

Geological, mineralogical, petrographic, hydrogeological, and environmental evaluation of a marble site: Could the water resource protection zone be damaged due to the site?

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Abstract

According to the legislation in Turkey, mining activities can be allowed outside the absolute and short-distance protection zones of water basins, at distances determined by considering certain conditions. However, these distances are not always compatible with the catchment areas of water dams. Furthermore, not all mining activities may have negative environmental impacts on water protection basins. At this point, it is very valuable to evaluate whether the geological orientation of the mineral deposits underground damages water resources and under which conditions mining can be conducted. In this study, whether a marble field in the Bursa City of Turkey harms the watersheds were determined by evaluating the orientation of the marble deposit, geological-structural, hydrogeological, mineralogical-petrographic, physico-mechanical, and chemical. It was also evaluated whether there is a feasible and technically appropriate marble operation. In addition, the relevant legislation on the conditions under which mining activities can be conducted in different protection zones of water basins was explained and it was determined whether the activities in the field comply with the legislation. The study is a reference for the mining & geology disciplines to demonstrate the feasibility of mining at medium and long distances other than absolute and short-distance water reservoir protection distances. The study provides practical solutions, especially for developing and underdeveloped countries, by determining whether there is a negative environmental impact of marble mining in water basins in a multidisciplinary manner.

1. Introduction

1.1. Impacts of mining activities on water resources & protection projects around the world

Water is used as an auxiliary material in any mining process. The need for technically efficient & safe water management in the mining environment has become imperative with the importance of environmental constraints and increasing demand for water resource conservation (Soni and Wolkersdorfer, 2015; Kumar and Kumar, 2023). Integrated mine water management planning, often neglected in mine planning, is recommended as an essential component to avoid expensive solutions and maximize the productive capacity of the reclaimed mine site. One of the objectives of integrated mine water management planning is to ensure that remediation can be achieved at low cost during mine operation. Compatibility between environmental protection and mine profitability can be achieved through integrated mine water management planning (Sawatsky et al., 1998). Water management is directly related to the land reclamation project. Most reclaimed surface mining sites release more surface runoff at a faster rate than undisturbed areas. This results in higher flood peaks, reduced baseflow, shorter lag times between precipitation and flood peaks, reduced groundwater recharge, and higher sediment loads in the affected basins. Therefore, the success or failure of a land reclamation project depends significantly on the management of surface runoff and drainage (Kilmartin, 1989). Studies are needed to establish the relationship between the restoration of the natural groundwater regime to its pre-mining operations equilibrium and the disposition of mine waste (Ardejani et al., 2007).

The management of the properties of water to be used for drinking and cleaning purposes becomes even more important as human health is at stake (Yildiz, 2015). Fresh water is a natural and valuable resource and can be easily contaminated. The degree of pollution causes fresh water to be considered polluted. Increasing industrialization and urbanization put water resources under pressure and can cause pollution of clean water (Tripathi et al., 2021; Peker and Gülbaz, 2025). Drinking water catchments around the world face the threat of pollution by rural and urban environments and by various activities, including mining activities (Coskun and Alparslan, 2009; Pasten et al., 2016; Cardiff, 2018; Gyamfi et al., 2019; Tan et al., 2020; Chen et al., 2021b; Feng et al., 2021; Economou-Eliopoulos, 2022; Qi et al., 2023). Land use, meteorology, and hydrology can critically affect water quality in rivers (Zhou et al., 2020). Apart from water resources, mining wastewater can also cause soil pollution in agricultural areas (Humsa and Srivastava, 2015; Sun et al., 2018; Cheng et al., 2022).

Studies evaluating the pollution levels of water resources by coal mines (Brenner and Helm, 1991; Gzyl et al., 2017; Liu et al., 2021; 2023; Krodziewska et al., 2022; Chen et al., 2023), and studies on the protection or control of water resources against coal mining activities (Adamczyk, 1999; Xu et al., 2012; Ignatova et al., 2019; Liu et al., 2019; 2022; Zhang et al., 2020; 2022; Huang et al., 2022) are more abundant in the literature (partly compared to other mineral groups). The production process is conducted with the help of water in many types of minerals (Li et al., 2023). Both reducing water use and preventing pollution of mines should be a top priority (Wang et al., 2022; Zhan et al., 2023). Efforts can benefit the protection of water resources while simultaneously increasing the

safety of coal production (Bukowski, 2009; Sun et al., 2020). There have also been many studies (Jones and Ellenberger, 1994; Król and Kot, 2010; Kaźmierczak, 2014; Tan et al., 2021; Chi et al., 2021; 2022; Deng et al., 2023) on cleaning and protecting water resources through remediation projects against contamination of water resources due to extraction and processing of minerals other than coal. The operation of sulphide-containing mineral deposits can generate large quantities of sulphur-rich waste. Sulfides form Acid mine drainage (AMD) when exposed to oxygen and water. Oxidative dissolution of sulfidic minerals releases highly acidic leachate, sulfate, and potentially toxic elements such as As, Ag, Cd, Cr, Cu, Hg, Ni, Ni, Pb, Sb, Th, U, Zn from different mine wastes. This causes the pH to drop and heavy metals to leach from the wastes. AMD-enriched waste piles mix with runoff, increasing the heavy metal load. Leaching of heavy metals from waste piles contaminates groundwater, with a greater impact in shallow aquifers. AMD can damage the environment and ecosystem in this way. Abandoned (surface and underground) mines that remain after ore extraction are also a major source of water pollution. In addition, changes in land use and land cover due to over-exploitation of water resources and mines lead to deterioration of recharge & discharge capacity and water quality of aquifers and changes in hydrogeochemical processes. Therefore, there is an urgent need to implement appropriate waste management and treatment policies and to control AMD to protect the quality and quantity of water resources in mining regions (Lapointe et al., 2005; Akbulut et al., 2006; McCullough, 2008; Fytas, 2010; Heviánková et al., 2011; Öztüfekçi-Önal et al., 2013; Anawar, 2015; Sandlin et al., 2020; Punia and Singh, 2021; Koc et al., 2023). Studies (Dudeney et al., 2012; Pavlowsky et al., 2017; Tapia et al., 2018; Zhu et al., 2020; Santana et al., 2020; Mudd, 2020; Zhang and Xhang, 2021; Wang et al., 2023; Chen et al., 2024) have found that water basins in many countries are polluted by metallic mines. Uranium contamination in groundwater has also become a serious problem worldwide. Even at low concentrations, uranium in tailings has both radiological and toxicological effects on human health (Kazakis et al., 2022; Osmanlioglu, 2022; Yıldız and Tombal-Kara, 2024). Coal mining is often associated with AMD from tailings and waste rock piles containing sulfide minerals. (Koppe et al., 1995; Corrêa et al., 2003) conducted water table fluctuation tests, geotechnical characterization, physical, chemical and mineralogical analyses and hydraulic conductivity tests in wells in open pit coal mines in southern Brazil, (Shimada et al, 2012) conducted in open pit coal mines in Indonesia with the objective of controlling AMD of sulfide-containing waste rock piles. (Mardonova and Han, 2023) studied the hydrological and environmental impacts of coal and non-metal mining activities. (Erg and Pastarus, 2008) conducted hydrogeological issues related to water flow in a bituminous shale mine, examining sulfate ion distribution and groundwater movement in lateral & transverse directions. (Dobchuk et al., 2012) analyzed the extent to which the water table is affected by saline tailings by studying the tailings sand associated with oil sands mining. (Guney and Demirel, 2021; 2024) aimed to identify critical points by calculating the water footprint of a mine and assessing the environmental impact of this water use. Effective monitoring of mine groundwater with a standardized methodology facilitates the assessment of the impact of mine water on the environment. The ultimate impact of mine water monitoring allows for ecochemical and economic assessment. (Bzowski and Dawidowski, 2002) examined monitoring issues and proposed a groundwater monitoring system for existing and flooded abandoned mines. (Chen et al, 2021a) found that failure to take necessary measures against the impacts of sand mining in China may lead to an increased concentration of chemicals (including sulfuric acid, arsenic, and mercury) in surface water. (Noreen et al., 2019) investigated the physicochemical parameters, heavy metal concentration, and heavy metal bioaccumulation in the wastewater of the marble industry in Mardan Industrial Estate in Khyber Pakhtunkhwa province of Pakistan. Water samples were collected for the analysis of physico-chemical parameters such as electrical conductivity, pH, turbidity, Na, K, Ca, hardness, Cl, and heavy metals such as Mg & Cu. The concentrations of Cu, Mn, Zn, and As were compared with the National Environmental Quality Standards of the World Health Organization. Therefore, it was proposed to construct a wastewater treatment plant in Mardan to treat the polluted water discharged from the marble production units before entering the freshwater resources in the study area. (Hanieh et al., 2014) focused on the environmental, economic, and social impacts of the natural stone and marble industry in the Middle East and North Africa region, taking Palestine as an example. They evaluated the life cycle of natural stone and marble with some indicators and proposed strategies for the proper and efficient use of resources such as natural stone, water, and energy in production processes.

1.2. Literature on protection of watersheds from mining & other activities in Turkey

1.2.1. Literature on the protection of watersheds in Turkey

Turkey, which is threatened by water scarcity, has faced ecological degradation in water basins in the past years (Pouya and Turkoglu, 2020). In Turkey, there are 10 different types of protected areas covering a total of 5,647,568 hectares (ha), as well as areas protected by legislation in various forms, such as drinking water protection zones and thermal source protection zones

determined by State Hydraulic Works (SHW) (Akbaş, 2014). (Köse, 2015) made a comparison of Turkish legislation with other countries' legislation for the protection of drinking water basins and developed recommendations. (Koç, 2014) examined protection zone approaches for groundwater bodies used as drinking water sources in some countries. (Adalı, 2023) evaluated the principles for the management of sensitive areas to determine sensitive areas in terms of water pollution and water quality targets. In recent years, Turkey has initiated a comprehensive planning process for watershed protection in line with international agreements. (Pouya and Turkoglu, 2020) evaluated the water resources planning approach and management changes in Turkey according to sustainable development principles. (Taze and Aydın, 2022) explained the plan hierarchy in river basin management. The preparation of special protection policies for drinking water basins is important for ensuring sustainable drinking water management. (Özdemir, 2020) applied a decision support system consisting of hydrogeological, hydrogeochemical, soil type, and topological parameters to define the protection zones of the watersheds of Sapanca Lake in Turkey. According to the proposed methodology, green belt, wellhead, absolute, short, and medium-distance groundwater protection zones were defined in the basin. Designation of drinking water protection areas is defined as a strong protection method to restrict inappropriate activities that affect the quality and quantity of water. These areas are determined according to basin characteristics to ensure sustainable drinking water management (Özdemir, 2021). As (Qi et al., 2023) found in their study, the distances of the protection zones of rivers can be variable as a result of scientific studies. (Özdemir, 2021) presented a framework for drinking water protection. It established a standardized approach to be applied to each different drinking water basin. Protection zones for river drainage systems or water supply reservoirs serve as an important conservation measure to reduce water restriction. In this context, (Gül et al., 2009) analyzed a set of spatial criteria to assess the functionality and efficiency of potential protection zones in a region. (Varol et al., 2020) created a vulnerability map by identifying water pollution potentials for groundwater of the Salda Lake wetland basin in an area with intensive agricultural activities around it. (Erdoğan and Karagüzel, 2016) conducted hydrogeologically based studies to ensure water quality in the drinking water reservoir drainage basin in the Ağlasun Sub-basin in Burdur city of Turkey. They prepared groundwater vulnerability maps, which are an effective tool in determining the protection areas of water resources. Groundwater depth, net recharge, aquifer type, soil environment, topography, regional influence, and hydraulic conductivity parameters were used to create the maps. He stated that traditional protection zones set after the maximum water level are insufficient to protect water quality in a drinking water basin. In addition to the existing protection zones, this study proposed new hydrogeological-based protection zones, including streams flowing into the reservoir. (Simsek et al., 2022) used the GIS-integrated vulnerability technique to identify highly productive aquifer zones and evaluated the protection of these productive zones and the Küçük Menderes River Basin from pollution sources such as nearby industrial & residential areas.

1.2.2. Impact of natural stone & marble quarries on water resources & protection of water basins projects

Compared to other minerals, natural stone production processes have a relatively low carbon footprint and water use (Nalbantoğlu, 2023). Block extraction in marble quarries can be achieved by cutting with water jets (Karadeniz, 2017). In addition, marble sludge is produced as water is used to trap the dust released. If marble sludge is discharged into the environment, physical, chemical, and biological risks may occur for the ecosystem. When the marble sludge poured on the soil dries, it can cause the stream beds to fill up and the stream cross-section to narrow. During rainy seasons, marble sludge can flow into rivers, canals, and roads, adversely affecting water quality, reducing water storage capacity, and harming aquatic life. It can flow with solids, reducing the water-holding capacity of lakes and ponds. Marble factories can discharge marble sludge in any valley or empty land close to their factories, despite the areas designated for discharge. This can lead to serious environmental problems such as the occupation of large areas of land and dust pollution, especially after the sludge dries, and can also pollute groundwater reserves¹. For these reasons, marble sludge can bring serious dangers to the environmental ecosystem and its physical, chemical, and biological components (Güçer and Erdemir, 2018). (Ceylan, 2008) examined the environmental impacts of marble operations according to environmental legislation. Systematic land suitability planning of mining sites is important to prevent environmental problems and accidents that may occur. (Cınar and Ocalır, 2019) defined a methodology to determine the best future active land use alternative in the research area covering 715 marble quarries in Turkey. (Ozcelik, 2016) analyzed the impact of pollution from marble operations on water resources in Turkey. The measured concentrations were compared with the standards set in the Turkish Environmental Protection Law for the marble industry. Water quality was assessed for four different marble operations. The water quality data was divided into two periods: before the quarry operations started and during the operation period. Field investigations and water quality data showed that natural stone waste can be a source of pollution to water and soil resources as a result of inadequate solid and liquid waste disposal. Another study (Çelik and Tur, 2012) was conducted in Afyon city of Turkey. In Afyon, ~ 300000 tons of wet and 200000 tons of solid marble tailings are generated annually in ~ 400 marble processing plants. These tailings are collected in landfills

located in 3 regions (İscehisar, Susuz Boğazi, and Organized Industry). 40 marble processing plants in the Afyonkarahisar Organized Industrial Zone generate 60000 tons of solid and 120000 tons of aqueous marble tailings annually. Among these residues, 45500 tons of solid and 97500 tons of aqueous residues were used in cement production. (Çelik and Tur, 2012) examined the effect of marble wastes in the Industrial Zone on groundwater. The typical indicator of water pollution from marble wastes in groundwater is the change in the concentration of Ca and Mg ions. The rate of increase in Ca and Mg ions between 2000–2007 was determined as 1.22%, 2.94%, 0.72% and 0.17%, respectively. No significant increase in Ca and Mg ions has been observed in the last 7 years. According to these data, it was determined that the marble waste storage area in Afyon does not have any negative impact on groundwater.

2. Literature on Marble Activities & Geology in The Vicinity of the Study Area & Study Method and Scope

Previous geological studies in the vicinity of the study area (Akkuş, 1963; Granit and Tintant, 1960; Lisenbee, 1972; Altınlı, 1965; 1973; Saner, 1980; Yılmaz, 1981; Genç, 1986; Emre, 1986; Ergül et al., 1986; Altınır et al., 1989; Ercan et al., 1990; Kandemir et al., 2013; URL-1) were mentioned in the survey and evaluation of a research site close to this region (Yıldız et al., 2020). The main studies² in which technical investigations were conducted in terms of marble production potential in the region are as follows:

- The marble site located in and around Bursa Mustafakemalpaşa-Sincansarnıç was analyzed in terms of geological & marble and evaluated in terms of production potential (Uz, 1991).
- Marble-forming limestones were evaluated in the vicinity of Bursa-Doğanalan-Körekem (Uz and Yıldız, 2017a).
- Survey and evaluation of limestone-based marble formations in the vicinity of Bursa-Akçapınar-Kazanpınar (Okay, 1989).

Past research has demonstrated the technical suitability of marble production in the region and has brought about the need to examine the feasibility of producing new marble potentials under different topographical and environmental conditions. In the literature on the effects of mining on water basins, there is no case study evaluating the conditions under which mining can be conducted in different water protection basins in accordance with the legislation. This study, considering this deficiency in the literature, includes technical and scientific studies conducted as a result of a dispute arising from the allegation that the marble quarries in operation are damaging the nearby water basins. In this direction, the mining & geological characteristics of the marble site were technically evaluated to help determine whether a marble site located in the vicinity of Dağakça Village of Osmangazi District of Bursa and Erenler Village of Orhanlı District of Bursa could adversely affect a nearby water reservoir environmentally. General Directorate of Mining and Petroleum Affairs (MAPEG) under the Turkish Ministry of Energy and Natural Resources granted a 10-year operating permit for the production of this marble quarry. However, 3 years after the start of production, the production of the quarry was stopped as a result of the decision taken at the initiative of Bursa Water and Sewerage Administration (BUSKI) due to the possibility of contaminating the water of the Doğanlı Water Dam. Subsequently, it was scientifically and technically evaluated whether the operation of this marble site would cause any damage to the environment and water resources by analyzing field and laboratory-based data. In this framework, this study aims to determine whether the marble site damages the water resources in terms of geological-structural, mineralogical-petrographic, environmental structure, and properties. Another aim of the study is to draw attention to the necessity of implementing the same practices in certain criteria both for all enterprises in the region and throughout Turkey in the decisions taken by public institutions regarding the restriction of mining production from an environmental point of view. Regarding the marble site in question, BUSKI has taken different measures at different times regarding the pollution of the Doğanlı Water Dam. Scientific and technical investigations on the alleged pollution of the Doğanlı Dam by the marble quarry and the legal provisions regarding pollution were not conducted. With the measures taken, the water protection zones' boundaries have been moved to points at very long distances. In this study, geological-structural, mineralogical-petrographic, and environmental geology studies were conducted to determine these boundaries technically:

1) Site-based investigations cover the vicinity of the marble quarries, Nilüfer Stream, and Doğanlı Dam in terms of geological-structural and environmental geology.

2) Laboratory-based examinations include mineralogical-petrographic analysis and composition of the marble and the rocks that form the foundation under the marble, determination of the pollution that may occur due to the composition of the marbles extracted from the operating permit area, and its transportability to the dam lake.

3) Considering all these data, including laboratory data, the distances and formations related to marble production and the environmental impact on the dam were explained in this study.

The operating permit area, where marble production is envisaged, covers an area of 29.49 ha in the southern part of the study area. In terms of geological-structural & marble formations in the study area, the surrounding structures and quarries with operating permits were examined in detail. The upper and lower zones of the quarries where marble is produced and other underlying rocks were identified. The stopping places in the marble field determined by GPS coordinates and in the water dam basin were examined. Necessary samples were taken from the site and these samples were photographed. In addition, the opening of quarry location was sketched and geological cross-sections were prepared. Compass, GPS, camera, 1/25000 and 1/500000 scale geological and topographical maps were used in the study. The scope of the study is as follows:

- Section 3 presents the field-based investigations of the study area, complemented by maps, cross-sections, photographs, and GPS measurements. Geological-structural elements and their characteristics at the regional scale and in the vicinity of the study area were analyzed. Firstly, the regional geology of the study area was given without going into detail. Subsequently, the mineralogical-petrographic and physico-mechanical properties of the samples taken from emperor marble (N-1) and base metamorphic unit (N-2) from the marble operation were determined. Firstly, the mineralogical and petrographic properties of the marble and the underlying basement rocks were analyzed. In the macroscopic examinations, properties of the rocks such as color, structure, texture, hardness, and suitability for polish and shear were determined. In microscopic examinations, the mineral composition and modal ratios of the rock were determined. Technological tests that determine the economic production of marble such as hardness, cutability, suitability for polish, color, structure, and texture of marble were conducted. Physico-mechanical tests such as unit volume weights, water absorption, and porosity of marble were conducted. In the light of all the findings obtained, the quality differences of the rocks were compared and the reasons for the quality differences were analyzed. The suitability of these areas for block marble production, slab production, and polishing were also determined and quality differences were revealed. Geological characteristics of the marble and quarry site selection in the study area were analyzed. Thus, it has been determined whether there is a feasible marble mining activity.
- In Section 4, the legislation (Mining Law No. 3213, Mining Regulation, Regulation on the Protection of Drinking and Potable Water Basins (RPDPWB), Water Pollution Control Regulation (WPCR), etc.) determining the conditions under which mining activities can be conducted in water resources protection zones were explained. Then, the distances measured by SHW between Doğançı Dam and the study area were evaluated. By considering these distances, it was determined whether the marble operation was conducting its activities in compliance with the legislation.
- In Section 5, geological cross-section & other geological maps and different distances of the marble site to water resources were evaluated and geological/structural assessment was made on site basis. In this way, the geological characteristics of the marble field, ore deposit orientation, and the chemical properties of the marble samples were considered to assess whether there would be any damage to the water resources.
- In Section 6, the results of the study were explained.
- In Section 7, considering the literature on mining & watersheds and the results of the study, suggestions were presented for different results that may arise in such mining & watershed land conflicts. It is also suggested that future studies can fill the gaps in this study.

3. Geological/Structural Investigation - Physico-Mechanical Properties

3.1. Geographical location of the study area and its surroundings

The vicinity of Dağakça Village of Bursa, where the study area is located, is quite hilly and mostly covered with vegetation. Access to Dağakça Village from the Doğançı Dam location on the Bursa-Orhaneli road is provided by asphalt road. From Dağakça Village, the study area is reached by a dirt road. The 29.49 ha operating permit area, 183.75 ha operation license area³, the Doğançı Dam location and morphological structures marked on the 1/25000 scale topographic map on the H21c3 plot are presented in Fig. 1. Seven locations in and around the study area were identified, detailed investigations were made and identified with photographs (Table 1). The elevations of some important points in and around the study area are as follows: Kocakır Hill (882 meters (m)), the western part of Open-pit-2 (835 m), Open-pit-1 (828 m), the top elevation of the dam lake (432 m), and the Doğançı Dam axis (381

m). Based on this, the elevation differences are as follows: 501 m between Open-pit-1 and Kocakır Hill, 450 m between Open-pit-1 and the end of the dam, and 51 m between the end of the dam and the dam axis. This calculation was made with GPS data.

Table 1
Some locations in the study area and their relationships with Figures.

No	K-1	K-2	K-3	K-4	K-5	K-6	K-7
Location	Dağakça marble, Open-pit-1	Examination area, inside Open-pit	Location of Open-pit-2 with its western part	The western part of the area with the operating permit and location of Open-pit-2	Roadside of Dağakça Village, A side stream	Doğancı Dam lake upper limit	Dam arch filling
Its properties and the figures it represents and samples.	N-1, Fig. 5a-d	N-2, Dark calcschist, Fig. 5-h, 7-b, 8 a-b	The gray-colored base formation, marble level on top, Figure 6e-i, 7-a, 8-h	Small open pit with a width of 50x50 m, Fig. 13a-b, marble quarries working in the west, Fig. 7c-i	A barbecue charcoal production area by a stream at the lower elevation of Dağakça Village, Fig. 13c-d	Figure 13c-d, Dam area and lake	Figure 13e-f, Dam area, and arch filling

The 1/100000 scale Bursa H21 map is located between the Marmara Sea-Ulubat Lake and Osmaniye region in the borders of Balıkesir-Bursa provinces (Kandemir et al., 2013). The study area is located in the 1/25000 scale Bursa H21-c3 map in this map. In Fig. 2, the study area is marked in the black-colored frame in H21 and the red-colored frame in the H21c3 map area. The study area is bordered by Dağakça Village to the east, Erenler Village to the west, Göktepe & Osmaniye Villages to the south, and Doğancı Dam to the north.

3.2. Geological investigation of the study area and surroundings

H21 is an area where three different tectonostratigraphic units come together in Northwestern Anatolia. Units belonging to the Istanbul Zone, Sakarya Zone, and Tavşanlı Zone are located in this area (Kandemir et al., 2013). These tectonostratigraphic units are the Istanbul Zone, Sakarya Zone (Okay, 1989), and Tavşanlı Zone (Okay et al., 1990) from north to south. These units are tectonically related to each other. The relationship between the Istanbul Zone and the Sakarya Zone cannot be observed in the H21 map due to the Marmara Sea between them (Fig. 2). The units belonging to the Tavşanlı Zone are tectonically located on the Sakarya Zone units. Tertiary units cover all units unconformably. There are two different granitoids in the region. The first one is the Devonian-Carboniferous aged Çamlık meta granodiorite, which cuts only the Sakarya Zone, while the Eocene aged Kapıdağ granodiorite cuts all zones. During the Eocene, marine units of the Sarısu Formation overlie the Istanbul Zone and Sakarya Zone units with angular unconformity. In the Neogene, terrestrial sediments cover all previous units with angular unconformity (Kandemir et al., 2013). In the region located in the belt called Sakarya Continent (Şengör and Yılmaz, 1981) or Sakarya Zone (Okay et al., 1990), tectonically related, generally NW-SE extending Late Paleozoic and Triassic age units are surfaced as bedrock (Kandemir et al., 2013). The study area hosts the Sakarya Zone cover units. The study area is presented in Fig. 3 in a 1/25,000 geological map. 1/500,000 scale regional geological map between Bursa and Orhaneli is presented in Fig. 4 (a). Dağakça Village and its vicinity including the study area are shown in Fig. 4 (a). Doğancı Dam and the study area are marked on the map. The characteristics of the formation types and their distribution in the regions are also presented in Fig. 4 (b). As summarized in Fig. 4 (b), between Bursa and Orhaneli, alluvium is at the top, followed by Neogene sediments, granite, and Paleozoic-Mesozoic igneous and metamorphic units towards the bottom.

3.3. Mineralogical-petrographic investigation

Samples of emperor marble and basic metamorphic unit were taken from the marble operation and their mineralogical-petrographic and physico-mechanical properties were determined. The macroscopic properties of two different samples taken from the site are presented in Table 2. In the macroscopic examinations of the samples (N-1 and N-2), properties such as color, structure, texture, hardness, weathering, suitability for polish, shear, and reaction in acid were determined. As a result of fracture-deformation in some zones in the crystalline rock of N-1, it was observed that the grain size of the grained and micrograined grains decreased and a matrix was formed. This matrix surrounded the fragments of the granular and crystalline parts. Along with calcite, there are

dolomite minerals in the granular and crystalline structure. Opaque minerals are also common. The grain size of calcite is 0.3–0.5 mm and that of dolomite is 0.4–0.7 mm. Opaque minerals are hematite and limonite. Grain sizes are as follows: Quartz + feldspar: 0.15–0.25 mm, Calcite: 0.03–0.25 mm, Mica: 0.15–0.2 mm. With these characteristics, the rock is a "cemented and micaceous sandstone calcchist". In the study area, thin sections of samples taken from marbles for mineralogical and petrographic examination were prepared. The thin sections were examined under a polarizing microscope in the research laboratory of the Geological Engineering Department of Istanbul Technical University and photographed to reveal the mineralogical composition and petrographic textural characteristics of the rocks formed in different conditions & periods. The mineral compositions & modal ratios and textural characteristics of the samples are presented in Table 2.

Table 2
Macroscopic properties & mineral compositions and modal ratios of the samples.

Samples / Features	Grain size	Mineral type	Modal ratio (%)	Features	N-1	N-2
N-1	0.3–0.5 mm	Calcite	47–55	Location of sample	Dümenkırıaltı Hill - study area, opening of quarry	Open-pit-1, bottom of the open-pit level
		Calcite (secondary)	8–10	Color	It looks like a mixture of very light beige and very light greyish color.	Dark grey
	0.4–0.7 mm	Dolomite	35–40	Structure/texture	There are massive, compact, granular, brecciated, angular-semi-angular, light grayish rock fragments.	It looks like fine-grained and secondary white mineral-filled rock. Slight orientation is observed.
	-	Opaque mineral (imprute)	2–3	Weathering	No weathering is observed on a macro scale.	Macroscopically, weathering is visible.
	Rock name	Brecci textured and emperador type, less dolomitic limestone		Hardness	3-3.5 Mohs	4–5 Mohs
N-2	0.15–0.25 mm	Quartz+feldspar	20–25	Cutting feature	During 0.5 cm plate cutting, edge-corner breakage is observed.	In 0.5 cm sheets, no edge-corner breakage is observed during cutting.
	0.15–0.20 mm	Mica-biotite	8–10	Suitability for polish	Good-very good	Good-very good
	0.03–0.25 mm	Cement, calcite, opaque minerals	65–70	Reaction in acid	Very fast foaming was observed in 10% HCl acid. The rock belongs to the carbonate group with this feature. Calcite, dolomite, and aragonite minerals are observed in the rock.	Foaming is observed when treated with 10% HCl. Belongs to the carbonate group.
	Rock name	Calcschist, which is a cementitious and micaceous sandstone				

If a stone cannot be cut in various sizes, fineness, and directions, it cannot have any value as marble, no matter how much it is appreciated. In addition, the edges and corners of these stones, which are turned into slabs, should also be cut smoothly. The hardness value determined according to the Mohs scale is a feature that affects the cutability and workability of the marble as well as its polishing capacity. E.g., rocks in the hard marble group (6–7 Mohs) can be difficult to cut and despite their negative properties such as high cutting and polishing costs, these rocks can have advantages such as obtaining slabs with smooth surfaces and suitability for polish (Onargan et al., 2006). The hardness of the marbles in the study area is 3–5 Mohs. It has the advantages and disadvantages mentioned with this hardness value. Considering that the samples contained large amounts of calcite and dolomite and had a hardness of ~ 3–5 Mohs, it was determined that they were of carbonate origin and partially soft marble. These

characteristics have led to the good cuttability, workability, and polishing capacity of these marbles. In addition, the opaque mineral content of these rocks allows them to take different colors. In addition, structural and textural features such as slices, twinning, crystal shapes and sizes, secondary minerals cutting primary minerals, and intergrowths add different patterns to marbles.

3.4. Physico-mechanical features

To be suitable for physico-mechanical processes and to show color and pattern sizes, it is generally necessary to take block samples larger than 40 cm x 50 cm x 40 cm (Onargan et al., 2006). In this regard, the physico-mechanical properties of the samples taken from the field were determined. In terms of physico-mechanical properties, density was determined as 2.74 g/cm³, water absorption as 0.6%, porosity as 1.3%, and uniaxial compressive strength as 1530 kg/cm² (Table 3). According to the physico-mechanical tests applied to the samples taken from the field, it was determined that the water absorption, porosity, unit volume weight, and uniaxial compressive strength values were partially suitable and close to the TS values. Based on these results, it was concluded that the marbles produced in the region belong to the very durable, compact, massive rock group and are suitable for block/plate production and polishing. According to the experimental studies, the unit volume weight values⁷ and water absorption values of the samples were found to be slightly above the TS value. Porosity in marble is an undesirable condition and generally varies in direct proportion to the water absorption capacity. It can be seen in Table 3 that the porosity value is 1.3% and the water absorption value is 0.6%. The structure and texture of the rock, its type, mineral grain size, and bond, location and environment, lithology, discontinuities, water content, degree of cementation and crystallization, homogeneity, isotropy, and degree of weathering are the features that affect the compressive strength of rocks. It is seen that the compressive strength of the samples (in a positive direction) is above the TS 10449 limit value. According to the physico-mechanical properties of the sample marble samples, it has been determined that these marbles in the region belong to the strength rock group.

Table 3
Physico-mechanical properties of the samples.

Tests	Results	TS 10449 Limit values (TSE, 1992)
Specific gravity (gr/cm ³)	2.74	
Unit volume weight (gr/cm ³)	2.69	< 0.40
Water absorption (%)	0.6	< 0.40
Porosity (%)	1.3	< 2.00
Uniaxial compressive strength (kg/cm ²)	1530	> 500

3.5. Marble quarries and their characteristics in the study area

The first thing to do in a marble deposit with a proven (exploitable) reserve is the selection of the quarry location where production will start (Şentürk et al., 1996; Onargan et al., 2006; Yavuz and Özer-Çolpan, 2012; 2013). Things to consider when choosing an open pit location are as follows (Uz and Yıldız, 2017b): a) Existence of suitable marble reserves, b) Existence of massive structures for suitable block production, c) Suitable crack system⁸, d) Existence of suitable topography for suitable slope height for quarry opening and formation of stages, e) Laboratory tests to be under suitable conditions for slab marble production. The marble quarry should be opened starting from the thickest place in the marble deposit. In addition, the longer the quarry pithead and the more opposite the structure from which the block can be extracted is aligned, the easier it is to extract the block (Onargan et al., 2006). In this regard, the section where geological and topographic conditions are very suitable for quarry location selection is determined as the quarry location (Şentürk et al., 1996; Uz and Yıldız, 2017b). Incorrect and random quarry location selection can cause significant environmental pollution as well as great economic losses. These environmental pollutions can bring about results that are difficult to correct and very expensive to compensate for (Kadioğlu et al., 2005). In the operating permit area, two marble quarries were opened: Open-pit-1 in the eastern part (Fig. 5a-b) and Open-pit-2 (small) in the western part (Fig. 5c-d). In the eastern part of the study area, the crushed and rusty part of Open-pit-1 with plenty of iron and its levels and surfaces neatly formed by wire cutting is observed. (Fig. 5c-d) shows the wastes, blocky marble fragments, and a few of the other 6 marble quarries on Orhaneli Road. Production work continues in these marble quarries. In (Fig. 5e-f), marble fragmented waste material in Open-pit-1 and metamorphic units towards the bottom, marble production stages, surfaces, and primary stratification towards the south are seen. In addition, the lower part is blocky and fragmented waste material and its base is composed of metamorphic rocks. In (Fig. 5g-h),

Open-pit-1, blocky-fragmented marble (rust), and the gray-colored metamorphic basement formation underneath are seen. (Fig. 7-b), similar to (Fig. 5g-h), shows the spoil and metamorphic units at the bottom. In (Fig. 5-i), karst construction, marble block stone production residues, and metamorphic schist units in the waste area can be seen. In open-pit-1, a rifted and crushed zone (Fig. 6-a) and intact marble levels and crushed units containing abundant hematite in the foreground (Fig. 6-b) are seen. (Fig. 6c-d) shows the marble outcrops and surface shapes that continue towards the top with Open-pit-1, and the block production and stock area from emperor-type brecciated carbonate neritic limestones produced at the bottom. Stalactite-stalagmite structures formed in karstic cavities and cracks with abundant iron-containing walls (Fig. 6e-f), rift, fracture zone, and karst structures (Fig. 6g-h), close view of the crushed and rift zone in Open-pit-1 is presented in (Fig. 6-i). Gray-colored metamorphic rocks or detrital carbonates and block stone-marble pieces are presented in (Fig. 7-a), and distant and close-up views of the opening of Open-pit-2, located in the western part of the operating permit area, are presented in (Fig. 7c-d). Although it is outside the study area, there is another marble quarry near this marble quarry. Open-pit-2 and blockstone marble stocks can be seen in (Fig. 7e-f). In Open-pit-2, clastic fragments and terra rossa formations are seen at the bottom as spoils. The marbled zone continues from Open-pit-2 to Open-pit-1 and towards the hill (Fig. 7g-h). In Open-pit-2, (emperor) marble is in (Fig. 7-i), in Open-pit-2, the opening and upper marble level of Open-pit-1 is in (Fig. 8-a), and in Open-pit-2, The blockstone exhibition area in front of pit-2 is presented in (Fig. 8b-c). (Fig. 8-d) shows block stone-marble and surrounding fields, and (Fig. 8-e) shows the partially forested and marble potential area in the western part. Marble pieces and terra rossa (Fig. 8-f), marble-forming limestones, and underlying metamorphic units (Fig. 8-g) are seen in the spoils. Orhaneli Road continuing towards the west, the gravel quarry of the General Directorate of Highways and Four-stage marble quarry in the background (Fig. 8-h), and the general view of the east of Open-pit-1 and Open-pit-2 from the south is presented in (Fig. 8-i).

3.6. Examination of marble quarry locations

The layering in the open-pit pithead (K-1), determined by photographs in Fig. 5 (a-d) and others and shown in the measured geological cross-section in Fig. 9, is N35W/45SW. The location of the rift, which is ~ 1.5–5.5 m thick, has many cracks on the surface and cuts the pithead towards the south, has been determined as N45E/42SE. This rift zone is a very opaque and ferruginous zone with lots of cracks, and dents, and continues with parallel rifts. The limestones forming the marble blockstone shown in the sketch in Fig. 9 have a very fractured and crushed structure at the upper levels. The A-A geological cross-section in Fig. 10 was prepared based on the 1/25,000 scale topographic map (Fig. 1). As can be seen from the section, the operation license area and the operating permit area face south. There is no marble quarry facing Kapıkaya Stream to the north. There are metamorphic units on both slopes of the Kapıkaya Stream. The elevation of Dümenkırı Hill and Kocakır Hill, where marble-forming limestones are found, is ~ 982 m. In marble quarries, the limestone on the surface (Fig. 6c, e) is layered and abundantly cracked, showing characteristic melting surfaces. Kocakır, Dilmenkırı, Yapağıçam, and Alacakaya Hill and plains where limestones are seen are quite rugged and undulating. Here, water collection and discharge structures (dolins, stalactite-stalactite, and travertine-like formations) formed as a result of the limestone-water relationship are located (Fig. 6e-f). The metamorphic rocks that form the basement beneath the limestones are found in dark-colored "calcschist" and schist structures.

4. Limits of Marble Operational Activities in Water Protection Zones According to Legislation

4.1. Legislation

Even if there is a mineral (proven) reserve on some types of land, mining activities are not allowed in Turkey. These areas; areas such as conservation forests, special environmental protection zones, national parks, wildlife protection and development areas, absolute & short-distance protection zones of drinking water dams, and archaeological/heritage areas (Official Gazette, 1985). In the scope of control and supervision of the extraction of marble located close to water basins, marble quarries are subject to the Mining Law No. 3213 and its relevant regulations, the Environmental Law No. 2872 and its relevant regulations, and the Istanbul Water and Sewerage Administration (ISKI) Law No. 2560 and its relevant regulations. (Official Gazette, 1983; 1985; 2017a; ISKI, 2011). As it is known, the WPCR and RPDPWB Regulations (Official Gazette, 2004; 2017b) are the most important legislation implemented in the protection of water resources in Turkey. The Regulations cover the principles and prohibitions regarding the protection of water resources, wastewater discharge, and (its permit) principles, principles regarding wastewater infrastructure facilities, and monitoring and inspection procedures and principles to prevent water pollution. In Turkey, only physicochemical parameters are monitored in water resources, and water quality classification is made according to these parameters (Ministry of Development, 2018). WPCR, which made administrative, legal, and technical regulations regarding the protection of water resources

and prevention of pollution in Turkey based on the Environmental Law, came into force in 1988. Considering the developing and changing conditions, WPCR was revised and came into force again in 2004 (Official Gazette, 2004). In this Regulation, the areas where mining is allowed and not allowed (absolute, short, medium, and long-distance protection zones) are explained in articles 16–20. The articles were repealed on 14/02/2018. These articles were transferred to the RPDPWB, which came into force in 2018 (Official Gazette, 2017b). Mining activities are completely prohibited in the 100-meter wide strip from the maximum water level of the drinking and utility water reservoir, referred to as the "absolute protection zone", and in the 900-meter wide strip of the absolute zone, referred to as the Short distance protection zone (Fig. 11). According to the current Mining Regulation and RPDPWB (Official Gazette, 2017a; 2017b); Other provisions regarding mining activities in drinking and utility water basins are as follows: (1) Conditions are required that blasting should not be done with the gallery method in the strip with a distance of 1000–2000 m horizontally from the maximum water level of the drinking and utility water reservoir and that water should not be discharged directly to the receiving environment without treatment. Provided that vested rights are protected, mineral exploration & operation activities and infrastructure facilities that are scientifically/technically determined to not harm the environment/human health are allowed under these conditions. (2) Mineral production and all kinds of facilities that are deemed appropriate according to the Environmental Impact Assessment (EIA) report can be conducted in the protection area beyond 2000 m horizontally from the maximum water level of the drinking and utility water reservoir. However, it is mandatory to comply with the limits specified in the relevant legislation in discharges to the receiving environment during the activity⁹. Industrial establishments that operate completely dry and do not produce waste are allowed in the 3 kilometers (km) wide section of the Long distance protection zone (LDPZ) of the drinking and utility water reservoir, horizontally from the Medium distance protection zone (MDPZ) border. (3) In mining activities conducted in drinking and potable water protection basins, if the obligations specified in this Regulation are not complied with and the necessary permission is not obtained, production activities in the field are stopped until the necessary measures and permission are taken.

Wastewater refers to water that is contaminated or whose properties have changed as a result of domestic, industrial, agricultural, and other uses. Wastewater cannot be discharged into the drinking and utility water reservoir. Discharge of wastewater in a way that would change the water quality is not allowed into the streams and dry streams that feed the water source. Disposal of all kinds of solid waste/residues into such water resources cannot be allowed. All wastes generated in marble quarries, whether resulting from production or not, must be determined in advance and temporarily stored, evaluated and finally disposed of according to the type of waste. According to RPDPWB, marble factories are obliged to obtain a discharge permit if they discharge their wastewater to the receiving environment. For this purpose, wastewater must be treated and meet the limit values specified in the Regulation. However, if the factory has a closed-circuit system such as a filter press and no wastewater is discharged, a discharge permit is not required. To obtain a discharge permit, wastewater must not exceed the limit values of the parameters in the tables given in the annex of the regulation. If it exceeds these limit values, it is necessary to ensure these limit values by applying a purification process. The discharge permit is issued by the Governorship (Ministry of Environment, Urbanization and Climate Change (MEUCC) City Directorate). All transactions regarding this issue are carried out in the city where the activity takes place (Official Gazette, 2004; 2017b; Ceylan, 2008). If it is determined that the environment and human health are harmed, mining activities are stopped by the Governorship (Official Gazette, 2017b).

4.2. Detections in the study area & compliance with legislation

Marble production has been conducted in the marble quarry for ~ 3 years. Subsequently, a legal process was initiated regarding this marble quarry in the study area. Thereupon, as a result of the examination carried out by the 1st Regional Directorate of SHW affiliated with MEUCC, the distances of the marble operation license and operating permit areas to Doğançı Dam were determined (Table 4). Marble quarries belonging to the study area and its surroundings located around Dağakça Village and crushed stone quarries belonging to the General Directorate of Highways (Fig. 1; Fig. 4; Fig. 8-h) are presented. It has been determined that the average distance of the marble operating license area to the Doğançı Dam axis is 4300 m (K-3), and the distance of the marble operation license area is 5750 m away (Fig. (b); Fig. 12) (K-4). Considering these distances, it has been determined that the marble operation license area is in the LDPZ and MDPZ of Doğançı Dam, and the marble operation license area is in the LDPZ of Doğançı Dam. All water collection basins outside the protection areas of the reservoirs from which drinking water is taken are LDPZ. Considering that mining production activities and all kinds of facilities that are scientifically and technically determined not to cause pollution according to the legislation or approved by MEUCC according to the EIA report can be conducted in the LDPZ, the current marble quarry does not have any activities contrary to the legislation. In addition, it should be remembered that mining can be permitted by MEUCC, provided that the extraction of minerals is not harmful to health, that they are extracted in a way that does not

disrupt the amount/quality of existing water, and does not cause wastewater discharge to the receiving environment, and that the activity owners give a notarized written commitment to reclaim the land for nature at the end of the activities. The marble quarry also meets these conditions.

Table 4
Distances measured between Doğancı Dam and the study area.

Coordinate number	Fig. number	Measured places	Distance (meters)	Explanation
K-1	Figure 1 (a)	Dam end - north end of the study area	2258	in MDPZ
K-2	Figure 1 (b)	Dam lake-open-pit point	3825	in LDPZ
K-3	Figure 12	Dam body-study area	4300	in LDPZ
K-4	Figure 12	Dam body – locations of marble quarry	5750	in LDPZ
K-5	Figure 10	Dam pond - study area	2258	In MDPZ. This distance is in the Dam feeding area in the northern part. However, the distance is outside the border of the study area and the rainfall area. Additionally, the study area and the southern dam area are outside the feeding area.

Blockstone production in marble quarries is achieved either by hand and with primitive tools or by mechanical and special extraction methods (Onargan et al., 2006; Kulaksız, 2007; Kulaksız and Özçelik, 2007; Özçelik et al., 2017). Then, natural stone cutting & polishing operations are carried out (Özçelik et al., 2007). According to the Mining Law, marbles are included in the 2nd mineral group (Official Gazette, 1985). In the marble quarry in question, marble production is conducted by the surface cutting method. The economic value of marbles is parallel to the beauty of their patterns. No further added value can be achieved by physical or chemical processing. Marbles can only be shaped. Therefore, unlike known mineral processing and extraction methods, no chemicals are used during marble mining and processing activities, and no metallurgical enrichment is performed. In addition, blasting is never done using the gallery method to avoid damaging the underlying layers. The state granted all marble-related activity permits to marble quarries through MAPEG, first with an exploration license and then with an operating permit in the area narrowed down to proven reserves in the operating license area. When the dispute arose about whether the marble fields would harm the dam basin, the quarry had been operating in this area for 3 years (by opening 2 marble quarries, one of which had 4 stages (Fig. 9). At this moment, Bursa Metropolitan Municipality, Osmangazi Municipality, Bursa Chemists Association, and MEUCC participated in the debate on whether the marble quarry harms water resources. However, when the provisions explained above are considered, it has been revealed that the marble quarry operates in accordance with the legislation.

5. Evaluation of the Relationships and Characteristics of Marble Production Quarries With Their Surroundings

5.1. Site-based geological/structural assessment

Production quarries were examined on-site in the marble operating permit area and field-based evaluations from a geological-structural perspective are given in Section 3. In these studies, samples of emperador marble and basic metamorphic unit were taken from the quarries and their mineralogical-petrographic and physico-mechanical properties were revealed (Chemical properties are presented in this title). On a regional scale, in the study area and its surroundings (as can be seen in Fig. 7 and Fig. 8), geologically, limestones & marbles are covering the license area in the upper part, and schists forming the basement rocks in the lower part. In marble-forming limestones (in Open-pit-1), fractured, rifted, melting cavities, travertine and stalactite-stalagmite features are evident.

5.1.1. Northern Slope (Slope of Kapıkaya Stream – Sulu Stream)

Limestone formations are widespread in Kocakır Hill and Dümenkırı Hill. These areas are bare-semi-maquis and contain doline structures that collect water in many places. The limestones located on the metamorphic basement have a total thickness of 65–70 m. Metamorphics have calcschist, micaschist, and gneiss structures. These continue up to the water collection level of Doğancı Dam. Their thickness is ~ 500 m.

5.1.2. Southern Slope (Kıranlık Stream and Değirmen Stream)

As can be seen in the geological cross-section in Fig. 10, limestones have a 70-meter-thick hat-like position on top of metamorphic schists. Metamorphics have a slope of 10–15 degrees. Değirmen Stream is a waterless stream that merges with the watery Kapıkaya Stream on the Orhaneli road and enters the pond area. There are also irrigated and dry streams coming from the marble quarries area in the western part.

5.1.3. Geological structures & streams and features in marble quarries and surroundings

Among the 2 quarries opened in the marble operating permit area, the one in the eastern part has 4 stages (Fig. 5a-d), and the one in the western part has a single-stage quarry opening (Fig. 7c-f). The operating license area, but not the operating permit area, is adjacent to Kapıkaya Stream, where the second branch of Doğancı Dam is located (Fig. 1). In addition, Doğancı Dam is located in the west of Kapıkaya Stream and the Doğancı Dam feeding areas. Other quarries continue to produce marble in this section. A marble quarry (Fig. 13-a) and another marble quarry and marble units around Kapıkaya (Fig. 13-b) can be seen in the west of the study area. The source of the Nilüfer Stream begins in the Uludağ-Soğukpınar region in the eastern part of Doğancı Dam. This stream reaches Doğancı Dam by traveling 50–60 km. It is noteworthy that in the upstream section of Doğancı Dam, there is a charcoal production facility and buildings (Fig. 13-c) on the edge of an irrigated side stream (close to the upper water level of the dam, at an elevation of 389 m on the Dağakça Village road) that connects to Nilüfer Stream from the south (K-5 in Fig. 12). Similarly, oak charcoal production facilities and the like are known to be widely available in this environment. The end of the arch-type dam is presented in (Fig. 13-e), and the dam pond and the Orhaneli road are presented in (Fig. 13-f). Therefore, there are 7 other marble quarries & facilities, also quarries (belonging to the General Directorate of Highways), and facilities producing oak coal, along with the marble quarry under the study, near the dam lake and the streams reaching the lake.

5.2. Evaluation of the operation license area with streams in terms of environmental geology

As can be seen in Fig. 10, the most prominent areas in and around the study area are the operation license area and Doğancı Dam. In terms of geological formations, the license area is "limestone-marble" and there are metamorphic units of different ages - that is, Paleozoic age - under this 70-meter Jurassic-aged limestone. In this regard, the Doğancı Dam feeding area basically consists of schists and limestones, especially Kapıkaya Stream (Fig. 4). There are limestones, which are carbonate rocks, at the base of the drinking water dam and especially in the feeding area. In this context, the rocks in the pond inevitably contain CaCO_3 along with the water coming from the adjacent streams due to these formations.

On the other hand, there are dolines in the license area where surface water is collected in Kocakır Tepe. Water collected from different channels in limestone reaches the dam pond in another way. The area where the quarry with an operating permit is located within the operating license area is located in a small area (29.49 ha) to the south of the license area. As seen in Fig. 10, a line separating the flow directions of atmospheric water passes through the license area and this line shows the water flow directions towards the dam in the northern part. Surface and groundwater within the license area of this line flows towards the south. Due to this line, there is no stream leading directly to the dam from the operating license area and operating permit area. The flow direction of all slopes and all surface waters in and around the license area is toward the south. In addition, the streams in this section (e.g., Karanlık Stream) have the characteristics of dry streams.

5.3. Evaluation of chemical properties of marble

The chemical composition of the marble sample taken from the operating permit area is presented in Table 5. Total CaCO_3 is 68.32%. 38.26% of this belongs to CaO and 47.47% to CO_2 composition. There are no heavy metals or contaminants such as Pb in the sample. Hg, As, and Zn rates are well below acceptable limit values. According to the Mining Wastes Regulation and the ISKI

Drinking Water Basins Regulation, the samples taken from the marble material in terms of their chemical properties and heavy metal-pollutant contents do not contain any heavy metals or pollutants that would deteriorate or pollute the water quality of the Doğancı Dam lake basin. According to the results of this analysis, the total carbon rate is 97.5%. The other component of marble, other than 1.24% quartz, is $\text{CaMg}(\text{CO}_3)_2$. As stated above, limestone (marble), as a pure rock at this level, has no properties that would deteriorate water quality, considering that many streams connecting to Doğancı Dam pass through limestone. In marble production, gallery blasting and metallurgical processes with chemicals, which are prohibited by the legislation, are not carried out. In addition, there is no production of polluting Pb-Zn-Cu ores or similar elements, or these elements are not used in marble processing. The CaCO_3 composition, which the administration claims against mining operations to prevent pollution with wastewater and water loss or decrease in the study area, has nothing to do with pollution.

Table 5
Chemical composition of the marble sample taken from the marble operating permit area.

Compound	Ratio (%)	Compound	Ratio (ppm)	Compound	Ratio (ppm)
Ca	27.33	Cu	0.038	Hg	0.0001
CaO	38.26	Zn	0.080	SO_4	0.31
CaCO_3	68.32	Fe	0.100	Cl	0.23
Fire casualties, CO_2 , H_2O , etc.	47.47	Pb	Yok	pH	7.32
Mg	7.85	Al	0.055		
MgCO_3	28.29	Cr	0.020		
SiO_2	1.24	As	0.005		

According to the protection areas determined by the SHW, the marble license area is in the LDPZ (Fig. 12). Marble, which has no health hazards and has a composition that will not harm the quality of existing water, consists of 97.5% $\text{CaMg}(\text{CO}_3)_2$. On the other hand, there are commitments to restore mining areas to nature if they are abandoned. It is stated in detail in WPCR and RPDPWB that operations that meet these conditions will be permitted (See Section 4). According to the article titled LDPZ of the Regulation, in cases where it is not technically and economically possible, discharge of wastewater into the basin may be allowed, provided that it is brought to 1st class water quality by using advanced technologies (Official Gazette, 2017b).

6. Results

The technical properties of the marble in the operating permit area, which covers a small area (29.5 ha) of the marble operation license area (183.7 ha) whose geological-structural, mineralogical, and petrographic characteristics are given, were investigated, and the characteristics of marble production in this area were determined. Emperor marble is known to be rare in the world. It is a very valuable and widely used marble, mined locally in Turkey. As can be seen in (Fig. 5a-d), Emperor marble was produced in two marble quarries, the eastern one with a vertical section of 70x100 m and the western one being smaller. The results of the study on whether these marble quarries have the potential to harm water resources are as follows:

- Legislative provisions (Section 4) and the distances of the marble quarry to water protection basins (Fig. 1 (b); Fig. 12) show that the examined quarry and the marble quarries in its vicinity operate in accordance with the legislation.
- The marble operation license area and operating permit area are not directly within the Doğancı Dam feeding area (Fig. 10).
- Doğancı Dam is mainly fed by the limestones and Dolin structures in and around Kocakır Hill in the north of the license area and the limestones (marble) in Kapıkaya Stream (Fig. 10).
- Drinking and potable water basins & protection zones should be defined together with geological structures, underground hydrogeological features, and streams. However, limiting protected zones by distance is not based on scientific data.
- In the Doğancı Dam protection zones, there are 7 marble quarries producing marble block stone and a gravel quarry belonging to the General Directorate of Highways, except for the marble quarry examined and related to the dam water collection streams.

In addition, it has been determined that artificial charcoal is produced in the irrigated side stream connected to the Nilifer Stream and in many places.

- The marble operation in the study area and the sites of other quarries in the vicinity, which have operating permits by MAPEG, have an orientation facing the Doğancı Dam and the feeding streams, facing south rather than north (Fig. 5a-c; Fig. 6-a).
- Marble production in quarries is made by wire cutting method. However, the transport water used for this process flows south from the surface, is collected at one point, and prepared for reuse. In addition, the pieces that come out of the marble quarry as spoil are stockpiled and these do not reach any streams related to the dam.
- According to the investigation conducted by SHW, the marble operating permit area, which does not contain pollutants and does not involve metallurgical processes, blasting, or underground production, is located within the LDPZ at a distance of 5700 m from the Dam (Fig. 12).
- Emperor marble produced from the quarries and the units located in its foundation were examined in terms of their mineralogical-petrographic, physico-mechanical, and chemical properties (Sections 3 and 5). Accordingly, it has been determined that the marble is quite pure (98% carbonate component) and does not contain chemically harmful pollutants and heavy metals (or contains ppm & ppb levels). As a matter of fact, the samples taken from the marble-produced material do not have heavy metal or pollutant content that would deteriorate or pollute the water quality of the Doğancı Dam lake basin in terms of their chemical properties and heavy metal-pollutant contents, according to the Mining Wastes Regulation and the ISKI Drinking Water Basins Regulation.

7. Discussion and Suggestions

In this study, it was determined as a result of field and laboratory research whether a marble quarry caused environmental damage to the drinking and utility water basin located nearby. According to this determination, the marble quarry -including the marble quarries in its vicinity- does not cause any environmental damage to the drinking and utility water basin in question. Environmental assessments should be made from the same perspective for this marble quarry, as well as all nearby marble & natural stone quarries and coal production facilities, and this equality should be maintained in practice.

As stated in the literature, waste containing sulfur or nuclear raw materials can have extremely negative environmental effects on water resources. There are also examples where coal mining has damaged water resources, especially in the past years. Although there are limited studies in the literature showing that marble/natural stone wastes harm water resources compared to those containing sulfur and nuclear raw material elements or coal, environmental impacts are variable in the overlap of each mining site and water conservation basins. In determining this, it is especially useful to conduct investigations from the discipline of geology/hydrogeology. As shown in the case study examined, it has been determined that marble operating and processing does not cause any negative environmental impact on water resources.

When RPDPWB provisions are evaluated in terms of marble operating, since blasting, crushing, sifting, washing, ore preparation, and enrichment operations are not carried out, marble mining can be conducted in areas 2 km away from drinking water with the permission of MEUCC. However, in such cases, there is a very high probability that the relevant administration will not allow it (PIA, 2006). MEUCC has WPCR and RPDPWB Regulations. However, despite this regulation of the Ministry, municipalities are making their own regulations and trying to implement them. E.g., Bursa and Izmir Municipalities have issued regulations in this direction. As a result, mining has become impossible even in the LDPZ. However, the LDPZ of water basins starts after 2000 m and it is not clear how long the long distance area continues after 2000 m. This distance depends on the topography of that area. E.g., this distance can be 500 m or 5 km. For this reason, municipalities regulating this issue with their regulations produce extremely erroneous results. However, the Mining Regulation already allows mining even in the MDPZ of water basins (provided that no gallery blasting is done). In the LDPZ, which is further away from this distance, mining can be conducted in accordance with the EIA (Kasapoğlu, 2010).

To protect water, it should be discussed that instead of general prohibitory provisions in the legislation, it would be more accurate to make evaluations according to the criteria to be determined on a basin basis, depending on the condition of the water basin, and that some practices should be taken as a result of these evaluations. For this purpose, environmental plans can be made in such water basins in Turkey and necessary measures can be taken on a basin basis (PIA, 2006). Effective planning methods should be developed for land use in nature conservation (Yazıcı-Gökmen and Gülersoy, 2018). In Turkey, there is a lack of a system (a new

planning model) that can be integrated into existing laws by ensuring broad participation in the law-making process (where basin ecosystem boundaries and protected zones are based on scientific facts and the system is managed from a single center) (Suri, 2018). In this planning, the production of mineral reserves in an environmentally friendly manner and considering the country's interests should also be considered (Yıldız, 2020). In the face of this deficiency, the study in this article determines whether marble mining hurts water basins in a multidisciplinary manner and brings practical solutions to the practices in developing and underdeveloped countries, especially those that have a weak ability to cover the scientific, and technical and economic costs of environmental analysis. It is a practical study that can be implemented by independent experts to prevent mining operations from harming water basins. It may shed light on new evaluations with different conditions on whether a marble operation around the world has similar environmental impacts on a drinking water basin. In future studies, different studies in which the effects of not only marble or mining operations in different mineral groups, but also industrial and energy production facilities on drinking water basins across the country are examined by different disciplines, or evaluated in terms of land use, can complete the deficiencies in this study.

Declarations

Declaration of Interest statement

This study does not have any financial support.

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Footnotes

1. On the other hand, the presence and interaction of groundwater are not always in favor of marble enterprises and may reduce the quality of marble. In this direction (Sarıışık et al., 2010), the effect of sulfate water compounds on natural stones was investigated.
2. As an example of these studies, for studies on the geological, petrographic, and technological evaluation of marbles in cities close or partially close to the study area, see (Uz et al., 2001; 2003a; 2003b; 2003c; 2006).
3. To conduct mining activities in Turkey, the investor must first obtain a mining operation license. After this license, an operating permit is required to conduct the activities shown in the mining operation project. The operating permit area is determined by reducing the mineral reserve in the operation license area to the proven reserve. The operating permit indicates that all other permits have been obtained for the production of minerals in the operation license area and that there is no obstacle to mineral production (Yıldız, 2020; 2022).
4. Figure 1 is a revised version of the map quoted from (MND, 1956), with additional drawings made using the data in this study.
5. Figure 3 is a revised version of the map quoted from (URL-1), with additional drawings made using the data in this study.
6. Figure 4 (b) is quoted from URL-1. Figure 4 (a) is a revised version of the map quoted from (URL-1).

7. Knowing the unit volume weight of marble is especially useful in calculating the thickness of sling ropes used in loading and transportation costs (Onargan et al., 2006).
8. The presence of discontinuities in the marble can create negativities in situations such as block extraction, cutting, and processing of marble. In block production, e.g., chert zones should be avoided and attention should be paid to these zones (Uz and Yıldız, 2017b).
9. For mining to be carried out in accordance with RPDPWB, the EIA report must be approved by MEUCC in the scope of the EIA Regulation. Then, inspections are conducted by MEUCC to determine whether mining is carried out in accordance with the EIA Regulation (Değerli and Dikmen, 2005; Yıldız, 2021).

Figures

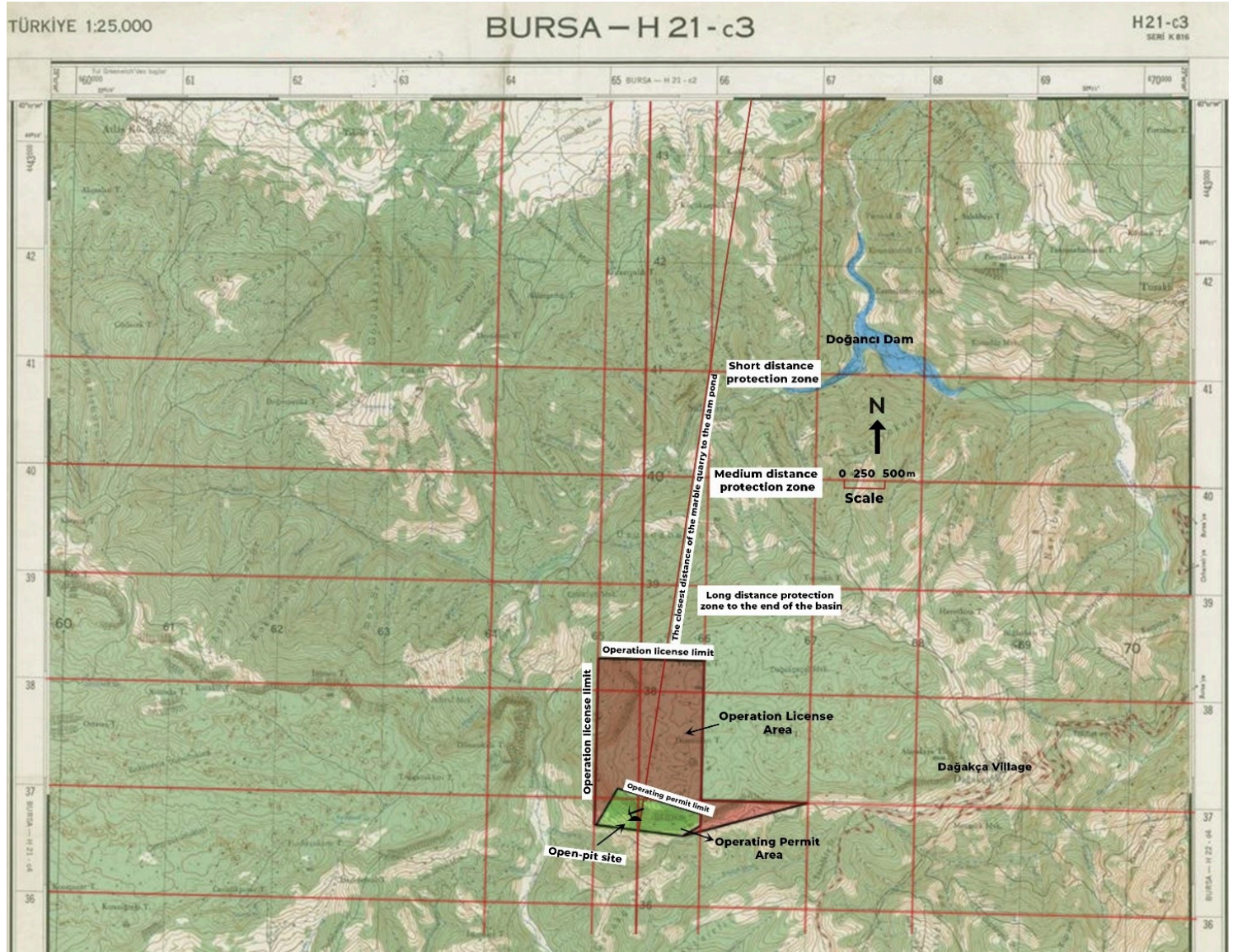


Figure 1

Map of the distances of the mining area to the Doğancı Dam protection area on a 1/25000 scale topographic map^[4].

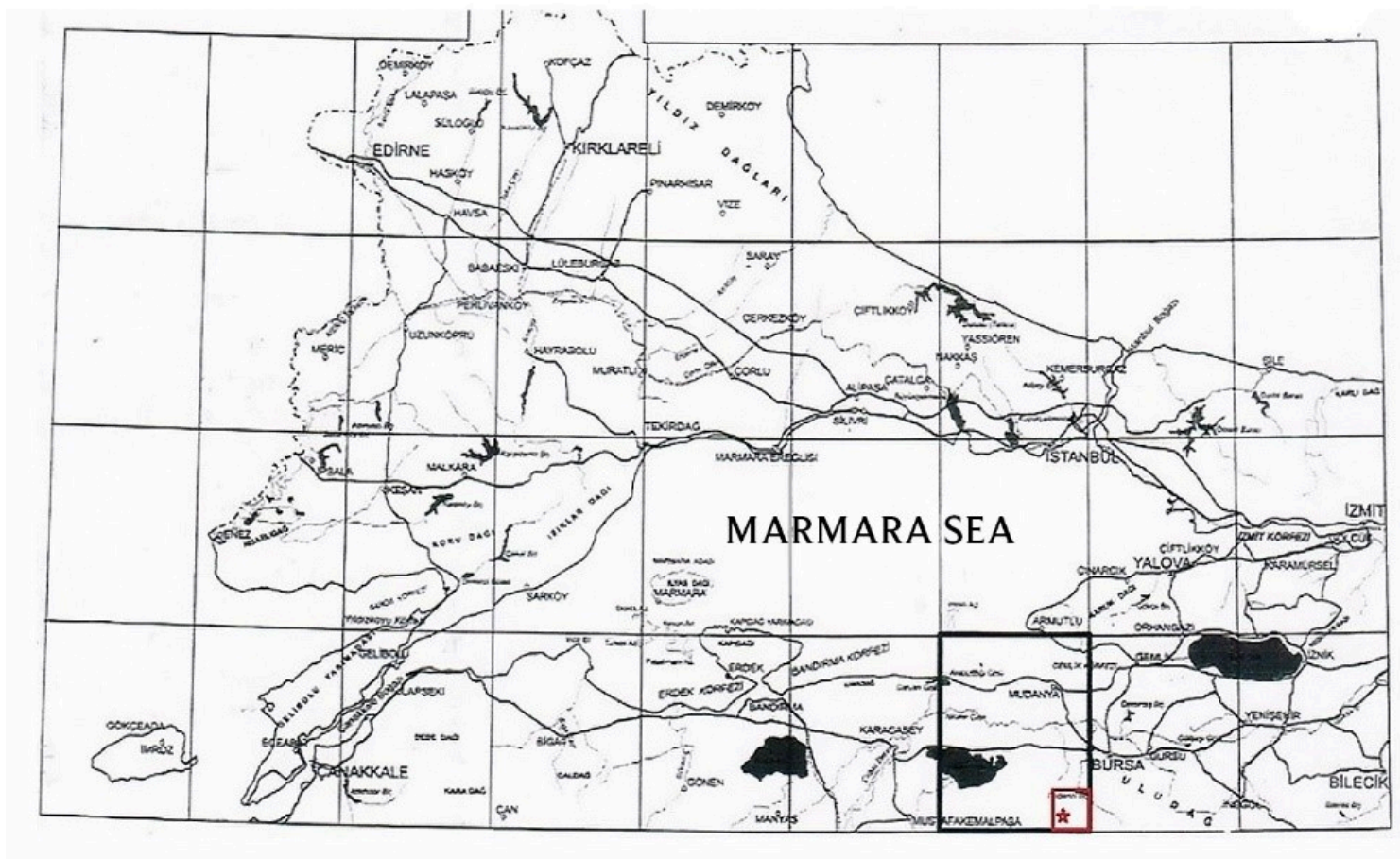
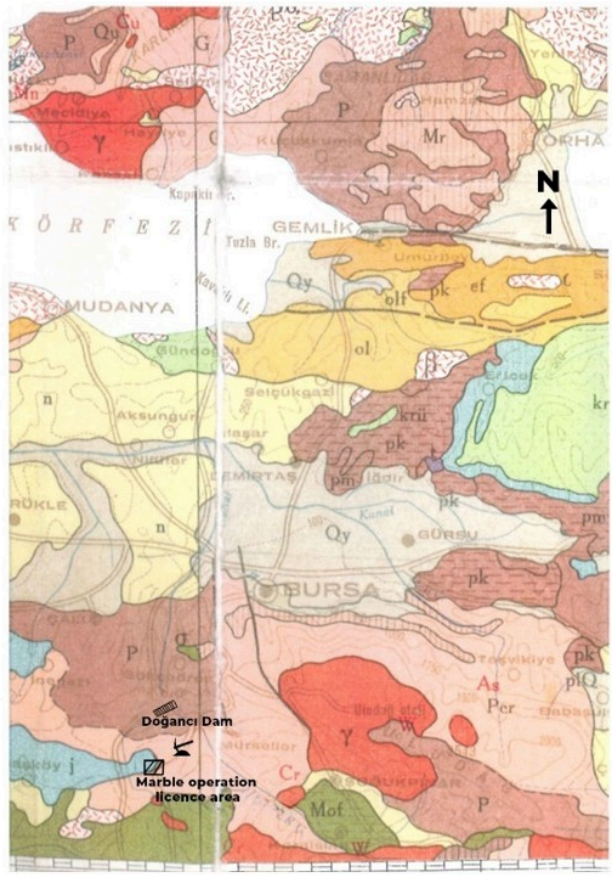


Figure 2

Location of the study area in the H21 map (Kandemir et al., 2013).



(a)

Icon-color	Formation type	Feature and distribution
Q2 grey	Alluvium: sand gravel, clay Quaternary	Around Bursa Plain in the north
n yellow	Young volcano-sedimentary deposits	Görük and Selçukgazi in the north
	Neogene	Soğukpınar in the south
γ red	Uludağ granite, Miocene	In the south and west
J blue	Limestone-marble	Around the study area
P brown	metamorphic series	Around the study area
Cr pink	Metamorphic series under Jurassic limestones	Around the study area

(b)

Figure 4

(a) 1/500,000 scale MTA geological map and study area, (b) Regional geological formations (from top to bottom)^[6].

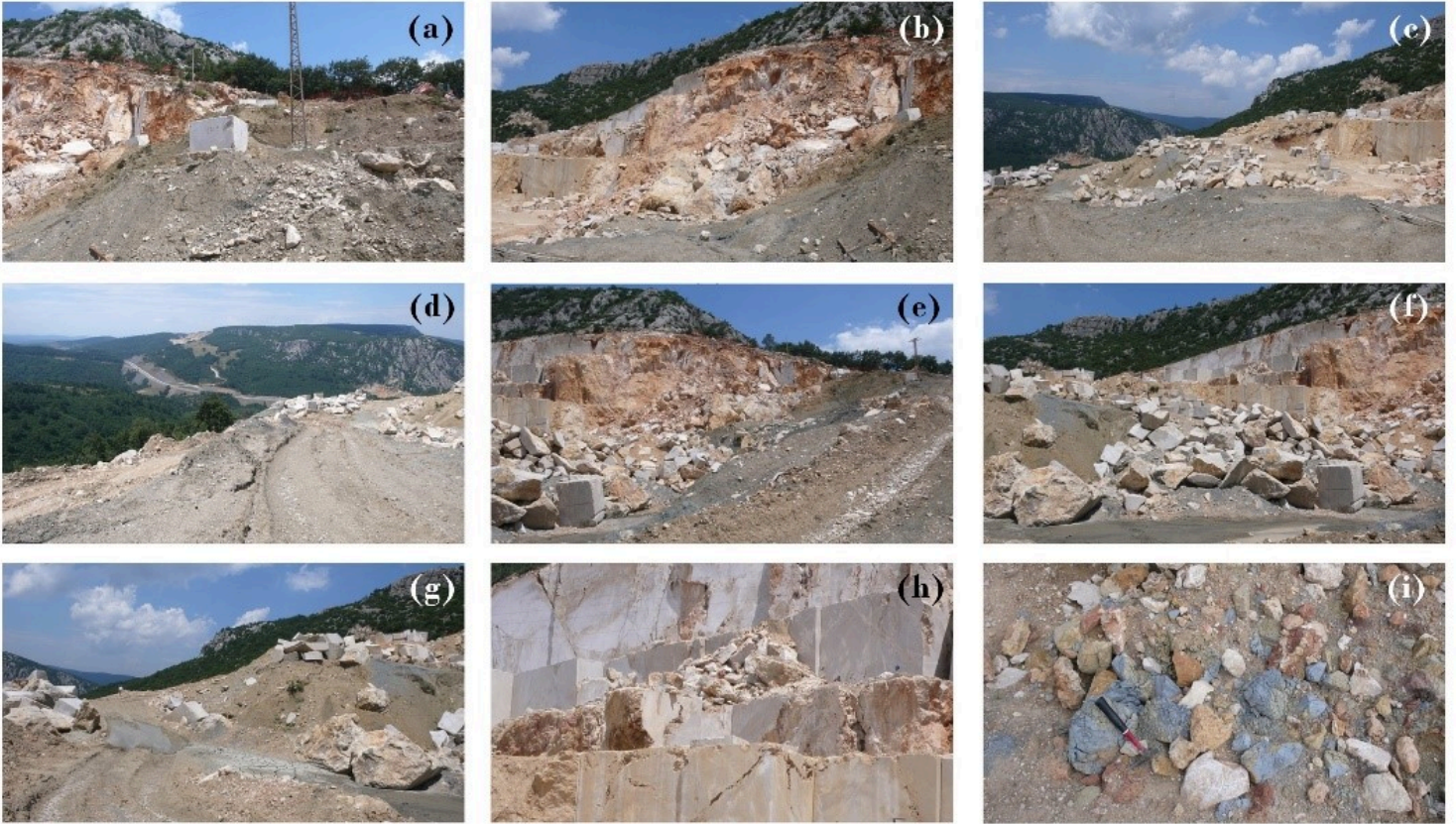


Figure 5

(a-b) Open-pit-1 and its stages in the study area, **(c-d)** Other marble quarries on the Orhaneli road close to Open-pit-1, **(e-f)** View of Open-pit-1, **(g-h)** Open-pit, opening, stages, and cracked structures. (i) Spoils- residues, marble blockstone fragments, and metamorphic schist.

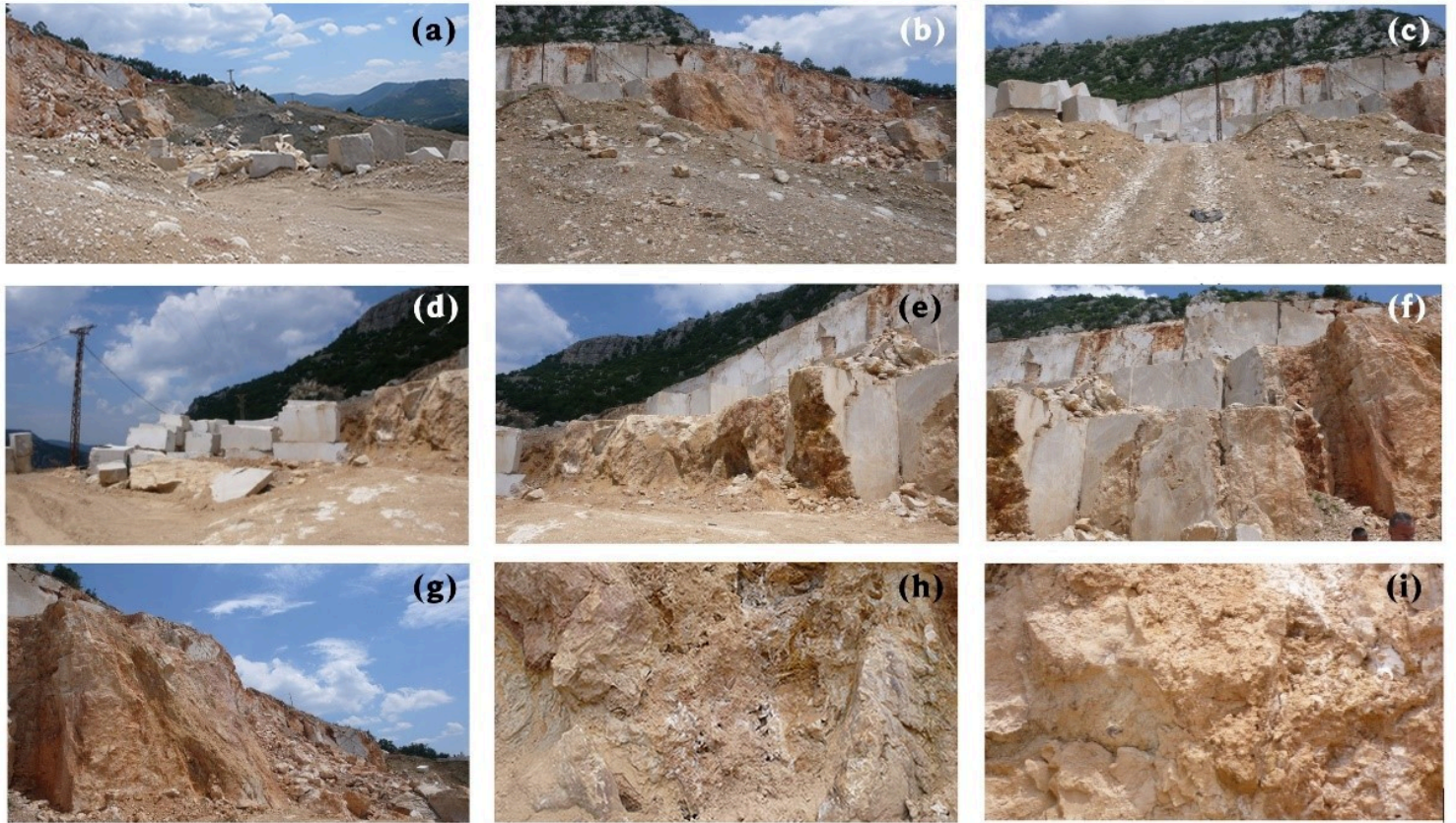


Figure 6

(a-b) Open-pit-1, view of the pithead and rift zone from the west, **(c-d)** Upper top part with marble level and levels separated by wire cutting, **(e-f)** Karst gaps in the pithead and stage gaps, **(g-h)** Rifts and crushes view of the zones, **(i)** Close-up view of the crushed rift zone in Open-pit-1.

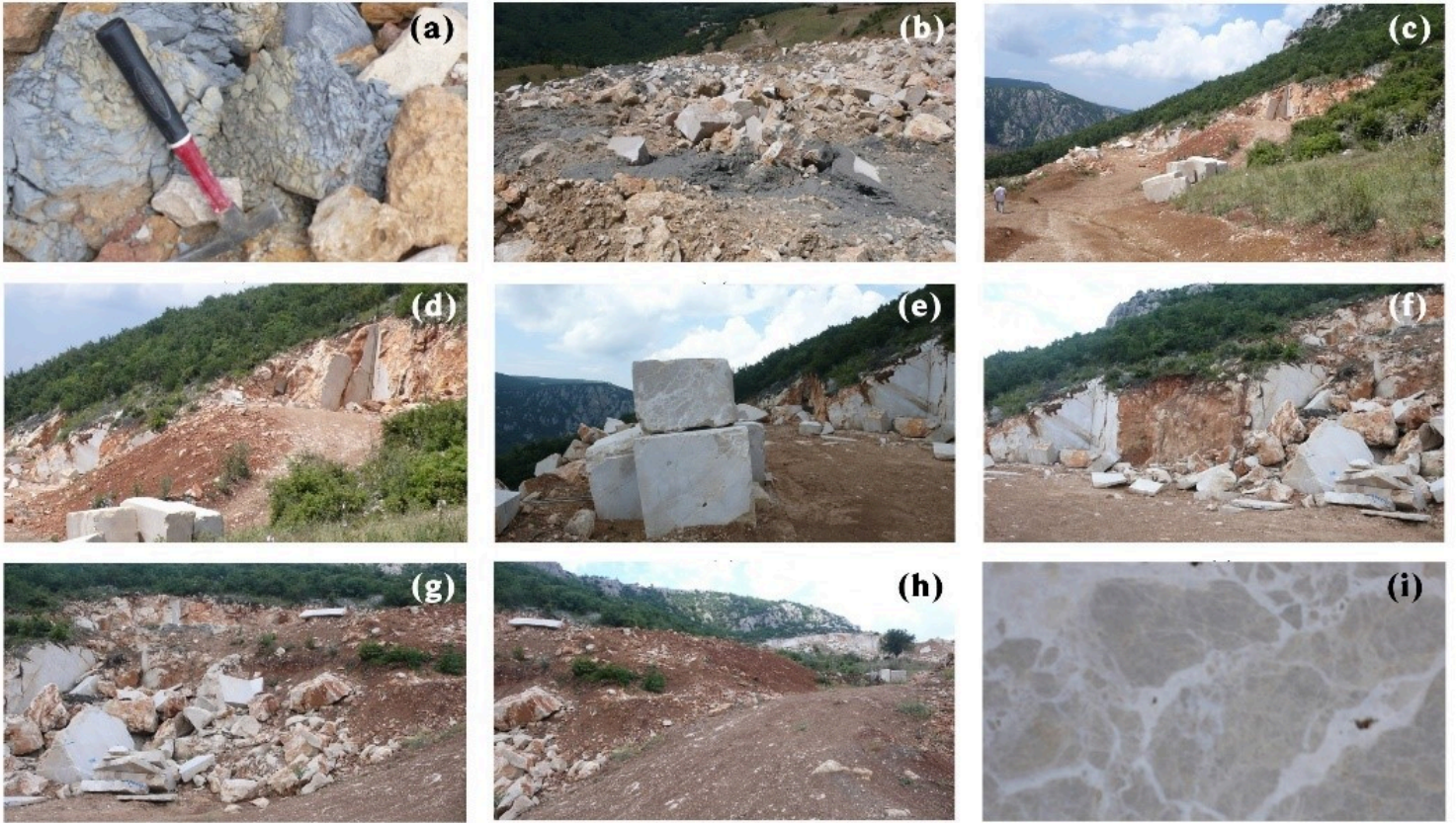


Figure 7

(a) Spoil material in front of the open-pit, **(b)** Blockstone waste material and small-sized material in Open-pit-1, **(c-d)** Pithead of Open-pit-2 in the western part of the operating permit area, **(e-f)** Close-up view of Open-pit-2, **(g)** Detrital fragment material as spoil in Open-pit-2, **(h)** From Open-pit-2 to Open-pit-1 and continuing towards the top marbled zone, **(i)** Close-up view of (emperor) marble in Open-pit-2.

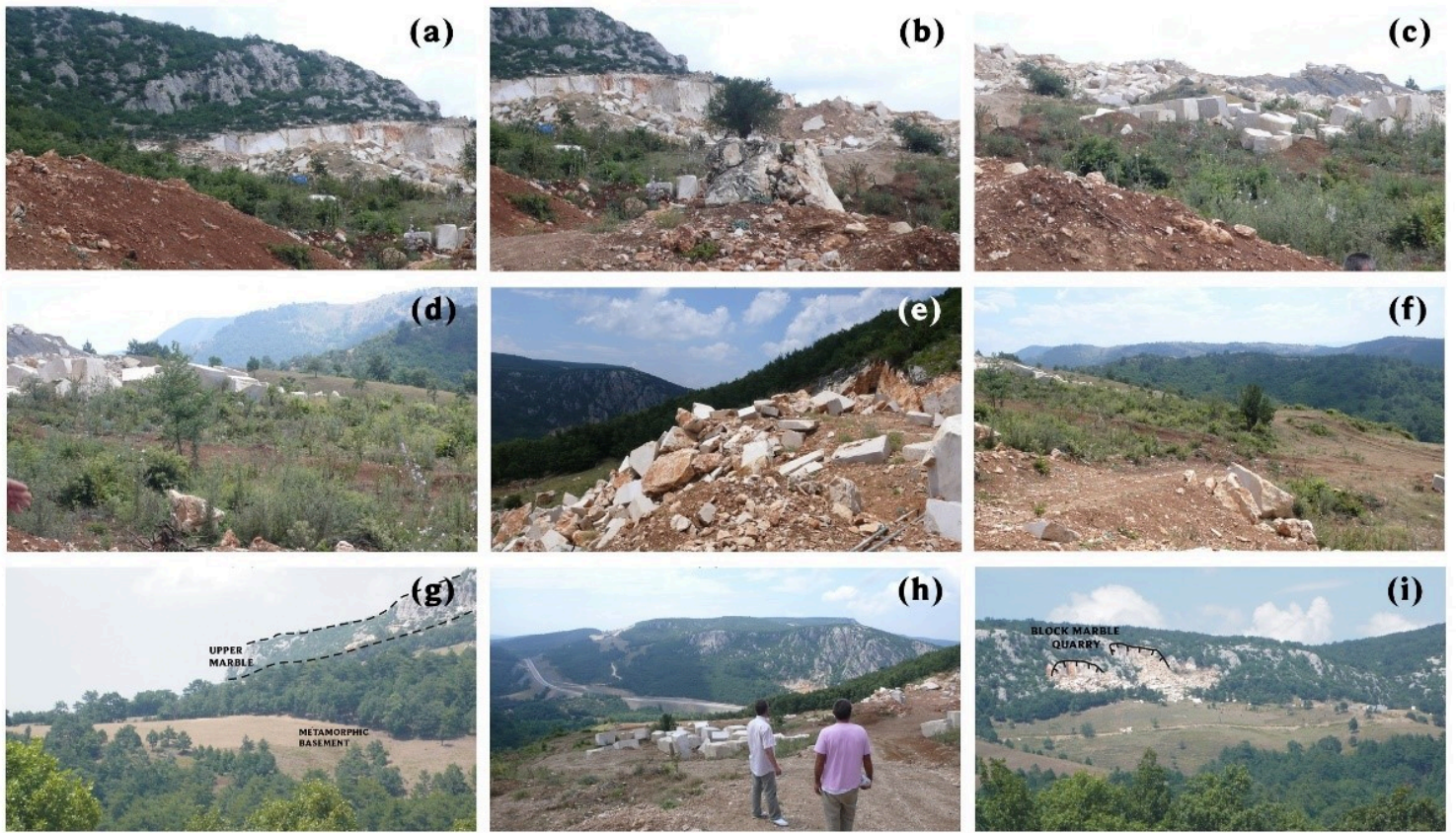


Figure 8

(a) View of Open-pit-2 and Open-pit-1 pithead and upper marble level. **(b-c)** Blockstone exhibition area in front of Open-pit-2 and Open-pit-1, **(d)** View of fields with blockstone-marble, **(e)** Field in the western part that is partly forested and partly has marble potential, **(f)** Basic metamorphic units in the southern part of Open-pit-2, **(g)** Marble zone at the top and appearance of metamorphics at the bottom, **(h)** Blockstone-marble products and basically metamorphic unit in the south of the marble quarries, **(i)** General view of the east of Open-pit-1 and Open-pit-2 looking south.

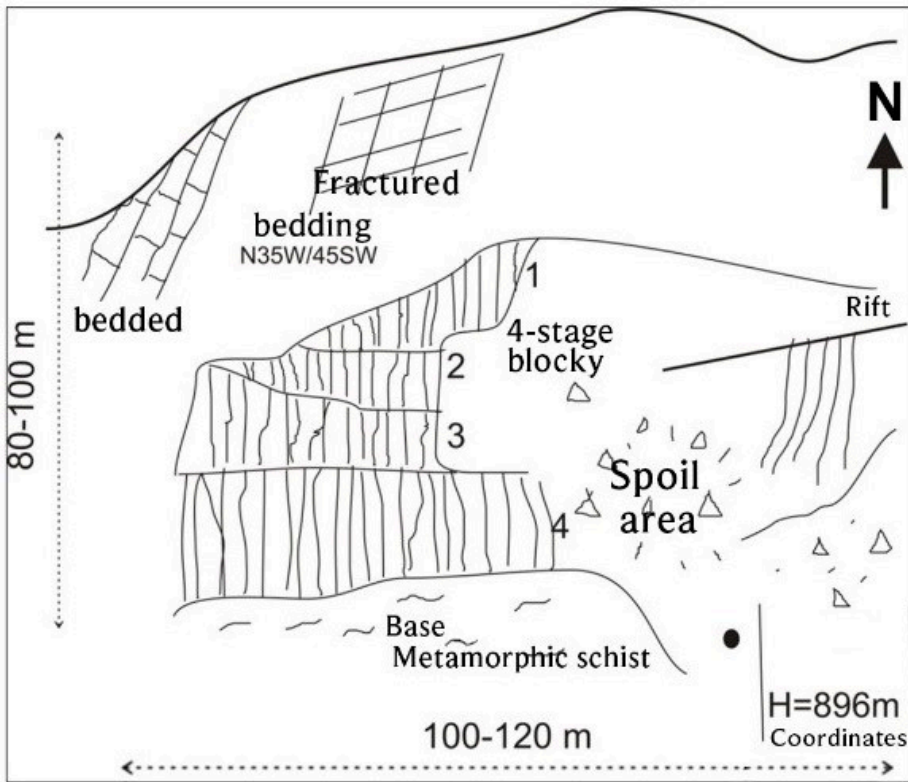


Figure 9

Non-scale view of the Four-stage marble quarry that is operational in the study area.

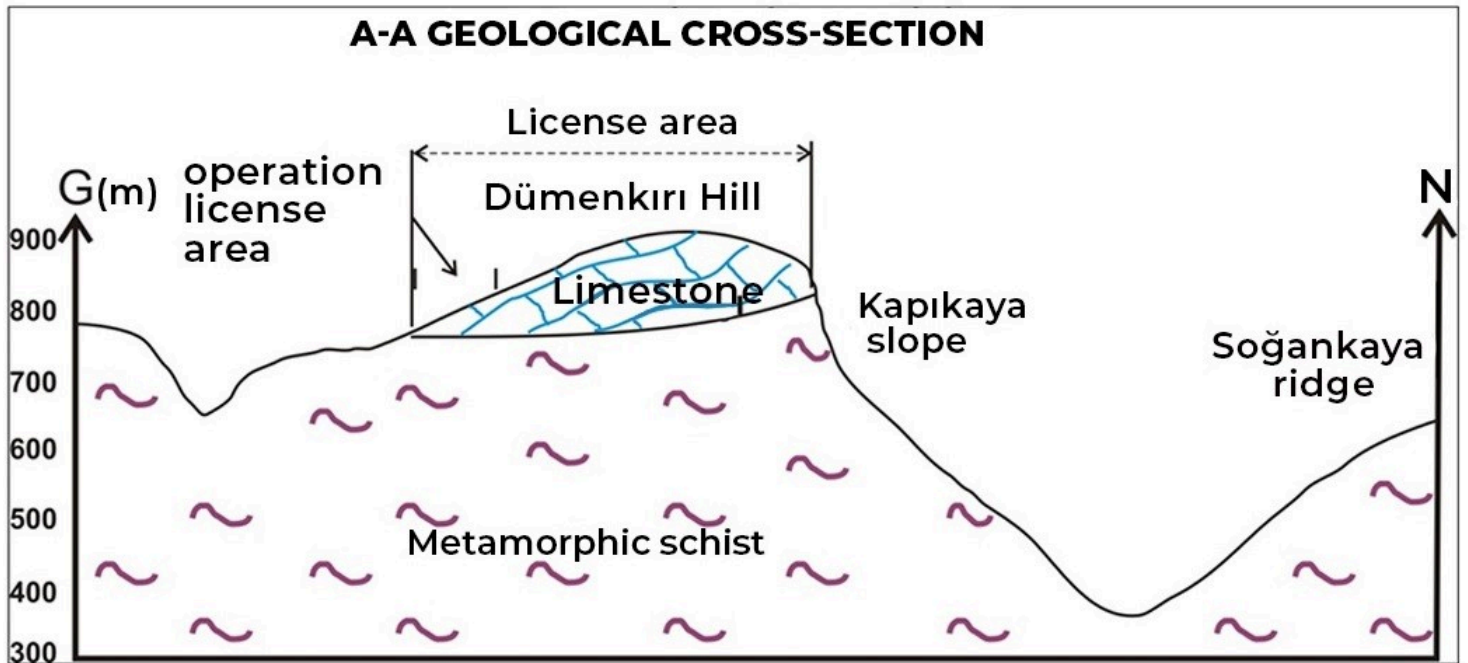


Figure 10

Cross-section of the study area in N-S direction.

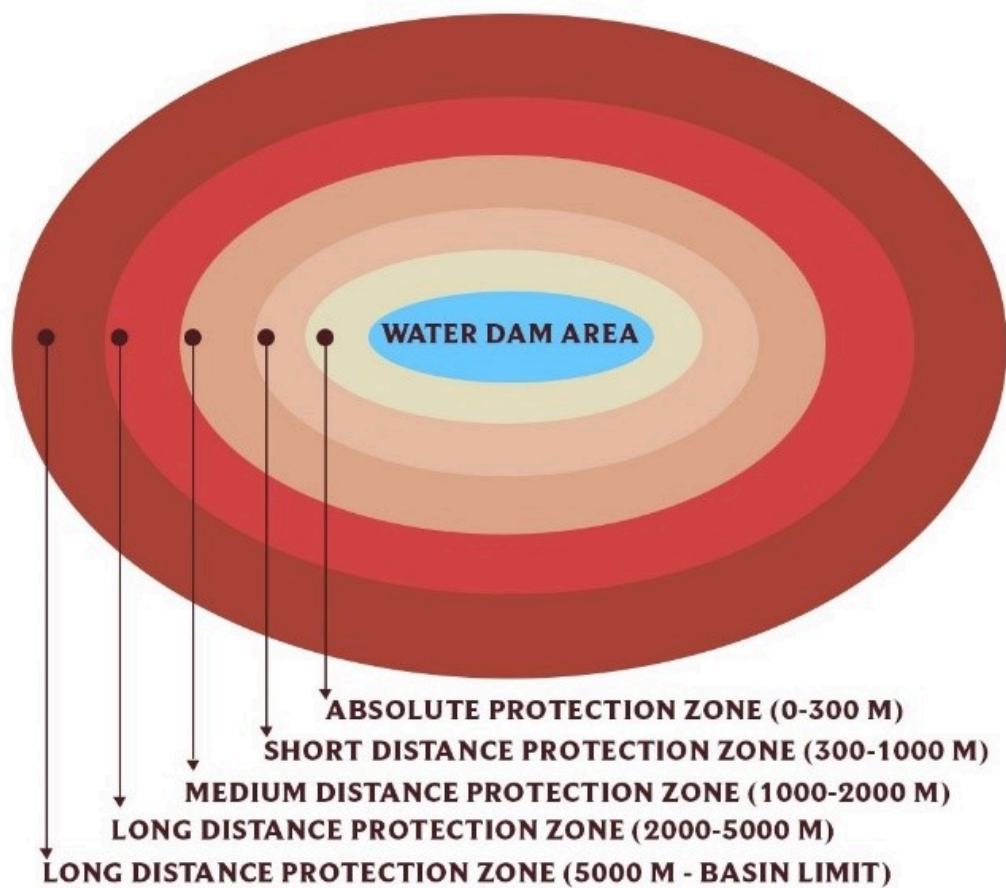
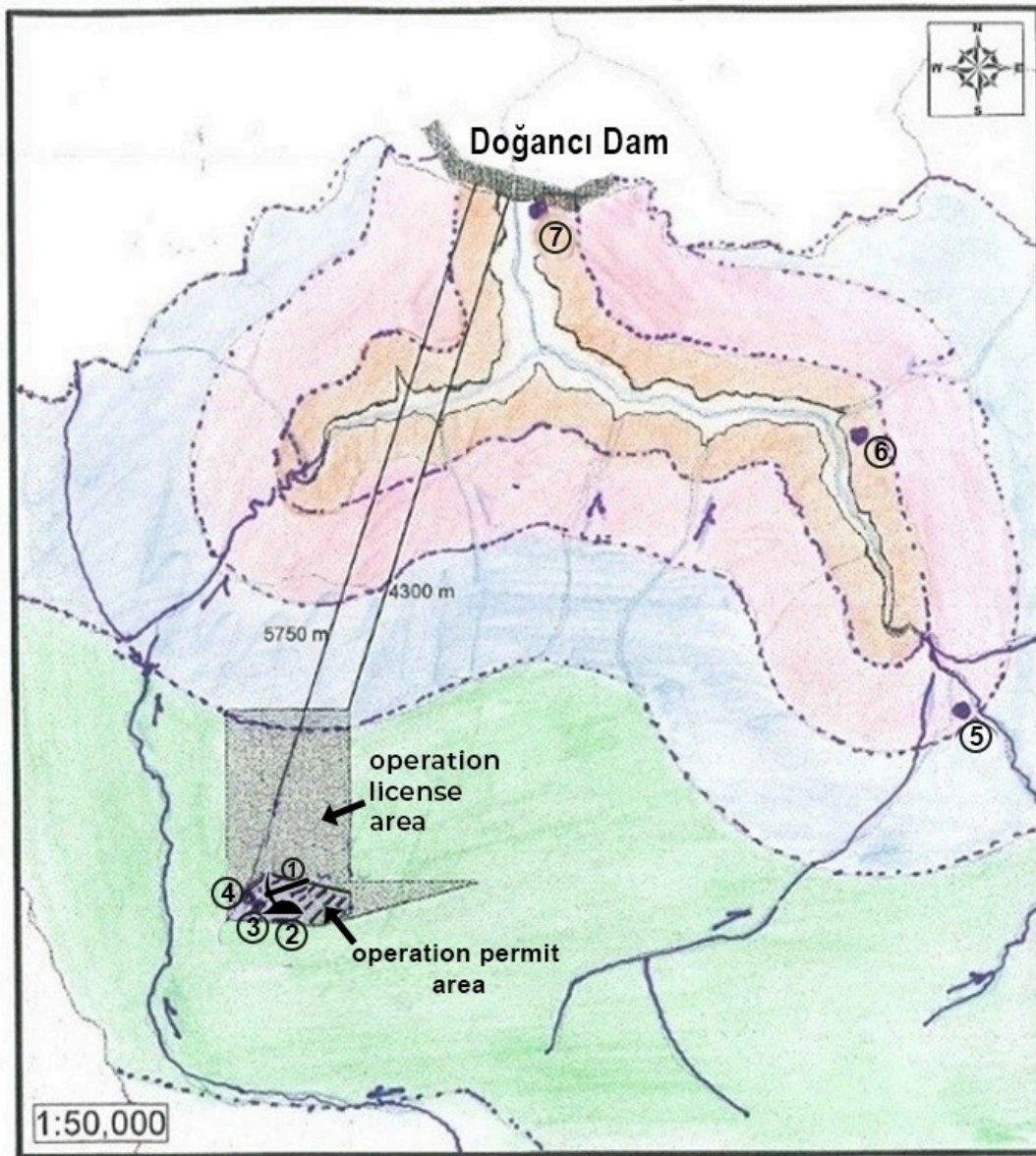


Figure 11

Protection zones around the water source in Turkey.



LEGEND

- Marble quarry
- Basin boundary of drinking water dams
- Drinking water protection zones**
- Explanation**
- Absolute protection zone
- Short distance protection zone
- Medium distance protection zone
- Long distance protection zone (First 3 km)
- Long distance protection zone (Except the first 3 km)

Figure 12

Location and characteristics of marble operating license & permit areas compared to Doğancı Dam protection areas (SHW, 2007).



Figure 13

(a-b) Different marble quarries and formations in the west of the study area, **(c)** charcoal production place on the Dağakça Village - Bursa road, **(d)** End of the dam pond from Bursa road, **(e)** End of the arch type dam, **(f)** Dam lake and Orhaneli road.