Ruptures on surface and buildings due to land subsidence in Anargyri village (Florina Prefecture, Macedonia)

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Abstract This paper deals with the land subsidence due to groundwater overexploitation in Anargyri village (Florina prefecture, West Macedonia). The decline of groundwater table is necessary for lignite exploitation by the Public Power Corporation (PPC). The lignite deposits are occurred in Neogene sediments, consisting of alternations of clayey and marly layers. In these deposits are developed successive confined aquifers. The overexploitation of these aquifers had led in a decline of groundwater table, ranging between 30-40 m during the last years. Land subsidence phenomena resulted in ruptures on surface and buildings, rendering most of the houses uninhabitable. The ruptures on surface were examined in relation to geological and hydrogeological conditions and conclusions are drawn.

1 Introduction

In 1982 the Public Power Corporation (PPC) started the construction of thermal power plant of Amyntaio, which operated in 1987 using the lignite deposits of both mines Amyntaio and Anargyri. The excavations at the Anargyri mine started in 1984 and the first amounts of lignite produced in 1986. The excavations at the large Amyntaio mine started in 1989 and the first amounts of lignite produced in 1990.

Today, the excavations at the Amyntaio mine are from a depth ranging between 140 m and 170 m below ground surface. Before the excavation, groundwater table was at a depth of 2-5 m below ground surface. The exploitation of lignite deposits from PPC requires the drawdown of water table. For this reason extraction of groundwater began in this period with an annual amount of water equal to $2.4x10^6$ m^3, which increased continuously with the expansion of the mine. Thus, the annual abstracted amounts of water during the period 2007-2009 were estimated to be approximately $6\text{-}7x10^6$ m^3.

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The excavations started from East toward West, near the thermal power plant, about 2 Km from the village Anargyri. Nowadays the front of excavations is only 300 m from the first houses of the village. Ruptures on surface and buildings in the village Anargyri are first observed in the end of 1998 and mainly in 1999, when the front of excavations was 750 m from the village and the depth was 100 m. Since then, the ruptures have been increasing and enlarging continuously, so many buildings in the village were damaged and many houses are uninhabitable.

This paper examines the land subsidence phenomena in relation to hydrogeological conditions of the study area. This scientific work was carried out by the Aristotle University of Thessaloniki (Dept. of Geology), in the framework of a research project funded by Municipality of Aetos (Soulios et al. 2010).

2 Geological setting

From a geological point of view, the study area is part of the Pelagonian geotectonic zone. The crystalline bedrock (schists, gneisses, marbles, limestones) occurs at great depth from the ground surface in the study area. Neogene and Quaternary deposits overlay the aforementioned bedrock.

According to the geological map of I.G.M.E. (Ptolemaida sheet, scale 1:50,000, Koukouzas, Ioakeim 1997) and the field investigation, the Neogene and Quaternary sediments consist of the following geological formations, as illustrated in geological map (Fig. 1) and geological section (Fig. 2):

- **Soil cover** (Fig. 2, layer Z) with a thickness of 0.20-0.50 m, consisting of sapropel (swamp facies) and calcitic- clayey materials (lacustrine facies) of Holocene age.
- **Alternate layers** (Fig. 2, layer E) of fined size sand with layers consisting of clayey-sandy-loamy and marly materials. Their depth is 10 m increasing toward West. The thickness of sand layers is about one meter each. It is one lacustrine formation of Upper Pleistocene-Holocene age.
- **Loam-clay-clayey marls** (Fig. 2, layer D) with intercalations of fined size sand or sandy-clayey materials. The thickness of aforementioned deposits ranges between 10 and 15 m increasing toward West and North. This formation can be considered as an aquifuge bed of Upper Pleistocene age.
- **Sand** with interlayered fine size materials (Fig. 2, layer C) consisting of clayey marls with a thickness of 20-30 m. These deposits are mainly of medium grain size sand or cross-bedding of sand. The intermediate layers of clayey marls are thin with a thickness of 0.5 m. This formation is terrestrial and fluvial of Middle-Upper Pleistocene age and it can be considered as permeable layer.
- **Clays** (Fig. 2, layer B) of red color with intercalations at places of gravels and pebbles. This terrestrial formation is of Middle Pleistocene age with a thickness of 15-30 m and it can be considered as aquifuge bed.

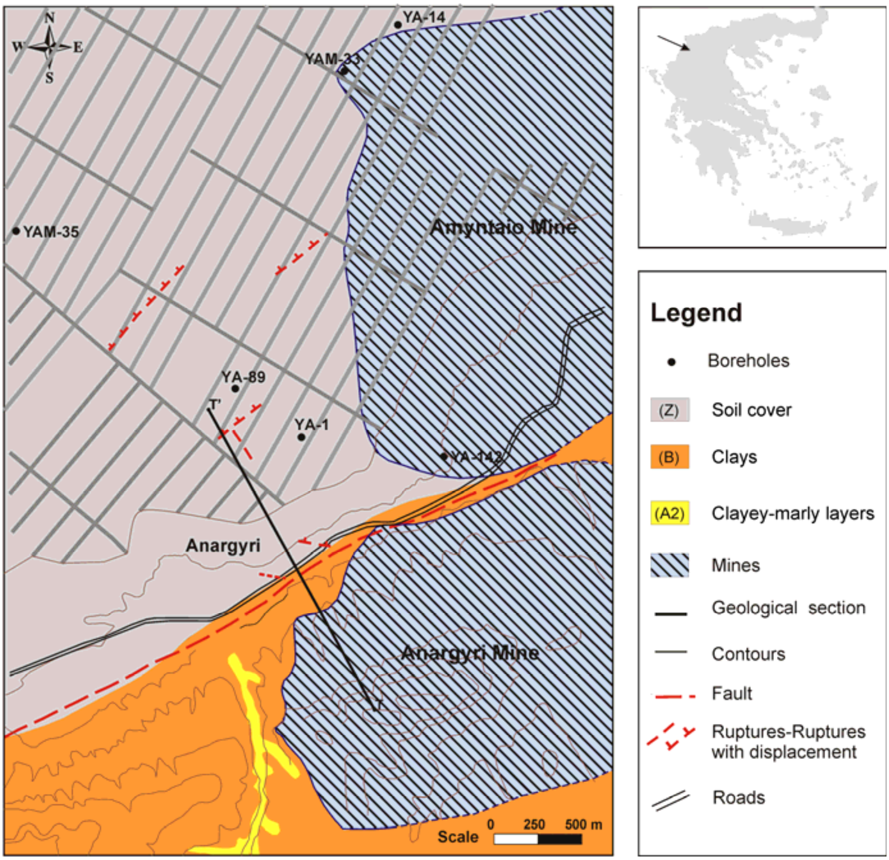

Fig. 1. Geological map of the study area (see text).

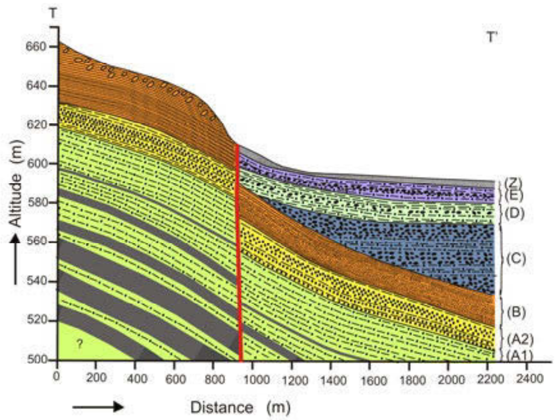

Fig.2. Geological section (see text). Direction T-T' is shown in Figure 1.

- **Clayey-marly layers** (Fig. 2, layer A2) of gray-yellow color with a thickness of 15-20 m, passing progressively to the following deposits. They are lacustrine deposits of Upper Pleistocene age and are characterized as aquifuge beds.
- **Marls** (Fig. 2, layer A1) of yellow-green to gray-green color with lignite intercalations. Lignite deposits in the upper part have a thickness of 0.10-0.20 m, while in the deep layers have a thickness of 0.5-2 m with intermediate thin marly intercalations. The whole sequence is lacustrine to lacustrine-marsh with a thickness of 50 m of Upper Miocene age. It is characterized as aquifuge bed.

3 Land subsidence phenomena

Land subsidence phenomena are caused by the overexploitation of the aquifers, and the consequent significant groundwater level drawdown. These phenomena have been recorded in many different places on earth and have been referenced by many researchers: in San Francisco and Texas of U.S.A. (Jumikis 1963), in Japan (Akagi 1979), in Bangok of Thailand (Premchitt 1979), in China (Chen et al. 2003), in Bordaux of France (Schneebeli 1991), in different places of Italy (Astori and Bezoari 1991), etc.

In Greece these phenomena have been observed in many regions, such as:

- Kalabaka area (Kallergis 1971)
- Karla, Thessaly area (Kaplanidis and Fountoulis 1997, Soulios 1997)
- Kalochori, Thessaloniki area (Andronopoulos et al. 1983, Soulios 1980, Loupasakis and Rozos 2010)
- Megalopoli, Arkadia area (Dimitrakopoulos and Koumantakis 1995)
- Stavros, Farsala, Thessaly area (Rozos et al. 2010) etc.

The main reason for the creation of these phenomena is the significant long term (over 1 year) groundwater level drawdown (usually over 10 m). The water level drops causes a reduction to the upward pressure born by the fluid and causes an increase of the effective stress ($\Delta\sigma$) born by the aquifer: $\Delta\sigma=\Delta h.\gamma$ (where Δh=change in water level, γ=specific weight of water). In the case of alluvial aquifer, recently formatted and unconsolidated with great compressibility, land subsidence is caused, that means reduction of the thickness and therefore withdrawal of its surface. As a result, ruptures are appeared due to the heterogeneity which implies differential land subsidence (Schmeebeli 1966).

Consequently, the progress of the piezometric surface and the geological composition of an area is the main reason that causes land subsidence and ruptures manifestation.

4 Monitoring of the piezometric surface in the area

It is important to examine the progression of the piezometric surface starting before the beginning of the excavation and water pumping until the manifestation of the ruptures and cracks on the buildings.

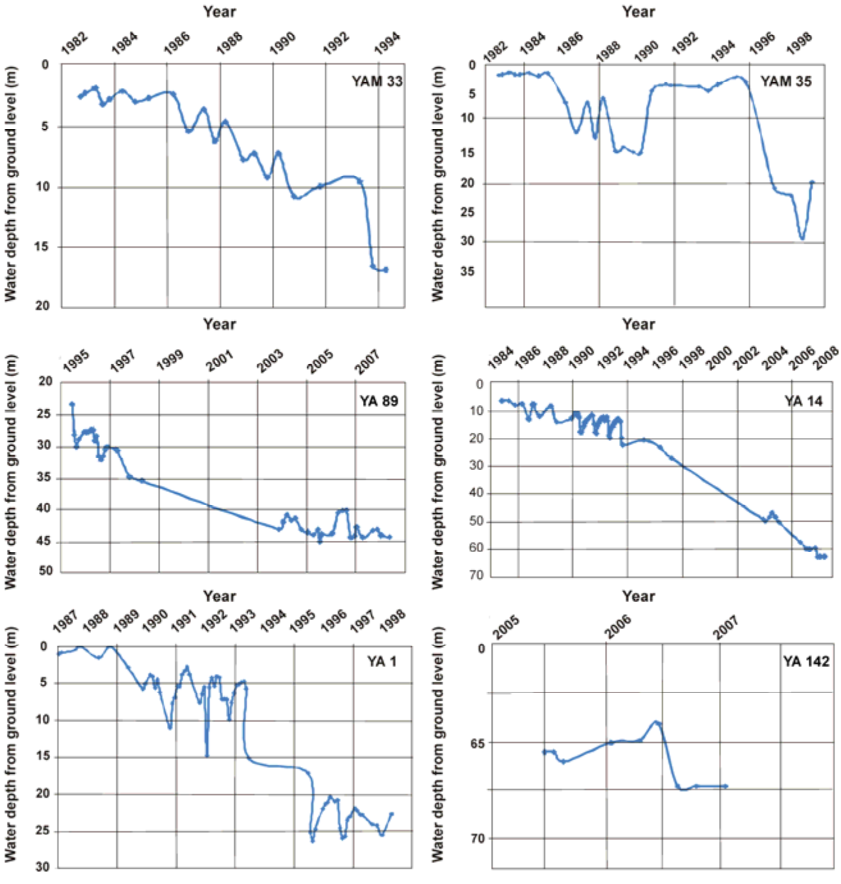

Fig. 3. Water level drawdown (see text).

There are totally nine (9) piezometric boreholes in the study area drilled by P.P.C. and seven (7) by Institute of Geology and Mineral Exploitation (I.G.M.E.). There are no continuous measurements for all these boreholes, because some of them were destroyed during the advance of the excavation front and also because the piezometric programs were not continuous. There are six (6) boreholes with the most complete data records the locations of which are shown in the map of Figure 1. For these boreholes the following comments are given:

- Borehole YAM33. Given that the period 1989-1990 was particularly dry, it seems that the water level continued to decline with a very intense rate during the following years, due to the mining excavation (Fig. 3). In 1994 the water level drawdown was 15 m. Apparently, in 1998, when the fissures got visible, the drawdown was greater.
- Borehole YAM35. It is located far from the mine and in even longer distance. For this reason the water level cone of depression reached this borehole in a later time. Therefore, the rapid water level drawdown began in 1995 and in the years 1998-1999 was about 25 m (Fig. 3).
- Borehole YA1. It is located very close to the Anargyri village at a distance of 2.0-2.5 Km away from the place where the water-pumping began. The rapid water level drawdown started in 1993 and in the year 1998 it was about 25 m (Fig. 3).
- Borehole YA89. It is located very close to the Anargyri village, at a distance of about 2.5 Km from the place that the excavation works began. The borehole was drilled in 1995, by the time that other boreholes had already been destroyed due to the mining excavation. At that time, the water level drawdown was over 20 m. During the years 1998-1999, the total water level drawdown was more than 30m (Fig. 3).
- Borehole YA14. It is located close to the Anargyri village, 2.0-2.5 Km away from the place that water pumping began. The water level started to drawdown rapidly since 1993. In the years 1998-1999 a water table drop of more than 20 m was recorded, while in 2008 the water decline was 50 m (Fig. 3).
- Borehole YA142. It was drilled in 2005 inside the mine area. Since then, the groundwater level was at depth of 65 m below ground surface approximately depth, which means that the water level drawdown is about 60 m (Fig. 3).

Conclusively, already since 1993 the groundwater level decline was more than 20 m around the village Anargyri. Consequently, according to the widening and deepening of the depression cone it is concluded that, the water level drawdown around the village area should be more than 10-15 m in 1998, and already over 20-25 m nowadays (2011).

5 Surface ruptures and cracks on the buildings

As it has been mentioned, the ruptures were first observed in 1998-1999 and since then their number and size were constantly increasing until 2008. On the ground surface they follow two dominant directions:

- One almost E-W direction with displacements towards the north, i.e. to the center of the plain, where the thickness of the Quaternary sediments increases.
- Another one of circular shape, almost parallel to the advance of the mine excavation front, with a displacement towards the front, i.e. to the direction of the greater water level drawdown.

The cracks and fractures on the buildings are more dense and intense to those that are closer to the mine, as well as to those buildings located in the recent Quaternary formations. On the contrary, they are smaller to negligible or almost non-existent to the buildings that are distant from the mine and especially to those located in the Lower-Upper Pleistocene red beds.

6 Discussion-Conclusions

The ground ruptures and the building cracks observed in the Anargyri village could theoretically be attributed to:

- Earthquake: There is no earthquake of magnitude $M \geq 5R$ recorded in the broader area since 1998. Furthermore, in case of an earthquake all fissures should had been developed simultaneously and not in a continuous manner for more than a decade (1998-2008).
- Landslide: Not even a single horizontal dislocation was observed, neither superficial nor underground, as deduced from inclinometer measurements in selected boreholes.
- Land subsidence: In fact, the space-time progression of the phenomenon coincides with the groundwater level drawdown, which is greater than 10-15 m and maybe exceeds 20 m and lasted for many years. In addition, the geologic layers are very recent with high compressibility. Finally, it is concluded that the excessive extraction of groundwater has caused the ground ruptures in the study area.

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