A scale-model experiment to enhance dissemination of land subsidence accompanying groundwater extraction

R. Tomás[1], J. Valdes-Abellan[1], C. Pla[1], J.L. Pastor[1], M.I. Navarro-Hernández[1], M. Cano[1], A. Riquelme[1], J.M. Lopez-Sanchez[2]

1 Departamento de Ingeniería Civil. Universidad de Alicante.
2 Departamento de Física, Ingeniería de Sistemas y Teoría de la Señal. Universidad de Alicante
Contact: roberto.tomas@ua.es

Abstract

Land subsidence accompanying groundwater extraction is a complex and increasing environmental issue worldwide. To explain the phenomenon to a young (over 10 years of age) and adult non-expert audience is a difficult, and in turn, an important challenge. Therefore, a scale-model experiment to enhance dissemination of land subsidence due to groundwater withdrawal has been designed and implemented during a scientific dissemination activity developed in Spain. Basically, the model is built using a glass-wall aquarium filled by expanded clay aggregates and water. Groundwater extraction is simulated by means of a water pump, which empties the aquarium and triggers land subsidence. The experiment is suited for a non-expert audience, leaving lasting visual impressions and raising public awareness about this growing environmental issue related to groundwater extraction.

Introduction

Land subsidence caused by groundwater withdrawal is a complex environmental problem that basically consists in the lowering of Earth's land surface produced by the compaction of susceptible aquifer systems (Galloway and Burbey, 2011). The economic and the global population growth developed during the last decades is expected to considerably increase groundwater demand leading to groundwater level depletion and subsequent land subsidence. According to the work published by Herrera et al. (2021), nineteen percent of the global population and twelve percent of the global gross domestic product might face a high probability of land subsidence during the coming decades. Therefore, to raise social awareness about this phenomenon, it is of paramount importance to prevent land subsidence through a more sustainable management of groundwater resources. To this aim, we have designed a scale model experiment to enhance visual dissemination of land subsidence accompanying groundwater extraction. The experiment enables the reproduction of land subsidence, amplifying and accelerating the process in a visually clear, simple and educational way. This model was used during the science fair of the Mediterranean Researchers' Night 2022 held at the University of Alicante (Spain). In this work we describe the built scale-model and the actual experimental experience.

Methods

The developed scale-model was built using the following components (Figure 1 and 2c): a) a 300-litre glass-wall aquarium; b) a water pump with a maximum flow of 30 l/min to simulate the groundwater extraction; c) expanded clay aggregates to fill the aquarium that simulates the soil; d) a hose to pump out the water; e) a rigid transparent pipe divided into two semi-circular halves, glued to the frontal glass wall by using silicon used as piezometers; f) flexible artificial turf placed on the soil surface to simulate the vegetation; and g) scales attached to the front part of the aquarium to measure the groundwater changes.

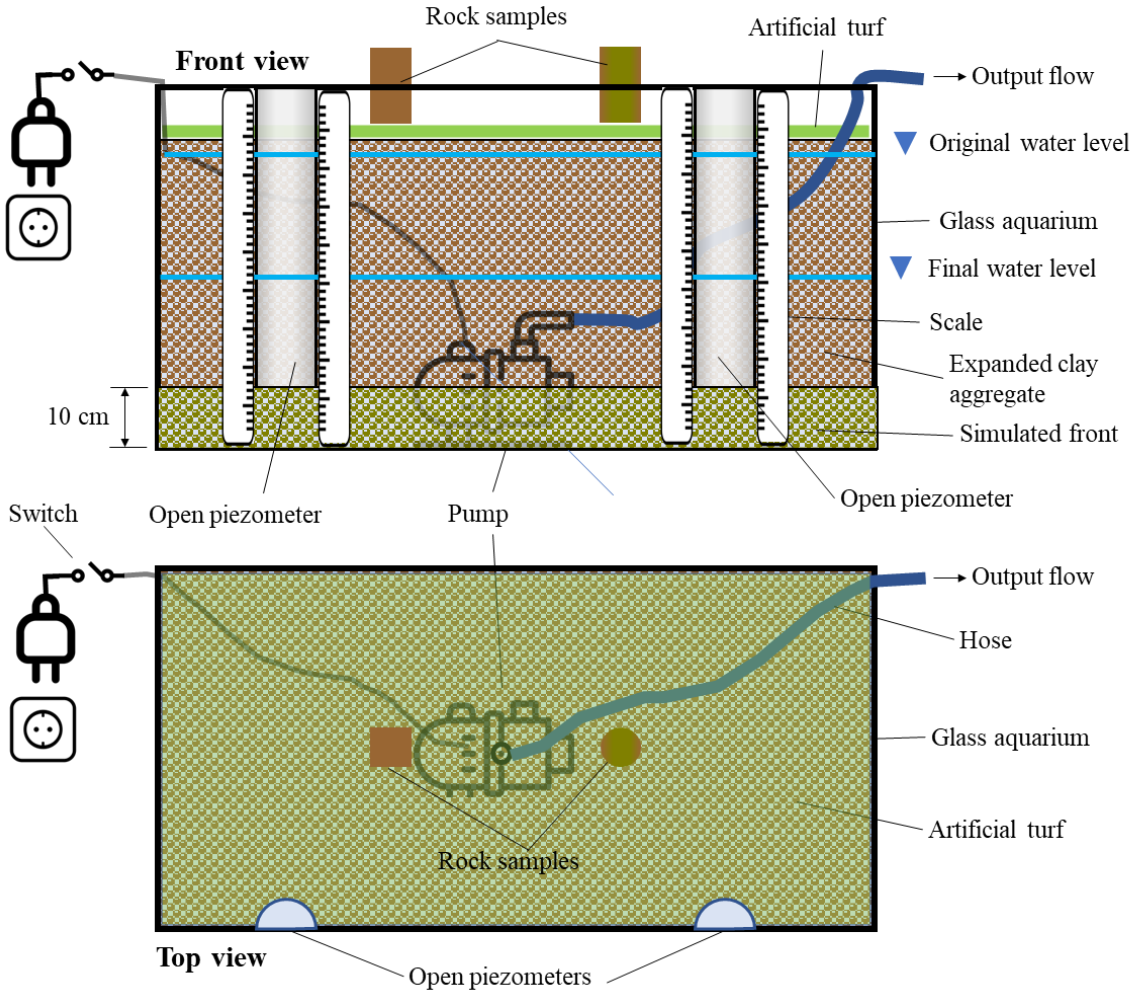

Figure 1 Scheme of the scale-model used for dissemination of land subsidence drawn using the first angle projection system (ISO standard).

Once the different elements were put in place as shown in Figure 1, the tank was filled with tap water up to near the surface of the expanded clay. Since the density of the expanded clay varies between 300-500 kg/m3, the soil mass is then affected by the buoyancy force that is superimposed on the much larger pore water pressure. This uplifting force causes the floating of the expanded clay and its separation from the bottom part of the tank. We placed a simulated front in the bottom 10 centimetres of the tank (Figure 1) to prevent this unwanted visual effect. Then, when groundwater is pumped out, the original groundwater level falls and the ground surface settles by several centimetres. It should be noted that some tests were performed with real soils, but unfortunately the subsidence was not easily perceived with the naked eye. Therefore, expanded clay was used to replace natural soils in order to emphasize the phenomenon and to make it more visually instructive.

Additionally, the model was designed to reproduce the experiment many times in a row, so the use of expanded clay lets us fill and empty the water of the aquarium quickly to its initial position.

Results

The experiment for dissemination of land subsidence was carried out for the first time during the Mediterranean Researchers' Night 2022 (Figure 2). This is an internationally coordinated science related event in which several Mediterranean countries come together to make visible their common problems and to reinforce and support the science of major national concern (Mednight, 2022). The experiment is suited for young (over 10 years of age) and adult non-expert audiences and leaves lasting visual impressions while raising public awareness about this growing environmental issue.

Figure 2 Use of the land subsidence scale model during the Mediterranean Researchers' Night 2022 at the University of Alicante (Spain). (a) General appearance of the stand with the informative poster in the background and the interaction of the children with the scale model; b) Development of the experiment with the families; c) General view of the developed scale-model for the dissemination of land subsidence accompanying groundwater extraction. P: poster; S: monitoring satellite; Sh: worksheet.

The activity begins with very basic hydrological idea about precipitation, groundwater recharge and surface runoff generation. It continues with an explanation (Figure 2b) about the importance of groundwater resources and the problem of aquifer overexploitation (we used the analogy of the piggy bank, in which if the number of coins you introduce is lower than the number of coins you withdraw, then the piggy bank is emptied). Subsequently, we provide non-permanent markers to children to set the level of the water (in blue) and the level of the ground surface (in black) on the front part of the glass tank at the initial time (prepumping) and, for older children, we encouraged them to measure these levels on the scale and to write them in a provided worksheet. Then, the pump is switched on and the water extraction starts. During the extraction, we talk about the uses of water (e.g. for irrigation and for human consumption). After nearly one minute, the water level has fallen considerably, and the ground surface has clearly lowered by as much as several centimetres. The participants could then record the new water and ground surface levels to calculate the water decline and the associated land subsidence. It should be noted that some elements (we used some rock

cylindrical and prismatic samples) are placed on the artificial turf to simulate buildings being tilted and even knocked down at the end of the test as a consequence of the land subsidence.

The activity finished with an explanation of some very general recommendations that can be implemented to avoid land subsidence (e.g. save water at home, looking for other alternative water resources, as desalination plants, or to change the type of crop in agricultural areas). These include the application of satellites to monitor ground deformation (S in Figures 2a and b). The activity was accompanied by a poster to support the explanation of the scientific experiment (P in Figure 2a). Additionally, the youngest participants can fill in a worksheet with some questions related to the activity (Sh in Figure 2b), with the support of the organizers.

It is worth noting that the experiment can be repeated as many times as necessary by simply refilling the tank and levelling the soil surface slightly just with hands, since the original level of the expanded clay is quickly recovered.

Conclusion

A scale-model experiment to enhance dissemination of land subsidence accompanying groundwater extraction was developed and used during the Mediterranean Researchers' Night 2022 in the University of Alicante (Spain). This experiment enables the reproduction of the lowering of the ground surface caused by groundwater extraction in a quick, visually clear, simple and educational way. Furthermore, the activity, which is performed around the scale-model with the support of a worksheet and a poster, enables the attending public (i.e. children and adults) to raise awareness of the importance of groundwater resources management in order to limit environmental problems caused by land subsidence.

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