MONITORING SEVERE AQUIFER-SYSTEM COMPACTION AND LAND SUBSIDENCE IN TAIWAN USING MULTIPLE SENSORS: YUNLIN, THE SOUTHERN CHOUSHUI RIVER ALLUVIAL FAN (HUNG ET AL. 2010)

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Date: 2018/05/31
1. Introduction

2. Methodology

3. Results
   3.1. Monitoring of subsidence by leveling
   3.2. Monitoring of subsidence by multi-level compaction monitoring wells and continuous GPS (MCMWs and GPS Station)
   3.3. Spatially detailed monitoring of subsidence by differential radar interferometry (DInSAR)

4. Discussion and conclusions

5. Future work

6. References
During 1992–2007, excessive pumping of groundwater caused large-scale aquifer-system compaction and land subsidence in the Choshui River Alluvial Fan (CRAF), especially in the area of Yunlin county.

The Taiwan High Speed Rail (THSR) passes through Yunlin, where subsidence poses a serious threat to its operation.
Study area:

- Cover total area: 2000 km²
- The elevation ranging from: 0–100 m
- In this study, the authors investigated within depth 300 m.

Fig. 1 Geographical location of Choshui River Alluvial Fan. Inserted is a map showing Chuanghua and Yunlin in Taiwan.
Study area:

Fig. 2 Geological settings of Choshui River Alluvial Fan (modified from Central Geological Survey of Taiwan, http://www.moeacgs.gov.tw/)

Fig. 3 A concept for hydrogeological profiles a-b and c-d (see Fig. 2).

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Study area:

Fig 4: The cross-section line e-f indicates the hydrogeological profile of Choshui (Jhuoshuei) River Alluvial Fan, and distribution of monitoring wells in Yunlin county and Chuanghua county (from Wang et al, 2015)
Table 1: Multi-sensor comparison table

<table>
<thead>
<tr>
<th></th>
<th>Leveling</th>
<th>Continuous GPS</th>
<th>Multi-level Compaction Monitoring well (MCMWs)</th>
<th>DInSAR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spatial resolution</strong></td>
<td>1.5–2 km</td>
<td>10–15 km</td>
<td>5–10 km</td>
<td>25 m</td>
</tr>
<tr>
<td><strong>Measurement frequency</strong></td>
<td>1 year</td>
<td>1 day</td>
<td>1 month</td>
<td>35 day</td>
</tr>
<tr>
<td><strong>Measurement (vertical) accuracy</strong></td>
<td>0.5-1 cm</td>
<td>0.5–1 cm</td>
<td>0.1–0.5 cm</td>
<td>2 cm</td>
</tr>
</tbody>
</table>
3.1 Leveling

- Leveling network covers an area of 1,087 km².
- The network has a total length 434 km and density of one benchmark every 1.5 km.
- There are 53 main routes in the network, forming 13 loops.

Fig. 6 Distributions of leveling routes, monitoring wells and GPS stations in Yunlin.
### 3.1 Leveling

Table 2: Maximum annual rate of subsidence and area of subsidence during 2002–2007 in Yunlin

<table>
<thead>
<tr>
<th>Year</th>
<th>2002</th>
<th>2003</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max rate (cm/year)</td>
<td>9.5</td>
<td>12.2</td>
<td>11.6</td>
<td>10.1</td>
<td>8.2</td>
</tr>
<tr>
<td>Area with rate &gt;3 cm/year (km²)</td>
<td>610.5</td>
<td>703.1</td>
<td>678.6</td>
<td>557.1</td>
<td>551.5</td>
</tr>
</tbody>
</table>
3.1 Leveling

Fig. 8 Cumulative subsidence over 2002–2007 from leveling
Fig. 7 Relationship between rainfall (both monthly and yearly) and area of subsidence where the annual rate of subsidence was greater than 3 cm/year.

A yearly rainfall is given at the representative epoch of June of the year.
3.2 MCMWs and continuous GPS

Fig. 9a: Principle of measurement of MCMWs

Fig. 9b: A multi-level compaction monitoring well, (a) Major components of the device; (b) Collect data at MCMWs (Hung et al, 2017)

Fig. 10: The continuous GPS station near the TKSH monitoring well

Depending on the stratigraphy of the borehole that the magnetic ring is anchored at different depths.

=> The distance change of two rings indicates compression or expansion of the stratigraphic section.
3.2 MCMWs and continuous GPS

Fig. 6 Distributions of leveling routes, monitoring wells and GPS stations in Yunlin
### 3.2 MCMWs and continuous GPS

Table 3: A summary of compactions measured at four monitoring wells

<table>
<thead>
<tr>
<th>Monitoring well</th>
<th>HWSH</th>
<th>TKSH</th>
<th>YCSH</th>
<th>KCSH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (m)</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>No. of magnetic rings</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>21</td>
</tr>
<tr>
<td>Depth range of major compaction stratum (m)</td>
<td>270-300</td>
<td>240-300</td>
<td>250-300</td>
<td>250-300</td>
</tr>
<tr>
<td>Co-located with GPS</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
3.2 MCMWs and continuous GPS

Fig. 11a Comparison of vertical displacements from GPS (weekly averages from daily solutions), monitoring well and leveling (at TKSH)
Fig. 11b Comparison of vertical displacements from GPS (weekly averages from daily solutions), monitoring well and leveling at TKSH (from Monitoring and Analyzing subsidence of Changhua and Yunlin area report in 2016)
3.2 MCMWs and continuous GPS

Fig. 12a Subsidence rate at the TKSH monitoring well. The column shows sediment types from surface (0 m) to the reference depth (300 m).

- In 2004, subsidence rate 6 cm/year
- In 2007, subsidence rate less than 3 cm/year

Compaction at depths greater than 200 m
3.2 MCMWs and continuous GPS

Fig. 12b Cumulative compactions at the TKSH monitoring well from surface (0 m) to 300 m (from Monitoring and Analyzing subsidence of Changhua and Yunlin area report in 2016)
3.3 DInSAR

- DInSAR (Differential Interferometric Synthetic Aperture Radar) uses SAR-images of different times to measure the line-of-sight component of surface displacement.

Fig. 13 ENVISAT SAR data used in this study. Cross axle shows the time and the vertical axle shows the vertical baseline offset of each image pair.

The authors chose the time from 2006-2007 to create 13 image pairs, perpendicular baseline B < 400 m.
3.3 DInSAR

Fig. 14 DInSAR result over 2006–2007. *Circles* along lines AB and CD.

Fig. 15 Leveling result over 2006–2007. *Circles* are the same as those in Fig. 14

Fig. 16 Vertical displacement rates over 2006–2007 from leveling and DInSAR on leveling benchmarks along AB and CD
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Total subsidence

- Leveling
- Continuous GPS
- DInSAR
- MCMWs

Measuring compaction in different layers in the subsurface within the aquifer system. Showing that about 70% of subsidence at depth below 200 m.

From the wells:

MCMWs result (high accuracy about 1-5 mm)

Occurring subsidence in the deeper part (below 300 m)

Leveling result

GPS result
According to the authors:

In particular, Yunlin is covered by different vegetations over different seasons

A degraded or incorrect deformation result.

Future study, which can be reduced by the PS-InSAR technique (Ferretti et al. 2001; Hooper et al. 2007) or the SBAS technique (Berardino et al. 2002)
Conceptual model for tectonic subsidence

GPS Station => Total subsidence

Within 300 m

2 methods:

MCMWs

Nonlinear Poroelastic Model (NPM)

Subsidence due to groundwater over pumping

Subsidence at deeper part

Subsidence due to tectonic activity

Normal fault

Hanging wall

Footwall

Thrust fault

Tectonic subsidence = Total - Groundwater subsidence - Deeper part
6. References


THANK YOU FOR YOUR ATTENTION