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Evaluating geological and geotechnical data for the study of land subsidence phenomena at the perimeter of the Amyntaio coalmine, Greece

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1. Introduction

Mining activities almost always causes large scale impact to the natural environment [1]. These effects can be observed in all production stages, such as the excavation stage, the transportation and the storage of the by-products, as well as their management and disposal [2]. The effects of the mining activity can be divided into those occurring during the operation of the mine and last till the mine closure and those that are permanent, unless the right measures are taken.

Typical geohazards recorded to both active and inactive mines affecting the nearby natural environment include: pollution of air, soil and water [3–10], failures of tailing ponds [11–15], sinkholes due to the collapse of underground cavities [16–21], slope failures at opencast mines [22–26], land subsidence phenomena [27–31], and furthermore triggering of small earthquakes [32–36].

In Greece mining activity exists since the Bronze Age. As a result, too many active and abandoned mines can be located all around the country. The geohazards and generally the environmental hazards related with the operation of the mines cover a wide range of mining hazards [37–44].

This study refers to the land subsidence phenomena caused around an open cast coal mines due to the overpumping of the ground water, for the protection of the slopes. These geohazard combines hydro-geological and geotechnical factors, and slowly affect extensive areas [40,45–47].

The study area, Amyntaio sub-basin, is located in the wider Kozani-Amyntaio-Ptolemaida- Florina-Bitola basin, extending from Kozani, on the south, to Monastery (FYROM), on the north (Fig. 1a). Amyntaio sub-basin includes the homonymous open cast coal mine, surrounded by numerous villages (Fig. 1b).

The mining activities as well as the rising agriculture activities have led to a significant drawdown of the ground water level, during the last decades. The hydrogeological and tectonic setting of the site along with the geotechnical parameters of the formations, trigger extensive ground subsidence phenomena, causing damages at the nearby villages, infrastructure and farmlands. This phenomenon has been studied by many researchers during the last decades [40,48–51], but still several issues remain unknown such as the distribution of the geotechnical characteristics of the formations occupying the basin, the spatial distribution of the deformation and all the implicated land subsidence mechanisms etc.

The main purpose of this study is to provide an engineering geological- geotechnical map as well as of thematic tectonic and hydrogeological maps of the Amyntaio basin and to correlate the characteristics of the formations with the spatial distribution of the deformations recoded along the basin. These maps can be generally used for the mitigation of the mining geohazards during the mining as well as the post-mining period.

2. Geological, tectonic and hydrogeological setting

The wider Ptolemaidas-Amyntaio basin belongs to the Pelagonian geotectonic zone of Greece and it consists of a crystalline-schist bedrock covered by Neogene and Quarternary sediments. The pre-Neogene formations are distinguished into the Palaeozoic metamorphic rocks (gneiss, amphibolite schists and quartzes) and the mesozoic carbonate cover (crystalline limestones, marbles and dolomite marbles) [52,53].

The Neogene sediments filling the large tectonic trench can be divided in two series, the lower and the upper. The lower series of Neogene sediments, deposited at a lacustrine environment, consists of clays and sands alternating with hard lenticular intercalations of sandstones and siltstones [54]. This series contain xylite layers [55] constituting the so called Vegora and Komnina deposits. The thickness of this lignite series decreases progressively westward [56].

The Upper Neogene series consists of alternations of marls, clay marls, clay sands and fine sands of grey to grey green tinge [54]. Intercalations of lignite layers are often found. The lignite deposits of the Amyntaio basin [57] and of the south lignite field of Ptolemaida [58] belong to this upper series. The total thickness of Neogene sediments is approximately 450 m [59,60].

The tectonic activity in the early Pleistocene divided the Neogene basin into new sub-basins, which were filled with Quaternary

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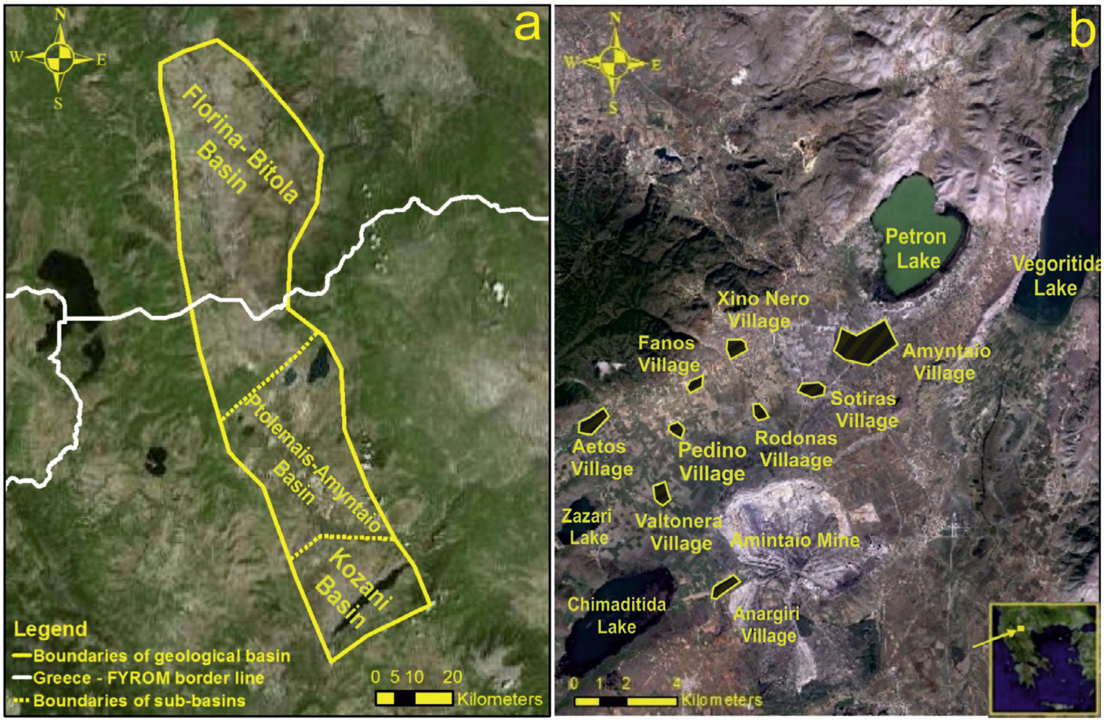

Fig. 1. a Satellite images (©Virtual Earth) presenting the trench graben of Florina-Ptolemaida-Kozani basin. b Satellite image (©Google Earth) presenting the narrow study area.

fluvial-stream deposits and alluvial fans. The phreatic aquifers of the Amyntaio basin are hosted in those formations. The Quaternary deposits are divided (from the older to the recent ones) into the following formations:

- The Proastio Formation: Fluvial-stream deposits of the Low-Middle Pleistocene age [54], which overlie uncomfortably over the lignite Neogene deposits. They consist of alternating loose sands to clayey sands and conglomerates with red clays [59].
- The Perdikas Formation: Lacustrine and river deposits of the Low- Middle Pleistocene age [54]. They consist of fine sand with alternating layers of sandy clays, clays and marls, as well as lenticular intercalations of conglomerates with small sized pebbles [59].
- The Anargyroi Formation: Fluviotorrential deposits of the Middle-Pleistocene, consisting of clayey sands or thin sands including clay layers or lenses with gravels [54].

Furthermore, the recent deposits include clastic lacustrine deposits and old scree talus cones and alluvial fans. During the Holocene travertine formations, of limited extend, have been deposited, as well as peat and recent lacustrine deposits. The stratigraphy is completed by thin surface deposits constituting of eluvial and recent alluvial soil layers.

The neotectonic activity of the area is controlled by an extensional strain field, active since Middle–Upper Miocene, affecting the wider northern Greek territory [61–64]. There are two main faults direction identified at the site. The initial graben was shaped by normal faults extending with a NW–SE to NNW–SSE direction [59,65,66], affecting the pre-Neogene formations [61,67,68]. During the Pleistocene, a new strain field has been developed. This led in the creation of a second group of faults with NE-SW to ENE-WSW direction. These faults along with their antithetic faults separated the initial basin into smaller sub-basin of Florina-Bitola, Amyntaio – Ptolemaida and Kozani (Fig. 1a) [61,69–72].

The basin of Amyntaio is bordered by three main tectonic lines, clearly presented at the thematic tectonic map of Fig. 2. The Petron-Xino Nero-Aetos fault (Fpxa), borders the northwest end of the sub-basin and separates the Florina basin from the Amyntaio-Ptolemaida basin. Its overall length exceeds 30 km while its direction is NE-SW leaning SE. The Vegoritida fault (Fveg), identified at the northern side of the homonymous lake Vegoritida (Fig. 1b). It extends with a NNE - SSW direction and its length is approximately 9 km. It is a typical normal fault with neotectonic activity. The Anargiroi fault (Fang) has the same direction with the Vegoritida fault. With a total length of 10 km, it crosses through the village of Anargiroi and borders the Cheimaditida lake from the southwest. The fault was clearly identified at the slopes of the Amyntaio mine [48]. It should be noted that due to the fault‘s offset and the erosion activity the Perdikas formation is absent from the lithostratigraphic column of the formations extending at the uprising (SE) segment of the fault [60].

At this point it should be noted that the faults presented at tectonic map (Fig. 2) were verified by evaluating numerous studies [49,50,54,61,73] and they were also identified in the field.

Regarding the aquifers, at the Amyntaio basin they occupy the quaternary deposits and they are mainly unconfined. Their maximum thickness reaches approximately the 120 m, at the center of the basin, decreasing toward the boundaries of the field [74]. The aquifers recharge both by the infiltration of surface water and the lateral inflow from the karstic aquifers of the surrounding pre-alpine carbonate formations.

The beginning of the lignite mining activities changed radically the hydrogeological status of the study area as it was combined with the construction of numerous wells for the protection of the opencast slopes. Although that most of the water pumped out of the opencast was led to the irrigation canals surrounding the mine, the aquifers were not recharged and the ground water level kept on falling. Besides the mining activities, the overexploitation of the aquifers in the wider basin is also amplified by the increasing