Evaluation and mitigation of soil subsidence in Mexico City

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Abstract

The general subsidence of the lacustrine zone of Mexico Valley has serious implications for the conservation of the urban heritage and proper functioning of public utilities in the Mexican Capital. It is well known that subsidence is mainly a consequence of extraction of potable water from the deep aquifers located below the metropolitan area. This paper presents a brief state of the knowledge on this phenomenon and describes the actions undertaken to obtain a more accurate and updated information on its evolution. Possible strategies that could be considered to mitigate the consequences of subsidence and to control the phenomenon are also reviewed.

Introduction

The demographic development of Mexico City has created an accelerated demand for services, among which stands out supply of drinking water. One of the cheapest ways to respond to this demand has been the exploitation of the aquifer underneath the urban area by pumping water from deep wells. This activity has produced a regional subsidence phenomenon of the lake and alluvial-lacustrine areas of Mexico City. Due to the high cost of other alternatives, it is expected that extraction of water from the local aquifer will continue for many years. The regional subsidence in Mexico City affects the drainage system, transport infrastructure, foundations of buildings and generates serious risks to the population, since it induces other problems such as flooding of low areas and fissuring of the highly compressible soil. Therefore, although the regional subsidence is an ancient phenomenon, its study and analysis remain a priority nowadays.

Evaluation of regional subsidence

Based on the historical data and on the results of systematic levelling surveys performed in Mexico City during more than 100 years, it has been possible to reconstruct the history of the regional subsidence at some points of the downtown area of the City (Fig. 1). It has also been possible to define the original topographic configuration of the Valley of Mexico, prior to the start of water pumping from underground aquifers, on the basis of technical reports of geodesic and topographic surveys carried out in 1856.

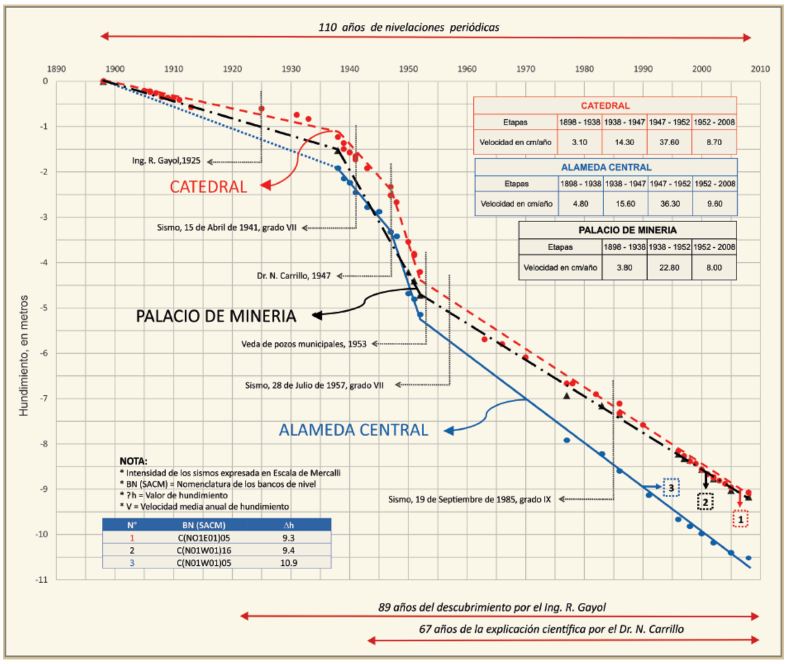

Figure 1 Evolution of regional subsidence at three sites of the Historic Center of Mexico City (Metropolitan Cathedral, Mining Palace and Alameda Central park) from 1898 to 2008. (horizontal scale: time in years; vertical scale: accumulated subsidence in meters)

A decision has been made to modernize the Monitoring System of piezometer readings and regional subsidence to suit the actual conditions of the urban zone covering the Valley of Mexico. For this purpose, in 2013, support was received to launch a system known as *"Sistema de Monitoreo de la Piezometría y de los Hundimientos del Valle de México por extracción de agua subterránea* (SIMOH, *Monitoring System of Piezometry and Subsidence of Mexico Valley due to water extraction",* Auvinet *et al.,* 2015) at the Laboratory of Geo-Informatics of *Instituto de Ingeniería (Institute of Engineering),* UNAM.

The SIMOH system generates databases and Geographic Information Systems containing historical and recent information on piezometric behaviour and on the subsidence of the Valley of Mexico. SIMOH was initially focused on the collection, retrieval and processing of information and on the diagnosis of the current status of the instrumentation, including an inventory of the existing benchmarks, piezometers and water wells.

To evaluate the spatial distribution of the regional subsidence covering the wide area occupied by the former lakes of the Valley of Mexico, a Geographic Information System was developed to store the huge collection of numerical data coming from the levelling surveys executed in a period of more than 100 years so as to expedite their processing and analysis.

Rates of subsidence in the Valley

The evaluation of the subsidence phenomenon implies basically the execution of periodic observations of the pore water pressure conditions existing in typical strata of the subsoil together with leveling of superficial benchmarks.

Figure 2 shows the spatial distribution of the subsidence rate for the 1999–2008 period in the lacustrine zone of the Valley of México (Auvinet et al., 2017). It can be noticed that the settlement rate is close to 40cm/year at some points. This map was plotted by combining topographical data supplied by several agencies and results of indirect measurements performed using the LIDAR and INSAR techniques. A geodetic network consisting of a number of GNSS stations is being implemented in Mexico Valley to improve the accuracy of indirect measurements. Mention should be made that at present the sites with the fastest rates are no longer located in the downtown area of the City but rather at several sites to the east and south of the Valley of Mexico. These sites correspond to the zones where the thickest clay deposits are found in the subsoil.

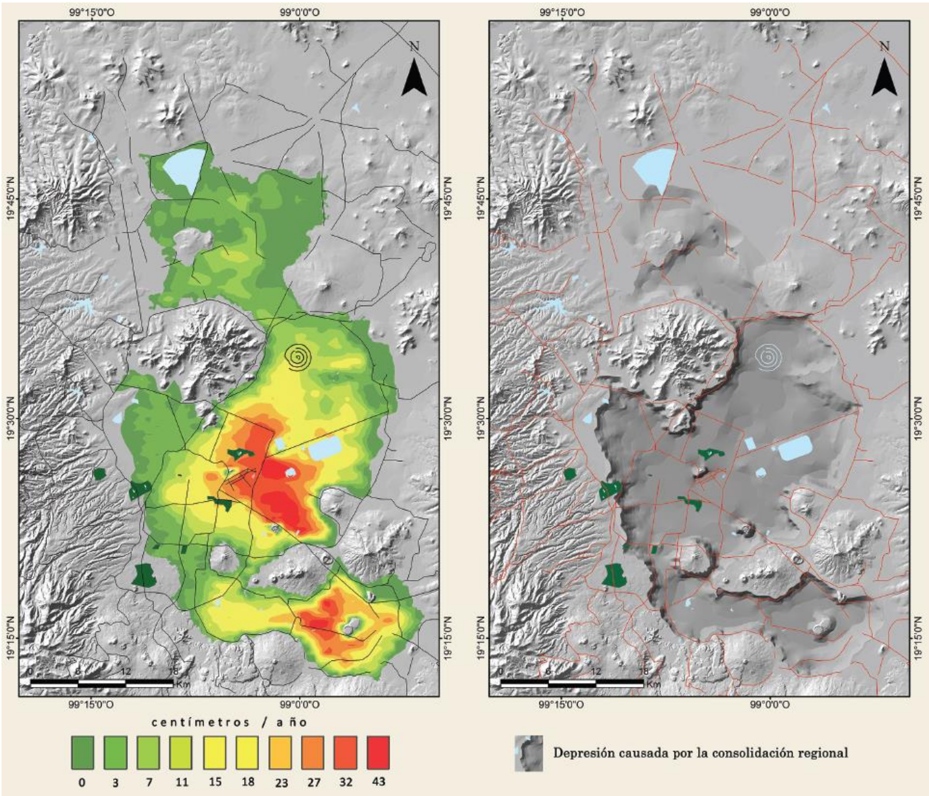

Figure 2 Mapping of rates of regional subsidence (in cm/year) and depression created by this phenomenon.

Perspectives for control of subsidence and mitigation of its effects

The control of subsidence demands the implementation of a policy for water supply different from the present one (Tortajada & Castelán, 2003). To be able to reduce local pumping it is possible to exploit external or deeper sources (Aguirre, 2014), although priority should be assigned to other actions such as the promotion of a more rational use of water and effective control of leaks in the potable water distribution network.

Strategies based in the concept of sustainability have been proposed to attain this objective (Calderhead et al., 2012; Reséndiz et al., 2016). It has also been suggested to adopt a pumping strategy such that, at no point of the subsoil, the overconsolidation pressure is exceeded (Larson et al., 2001; Reséndiz et al., 2016).

Locally, the possibility exists of a partial control of the subsidence effects. For this purpose, in several projects, the injection or extraction of water from the clays of the upper clay formation has been attempted (Pliego, 2008). It has also been proposed to resort to the injection of water into the pervious strata interbedded in the aquitard and, in particular, into the so called “first hard layer”. This possibility has been evaluated theoretically (García et al., 2012). The results obtained tend to demonstrate that with reasonable flow rates of water injected in the subsoil it would be possible to protect very important areas such as the Historic Center of Mexico City against the main effects of the regional subsidence. These conclusions should be, however, confirmed by the results of large scale trial injection tests.

Mitigation of the effects of subsidence demands on the other hand the development of increasingly refined methods of design of the civil works. Deep extensometers have been used to assess the contribution of different strata to the subsidence (Rángel, 2021). This information is required for a realistic evaluation of the effects of subsidence on deep foundations and underground structures, including negative skin friction.

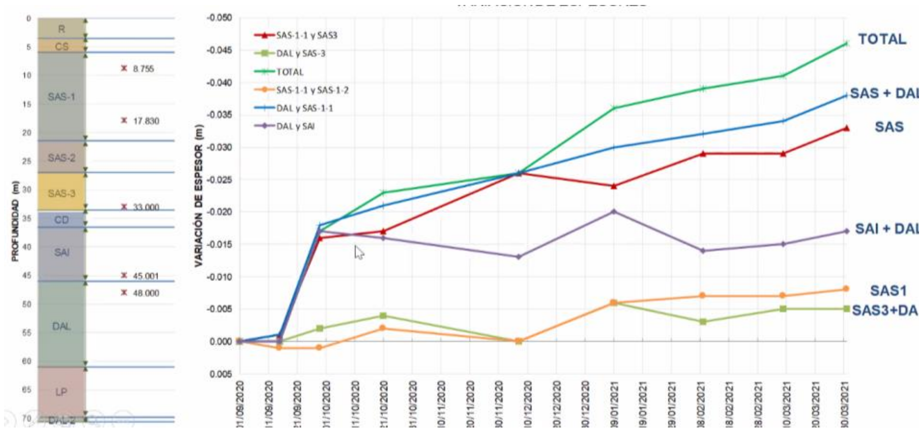

Figure 3 Contribution of different strata to the total subsidence.

Conclusion

The efforts undertaken by different groups and in particular by the Geo-Informatics Laboratory of the Engineering Institute, UNAM to achieve a satisfactory evaluation of the phenomenon of subsidence in Mexico City, and to deal with other geotechnical problems such as soil fissuring have given useful and promising results, but this is only the first stage of a huge job to be performed consistently in the future.

References

Auvinet, G., Méndez, E. y Juárez, M., 2015, Sistema de Monitoreo de la Piezometría y de los Hundimientos del Valle de México por extracción de Agua Subterránea (SIMOH), *Informe final de proyecto del Instituto de Ingeniería,* UNAM, Ciudad de México, México.

Auvinet, G., Méndez, E. and Juárez, M., 2017, "*The subsoil of Mexico City*, Vol. 3/El subsuelo de la Ciudad de México, Vol. 3", Instituto de Ingeniería, UNAM. ISBN Vol. 3 978-607-02-8198-3.

Calderhead, A.I., Martel, R., Garfias, J., Rivera, A. and Therrien, R., 2012, "Sustainable Management for Minimizing Land Subsidence of an Over-Pumped Volcanic Aquifer System", *Tools for Policy Design, Water Resources Management*, 26:1847–1864. DOI 10.1007/s11269-012-9990-7.

García, C., López Acosta N.P. y Auvinet, G., 2012, "*Análisis teórico para la inyección de agua en el subsuelo del valle de México*", Memoria, XXI Reunión Nacional de Mecánica de Suelos e Ingeniería Geotécnica, Sociedad Mexicana de Ingeniería Geotécnica, Cancún, Quintana Roo, México. Vol. 3: 1195-1204.

Larson, K. J., Basagaoglu, H., and Marino, M. A., 2001, "Prediction of optimal safe groundwater yield and land subsidence in the Los Banos-Kettleman City area, California, using a calibrated numerical simulation model", *Journal of Hydrology*, 242(1–2), pp. 79–102.

Pliego, L., 2008, “*Control de los efectos de la subsidencia regional mediante extracción e inyección de agua”,* Proceedings, ISSMGE TC36 Workshop Geotechnical Engineering in Urban Areas Affected by Land Subsidence, pp. 117-130, Ciudad de México, México.

Rángel, J.L., 2021, “*Results of instrumentation, Barrio Letrán*”, Personal communication.

Reséndiz, D., Auvinet G. y Méndez E., 2016, Subsidencia de la Ciudad de México: un proceso centenario insostenible, *Publicación en las Series del Instituto de Ingenie¬ría*, UNAM, Ciudad de México, México.

Tortajada, C. and Castelán, E., 2003, “Water Manage¬ment for a Megacity: Mexico City Metropolitan Area”, *AMBIO,* 32(2):124-129. DOI: http://dx.doi.org/10.1579/0044-7447-32.2.124.