The sinking Mekong delta
Modeling 25 years of groundwater extraction and subsidence

Philip S.J. Minderhoud1,2, G. Erkens1,2, H.V. Pham1,2,3, V.T. Bui3, H. Kooi3, L.E. Erban4, E. Stouthamer1

1 Universiteit Utrecht, Department of Physical Geography, The Netherlands, P.S.J.Minderhoud@uu.nl
2 Deltares Research Institute, Department of Subsurface and Groundwater Systems, Utrecht, The Netherlands
3 Division of Water Resources Planning and Investigation for the South of Vietnam (DWRPIS), Ho Chi Minh city, Vietnam
4 US EPA Office of Research and Development, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, Narragansett, RI, USA

Figure 1. A) Hydrogeological cross-section with the interpretation of the deltas subsurface aquifer-system identifying the main units. Each unit consists of a permeable bottom layer (aquifer) and an occasionally discontinuous, confining top layer (aquitard). B) Ten hydrogeological cross-sections distinguishing aquifers and aquitards used to create the 3D subsurface model of the Mekong delta.

Introduction

Many major river deltas in the world are subsiding and consequently become increasingly vulnerable to flooding and storm surges, salinization and permanent inundation. For the Mekong Delta, annual subsidence rates up to several centimetres have been reported. Excessive groundwater extraction is suggested as main driver. As groundwater levels drop, subsidence is induced through aquifer compaction.

Approach: 3D hydro-geological model with an integrated subsidence module

- Subsurface model based on hydrogeological cross-sections and borehole logs (Fig. 1).
- Transient groundwater flow model (1991-2015) simulating groundwater extraction at monthly increments (Fig. 2&3).
- Recharge: measured time series of precipitation and evaporation.
- PEST model calibration using measured piezometric levels at 101 locations and 10 pilot points.
- Deltares Open-source modelling software: iMOD (Modflow-based).

Groundwater extraction

3D subsurface model

- Hydrogeological model calibration

Subsidence calculation

1D consolidation through aquifer-system compaction following the hydraulic head decline (i.e. decreasing pressure) was calculated with SUB-CR, an elasto-visco-plastic module in iMOD, using the abc model based on the isotach concept including creep.

Results

3D subsurface model

- Subsurface model based on hydrogeological cross-sections and borehole logs (Fig. 1).
- Transient groundwater flow model (1991-2015) simulating groundwater extraction at monthly increments (Fig. 2&3).
- Recharge: measured time series of precipitation and evaporation.
- PEST model calibration using measured piezometric levels at 101 locations and 10 pilot points.
- Deltares Open-source modelling software: iMOD (Modflow-based).

Aquifer drawdown after 25 years

1. Mekong (m)
2. Upper Phan (m)
3. Marine (m)
4. Lower Phan (m)
5. Middle Isopem (m)
6. Lower Isopem (m)

InSAR-measurements compared to modelled subsidence

Impact of 25 years groundwater extraction

Figure 2. Annual modelled groundwater extraction and modelled extraction volume adopting a 5 km radius around a single well for 2015.

Groundwater extraction-induced subsidence

Figure 3. Extracted volume for each aquifer in the Mekong delta.

Figure 4. Left: monthly measured versus modelled hydraulic heads (R² = 0.73; median cross-correlation (r) = 0.94). Right: >75% of modelled head residuals within 2 meters of observed heads.

Figure 5. Modeled aquifer drawdown at the start of 2016 after 25 years of simulated groundwater extraction.

Figure 6. A) Modeled subsidence following groundwater extraction during 25 years from 1991 to 2015.

Figure 7. a) InSAR-measured subsidence (after Erban et al 2014, data © JAXA, METI 2011). b) Modeled subsidence of the best estimate model. c) Fit between modelled subsidence rates and InSAR measurements. Rates in annual averages between 2006-2010.

Impact of 25 years groundwater extraction

Figure 8. I-V) Annual groundwater extraction-induced subsidence rates for each five year period. A-H) Modelled and measured hydraulic head time series at monitoring well locations. Cumulative calculated subsidence in red. Red dots represent InSAR-measured subsidence.

Conclusions

- The hydrogeological situation has changes drastically during the past 25 years; from almost undisturbed to the current state with increased aquifer depletion.
- Groundwater extraction-induced subsidence started ~2 decades ago, with highest subsidence rates modelled at present.
- Groundwater extraction is a dominant subsidence driver, but does not explain all InSAR-measured subsidence, leaving room for other subsidence drivers.

Link to full article:
The sinking Mekong delta
Modeling 25 years of groundwater extraction and subsidence

Philip S.J. Minderhoud1,2, G. Erkens1,2, H.V. Pham1,2,3, V.T. Bui3, H. Kooi3, L.E. Erban4, E. Stouthamer1

1 Universiteit Utrecht, Department of Physical Geography, The Netherlands, P.S.J.Minderhoud@uu.nl
2 Deltares Research Institute, Department of Subsurface and Groundwater Systems, Utrecht, The Netherlands
3 Division of Water Resources Planning and Investigation for the South of Vietnam (DWRPIS), Ho Chi Minh city, Vietnam
4 US EPA Office of Research and Development, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, Narragansett, RI, USA


4 US EPA Office of Research and Development, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, Narragansett, RI, USA

UnivPorretta Universiteit Utrecht

AGU Fall Meeting – 11-15 Dec. 2017 – New Orleans

Philip S.J. Minderhoud, G. Erkens, H.V. Pham, V.T. Bui, H. Kooi, L.E. Erban, E. Stouthamer

3 Utrecht University, Department of Physical Geography, The Netherlands
2 Deltares Research Institute, Department of Subsurface and Groundwater Systems, Utrecht, The Netherlands
4 US EPA Office of Research and Development, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division, Narragansett, RI, USA
