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NEW DATA REGARDING THE GROUND WATER LEVEL CHANGES AT THE AMYNTAIO BASIN- FLORINA PREFECTURE, GREECE

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Abstract

The site investigated is the Amyntaio basin where a productive semi-confined aquifer is developed at the quaternary deposits. In the present study, the piezometric curves which have been extracted before the beginning of the mine activity (1992), were compared with the recent ones (2015), aiming to study their diachronic changes. From the subtraction of the two aforementioned piezometric surfaces, a significant ground water drawdown that reaches 70 m near the mine was observed. This drawdown, during the last decades, proves that the aquifer has been overexploited by both the mine of PPC -to protect the slopes and to prevent the water outflow in the mine- and the wells for irrigation purposes. The level drop extends, on the west, to the villages of Valtonera and Anargyroi and the underground water flow directs towards the mine. The Amyntaio mine can be described as a well with a diameter up to a few kilometers. The interaction of the groundwater level drawdown with the intense fragmentation and the geotechnical characteristics of the geological formations of the region triggered extensive land subsidence phenomena damaging numerous villages, infrastructures and extensive farmlands.
Keywords: *Overexploitation of aquifers, Opencast mines, Land subsidence.*

Περίληψη

Η περιοχή διερεύνησης είναι λεκάνη Αμυνταίου στην οποία αναπτύσσεται υδροφόρος ορίζοντας εντός των τεταρτογενών αποθέσεων. Στη παρούσα μελέτη, οι πιεζομετρικές καμπύλες που είχαν δημιουργηθεί πριν την έναρξη του ορυχείου (1992) συγκρίθηκαν με τις πρόσφατες (2015) με σκοπό να μελετηθούν οι διαχρονικές αλλαγές. Από την αφαίρεση των δύο πιεζομετρικών επιφανειών παρουσιάζεται μία σημαντική πτώση στάθμης η οποία φτάνει τα 70 μέτρα στη περίμετρο του ορυχείου. Αυτή η πτώση, αποδεικνύει ότι κατά τις τελευταίες δεκαετίες ο υδροφόρος ορίζοντας υπεραντλείται τόσο από τη λειτουργία του ορυχείου της ΔΕΗ (για την προστασία των πρανών καθώς και για την αποφυγή εκροής νερού στο ορυχείο) όσο και από τις υδρογεωτρήσεις για αρδευτικούς σκοπούς. Η πτώση στάθμης, εκτείνεται δυτικά έως τους οικισμού των Βαλτονέρων και Αγ. Αναργύρων και η κατεύθυνση ροής των υπογείων υδάτων είναι προς το εσωτερικό του ορυχείου. Το ορυχείο μπορεί να περιγραφεί ως ένα τεράστιο φρέαρ διαμέτρου μερικών χιλιομέτρων. Ο συνδυασμός της πτώσης στάθμης με τον έντονο κατακερματισμό της περιοχής αλλά και των γεωτεχνικών χαρακτηριστικών των σχηματισμών πυροδότησαν εκτενής εδαφικές υποχωρήσεις προκαλώντας ζημιές σε χωριά, υποδομές και γεωργικές εκτάσεις.

Λέξεις κλειδιά: *Υπεράντληση υδροφόρου ορίζοντα, Επιφανειακά ορυχεία, Εδαφικές υποχωρήσεις.*

1. Introduction

Every mining activity has an impact on the nearby environment, causing the so-called mining hazards. Active mining operations are usually well monitored by the owners and by the mining authorities.

This study focuses on the land subsidence phenomena caused by the overexploitation of the ground water for the dewatering of the open pit coal mines. These large-scale geohazards are related both to hydro-geological and geotechnical factors, and they slowly affect extensive areas around the opencasts (Hill and Price, 1983; Donnelly, 2000; Kim et al., 2006; Galloway and Burbey, 2011).

The area taken into consideration is the one belonging to the basin of Amyntaio and its aquifer has been over pumped during the last decades by the PPC and farmers.

This drawdown changes the stress field of the loose Quaternary deposits. These conditions combined with their mechanical properties have caused strong land subsidence. More specifically, the overexploitation of the aquifers has triggered, since 2005, extensive land subsidence phenomena. These phenomena extend 3-4 km around the mine causing damages to two villages so far: Anargiroi and Valtonera (Loupasakis et al., 2014).

The purpose of this study is to investigate the relationship between the intense drawdown of the aquifer with the operation of the mine and irrigation activities. This is considered as important because the drawdown is a causal factor of subsidence.

1.1. Study area

The study area is located in West Macedonia at Florina prefecture (Figure 1), and surrounded by the mountain ranges of Vermio on the east and Askio on the west; the basin of Amyntaio extends to Chimaditida lake on the south and to the mountain range of Kleidi on the north. This area includes the villages of Anargyroi, Valtonera, Aetos, Fanos, Xino Nero, Amyntaio and Sotiras. The area is characterized by rich surface water as it includes four lakes- Cheimaditida, Zazari, Petron and Vegoritida- which communicate with each other either naturally or artificially. Finally, a part of the region is occupied by the PPC lignite mine of Amyntaio.

1.2. Geological setting

The wider Florina-Ptolemaida basin is a part of the Pelagonian geotectonic zone, consisting of crystalline-schist bedrock overlapped by Neogene and Quarternary sediments. The bedrock formations are either members of the Triassic-Jurassic carbonate cover or upper Cetaceous pelagic sediments, of the Pelagonian zone lithostratigraphic series (Loupasakis *et al.*, 2014).

The Neogene sediments were deposited after the creation of large tectonic trench which extends from Servia Kozanis, on the south, to Yugoslavia, on the north. These deposits are distinguished in three series (lower, the lignite and upper).

The upper series overlying the lignite series, consists of two different layers of different graded sediment. The thickness varies in the range of about 100 meters.

The lignite series comprises of the upper and the lower lignite layer and the one between those two layers, the intermediate line, of the so-called ''sterile'' layer, consisting of light grey marls up to 15 m. The total thickness of the lignite series is more than 150 m.

The lower series is divided into an upper and a lower part. The upper part consists of ash clay loam, locally sandy with lenticular intercalations of marly limestones. The low portion is composed of sandy clays with marly intercalations. Its thickness is more than 200 metres.

The maximum total thickness of the Neogene deposits exceeds the 450 m (Koukouzas *et al.*, 1979, 1981).

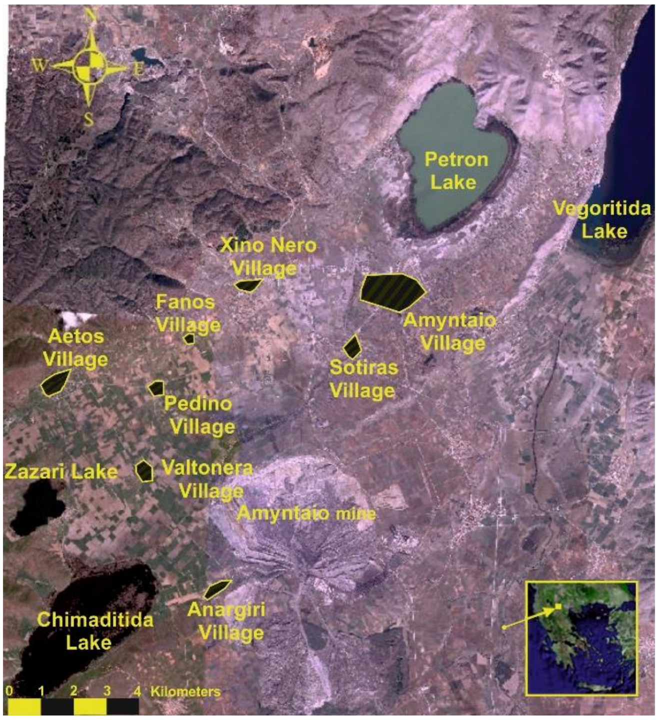

Figure 1 - Satellite images (Google) demonstrating the position of the study area inside Greek territory.

After the deposition of the Neogene sediments and the creation of lignite in the early Pleistocene, there were new tectonic disruptions which caused vertical movements of the basin's parts. This tectonic activity divided the initial basin in new sub-basins. Weathering processes supplied the sub-basins with Quaternary fluvial-stream deposits and alluvial fans. Aquifers are formed in almost every quaternary formation of the wider region up to Florina.

The Quaternary deposits are divided (from the recent to the older ones) into the following formulations:

The Anargyroi Formation: Fluviotorrential deposits of the Middle-Pleistocene, which, as mentioned in the geological map (IGME, 1997), consists of clayey sands or thin sands which in places show clay layers or lenses with angular fragments.

The Perdikas' Formation: Lake and river sediments of the Low- Middle Pleistocene age (IGME, 1997). Across the basin, Perdikas' formation consists of intercalations of fine sand with alternating layers of sandy clays, clays and marls, as well as lenticular intercalations of conglomerates with small sized pebbles (Koukouzas *et al.*, 1979).

The Proastio Formation: Fluvial-stream deposits of the Low-Middle Pleistocene age (IGME, 1997), which overlie uncomfortably over the lignite Neogene deposits. Generally, throughout the basin, this formation consists of alternating loose sands to clayey sands and conglomerates with red clays (Koukouzas *et al.*, 1979).

The neotectonic activity of the area is controlled by an extensional strain field, active from Middle-Upper Miocene till now, affecting the wider northern Greek territory (Pavlides, 1985; Pavlides and Simeakis, 1988; Mountrakis *et al.*, 1998, 2006). The initial large Florina-Ptolemaida basin was shaped by normal faults extended from NW-SE to NNW-SSE direction, while a second group of NE-SW to ENE-WSW direction faults was contemporary formed. The faults of the second group in combination with their antithetic faults form successive basins along a N-S axis (Pavlides, 1985; Atzemoglou *et al.*, 2003).

The basin of Amyntaio is bordered by two main tectonic lines. At first, the fault of Vegoritida, which starts from the northern side of the lake (village Agios Spyridon), passes through the Ag. Panteleimon reaches the Vegora and continues in the basin. The direction is NNE - SSW and the length of the northwest side of the lake, which defines, is about 12 km. It is a typical normal fault with neotectonic activity. Continuing to the fault of Vegoritida, with a shift to the southeast, locates the fault of Anargiroi which has the same address direction to the Vegoritida's one. It passes through the village of Anargiroi and is developed to the southwest bordering Lake Cheimaditida. The continuity of the fault detects also within the mine of Amyntaio (Loupasakis *et al.*, 2010).

1.3. Hydrogeological setting

The aquifer of Amyntaio is formed in the quaternary deposits and during the past it was exploited mainly for irrigation and water supply. These sediments display satisfactory porosity in their mass and store important groundwater reserves. The area of the mine of Amyntaio is surrounded by a significant part of the aquifer. Its thickness reaches approximately the 120m under the surface (Stamos and Giannoulopoulos, 2010). The limits and its extent are shown in the attached hydrogeological map (Figure 2). The aquifer is fed by both the precipitation and the filtration of the water coming of the streams.

Their systematic exploitation started taking place after the exsiccation of the swamp, extending at the northeast of the Chimaditida Lake and the re-allotment of the land, in 1974. Since then, several wells were bored as buck up sources of irrigation water, supporting the canals system. The beginning of the lignite mining activities, in 1989, 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 number of farmers' irrigation wells.

The contribution of these wells in the ground water level drawdown cannot be estimated as no records exist about the irrigation water consumption (Loupasakis *et al.*, 2014).

Finally, as it was proved at the research of Stamos and Mathaiopoulos (2010), the aquifer is over-pumped and its water is used in both agriculture and industry (PPC). After evaluating the hydraulic grade status of the aquifer in the area, by measuring existing drillings, it was found that during the last decades the groundwater drawdown is around 35 m in a radius of about 300 m to the west and northwest of the mine Amyntaio, whereas the level is more than double (70 m) next to the mine. As a result, the water reserves of the aquifer have been reduced near the mine having also a direct impact on the quantities available for irrigation. Moreover, this drawdown changes the geostatic stress field of the loose quaternary sediments.

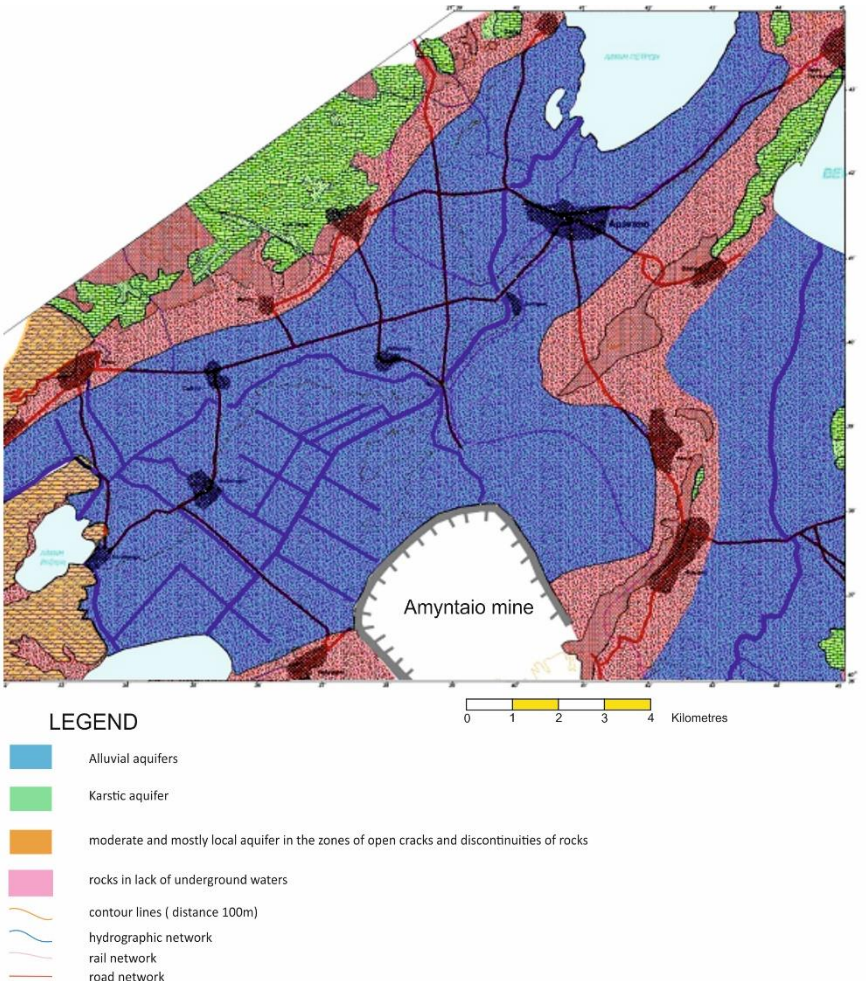

Figure 2 - Hydrolithological map of the study area made by Stamos and Giannoulopoulos (2010).

1.4. Methods

For the purpose of this study, the geological and hydrogeological conditions of the study area were evaluated. In addition, the piezometric curves were processed in a chronological order aiming to determine what the aquifer level was before and during the mining activity. Then two ground water level measurement field campaigns were conducted to the study area at September 2014 and May 2015. The drill network used for the campaigns was based on formerly established networks, mainly by IGME, but also several new drills were added. The destruction of several old network drills as well as changes on the land use forced these additions. After measuring the ground water level, surfer and Arc GIS 10.1 were launched in order to construct the necessary piezometric maps.

2. Hydrogeological setting -Diachronic changes of the piezometry at the study area

The effect of the overexploitation of the ground water can be easily examined by comparing successive isopiezometric contour lines. This procedure was applied at first at the paper of Loupasakis *et al.* (2014) that compared the isopiezometric lines drawn by Dimitrakopoulos (2001), based on measurements conducted in May 1992 (Figure 3), with contour lines based on measurements conducted by the Laboratory of Engineering Geology and Hydrogeology of the NTUA, in April 2011. The actual ground water drawdown is clearly presented in the drawdown contour lines map of Figure 4, drawn by subtracting the two aforementioned piezometric surfaces. In this map, it is clearly presented that the depression cone formed at the west of the mine extents to the Chimaditida Lake and the maximum drawdown, next to the mine, is more than 40 m.

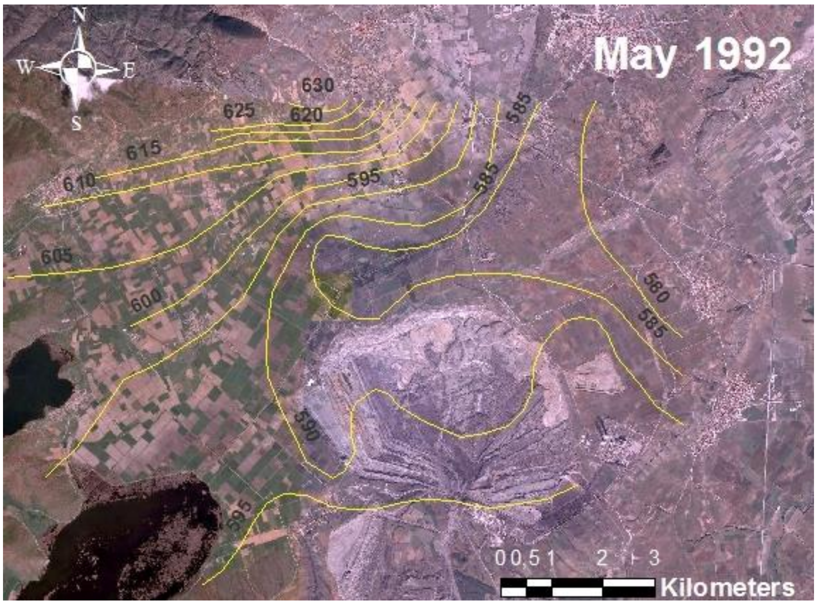

Figure 3 - Isopiezometric contour lines based on measurements taken in May 1992 (Dimitrakopoulos, 2001). Note that the extent of the opencast presented at the satellite image does not present the extent of the opencast during 1992.

It should be noted that the Anargiri Fault forms an impermeable barrier by bringing the permeable Quaternary deposits, located at the descending segment, right next to the impermeable Neogene marly formations, of the ascending segment, as it presents more than 100 m offset. Actually, because of the faults offset, Perdikas formation is absent from the lithostratigraphic column of the formations extending SE of the Anargiri fault (Loupasakis *et al.*, 2014; Koukouzas *et al.*, 1981).

Based on the data collected during the two ground water level measurement campaigns, at October 2014 (end of dry period) and May 2015 (end of wet period) the following illustrations presenting the isopiesometric contour lines were designed. Both images clearly present the drawdown cone extending at the perimeter of the mine. Furthermore, the isopiezometric curves of May 2015 indicate a dynamic drawdown cone at the south of Valtonera, probably caused by the pumping applied for irrigation purposes.

Finally, drawdown contour lines were designed by subtracting the two aforementioned piesometric surfaces referring to the periods May 1992 (Dimitrakopoulos, 2001) and May 2015 (Figure 7). This figure presents a significant groundwater drawdown towards to the mine. Its maximum value exceeds the value of 70 m, next to the perimeter of the mine.

Figure 4 - Drawdown contour lines map drawn by subtracting the piezometric surfaces of May 1992 (Dimitrakopoulos, 2001) from the ones of April 2011 (Aggelitsa, 2012; Loupasakis *et al.*, 2014).

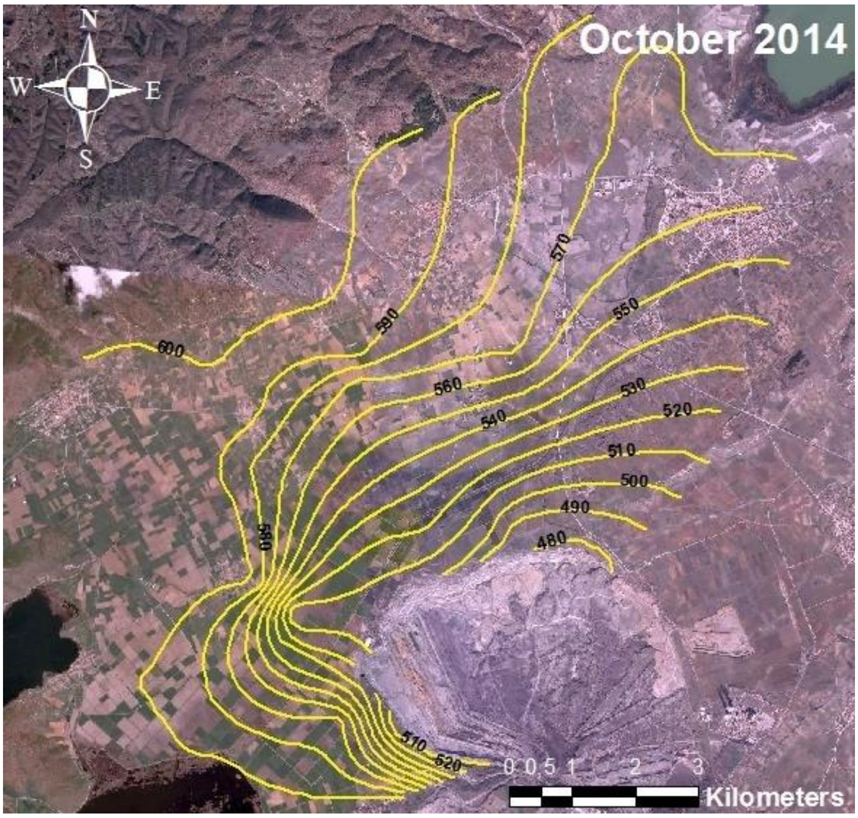

Figure 5 - Isopiezometric contour lines based on measurements taken in October 2014.

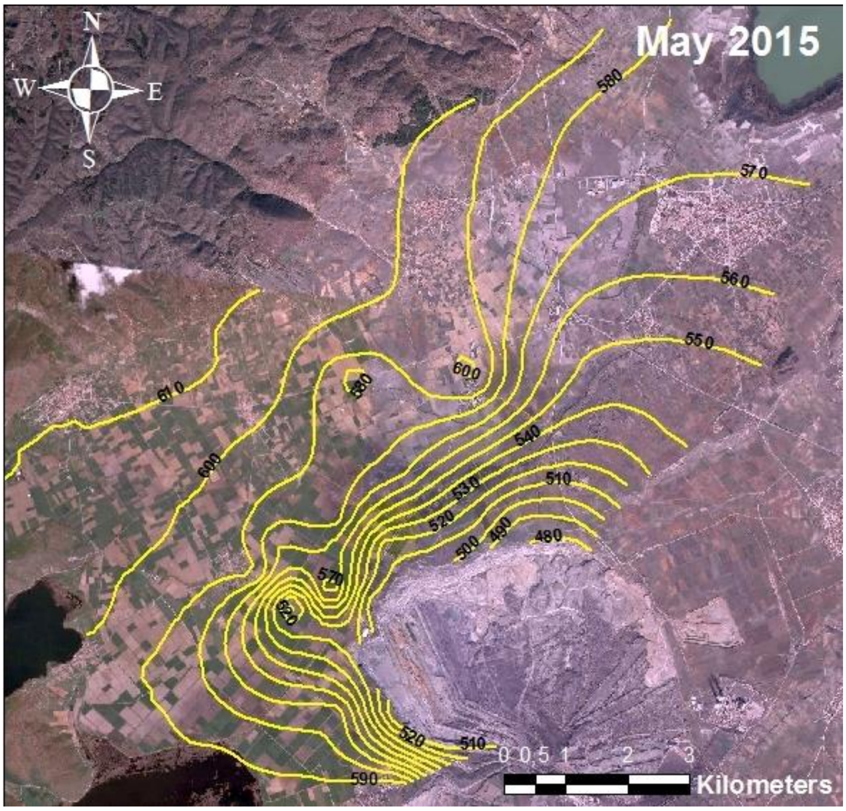

Figure 6 - Isopiezometric contour lines based on measurements taken in May 2015.

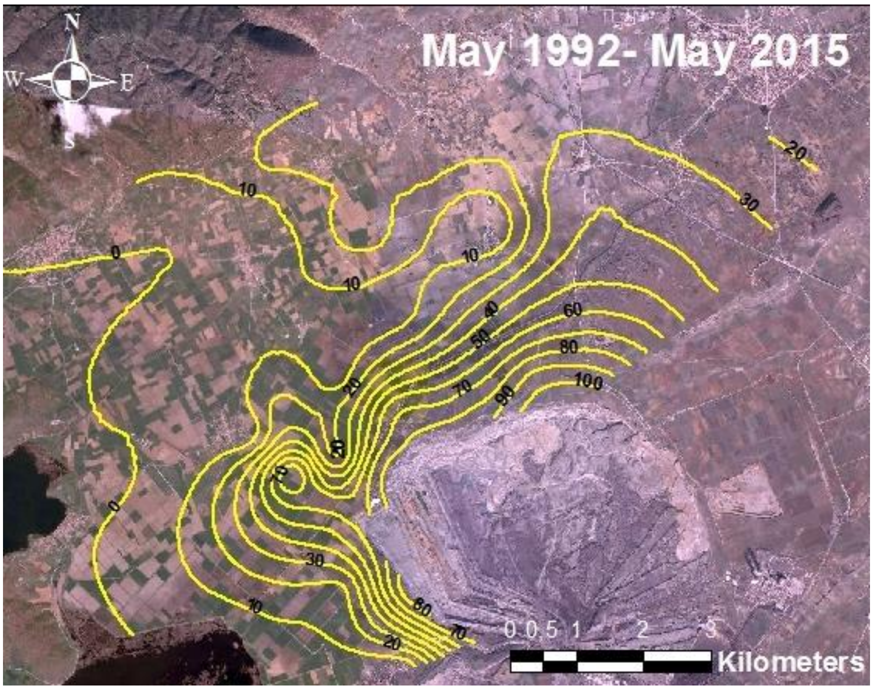

Figure 7 - Drawdown contour lines map drawn by subtracting the piezometric surfaces (from May 1992 to May 2015).

3. Conclusions

The piezometric surface drawdown observed by comparing the ground water level between 1992 and 2012 is clear that it is diachronically increasing. Particularly, this drawdown increases at the perimeter of Amyntaio mine from 45m in 2012 to 70m at 2015.

Moreover, by observing the piezometric curves, it is concluded that the flow of the groundwater is directed to the mine. So, former studies (Loupasakis *et al.*, 2014) claiming that the mine operates as an oversized well-draining the plain and forming an excessive depression cone around it, are confirmed.

It has to be mentioned that some small scale depression cones are also observed due to the operation of irrigation wells.

In general, the variations in the level of groundwater during the years show a steady downward trend with seasonal fluctuations. The steady downward trend can be attributed to the continuous flow of the underground water towards the mine, while the seasonal variations happen due to the precipitation and the seasonal pumping of wells for irrigation purposes.

As all surface raptures are confined within the limits of the depression cone it is clear that the groundwater drawdown is responsible for the land subsidence phenomena observed both in Anargyroi and in Valtonera villages.

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