply with all prescribed environmental norms and standards.

In order to obtain a competitive economic branch that implies sustainable growth in the exploitation and processing of construction aggregates, it is necessary to pay special attention to geological research, both of the deposits known so far, as well as areas promising to find these useful mineral raw materials. Suitability for the exploitation of any mineral raw material, including construction aggregates, is defined above all by the existence of deposits with reserves for long-term exploitation, proximity to the market, as well as the possibility of profitable production. The authors of this paper, on the basis of previous experiences, as well as their own knowledge, proposed several locations where geological formations of different ages and with high-quality limestone masses were found, suitable for finding economically profitable deposits of construction aggregates in the relative proximity of the route of the future highway in the territory of the Tuzla Canton.

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ORGANIZATIONAL ASPECT OF MANAGING THE CONSTRUCTION OF HIGH-RISE BUILDINGS

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Summary

This paper presents a detailed planning process for the construction of the residential-commercial building "Lamela B1" in Banovići, with a structure consisting of a basement, ground floor, and five upper floors. The planned construction period for this project is a total of sixteen months.Within the study, an assessment of the average monthly workforce requirements has been conducted, along with an analysis of the diagram depicting the average daily workforce needs for each month. Additionally, a static material plan has been developed, correlating with dynamic construction schedules created using network planning methods and Gantt charts.The duration of individual construction operations has been determined based on applicable norms and standards in the construction industry. Special attention has been given to the gradual introduction of machinery and labor, as well as the procurement of necessary materials. This planning approach ensures the continuous operation of essential machinery and workforce while also securing the periodic procurement of required construction materials. During the development of the network plan, Gantt chart, and static material plan, careful consideration was given to the logical sequence of operations, ensuring that the necessary conditions for starting a specific operation were met, as well as identifying opportunities for parallel execution of multiple operations.Based on the developed dynamic schedules and workforce requirements, a diagram representing the average monthly workforce demand has been constructed. This study contributes to a better understanding of construction planning methods and resource optimization in the context of project dynamics and time management.
Keywords: building, planning, execution, workforce, network planning, work dynamics

1. INTRODUCTION

Project management is a set of processes in which knowledge, skills, tools and techniques are applied with the aim of realizing project goals. During the creation of this work, the project solution of a business-residential building built in Banovići, with floor plan dimensions of 35.00 × 15.00 m, called "Lamela B1" was used as a basis.
The building consists of: basement, ground floor and five floors. The location of the object is characterized by the following elements:

- The building is located along a section of the city street
- Connections to all installations are provided on the plot.

All the walls around the reserved space for shelter are made of reinforced concrete: outer thickness d=25 cm, and inner d=20 cm, reinforced with mesh on both sides. The ceilings above

all floors are monolithic ab ceilings with a thickness of d=18.00 cm, reinforced according to the reinforcement drawings.
In the basement of the building, five business spaces with wet rooms have been designed.
Nine residential units were designed on the ground floor and upper floors of the building. Each residential unit consists of rooms: kitchen, living room, hallway, bathroom with toilet, and different number of bedrooms depending on the size of the apartment.
The external and internal load-bearing walls of the ground floor are a combination of ab walls and giter blocks or siporex d=25 cm, and partitions made of siporex d=10 cm. The outer walls in the basement are made of reinforced concrete. At the junction between the base plate and the walls, waterproofing from sika mortar is provided.
The other walls are made of giter blocks or siporex d=25 cm and d=20 cm, and the partitions are made of siporex blocks d=10 cm. All load-bearing walls in the basement are based on the AB base plate, which is placed on a cement glaze that protects the horizontal waterproofing.
Finishing of the floors and interior walls was carried out according to the project documentation.
Facade walls are lined with styrofoam d=8.00 cm with other shops and finished with a facade.
The roof structure is a multi-gable roof made of Class I fir, and it is attached to an AB cerclage and a plate with steel anchors, which have a thread on the tops, on which metal plates with fastening nuts are placed. The roof covering is a metal sheet placed on a wooden base over which terpaper is placed.
The facility has an elevator for 6 people, which consists of an elevator shaft and a house according to the manufacturer's instructions, while the elevator project will be the responsibility of the manufacturer.
The building's foundation is made on a 50 cm thick reinforced concrete slab placed on a cement glaze.
A 40 cm thick buffer layer is projected under the concrete base, which is compacted to a compressibility modulus of M 80.
The depth of the foundation and the bearing capacity of the terrain was determined based on the Elaborate on geomechanical testing of the soil for the needs of the construction of a residential and commercial building.[2]

2. CALCULATION OF AVERAGE WORKFORCE REQUIREMENTS PER MONTH

The calculation of the average labor needs per month was done in such a way that the expected term for the construction of a residential and commercial building is 16 months, taking into account the norms and all the positions of the works from the bill of quantities and estimate of the works, which is an integral part of the project documentation.

The basis for this budget is the dynamic work execution plan, average norms and standards, and a diagram of the average labor needs per month for the total execution period of 16 months has also been drawn up.

Table 1. Average labor needs by month

Month	Number of workers	Number of working days	Average number of workers
April	184	23	8
May	260	22	12
June	310	21	15
July	333	22	15
August	425	22	19
September	528	22	24
October	332	22	15
November	316	21	15
December	330	22	15
January	318	21	15
February	340	22	15
March	575	22	26
April	575	22	26
May	572	22	26
June	546	21	26
July	260	22	12

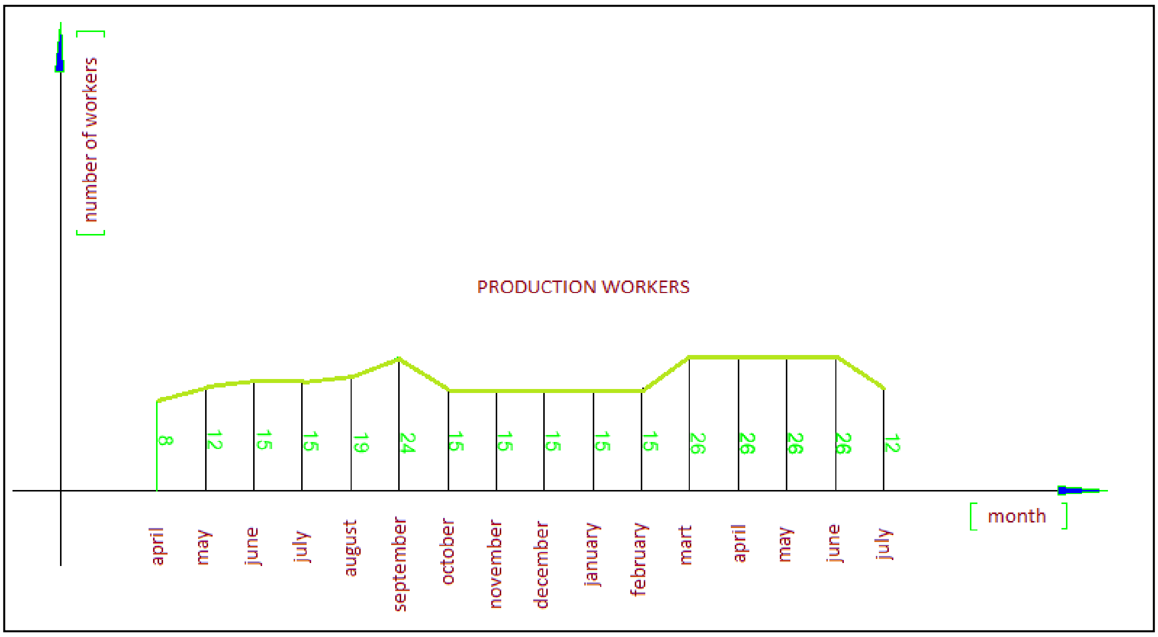

Figure 1. Diagram of average daily labor needs during the month

3. DYNAMIC WORK EXECUTION PLAN

The creation of a dynamic work execution plan is the determination of the order of execution of operations with the calculation of the time duration of the activity, which is determined on the basis of work norms and the amount of work on a certain activity and is calculated according to the form [1] [4]:

$$T= Q \times 1,2 \times N_{č} / n \times m \qquad (1)$$

Where is:
T-time of an activity

Q-quantity of work on an activity
1,2 -factor of increase of activity time by 20% due to unforeseen delays in construction (annual, vacations, sick days, absences)
$N_{\check{c}}$-norm hour for the unit of measure from the bill of quantities of works Q
(taken from norms and standards in construction)
n-number of workers
m-number of working hours [5] [6].

Since it is a building with four characteristic floors, the duration of activities for the execution of all earthworks is defined; the duration of activities required for the construction of the basement, ground floor and first floor is defined, and the duration of activities for the construction of the second, third and fourth floors and the need for labor are identical to the duration of activities for the need for labor on the first floor due to their repetition. [7]

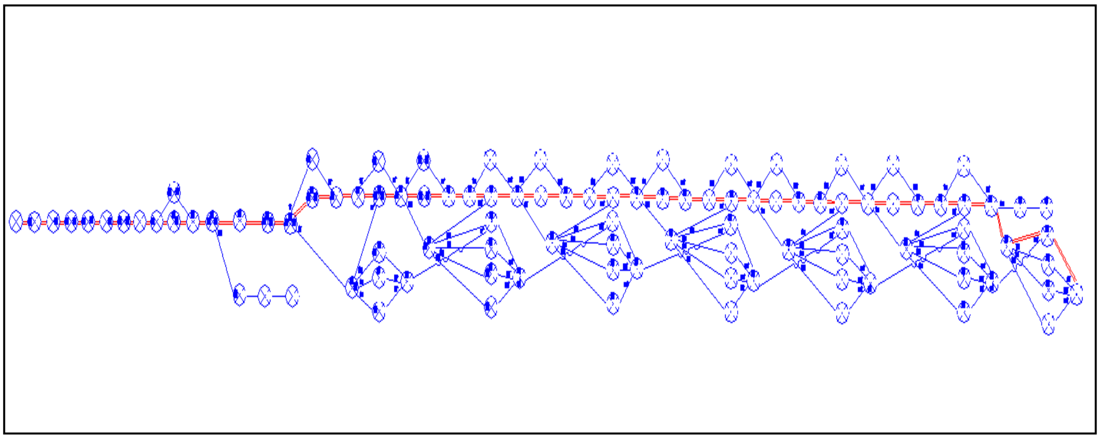

Figure 2. Network plan

This paper describes in detail the dynamics of work execution with a network plan and a Gantt chart, which enables:

- ➢ Graphical way of displaying the technological process via the network and gives a good visibility of the progress of the works;
- ➢ Marking the so-called "critical works", i.e. those that do not contain any time reserve and on which the execution deadline depends;
- ➢ Determining the optimal sequence of works.

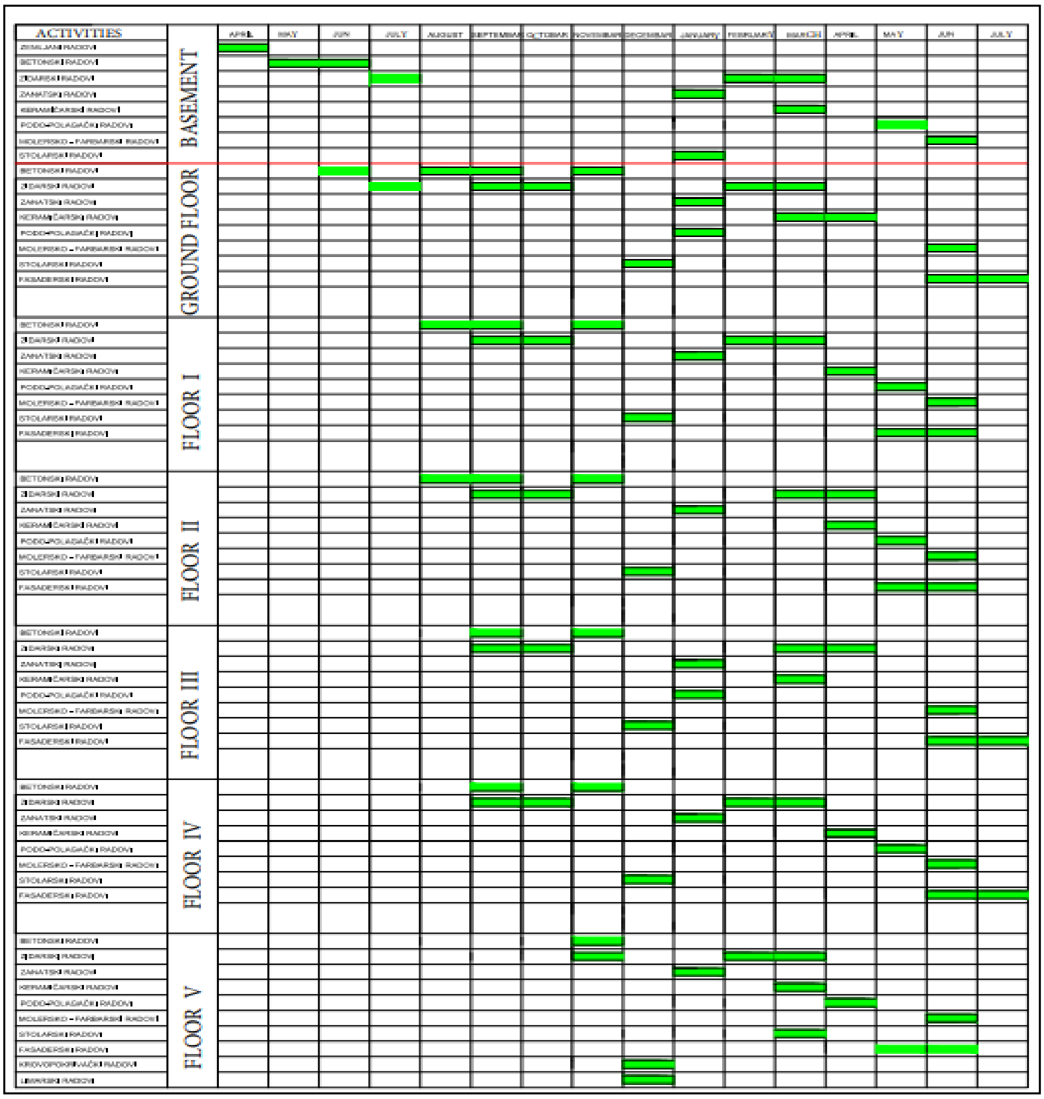

Figure 3. Gantt chart

Creating a network plan includes three phases:

- Which activities can start immediately after some observed activity;
- Which activities can take place in parallel with the observed activity;
- Which activities must be completed in order for the observed activity to start. [3]

In this paper, a network plan was created using circles, where activities are represented with one circle in which:

- No - Serial number (or some other activity mark)
- Rz - Early completion of works
- Kz - Late completion of works
- t_i - Activity duration

- The calculation of early terminations Rz is determined by the "forward" procedure and was calculated according to the form;

$$R_{zi}=max\ [R_z(p_a) + t_i \qquad (2)$$

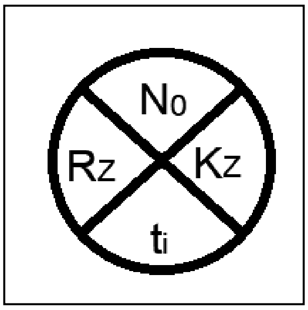

Figure 4. Activities in the network plan

➢ The calculation of late terminations Kz is determined by the "backward" procedure and was calculated according to the form;

$$K_{zi}=min\ [\ K_z(n_a) - t(n_a)\ ] \qquad (3)$$

Where is:
i – observed activity
n_a – the next activity
p_a – previous activity

➢ The mark *max* means that when determining the earliest completion time for a subsequent activity, we take the highest value of the sum of the earliest completion time of the previous activity with the duration of the observed activity.

➢ The mark *min* means that when determining the time of late completion, the smallest value that results when its duration is subtracted from each of the following activities is taken. When the calculation is "back" to the initial activity, the process is complete and the critical path is drawn.

The critical path consists of a series of activities for which the time reserve is Tu=0, which means a series of activities with the same values for R_z and K_z.

4. STATIC PLAN OF MATERIALS

For each project, although it may seem similar to another project, a separate time plan should be developed to avoid exceeding the deadline, because no project is actually the same and no project is repeated twice. Without a good plan, monitoring and control of the execution of construction works, it is difficult to run a successful business and it follows that planning is always useful, although it does not guarantee the success of the project, since, in addition to the plan being developed in detail, it must also be implemented consistently.

For the consistent application of dynamic plans that describe the production of items on the project over a period of time, it is also necessary to develop a static material plan that provides visibility and the needs of a certain type of material in the same time interval in which the production of certain items is planned.

Specifically, for the project that was used as a basis for the development of this work, a static material plan was developed, presented in figure 5.

MATERIAL		unit of meas.	quantity	OIL (kg)		NATUR GRAVEL (m^3)		CEMENT (kg)		AGGREGATE (m^3)		WATER (m^3)		SANDS (m^3)		ARMATURE (kg)		LIME (m^3)	
No	DESCRIPTION			unit	total	unit	total	unit	total	unit	total	unit	total	unit	total	unit	total	unit	total
1.	CATEGORY III EARTH EXCAVATION	m^3	2029,95	0,278	564,33														
2.	FILLING THE TAMPON UNDER THE FOUNDATION PLATE	m^2	494,9			0,2	99,0												
3.	FILLING GRAVEL AROUND THE BUILDING	m^3	209,66			1,0	209,66												
4.	MAKING A LEVELING BOARD d=10 cm	m^3	49,49					300	14847	1,282	63,45	0,18	8,90						
5.	[illegible]	m^2	494,9					470x0,04	9304,1			0,35x0,04	6,92	1,01x0,04	20,0				
6.	concreting of the foundation slab d=50 cm MB30	m^3	242,6					350	84910	1,25	303,25	0,20	48,52			60,0	14556		
7.	concreting of columns with MB30 concrete	m^3	347,48					350	121618	1,25	434,35	0,20	69,49			60,0	20848,8		
8.	concreting of beams with concrete MB30	m^3	100,63					350	35220,5	1,25	125,79	0,20	20,13			60,0	6037,8		
9.	concreting of slabs with MB30 concrete	m^3	583,63					350	204270,5	1,25	729,54	0,20	116,73			60,0	35017,8		
10.	concreting of the cerclage with concrete MB30	m^3	69,08					350	24179,4	1,25	86,36	0,20	13,82			60,0	4145,04		
11.	concreting of stairs with concrete MB30	m^3	15,74					350	5509,0	1,25	19,68	0,20	3,15			60,0	944,4		

Figure 5. Excerpt from the static material plan

5. CONCLUSION

Based on the research conducted, it was concluded that dynamic planning is one of the key phases in the execution of construction works, as it allows for the optimal use of labor in a certain period of time. The research results show that with proper and detailed planning, the planned works can be completed within the given deadline. When creating the network plan and Gantt chart, special attention was paid to the sequence of operations - dependencies between activities were clearly defined, i.e. which operations must be completed before the start of the next, as well as those that can be performed in parallel. All operations during the execution of the works were accompanied by a static material plan, i.e. the calculated amount of material required to produce a certain position. Also, care was taken to gradually introduce the workforce and its continuous work, which is shown through diagrams of average daily labor needs on a monthly basis, as well as within individual months. This work can serve as a good basis for further research and improvements in the field of planning and execution of works in building construction.

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ANALYSIS OF RISK FACTORS IN CHANGES IN CONSTRUCTION COSTS

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Summary

This paper presents the formation of construction costs and the risk factors influencing price changes in the construction of a residential-commercial building for the market, "Lamela B1," in Banovići. The building consists of a basement, ground floor, and five floors, with a planned construction period of 16 months.The study includes an analysis of labor and material costs, as well as risk factors that affect construction price fluctuations, in accordance with market demands and the surrounding conditions specific to the construction site. All relevant influences on market price formation have been identified, along with potential price changes and a risk analysis of cost variations during construction.The most significant challenges arise in aligning planned construction costs with actual expenditures and assessing their overall impact on the project. The aim of this research is to demonstrate, through a specific case study and within the context of the surrounding conditions, the importance of improving existing planning and project management processes in high-rise construction by applying scientific and professional methodologies.
Keywords: cost, construction, planning, risk, environment

1. INTRODUCTION

Specific environmental conditions directly affect the cost of construction, as well as risk factors during project execution. In the construction industry, there is always a need for precise cost estimation.

The most commonly used cost estimation method is the so-called "AD-HOC" approach, which indicates a lack of a more structured planning system. Therefore, it is necessary to apply rational project planning and management methods using software tools, construction standards, and other relevant parameters to optimize the construction process.

One of the biggest challenges in construction is aligning planned and actual construction costs while analyzing the effects these costs have on the overall project. The aim of this research is to highlight the need for improving existing planning and project management processes in high-rise construction through the application of scientific and professional methods, using a concrete example and specific environmental conditions.

This research enables:

Making optimal decisions based on modern planning and construction management methods while optimizing technological and organizational processes, construction timelines, costs, and the quality of completed work.

Improving business processes through the application of an efficient project planning and management methodology, thereby contributing to a better business environment.
The bill of quantities was prepared based on the available documentation and includes earthworks, while other construction works, such as concreting and wall masonry, were analyzed by floors. The price analysis was conducted for each item in the bill of quantities, while the cost estimate was obtained by multiplying the quantities of work by unit prices, which were determined based on the cost analysis.

2. PRICE ANALYSIS

When analyzing the prices of construction services for the items in the bill of quantities, the following empirical formula was used:

$$C_p = E_m + E_{ld} \cdot \varphi \; ; \qquad (1)$$

Where is:

C_p- the selling price of a construction service
E_m- costs of materials (basic, auxiliary and operating), with transport costs.
E_{ld}- labor costs (personal income, on which the calculation factor φ depends)

The calculative factor φ also depends on the level of mechanical equipment and includes all costs except for materials and labor. [5] [7]
Characteristic was the preparation of price analysis for complex operations, for example, for the operation of concreting a slab in which the price of the formwork was included, especially the price of the formwork and the calculation of how many m2 of formwork is needed for the installation of m^3 of concrete.
Databases on already built buildings were used and comparison was made based on experience.
The analysis of the construction structure itself is divided into phases:
- Phases of the project
- Organizational units
- Working units
- Key project resources
- Types of expenses.

In the work, and as an example, we give some of the price analyzes of the works that were done on the prescribed forms, table 1, table 2 and table 3.

- analysis of the price of 1m2 formwork for concreting the slab
- analysis of the price of installing 1 m3 of concrete with the price of formwork
- price analysis of the position of building the walls on the building.

Table 1. Analysis of the price of $1m^2$ of formwork for concreting a slab

ZA OBJEKAT : STAMBENO POSLOVNI "LAMELA B1" BANOVIĆI						VRSTA RADA: **TESARSKI RADOVI**	
OPIS RADA: OPLATA RAVNIH,KOSIH ILI NAGNUTIH BETONSKIH PLOČA						GN:601-204	
BEZ OBZIRA NA VELIČINU SA PODUPIRANJEM						160701	
DO 3 M PODUPIRANJEM DRVENIM PODUPIRAČEM						1.1	
(OPLATA ZA BETONIRANJE PLOČA)							
Obračun po: $1m^2$ oplate							
Redni broj	OPIS	Jed. mjere	KOLIČINA	CIJENE		IZNOS	
				Materijal	Radna snaga	Materijal IV x V =VII	Radna snaga IV x VI =VIII
I.	II.	III.	IV.	V.	VI.	VII.	VIII.
1.	IZRADA OPLATE TV TIII	h	0,24 0,24		4,0 3,0		0,96 0,72
2.	MONTAŽA TV TIII	h	0,25 0,25		4,0 3,0		1,0 0,75
3.	DEMONTAŽA TIII	h	0,18		3,0		0,54
4.	ČIŠĆENJE RII	h	0,14		2,5		0,35
5.	DASKA	m^3	0,004	200		0,80	
6.	GREDICE	m^3	0,002	150		0,30	
7.	EKSERI	kg	0,06	5,0		0,30	
8.	MOTKA BUNARSKA	m'	0,25	5,0		1,25	
9.	DASKA	m^3	0,0007	200		0,14	
10.	EKSERI	kg	0,09	5,0		0,45	
11.							
12.							
13.							4,32 x3,0
14.							
15.							
				SVEGA:		3,24	12,96
				PRODAJNA CIJENA: (KM)		16,20	

Table 2. Analysis of the cost of installing 1 m^2 of concrete with the cost of formwork

ZA OBJEKAT : STAMBENO POSLOVNI "LAMELA B1" BANOVIĆI						VRSTA RADA: **BETONSKI RADOVI**	
OPIS RADA: MAŠINSKO UGRAĐIVANJE BETONA SA HORIZONTALNIM						GN: 400-932	
TRANSPORTOM BETONA PUMPOM KAPACITETA 50 m^3/čas BETON						159967	
SPRAVLJEN FABRIKOM BETONA ZA KONSTRUKCIJE DO 0,3 m^3 NA m^2						3.1.	
(IZRADA PLOČA MB30)							
Obračun po: $1m^3$ugrađenog betona							
Redni broj	OPIS	Jed. mjere	KOLIČINA	CIJENE		IZNOS	
				Materijal	Radna snaga	Materijal IV x V =VII	Radna snaga IV x VI =VIII
I.	II.	III.	IV.	V.	VI.	VII.	VIII.
1.	SPRAVLJANJE RII	h	0,085		2,5		0,2125
2.	UGRADIVANJE RV RIII	h	0,730 0,730		4,0 3,0		2,92 2,19
3.	BETON MB 30	m^3	1,0	86,70		86,70	
4.	OPLATA	m^2	5,6m^2OP./m^3BET.	16,20		90,72	
5.							
6.							
7.							
8.							
9.							
10.							
11.							
12.							
13.							5,32 x3,0
14.							
15.							
				SVEGA:		177,42	15,97
				PRODAJNA CIJENA: (KM)		193,39	

Table 3. Analysis of the cost of building 1 m^2 of wall

ZA OBJEKAT : STAMBENO POSLOVNI "LAMELA B1" BANOVIĆI						VRSTA RADA: **ZIDARSKI RADOVI**	
OPIS RADA:ZIDANJE ZIDOVA „SIPOREKS" ZIDNIM BLOKOVIMA						GN:301-927	
(PRENOS KRANOM)						126869	
Obračun po:$1m^2$							
Redni broj	OPIS	Jed. mjere	KOLIČINA	CIJENE		IZNOS	
				Materijal	Radna snaga	Materijal IV x V =VII	Radna snaga IV x VI =VIII
I.	II.	III.	IV.	V.	VI.	VII.	VIII.
1.	SPRAVLJNJE MALTERA RII	h	0,156		2,5		0,39
2.	PRENOS BLOKOVA RII	h	0,197		2,5		0,4925
3.	PRENOS MALTERA RII	h	0,006		2,5		0,015
4.	ZIDANJE RVI	h	0,720		4,5		3,24
5.	DERSOVANJE RV	h	0,200		4,5		0,80
6.	SIPOREKS	m^3	0,206	100,00		20,60	
7.	CEM.MALTER 1:3	m^3	0,06	100,20		6,01	
8.							
9.							
10.							
11.							
12.							
13.							4,94 x3,0
14.							
15.							
				SVEGA:		26,61	14,81
				PRODAJNA CIJENA: (KM)		41,42	

The cost models used in the analysis are:
- activity-based cost model,

- a cost model based on the estimate and estimate of the works
- cost simulation.

In the construction process of the "Lamela B1" facility, appropriate cost models were applied, which included work norms, material and service norms, internal norms, as well as experiences from earlier projects with similar construction processes. This approach enabled realistic cost estimation and budget optimization, taking into account the specifics of the local market and the technical requirements of the project.
Several variants of construction plans were created, with special attention paid to cost optimization, work execution deadlines and preservation of construction quality. Through a detailed analysis, optimal strategies were selected that enable efficient management of resources and minimization of unforeseen costs. The network plans were created with maximum adaptation to the descriptions of the works from the project documentation, which ensured compliance of all phases of construction with the planned activities and the budget.
One of the key challenges in the cost formation process is the difference between planned and actual prices, which is often not adequately accounted for due to limitations in the availability of precise statistical data. [2] [3]
Although statistical data serve as a basis for cost estimation, they do not always reflect all price changes in the local market, which can lead to deviations in the project budget. A stable fixed ratio of the convertible mark (KM) to the euro (€) contributes somewhat to the stabilization of the market, but at the same time it can pose a challenge in terms of harmonizing construction costs with real market movements.
Revenues from the project are planned based on the analysis of the minimum selling price of the apartments, taking into account the expected increase in construction costs, the planned profit and the risk assessment in the implementation of the project. Proper management of these factors is essential for ensuring financial sustainability and successful implementation of the project.
This cost and revenue analysis model can serve as a reference framework for future projects, enabling more precise budget planning, more efficient risk management and better informed decision-making in the construction industry.

3. RISK FACTORS IN PRICE CHANGES

The total cost of the project was obtained as a random independent variable. We determine any random project cost as the value of the project cost components.
The individual value of the project component is the sum of the minimum value and the price increase corresponding to the random probability values of individual risks. [1]

$$randP_i = P_{i,min} + \sum_{i=1}^{n} randP_1 \Delta P_i(rand(p(x)_{i,j})) \quad (2)$$

$$P_k = \sum_{i=1}^{n} randP_i \quad (3)$$

The risk distribution within the limits of Pmax - Pmin can be different.
The risk control and risk management model consists in searching for a function that represents different distributions of changes in project components by the desired distribution while determining the differences.
The distribution of risk is monitored through the total change in the cost price according to different distributions and quantifies the impact of the risk and the probability of the cost price of the components and the total for which we set price limits. This is very practical for individual works that we group by subcontractors that influence the way these works are contracted. Changes by activity and collectively are shown with a certain distribution. The price limits are determined and the most probable price is planned by processing the databases, based on experience and similarities with the activities that have already been used in the description of the works, and comparing the differences in distributions. [4]
The determination of the impact of risk is taken according to the scale in the risk matrix:
A – insignificant risk (3%) in project costs. Includes errors in technical documentation due to calculation of areas. Error included in the contract for the sale of apartments.
B - probable risk (10%) of the price of works that are assigned to subcontractors. It enters into the contract through the assessment of the increase in construction costs and excess, subsequent and unforeseen works.
C – moderate risk (-7%) includes a real increase in the total costs of the building project,
D – the most probable risk (-10.6%) includes the risk of realizing income from the planned sale price of housing, which also includes intercalary interest on loans.
E – rare risk (over 32.7%) includes business without making a profit.
The selling price of m2 of living space is determined by the real estate market from the bid prices of other sellers in the same or similar location.
The nature of the business requires an assessment of legal risks in the overall business as a result of securing the location and approval for the construction of facilities, which was not taken into account in this case because the location was secured, and the results of these risks did not affect the overall result of the company's business.
If the projection of the investment program is made for a longer period, they can play a significant role, so they should be taken into account because the overall business success of the company depends on them. [6] [8]

4. CONCLUSION

During the construction of the residential and commercial building "Lamela B1" in Banovići, detailed price analyses were conducted for all work positions, as well as the identification of key risk factors affecting the overall construction costs. The research provided an overview of all significant factors that play a crucial role in determining the prices of individual work positions, with special attention paid to potential price changes during the course of construction.
One of the most prominent challenges in the construction process is reconciling the planned and actual costs, which may deviate significantly due to various factors. These include fluctuations in construction material prices, changes in labor costs, unforeseen technical problems, and administrative obstacles. For this reason, analyzing these variables is a key step

in accurately determining investment needs, optimizing the budget, and minimizing the risk of financial losses.

In addition to economic factors, organizational and technical aspects of construction were also considered, including the dynamics of work execution, efficiency of the employed workforce, and the impact of weather conditions on project timelines. Potential risks related to changes in legislation, market trends, and unforeseen delays were identified, enabling a more realistic assessment of total costs and the development of strategies for controlling them.

This research provides a solid foundation for further market studies and methodologies for price formation in the construction sector. The obtained data can serve as a reference for future projects aimed at improving planning, risk prediction, and informed decision-making. Understanding trends in the construction industry is particularly important for enabling more accurate cost estimation and enhancing the financial stability of projects.

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ENGINEERING-GEOLOGICAL AND GEOTECHNICAL CHARACTERISTICS OF THE LANDSLIDE AT "CRVENE NJIVE" SITE IN TUZLA

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Summary

In the early morning hours of 05th December 2010, a small landslide was activated in the settlement of "Crvene Njive" in the MZ Mosnik, in the municipality of Tuzla. The activated landslide resulted in human casualties, major material damage and the collapse of an individual residential building located at the foot of a degraded slope, in which 3 people died. Two individual residential buildings were structurally severely damaged in the front part of the landslide. At the suggestion of experts, the population was assessed and temporarily evacuated from 12 endangered buildings. According to the existing geological and engineering-geological documentation, there was not registered any landslide or unstable slope at the micro-locality of "Crvene Njive" before the landslide was activated. At the location of the active landslide, there are several morphological forms of different hyposmetry levels, which were directly influenced by the geological structure of the terrain and human activity.
Based on the conducted geotechnical investigations, determined engineering geological and hydrogeological composition and properties of the terrain, the terrain was selected in zones according to the degree of stability, and important recommendations and conditions for the rehabilitation of the endangered area were presented.
Keywords: landslide, geotechnical investigations, landslide rehabilitation

INTRODUCTION

Due to the great impact on space, people and property, geohazard management is only possible through a systematic approach to study, cadastral data processing and by taking appropriate measures [1]. The record of landslide data in the Tuzla Basin area is very scarce, at a low level both professional and technical. The approach to landslide records in local communities in the Tuzla Canton area is also different. Previous experiences have shown attempts to record landslides using different forms for filling in landslide data, in which a significant amount of professional data is omitted, or the answers are very general, so that many are not relevant for further study, processing or integration into a database in digital form. In order to process cadastral landslide data and zone the area, it is necessary to have the results obtained from detailed geological, geomorphological, engineering geological, geomechanical, hydrological and hydrogeological surveys and tests. Namely, the engineering geological maps used as a basis for the spatial plan of the local community cover larger areas in the Tuzla Basin, and were prepared based on terrain reconnaissance, direct and indirect mapping. Such data are quite imprecise and do not provide a realistic picture of the terrain's vulnerability to landslides. Therefore, it is necessary to conduct detailed research to categorize the terrain as the terrain category conditions its use. With a deterministic approach, it is possible to reliably determine the degree of exposure to the risk of damage and endangerment of life. It is also necessary to prepare a cadastral list for other types of soil and rock material movements, such as landslides that have been recorded in the Tuzla Basin, and one such is presented in this paper. Based on the zoning of the terrain according to the degree of stability, it is possible to adjust the purpose of land use to geological conditions.

1. RESEARCH METHODS

For defining geotechnical parameters, composition and properties of the terrain, the following research and testing were performed:

- Geodetic surveys,
- Exploratory drilling,
- Standard penetration testing,
- Laboratory testing,
- Slope stability analysis,
- Engineering geological mapping,
- Geophysical testing of the terrain using the shallow seismic reflection method,
- Reionization of the terrain according to the degree of stability,
- Elaboration.

As part of the geodetic survey, a situation in the state coordinate system was made in a scale of 1: 500. The locations of the exploration boreholes were recorded in absolute coordinates.
Of the exploration works, two 15.00 m deep boreholes were drilled by a mechanical probe. The drilling of the MB-1 probe borehole was done without the injection of water and mud, and the MB-2 borehole was drilled with mud. The core was placed in appropriate boxes, mapped, determined and photographed by a geologist. The diameter of the boreholes in the cover materials is 101 mm, and in the geological substrate, a minimum of 86 mm. Disturbed and undisturbed samples were taken from a completely fresh extracted core and properly preserved. The samples were taken in-situ, i.e. in the medium, at intervals in the borehole, so that all varieties of soil and rock that occur during the research are represented. In addition to machine drilling, additional continuous penetration tests were performed to determine the compaction of the surface layer of sand that was poured into the landslide face during the first phase of rehabilitation and construction of the drainage system.
During the geomechanical testing, hydrogeological monitoring of groundwater phenomena present in the soil was carried out. Groundwater levels were measured 24 and 48 hours after the completion of the testing.
Laboratory tests were performed to define the classification and physical-mechanical characteristics of the soil [2], according to the current procedures in the accredited laboratory "GIT" Institute for Civil Engineering, Building Materials and Non-Metals Tuzla: "BATA" accreditation is registered under number LI-04-01. Natural humidity was determined by the procedure: BAS ISO/TS 17892-1 Geotechnical investigations and testing - Laboratory testing of soil - Part 1: Determination of humidity. Soil bulk density was determined by the procedure:

BAS ISO/TS 17892-2 Geotechnical investigations and testing - Laboratory testing of soil - Part 2: Determination of density of fine-grained materials. Specific gravity, at the prescribed temperature and humidity of the environment: determined by the procedure: BAS ISO/TS 17892-3. Atterberg consistency limits represent the yield point, plasticity and shrinkage limit, and were determined according to BAS ISO/TS 17892-12. The direct shear test was performed in a controlled shear deformation apparatus, under three vertical loads. The analysis serves to determine the parameters of shear strength, cohesion c (kNm^{-2}) and the angle of internal friction φ (°). The test was performed according to the provisions of BAS ISO/TS 17892-10 Geotechnical investigation and testing - Laboratory soil testing - Part 10: Direct shear test. The shear resistance parameters for the soil were determined in a controlled rate translational direct deformation apparatus with dimensions of 60 x 60 mm and height of 25 mm. The samples were made in an undisturbed state and consolidated under vertical loads σ': 50, 100, 150 kN^{-2}, shear resistance ζ: 50, 100, 150 kNm^{-2}. The tangential stresses were increased in steps Δ=σ'/40 in time intervals Δt1 from 5 to 30 minutes. Shear rate is 0.3048 mm/min, dynamometer constant 0.034 mm/kp (0,33 mm/N). Obtained shear strength values and parameters c and φ obtained on soil samples for appropriate intervals range from 38 to 67 kNm^{-2} for cohesion (c) and from 22° to 34° for the angle of internal friction (φ). Proper sampling provided representative values of material properties (for a given realistic case). For the calculation of slope stability input geomechanical parameters that reflect the most unfavorable conditions on the slope were adopted. Analysis and stability calculations were performed with recorded terrain elevations, computer records, using a licensed program and the Morgensteem-Price method. The method is based not only on the conditions of force balance along the x axis, but also the moment balance for each lamella. The analysis also allows for the search for the critical landslide surface. Based on the conducted research, tests and obtained results, a detailed engineering geological map was created in the scale of 1:500. The engineering geological map contains all relevant data for design and is prepared according to the Guidelines for the Preparation of Engineering Geological Maps (Guidelines of the International Association for Engineering Geology – IAEG) [3,4,5]. Within the research area, the terrain was sectioned according to the degree of stability with separate zones: stable, conditionally stable and unstable terrain, according to the area of representation (m^2) and percentage (%). After the completion of field work and laboratory tests, office data processing, analysis and interpretation of the collected data and obtained results were carried out with the elaboration of the same.

2. GEOLOGICAL COMPOSITION AND ENGINEERING-GEOLOGICAL CHARACTERISTICS OF THE TERRAIN

Part of the terrain in the zone of the activated landslide is located in the western part of Tuzla in the settlement of "Crvene Njive" [6]. The terrain is located at 44° 31' 41.65" north latitude and 18° 39' 17.79" east longitude according to Greenwich Mean Time. On this part of the terrain there was a wide ridge-like formation that had a general direction of extension southeast - northwest with a slope in the northwest direction of 10°. Because the mentioned ridge is mainly made of weakly bound quartz sandstone and clay, sandstone was exploited here for the purposes of backfilling the Moluhe mine until 1963. Due to the deficit of mass, a larger depression remained with two striking high (8-12 m) and subvertical slopes (west and south) with a slope of 80 to 90° (Figure 1).

Figure 1. Subvertical western slope. (Photo: J. Čomić, 2010).

After the exploitation of quartz sand was completed, the slope of the terrain was mitigated in the depression. Over time, part of the terrain in the southern slope zone became overgrown with low vegetation. Many buildings were illegally built in the hinterland of the southern slope about 20 years ago. The density of construction in the hinterland of the southern slope is very high, so some of the buildings were built on the sides of the ridge as well as near the high and steep southern slope. The buildings were 3 - 17 m away from the slope. The buildings did not have regulated drainage of rainwater and wastewater, and various materials were disposed of in the southern slope zone. Due to the high-altitude position, several buildings were connected to the water supply system from the direction of Krojčica, while the drains were directed towards the formed depression in the terrain.

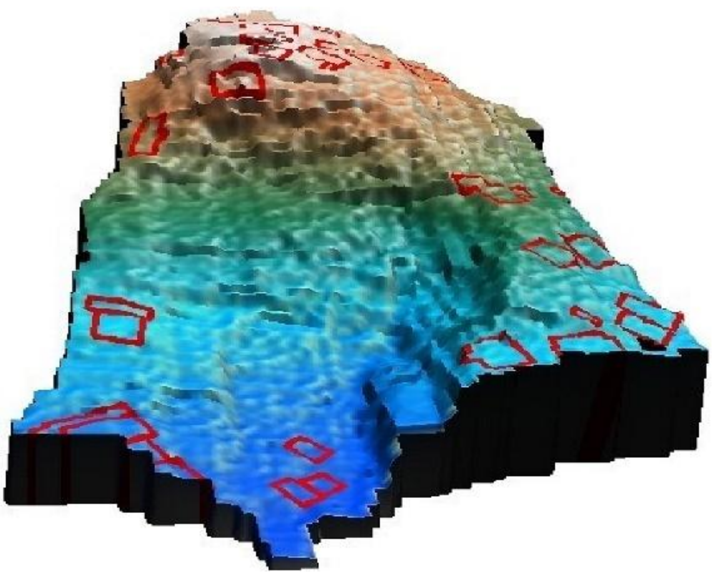

Figure 2. 3D model of the terrain at the site "Crvene Njive"

The average absolute elevation of the terrain in the hinterland of the southern slope was about

300.0 m.a.s.l., and at the foot, where the individual residential building was destroyed, 273.0 m.a.s.l. Figures 2 and 3 show models of terrain and buildings in the research area.

Figure 3. 3D model of buildings, digital terrain model and digital orthophoto plan (2021).

The research area is located on the northeastern side of the Northern Kreka Synclinorium. Pannonian sediments are represented by marls, clays, sands and sandstones with coal layers [7]. Previous research on coal seams has defined the hydrogeological relations of the area, according to the spatial distribution of individual lithological members, their mutual relationship, hydrogeological function and the relationship of individual collectors to surface waters [8]. In the wider area, aquifers can be distinguished by depth of occurrence: I aquifer (water bearing layer) sand in the bed of the bed coal seam - in deeper parts, II aquifer (water bearing layer) of weakly bonded sandstone in the bed of the main coal seam where the landslide was activated. These two aquifers are separated by overlying clays that represent a hydrogeological insulator. Increased flooding of quartz sands and weakly bonded sandstones have been determined by geophysical research.

In order to determine the engineering geological composition and properties of the terrain in the area where the landslide occurred, detailed engineering geological mapping of the terrain and geophysical research on three profiles were carried out. Mapping of open outcrops and high slopes was also carried out. On the ground, there are very high and open profiles where sandstones and clays were registered, and it was possible to measure the elements of the inclination of layers and cracks (Figure 4). The seismic method indicated the inclination depth of the lithological members and registered the spatial distribution of discontinuities in the sandstones.

Figure 4. Measurement of elements of the inclination of strata - western slope. (Photo A. Čomić, 2011)

During the engineering geological mapping of the terrain on the open outcrops of sandstone and interlayers of clay, elements of inclination 300/12° and 312/14° were determined. In addition to the measurement of the inclination elements of the layers, the measurement of the inclination of elements of the larger striking cracks in the area of the landslide scar was carried out (Figure 5).

Figure 5. Measurement of crack inclination elements in the landslide scar zone. (Photo A. Čomić, 2011).

Geophysical investigations (refraction seismic investigations using multiple interpretation methods) as well as field analyses defined discontinuities with elements of fracture inclination that are located deeper in sandstones and clays (on 3 geophysical profiles). In addition to the fractures, two faults (or deeper and wider fractures) were registered, extending in the east-west direction with the inclination of 85°. One fault was located in the landslide scar zone. The location where the landslide was formed is represented as a ridge that is composed of underlayer quartz sandstones of the main coal seam of the Northern Kreka synclinorium, where the layers incline in the northwest direction at an angle of 12^0 to 14^0 [9]. Quartz sandstone, according to its geotechnical properties, represents a conditionally stable terrain. However, stable terrain changes the stress state and becomes unstable due to inadequate anthropogenic works and activities, which happened at this location. Illegally constructed structures significantly loaded part of the terrain in the hinterland of the southern slope which led to additional changes in stress conditions. Only after geophysical investigations were conducted, it was determined that in the part of the formed landslide scar there was a fault with a narrow-weakened zone of similar orientation and inclination as the southern slope, which was the main cause of instability. After a period of relaxation of the stressed and naturally flooded material, a major separation and detachment of blocks (Figure 6) of sandstone occurred along the unfavorably oriented fault and neotectonics cracks, so that a classic landslide in sandstone with block detachment was formed.

Figure 6. Blocks of detached sandstone. (Photo by J. Čomić, 2011)

Due to the sudden separation of the sandstone mass along the fault, a larger block with a width of about 55 m and a length of about 17 m was torn off, which subsequently broke up into several smaller sandstone blocks of different shapes and volumes (from 1 to more m^3). Geophysical tests have determined that the depth of the landslide ranges from 10 - 12 m and is related to the depth of the clayey layer (substrate layer of the subfloor coal layer) located under the sandstone. Block tearing off and crushing was carried out along the lower order of cracks in the sandstone. As a subject is a semi-bonded and bonded material (sandstones), as a result of block tearing off along predisposed discontinuities, there was a sudden movement of sandstone blocks towards the foot of the slope where an individual residential building was located what resulted in casualties of 3 people. [10]

In the aim of rehabilitation of the southern slope, two 15.00 m deep boreholes were drilled by machine. The drilling of probe borehole MB-1 was done without the injection of water and mud, and borehole MB-2 was drilled with mud. In addition to machine drilling, additional continuous penetration tests were carried out to determine the compaction of the surface layer of sand that was poured into the landslide face during the first phase of rehabilitation and the construction of the drainage system. A geodetic base with a scale of R 1:500 was used to create the engineering geological map that was recorded in the national coordinate system. Based on the results of the research and testing, 3 engineering geological units were identified in this area, one of which belongs to the geological substrate, and two to the cover layers group.

Geological substrate

As a geological substrate recognized were one lithological type and one lithological complex were: weathered quartz sandstones (I), clays and calcitic clays with burnt fragments (II).

Weathered quartz sandstone (subfloor of coal layer I)

The color of quartz sandstones is primarily gray, and various shades of yellow also occur. They are characterized by satisfactory geotechnical properties. Stratification is registered on open profiles, clearly expressed in some places, and weaker in some parts. In the western slope zone between two layers of sandstone there is a thinner layer of clay (10 cm), which indicates a change in sedimentation conditions. In hydrogeological terms, weathered sandstones (partially consolidated quartz sands) represent hydrogeological collectors and a significant amount of groundwater is accumulated in them, especially in deeper parts. According to GN-200, weathered sandstones can be classified as category IV.

Clays and clays with burnt fragments - (coal seam overburden) (II)

At the site of the landslide "Crvene Njive", the overburden clays are located below a layer of weathered sandstone with visible outcrops in the flanks of the formed landslide. In the west of the landslide, a layer of clay with burnt fragments is located above a layer of weathered sandstone. The registered clays on the eastern flank of the landslide represent the overburden of the floor coal seam, and in the western flank the immediate overburden of the main coal seam. On the open outcrops of the overburden clays are gray-brown, well consolidated, with weakly expressed stratification. From a hydrogeological point of view, these materials represent insulators, and according to GN-200 they belong to category IV.

Covers

Two different genetic types can be distinguished in the cover group in the research area: eluvial-diluvial (ed) and colluvial (co) cover.

Eluvial-diluvial cover (ed)

This type of cover appears in zones where the striking reef has not been devastated by technogenic activity, in other words it is located outside the contours of the abandoned sand borrow pit. The lithological composition of this mixed slope cover is composed of yellow-brown dusty-sandy clays, varying in thickness from 0.5 to 1.5 m. In hydrogeological terms this cover has the role of a hydrogeological conductor, and according to GN-200 they belong to category III. Several buildings have foundation in this type of cover.

Colluvial cover (ko)

In the engineering-geological sense, the colluvial cover - the landslide consists of materials that were moved by gravitational movement, and which were accumulated in the lower parts of the slope. After the activation of the landslide, larger blocks of sandstone were torn off in the area of the former southern slope of the sand borrow pit, so that larger or smaller blocks of sandstone were accumulated in the lower part. This cover represents a degraded, cracked and loose environment of variable geotechnical characteristics. In certain landslide zones where large blocks of sandstone are separated, the primary stratification has been preserved. The thickness of the colluvial cover is variable and is shown on engineering geological profiles 1-1', 2-2' (Figures 7 and 8).

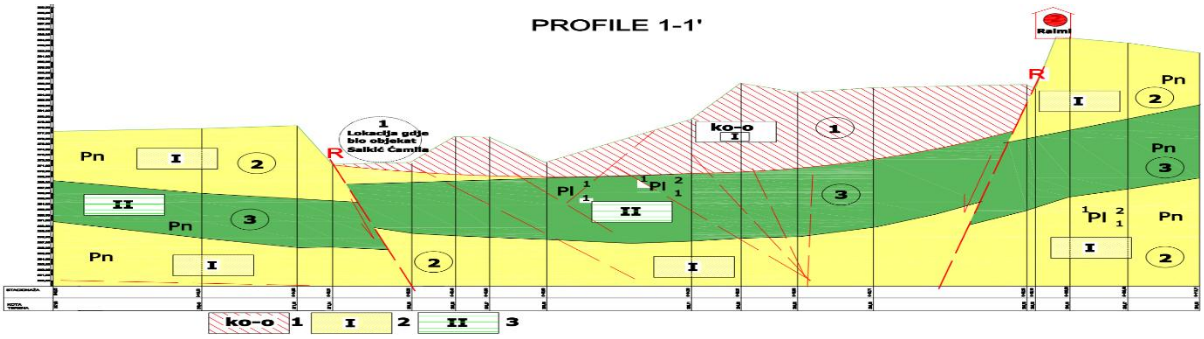

Figure 7. Engineering geological profile 1-1', southern slopes.

1. Landslide colluvium, 2. Soft quartz sandstones (bottom of the coal layer I), 3. Clays and clays with burnt fragments - (coal layer overburden) (II).

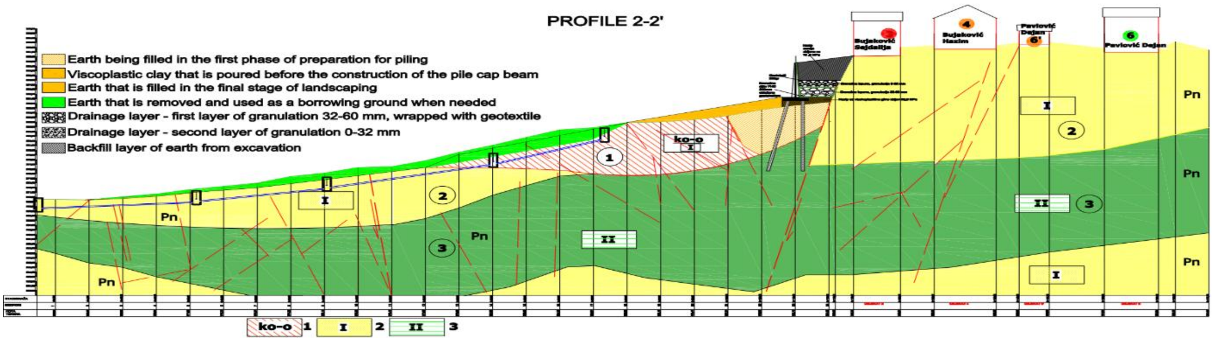

Figure 8. Engineering geological profile 2-2', with measures of the southern slope rehabilitation.

1. Landslide colluvium, 2. Soft quartz sandstones (floor of coal layer I), 3. Clays and clays with burnt fragments - (coal layer overburden) (II).

A detailed engineering geological map (R 1:500) was prepared after geomechanical and field investigations of the terrain, geophysical site investigations of the terrain using the refraction method and hydrogeological investigations. Within the research area, the terrain was regionalized [11] according to the degree of stability with separated zones: stable, conditionally stable and unstable terrain, according to the area of occurrence (m^2) and percentage (%). (Figure 9).

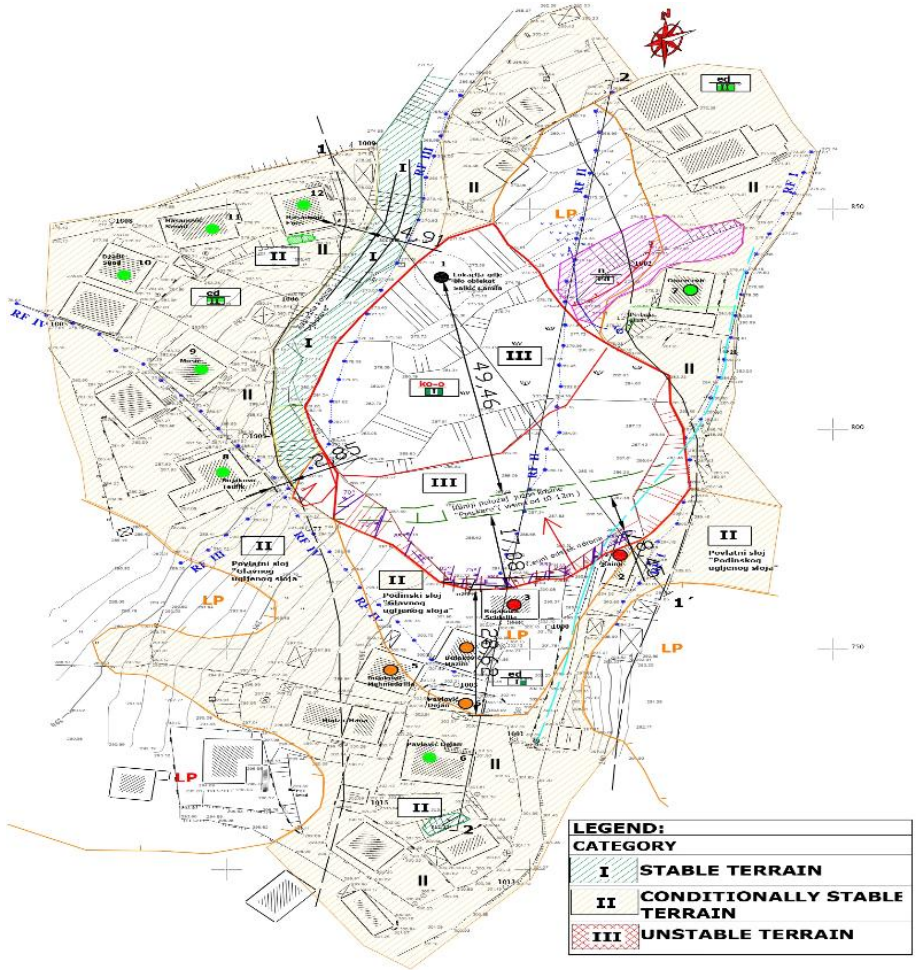

Figure 9. Terrain regionalization according to the degree of stability

2. RESULTS AND DISCUSION

The researched area is characterized by a distinguished interaction of natural factors (unfavorable orientation of cracks from the aspect of stability, hydrogeological conditions) and anthropogenic factors (decades of uncontrolled exploitation of sandstone, unplanned construction of buildings, unregulated drainage of rainwater and wastewater, illegal dumpsites, and inadequate and unprofessional implementation of rehabilitation measures at the first signs of instability. Based on the identified causes and vulnerability of the area with regard to (the possibility of landslide spread and further endangerment of residents and buildings), it is necessary to carry out a complete rehabilitation of the terrain, divided into two phases. At the beginning of March 2012, the first phase of the terrain rehabilitation was carried out by constructing a drainage system. The slope stability was increased by constructing a drainage system with the aim of draining flooded soil masses in the zone of flooded geological substrate, controlled drainage by drainage collectors. The first phase of the rehabilitation in the settlement also includes the recultivation of the terrain. The second phase of the rehabilitation is planned to include the construction of a supporting structure (reinforced concrete wall), based on reinforced concrete piers 10.00 m long, arranged in two axes according to the design of the supporting structure, supported in a layer of geological substrate. The safety factor of the repaired slope is FS=1.69 (Figure 10).

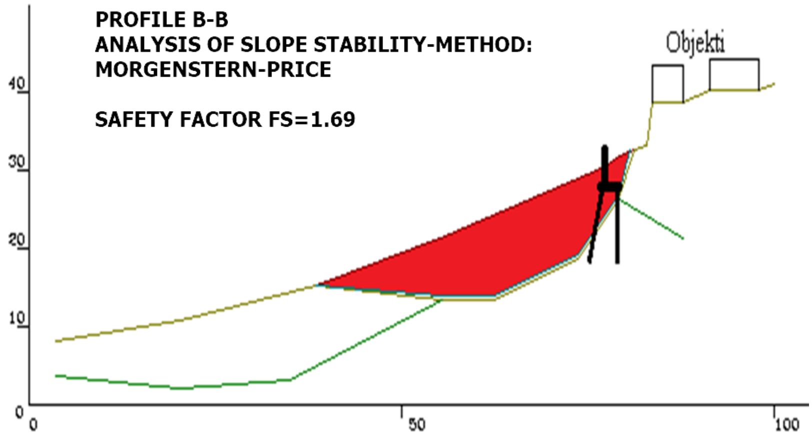

Figure 10. Model for stability analysis (repaired condition), profile B-B'.

After conducting research and zoning the terrain according to the degree of stability, a potential landslide propagation zone of about 28 m in length was defined in the hinterland of the frontal section, where many discontinuities in the sandstone massif were registered. All buildings and their residents located in this part where landslide propagation can be expected to be exposed to the risk of damage and endangerment of life. Ensuring the safety of facilities can only be achieved by implementing comprehensive rehabilitation. After the rehabilitation of the terrain is completed, geodetic monitoring is required [12].
On the engineering geological map (Figure 9), all three categories of terrain according to the degree of stability are spatially defined and marked:

Unstable terrain
This terrain category represents a part of the area affected by the landslide process. The unstable part of the terrain within the researched area occupies an area of 5,416.22 m^2, which represents 32.37% of the total area of the investigation area, which is 16,734.49 m^2. In the unstable terrain category, which is clearly defined in terms of space, no new construction or legalization of existing buildings can be carried out due to the possible reactivation of the landslide. Legalization of existing buildings cannot be carried out until the landslide has been completely rehabilitated, under expert supervision and monitoring of the success of the rehabilitation measures. In this part of the terrain any cutting of the terrain or the formation of larger embankments shall not be carried out.

Conditionally stable terrain
It occupies an area of 10,780.71 m^2, which makes up 64.42% of the total area of the researched area. With prescribed measures and performed rehabilitation, it can be transferred to the stable terrain category. Legalization of buildings can be carried out only after the rehabilitation of unstable terrain is completed. This terrain category can be transformed into the stable terrain category with prescribed measures.
Stable terrain
This zone belongs to the stable terrain category which is characterized by favorable geotechnical characteristics.
In the zone of the western slope or left side of the landslide with an area of 537.56 m^2, the

landslide is not expected to spread, but only to shed of the material, which should be prevented by protecting the slope from the effects of erosion.

CONCLUSION

Based on the results of the conducted engineering-geological and geomechanical research, the determined engineering-geological and hydrogeological composition and properties of the terrain, the degree of presence of exogenous geological processes, the zonning of the terrain according to the degree of stability, recommendations and conditions for the methods of rehabilitation of unstable and conditionally stable terrain are given. Based on the zonning of the terrain according to the degree of stability, it is possible to adapt the purpose of land use to geological conditions, which will certainly minimize material damage. With a deterministic approach, it is possible to reliably determine the degree of exposure to the risk of damage and endangerment of life.

At the Crvene Njive site, before the landslide was activated, the edge of the southern slope was 17 m. Three people lost their lives when the landslide was activated in December 2010. The estimated value of 12 residential buildings located in the immediate vicinity of the landslide is almost one million convertible marks.

After detailed research and testing on the southern part of the slope (where many discontinuities in the sandstone massif have been registered), a tendency for further landslide expansion and destabilization of the southern slope by another 26.68 m is expected. This would endanger 4 more individual buildings and the people living in them. These buildings are located in a high-risk zone, and their estimated material damage is around 320,000 KM. Calculated price of the rehabilitation of phases I and II (drainage and protection of the southern slope with a supporting structure) is around 470,000 KM. By conducting a site visit and comparing geodetic bases in vector and raster form (during the research and new ones), it can be concluded that more than a decade has passed, and that the designed rehabilitation measures (except for the implementation of the first phase) at the Crvene Njive site have not been implemented, although they were marked as urgent.

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IMPROVING THE OPERATION OF THE DEEP PUMP ON PISTON RODS BY MODIFYING THE THRUST VALVE

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Summary

For a long time during the history of oil production, deep pumps on piston rods have been the first, and in many cases, the only choice when it comes to mechanical exploitation methods. The correct selection of each individual element of the system enables optimization, which entails benefits in the form of increased efficiency and reduced production costs. The currently applied system of deep pumps on piston rods at the "T" bed ensures stable production and realization of annual production plans without major problems. This paper presents the method of optimizing the system for the mechanical method of exploitation with deep pumps on piston rods. Calculations were made for 2 wells with the lowest pump efficiency, in order to define the application of a new system of deep pumps with changed technical characteristics (double pressure valve).
By installing a submersible pump with changed technical characteristics during overhaul, these two wells also showed a significant improvement in the duration of the inter-overhaul period.
Key words: submersible pump, optimization, equipment calculation, pressure valve.

INTRODUCTION

The oil in the reservoir is under a certain pressure, which enables the fluid to move from the reservoir to the well and further through the production system to the surface of the field. When the reservoir energy is weakened to such an extent that the reservoir pressure is no longer sufficient to enable fluid flow through the well, pipeline and surface equipment, i.e. when production has reached the minimum economically profitable value, it is necessary to provide additional energy for continued exploitation. If the production of fluids is realized with the use of additional energy, such a method of exploitation is called mechanical.
For a long time in the history of oil production, piston rod submersible pumps have been the first and, in many cases, the only choice when it comes to mechanical extraction methods. This is the reason why piston rod deep pumping is the oldest and most used type of mechanical oil extraction method worldwide. In general, about two-thirds of all production wells in the world use this method to obtain fluids.
In the first part of the work, the underground and above-ground equipment of the deep-water pump is presented and the operation of the entire plant is described, while in the second part, in

the wells of the "T" deposit, and in order to improve its utilization, an analysis of the operation of the existing equipment was performed, as well as calculations using the "RODSTAR" software, which will define the application of the new system of deep-water pumps with a double pressure valve on the selected deposit.

1. SYSTEM FOR DEEP PUMPING ON PISTON RODS

The mechanical method of oil production using deep pumps on piston rods, which is shown in Figure 1, is the oldest method of obtaining fluid from wells to the surface, and it is also the most widespread in practice in the world (over 80%). The basic principle of the submersible pump is based on the transfer of drive energy from the surface to the immersion level of the submersible pump by mechanical means, i.e. piston rods. The submersible pump, by transforming mechanical work into potential energy, raises the pressure of the fluid. The pressure at which the fluid from the reservoir enters the pump is called the suction pressure, and the pressure at the fluid exit from the pump is the discharge pressure. The difference between pressure and suction pressure is called pumping pressure, and it represents an increase in the potential energy of the fluid.

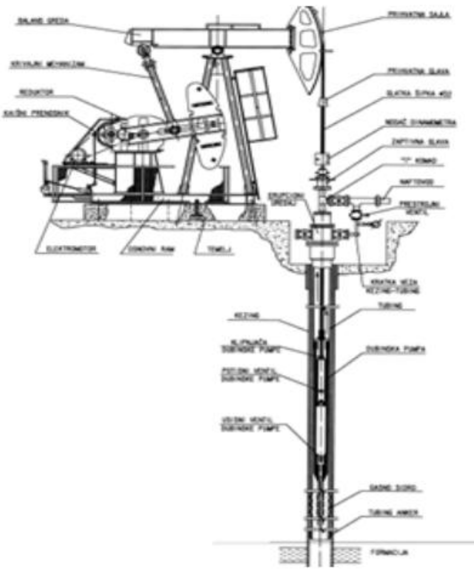


Figure 1. *Components of a conventional deep pumping system on piston rods [1].*

1.1. Work cycle of the submersible pump

The alternating movement of the piston rods in the well is caused by the movement of the smooth rod on the surface, and the piston rods, when moving, force the piston to also move alternately through the cylinder. The cycle begins when the piston begins to rise from the bottom of the cylinder. As the piston is raised, the difference in volume between the suction and discharge valves increases, causing the fluid contained in the cylinder to expand and thereby reducing the pressure in the pump cylinder. The drop in pressure causes the discharge valve to close, and the expansion cycle continues until the pressure drops below the suction pressure. When the intake pressure exceeds the pressure inside the cylinder, the ball on the intake valve is lifted from the intake valve.

Then the fluid, which is in the well, enters the cylinder through the suction valve and fills the space, during which the piston rises up. This represents the intake part of the cycle, during which the pressure under the piston and the thrust pressure remain constant, and they are equal to the difference between the intake pressure and the pressure drop through the intake valve body (seat, ball and assembly). At the very top of the cylinder, the piston changes its motion and begins to move towards the intake valve, which causes a decrease in the volume in the cylinder between the intake and discharge valves and the fluid inside the cylinder is compressed, which causes an increase in the pressure inside the pump.

The reverse flow and increase in pressure force the intake valve to close and the compression cycle continues until the pressure inside the cylinder exceeds the pressure above the discharge valve. Then the pressure valve opens and the piston moves down through the fluid in the pump cylinder. This part is called the discharge part of the pumping system, during which the pressure inside the cylinder remains constant, and is equal to the sum of the discharge pressure and the pressure required for the movement of the fluid through the pressure valve and inside the piston. During the discharge cycle, the piston moves towards the bottom of the cylinder. The relationship between the distance traveled by the piston and the change in pressure caused by the fluid inside the pump depends on the compressibility of the fluid mixture inside the cylinder. If the fluid is almost incompressible, then a very small change in volume, due to the small movement of the piston, causes large changes in pressure. In the case that the fluid is more compressible (a mixture of gas and liquid), a change in volume is necessary for the pressure to decrease or increase, that is, to close and open the valve. This required volume is achieved only through increased movement through the cylinder (Figure 2).

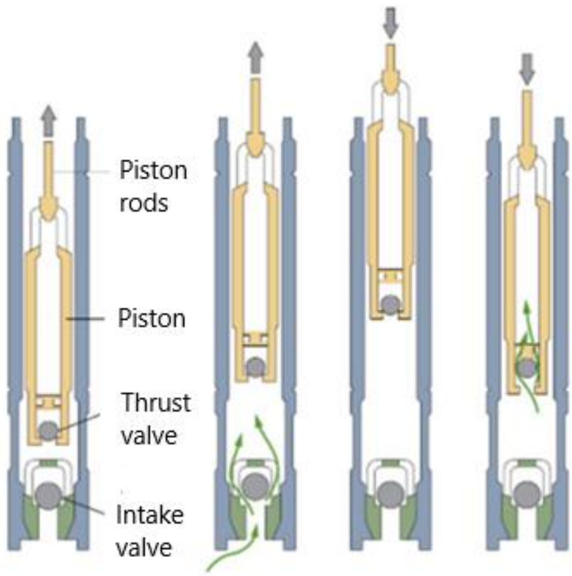


Figure 2. *Display of expansion, intake cycle, compression and push cycle [2].*

1.2. Submersible pump valves (suction/discharge)

The suction valve (Fig. 3) of the submersible pump is installed at the bottom of the cylinder, and is designed to work on the ball and seat principle. Its role is to allow the cylinder to be filled with fluid from the reservoir when the piston is moving upwards, or to prevent its return when the piston is moving downwards. Due to the impact of the ball on the seat, both the ball and the seat are of special construction and are made of high-alloy steel with special surface treatment. This is very important, because any small damage or change in shape results in leakage, and thus in reducing the efficiency of the pumping process. For new valves with different diameters, the deviation of the shape of the ball from ideal circle must not be greater than 1 to 4 µm. [5,18].

Figure 3. *Construction of the suction valve [5]*

Analogous to the suction, the discharge valve (Figure 4) works on the ball and seat principle. Its role is to allow the passage of liquid from the cylinder to the piston when the piston is moving down, and not to allow it to return when the piston is moving up [5]. With the pressure valve, there is also the option of installing a double valve. The mentioned benefits of installing such a construction also apply to the pressure valve, with the fact that, in the case of installing a double pressure valve, when the pump works without a level ("fluid pound"), the ball and seat of the upper valve are protected from mechanical damage during a sudden change in pressure when the pump cylinder hits the fluid. Also, this design of the pressure valve prevents the occurrence of "gas lock", as the weight of the fluid column is held by the upper pressure valve and thus enables easier opening of the lower pressure valve. Everything that is stated for the suction valve, with regard to the operating conditions, also applies to the pressure valve.

Figure 4. *Construction of pressure valve [5]*

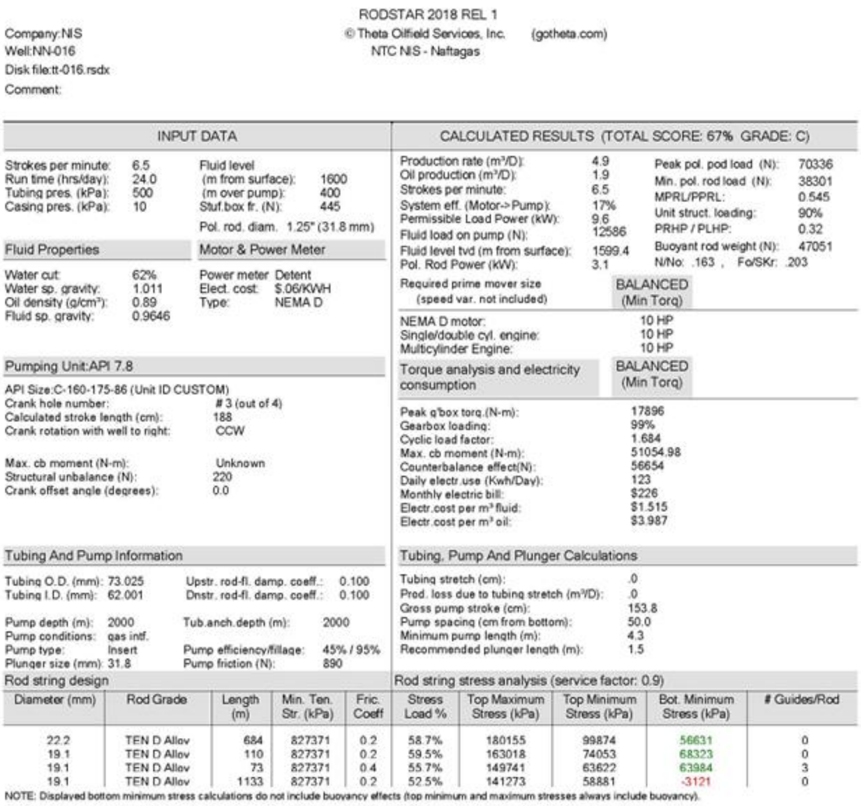
2. ANALYSIS OF OIL PRODUCTION WITH THE EXISTING TYPE OF PISTON ROD DEEP PUMPS IN THE WELLS OF THE "T" RESERVOIR

The currently applied system of submersible pumps on piston rods on the "T" bed ensures stable production and realization of annual production plans without major problems. However, in order to optimize the system for the mechanical method of exploitation with deep pumps on piston rods in the wells of the "T" deposit, it is necessary to analyze the operation of the existing equipment on the candidate wells, and then make calculations that will define the application of the new system of deep pumps with a double pressure valve on the deposit.

All wells of the "T" oil field are equipped with deep pumps on piston rods with upper or lower mechanical seating. The pool of wells for analysis, to select candidates for the installation of a deep pump on piston rods with modified technical characteristics, was made up of wells equipped with deep pumps on piston rods with upper mechanical seating, because pumps with lower mechanical seating proved to be a very efficient pumping system. The calculation of the deep pumping system was made for the selected pool of wells of the "T" deposit, which were in operation at the given moment.

The calculation was made with the software of the American company "Theta" called "RODSTAR". Calculation results for well T-016 are shown in Figures 5 and 7. Calculation results for well T-061 are shown in Figures 6 and 8.

The input data for the calculation of deep pumping systems on piston rods are: pump installation depth (m), smooth rod diameter (m), tubing and casing pressure (bar), water percentage (%), fluid density (g/cm3), pump suction pressure (bar), expected fluid production (m3/day), tubing inner and outer diameter (mm), pump piston diameter (m), tubing anchor depth (optional) (m), piston rod diameter (m), rod string length (m), rod protectors (cast / roller), rod string software selection (manufacturer/range), borehole inclinometry (measured depth/tilt angle/azimuth), hook type (manufacturer/API designation), smooth rod stroke length (m), drive motor type (electric), drive motor power (kW), clearance between piston and cylinder (m), fluid viscosity (cP).



RODSTAR 2018 REL 1
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NTC NIS - Naftagas

Company:NIS
Well:NN-016
Disk file:tt-016.rsdx
Comment:

INPUT DATA

Strokes per minute: 6.5
Run time (hrs/day): 24.0
Tubing pres. (kPa): 500
Casing pres. (kPa): 10
Fluid level (m from surface): 1600
(m over pump): 400
Stuf.box fr. (N): 445
Pol. rod. diam. 1.25" (31.8 mm)

Fluid Properties

Water cut: 62%
Water sp. gravity: 1.011
Oil density (g/cm³): 0.89
Fluid sp. gravity: 0.9646

Motor & Power Meter

Power meter: Detent
Elect. cost: $.06/KWH
Type: NEMA D

Pumping Unit:API 7.8

API Size:C-160-175-86 (Unit ID CUSTOM)
Crank hole number: # 3 (out of 4)
Calculated stroke length (cm): 188
Crank rotation with well to right: CCW

Max. cb moment (N-m): Unknown
Structural unbalance (N): 220
Crank offset angle (degrees): 0.0

Tubing And Pump Information

Tubing O.D. (mm): 73.025
Tubing I.D. (mm): 62.001
Upstr. rod-fl. damp. coeff.: 0.100
Dnstr. rod-fl. damp. coeff.: 0.100

Pump depth (m): 2000
Pump conditions: gas intf.
Pump type: Insert
Plunger size (mm): 31.8
Tub.anch.depth (m): 2000
Pump efficiency/fillage: 45% / 95%
Pump friction (N): 890

CALCULATED RESULTS (TOTAL SCORE: 67% GRADE: C)

Production rate (m³/D): 4.9
Oil production (m³/D): 1.9
Strokes per minute: 6.5
System eff. (Motor->Pump): 17%
Permissible Load Power (kW): 9.6
Fluid load on pump (N): 12586
Fluid level tvd (m from surface): 1599.4
Pol. Rod Power (kW): 3.1

Peak pol. pod load (N): 70336
Min. pol. rod load (N): 38301
MPRL/PPRL: 0.545
Unit struct. loading: 90%
PRHP / PLHP: 0.32
Buoyant rod weight (N): 47051
N/No: .163 , Fo/SKr: .203

Required prime mover size (speed var. not included): BALANCED (Min Torq)

NEMA D motor: 10 HP
Single/double cyl. engine: 10 HP
Multicylinder Engine: 10 HP

Torque analysis and electricity consumption: BALANCED (Min Torq)

Peak g'box torq.(N-m): 17896
Gearbox loading: 99%
Cyclic load factor: 1.684
Max. cb moment (N-m): 51054.98
Counterbalance effect(N): 56654
Daily electr.use (Kwh/Day): 123
Monthly electric bill: $226
Electr.cost per m³ fluid: $1.515
Electr.cost per m³ oil: $3.987

Tubing, Pump And Plunger Calculations

Tubing stretch (cm): .0
Prod. loss due to tubing stretch (m³/D): .0
Gross pump stroke (cm): 153.8
Pump spacing (cm from bottom): 50.0
Minimum pump length (m): 4.3
Recommended plunger length (m): 1.5

Rod string design / Rod string stress analysis (service factor: 0.9)

Diameter (mm)	Rod Grade	Length (m)	Min. Ten. Str. (kPa)	Fric. Coeff	Stress Load %	Top Maximum Stress (kPa)	Top Minimum Stress (kPa)	Bot. Minimum Stress (kPa)	# Guides/Rod
22.2	TEN D Alloy	684	827371	0.2	58.7%	180155	99874	56631	0
19.1	TEN D Alloy	110	827371	0.2	59.5%	163018	74053	68323	0
19.1	TEN D Alloy	73	827371	0.4	55.7%	149741	63622	63984	3
19.1	TEN D Alloy	1133	827371	0.2	52.5%	141273	58881	-3121	0

NOTE: Displayed bottom minimum stress calculations do not include buoyancy effects (top minimum and maximum stresses always include buoyancy).

Figure 5. *Calculation results for well T-016 ("Theta" - RODSTAR, NIS Novi Sad)*

RODSTAR 2018 REL 1
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NTC NIS - Naftagas

Company:NIS
Well:TT-061
Disk file:TT-061.rsdx
Comment:

INPUT DATA

Strokes per minute:	6.1	Fluid level	
Run time (hrs/day):	24.0	(m from surface):	1550
Tubing pres. (kPa):	600	(m over pump):	303
Casing pres. (kPa):	10	Stuf.box fr. (N):	445
		Pol. rod. diam.	1.25" (31.8 mm)

Fluid Properties

Water cut:	78%
Water sp. gravity:	1.011
Oil density (g/cm³):	0.89
Fluid sp. gravity:	0.9842

Motor & Power Meter

Power meter	Detent
Elect. cost:	$.06/KWH
Type:	NEMA D

Pumping Unit:UP90

API Size:C-310-202-118 (Unit ID CUSTOM)

Crank hole number:	# 4 (out of 5)
Calculated stroke length (cm):	248.8
Crank rotation with well to right:	CCW
Max. cb moment (N-m):	Unknown
Structural unbalance (N):	1120
Crank offset angle (degrees):	0.0

Tubing And Pump Information

Tubing O.D. (mm):	73.025	Upstr. rod-fl. damp. coeff.:	0.100
Tubing I.D. (mm):	62.001	Dnstr. rod-fl. damp. coeff.:	0.100
Pump depth (m):	1853	Tub.anch.depth (m):	1853
Pump conditions:	gas intf.		
Pump type:	Insert	Pump efficiency/fillage:	41% / 95%
Plunger size (mm):	38.1	Pump friction (N):	890

CALCULATED RESULTS (TOTAL SCORE: 75% GRADE: B-)

Production rate (m³/D):	7.5	Peak pol. pod load (N):	77223
Oil production (m³/D):	1.7	Min. pol. rod load (N):	32956
Strokes per minute:	6.1	MPRL/PPRL:	0.427
System eff. (Motor->Pump):	16%	Unit struct. loading:	86%
Permissible Load Power (kW):	16.8	PRHP / PLHP:	0.32
Fluid load on pump (N):	18012	Buoyant rod weight (N):	44136
Fluid level tvd (m from surface):	1548.8	N/No: .153 ,	Fo/SKr: .201
Pol. Rod Power (kW):	5.4		

Required prime mover size (speed var. not included) — BALANCED (Min Torq)

NEMA D motor:	15 HP
Single/double cyl. engine:	15 HP
Multicylinder Engine:	15 HP

Torque analysis and electricity consumption — BALANCED (Min Torq)

Peak g'box torq.(N-m):	32187
Gearbox loading:	92%
Cyclic load factor:	1.606
Max. cb moment (N-m):	67221.17
Counterbalance effect(N):	59046
Daily electr.use (Kwh/Day):	205
Monthly electric bill:	$375
Electr.cost per m³ fluid:	$1.601
Electr.cost per m³ oil:	$7.277

Tubing, Pump And Plunger Calculations

Tubing stretch (cm):	.0
Prod. loss due to tubing stretch (m³/D):	.0
Gross pump stroke (cm):	195.6
Pump spacing (cm from bottom):	46.3
Minimum pump length (m):	4.9
Recommended plunger length (m):	1.5

Rod string design / **Rod string stress analysis (service factor: 0.9)**

Diameter (mm)	Rod Grade	Length (m)	Min. Ten. Str. (kPa)	Fric. Coeff	Stress Load %	Top Maximum Stress (kPa)	Top Minimum Stress (kPa)	Bot. Minimum Stress (kPa)	# Guides/Rod
22.2	TEN D Alloy	439	827371	0.2	77.8%	197908	86095	57942	0
22.2	TEN D Alloy	283	827371	0.4	63.0%	155209	55080	42986	3
19.1	TEN D Alloy	512	827371	0.4	75.1%	174479	55226	24420	3
19.1	TEN D Alloy	256	827371	0.2	56.1%	116850	17112	8639	0
19.1	TEN D Alloy	229	827371	0.4	48.7%	90556	-100	-3192	3
19.1	TEN D Alloy	134	827371	0.2	39.3%	62571	-13198	-3121	0

NOTE: Displayed bottom minimum stress calculations do not include buoyancy effects (top minimum and maximum stresses always include buoyancy).

Figure 6. *Calculation results for well T-061 ("Theta" - RODSTAR, NIS Novi Sad)*

Figures 7 and 8 show, on the left, a graphic representation of the expected surface and depth dynamogram based on the calculation results, while on the right is a diagram of the expected load on the reducer during one stroke of the hook.

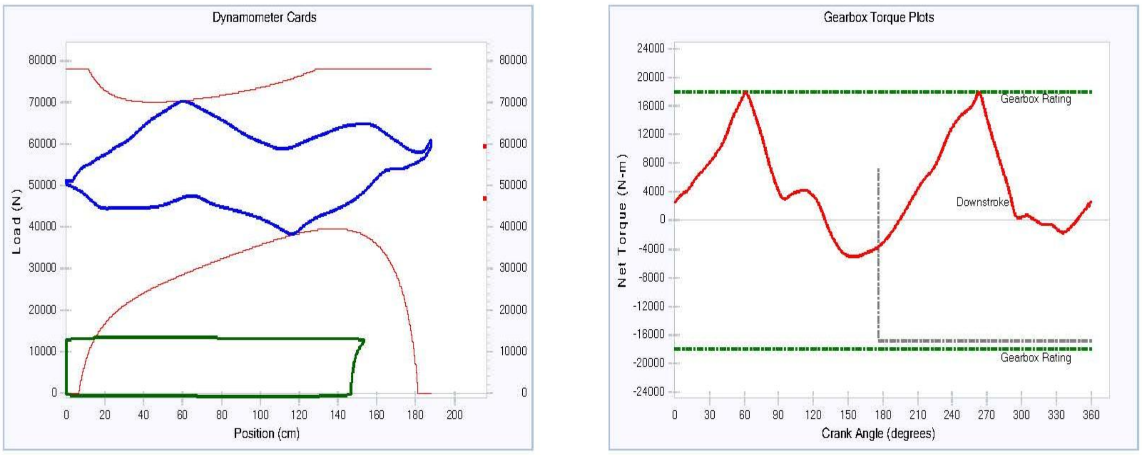

Figure 7. *Graphic display of results for well T-016 ("Theta" - RODSTAR, NIS Novi Sad)*

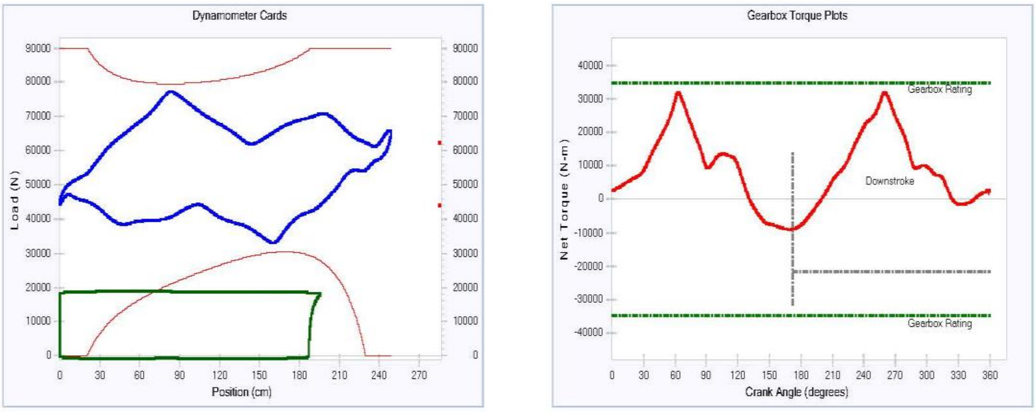

Figure 8. *Graphic display of results for well T-061 ("Theta" - RODSTAR, NIS Novi Sad)*

The efficiency of the pumps of the selected pool of wells ranged within narrow limits, and the average efficiency of the installed pumps, which represents a measure of the influence of both the characteristics of the reservoir fluid being pumped and the technical characteristics of the pump, was around 57 %.

From the entire pool of wells, two candidates, T-016 and T-061, with the lowest pump efficiency of 40 %, were selected for the installation of a pump with modified technical characteristics.

3. ANALYSIS OF OIL PRODUCTION USING A MODIFIED TYPE OF PISTON ROD DEEP PUMPS IN THE WELLS OF THE "T" RESERVOIR

In order to increase the efficiency coefficient, new calculations were made. Using the same input data, as in the previous case, with a variation related to the technical characteristics of the pump (double pressure valve), a series of calculations was made with the same software for the selected well candidates of the reservoir "T". The best efficiency of the pump itself was achieved by installing a double pressure valve. The results of the new calculation for wells T-016 and T-061 are shown in Figures 9 to 12. The result of the calculation showed a pump efficiency of 70 %, which is an increase of 30 % compared to the currently used pump.

RODSTAR 2018 REL 1
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NTC NIS - Naftagas

Company:NIS
Well:NN-016
Disk file:tt-016.rsdx
Comment:

INPUT DATA

Target Prod. (m^3/D): 5
Run time (hrs/day): 24.0
Tubing pres. (kPa): 500
Casing pres. (kPa): 10

Fluid level
(m from surface): 1600
(m over pump): 400
Stuf.box fr. (N): 445
Pol. rod. diam. 1.25" (31.8 mm)

Fluid Properties

Water cut: 62%
Water sp. gravity: 1.011
Oil density (g/cm^3): 0.89
Fluid sp. gravity: 0.9646

Motor & Power Meter

Power meter: Detent
Elect. cost: $.06/KWH
Type: NEMA D

Pumping Unit:API 7.8

API Size:C-160-175-86 (Unit ID CUSTOM)
Crank hole number: # 3 (out of 4)
Calculated stroke length (cm): 188
Crank rotation with well to right: CCW

Max. cb moment (N-m): Unknown
Structural unbalance (N): 220
Crank offset angle (degrees): 0.0

Tubing And Pump Information

Tubing O.D. (mm): 73.025
Tubing I.D. (mm): 62.001
Upstr. rod-fl. damp. coeff.: 0.100
Dnstr. rod-fl. damp. coeff.: 0.100

Pump depth (m): 2000
Pump conditions: Full
Pump type: Insert
Plunger size (mm): 31.8
Tub.anch.depth (m): 2000
Pump vol. efficiency: 70%
Pump friction (N): 890

CALCULATED RESULTS (TOTAL SCORE: 76% GRADE: B-)

Production rate (m^3/D): 5
Oil production (m^3/D): 1.9
Strokes per minute: 4.23
System eff. (Motor->Pump): 28%
Permissible Load Power (kW): 6.3
Fluid load on pump (N): 12587
Fluid level tvd (m from surface): 1599.4
Pol. Rod Power (kW): 1.9

Peak pol. pod load (N): 67063
Min. pol. rod load (N): 41451
MPRL/PPRL: 0.618
Unit struct. loading: 86%
PRHP / PLHP: 0.30
Buoyant rod weight (N): 47051
N/No: .106 , Fo/SKr: .203

Required prime mover size (speed var. not included): BALANCED (Min Torq)

NEMA D motor: 5 HP
Single/double cyl. engine: 5 HP
Multicylinder Engine: 5 HP

Torque analysis and electricity consumption: BALANCED (Min Torq)

Peak g'box torq.(N-m): 15826
Gearbox loading: 87.5%
Cyclic load factor: 1.626
Max. cb moment (N-m): 50244.04
Counterbalance effect(N): 55757
Daily electr.use (Kwh/Day): 75
Monthly electric bill: $137
Electr.cost per m^3 fluid: $0.894
Electr.cost per m^3 oil: $2.353

Tubing, Pump And Plunger Calculations

Tubing stretch (cm): .0
Prod. loss due to tubing stretch (m^3/D): .0
Gross pump stroke (cm): 148.1
Pump spacing (cm from bottom): 50.0
Minimum pump length (m): 4.3
Recommended plunger length (m): 1.5

Rod string design / **Rod string stress analysis (service factor: 0.9)**

Diameter (mm)	Rod Grade	Length (m)	Min. Ten. Str. (kPa)	Fric. Coeff	Stress Load %	Top Maximum Stress (kPa)	Top Minimum Stress (kPa)	Bot. Minimum Stress (kPa)	# Guides/Rod
22.2	TEN D Alloy	684	827371	0.2	48.0%	171719	107994	60765	0
19.1	TEN D Alloy	110	827371	0.2	51.4%	155159	79681	73478	0
19.1	TEN D Alloy	73	827371	0.4	48.3%	142312	68776	68878	3
19.1	TEN D Alloy	1133	827371	0.2	45.6%	134248	63775	-3121	0

NOTE: Displayed bottom minimum stress calculations do not include buoyancy effects (top minimum and maximum stresses always include buoyancy).

Figure 9. *Calculation results for well T-016 ("Theta" - RODSTAR, NIS Novi Sad)*

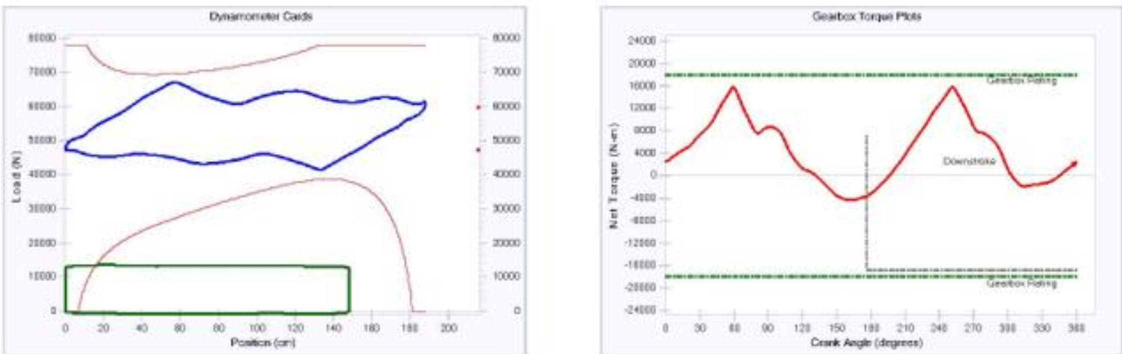
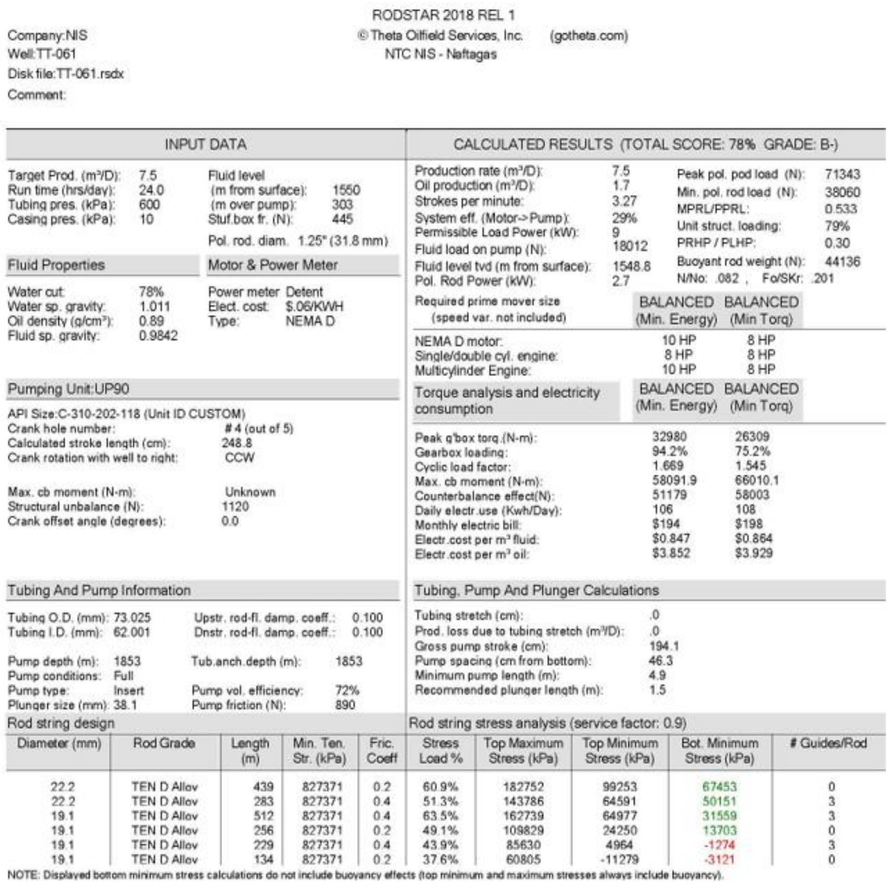


Figure 10. *Graphic display of results for well T-016 ("Theta" - RODSTAR, NIS Novi Sad)*



RODSTAR 2018 REL 1
© Theta Oilfield Services, Inc. (gotheta.com)
NTC NIS - Naftagas

Company:NIS
Well:TT-061
Disk file:TT-061.rsdx
Comment:

INPUT DATA

Target Prod. (m³/D):	7.5	Fluid level	
Run time (hrs/day):	24.0	(m from surface):	1550
Tubing pres. (kPa):	600	(m over pump):	303
Casing pres. (kPa):	10	Stuf.box fr. (N):	445
		Pol. rod. diam.	1.25" (31.8 mm)

Fluid Properties		Motor & Power Meter	
Water cut:	78%	Power meter	Detent
Water sp. gravity:	1.011	Elect. cost:	$.06/KWH
Oil density (g/cm³):	0.89	Type:	NEMA D
Fluid sp. gravity:	0.9842		

Pumping Unit:UP90

API Size:C-310-202-118 (Unit ID CUSTOM)	
Crank hole number:	# 4 (out of 5)
Calculated stroke length (cm):	248.8
Crank rotation with well to right:	CCW
Max. cb moment (N-m):	Unknown
Structural unbalance (N):	1120
Crank offset angle (degrees):	0.0

Tubing And Pump Information

Tubing O.D. (mm):	73.025	Upstr. rod-fl. damp. coeff.:	0.100
Tubing I.D. (mm):	62.001	Dnstr. rod-fl. damp. coeff.:	0.100
Pump depth (m):	1853	Tub.anch.depth (m):	1853
Pump conditions:	Full		
Pump type:	Insert	Pump vol. efficiency:	72%
Plunger size (mm):	38.1	Pump friction (N):	890

CALCULATED RESULTS (TOTAL SCORE: 78% GRADE: B-)

Production rate (m³/D):	7.5	Peak pol. pod load (N):	71343
Oil production (m³/D):	1.7	Min. pol. rod load (N):	38060
Strokes per minute:	3.27	MPRL/PPRL:	0.533
System eff. (Motor->Pump):	29%	Unit struct. loading:	79%
Permissible Load Power (kW):	9	PRHP / PLHP:	0.30
Fluid load on pump (N):	18012	Buoyant rod weight (N):	44136
Fluid level tvd (m from surface):	1548.8	N/No: .082 ,	Fo/SKr: .201
Pol. Rod Power (kW):	2.7		

Required prime mover size (speed var. not included)	BALANCED (Min. Energy)	BALANCED (Min Torq)
NEMA D motor:	10 HP	8 HP
Single/double cyl. engine:	8 HP	8 HP
Multicylinder Engine:	10 HP	8 HP

Torque analysis and electricity consumption	BALANCED (Min. Energy)	BALANCED (Min Torq)
Peak g'box torq.(N-m):	32980	26309
Gearbox loading:	94.2%	75.2%
Cyclic load factor:	1.669	1.545
Max. cb moment (N-m):	58091.9	66010.1
Counterbalance effect(N):	51179	58003
Daily electr.use (Kwh/Day):	106	108
Monthly electric bill:	$194	$198
Electr.cost per m³ fluid:	$0.847	$0.864
Electr.cost per m³ oil:	$3.852	$3.929

Tubing, Pump And Plunger Calculations

Tubing stretch (cm):	.0
Prod. loss due to tubing stretch (m³/D):	.0
Gross pump stroke (cm):	194.1
Pump spacing (cm from bottom):	46.3
Minimum pump length (m):	4.9
Recommended plunger length (m):	1.5

Rod string design / Rod string stress analysis (service factor: 0.9)

Diameter (mm)	Rod Grade	Length (m)	Min. Ten. Str. (kPa)	Fric. Coeff	Stress Load %	Top Maximum Stress (kPa)	Top Minimum Stress (kPa)	Bot. Minimum Stress (kPa)	# Guides/Rod
22.2	TEN D Alloy	439	827371	0.2	60.9%	182752	99253	67453	0
22.2	TEN D Alloy	283	827371	0.4	51.3%	143786	64591	50151	3
19.1	TEN D Alloy	512	827371	0.4	63.5%	162739	64977	31559	3
19.1	TEN D Alloy	256	827371	0.2	49.1%	109829	24250	13703	0
19.1	TEN D Alloy	229	827371	0.4	43.9%	85630	4964	-1274	3
19.1	TEN D Alloy	134	827371	0.2	37.6%	60805	-11279	-3121	0

NOTE: Displayed bottom minimum stress calculations do not include buoyancy effects (top minimum and maximum stresses always include buoyancy).

Figure 11. *Calculation results for well T-061 ("Theta" - RODSTAR, NIS Novi Sad)*

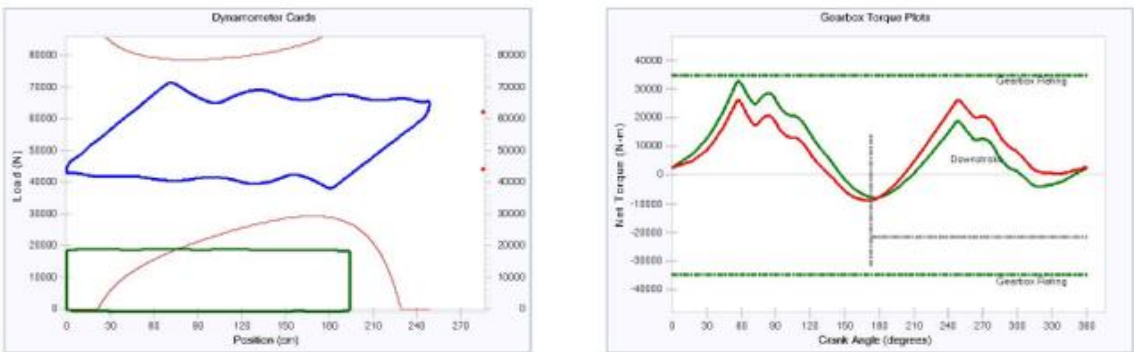


Figure 12. *Graphic display of results for well T-061 ("Theta" - RODSTAR, NIS Novi Sad)*

In addition to the greater efficiency of the system for deep pumping on piston rods while maintaining the same produced amount of fluid, by installing a double pressure valve in deep insert pumps on piston rods with upper seating, it is possible to optimize the pumping parameters, which are very important for pumping conditions in obliquely directed wells, as well as the use of a smaller pump diameter, which also enables the optimization of above-ground equipment.

The obtained results of the calculation of the deep pumping system were in accordance with the expectations and showed a significant improvement of the operation of the entire system. This improvement came about due to the better airtightness of the pressure valve, which results in the same fluid production, with the possibility of reducing the diameter of the pump and/or optimized operation of the overhead equipment, and the positive effects of this are: less wear of the moving parts of the hook, less load on the reducer, less load on the structure of the hook, increasing the stroke length of the piston in the pump cylinder, safer operation of the hook from the HSE point of view, a weaker electric motor is needed, less wear of the smooth rod and its sealing elements, extension of the working life of piston rods and their couplings due to fewer cycles of load changes, extension of service life of tubing in case of contact with piston rods due to reduced number of cycles, extension of service life of pump valve assemblies due to reduced number of cycles, extension of service life of pump cylinder and piston due to reduced number of cycles.

CONCLUSION

Based on all calculations and practical checks on the existing wells of the "T" reservoir, a decision was made to install insert pumps with an upper seating and a double pressure valve in all wells that will be drilled on the "T" reservoir, in order to achieve more efficient operation of the complete system, instead of insert pumps with an upper seating and one pressure valve.
During the purchase of equipment for submersible pumps on piston rods, several seats and balls for pressure valves were specially ordered, in order to test them in wells in combination with all other equipment that was currently in stock in the company's warehouses.
Pumps with changed technical characteristics, by adding another pressure valve, were installed during the overhaul of the wells, and the data of actual measurements coincided again with the results from the calculations.
Both candidate wells, where the double pressure valve was installed, also showed a significant improvement in the duration of the intermediate overhaul period.
In the case of well T-016, the interim overhaul period, before the installation of a deep-seated pump on piston rods with upper seating and a double pressure valve, was 105 days, and after that 401 days, with a note that the well is still in operation.
In the case of well T-061, the interim overhaul period, before the installation of a deep-seated pump on piston rods with upper seating and a double pressure valve, was 143 days, and after that it was 655 days, with a note that the well is still in operation.
Due to the same characteristics as all other wells in the "T" oil field, the same type of pumps will be successively installed in all other wells of the oil field during the overhaul.

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EXPLOITATION OF CRITICAL RAW MINERALS IN THE CONTEXT OF MINING METHODS

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Summary

Mining methods of excavating and extracting critical raw minerals, where lithium ores belong, do not differ from the mining methods applied for metallic or non-metallic raw minerals. Each of the methods has variations and modalities that are applied depending on the ore body genesis and properties, and the applied digging or extraction mining mechanization. Globally, critical raw minerals are mined applying surface, underground and borehole - well exploitation mining methods, as well as a combination of surface and underground mining. The exploitation principles of critical raw minerals are identical to the principles of other solid mineral raw minerals exploitation, so the extraction of lithium ores, and other critical raw materials, must be considered exclusively from the perspective of mining practices and since only.
Key words: critical raw minerals, lithium, surface mining, underground mining, well exploitation.

1. INTRODUCTION

Mining is the essence of humanity's existence and progress. In today's time, absolutely everything that serves humanity, and that was made as a product of human activity, contains a mining component. Clothing, energy, communications, traffic, food, infrastructure, healthcare - it cannot function without mining products, primarily without metallic and non-metallic raw minerals. There is a wide spectrum of types of raw minerals and materials necessary for life functions, and this category also includes critical raw minerals, among which the metals lithium and boron are currently the most relevant. This "invisible" fact is rarely talked about, and mining is often seen as a difficult, dangerous and undesirable activity. And that is an activity that cannot be done anything without it. The logical sequence of the statement is that it is necessary to explore raw minerals, open mines, exploit raw minerals and in this way enable the functioning of humanity. BiH has significant reserves of various raw minerals and can build its prosperity on mining industry. In the context of the use of mineral resources, the EU believes that BiH has several opportunities for strategic partnership with the EU in the field of mineral resources, with the aim of promoting economic development and other areas, and therefore encourages BiH to identify sustainable projects, including potential in the field of critical raw minerals.

It is the fact that the exploitation of raw minerals – mining, may have a negative impact to the environment through soil degradation, soil and water pollution, disruption of biodiversity, reduction of forest areas and damaged ambient landscape. At the beginning of the 21st century, the concept of controlling the extraction of raw minerals changed significantly, so new approaches to the use of mining equipment and the process of processing mineral raw materials were applied, as well as the application of strict environmental protection regulations. Mining facilities opened in the last 20 years in Bosnia and Herzegovina already respond to new concepts of control the mining operations and processing of raw minerals, but incidents that endanger or damage the environment still occur sporadically.

Prevention of threats for the environment are:

• compliance with the legislative framework (which foresees the recultivation and reuse of degraded areas resulting from the exploitation of minerals and form overburden dumps), monitored by the responsible mining inspections and

• the application of new technologies that prevent the negative impact of mining actions on the environment, and which provide increased safety for personnel and equipment in mining facilities, as well as safety in the raw mineral processing, especially in the area of industrial waste water treatment and percolation of overburden dump sites at open pit mines of metallic deposits.

Bosnia-Herzegovina mining works traditionally lean on the exploitation of ores of lead, zinc, barite, cobalt, gold, silver, bauxite, copper, iron, manganese, as well as the exploitation of coal, sand, gypsum, clay, salt, gravel and other raw minerals. Exploitation is based on surface and underground mining, as well as on well exploitation of salty water at the Tetima rock salt deposit near Tuzla. Bosnia and Herzegovina possess significant reserves of various metallic mineral raw materials, and exploitation is dictated by market needs, so new mines are opened, and financially unprofitable ones are closed (or conserved - sealed). Changes in the market prices of mineral raw materials or products based on raw minerals occur very frequently and often unexpectedly, which has a direct impact on mining, and thus on the effects of mining exploitation. The use of information taken from the Internet enables high-quality and efficient planning of the dynamics of mining operations, which can be adapted to changes in the market price of mineral raw materials. An example of the impact of the final product price on the mining industry is the example of the ArcelorMittal Zenica Steel and Iron Factory, where on 7 January 2024 began the process of restarting the blast furnace in order to continue the production that was interrupted in November 2023. Production was suspended on 11.11.2023 due to, as the management announced at that time, unfavourable status of the steel market. The ArcelorMittal corporation, apart from production in Zenica, also manages the largest regional iron open pit mine in Prijedor, which also suspended production during the period when the steel factory was not working. An example of internet information relevant to the raw mineral market is at the site https://markets.businessinsider.com/commodities/ , where the change in market conditions for each commodity can be monitor on a daily basis.

2. CRITICAL RAW MINERALS MINING METHODS

Availability of critical raw minerals is a condition for the global industry development of technological progress. The term raw material includes metal minerals, industrial minerals, building materials, wood and natural rubber. In 2011, the European Commission passed a decision - the law on the official list of critical raw materials, and the list is updated every 3 years, therefore the number of raw materials that are considered critical also changes. Thus, in 2011, there were 14 raw materials on the list, 20 in 2014, 27 in 2017, 83 raw materials in 2020, and 87 candidate elements on the list in 2023. Raw materials are divided into three categories: strategic, critical and non-critical. Candidates in 2023 are 34 critical mineral resources, including 17 strategic mineral resources. Strategic mineral raw materials (and mineral products) for the EU are: aluminium/bauxite, lithium, light rare earth elements, heavy rare earth elements, silicon metal, gallium, manganese, germanium, natural graphite, bismuth, titanium metal, boron, group metals platinum, tungsten, cobalt, copper and nickel. Other critical minerals are coal (for households), phosphorus, antimony, feldspar, scandium, arsenic, magnesium, barite, strontium, beryllium, tantalum, hafnium, niobium, helium, rock phosphate and vanadium[1].

Bosnia and Herzegovina has not defined at any level of administration / entity what strategic mineral resources are for BiH, except the decision of the Government of the Federation of BiH (FBiH) that specifies that oil and gas are strategic mineral resources for FBiH.
Critical raw minerals are exploited in solid, liquid and gaseous state, and according to the aggregate state, a certain method of exploitation is applied. Raw minerals in a solid shape are usually exploited by classical methods of surface and underground mining, as well as by a combination of surface and underground mining. Raw mineral in liquid or gaseous state (oil, gases, mineral and thermal waters, lithium and boron in underground aquifers) are exploited by wells - boreholes. Well exploitation, i.e. hydro-dissolution also produces raw mineral that are in a solid aggregate shape, but which are dissolved by a liquid substance. Thus, salt rock, which is in a solid shape, is dissolved by water, which is extracted in the form of brine - salt dissolved in water. The dissolution of mineral raw materials in a solid shape is also done with chemical substances that are injected through wells, which dissolve e.g. lithium and boron ores that are in a solid shape, and are extracted by boreholes in the form of (hot) liquid concentrate.

The application of the excavation method, as well as the site location opening of the exploitation facility, depends on the genesis and geological deposit properties, the spatial location of the deposit, local conditions (water, climate, infrastructure), financial capacity of investors (land expropriation, procurement of equipment and personnel, obtaining permits) and security of materials supply needed for production processes.

2.1 surface mining of critical raw minerals

The surface mining of critical raw minerals is carried out according to the same concept as the surface mining of any raw mineral in a solid shape. It is characterized by an excavated area visible on the terrain that forms craters in the ground and overburden waste dumps in the nearby area. A crater is a formation of benches and other mining facilities that expands in surface (in all directions or in a certain direction - depending on the mining system) and down wording in

[1] European Commission, Study on the Critical Raw Materials for the EU 2023 – Final Report, Brussels, 2023.

depth during exploitation, up to the economically profitable pit bottom. In surface mining, the processes of drilling and blasting in hard rocks, digging, loading and transporting mineral raw materials are carried out. Waste material from the mine crater is disposed of in waste dumps, which belongs to the special mining facility. Overburden dumps can be internal or external. Internal dumps are the sites where overburden is deposited in an already excavated space within the pit mine contour - limits. The second type is external waste dump, where the overburden is deposited, and will remain permanently, at the sites where it was deposited outside the pit contour. Surface mining of critical raw minerals is often carried out by deep surface pit mines due to the nature of the mineral deposit. In the process of exploitation, the system of discontinuous mining system is most often applied, which includes the use of basic machinery: shovel excavators (rope or hydraulic) and trucks (dumpers). In addition to the basic mechanization, auxiliary mechanization is also necessary - bulldozers, draglines, graders, etc.
In the last 20 years, developed countries have been applying automatization processes based on the satellite technologies for autonomic mining machinery management (machines without human crew). Surface mining has a negative impact on the environment from the aspect of soil degradation and eventual leaching of waste dumps on metallic deposits. In both cases, environmental protection measures can be undertaken by recultivation, conversion of excavated areas and waste dumps, and treatment of leachate from wasted dumps. Figure 1 shows the layout and size of Kathleen Valley, Liontown, Australia lithium open pit mine, and Figure 2 shows part of the discontinuous mining system of the backhoe – truck at the Greenbushes open pit mine, while the Figure 3 shows autonomous drilling rigs on lithium pit mine Greenbushes in Australia.

Figure 1. Lithium open pit mine Kathleen Valley, Liontown, Australia

Figure 2. Lithium ore truck loading by hydraulic excavator backhoe at Talison Lithium's Greenbushes in Australia

Figure 3. Drilled blastholes at Talison Lithium's Greenbushes in Australia

The impact on the environment of surface mining is primarily reflected in the large land degradation and the disturbance of the natural landscape. At the waste dumps of raw metallic minerals, leakage of water contaminated by metals can affect soil and water pollution in the vicinity of mining works, but also in remote sites where the soil and water are contaminated by polluted underground water inflow.

2.2 Underground mining of critical raw minerals

Underground mining of raw minerals is a way of extracting raw minerals by digging in underground spaces - mines. The concept and principle of mining critical raw minerals does not differ from the principle of mining metallic raw minerals applying underground hard rock mining methods.

Mining operations of digging and transportation take place in underground rooms / chambers, and the second part of the exploitation raw minerals takes place on the surface. Other elements

of the process are the transport and processing of raw minerals accompanied by supporting facilities and mine infrastructure. Several mining methods are applied in underground mining, depending on the type of raw minerals, the natural ore deposit properties and the machinery used. The production capacities are smaller compared to surface mining due to requirement to leave safety pillars, working conditions and other production influencing factors. Depending on the mining-geological conditions, mining machinery is used for digging the rock, the process of drilling and blasting, manual or mechanical loading of rock materials into the transport means and the transport of materials to the surface by conveyor belts, wagonettes, underground trucks or other means of transport . Since the beginning of the 21st century, digging and transport processes have been carried out by autonomous machinery without a human crew, i.e. processes are managed from monitoring stations located in the offices at the surface.
The lithium mine project in Jadar near Loznica, Serbia, envisages the construction and development of an underground mine with supporting infrastructure and equipment, including electric underground trucks, as well as the construction of lithium preparation and lithium carbonate production facilities.

Figure 4. Lithium underground mine Mt Marion in Goldfields region, Western Australia

Figure 5. Lithium underground mine Wolfsberg Project in Carinthia, Austria, obtained all required permits for the production in 2025

Figure 6. Lithium underground mine Wolfsberg Project in Carinthia, Austria officially starts production in 2025

The impact on the environment of underground mining is primarily reflected in the (small) possibility of land subsidence due to the formation of underground rooms - chambers (which are usually filled with solid or muddy material after the end of exploitation).

2.3 Combined mining methods of critical row minerals

Combined mining methods in mining industry generally are applied to generate maximum quantity of material to be extracted out of available ore deposit, and represent mining operations that take place in two ways.

The first combined mining method is applied in cases of simultaneous application of surface and underground mining methods. Simultaneous exploitation is, in most cases, realized by the construction of underground mining rooms starting from the area of pit crater, and the opening of underground rooms done from the bench level of the open pit mine. Thus, one spatial part of the deposit is exploited, in most cases, by a system of discontinuous mining machinery (excavator/shovel - truck), and the other part of the same deposit, which is outside the contour of the pit limits, is mined by one of the underground mining methods. In this concept, the transport of excavated raw mineral is carried out to the exit located on the of the surface mine bench where is the entrance to the deposit is, and the transport to the surface is carried out by trucks using the transport infrastructure in the contour of the pit mine - benches, berms, ramps. Another way of transporting mined raw mineral is vertical transport through a constructed shaft, which is used to transport wagonettes loaded by raw mineral and lifted to the surface. The second combined mining method is applied in cases of completion of surface mining with continuation of works applying underground mining methods. With the completion of the planned mining works in the open pit mine, the mine crater remains with the elements of the final pit contour. If the deposit of critical raw mineral has not been fully extracted (because the financial and operational unreasonableness of further deepening of the pit mine has been shown), then an underground mine is opened from the pit bottom or from one of the non-working pit benches. The opening takes place using the classic method of underground mining by creating a vertical entrance - shaft, with the subsequent development of underground mining rooms along the horizons. By advancing the works into the depth, it is possible to fully exploit the mineral deposit. The transport of excavated raw mineral is carried out by classic transport means in underground mines (chain conveyors, conveyor belts, wagonettes, mining trucks), and upon exiting area of the surface mine, the transport to the surface is carried out by trucks using the transport infrastructure in the pit contour - benches, berms, ramps. Lithium ore in Whabouchi Lithium Mine, Quebec, Canada has been exploited by surface mining methods since 2020, and after exploitation of the deposit by surface mining (after 25 years), the opening of an underground mine is planned, which will be in operation for another 8 years.

Figure 7. Open pit mine Whabouchi Lithium Mine, Quebec, Canada

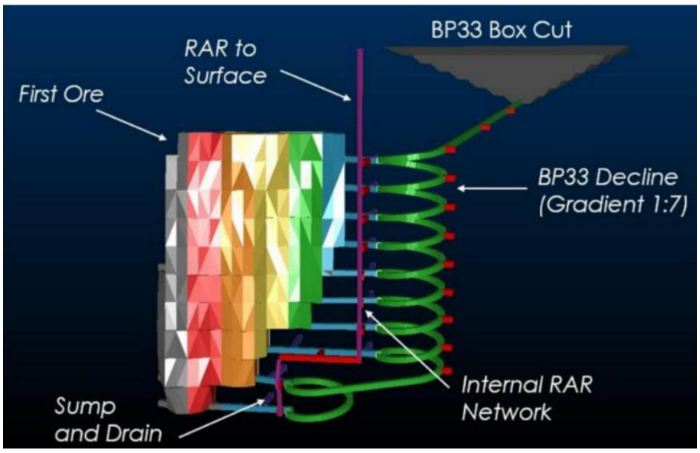

Figure 8. Projection of transfer from surface mining to underground mining in lithium mine

Figure 9. Combination of underground and surface mining with the opening of underground rooms from the pit crater floor level at open pit mine in Kathleen Valley, Australia

In the combined methods of exploitation of critical raw minerals, the processes of drilling, blasting, digging, loading, transportation, waste disposal and preparation of mineral raw materials are applied.

The impact on the environment of the combination of surface and underground mining is reflected in the combined harmful impact of soil degradation and the possibility of land subsidence due to the formation of underground empty spaces. In addition to the aforementioned key adverse impacts, there are adverse impacts caused by noise, air and water pollution, vibrations, disruption of biodiversity, removal of infrastructure for the advancement of mining operations, occurrence of landslides, and so on.

2.4 Well mining of critical raw minerals

Well (continental) exploitation is characterized by the exploitation of liquid and gaseous mineral resources, where the resource is extracted to the surface by pumping facilities and transported for further processing. Well - borehole mining is also the exploitation of solid raw minerals that are dissolved by means of a liquid medium and in the liquid form are pumped to the surface and transported for further processing.
Critical mineral resources, especially lithium and boron, can be exploited by well mining. The process of exploitation takes place by drilling vertical wells till the raw mineral deposit (injection well), drilling reversible vertical wells to the deposit (production well), cementing the wells, building an injection system, i.e. filling the wells with a concentrate of reagents that decompose and absorb lithium and accompanying minerals, installation of pumping systems for extraction of saturated liquid concentrate (brine) and directing the concentrate to further processing raw minerals.
This method of lithium extraction is considered to be the most economical and is widespread as a method in a number of countries.

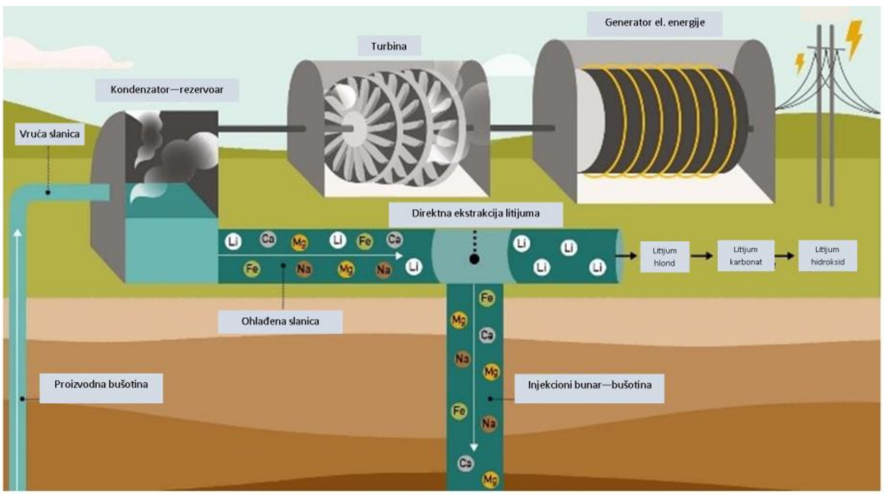

Figure 10. Borehole mining conception with concentrate injection

Figure 11. Pumping facility for injecting concentrate

With the development of technique and technology, various methods of critical raw mineral exploitation are invented and applied. Innovative methods are often an experimental works, and do not yet have mass application and often do not have proven efficiency and financial profitability of production processes. One of the new methods is the so-called "The method of direct lithium extraction"[2], and lithium is exactly the element that is obtained in different ways, depending on the natural circumstances of the environment that contains lithium and other critical raw minerals. The innovativeness of the method primarily refers to the use of evaporation basins and methods of raw mineral processing, and using basic exploitation tools - wells. Methods of lithium extraction from thermal waters, seawater, clay deposits and other natural resources are not the subject of this paper.

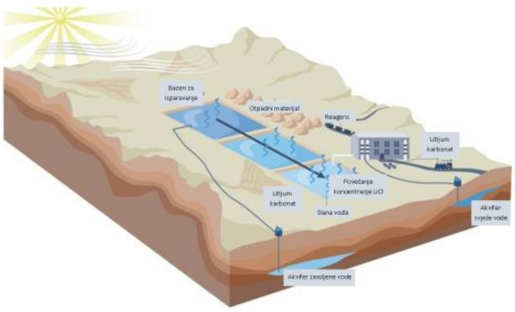

Figure 12. The concept of direct well mining for lithium extraction from saline aquifer

Figure 13. Well mining of lithium in Kachi Lithium Brine Project near Catamarca, Argentina

[2] https://lithiumharvest.com/knowledge/lithium-extraction/lithium-extraction-methods/

Figure 14. Direct well mining of lithium in The Smackover Formation deposit, Arkansas, US, which is a limestone aquifer with a high concentration of lithium

3. RECLAMATION MINING AREAS

The impact on the environment of borehole mining is reflected in the harmful effect of the concentrate containing aggressive acids that can affect the soil and water quality in the area of where of the deposit is mined, namely in the area below the wells or at least above the bottom of the well, considering that the wells are cemented (sealed), which prevents the impact of concentrates and acids to the ground where the wells are constructed.

Figure 15. Recultivated waste dump at Thacker Pass, Nevada pit mine

Elimination of the harmful effects of lithium ore exploitation is carried out by constant monitoring of production processes, processing and preparation of mineral raw materials, compliance with legislative frameworks and application of the concept of sustainable mine development. The public often believes that the exploitation of lithium ores irreversibly devastates the environment, however, there are a large number of examples that prove the opposite. A common way of rehabilitating a devastated or degraded environment is the planned reclamation and reuse of devastated areas, such as the case of the Thacker Pass surface mine in Nevada, the Canadian-American company Lithium Americas, where after the end of each mining phase of lithium exploitation, the waste dump and the surrounding area are completely recultivated, which gives it a new value and purpose. The concept of reclamation is based on filling the craters of previously excavated areas with useless mine material (overburden or waste rock) that is created in active surface mines. In situations where this concept is inapplicable, a waste dump is formed after the mining life is first covered with soil suitable for the growth of grass and low vegetation, and then a plant cover is sown.

CONCLUSION

Lithium, like most other critical raw minerals, is exploited by various methods are applied in the mining industry. The most commonly applied methods are surface, underground, combined and well mining. Each of the methods has its own varieties, primarily in the choice of digging or extraction technique, the application of mining machinery and the execution of drilling and blasting works. The EU supports research and exploitation of critical raw minerals in BiH, and according to that strategy, it is necessary to direct and intensify the production of critical raw minerals in BiH. The intense need for lithium has caused public concern as lithium is being talked about in a negative light. Lithium ore exploitation, as well as exploitation of any other raw mineral, leaves negative impact to the environment, however, those impacts can be effectively reduced and mitigate by:

- applying regular monitoring of all mining processes,
- compliance with legal regulations,
- applying innovative techniques of lithium mining and extraction, processing and preparation of mineral raw materials and
- efficient reclamation and reuse of excavated or degraded mine sites.

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PROPOSAL OF MEASURES TO MITIGATE ENVIRONMENTAL IMPACTS ON THE AREA OF ABANDONED VAREŠ MINE

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Summary

The negative impacts of the old mining operations both in our country and throughout the world represent one of the biggest environmental problems.
The analysis of the previous practice in Bosnia and Herzegovina regarding the closure of mines in the past decades lead to the conclusion that very few were closed in accordance with the regulations. The problem was further complicated by the war that took place in our country from 1992 to 1995 which in certain number of cases led to the sudden stoppage of mine operations, many of which did not continue to operate even after the cessation of war activities. In the period 2013-2014 the Japanese Agency for International Cooperation (JICA) did an initial analysis of black industrial spots (Hot spots) in the Federation of Bosnia and Herzegovina and 4 such locations were determined , one of which was the former mine in Vareš. The mine consisted of several units at different locations where various types of raw mineral materials were exploited , which made reasearch even more difficult. This primarily refers to the location of surface mine (SM) „Smreka“, the ore processing and packing plant at SM „Veovača“ and the water accumulation with flotation tailings. For the mentioned sites, a field inspection and analyses of the existing condition were carried out to obtain results required to serve as a basis for proposal of measures to reduce the impact on the environment as well as the rough estimate of the relating remediation costs, which were done separately for each of the research polygon sites.
It should be emphasized that Bosnia and Herzegovina's accession to European Union implies significantly stricter environmental protection practices in the mining industry as well. Today, environmental protection in mining is an international standard and obligation. At the same time, the need should be pointed out to the contribution of each country in reducing the negative impact on the environment and climate changes.
Key words: abandoned mines, environmental risks, measures to reduce environmental impacts, remediation.

1. OVERVIEW OF MINING ACTIVITIES IN THE VAREŠ AREA

1.1. Iron ore mines

In the area of Vareš municipality in the period 1945-1990 intensive exploitation of iron ore and its processing, i.e production of hematite and siderite ore concentrates were carried out . Vareš mine and iron factory are the oldest units in RMK Zenica company. The industrial production

of this work organization dates back to the commissioning of the first blast furnace for the production of iron in 1981.
The labor organization Mine and Iron factory Vareš employed 3.350 workers, of which „Mining" employed 1.180 workers. Surface exploitation was carried out at SM „Smreka" and SM „Brezik", along with underground exploitation carried out in „Droškovac" mine. [6]

1.1.1. *Surface mine "Smreka"*

One of the largest iron ore deposits in Vareš is located in the central part of the metallogenic area of Vareš. This surface mine worked on the production of siderite and hematite raw ore, from which siderite and hematite concentrates were obtained after separation process. In addition to the mined ore that was transported to the heavy liquid separation unit, direct transport was also included for all tailings, transported to the landfill. Combined transport was also applied. Upon closure of activities at the surface mine „Smreka" it was planned to start the underground exploitation of the deposit.
At „Smreka" surface mine after the stoppage of mining activities in 1992, a lake with a volume of about 3,000.000 cubic meters of water was formed in the crater. The lake is surrounded by hills with the height of 1100 and 1350 meters above sea level (Kota and Veokovac). The surface of the lake was 125.000 cubic meters , length 610 m and depth 107 m. [6].

1.1.2 Surface mine "Brezik"

SM „Brezik is located about 10 km away from Vareš, east of the town near the village of Pržići.This surface mine worked on the production of siderite and hematite raw ore, from which their concentrate was obtained after separation process. Distribution of concentrate was ensured to Zenica iron factory and in the smaller quantities to Smederevo iron factory.
Overburden was transported to the external disposal site by trucks. The transport of ore from the mine to the preparation/separation plant „Smreka" was carried out using combined transport, trucks-chute-pit locomotive in the pit „Droškovac" . The SM „Brezik is of the deep type of surface mines (open pit). It is not flooded due to existance of the pipe that connects it to „Droškovac" undeground mine. The preparation of the pit ore was carried out at heavy liquid separation plant located within the SM „Smreka" area.

1.1.3 Underground mine "Droškovac"

„Droškovac" deposit is located in the central part of the metallogenic area in Vareš, in the valley of Ruda stream, the right tributary of the Stavnja river, south of the town of Vareš. It is a deposit where underground mining was carried out. This mine served for production of siderite and hematite ores, from which after separation process, siderite concentrate was obtained,
Distribution of concentrate was carried out to Zenica iron factory, and to Smederevo iron factory but to a smaller degree. Preparation of raw ore, i.e. production of concentrate was carried out using heavy liquid separation method performed in the plant on SM „Smreka". [6]

1.2 "Veovača" lead, zink and barite mine

„Veovača“ deposit is located on the slopes of Zvijezda mountain in the immediate vicinity of the villages of Daštansko and Tisovci. Exploitation from this area, namely overburden removal operations were started in 1979 by „Energoinvest“ Sarajevo. Ore exploitation was carried out using the surface mining method, performing excavation in the south-north direction, so that the progress of the excavation was in the north direction, and the overburden and tailings were deposited in the south side of the mine area. The exploitation of complex lead, zink and barite ore at this mine was interrupted in 1987 and 1988 due to instability of dam of water accumulation containing flotation tailings. In 1989 the mine continued production, only to stop production again in 1990 due to the imposibility of selling sulphide concentrates due to presence of mercury and the financial over-indebtness. [6]

1.3 „Tisovac“ ore preparation/processing plant

The process of preparing the ore and obtaining a useful product was carried out at the plant located three km southwest of the surface mine near the settlement of Tisovac.
The technological process of preparation consisted of crushing, separating, grinding, flotation and depositing lead and zinc concentrates, either as separate or collective concentrates, then followed by drying, depositing and packing of the product. Ore exploitation from Veovača mine commenced in June 1990 while the flotation unit began operating in mid-1982 and by the end of 1985 870,955 tons of ore with an average content of Pb-0,95 %, Zn – 1,66 % $BaSO_4$-17,40 %. had been processed . The operation of the plant was stopped in 1990. [6]

2. THE RESEARCH POLYGON- BRIEF REVIEW OF THE CURRENT STATUS

Based on previously conducted research in the Federation of Bosnia and Herzegovina, it was established that there are environmental hotspots contaminated with hazardous substances, These localities represent a negative legacy from the time of former SFR Yugoslavia and then from the period of war, when they were abandoned and left unattended. The research carried out as a part of the subject research includes one of the established hotspots- the former Vareš mine.
Metal mines, mostly destroyed in the previous war period in BiH were not the object of interes of domestic or foreign investors until recently. Many are not adequately closed, so an thorough inventory of abandoned metal mines is necessary to define hotspots, environmental hazards and risks, as well as a preconditions to set priorities for remediation. The problem also present undefined successors to the mine property, because the companies that managed the mines mostly no longer exist in the mining sector. [7]
The unsetlled situation in the sphere of interrupted surface exploitation is evident in the subject research area. Namely, operation on the last surface mine was stopped in 1992, and to this day the situation is only getting worse. It concerns the abandoned iron ore mine SM „Smreka“ and SM „Brezik“, as well as polymetallic lead-zin-barite deposit at SM „Veovača. Also during the operation phase of the mine an underground iron ore mine „Droškovac“ was also functioning.

Apart from the surface mines where no form of land reclamation was performed, the same unsetlled situation is present at other mine facilities and objects. [3]

The subject research polygon includes:

- SM "Smreka" – a lake formed at the abandoned iron ore
- SM "Veovača" and abandoned lead, zink and barite processing plant, and
- Water accumulation with flotation tailings. [6]

Figure 1. Water accumulation at SM "Smreka"

Figure 2. Water accumulation with flotation tailings

Figure 3. SM "Veovača"

Figure 4. Remnants of the preparation/processing plant

2. ASSESMENT OF THE ENVIRONMENTAL IMPACTS ON THE RESEARCH POLYGON

3.1 Proposal of criteria for assessment of related environmental impacts

Criteria for assessment of impacts caused by the subject mining operations are shown in Table 1. Numbers in parenthesis relates to rating for subject sites. SM „Smreka (1), SM „Veovača“ (2), and water accumulation with flotation tailings (3)

Table 1. *Criteria for assessment of environmental impacts* [6]

A – Exploitation of processing of mineral raw materials

	POINTS
Existing	20
Recently completed	15
Production stopped several decades ago or long ago (1,2,3)	10

B – Usage of chemicals in the technological process

	POINTS

Chemicals or toxic substances were (are) used to a great extent	20
Chemicals or toxic substances were (are) used to a limited extent (2,3)	15
Chemicals or toxic substances were not used (1)	0

C – Land subsidence caused by mining activities, collapses, old works, land slides

	POINTS
Significant impacts (over 10 ha, at the depth of more than 40 m) and established on the basis of detailed research, endangering people, settlements and property to a significant extent	20
Less pronounced impacts (bellow 10 ha, shallower works, endangering people, settlements and property on a local scale or isolated zones, possibility of occurrence and extent of damage must be investigated in more details (1, 2)	10
Insignificant impacts, area of impact and impacts are small or non-existent (3)	1

D – Slope deformations and other geodynamic phenomena (erosion, abrasion, atmospheric influence, volume changes, floods, karst phenomena, inundation, liquefication

	POINTS
Pronounced impact (large areas, destruction of many buildings of various purposes), defined on the basis of detailed research, jeopardizing people, settlements and property to a significant extent	20
Geodynamic phenomena that threaten the environment to a lesser extent with low intensity (local impact, individual residential buildings, minor damage to property (1,2,3)	15
Geodynamic phenomena that threaten the environment to an insignificant extent with low intensity (local impact, individual residential buildings, minor damage to property	1

E – Negative changes in relief or terrain (collapses of an older date, old mining works, places were ore was mined, long-initiated landslides, pits, etc.)

	POINTS
Regional and pronounced influence (over 10 ha of area)	20
Local impact (limited in the field of operations) (1,2,3)	15
Minor changes	1

F – Hydrogeological condition and impacts on water supply

	POINTS
Pronounced impact on sources of drinking water of regional character, pronounced impact on hydrological conditions	20
Impact on local sources of drinking water of regional character, pronounced impact on hydrological conditions (1,2,3)	15
Minor impact on drinking water sources and water courses	1

G – Mine waters

	POINTS
The quantity and quality of mine waters that produce impacts on the environment that are potentially regional in scale (disruption of hydrogeological structures and flow patterns, emission of metallic and toxic elements into surface waters at a critical level (1,2,3)	20
The impact on surface waters and hydrological conditions is of medium value, several mine rooms where mine waters in drained, local disruption of hydrogeological structures, local impacts due to the emission of mine water)	15
Minor changes or no hazardous mine water is created	1

H – Hydrogeochemical anomalies (geogenic or anthropogenic contamination of water)

	POINTS
Geogenic or anthropogenic contamination of water is potentially regional in nature (1,2,3)	20
Local extent	15
Minor extent	1

I – Lithogeochemical anomalies (geogenic or anthropogenic contamination of soil and river sediments , mainly with Cu, Pb, Hg, Sb, Cd, Cr, pH values changes)

	POINTS
Potentially of regional character (1,2,3)	20
Potentially of local character	15
Minor extent	1

J – Biogeogenic anomalies (Geogenic or anthropogenic impact on vegetation)

	POINTS
Potentially of regional character	10
Local extent (1,2,3)	5
Minor extent	1

K – Depots of materials (overburden dump sites, dumped piles of materials, disposed tailings material from mineral processing plants, disposed hips of rock materials, ore disposal site)

	POINTS
Active process	20
Recently completed or long overdue disposal process (1,2,3)	15
No landfill/dumps present	0

L – Tailings from processing plants (overburden dumps, hydraulic dumps, settling tanks, precipitators)

	POINTS
Active and with monitoring, remediation must be included	20
Out of use or currently inactive, no remediation performed, no monitoring plan (1,2,3)	15
Old tailings, fully or partially remediated or not at all, without significant impact on the environment) or there is no tailings disposal site from processing plants	0

M – Method of land use (aspect of population density, infrastructure, industry, agriculture, arable land, zones under forests)

	POINTS
Contact with settlements, urbanized zones industrial zones, zones where construction works are carried out, commercial zones, communications	20
Agricultural land, arable land, meadows, pastures, no-arable land, artificially modified green zones	15
Forests (1,2,3)	10

N – Monitoring

	POINTS
Systematic monitoring of the environment is inevitable, but it was not carried out despite the fact that it was an legal obligation, or the monitoring is not carried out in a satisfactory manner. Partial, did not cover all aspects of potential impacts (1,2,3)	20
Monitoring is carried out , the scale and frequency is satisfactory, the risks refers only to rapid changes in the transition period (for example, a change of owner) with the possibility of being interrupted in a transition period, or monitoring is not carried out in an adequate way after that.	10
Monitoring is not required. Some environmental aspects are satisfactory covered with the established state/local environmental monitoring network	0

Based on the criteria scoring system, the impacts are divided into three categories, Table 2.

Table 2 – Ranking system by impact categories

I. Category (more than 150 points)

Locations or mining zones where remediation is required as an acute step in the prevention of possible negative impacts on human health, the environment (water, air, biota) and property. The impacts have been registered, documented and are of significant proportions.

II. Category (100-150 points)

Locations or mine zones with a transition period (in the midst of activities) where the impacts are partially defined as well as their scale, but as a result of specific factors (such as type of ore and natural conditions, changes in technology applied, cessation of exploitation of mineral materials) at the present the threat of damage is either not so critical or requires additional research to clarify the situation (with the possibility of changing category for the mine site)

III. Category (under 100 bodova)

Locations or mining zones with an apparently low impact on human health, the environment and property due to various factors, such as long-finished mining operations, temporarily interrupted exploitation operations, etc. Monitoring systems are sufficient to identify the impact or special conditions for accident management are already set there (old-new mine)

Based on results of the analysis three locations have been identified and rated as priority where environmental remediation measures have to be implemented.

1. SM “Smreka 190 points
2. SM “Veovača 205 points
3. Flotation tailings lake 181 points

3.2. Assesement of the subject locations using Preliminary Hazard Analysis method (PHA)

The authors of the paper within the subject research carried out preliminary hazard analysis (PHA) [3]

Table 3. Hazard identification and probability of risk occurences and consequences

Rb	HAZARD	PROBABILITY	CONSEQUENCES	RISK
1.	Health consequences of consuming fish from lake at SM Smreka	**Small**	**Medium**	**Small**
2.	Sliding of the western and southern slopes of SM "Smreka"	**Small**	**Medium**	**Small**
3.	Displacement of a large amount of water due to sliding and flooding downstream area	**Small**	**Medium**	**Small**
4.	Pollution of watercourses by acid water streaming out of the mine audit connected to SM "Brezik".	**Medium**	**Small**	**Small**
5.	Pollution of watercourses by washing out ore deposits from benches of SM "Veovača".	**Medium**	**Small**	**Small**
6.	Pollution of surface and ground waters by toxic materials from abandoned surface mines	**Medium**	**Medium**	**Medium**
7.	Pollution of soil and air by dust from tailings disposal sites and surface mines	**Medium**	**Medium**	**Medium**
8.	Soil pollution by leachate at overburden and tailings disposal sites.	**High**	**Medium**	**High**
9.	Further impact on the flora and fauna at the location of the breakage of the transport troughs and spillage of flotation waste	**High**	**Medium**	**High**
10.	The destruction of aquatic life, and the impossibility of using watercourses for water supply and recreation, which is associated with the change in water color due to the introduction of iron hydroxide salts and others.	**Medium**	**High**	**High**
11.	Health problems caused by the intake of heavy metals into the organisms.	**Small**	**High**	**Mediu m**
12.	Wind carrying toxic dust from the dam along the lake towards the settlements	**High**	**Small**	**Mediu m**
13.	Soil pollution with heavy metals, such as: Cu, Pb, Cd. Ni and As on the site of abandoned processing plant of lead, zinc and barite, due to leaching and transport down the slope	**High**	**High**	**High**
14.	Risk of landslides and destruction of tailing dam.	**Medium**	**High**	**High**
15.	Pollution of watercourses in the case of the dam breakage and spillage of water and sediment for the tailing pond due to toxicity from copper, zink, led, cadmium, arsenic and nickel.	**Medium**	**High**	**High**
16.	Raise of water level and overflow of water across the tailing dam in the case of clogging of vertical shafts for intake of water that stream down into the tailing pond.	**Medium**	**High**	**High**

4. PROPOSAL OF MEASURES TO REDUCE ENVIRONMENTAL IMPACTS ON THE RESEARCH POLYGON

Results of the given analyses clearly indicate the locations with pottentially greatest environmental impacts [6]. It concerns SM „Smreka“, SM „Veovača and water accumulation with flotation tailings. The situation at the sites, the key results of the research, the proposed remediation plan and the estimated costs of remediation are given in Tables 4, 5 and 6. Taking into account that the situation at the research polygon is complex and a comprehensive approach requires the readiness of institutions, the involvement of experts from various disciplines and a financial support, the proposed remediation plan, aimed at mitigating environmental impacts, authors also took into account the findings of previously conducted research including the master plan of the Japanese International Cooperation Agency (JICA) related to hotspots in the Federation of Bosnia and Herzegovina [7].

4.1 . The lake at SM „Smreka“ PK "Smreka"

Table 4. Status and proposed solutions -SM „Smreka“

Category	Summary
Status of the site	The 116 m deep lake was formed in the crater of the abandoned surface mine, as an accumulation of rainwater and undergorund water The surface of the lake is about 132.000 m^2. After the site was abandoned no rehabilitation measures were taken. Mining machines were abandoned within the mine area, which were then submerged after the formation of the lake. Around the lake there are several abandoned buildings and some equipment that were used during the mine operation.
The main findings	*Water quality:* - Concentration of heavy metals are high in some places, but not higher than those found in the close vicinity. *Sediment quality:* - Concentration of some heavy metals are higher than Canadian PEL values (Probable Effect Level), but analysis of samples taken from the local environment exceeded PEL. [11]
Proposed remediation plan	The proposed measures consist of (I) Development of a detailed project (II) Biological remediation. It is possible that a technical remediation would be required before the biological. In addition a regular monitoring is suggested. In the period ahead it will be neccesary to carry our regular visual control of the benches at surface mine and waste dumps in order to detect in time possible deformations (cracks, local separation of rock massifs, landslides, etc) and other potential hazards. The rough estimate of remediation costs is 350.000 KM. [6]

3.3. SM "Veovača" lead, zink and barite mine

Upon cessation of work operations, both, at the surface mine „Veovača“ and preparation/processing plant the facilities and equipment were left unattended. As the result of exploitation interruption open benches remained at the surface mine, and the ores from the deposit are exposed to erosion, washing, consequent dust dispersion, etc.

The facilities and equipment at the "Tisovci" processing plant were abandoned without implementing required cleaning, conservation and preparation measures for such a long stoppage in production. During the war, part of the equipment was stolen and in the post war period , the remaining equipment was scrapped and sold as scrap metal.
At the same time, a certain amount of finished products (lead, zinc and barite concentrates in bulk or packed in paper packing) and raw materials remained in the warehouse and at the depot.
At the time of the research, the surface soil at the site of the abandoned factory for processing of lead, zinc, and barite was heavily contaminated with heavy metals, namely: Pb, Cd, Ni and As even though most of the dangerous substances were previously removed from the site. [6]

Table 5. Status and proposed solutions -Ore processing plant site

Category	Summary
State of the site	The parts of the plant have been partially or completely demolished, water is still present in several settling tanks, and they can be used if needed in future in case of reinstatement of production process. There are some remains on the plateau of the plant (uselles waste) and part of the products, exposed to washing and carrying/draining down the slope.
The main findings	*Surface soil:* - Cd max. 27,3 mg/kg (Maximum allowed concentration MAC - 10 mg/kg). - Pb max. 3.005 mg/kg (MAC - 500 mg/kg). - Concentrations of Ni, Zn, Mn i As are above permissible levels as well. [3]
Proposed remediation plan	Proposed measures include: (I) development of the remediation plan, (II) decommissioning and demolition of the remaining buildings, (III) extraction and disposal of contaminated land. The rough estimate of remediation costs - 920.000 KM. [6]

Given that the exploitation and processing operations were stopped but that there is an intention to reinstate the production it would be necessary to:

- Analyse posibilites for future ore exploitation/production,
- Create project documentation for the continuation of exploitation and/or rehabilitation of the existing parts of the processing plant, along with technical and biological reclamation of the devastated area of the surface mine and the external disposal site. [10]

The site has recently been taken and operated by a mining company, and there is a possibility that the contaminated land could be processed if the processing plant is rehabilitated. Since then certain activities were carried out including: demolition of the remaining facilities for ore processing, removal of construction waste materials, new processing plant was built. Future plan should include technical and biological reclamation with a special attention paid to water protection.

3.4. Accumulation with tailings from flotation process

An earthen dam for tailings from the processing plant of lead, zink and barite ores was used to retain tailings generated during the flotation operations. It concerns a lake with a significant volume of accumulated water separated after the setlling process. Upon the cessation of concentrate production, it represents a potential environmental threat especially for water courses belonging to Bosna river basin. The crown of the dam is damaged by wind erosion. In addition to surface erosion, traces of furrow and ditch erosion are evident, see figure 7. [6]

Figure 7. Ersion on the flotation tailings dam

Table 6. Status and proposed solutions – Water accumulation with flotation tailings

Category	Summary
State of the site	The dam was designed and built as a homogenous dam, constructed with a 15 m high centered core made of clay and filled with stone. The crown of the dam is damaged by wind and water erosion. [6]
The main findings	*Water quality:* - Concentration of Cd, Pb, Cu and Zn exceeded the quality criteria for surface waters in FBiH, but are still close to acceptable limits, and it is assumed that these concentrations are caused by natural phenomena, and the deposition of constituent particles. *Soil and sediment on the dam:* - Concentration of Cd, Pb, Cu, Zn and As exceeded maximum allowed concentrations several times. [3]
Proposed remediation plan	The proposed measures consist of : (I) geotechnical examniation, (II) detailed project, (III) construction and related works, and other measures required for rehabilitation of the dam along with constrcution of two peripheral water draining channels The rough estimate of remediation costs is 570.000 KM.

The earthen dam is considered the greatest threat therefore its rehabilitation is required urgently.

CONCLUSION

The focus of the research paper is on the environmental impacts of mining activities in Vareš area interrupted by the previous war in BiH, and further taking into account post-war unsettled state in the entire country and a noticable tehnical-technological legging behind the world trends. A wider area of polymetallic deposits, with underground and surface exploitation

facilities was determined to be the research polygon primarily due to interest in state of environment affected by the mining oeprations.
Based on the previosly conducted analyses by the authors of the paper that included status of remaining facilities, surface mines, undeground mine, then the degree of water and soil pollution as well as the assessment of environmental risks [3], the paper presents a proposal of measures to reduce environmental impacts, whereby special attention is directed to several key locations as follows: SM „Smreka and the lake created in the crater of the mine, SM „Veovača and the relating plant for ore processing and packing, and water accumulation with flotation tailings.
As for the results concerning the SM „Smreka, concentration of heavy metals in the lake formed in the crater of the surface mine, as well as in the sediment is high at certain spots . Rough estimate of remediation costs for this location amounts to 350.000 KM. The research results relating to the location of the ore processing and packing plant at SM "Veovača" show that the content of heavy metals in the soil exceed the permitted limits many time over, especially when it comes to cadmium and lead contents. For the proposed remediation measures it would be necessary to alocate 920.000 KM. The analysis of water in the water accumulation with flotation tailings shows that the concentration of certain heavy metals exceeded the maxium permitted limits, while their value on sediment in the sediment samples taken from the dam of the water accumulation was exceeded several times. The approximate costs of remediation are estimated at 570.000 KM.
Test results with significantly exceeded limit values of certain parameters indicate that dangerous sites require urgent remediation measures. Rehabilitation of the dam at the flotation tailings water accumulation is considered the most urgent measure to be taken, since in the case of the dam collapse the consequences could be catastrophic possibly endangering some water courses that are in the catchment area of drinking water for Breza town.
European legislation set ambitious goals for environmental protection, and requires harmonization of domestic legislation with related EU legislation. The EU legislation is flexible in terms of the way to achieve the set goals as well as in terms of the organization and ownership of assets and financing of the necessary activities. The positive aspects of EU legislation are also reflected in the provision of a solid basis for long-term planning at the technical, financial and political level. Also, the positive side is the increased degree of civil society involvement, which provides a „living" example of good european governance.
Much more attention must be paid to environmental management, since it represents the key to transition to sustainable development.

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THE IMPACT OF MACROECONOMIC FACTORS ON THE PERFORMANCE OF COMPANIES IN THE MINING AND STONE EXTRACTION SECTOR

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Summary

The aim of this research is to examine the impact of macroeconomic factors on the business performance of companies in the mining and stone extraction sector in the Federation of Bosnia and Herzegovina. The research was conducted over a four-year period from 2020 to 2023. Business performance was observed through profitability, measured by return on total assets. The results of the research showed that macroeconomic variables, such as GDP growth rate and unemployment rate, are significantly related to return on total assets in companies that achieve a positive business result, primarily in companies from the subsector of metal ores extraction, other ores, and stone. On the other hand, no such connection was found in companies that operate at a loss, which mostly pertain to coal mines. The reason lies in the fact that the problems of coal mines in Bosnia and Herzegovina are primarily the result of internal and long-standing structural factors, rather than changes arising from the macroeconomic environment.
Keywords: *macroeconomic factors, business performance, profitability, return on total assets, companies in the mining and stone extraction.*

INTRODUCTION

The mining and stone extraction sector in Bosnia and Herzegovina (B&H) traditionally plays a significant role in the country's economy, with a special emphasis on providing energy resources, primarily coal for thermal power plants, thereby contributing to the stability of the overall energy system in B&H [9]. According to data from the Statistical Institute of Bosnia and Herzegovina for 2023, thermal coal power plants produced 56% of the total electricity in the country, while in 2022, this share was even higher at 65.34%. However, the sector faces numerous challenges that threaten its sustainability and competitiveness in both domestic and international markets.

The last four years have been marked by significant instabilities at local, state, regional, and global levels. In an economic context, these instabilities are reflected through volatility and pronounced fluctuations in macroeconomic indicators. A stable macroeconomic environment is essential for sustainable economic growth. Therefore, the goal of this paper is to explore whether and to what extent the fluctuations of macroeconomic variables have impacted the operations of enterprises in the mining and stone sector in the Federation of Bosnia and Herzegovina.

THEORETICAL BACKGROUND AND PREVIOUS RESEARCH

One of the key criteria for assessing the success of company management is the analysis of its profitability [13]. In this context, profitability is often used as a primary indicator of business performance [12]. Previous research has shown that profitability is influenced by both internal specific factors and external factors [11].

This research focuses on the impact of macroeconomic variables as external factors on the return on total assets (abbreviation: ROA). ROA is a profitability indicator that reflects a company's ability to generate returns based on all available resources and is interpreted as the rate of return achieved on total assets [13].

Macroeconomic variables are economic indicators that measure total activity and the condition of the economy at the national or global level. They are used to analyze economic trends, cycles, and policies, and their impact covers a wide range of aspects, from production and employment to inflation and international trade. The most commonly analyzed variables include gross domestic product (GDP), inflation, unemployment, and interest rates.

GDP reflects the total market value of all goods and services produced within a country over a specific period. In the mining sector, strong economic growth is typically accompanied by an increase in demand for mining products, which can positively impact the profitability of mining companies. On the other hand, inflation can significantly affect profitability by increasing operational costs due to rising prices of raw materials and labor, which can have a negative effect on profit margins [12]. Interest rates, as an instrument of monetary policy, can also have an impact on the profitability of companies. An increase in interest rates results in higher borrowing costs, which reduces the ability to invest and increases overall business expenses [12]. Previous research conducted on a sample of companies from the mining sector has shown a connection between interest rates and economic growth with the return on total assets, while no significant impact was established for inflation [12]. Furthermore, research shows that an increase in corporate profitability is associated with a decrease in the unemployment rate, where profit growth leads to a reduction in unemployment [8].

METHODOLOGY AND RESULTS OF THE RESEARCH

General economic data about the sector

According to the Standard Classification of Activities in Bosnia and Herzegovina (2010), the mining and stone extraction sector consists of four subsectors:

(a) coal and lignite extraction;
(b) crude oil and natural gas extraction;
(c) metal ores extraction; and (d) other ores and stone extraction.

Preliminary data from the Agency for Statistics of Bosnia and Herzegovina indicate that the value of sold products in this sector in 2023 amounted to 1.08 billion BAM. The structure by subsectors is presented in the table below.

Table 1. Value of industrial products sold according to NIP in 2023 – Mining and stone extraction sector [2]

T1. VALUE OF INDUSTRIAL PRODUCTS SOLD ACCORDING TO NIP, 2023	
Activity	*Total production value of sale and fee paid value (0+1)*

level		2023
	TOTAL	**2.275.530**
B	**MINING AND STONE EXTRACTION**	**1.079.766**
05	Coal and lignite	750.297
07	Metal ores	171.284
08	Other ores and stones	158.185

The largest share of the total value of sold products in the mining and stone sector is accounted for by the coal and lignite mining subsector, which makes up 69.5 %. This is followed by metal ores mining with a share of 15.9 %, while the extraction of other ores and stones contributes 14.65 %.
The coverage of imports by exports in the metal ores subsector significantly exceeds imports, while in the subsector of other products from ores and stones, it is also at high levels (table 2).

Table 2. Coverage of imports by exports – Mining and stone extraction sector [1]

Coverage of imports by exports - mining and stone in B&H					
	2020	2021	2022	2023	Average
Coal and lignite	5,64%	4,01%	12,57%	24,24%	11,62%
Metal ores	994,03%	440,39%	197,68%	294,43%	481,63%
Other ores and stones	97,32%	65,69%	62,20%	79,16%	76,09%

According to the data from the Financial Information Agency (FIA), in 2023, there were 152 companies operated in the mining and stone extraction sector in the Federation of B&H, accounting for 69.72 % of the total number of companies in this sector at the state level. These companies employed a total of 11,341 people and generated 748 million BAM in revenue, which constitutes 60.67 % of the total revenue in the sector at the state level (table 3).

Table 3. Structural statistics of the mining and stone extraction sector – Federation of B&H, 2023 [6]

	Number of business entities	Employees	Revenues (mil.BAM)	Export revenues (mil. BAM)	Number of profitable business entities	Total profit	Number of loss-making business entities	Total loss
Federation of B&H	152	11341	748	71	79	39	62	190
Share in total business sector of the Federation of B&H in which business entities operate	0,57%	3,08%	1,08%	0,71%	0,44%	0,73%	0,85%	14,84%

In the year 2023, in the territory of the Federation of B&H, 79 companies (52 %) recorded a profit, while 62 companies (40.1 %) operated at a loss. The total losses of these companies account for nearly 15 % (14.84 %) of the total loss recorded in the entire economic sector of the Federation of B&H, and are mostly related to companies in the coal extraction sub-sector. According to FIA data for 2023, seven coal mining companies generated a loss of 144 million BAM, which accounts for nearly 76 % of the losses for the entire sector at the level of the Federation of B&H.

Sample methodology

The research was conducted from the year 2020 to the year 2024 on a sample of companies that contributed the most to the results of the sector at the level of the Federation of B&H in terms of revenue, share in sector assets, and share in total profit/loss of the sector. The business data of the companies were taken from the official statistical bulletins on company operations from the website of the Financial Information Agency – FIA [6].

Table 4. Overview of the structure of companies included in the research sample – compiled by the author [6]

Description	**2020**	**2021**	**2022**	**2023**	**Total**
Number of observation units	35	35	35	35	140
Sample companies' revenue (mil BAM)	560	561	630	687	2,437
Total sector revenue (mil BAM)	635	571	654	748	2,608
Share of sample companies' revenue in the sector	**88.20%**	**98.16%**	**96.26%**	**91.85%**	**93.45%**
Asset value (mil BAM)	1,756	1,84	1,906	2,193	7,695
Total sector assets (mil BAM)	1,95	2,125	2,198	2,366	8,639
Share of sample companies' assets in the sector	**90.03%**	**86.60%**	**86.73%**	**92.67%**	**89.07%**
Sample companies' profit (mil BAM)	22	18	24	35	100
Total sector profit	23	23	30	39	115
Share of sample companies' profit in sector profit	**96.03%**	**79.75%**	**80.66%**	**89.68%**	**86.61%**
Sample companies' loss (mil BAM)	-82	-109	-131	-186	-508
Total sector loss	-85	-116	-136	-190	-527
Share of sample companies' loss in sector loss	**96.03%**	**94.01%**	**96.00%**	**98.08%**	**96.32%**

The presented data shows that this is a representative sample, considering that the companies in the sample accounted for almost 94 % of the total sector's revenue, had a share of 89.07 % in the sector's assets, and generated 86.61 % of the profit, but also 96.32 % of the sector's losses.

Definition of dependent and independent variables

The dependent variable in this research is the return on assets measured by the ratio of net profit achieved at the end of each observed period to the total assets of the observed companies [13]. The independent variables in this study are the GDP growth rate, inflation rate, interest rates on loans to businesses, and the unemployment rate. Data on the movement of the GDP growth rate, inflation, and interest rates on businesses were taken from the statistical bulletin of the Central Bank of B&H [5], while data on the unemployment rate were sourced from the statistical bulletin of the Agency for the Promotion of Foreign Investments in B&H [3].

Research Findings and Discussion

The research was conducted: (a) at the level of the entire sector (Model 1), (b) at the level of the sample of companies that operate positively and mostly (24/25) relate to companies from

the subsector of metal ores extraction and other ores and stones (Model 2); and (c) at the level of companies that operate negatively and mostly relate to coal mines (7/10). Coal mines operate in the subsector of coal and lignite extraction (Model 3).
The data were processed using the Excel Data Analysis Toolpak, employing both descriptive statistics and multiple regression analysis.
Descriptive statistics provide a summary of the dataset, making it easier to understand, interpret, and use for further analysis [11]. The results of the descriptive analysis for the dependent variable, return on assets (ROA), across each specific model are presented below:

Table 5. Descriptive Statistics Results for the Dependent Variable

	Model 1	Model 2	Model 3
Mean	0,02903	0,099618	-0,14699
Standard Error	0,015233	0,013382	0,024764
Median	0,020391	0,051817	-0,10032
Mode	0,03	0,03	-0,05841
Standard Deviation	0,180877	0,134486	0,158568
Kurtosis	4,954946	3,444089	7,927596
Skewness	-0,31563	2,036349	-2,68812
Minimum	-0,80455	0	-0,80455
Maximum	0,569853	0,569853	-0,01887
Count	140	100	40

From the observed data, a total of 140 units (Model 1) were analyzed. Out of these, 100 units (Model 2) achieved a positive return on assets (ROA), while 40 units (Model 3) reported a negative ROA. Return on assets (ROA) reflects how efficiently a company utilizes its assets to generate profit. At the sector level, the average ROA is slightly above zero (Mean Model 1 = 0.029). At the company level, results differ significantly between subsectors: Model 2 companies, which are predominantly engaged in metal and stone ores extraction, recorded an average ROA of 0.10 (0.099618). Model 3 companies, mostly coal mines, showed a negative average ROA of -0.15 (-0.14699). This indicates that companies in the metal ores, other ores, and stone extraction subsector are relatively efficient in asset utilization, generating approximately 0.10 BAM of profit for every 1 BAM of assets employed.

Table 6. Descriptive Statistics Results for the Independent Variable

	GDP	Inflation	Unemployment rate	Interest rates
Mean	0,026085	0,052305	0,15478	0,03522
Standard Error	0,003271	0,004764	0,001268	0,000314
Median	0,022	0,02	0,159	0,0379
Mode	-0,032	-0,01	0,159	0,038
Standard Deviation	0,038846	0,056574	0,01506	0,003731
Kurtosis	-1,11228	-1,13609	-1,00561	-0,76449
Skewness	-0,37899	0,549826	-0,34482	-1,02824
Minimum	-0,032	-0,01	0,132	0,0289

Maximum	0,074	0,14	0,174	0,038
Count	140	140	140	141

The average value of the GDP growth rate during the research period was 2.61 % (Mean = 0.026085), inflation was 5.23 % (Mean = 0.052305), unemployment was 15.48 % (Mean = 0.15478), and interest rates were 3.52 % (Mean = 0.03522).
Before conducting multiple regression, a correlation analysis between the independent variables was performed to avoid the problem of multicollinearity. The problem of multicollinearity is present if at least two regression variables are linearly dependent or approximately linearly dependent [4].

Table 7. Results of Correlation Analysis Between Independent Variables

	GDP	Inflation	Unemployment rate	Interest rates
GDP	1			
Inflation	0,39514557	1		
Unemployment rate	0,32599316	-0,3390821	1	
Interest rates	**-0,806393**	0,14625509	**-0,764323**	1

Interest rates on loans to companies have a significant negative high correlation with GDP (the correlation coefficient is greater than 0.8; = -0.806393) and a medium strong (the correlation coefficient is greater than 0.5) correlation with the unemployment rate (-0.764323), therefore they are excluded from further analysis to avoid distorting the regression results. A correlation coefficient from 0.5 to 0.8 implies a medium strong correlation and over 0.8 implies a strong correlation [10].

Table 8. Regression Analyses Results

	Model 1 - Total sector				Model 2 - Companies -Metal ores exploitation and other ores and stones				Model 3 - Companies - Lignit and coal exploitation			
Multiple R	0,19				0,33				0,30			
R Square	0,04				0,11				0,09			
Significance F	0,16				0,01				0,32			
Observations	140,00				100,00				40,00			
	Coeff	*StErr*	*t Stat*	*P-value*	*Coeff*	*StErr*	*t Stat*	*P-value*	*Coeff*	*StErr*	*t Stat*	*P-value*
Intercept	0,41	0,19	2,20	0,030	0,68	0,18	3,88	0,000	-0,14	0,26	-0,56	0,580
GDP	0,05	0,47	0,10	0,921	0,74	0,43	1,73	**0,087**	-0,70	0,65	-1,08	0,286
Inlation	-0,30	0,32	-0,93	0,353	-0,38	0,30	-1,26	0,211	-0,34	0,43	-0,78	0,440
Unemployment rate	-2,32	1,18	-1,97	0,051	-3,72	1,11	-3,37	**0,001**	0,35	1,65	0,21	0,832

From the presented data, it can be concluded that in Model 2, the macroeconomic variables GDP and unemployment are statistically significant, with unemployment significant at the 5 % level and GDP at the 10 % level. The significance test (Significance F = 0.011) shows that this model is statistically significant, meaning that the macroeconomic variables are relevant for explaining the variation in returns on invested capital in companies that are operating positively and mostly relate to the subsector of metal ores extraction, other ores, and stone. The movement of GDP and unemployment rates significantly explains the variation in returns on assets for these companies. On the other hand, for Model 1 (total sector) and Model 3, macroeconomic variables are not statistically significant. In Model 3, which primarily pertains to coal mines, it is possible that other factors such as long-standing structural issues in the sector (high fixed and operational costs, complex management, and lack of investment) have a more significant impact on the operations of these companies compared to the movement of macroeconomic variables. It is also evident that the results of this model were reflected in Model 1, which comprises the entire sector, which is not unexpected as the losses of coal mining companies exceed almost four times the total profit of the sector (144 million BAM in losses / 39 million BAM in profit) at the level of the Federation of Bosnia and Herzegovina. The factors that impact their operations at the total sector level are more significant than the macroeconomic variables that affect companies operating positively and are mostly related to the subsectors of metal ores extraction, other ores, and stone.

CONCLUSION

This research analyzed the impact of macroeconomic variables on the business operations of companies in the mining and stone extraction sector in the Federation of Bosnia and Herzegovina. The results showed a significant correlation between the unemployment rate and GDP with the return on assets for companies that achieve a positive business result. In contrast, for companies that operate at a loss, most of which are coal mines, such a connection was not established. Their operations depend more on internal specific factors than on the macroeconomic variables analyzed in this study. Also, at the overall sector level, no significant correlation was found between macroeconomic variables and return on total assets, indicating that specific factors related to coal mines have spilled over to the entire sector. Inflation, as a macroeconomic variable, was not significant in any sample, even though its rates were high during the research period (the average rate was 5.2 %).

The mining sector in B&H faces numerous challenges, particularly in the coal mining segment, but at the same time offers potential for development and transformation. Achieving greater competitiveness and sustainability requires investment in the modernization of production capacities, restructuring loss-making enterprises, applying green technologies, reducing emissions of harmful gases and substances, and optimizing operational costs. On the other hand, significant potential lies in the extraction of metal ores and other ores and stones, as confirmed by the export data of these raw materials (table 2).

The recommendation for further research is to expand the analysis to specific factors that affect the business of companies in this sector, as this study was limited solely to investigating the impact of macroeconomic variables on return on total assets.

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ANALYSES OF THE INFLOW AND RUNOFF FOR THE CATCHMENT AREA USING THE EXAMPLE OF THE MODRAC RESERVOIR

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Summary

The main task of the multi-purpose reservoir "Modrac" is to regulate the water regime in a given basin while making decisions on the amount of water released, as well as the amount of water that needs to be retained for future use. Decisions are made on the basis of available data and forecast data. Since no forecast model has been developed, the operator of these complex processes must rely on forecasts that are more or less precise. In practice, dam and reservoir operators, in most cases, usually follow the rules of the curves (volume, flow, etc.), which determine the actions to be taken depending on the current state of the system. With the construction of the Modrac dam in 1964, the reservoir of the same name was formed. The primary goals were to provide technical water for industry in the Tuzla region and mitigate downstream floods, as well as recreation and other purposes. The paper presents an analysis of the runoff coefficient in the correlation of annual precipitation and mean annual inflows for the catchment area of the multipurpose reservoir "Modrac" for the period 1999 - 2024.
Keywords: multipurpose reservoir, runoff coefficient, precipitation, inflow, catchment area

1. INTRODUCTION

The current method of electricity production is the main cause, along with human activities, of climate change, while the water regime is the first to be hit, with all its consequences. Climatic changes are reflected in increasingly frequent changes in hydrological peaks, minimums (droughts) and maximums (floods). That is, high waters are increasing and occurring more frequently, while low waters and droughts last longer [1].

Hydroaccumulation "Modrac", as a multi-purpose reservoir, was created by the construction of the Modrac dam in 1964 in the Modrac strait on the Spreca River. The reservoir consists of the rivers Spreca and Turija with their tributaries. The total area of the catchment area in the profile of the dam is approximately 1189 km^2, which makes up over 60% of the entire Spreca river basin. Of the total area of the basin, the river Spreca occupies 832 km^2, the river Turija occupies 240 km^2, while the rest of the basin belongs to the accumulation of the immediate basin 117 km^2 [2].

The elevation of the normal operation of the reservoir is 200.00 m.a.s.l., the reservoir provides an average of 2.30 m^3/sec of technical water and 4.70 m^3/sec as a hydrobiological minimum for the Spreča River, looking downstream from the dam (designed state) [2].
The multi-purpose reservoir "Modrac" solves several hydrological and extremely economic aspects, such as supplying the population and industry, the cities of Tuzla and Lukavac with technical water, mitigating the flood wave downstream of the Modrac dam and reservoir, and producing electricity in a small hydroelectric power plant.
The actual amount of water in the reservoir may vary in the short term depending on rainfall and other conditions [3].
The dam serves for partial flood control, retaining the flood wave or part of the flood waters in the reservoir, especially during the peak flow, and then releasing the water through the base outlets according to the operator's established procedure [4].
Considering the latest geodetic and hydrographic measurements, the technical data of the reservoir "Modrac" are listed [5]:
- the area of the "Modrac" reservoir is 16.69 km^2,
- the total volume of the "Modrac" reservoir is 102,759,629.92 m^3,
- the useful volume of the "Modrac" reservoir is 66,522,627.23 m^3,
- the maximum depth of the reservoir is 14.94 m,
- the mean value of the reservoir depth is 5.32 m,
- the maximum width of the "Modrac" reservoir is 2,411.17 m.

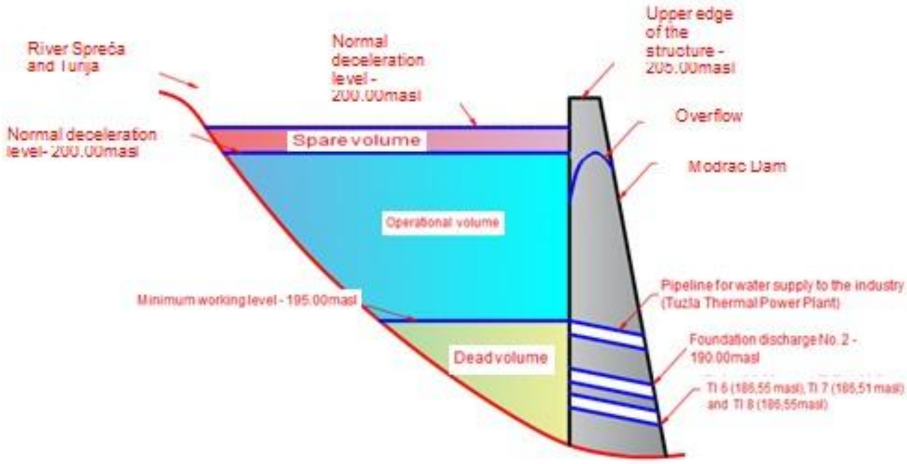

Figure 1. Characteristics of the "Modrac" dam

The "Modrac" dam is highly reinforced - a concrete arch dam with 11 buttresses, the technical characteristics of the dam are listed below, Figure 1:
- height of the structure H = 33.35 m;
- length of the dam crest L = 205.0 m;
- height of the upper edge of the dam is 205.00 m.a.s.l.;
- height of the spillway is 203.00 m.a.s.l.;
- working level of the dam is 200.00 m.a.s.l.;

- minimum working level is 194.00 m.a.s.l.;
- foundation spillways (number: 2, 6, 7 and 8). The maximum water discharge through the foundation spillways is 80.00 m^3/s [6].

The phenomenon of high water is an extreme hydrological phenomenon defined by an unusually high water level, flow or volume of water in a certain place in a certain period of time. The maximum recorded water level of the "Modrac" reservoir was 203.42 m.a.s.l. due to prolonged rainfall in May 2014.

The causes and consequences of flooding are usually unpredictable, but they can be mitigated. The consequences of floods are the endangerment of human lives and material goods, huge material damages, involvement of a large number of people and resources on the ground, social insecurity of the population [5].

Also, as a result of soil erosion in the catchment area of the "Modrac" reservoir, there is an increased production of sediment, which reaches the reservoir, which results in its deposition in the reservoir and a decrease in its useful volume.

According to literature data, the reduction in the volume of the reservoir, even 10-20 years after their construction, amounts to 20 to 30% of the general volume of the reservoir [6].

In Figure 2, the digital model (DEM) shows the catchment area of reservoir with the hydrographic network of rivers and tributaries that gravitate to the reservoir [7].

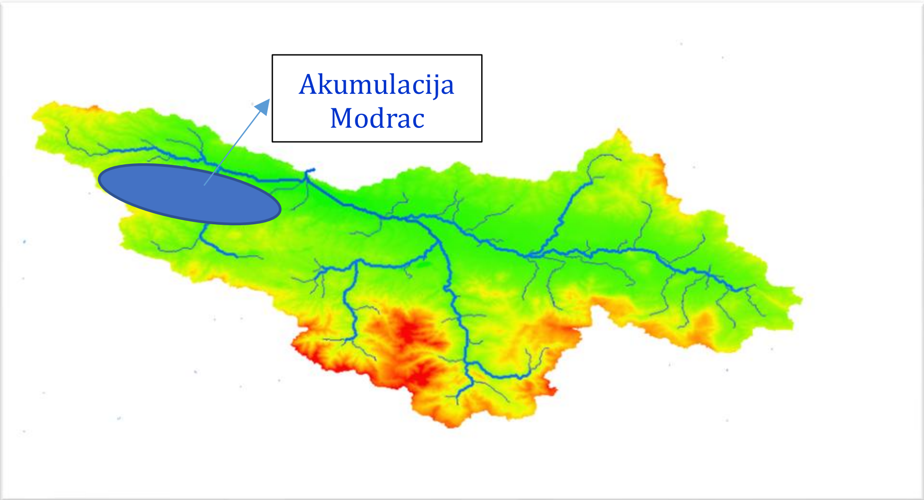

Figure 2. Map of the digital terrain model (DEM map) of the Modrac reservoir basin with river flows

The table below provides an overview of all recorded flood waves since the formation of the "Modrac" hydro reservoir until 2014 [7].

Table 1. Overview of flood waves from 1965 to 2014 [9]

The time of occurrence of the flood wave	Maximum level H	Inflow Q_{inf}	Discharge Q_{out}	Retention in the reservoir	Precipitation
	(m.a.s.l.)	(m^3/s)	(m^3/s)	%	(mm)
14.4. – 24.4. 1985.	201,09	406,50	201,10	50,53	81,16
15. 25.7. 1986.	200,74	272,10	154,90	43,07	117,57
3.5- 13.5 1987.	201,60	730,00	331,45	54,60	112,30
17.6. – 27.6. 2001.	202,12	619,10	466,36	24,56	60,20
29.5. – 8.6. 2010.	201,18	411,11	252,54	38,57	92,60
14. – 23.5. 2014.	203,42	1602,00	1137,00	29,00	213,90

Hydrograms of flood waves are determined on the basis of natural inflow into the reservoir. The discharge hydrogram is determined by the flow through the discharge facilities, the base discharges at the Modrac dam [10].
The flow is controlled via the flow curve at the downstream station Modrac.
The amount of discharge is regulated by lower discharges and overflow facilities and depends on the level of water in the reservoir. Given that the amount of flow is limited by the occurrence of large flood waves, the water level in the reservoir rises (accumulation charge), and thus absorbs part of the volume of the flood wave, i.e. reduces the maximum flow. The reduction of the maximum flow downstream ranges from 16% to 55% depending on the size of the water wave and the state of the Modrac reservoir level [9].

2. CHANGES IN PRECIPITATION AMOUNT

For a simpler overview of changes in the amount of precipitation for the period from 1999 to 2024, Figure 4. shows the maximum annual values of precipitation. Table 2 shows the mean annual precipitation values for the basin of the multi-purpose reservoir "Modrac" for the period 1999-2024.
Table 2 shows that the maximum value of average annual precipitation (1434 l/m^2) was achieved in 2014. All data on precipitation were taken from the climatological station "Modrac" (Modrac rain gauge station), which is located at the Modrac Dam.

Table 2. Mean annual precipitation for the catchment area of the multipurpose reservoir "Modrac" for the period 1999 - 2024.

Year	P_{sum} (mm)	Year	P_{sum} (mm)
1999	903.00	2012	709.47
2000	403.40	2013	850.50
2001	1021.00	2014	1392.33
2002	746.30	2015	687.10
2003	781.10	2016	989.20
2004	1037.80	2017	843.85
2005	1133.20	2018	966.50
2006	1022.52	2019	896.90
2007	928.81	2020	915.60
2008	803.20	2021	814.00
2009	850.60	2022	820.32
2010	1258.10	2023	1030.58
2011	530.50	2024	673.25

3. INFLOW TO THE "MODRAC" HYDROACCUMULATION

At the tributaries of the "Modrac" reservoir, no flow measurements were made, that is, inflow into the reservoir, and the water inflow into the reservoir was calculated from the dependence of changes in the volume and amount of water released through the main outlets and overflows, using the water balance equation. Considering the fact that the input data were measured, the calculation can be considered sufficiently reliable.

Calculation of inflow and discharge of water is based on the following equations:
1. Water balance equation: R= P – ET – IG – ΔS (1)
where: P – precipitation
R – onflow
ET – evapotranspiration
IG – deep/inactive groundwater
ΔS – changes in material/deposit

2. Inflow and outflow equations using the water balance equation:

$$\int_{t_0}^{t} Q_{inflow} dt = \int_{t_0}^{t} Q_{inflow} dt \pm \Delta V \qquad (2)$$

$$Q_{outflow} \cdot \Delta t = Q_{outflow} \cdot \Delta t \pm \Delta V \qquad (3)$$

Where is:

$$Q_{inflow} \cdot \Delta t = V_{inflow}$$
$$Q_{outflow} \cdot \Delta t = V_{outflow}$$

Q_{inflow} – the amount of water flowing into the reservoir

$Q_{outflow}$ – the amount of water released from the reservoir,
ΔV – the amount of water retained in the reservoir.

As an illustration, Figure 4 shows a typical diagram of mean annual precipitation in the reservoir, measured at the Modrac rain gauge station.

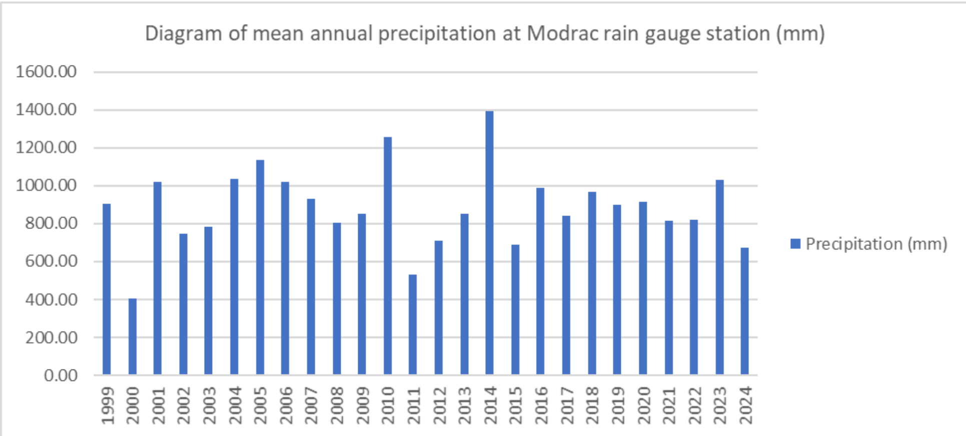

Figure 4. Diagram of average annual precipitation at the Modrac rain gauge station, from 1999-2024.

The following table shows the calculated values of the average annual inflows for the catchment area of the multipurpose reservoir "Modrac" for the period 1999 - 2024 (2).

Table 3. Average annual inflows for the catchment area of the multipurpose reservoir "Modrac" for the period 1999 – 2024.

Year	Q_{inflow} (m^3/s)	Year	Q_{inflow} (m^3/s)
1999	15.31	2012	9.53
2000	10.26	2013	12.83
2001	27.71	2014	15.98
2002	16.48	2015	16.03
2003	8.28	2016	13.48
2004	17.43	2017	14.88
2005	25.25	2018	17.10
2006	19.46	2019	15.02
2007	13.27	2020	15.51
2008	12.53	2021	8.48
2009	16.94	2022	11.78
2010	27.23	2023	17.02
2011	7.18	2024	9.28

4. COEFFICIENT OF RUNOFF FROM THE "MODRAC" ACCUMULATION BASIN

The average annual runoff coefficient η for the catchment area of the multi-purpose reservoir "Modrac" was calculated on the basis of data on the measured annual amounts of precipitation and the amount of water flowing into the multi-purpose reservoir and on the basis of the water

balance equation (1). Also, they are presented on an annual basis for the already considered period 1999 - 2024.
The average runoff coefficient η was obtained based on the following form:

$$\eta = \frac{V_{runoff}}{V_{precipitation}} \qquad (4)$$

Where is:
V_{runoff} – amount of water runoff (m^3)
$V_{precipitation}$ – rainfall (m^3)

Figure 5 shows the average runoff coefficient for the catchment area of the multipurpose reservoir "Modrac" for the period 1999-2024.

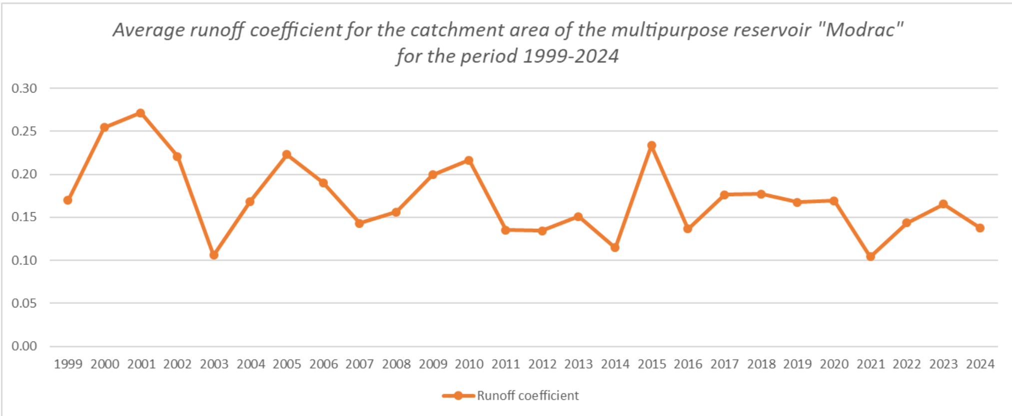

Figure 5. Average runoff coefficient for the catchment area of the multipurpose reservoir "Modrac" for the period 1999-2024.

In the continuation of the work, the functional dependence between the runoff coefficient and the calculated annual inflow (Qannual) into the multi-purpose reservoir is shown (Figure 6) and the dependence of the runoff coefficient and the annual sum of precipitation Psum (Figure 7) 1999 - 2024 is shown.

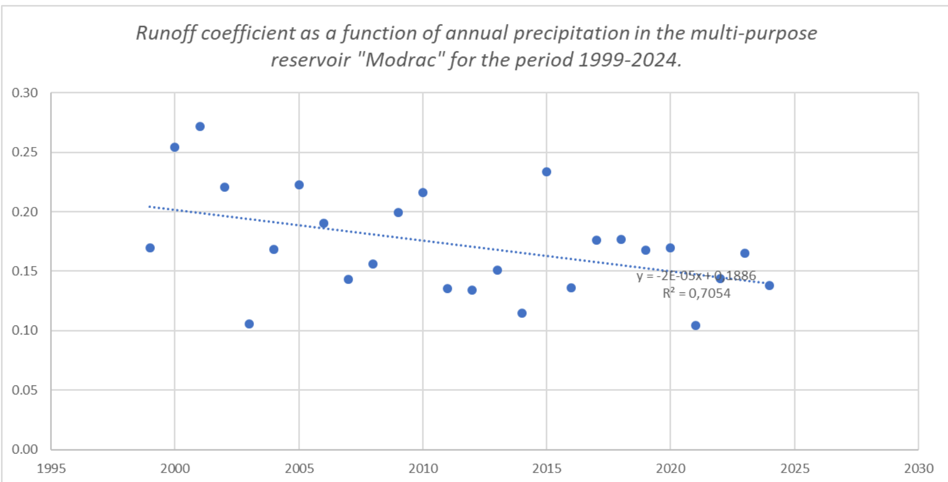

Figure 6. Runoff coefficient as a function of the mean annual inflow into the multi-purpose reservoir "Modrac" for the period 1999-2024.

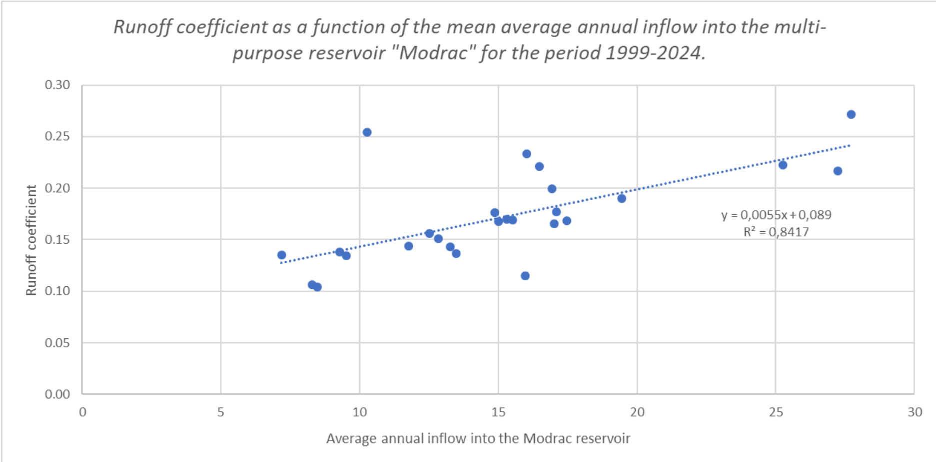

Figure 7. Runoff coefficient as a function of annual precipitation in the multi-purpose reservoir "Modrac" for the period 1999-2024.

CONCLUSION

This paper presents the runoff coefficient η in relation to the mean annual inflow into the multi-purpose reservoir "Modrac" and the annual sum of precipitation in the basin of the multi-purpose reservoir "Modrac" for the period 1999-2021. It is evident that the value of the correlation coefficient R in relation to the runoff coefficient and Qmean annual average inflow is R = 0.8417, which is a very positive correlation (Figure 6), while in relation to the runoff coefficient and the annual sum of precipitation, the correlation coefficient is R = 0.7054, which represents a positive correlative mean (Figure 7).
Also, it should be noted that the value of the mean annual runoff coefficient for the catchment area of the multi-purpose reservoir "Modrac" for the considered period was the lowest in 2002, and the highest in 2004 (Figure 5).

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ANALYSIS OF BACKFILLING BY SEDIMENTATION OF A MULTI-PURPOSE RESERVOARUSINGGIS MODELINGON THE EXAMPLE OF THE MODRAC HYDRO RESERVOIR

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Summary

Reservoirs are water management facilities that allow the regulation of the natural runoff regime. Depending on the natural characteristics of the hydrological system, the need for water and the volumetric capacity of the reservoir, and the characteristics of the evacuation organs, it is possible to manage the water resources of the basin. The increasing depletion of natural water resources and the increasing problems with meeting water needs have emphasized the need for the construction of reservoirs, often with multi-year equalization, as an integral element of integrated water resources management. Water resources management includes a number of activities such as planning, design, construction, management, maintenance, monitoring and control of constructed facilities, in order to assess and increase their efficiency. Accordingly, it is necessary to specifically plan all activities in relation to reservoirs as key facilities for managing the water regime of a basin.
Keywords: multipurpose reservoir, water resources, sediment, catchment area, sedimentation, GIS modeling

1. INTRODUCTION

The Modrac reservoir is the only available water resource in the Tuzla region and its surroundings. Bearing in mind the fact that the useful volume of the reservoir is limited, and that over time the reservoir is filled with hauled sediment and coal dust as floating sediment, and that consumers - the population, industry and others - must be provided with a water supply with a high degree of safety. Surplus water needs to be used to the maximum for the purpose of electricity production, and there is a need to optimize the system, i.e. more efficient management of the water resource of the reservoir, i.e. to prove the maximum utilization of the reservoir while constantly providing all the necessary amounts of water to which the Modrac reservoir is connected [1].

Hydroaccumulation "Modrac", as a multi-purpose reservoir, was created by the construction of the Modrac dam in 1964 in the Modrac strait on the Spreca River. The reservoir consists of the rivers Spreca and Turija with their tributaries. The total area of the catchment area in the profile of the dam is approximately 1189 km^2, which makes up over 60% of the entire river basin. Of the total area of the basin, the river Spreca occupies 832 km^2, the river Turija occupies 240 km^2, while the rest of the basin belongs to the accumulation of the immediate basin 117 km^2 [1].
With increasing and often conflicting requirements for the use of water resources, there is a need for more complex management methods, including reservoir volume management.
In some reservoirs, already 10-20 years after their construction, the sediment volume reaches 20-30% of the general volume of the reservoir [2].
The purpose of the assessment of the transfer of sediment to the hydroaccumulation is to realize the possibility of more effective management of natural water resources, protection from the harmful effects of water, as well as protection of water from pollution.
By analyzing the sediment transport at the inflow, and the total amount of sediment deposited in the Modrac reservoir, real data are obtained about the amount of sediment introduced into the Modrac reservoir, the dynamics of sediment input, and the degree of pollution of this type of water body.

2. GIS MODELING

A geographic information system (GIS) is a system for managing spatial data and the attributes associated with it. In the strictest sense, it is a computer system capable of integrating, storing, editing, analyzing and displaying geographic information. In a general sense, GIS is a "smart map" tool that allows users to create interactive questionnaires, analyze spatial information, and edit data. One of the oldest definitions of GIS is:
"GIS is a special type of information system in which the computer database includes precisely defined relationships between spatially distributed objects, activities and events, which are spatially defined as points, lines and surfaces (polygons) [3].
In GIS, the data are related to these points, lines and polygons and are thus stored for research and analysis" [3].
Modeling of the catchment area of the multi-purpose reservoir was done in the ArcGIS software package, in which all foundations and input data for the calculation were prepared, modeling of the Modrac reservoir basin and hydrological hydraulic calculation was done in ArcSWAT. In the mentioned software on the geoinformation platform (GIS) the results were obtained: the flow of the main watercourses in the catchment area of the Modrac reservoir, the saturation of the soil and the transport of sediments in the rivers and their transport to the Modrac reservoir.

3. INPUT DATA FOR THE MODEL

The input data for modeling in the ArcGIS software package, or in the GIS tool – ArcSWAT, are:

- digital terrain model,
- map of the catchment area's surface use,
- map of the pedological composition of the catchment area's soil,

- hydrometeorological data (precipitation, temperature, wind, solar insolation and air humidity).

The following figure (Figure 1) shows how the ArcSWAT software works, the required substrates and substrate analysis, and the results obtained with this approach to watershed research.

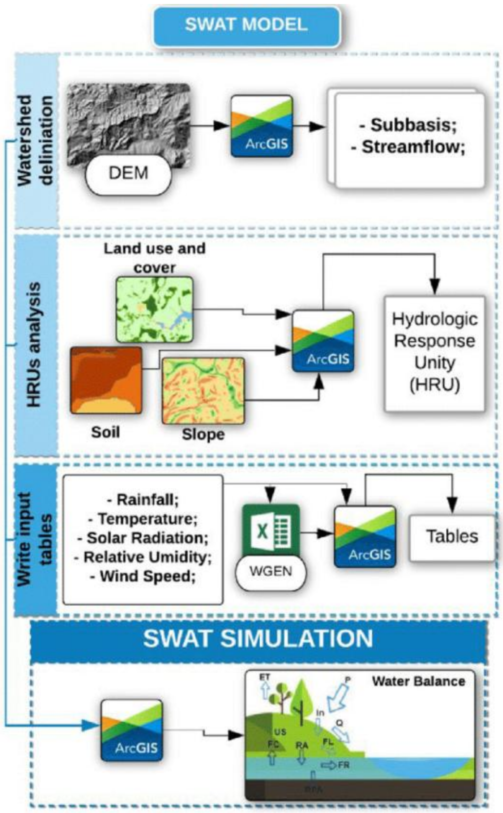

Figure 1. Presentation of the mode of operation of the ArcSWAT model [3]

The digital terrain model as one of the most important bases was downloaded from USGS Earth Explorer, the data of the digital terrain model is SRTM 30 m. SRTM 30 m is a file containing digital elevation data for an international research program, which produced digital elevation models at the global level.

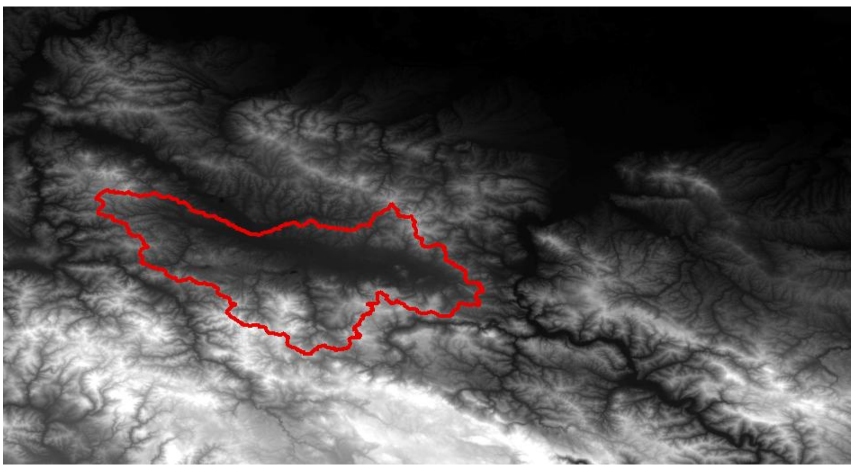

Figure 2. Digital terrain model of the wider area with the drawn boundary of the Modrac reservoir catchment area

The land use and land cover map is also a digital data map and a necessary basis for the analysis of the catchment area and for the calculation in the mentioned software package. The resolution of this map is quite high, and as of 2020 it is 10 m.

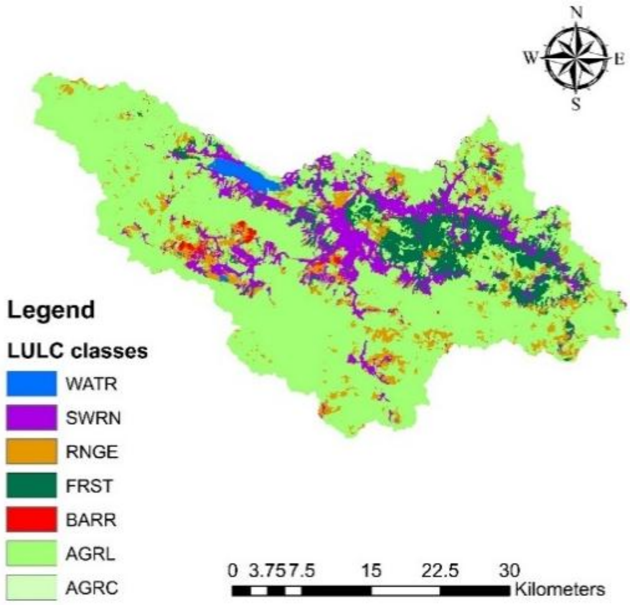

Figure 3. Land use and land cover map

Bearing in mind the available input data that are necessary for the modeling of the catchment area, in this work, data on the amount and transport of total suspended sediment were compiled for a series of 8 years, from 2014 to 2021.

The soil map is also a map with digital data and a necessary basis for the analysis of the catchment area and for the calculation in the software package ArcGIS, or ArcSWAT. For the region in question, to which the Modrac reservoir basin belongs, the soil map with pedological characteristics was taken from www.fao.org, which contains a database on pedological soil characteristics at the global level [4].

The above map contains databases related to data and maps compiled using field research supported by remote sensing and other environmental data, expert opinion and laboratory analyzes [4].

Figure 4 shows the soil map of the Modrac reservoir basin according to the dominant soil classification. The catchment area of the Modrac reservoir is dominated by three dominant soil types, namely:

- Rankers (U3-2c) indicates shallow rocks with solid or fragmented non-calcareous rocks;
- Luvisol (Lg43-2ab) are soils associated with short-term water saturation in the profiles; and
- Cambiosols (Bd66-1/2bc), are widespread soils developed on different lithologies that play a significant role in the pedological development of this relatively young soil [4].

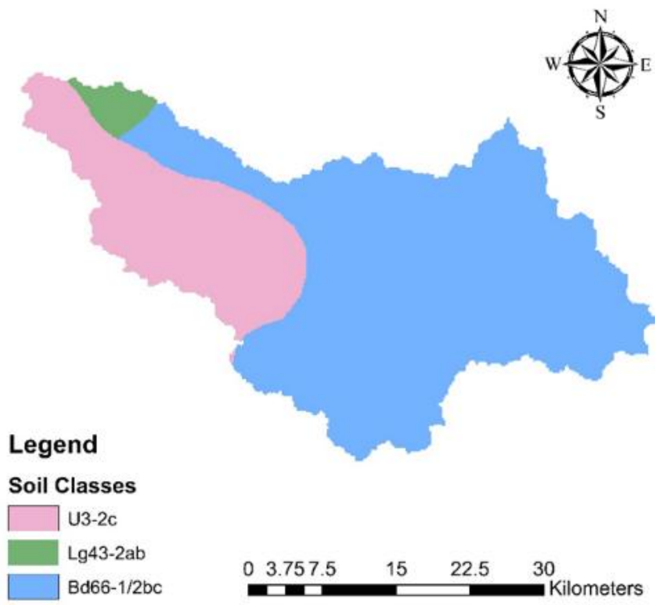

Figure 4. Soil map of the Modrac reservoir basin by dominant soil classification

Hydrometeorological data are also used as a basis for analyzing the catchment area and obtaining results about the flow in watercourses (inflow into the Modrac reservoir), sediment transport, soil saturation, nutrient input into the reservoir (organic load). Hydrometeorological data were taken for a series of 8 years (2014 - 2021) from Modrac rain gauge station.

4. MODELING RESULTS

In this paper, time steps (monthly as well as daily) were used to evaluate the SWAT model. Different evaluation parameters were used to evaluate the models and their performance as recommended by Moriasi et al. (2007), i.e.:
1. Nash–Sutcliffe efficiency (NSE),
2. graphic technique using hydrographs,
3. standard RMSE observation deviation ratio (RSR) i
4. percentage bias (Pbias).

In addition, the index of agreement (D) and coefficient of determination (R2) were also calculated and compared for all results obtained by modeling in SWAT software. The terrestrial part of the hydrological cycle is based on the water mass balance. Hydrological processes and the application of the SWAT model are simulated daily for each HRU - hydrological unit, in time steps using the following soil water balance equation [5].

$$SW_t = SW_0 + \sum_{i=1}^{n}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad (1)$$

where:
SW_t – total water content in the soil (mm)
SW_O – initial water content in the soil (mm)
R_{day} – amount of precipitation per day (mm)
Q_{surf} – amount of surface runoff per day (mm)

E_a – evapotranspiration per day (mm)
w_{seep} – amount of percolation (extraction) – raising the groundwater level (mm)
Q_{gw} – amount of groundwater (mm)

The Penman-Monteith method of real evapotranspiration as well as potential transpiration is used for the calculation. Modified method CN curves with a modified rational method are used to calculate surface and peak runoff [6].

The universal equation of soil erosion and amount of sediments was defined by Williams in 1995 [7]:

$$sed = 11{,}80 \times (Q_{surf} \times q_{peak} \times area_{hru})^{0{,}56} \times K_{usle} \times C_{usle} \times LS_{usle} \times CFRG \qquad (2)$$

where:
sed – amount of sediment (t/dan)
Q_{surf} – surface runoff volume (mm)
q_{peak} - peak surface runoff rate (m^3/sek)
$area_{hru}$ – hydrological unit area HRU (ha)
K_{usle} - soil erosion factor (taken: 0.013 t/ha)
C_{usle} - land cover and management factor
LS_{usle} - topographic factor
CFRG - coarse fragment factor.

Below are graphical results from the SWAT model in diagrams showing the relationship between precipitation as input data and sediment quantities as the result of this analysis.

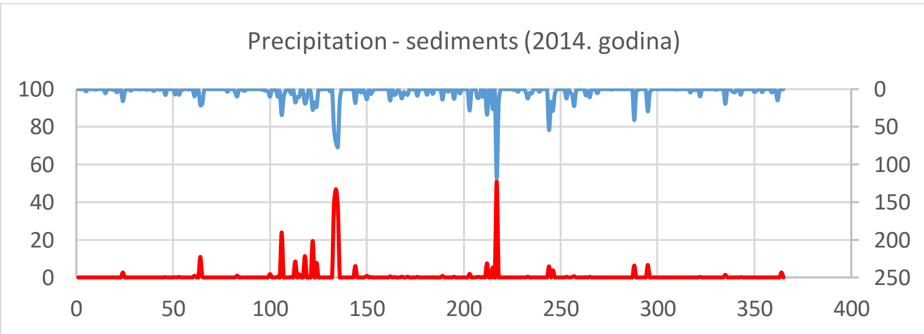

Figure 5. Diagram of precipitation and sediments in 2014

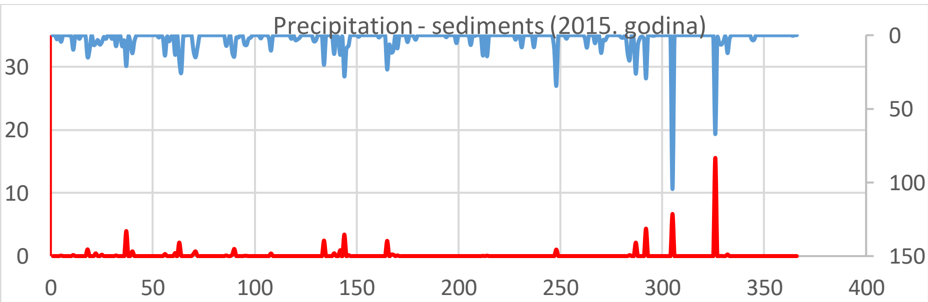

Figure 6. Diagram of precipitation and sediments in 2015

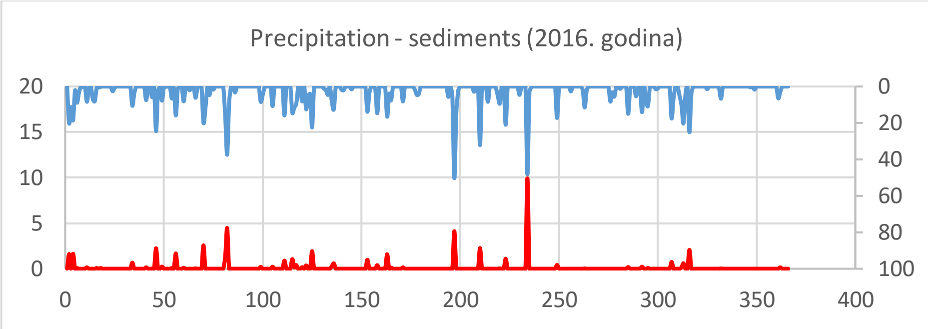

Figure 7. Diagram of precipitation and sediments in 2016

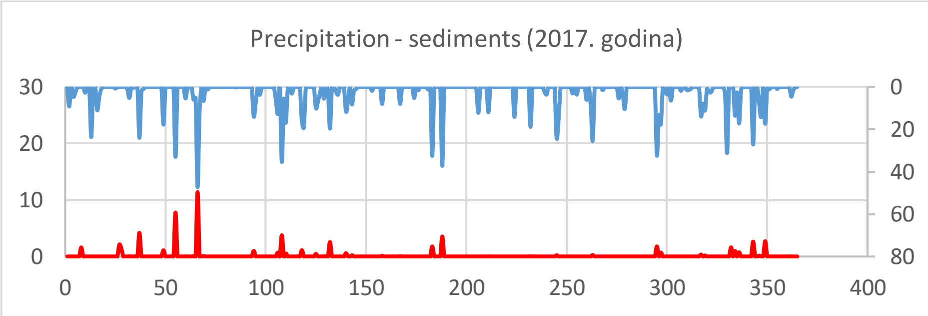

Figure 8. Diagram of precipitation and sediments in 2017

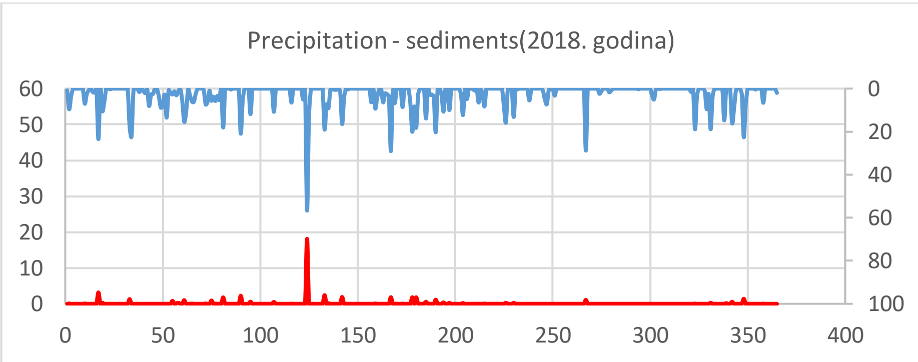

Figure 9. Diagram of precipitation and sediments in 2018

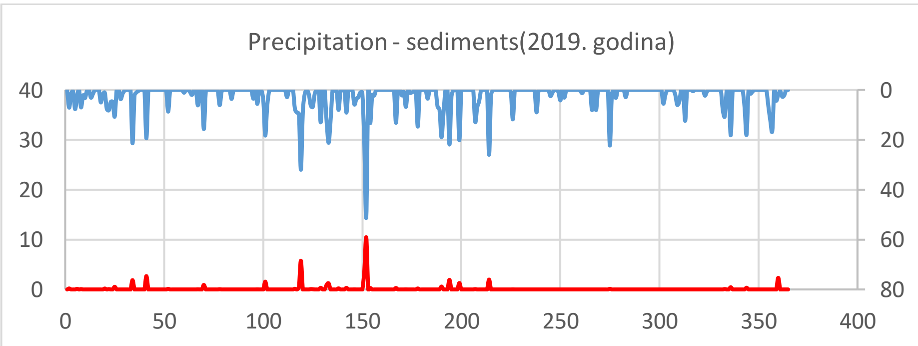

Figure 10. Diagram of precipitation and sediments in 2019

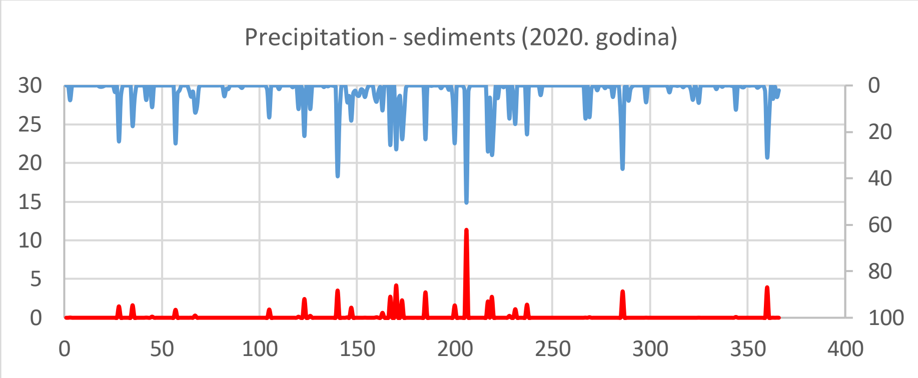

Figure 11. Diagram of precipitation and sediments in 2020

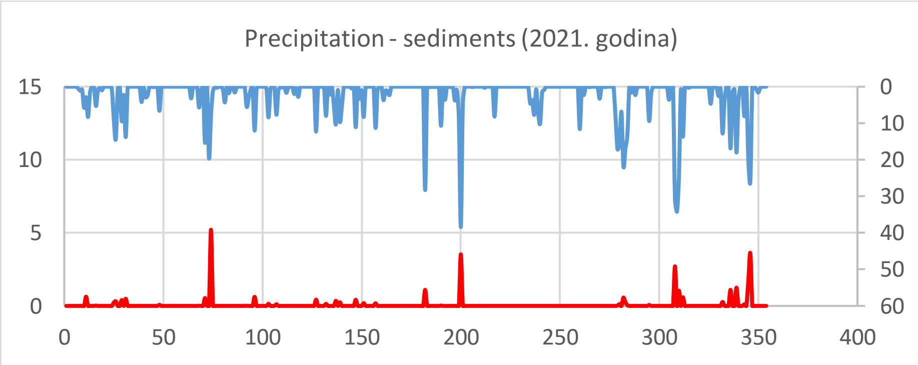

Figure 12. Diagram of precipitation and sediments in 2021

For the results obtained for the period 2014 - 2021, correlation and simple regression were performed, the relationship between precipitation and sediments (sediment), their mutual relationship shown through the Pearson coefficient R2. The stated Pearson coefficient R2 is tabulated for the period 2014-2021 [8].

Table 1. Tabular presentation of Pearson coefficient R2 for the period 2014-2021

Year	Average annual precipitation (mm)	Amount of sediment (deposit) t/ha	Pearson coefficient R^2
2014	1430,20	319,62	0,9527
2015	870,80	47,06	0,9348
2016	989,20	48,78	0,9248
2017	982,90	58,40	0,9593
2018	966,50	48,46	0,9369
2019	896,90	41,76	0,8643
2020	915,60	55,08	0,8935
2021	814,00	28,89	0,7366

CONCLUSION

This paper presents the modeling of the catchment area of the "Modrac" reservoir with GIS tools. In relation to the input data, the value of the daily amount of sediments (sediment) introduced into the "Modrac" reservoir was obtained. Correlation of precipitation as an input data and the amount of sediment as a result of this analysis, the Piroson coefficient R^2 is given, which describes their mutual connection. It is important to point out that the R^2 coefficient for 2014 is 0.9527, which is a very large positive relationship, as well as for other years in the given period. The highest Pearson coefficient was read in 2017 and is 0.9593, and the lowest in 2021, which is 0.7366 (Table 1).

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TASKS IN TORRENT CONTROL AND DETERMINATION OF THE EROSION COEFFICIENT OF THE TURIJA RIVER BASIN

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Summary

In a series of exogenous and endogenous processes that cause enormous damage almost all over the world, land erosion and torrential flows occupy a special place. Torrential flows are formed practically unnoticed and represent a mixture of a large amount of eroded material from mountainous and hilly areas, which, together with water, flows down the ravines formed at a high speed into the lower parts. These streams, which in dry weather have very little flow or their beds are completely dry, in a short period of time destroy everything in front of them, from bridges, roads, to other buildings. They fill canals and agricultural land with silt, and often endanger populated areas, often with human casualties. A true example of the above was witnessed in the destruction of settlements in the municipality of Konjic and municipality of Jablanica in October 2024, where torrential rains caused huge human losses and material damage in a few hours.

1. INTRODUCTION

Protection against erosion and torrential phenomena is the concern of all countries, as well as the wider international community. In this sense, it is particularly important to point out that at the conference on the Earth, held in Rio de Janeiro in 1992 under the auspices of the UN, the documents on the global plan Agenda 21 (program for the 21st century) were adopted, which, among other things, talks about the protection of land from the spread of erosion and flash floods, within the framework of the strategy of sustainable development and the protection of the human environment [1].

Annual damages in the world from soil erosion and torrential flows are extremely large, exceeding hundreds of millions of dollars. They can be significantly reduced and reduced to a minimum by arranging watersheds and taking the right approach to flood protection. In this case, a realistic assessment of the condition of the flood area, the implementation of efficient and complex anti-flood measures and the formation of expert teams for the prevention of flash floods are especially important [1].

The Turija river basin belongs to the Modrac reservoir basin. The Turija River in its upper and middle course, including its tributaries, is located in a mountainous area. It is characterized by a large drop in the bottom of the natural bed, which results in a high speed of water flow and water power that erodes the banks and carries a huge amount of sediment with its bed to the Modrac reservoir [2].

Figure 1. The bed of the Turija River in its middle course

The area of the Turija river basin is about 240.00 km2. It can be said that it belongs to medium watersheds according to the qualification of watersheds in hydrology [2].
In the following Figure 2, the catchment area of the Turija River is shown, taken from https://mghydro.com/watersheds/.

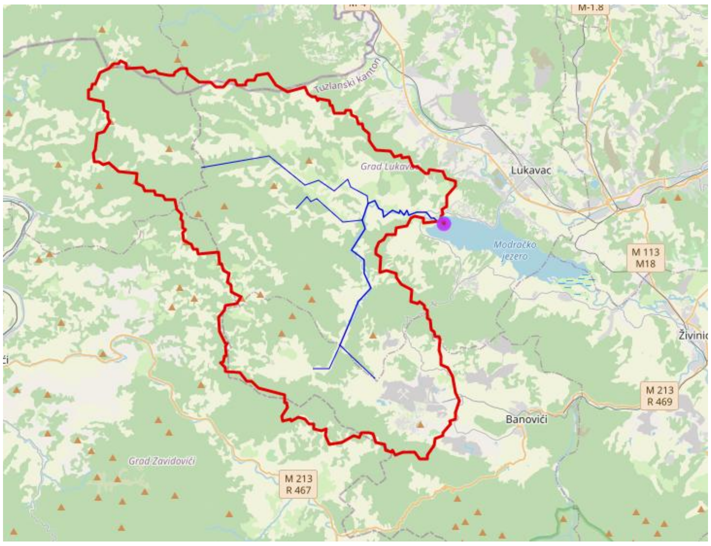

Figure 2. Turija River Basin

2. PREVIOUS RESEARCH AND WORKS

In order to prevent excessive backfilling of the Modrac reservoir with hauled sediment, several dams were built on the tributaries of the reservoir. Several such barriers were built on the Turija River, which collapsed after construction, due to poor foundations and insufficient

geomechanical research. The only two dams that still exist today are the dam on the Turija River and the dam on the Brijesnica River, which is a tributary of the Turija River.
The above-mentioned reinforced concrete dams do not perform their function for the simple reason that they are not maintained, that is, that sediment extraction on the upstream side is not carried out. The reason for this is that the dams were built in inaccessible places and the currently available construction machinery does not have access to clean it. It is important to point out that the aforementioned dams have cleaning openings of 40x40 cm size, but they are not large enough to clean the huge amount of sediment behind the dam.


Figure 3. Dam on Turija river


Figure 4. Dam on Brijesnica river

It is important to point out that during the design of the Modrac dam and hydroaccumulation, the harmful consequences of possible erosion and the occurrence of flash floods were not sufficiently investigated. The direct consequence of the above is the accelerated filling of the reservoir and its eutrophication, especially in the last few years when climate changes, uncontrolled cutting of forests, excessive construction of buildings on the basin of the reservoir, etc.

3. UNCOMMANDABLE FLOWS AND THEIR REGULATION

A frequent occurrence in practice are the so-called untamed torrents. They occur on very steep mountain slopes and have a relatively short course. Their arrangement requires extremely large and disproportionate resources, and the final effects are uncertain [2].
One of the measures in the case of an uncontrollable torrential flood that endangers the downstream area is the construction of a settling tank. One such solution is shown in the following figure 5.

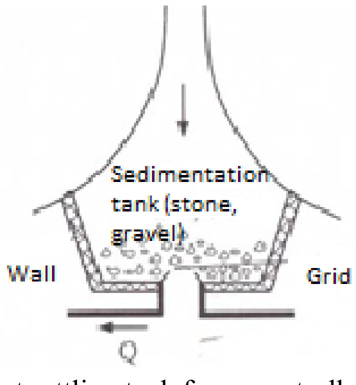

Figure 5. Sediment settling tank for uncontrollable torrential rain

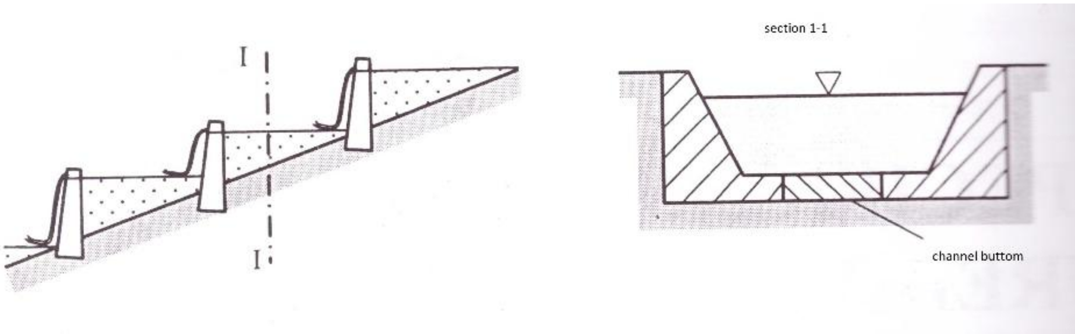

Figure 6. Regulation of an unruly torrent undermining with a trough in the form of a kinete and a series of cascades

5. LANDSLIDES AND THEIR REMEDY

In order to rehabilitate landslides, which is a common task in flood management, it is first necessary to determine the cause of the landslide. Most often, the sample is the abundance of surface and underground water, and the loose material of the slope [3].
Determining the cause of the slide is done by studying the conditions on the ground and the conditions that are present through reconnaissance, expeditionary and stationary research [3].
Basic works in landslide rehabilitation can be threefold [1]:

- regulation of surface water runoff,
- regulation of the underground water regime i
- formation of support in the lower part of the unstable slope.

If it is a flood of underminers on the side of which a landslide appeared (Figure 7). As a remedial measure, a transverse building (Figure 8) is considered, which should be used to establish the equalization drop.

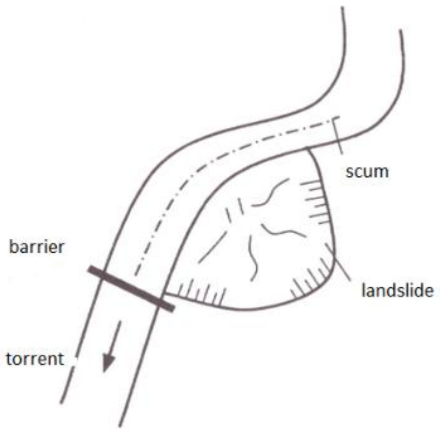

Figure 7. Landslides during torrential rain

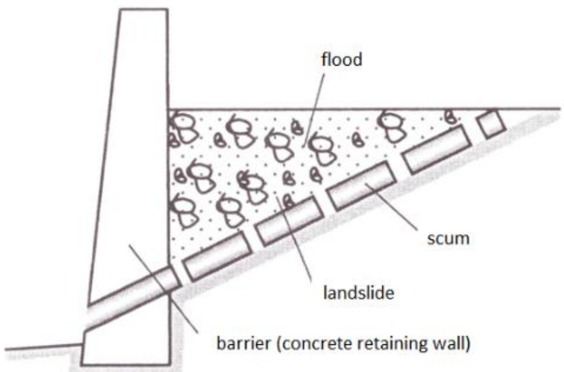

Figure 8. Remediation of landslides within the framework of flood control by means of a flood barrier

If it is a deep landslide, its rehabilitation requires a huge investment with a rather uncertain construction effect. In this case, the solution is often to cut a new torrent bed (Figure 9) or even tunnel it (Figure 10) [1].

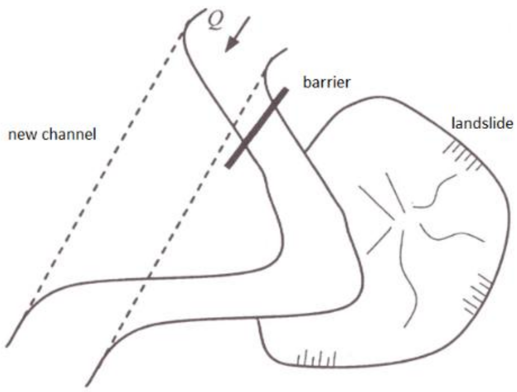

Figure 9. Avoiding landslides by building a new torrential riverbed

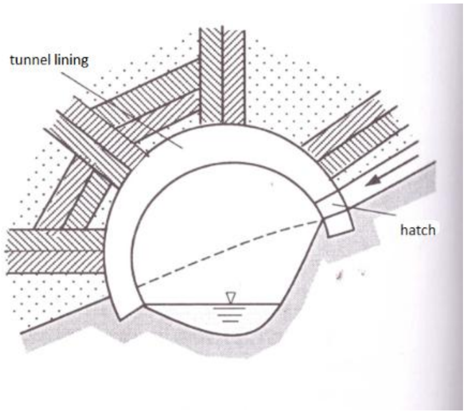

Figure 10. Tunnel method of breaking through a new torrent bed

6. MICRO ACCUMULATION AND RETENTION

Micro accumulations and retentions are very important hydrotechnical objects in the integral arrangement of the water regime, and therefore very important in the fight against erosion, flash floods and drought [4].

Small reservoirs can, in addition to being single-purpose, also serve the needs of irrigation, fishing, tourism and the like when they have a multi-purpose character.

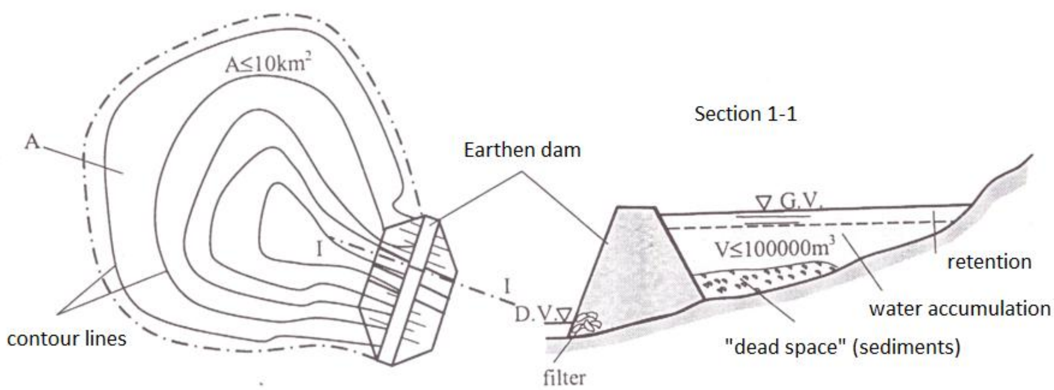

Figure 11. Presentation of one micro accumulation and characteristic parts of the volume on the upstream part of the dam

It is also important to point out an efficient solution with embanked dams, which are actually strong embankments that are maintained by gravity against external forces [4].

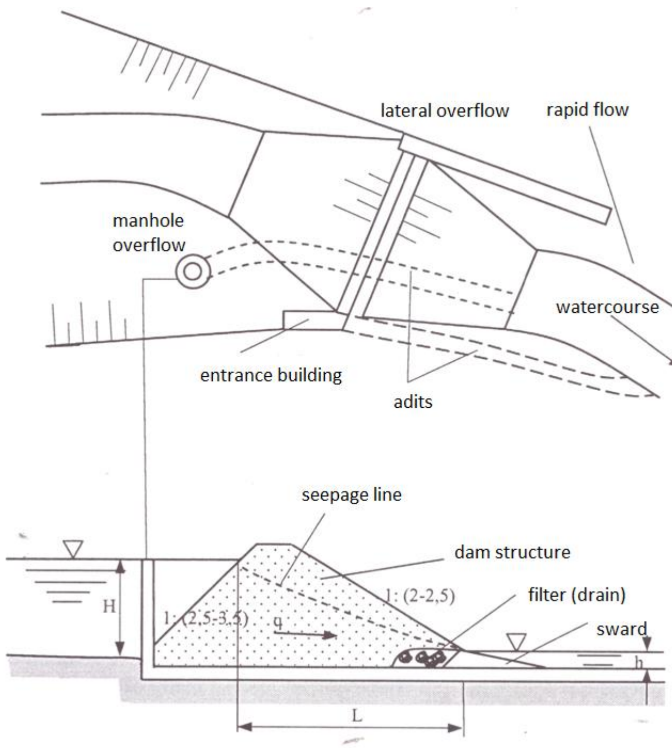

Figure 12. View of an embanked dam with evacuation (overflow) facilities for large waters

7. ANALYSIS OF THE EROSION COEFFICIENT OF THE TURIJA RIVER BASIN

In order to take preventive action and prevent the occurrence of erosion and flash floods, it is necessary to analyze and determine the coefficient of erosion of the catchment area in question with sufficient precision. If the erosion coefficient is known, other parameters can be managed more easily.

In practice, the formula of S. Gavrilović is often used for this method of calculation [7]:

$$W_{annual} = T \times H_{annual} \times \pi \times \sqrt{Z^3} \times A \quad (1)$$

where:

W_{annual} – the total amount of production of erosion sediment (m^3/god)

T – area temperature coefficient

H_{annual} – average annual precipitation (mm)

Z – basin erosion coefficient

A – catchment area (km^2)

The temperature coefficient is calculated according to the formula:

$$T = \sqrt{\frac{t_0}{10}} + 0.10 \quad (2)$$

where:
t_0 – average annual air temperature (°C)

For the results obtained for the period 2014 - 2021, the amount of sediment produced in the Turija river basin and introduced into the Modrac reservoir is shown in the following table 1. [8].

Table 1. Tabular presentation of the amount of deposition for the period 2014 - 2021 [9]

Year	Average annual precipitation (mm)	Amount of sediment (deposit) m^3/god
2014	1430,20	190,30
2015	870,80	28,01
2016	989,20	29,04
2017	982,90	34,77
2018	966,50	28,85
2019	896,90	24,86
2020	915,60	32,79
2021	814,00	17,20

If the most unfavorable case is taken in order to determine the maximum force of erosion processes in the Turija river basin, for the year 2014, with the temperature coefficient T=1.07 (empirical pattern 2), the result of the erosion coefficient is obtained, which is Z=0.68 [1].

4. CONCLUSION

This paper presents the tasks and measures that must be adopted and acted upon in accordance with the adopted measures in order to mitigate the effect of the erosion processes of the catchment area and the formation of torrents. It is necessary to come up with a strategy and hire an expert team that would actively work on planning documents, and with the available mechanization, carry out work on the ground, that is, in the catchment area and riverbeds that are torrential in nature.

Also, the goal of this work was to analyze and calculate as precisely as possible the erosion coefficient of the Turija river basin, using the available input data, and ultimately, based on it, define the ranking of the basin's vulnerability to erosion processes. Given that, according to literature data, the erosion coefficient ranges from 0.1 to 1.50, it can be concluded that the Turija river basin belongs to the basins that are moderately subject to erosion and the formation of torrents.

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ASSESSMENT OF SEDIMENT INPUT INTO THE MODRAC ACCUMULATION WITH DETERMINATION OF EROSION CHARACTERISTICS OF THE MODRAC ACCUMULATION CATCHMENT AREA

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Summary

Determining the erosion characteristics of a catchment area is very important in managing the catchment area itself, as well as in managing water resources, especially if it is a multipurpose reservoir. Factors that determine the erosion process in a watercourse catchment area, or the sediment regime of a watercourse, could be divided into those that practically do not change or those that do not change significantly over a period of several years, and factors that are subject to change during the year, depending on meteorological and climatic changes over the catchment area. For preventive action and prevention of erosion, and thus flash floods, and filling of reservoirs, it is necessary to analyze and determine precisely the erosion coefficient of the catchment area. On the other hand, water resources management includes a number of activities such as planning, design, construction, management, maintenance, monitoring and control of constructed facilities, in order to assess and increase their efficiency. Accordingly, it is necessary to specifically plan all activities in relation to reservoirs as key facilities for managing the water regime of a catchment area and processes within the catchment area.
Keywords: erosion, sediment, meteorological changes, climate change, erosion coefficient, water resources, sediment, catchment area, deposition.

1. INTRODUCTION

The Modrac reservoir is the only available water resource in the Tuzla region and its surroundings. Bearing in mind the fact that the useful volume of the reservoir is limited, and that over time the reservoir is filled with hauled sediment and coal dust as floating sediment, and that consumers - the population, industry and others - must be provided with a water supply with a high degree of safety. Surplus water needs to be used to the maximum for the purpose of electricity production, and there is a need to optimize the system, i.e. more efficient management of the water resource of the reservoir, i.e. to prove the maximum utilization of the reservoir while constantly providing all the necessary amounts of water to which the Modrac reservoir is connected [1].

Hydroaccumulation "Modrac", as a multi-purpose reservoir, was created by the construction of the Modrac dam in 1964 in the Modrac Strait on the Spreca River. The reservoir consists of the rivers Spreca and Turija with their tributaries. The total area of the catchment area in the profile of the dam is approximately 1189 square kilometer, which makes up over 60% of the entire river basin. Of the total area of the basin, the river Spreča occupies 832 square kilometer, the river Turija occupies 240 square kilometer, while the rest of the basin belongs to the accumulation of the immediate basin 117 square kilometer [1].
The increasing and often conflicting demands for the use of water resources have led to the need for more complex management methods, including reservoir volume management.
In some reservoirs, already 10-20 years after their construction, the sediment volume reaches 20-30% of the total reservoir volume. [2].
The purpose of the assessment of the transfer of sediment to the hydroaccumulation is to realize the possibility of a more expedient management of natural water resources, protection from the harmful effects of water, as well as protection of water from pollution.
By analyzing the sediment transport in watercourses, i.e. tributaries, and the total amount of sediment deposited in the Modrac reservoir, real data are obtained about the amount of sediment introduced into the Modrac reservoir, the dynamics of sediment input, and the degree of pollution of this type of water body.

2. WATERSHED AREA MODELING

At the time of today's technology, which is widely available, the most effective tool for modeling the catchment area is the geographic information system (GIS). GIS is a system for managing spatial data and the attributes associated with them. In the strictest sense, it is a computer system capable of integrating, storing, editing, analyzing and displaying geographic information. One of the oldest definitions of GIS is:
"GIS is a special type of information system in which the computer database includes precisely defined relationships between spatially distributed objects, activities and events, which are spatially defined as points, lines and surfaces (polygons) [3].
In GIS, the data are related to these points, lines and polygons and are thus stored for research and analysis [3].
Modeling of the catchment area of the multi-purpose reservoir was done in the ArcGIS software package, in which all the foundations and input data for the calculation were prepared, the modeling of the Modrac reservoir basin and the hydrological hydraulic calculation was done in ArcSWAT. In the aforementioned software, on the geoinformation platform (GIS), the results were obtained: the flow of the main watercourses in the catchment area of the Modrac reservoir, soil saturation and sediment transport in the watercourses and their transport to the Modrac reservoir.
The input data for modeling in the ArcGIS software package, i.e. in the GIS tool - ArcSWAT, are:

- digital terrain model,
- map of the catchment area's surface use,
- map of the pedological composition of the catchment area's soil,

- hydrometeorological data (precipitation, temperature, wind, solar insolation and air humidity).

The following figure (Figure 1) shows how the ArcSWAT software works, the required substrates and substrate analysis, and the results obtained with this approach to the catchment area's research.

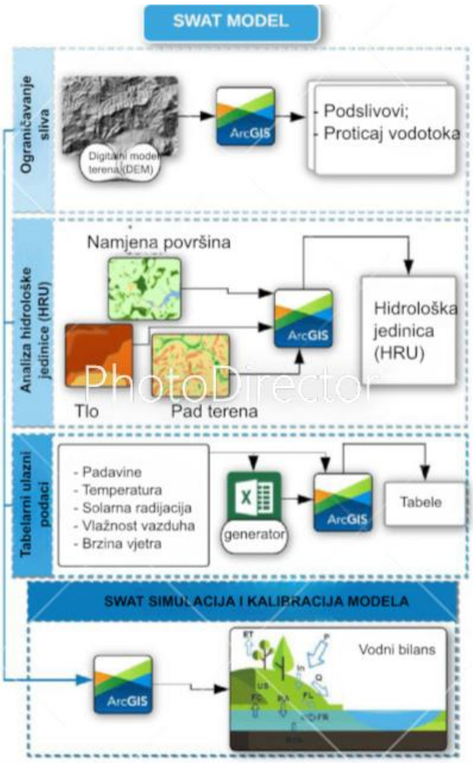

Figure 1. Presentation of the mode of operation of the ArcSWAT model [3]

The digital terrain model, as one of the most important sources, was downloaded from the USGS Earth Explorer, the data of the digital terrain model is SRTM 30 m. SRTM 30 m is a file containing digital elevation data for an international research program, which was used to obtain digital elevation models on a global level.

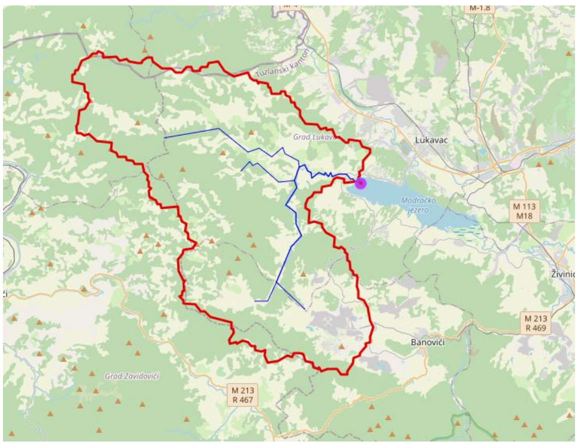

Figure 2. Digital terrain model of the wider area with the drawn boundary of the Modrac reservoir catchment area, https://mghydro.com/watersheds/

The land use and land cover map is also a digital data map and a necessary basis for the analysis of the catchment area and for the calculation in the aforementioned software package. The resolution of this map is quite high, and as of 2020 it is 10 m.

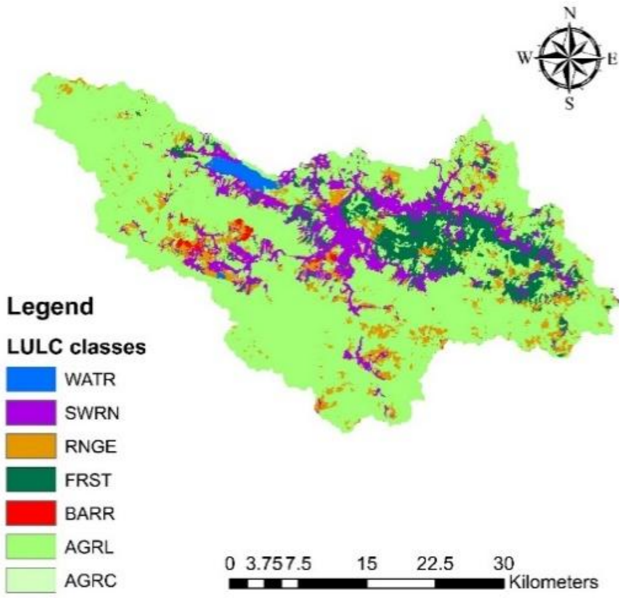

Figure 3. Land use and land cover map [3]

Bearing in mind the available input data that are necessary for modeling the catchment area, in this paper, data on the amount and transport of total sediment were compiled for a series of 8 years in the period 2014-2021.

The soil map is also a map with digital data on the pedological characteristics of the catchment area. For the subject basin of the Modrac reservoir, the mentioned soil map with pedological characteristics was taken from the website www.fao.org, which contains a database of pedological soil characteristics at the global level. [4].

The said map contains databases relating to data and maps compiled using field surveys supported by remote sensing and other environmental data, expert opinion and laboratory analyses [4].

Figure 4 shows the soil map of the Modrac reservoir basin according to the dominant soil classification. The catchment area of the Modrac reservoir is dominated by three dominant soil types, namely:

- Rankers (U3-2c) indicates shallow rocks with solid or fragmented non-calcareous rocks;
- Luvisol (Lg43-2ab) are soils associated with short-term water saturation in the profiles; and
- Cambiosols (Bd66-1/2bc), are widespread soils developed on different lithologies that play a significant role in the pedological development of this relatively young soil [4].

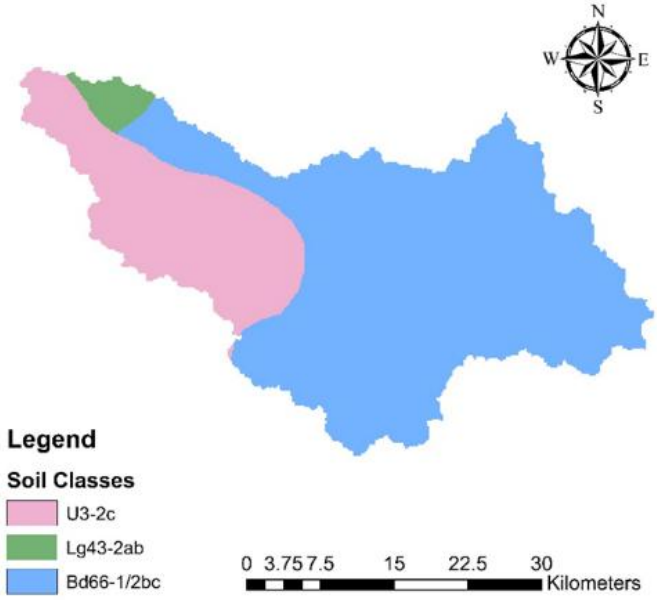

Figure 4. Soil map of the Modrac reservoir basin by dominant soil classification [4].

Hydrometeorological data are also used as a basis for the analysis of the catchment area and obtaining results on the flow in watercourses (inflow into the Modrac reservoir), transport of drift (sediments), soil saturation, input of nutrients into the reservoir (organic load). Hydrometeorological data were taken for a series of 8 years (2014 - 2021) from the Modrac rain gauge station.

3. MODELING RESULTS

In this paper, time steps are used to evaluate the SWAT model. Different evaluation parameters were used to evaluate the models and their performance as recommended by Moriasi et al. (2007), i.e.:
- Nash–Sutcliffe efficiency (NSE),
- graphic technique using hydrographs,
- standard RMSE observation deviation ratio (RSR) i
- percentage bias (Pbias).

In addition, the index of agreement (D) and coefficient of determination (R2) were also calculated and compared for all results obtained by modeling in SWAT software. The terrestrial part of the hydrological cycle is based on the water mass balance. Hydrological processes and the application of the SWAT model are simulated daily for each HRU - hydrological unit, in time steps using the following soil water balance equation [5].

$$SW_t = SW_0 + \sum_{i=1}^{n}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad (1)$$

where is:

SW_t – total water content in the soil (mm)

SW_O – initial soil water content (mm)

R_{day} – amount of precipitation per day (mm)

Q_{surf} – amount of surface runoff per day (mm)

E_a – evapotranspiration per day (mm)

w_{seep} – amount of percolation (extraction) – raising the groundwater level (mm)
Q_{gw} – amount of groundwater (mm)

The Penman-Monteith method of real evapotranspiration as well as potential transpiration is used for the calculation. Modified method CN curves with a modified rational method are used for the calculation of surface and peak runoff [6].
The universal equation of soil erosion and amount of sediments was defined by Williams in 1995 [7]:

$$sed = 11{,}80 \times (Q_{surf} \times q_{peak} \times area_{hru})^{0{,}56} \times K_{usle} \times C_{usle} \times LS_{usle} \times CFRG \qquad (2)$$

where is:

sed – amount of sediment (t/dan)
Q_{surf} – surface runoff volume (mm)
q_{peak} - peak surface runoff rate (m^3/sek)
$area_{hru}$ – hydrological area unit HRU (ha)
K_{usle} - soil erosion factor (taken: 0,013 t/ha)
C_{usle} - land cover and management factor
LS_{usle} - topographic factor
CFRG - coarse fragment factor

Below are graphical results from the SWAT model in diagrams showing the relationship between precipitation as input data and sediment quantities as the result of this analysis.

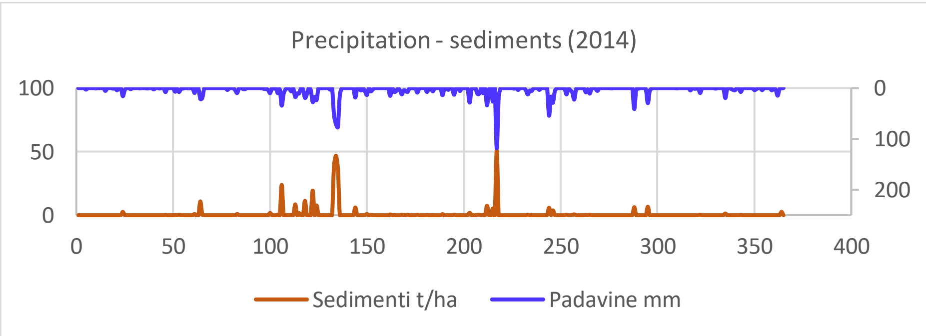

Figure 5. Diagram of precipitation and sediments in 2014

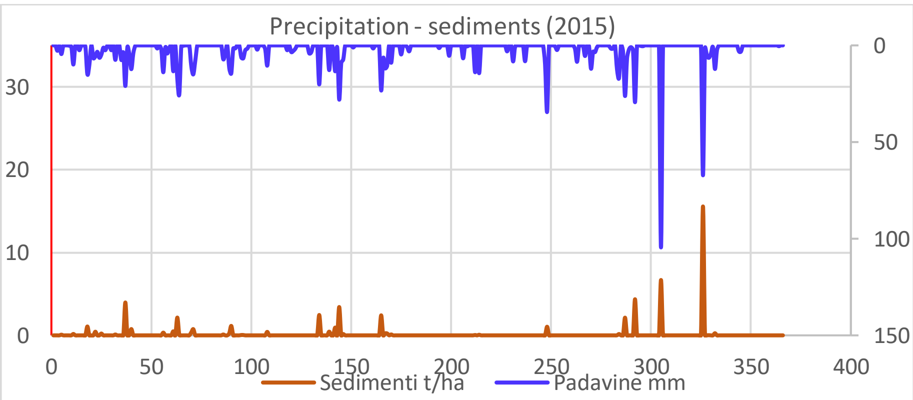

Figure 6. Diagram of precipitation and sediments in 2015

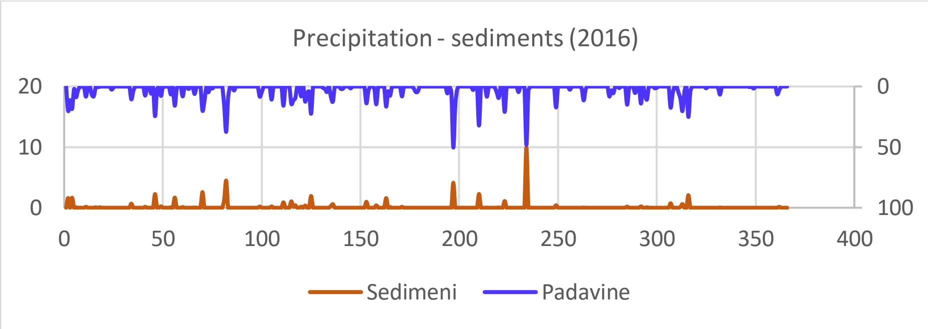

Figure 7. Diagram of precipitation and sediments in 2016

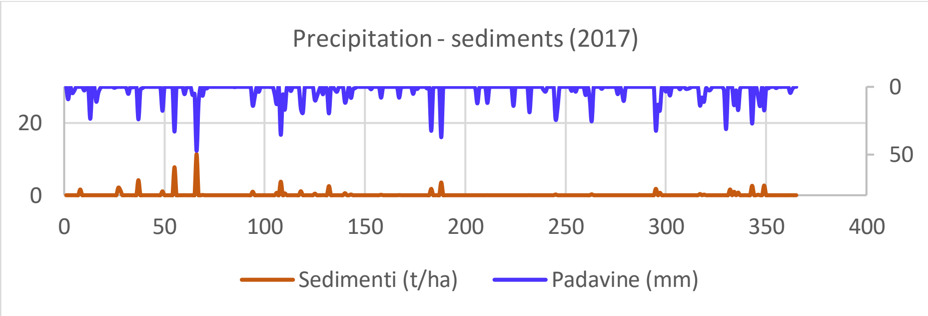

Figure 8. Diagram of precipitation and sediments in 2017

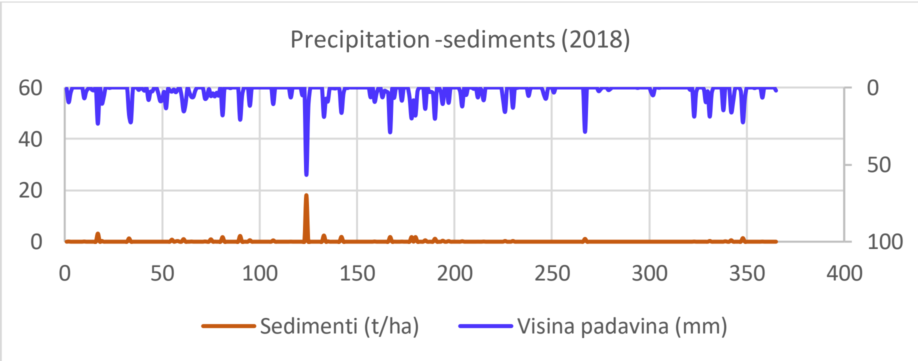

Figure 9. Diagram of precipitation and sediments in 2018

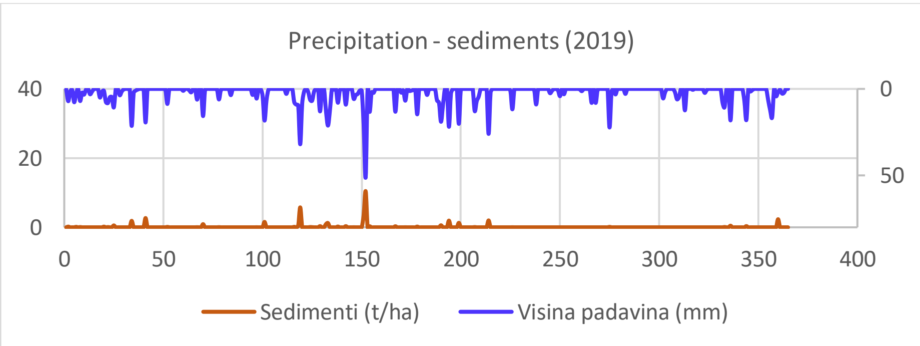

Figure 10. Diagram of precipitation and sediments in 2019

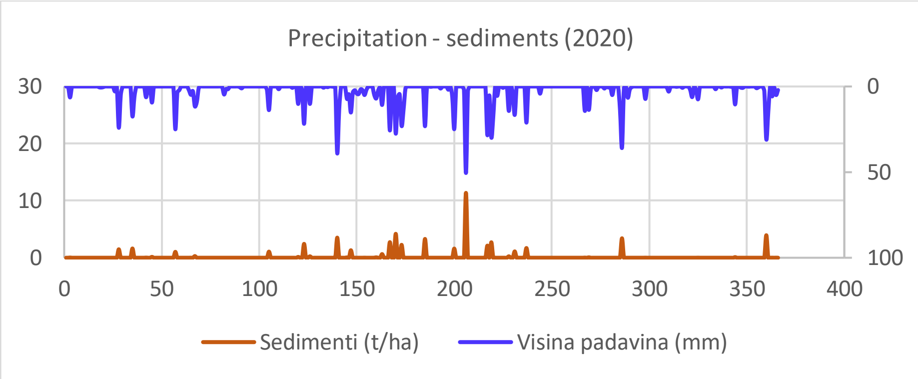

Figure 11. Diagram of precipitation and sediments in 2020

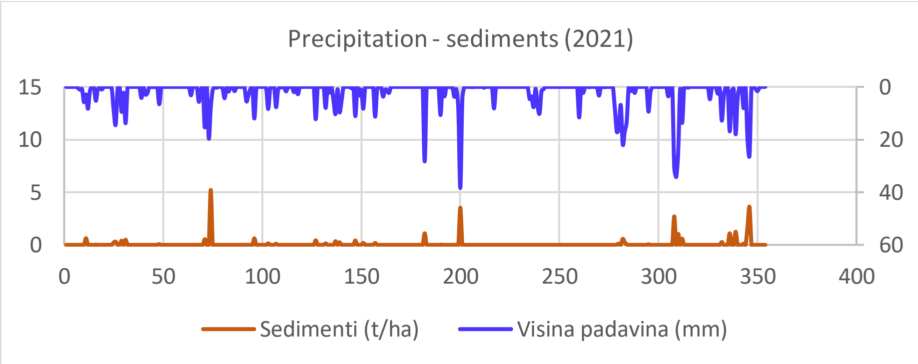

Figure 12. Diagram of precipitation and sediments in 2021

For the results obtained for the period 2014 - 2021, correlation and simple regression were performed, the relationship between precipitation and sediments (sediment), their mutual relationship shown through the Pearson coefficient R2. The stated Pearson coefficient R2 is tabulated for the period 2014-2021. [8].

Table 1. Tabular presentation of Pearson coefficient R2 for the period 2014-2021

Year	Average annual precipitation (mm)	Amount of sediment (deposit) t/ha	Pirson coefficient R^2
2014	1430,20	319,62	0,9527
2015	870,80	47,06	0,9348
2016	989,20	48,78	0,9248
2017	982,90	58,40	0,9593
2018	966,50	48,46	0,9369
2019	896,90	41,76	0,8643
2020	915,60	55,08	0,8935
2021	814,00	28,89	0,7366

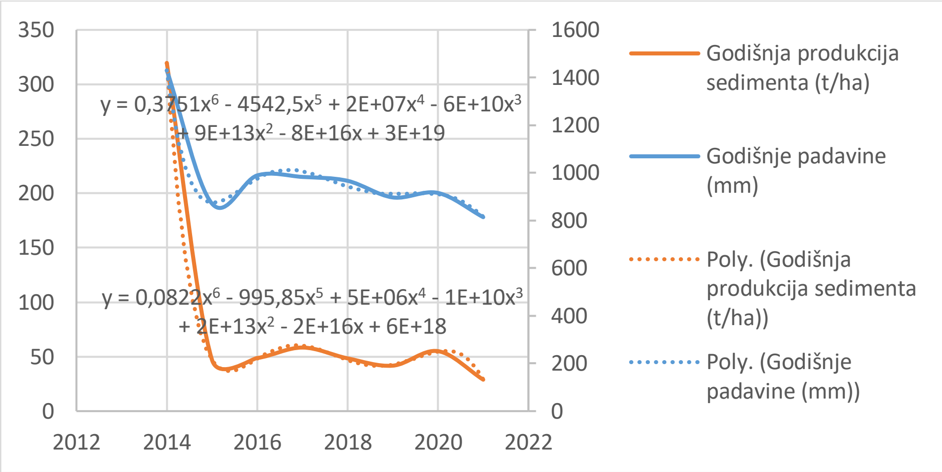

Figure 13. Diagram of precipitation and sediments (annual values) for the period 2014 - 2021.

4. ANALYSIS OF EROSION CHARACTERISTICS OF THE RIVER BASIN AREA

The influence of the erosion characteristics of the catchment area on the filling of a multipurpose reservoir depends on several key factors, including the intensity and annual frequency of erosion, as well as the specifics of the relief and position of the reservoir system. Erosion leads to the transport of sediment from the upper parts of the catchment area to the reservoir, which causes its filling process and a decrease in functional capacity. In order to take preventive action and prevent erosion, it is necessary to analyze and determine with sufficient precision the erosion coefficient of the catchment area in question. If the erosion coefficient is known, other parameters can be managed more easily and the actual situation on the ground can be improved. [9].

In practice, the formula of S. Gavrilović is often used for this method of calculation [10]:

$$W_{god} = T \times H_{god} \times \pi \times \sqrt{Z^3} \times A \qquad (3)$$

where are:
W_{god} – the total amount of production of erosion sediment (m^3/god)
T – area temperature coefficient (°C)
H_{god} – average annual precipitation (mm)
Z – basin erosion coefficient
A – catchment area (square kilometer)

If the most unfavorable case is taken in order to determine the maximum force of erosion processes in the basin of the Modrac reservoir, for the year 2014, with the temperature coefficient T=1.07 (4), the result of the erosion coefficient is obtained, which is Z=0.84 [9].
The temperature coefficient is calculated according to the formula [9]:

$$T = \sqrt{\frac{t_0}{10}} + 0.10 \qquad (4)$$

where is:
t_0 – average annual air temperature (°C)

CONCLUSION

This paper presents the modeling of the catchment area of the "Modrac" reservoir with GIS tools. In relation to the input data, the value of the daily amount of sediments (sediment) introduced into the reservoir "Modrac" was obtained. The correlation and regression value of precipitation as an input data and the amount of sediment as a result of this analysis, the Piroson coefficient R2, which describes their mutual connection, is given. It is important to point out that the R2 coefficient for the year 2014 is 0.9527, which is a very large positive relationship, as well as for the following years in the given period. The largest Pearson coefficient was read in 2017 and is 0.9593, and the smallest in 2021, which is 0.7366 (Table 1).
The diagram shown in Figure 13 shows the annual values of precipitation and sediment production in the Modrac reservoir basin for the period 2014-2021. The curves of the listed annual values are described by the following polynomials that most closely describe the given curve:

- annual precipitation $y = 0.3751x^6 - 4542.5x^5 + 2*10^7x^4 – 6*10^{10}x^3 + 9*10^{13}x^2 – 8*10^{16}x + 3*10^{19}$,
- annual sediment production $y = 0.0822x^6 - 995.85x^5 + 5*10^6x^4 - 10^{10}x^3 + 2*10^{13}x^2 – 2*10^{16}x + 6*10^{18}$.

Also, the goal of this work is to analyze and sufficiently accurately determine the erosion coefficient of the catchment area of the Modrac reservoir, using the available input data, and ultimately, on the basis of it, define the ranking of the catchment's vulnerability to erosion processes. Given that, according to literature data, the erosion coefficient ranges from 0.1 to 1.50, it can be concluded that the Modrac reservoir basin belongs to the basins that are moderately susceptible to erosion, and thus to the production and transfer of sediments into it.
The stated theoretical propositions highlight the complex connection between erosion processes in the watershed and the filling of the multi-purpose reservoir, which requires an integrated approach in the planning and protection of this ecosystem. [11].

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