Land Subsidence

- **Land subsidence** is the downward displacement of the land surface relative to certain reference surface, such as mean sea level (MSL) or reference ellipsoid.
- It may occur in active volcanic and tectonic areas, mining areas, oil and gas exploration areas, and large urban areas.
- Can be caused by natural and/or human activities.

**Ref:** Polland (1984) Land Subsidence in Indonesian Cities

- Jakarta
- Bandung
- Semarang

**Expected land subsidence:**
- Surabaya
- Denpasar
- Gliagon
- Medan

**Observed decrease in groundwater level**

**JAKARTA**

- 9.6 million people
- 661.52 km²
- 13 rivers
- 43 reservoirs

**Land Subsidence in urban areas (cities)** can be caused by the following factor(s):

- **excessive groundwater extraction**
- **load of constructions and infrastructures** (i.e. settlement of high compressibility soil)
- **natural consolidation of alluvium soil**
- **tectonic activity**

**Jakarta and its Surrounding**

- Jakarta Metropolitan Region (JMR)
- 7500 km²
- total population 27.9 million
IMPACTS OF LAND SUBSIDENCE IN URBAN AREAS (CITIES)

- Cracking of buildings and infrastructure
- The wider expansion of inland & coastal flooding areas
- Malfunction of drainage system
- Increasing the maintenance costs for the affected buildings and infrastructure
- Changes in river canal and drain flow systems
- Lowering the quality of living environment and life (e.g. health and sanitation condition) in the affected areas

Losses due to Land Subsidence

DIRECT EFFECTS

- Primary Subsidence Phenomena
  - Vertical subsidence
  - Tilt
  - Horizontaltal strains
  - Ground failures
  - Subsurface deformation

- Damage, Costs and Other Impacts
  - Man-made system
  - Natural system

- Adjustments and their Costs and Impacts
  - Studies
  - Subsidence control
  - Damage Mitigation

INDIRECT EFFECTS

- Aggravation of Other Hazards
  - Flooding
  - Faulting
  - Dam failures
  - Induced seismicity

- Damage, Costs and Other Impacts
  - Man-made system
  - Natural system

MAIN OBJECTIVES OF RESEARCH

- to map the spatial and temporal rates of land subsidence in Jakarta area from the results of Leveling, GPS surveys and InSAR methods;
- to map spatially the land subsidence impacts in Jakarta area; and
- to spatially analyse the impacts of land subsidence in Jakarta area, especially in relation with possible causes of land subsidence in various regions of Jakarta.

Karakteristik Penurunan Tanah di Wilayah Jakarta Dari Estimasi Metode Geodetik

Measurement and Observation of Land Subsidence in Urban Areas

- Leveling Survey
- GPS Survey
- InSAR
- Microgravity
- Geometric-historic
Geodetic Methods for Land Subsidence Monitoring

<table>
<thead>
<tr>
<th>City</th>
<th>Leveling</th>
<th>GPS</th>
<th>InSAR</th>
<th>Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>BANDUNG</td>
<td>Limited</td>
<td>Since 2000</td>
<td>Since 2007</td>
<td>Since 2008</td>
</tr>
<tr>
<td>SEMARANG</td>
<td>Since 1999</td>
<td>Since 2008</td>
<td>Since 2007</td>
<td>Since 2002</td>
</tr>
</tbody>
</table>

GRD of ITB mainly involved with GPS Surveys and InSAR.

Observed Subsidence Rates in Jakarta
(the rates vary both spatially and temporally)

<table>
<thead>
<tr>
<th>Method</th>
<th>Period</th>
<th>Subsidence Rates (cm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leveling</td>
<td>1982-1991</td>
<td>1 - 9</td>
</tr>
<tr>
<td></td>
<td>1991-1997</td>
<td>1 - 25</td>
</tr>
<tr>
<td>GPS surveys</td>
<td>1997 - 2011</td>
<td>1 - 28</td>
</tr>
<tr>
<td>InSAR</td>
<td>2006 - 2007</td>
<td>1 - 12</td>
</tr>
</tbody>
</table>

Principle of Leveling for Height Difference Determination

Land Subsidence from Leveling, 1982 - 1997

Land Subsidence in Jakarta from Leveling, 1982 - 1997
PRINCIPLE OF LAND SUBSIDENCE MONITORING USING REPEATED GPS SURVEY METHOD

GPS network Covering the study area

- Coordinates from Survey #1
- Coordinates from Survey #2

COORDINATES FROM SURVEY # 1
- LAND SUBSIDENCE
- HEIGHT DIFFERENCES
- LAND SUBSIDENCE CHARACTERISTICS

LAND SUBSIDENCE
- Hydrogeological and Geometrical Testings
- Working

GPS stations for studying land subsidence in Jakarta

- Surveys since 1997
- Yearly basis
- There about 65 GPS stations in 2012
- Reference Station: IGS BAKO Station at Cibinong

Contoh penurunan tanah di Cekungan Jakarta dari GPS (2000 – 2005) in cm

Land subsidence in Jakarta Basin in cm


Land subsidence in Jakarta Basin (2009 – 2010) dari Survei GPS
Lokasi yang mengalami land subsidence cukup besar:
- Jakarta Utara seperti Mutiara Baru, Pantai Mutiara, Pantai Indah Kapuk, dan Ancol;
- Jakarta Barat yaitu Cengkareng Barat;
- Jakarta Timur yaitu sekitar Kelapa Gading.

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**ZONASI KAWASAN SUBSIDENCE JAKARTA (2002 – 2010)**

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**PRINCIPLE OF DEFORMATION STUDY USING INSAR TECHNIQUE**

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**Land Subsidence in Jakarta from InSAR**

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**Cones of Subsidence**

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**Land Subsidence in Jakarta from PSI, ALOS PALSAR, 2007 to 2010**

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**Dampak Penurunan Tanah di Wilayah Jakarta**
IMPACTS OF LAND SUBSIDENCE IN URBAN AREAS (CITIES)

- Cracking of buildings and infrastructure
- The wider expansion of inland & coastal flooding areas
- Malfunction of drainage system
- Increasing the maintenance costs for the affected buildings and infrastructure
- Changes in river canal and drain flow systems
- Lowering the quality of living environment and life (e.g. health and sanitation condition) in the affected areas

Hasanuddin Z. Abidin, 2012

Genangan Rob (Gunung sahari)

Struktur jembatan turun (mutiara)

Bangunan miring (Tongkol)

Impacts of Subsidence in Jakarta

Hasanuddin Z. Abidin, 2008

Impacts of Coastal Subsidence in Jakarta

Hasanuddin Z. Abidin, 2013

Land Subsidence and Flooding in Jakarta

GPS-derived subsidence (2000-2011)

Land Subsidence and Flooding (1)

Expanded coverage and deeper water depth of flooded (inundated) areas
Land Subsidence and Flooding (2)

Expanded coverage and deeper water depth of coastal flooded (inundated) areas

Land Subsidence and Flooding (3)

Changes of water flow pattern in drainage, canal and river systems passing the subsidence area

Land Subsidence and Flooding in Jakarta

JAKARTA Easting - 2 m - 2 m - 1 m - 0.8 m - 0.3 m

Leveling-derived subsidence (1982-1997)
2002 Jakarta Flooding (flooding map based on LAPAN data)

InSAR-derived subsidence (2007-2011) (Houdogbo et al., 2012)

Coastal Subsidence and Flooding

Watch out subsidence along the coastal areas of North Jakarta

Sea Level Rise: 0.1 – 0.5 cm/year (IPCC)
Coastal Subsidence: 1 - 15 cm/year

- Tidal Flooding
- Surface water degradation
- Decrease in livelihood quality

Coastal Subsidence and Flooding

Rob in Priok Harbor
Rob in Rukindo Priok
Rob in Pluit
Rob in Tongkol Ps Ikan
Rob in PLTGU Priok
Rob in Muara Baru
Rob in Pluit
Rob in Muara Baru
Rob in Kamal Muara
Rob in G. Sahari
Rob in G.Sahari
Rob in P. Jayakarta
Rob in P.Jayakarta

Floods "ROB" in northern Part of Jakarta

Ref: Brinkman (2011)
"Sea level versus River and Sea Wall" somewhere in Jakarta

Ref: Brinkman (2011)

Evidence of Jakarta’s Land Subsidence Story: “Bridge Lowering”

Ref: Brinkman (2011)

“Bridge Lowering” in some places in Jakarta

Ref: Brinkman (2011)
Land Subsidence

Land subsidence in urban areas (cities) can be caused by the following factors:

• excessive groundwater extraction
• load of constructions and infrastructures (i.e. settlement of high compressibility soil)
• natural consolidation of alluvium soil
• tectonic activity

Geodetic-derived Total Subsidence

- Subsidence due to groundwater extraction
- Subsidence due to natural consolidation
- Subsidence due to building/infrastructure loading
- Subsidence due to tectonic activity

Penyebab Penurunan Tanah di Wilayah Jakarta

Ref: Brinkman (2011)

Ref: Brinkman (2011)

Ref: Brinkman (2011)

Ref: Brinkman (2011)
Land Subsidence & Urban Development

- Increase in built-up areas
- Increase in population
- Increase in economic and industrial activities
- Increase in groundwater extraction

URBAN DEVELOPMENT will cause LAND SUBSIDENCE will lead to

- Land use planning
- Groundwater extraction regulation
- Building and infrastructure codes
- Flood management and control
- Sea water intrusion control

Land Subsidence will affect Urban Development

Increase in Population and Built-up Areas

Urban development in Jakarta is going on rapidly

Jakarta has been the most attractive area in Indonesia for domestic and direct foreign investment because of [Firman and Dharmapatni, 1994]:
- better infrastructure,
- high concentration and access to mass markets
- pool of skilled labour and entrepreneurs
- high access to the decision makers

The increase in population and urban development activities in Jakarta lead to increase in built-up areas and decrease in green areas.

- New residential areas, industries, condominiums, malls, hotels, commercials and office buildings have proliferated in Jakarta in the last three decades.
- In 2006, there are already 306 hotels, in which 115 are star (classified) hotels; and 1955 large and medium manufacturing companies in Jakarta [BPS Jakarta, 2007].

Population Growth of Jakarta

<table>
<thead>
<tr>
<th>Year</th>
<th>Population ('000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1948</td>
<td>2,000</td>
</tr>
<tr>
<td>1961</td>
<td>2,973</td>
</tr>
<tr>
<td>1971</td>
<td>4,579</td>
</tr>
<tr>
<td>1980</td>
<td>6,503</td>
</tr>
<tr>
<td>1990</td>
<td>8,259</td>
</tr>
</tbody>
</table>


Population Growth of DKI Jakarta

[Lo and Yeung, 1995; BPS, 2011]

<table>
<thead>
<tr>
<th>Year</th>
<th>Population ('000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1948</td>
<td>2,000</td>
</tr>
<tr>
<td>1961</td>
<td>2,973</td>
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<td>6,503</td>
</tr>
<tr>
<td>1990</td>
<td>8,259</td>
</tr>
<tr>
<td>2002</td>
<td>8,379</td>
</tr>
<tr>
<td>2003</td>
<td>8,603</td>
</tr>
<tr>
<td>2004</td>
<td>8,725</td>
</tr>
<tr>
<td>2005</td>
<td>8,864</td>
</tr>
<tr>
<td>2010</td>
<td>9,588</td>
</tr>
</tbody>
</table>

Increase in Built-up Areas and Population of Jakarta

INCREASE IN BUILT-UP AREAS AND POPULATION

Decrease in Water Recharge Areas
Decrease in rechargeability of withdrawn groundwater
Increase in Groundwater Consumption & Extraction
Increase in Building and Infrastructure Loading

Land Subsidence from Leveling, 1982 - 1997


CONES OF SUBSIDENCE

18 cm/year
26 cm/year
17 cm/year

Land Subsidence from Leveling, 1982 - 1997


(1991 - 1997)

Groundwater Level Changes (CM)

2002 2003 2004 2005 2006 2007

Subsidence of KWIT GPS Station

Subsidence of KWIT GPS Station

Subsidence and GROUNDWATER
Jakarta basin

SUBSIDENCE AND GROUNDWATER
Jakarta basin

Piezometric water level contours (in metres) inside Middle and Lower Aquifers of Jakarta in 1992, adapted from (Murdohardono and Tirtomihardjo, 1993)
Laju Penyedotan Air Tanah di Jakarta (1879-2007)

[Graph showing the rate of groundwater level lowering in Jakarta from 1879 to 2007]

Rates of Groundwater Level Lowering

Lowering rates: 0.2 – 2.0 meter/year
Subsidence rates (typical): 0.02 – 0.20 meter/year

Source: Mining Agency of DKI Jakarta

Closing Remarks

Tectonic Contribution to Land Subsidence in Jakarta Basin?

Geological structures in Jakarta area, derived based on Landsat images and seismic profiling; from Harsolumakso (2001)

Roles of Geospatial Information for Risk Assessment of Subsidence in Urban Areas

<table>
<thead>
<tr>
<th>GEOSPATIAL INFORMATION</th>
<th>LAND SUBSIDENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed height differences in spatial and temporal domain</td>
<td>Location of land subsidence features in the field</td>
</tr>
<tr>
<td>Spatial distribution of man-made and natural features (e.g., built-up areas, industries, buildings, and infrastructures, forest, paddy fields, etc.)</td>
<td>Spatial characteristics and dynamics of groundwater, aquifers and confining beds</td>
</tr>
<tr>
<td>Physical properties of soil and rock in spatial domain</td>
<td>Spatial distribution and characteristics of population and economic activities</td>
</tr>
</tbody>
</table>

Roles of Geospatial Information for Risk Assessment of Subsidence in Urban Areas

Geospatial Information

Urban Development

Land Subsidence

Collateral Hazards

Sea Level Rise

• People
• Environment
• Infrastructure

Mitigation

Adaptation

Structural

Cultural

Characteristics • Causes • Impacts • Costs
