GROUNDWATER PUMPING, LAND SUBSIDENCE AND SEISMICITY

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ABSTRACT

The often neglected issue of seismicity caused due to over pumping of groundwater has been receiving due attention in the recent times. In the past decade, research on human-induced earthquakes has become a focal point of sociopolitical and scientific issues. The basic tenet of such research is that the crustal (un-) loading processes can influence strain accumulation process, and as a result of which, can modulate seismic activity beneath the causative source and in its peripheral zone. In most cases the world over, including the Indo-Gangetic plains of India, groundwater pumping and usage exceeds replenishment of aquifers, leading to substantial reduction in the mass. Such anthropogenic crustal unloading has the potential to promote long-term fault slip or may modulate seismic activity in the adjoining region. The groundwater withdrawal leading to crustal unloading in the Indo-Gangetic plains causes a significant component of horizontal compression. Although there are a number of different views on the issue, it is envisaged that the discussion presented here of such events emphasizes the importance of the seismic safety of various structures in areas where groundwater pumping is rampant, while promoting further research on the subject.

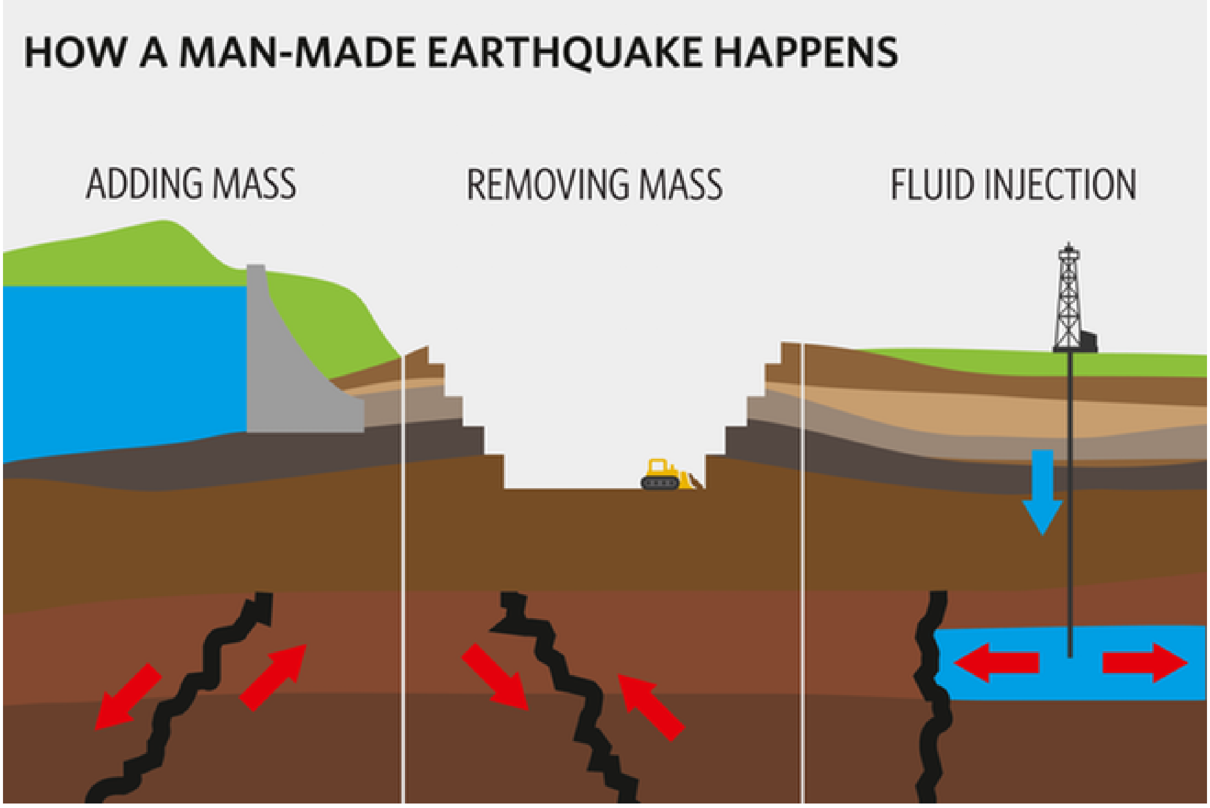
1. Introduction

Resent research proves that groundwater pumping over a long period is directly responsible for land subsidence and this is perhaps the most widespread and threatening geo-mechanical consequence. The first observation relating land subsidence to subsurface fluid removal was made in 1926 by the American geologists Pratt and Johnson [1926], who discussed the origin of the settlement noticed in the Gaillard peninsula, the center of Goose Creek Oil Field, Galveston Bay (TX), and concluded that ‘‘the Goose Creek subsidence was directly caused by the extraction of oil, water, gas, and sand from beneath the surface beginning in the year 1917’’ (G. Gambolati and P. Teatini 2015).

To be of major concern, the withdrawals need to take place in areas that are developed having high population density. To be of devastating consequence, the areas need to be located close to the sea or a lagoon or a delta and take place from unconsolidated geological basins of alluvial, lacustrine or shallow marine origin, formed typically, although not exclusively, in the Quaternary period (G. Gambolati and P. Teatini 2015). The phenomenon goes unnoticed during the initial phase (s) and gets discovered later on, when severe damage has already taken place. The additional threat arises due to tremors that may get triggered because of the land subsidence. While it may prove to be enormously expensive to undertake effective remedial measures at this stage, awareness concerning the probable damagethreatened by such phenomena has increased. Accordingly, incorporation of this aspect in plans and programmes will go a long way in scientific utilization of groundwater in near future. Such plans will have to provide numerical predictions of the expected land settlement in and around the exploited system.

2. General Concepts and the Mechanism

The postulation is that 'the pore spaces are occupied by water draining more slowly from the adjacent clays; and it is a well-known fact that the draining of clays causes them to become more compact, and this in turn would permit subsidence of overlying surface. However, Fuller [1908] had already theorized that fluid withdrawal and a decrease in fluid pore pressure (because of the removal of hydrostatic support) caused the sinking of the land surface. The process falls under the subject of groundwater geo-mechanics that is concerned with the ground deformation processes induced by subsurface water pumping and injection.



The effects that become visible due to over-pumping of groundwater include: lowering of the ground surface (land subsidence due to aquifer overdraft), formation of earth fissures, activation of preexisting shallow faults and triggering of seismic events because of changes in the natural effective and total stress regimes. This paper presents a discussion on the subject and is primarily intended for readers without much background on geology or groundwater and geo-mechanics.

3. Affected Areas

The figure below shows the areas of major anthropogenic land subsidence due to groundwater extraction worldwide.

1. Wadi Al-Yutamah, Saudi Arabia	2. Anthemountas Basin, Greece	3. Bangkok, Thailand	4. Beijing, P. R. China
5. Celaya, Mexico	6. Eloy Basin, Arizona	7. Hanoi, Vietnam	8. Ho Chi Minh, Vietnam
9. Houston, Texas	10. Jakarta, Indonesia	11. Kolkata, India	12. Las Vegas, Nevada
13. Latrobe Valley, Australia	14. Lorca, Spain	15. Taipei, Taiwan	16. Mexico City, Mexico
17. Ravenna, Italy	18. San Joaquin Valley, California	19. Santa Clara Valley, California	20. Shanghai, P. R. China
21. Su-Xi-Chang area, P. R. China	22. Tehran, Iran	23. Tokyo, Japan	24. Venice, Italy
25. Wairakei, New Zealand	26. Xian, P. R. China	27. Zamora de Hidalgo, Mexico City	

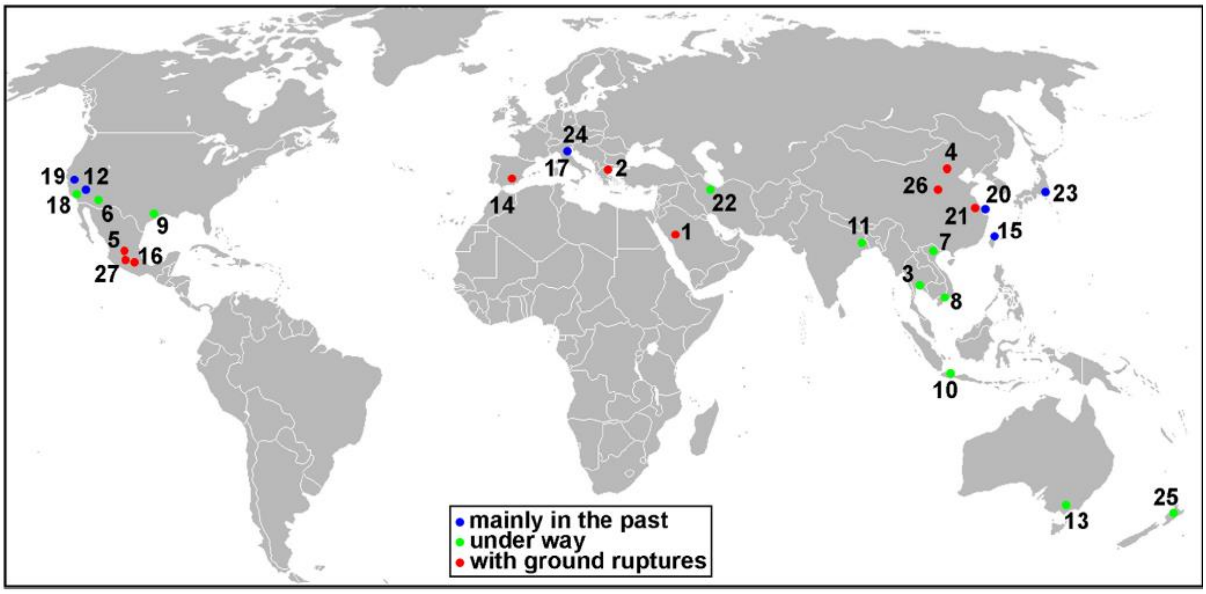


Figure-1: Major worldwide areas land subsidence due to groundwater withdrawal

5. Cases from the USA and Nepal

Case-1:

The widespread practice of extracting California groundwater to irrigate the state's agricultural belt is stressing the San Andreas Fault, which means it could also increase the likelihood of earthquakes occurring in the region. In a study published in the scientific journal Nature in 2014, scientists reported that groundwater depletion in California's Central Valley could mean "significant but unexplored potential impacts on crustal deformation and seismicity." The authors add that "these results suggest that human activity may give rise to a gradual increase in the rate of earthquake occurrence."Any earthquakes that do result from pressure on the fault line are likely to be very small, according to lead author Colin Amos. "The magnitude of these stress changes is exceedingly small compared to the stresses relieved during a large earthquake", said Amos. But his co-author, geoscientist Roland Bürgmann, warned that "in some circumstances such **small stress changes** can be the straw that breaks the camel's back". "It could just give that extra push to get a fault to fail."

Case-2:

Heavy extraction of ground water in the Indo-Gangetic basin for over five decades (since the advent of green revolution) contributed to the devastating magnitude 7.8 earthquake in Nepal in April 2015, a study suggests. The connection has been found by researchers at the National Geophysical Research Institute in Hyderabad and the National Centre for Seismology (NCS) in New Delhi, under the Ministry of Earth Sciences, GoI.

While seismic activity along a plate boundary is largely driven by plate tectonics, various surface or subsurface processes (natural or man-made) like reservoir impoundment, underground mining and groundwater extraction can also promote long-term fault slip and modulate seismicity, says V. Gahalaut, director of NCS.

The favorable response of the groundwater withdrawal in terms of the stress change implies that the anthropogenic or human-induced activities modulated the earthquake activity in the Nepal region.According to the study, groundwater extraction in the Ganga basin modulates the stress accumulation process on the Main Himalayan Thrust (MHT), beneath the Himalayan arc where earthquakes originate.

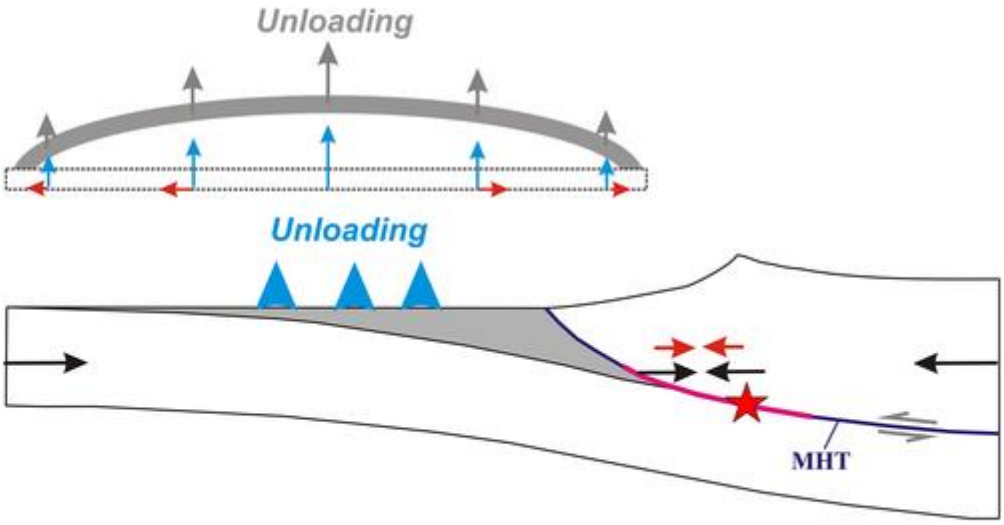


Figure-2: Significant component of horizontal compression was added to the secular interseimic compression at seismogenic depth due to crustal unloading process

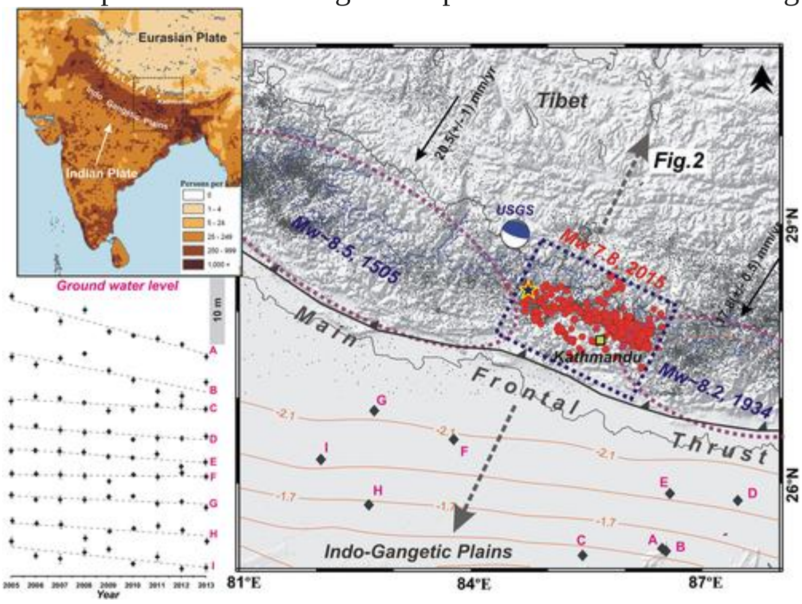


Figure 3: The 2015 Mw 7.8 Gorkha, Nepal earthquake nucleated in central Nepal along theHimalayan front (80 km N-W of Kathmandu)

6. The Contrary View

Mr. C.P. Rajendran of the Jawaharlal Nehru Centre for Advanced Scientific Research, Bengalurusaid although the above stated case study is a "fresh approach", he found the model validation "problematic". He argues as follows:

"The groundwater depletion in the Indo-Gangetic Plain goes back more than 40 years. We do not find any change in the rate of seismicity in the Himalayas during this period. In other words, the frequency of large earthquakes originating from the Himalaya should have gone up if the model was right. We don't see that. Thus, there is valid reason to believe that the model on which the above study was based lacks this fundamental validation, Rajendran told.

References

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This is to certify that Prof./Dr./Shri/Smt ....Arnab Sarma.......... has attended/presented a Paper (Oral/Poster) entitled ....Ground Water Pumping, Land Subsidence and Seismicity.... during the National Seminar on "Earthquake Hazards: Perception, Mitigation and Management" sponsored by Ministry of Earth Sciences, Government of India at North-Eastern Hill University, Shillong from February 6th to 8th 2020 as Chairperson/Resource Person/Participant Presenting Paper/Participant.

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