# International Union of Geodesy and Geophysics
# Indonesian National Committee

## Country Report
## IUGG General Assembly
## Melbourne, Australia
## June 28 – July 7, 2011

# *Introduction*

Asep Karsidi,
President of the Indonesian National Committe for IUGG

The Country Report for the IUGG General Assembly XXV at Melbourne, Australia prepared by the Indonesian National Committee for IUGG consists of reports for the associations: IAG, IAGA, IAHS, IAMAS, IASPEI and IAVCEI.

1. **Country Report for IAG consists of two parts:**
   A. Geodetic Activities in the National Coordinating Agency for Surveys and Mapping (BAKOSURTANAL)
   - Real Time Coastal Sea Level Network Supporting Indonesian Tsunami Early Warning System
   - Present Status of Indonesian Sea Level Monitoring Network
   - The Airborne Gravity Survey for Regional Geoid Mapping

   B. 2. Research Activities conducted by the Institute of Technology in Bandung, they are about:
   - Studying Land Subsidence In Semarang (Indonesia) Using Geodetic Methods
   - Land Subsidence And Urban Development In Jakarta (Indonesia)
   - Land Subsidence Characteristics Of Jakarta Between 1997 And 2005, As Estimated Using GPS Surveys
   - Land Subsidence Characteristics Of The Bandung Basin, Indonesia, As Estimated From GPS And Insar
   - Crustal Deformation Studies In Java (Indonesia) Using GPS
   - The Applications Of GPS Cors In Indonesia: Status, Prospect And Limitation
   - Land Subsidence Characteristics Of The Jakarta Basin (Indonesia) and Its Relation With Groundwater Extraction And Sea Level Rise

2. **Country Report for IASPEI presents**
   - Development of New Seismic Hazard Maps of the Indonesian Region

3. **Country Report for IAVCEI describes**
   - Volcanic Activity In Indonesia During Period of 2008-2011

4. **Country Report for IAHS presents**
    - Research and development of space weather model and observation method in Indonesia during 2008-2010

5. **Country Report for IAHS presents**
    - Impact of Climate Change on Water Resources In Java Island
    - Groundwater management issues in the Greater Jakarta area, Indonesia

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# Geodetic Activities in the National Coordinating Agency for Surveys and Mapping (BAKOSURTANAL)

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## Background

National Coordinating Agency for Surveys and Mapping (BAKOSURTANAL) is the Government institution that formulates the macro and national level policies governing survey and mapping in Indonesia. The agency works with a mission to build National Spatial Data Infrastructure (NSDI), which covers elements of institutional, regulation, spatial main data, human resources, and research and development in the field of survey and mapping. BAKOSURTANAL has duty to conduct governmental duties in the field of surveys and mapping according to prevailing regulation. Its Functions are 1) . to assess and create national policies is surveys and Mapping; 2). to develop national spatial data infrastructure (NSDI); 3). to coordinate functional activities in conducting BAKOSURTANAL task; 4). to monitor, guide and maintain activities of government institutions in the field of national surveys and mapping; and 5). to organize, develop and serve in the field of general planning, management, organization, personnel, financial, archive, regulation, code, and internal affair.

In order to fullfil its task, BAKOSURTANAL establish Geodetic Network covered whole Indonesia. The Network consists:

- National Vertical Control Network
- National Horizontal Control Network
- National Gravity Control Network
- National Sea Level Monitoring Network

As known, The islands of Indonesia lie at the junction of the Eurasia, Australia, Pacific, and Philippine Sea plates, resulting in rugged topography, frequent earthquakes, and active volcanism. In the west, the Australia plate is subducted beneath the Eurasia plate along the Java trench. The direction of convergence is normal to the trench of Java, but oblique to the trench southwest of Sumatera.

Further east, the island of New Guinea, the leading edge of the northward moving Australian continent, is dominated by the rapid oblique convergence (<110mm/yr) between the Pacific and Australian plates. The oblique convergence has produced a complex array of microplates whose motions result in rapid shear, arc-continent collision, oceanic and continental subduction, continental rifting, and seafloor spreading. In West Papua a large section of the continent (the Bird's Head) is being detached along a rapid (80mm/yr) shear zone and subducted at Seram trough.

The complexity of tectonic processes in Indonesia was recognized by geologists long before the widespread acceptance of the theory of plate tectonic and has resulted in numerous geologic and geophysical studies in the region.

Geodetic data with the level of precision available using Global Positioning System (GPS) give us the opportunity to address many outstanding issues by providing two important number of information. First, geodetic data enable us to directly estimate *recent* rates of plate motion. Second, geodetic data can provide an estimate of the regional horizontal surface velocity field that may be used in constructing and maintaining geodetic datum that take account of Earth deformation.

We have conducted GPS studies throughout Indonesia and South and Southeast Asia for the last ten years. For the first time, we integrate the information from these GPS data to gain a more complete picture of tectonic block interactions in the Indonesia region. And then incorporate velocity solutions from each of tectonic block into velocity model by repeated GPS surveys. The reference frame used in the analysis of the entire Indonesia GPS data set is the 2000 International Terrestrial Reference Frame (ITRF2000) computed by the International Earth Rotation Service (IERS).

## The Current Status of Indonesian permanent GNSS stations network

The objectives of main Maintenance of permanent GNSS stations network are as follows:

- To maintain national geodetic reference frame in active seismic zones for survey and mapping purposes,
- Mitigation, Crustal deformation monitoring for geological hazard mitigation
- Sea level change monitoring with continuous GPS and Tide Gauge stations collocation, GPS Meteorology to determine PW in the troposphere and TEC in the ionosphere,
- GPS for safety navigation.
- Permanent GPS station is part of the Ina-TEWS (Indonesian Tsunami Early Warning System)
- Maintenance of a national geodetic reference frame, which refers to the global geodetic reference frame (ITRF).
- Service instantaneous correction careful positioning with GPS (references in real-time positioning (DGPS / RTK)) for the purposes of surveying and mapping, navigation and transportation.
- Study geodynamics in Indonesian territory.
- Mitigation of earthquake disasters

- Spatial Planning

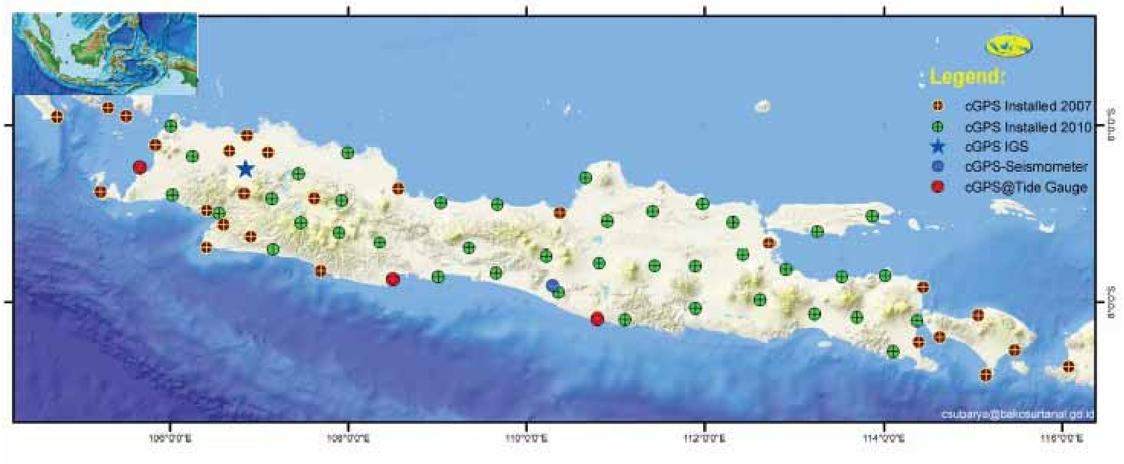


Figure 1. Distribution of Continous GPS-Stations in Java

At this moment BAKOSURTANAL maintaines 100 continous GPS distributed in whole Indonesia, as listed in table 1. Figure 1 shows the location of c-GPS stations in Java island.

Tabel. 1 Locations of 100 c-GPS Stations maintained by BAKOSURTANAL

| NO | Code | Location | Latitude | Longitude |
|---|---|---|---|---|
| 1 | CKUR | PULAU SUKUN NTT | -8.121 | 122.110 |
| 2 | CTOA | KALATOA NTT | -7.406 | 121.767 |
| 3 | CBON | BONERATE SULSEL | -7.382 | 121.078 |
| 4 | CDAI | TANJUNG BUNGA NTT | -8.068 | 122.867 |
| 5 | CPBR | PULAU PEMANA NTT | -8.348 | 122.318 |
| 6 | CLBR | LEMBAR MATARAM | -8.728 | 116.076 |
| 7 | CPBI | KLUNGKUNG BALI | -8.543 | 115.471 |
| 8 | CDNP | DENPASAR BALI | -8.818 | 115.146 |
| 9 | CSRJ | SINGARAJA BALI | -8.149 | 115.058 |
| 10 | CCAK | PERANCAK BALI | -8.393 | 114.628 |
| 11 | CBRN | BALURAN JATIM | -7.838 | 114.440 |
| 12 | CMCR | MUNCAR JATIM | -8.451 | 114.389 |
| 13 | CPMK | PAMENGPEUK JABAR | -7.655 | 107.691 |
| 14 | CLBG | LEMBANG JABAR | -6.824 | 107.616 |
| 15 | CSGT | SEGARANTEN JABAR | -7.256 | 106.905 |

| NO | Code | Location | Latitude | Longitude |
|---|---|---|---|---|
| 16 | CLDO | LIDO JABAR | -6.767 | 106.830 |
| 17 | CTVI | SURANGGA KAB. SUKABUMI | -7.121 | 106.597 |
| 18 | CPTN | CISOLOK P. RATU | -6.961 | 106.411 |
| 19 | CUJG | UJUNG GENTENG SUKABUMI | -7.382 | 106.405 |
| 20 | CPSR | PASAURAN BANTEN | -6.226 | 105.833 |
| 21 | CSBK | PULAU SEBUKU LAMPUNG | -5.902 | 105.505 |
| 22 | CLGI | PULAU LAGUNDI LAMPUNG | -5.812 | 105.297 |
| 23 | CUJK | UJUNG KULON BANTEN | -6.747 | 105.213 |
| 24 | CTCN | TANJUNG CINA LAMPUNG | -5.913 | 104.727 |
| 25 | CANG | SOREANG | -7.022 | 107.525 |
| 26 | CBLR | BLORA | -7.005 | 111.312 |
| 27 | CBTL | BANTUL | -7.887 | 110.327 |
| 28 | CCLP | CILACAP | -7.738 | 109.001 |
| 29 | CGON | CILEGON | -5.941 | 106.003 |
| 30 | CJEM | JEMBER | -8.175 | 113.693 |
| 31 | CJPR | JEPARA | -6.596 | 110.667 |
| 32 | CJUR | CIANJUR | -6.827 | 107.139 |
| 33 | CKBN | KEBUMEN | -7.668 | 109.654 |
| 34 | CLMG | LAMONGAN | -7.093 | 112.326 |
| 35 | CLUM | LUMAJANG | -8.214 | 113.114 |
| 36 | CMAG | MOSPATI | -7.606 | 111.451 |
| 37 | CMGL | MAGELANG | -7.476 | 110.217 |
| 38 | CMIS | CIAMIS | -7.326 | 108.343 |
| 39 | CMJT | MOJOKERTO | -7.466 | 112.442 |
| 40 | CMLG | MALANG | -7.979 | 112.663 |
| 41 | CMLP | MALIMPING | -6.792 | 105.900 |
| 42 | CNGA | NGANJUK | -7.604 | 111.905 |
| 43 | CNYU | BANYUWANGI | -8.212 | 114.375 |
| 44 | CPAC | PACITAN | -8.196 | 111.097 |
| 45 | CPAI | PAITON | -7.719 | 113.530 |
| 46 | CPAS | PASURUAN | -7.651 | 112.901 |
| 47 | CPBL | PURBALINGGA | -7.389 | 109.364 |
| 48 | CPES | PESANGGARAN | -8.534 | 114.110 |

| NO | Code | Location | Latitude | Longitude |
|---|---|---|---|---|
| 49 | CPKL | PEKALONGAN | -6.884 | 109.670 |
| 50 | CPTU | PELABUHAN RATU | -6.900 | 106.467 |
| 51 | CPWD | PURWODADI | -7.096 | 110.914 |
| 52 | CPWK | PURWAKARTA | -6.548 | 107.438 |
| 53 | CRBT | RANGKASBITUNG | -6.360 | 106.246 |
| 54 | CROL | PATROL | -6.315 | 107.991 |
| 55 | CRUT | GARUT | -7.212 | 107.921 |
| 56 | CSIT | SITUBONDO | -7.703 | 114.013 |
| 57 | CSLO | SOLO | -7.571 | 110.831 |
| 58 | CSMN | SUMENEP | -7.018 | 113.875 |
| 59 | CSMP | SAMPANG | -7.195 | 113.252 |
| 60 | CTAN | TANGGEUNG | -7.451 | 107.136 |
| 61 | CSUM | SUMEDANG | -6.859 | 107.922 |
| 62 | CTBN | TUBAN | -6.872 | 111.987 |
| 63 | CTGL | TEGAL | -6.871 | 109.136 |
| 64 | CTUL | TULUNGAGUNG | -8.065 | 111.906 |
| 65 | CJKT | JAKARTA | -6.118 | 106.865 |
| 66 | CMER | MERAUKE | -8.479 | 140.392 |
| 67 | CUAL | TUAL | -5.664 | 132.736 |
| 68 | CFAK | FAKFAK | -2.919 | 132.265 |
| 69 | CSAU | SAUMLAKI | -7.989 | 131.307 |
| 70 | CSOR | SORONG | -0.875 | 131.253 |
| 71 | CAMB | AMBON | -3.639 | 128.200 |
| 72 | CKDR | KENDARI | -4.085 | 122.391 |
| 73 | CBKL | BENGKULU | -3.785 | 102.253 |
| 74 | CSEL | BALAI SELASA | -1.806 | 100.855 |
| 75 | CPAR | PARIAMAN | -0.620 | 100.120 |
| 76 | CAIR | AIR BANGIS | 0.222 | 99.388 |
| 77 | CSAB | SABANG | 5.831 | 95.347 |
| 78 | CBTU | CIBITUNG Bekasi | -6.308 | 107.096 |
| 79 | CTGR | TANGERANG | -6.291 | 106.663 |
| 80 | CTER | TERNATE | 0.788 | 127.382 |
| 81 | CBIT | BITUNG SULUT | 1.4438 | 125.186 |
| 82 | CMAK | MAKASAR SULSEL | -5.135 | 119.408 |

| NO | Code | Location | Latitude | Longitude |
|---|---|---|---|---|
| 83 | CSBY | SURABAYA JATIM | -7.334 | 112.724 |
| 84 | CBAL | BALIKPAPAN KALTIM | -1.256 | 116.839 |
| 85 | CPON | PONTIANAK KALBAR | 0.075 | 109.191 |
| 86 | CBIK | BIAK PAPUA | -1.186 | 136.090 |
| 87 | CMAN | MANOKWARI PAPUA | -0.859 | 134.072 |
| 88 | CNAB | NABIRE PAPUA | -3.367 | 135.506 |
| 89 | CKAL | KALABAHI NTT | -8.213 | 124.517 |
| 90 | CKUP | KUPANG NTT | -10.169 | 123.597 |
| 91 | CMRE | MAUMERE NTT | -8.627 | 122.219 |
| 92 | CREO | REO NTT | -8.311 | 120.490 |
| 93 | CLWB | LEWOLEBA NTT | -8.371 | 123.422 |
| 94 | CTOL | TOLI-TOLI SULTENG | 1.042 | 120.817 |
| 95 | CBKT | BUKIT TINGGI SUMBAR | -0.309 | 100.371 |
| 96 | CPDG | PADANG SUMBAR | -0.954 | 100.363 |
| 97 | CCIR | CIREBON JABAR | -6.716 | 108.561 |
| 98 | CSEM | SEMARANG JATENG | -6.987 | 110.377 |
| 99 | BAKO | CIBINONG JABAR | -6.491 | 106.849 |
| 100 | BAK2 | CIBINONG JABAR | -6.491 | 106.849 |

## 3. Current Status of BAKOSURTANAL Sea Level Monitoring

Realizing the great loss in the tragedy and in support of the early warning system in Indian Ocean initiated by the United Nations, Indonesia has allocated national funding for establishing the Indonesian Tsunami Early Warning System (InaTEWS). As sea level monitoring is an important component of TEWS with its role for confirming the arrival time and height of the waves. Indonesia in joint efforts with international partners under the coordination of IOC/UNESCO has established real or near real time sea level monitoring stations.

Current status (April 2011), BAKOSURTANAL manage 113 stations comprising:

- 10 tide gauges in cooperation with Germany
- 10 tide gauges in cooperation with IOC/UHSLC
- 93 tide gauges purely financed by Indonesian Government

## 4. Airborne Gravity Surveys

The airborne gravity survey conducted since year 2008 has yielded a set of GPS kinematics position and Free-air gravity anomaly data along the flight strips. This set of data then be gridded into 6' interval data. Covered survey areas are as follows:

2008 : Sulawesi (44,000 line km)
2009 : South and East Kalimantan (45,000 line km)
2010 : Western Kalimantan and Western Papua (56,000 line km)
2011 : This year, it is planned to cover the rest of western Papua.

## 5. International Cooperation

BAKOSURTANAL cooperates with International institutions as follows:

- **Scripps Institution of Oceanography, USA**

  Our geodetic control network coordinates and velocity field for Indonesia is based on GPS surveys data collected annually which is part of scientific collaboration with Scripps Institution of Oceanography, Rensselaer Polytechnic Institute, DEOS Delft University of Technology and GeoForsung Zentrum Potsdam to monitor crustal deformation in Indonesia region. Beginning at year 1997 we were included GPS surveys data collected in Asia Pacific Regional Geodetic Project (APRGP) under Permanent Committee on GIS Infrastructure for Asia and the Pacific (PC-GIAP). More than 250 sites have had three or more occupations with at least a year between each observation. Sites in the GPS network were observed continuously for approximately three days during each occupation period. We used a combination of dual-frequency carrier phase and pseudorange GPS receivers of Trimble 4000's, Ashtech Z-XII, and Leica's in the data acquisition.

- **National Oceanic And Atmospheric Administration, USA**

  Concerning the collection of global of, and access to observations od sea level from tide gauges, BAKOSURTANAL and NOAA have established in Sibolga, Padang, Benoa and Sabang.

- **The University of Hawaii Sea Level Center (UHSLC), USA**

  USA Government under NOAA/University of Hawaii Sea Level Centre (UHSLC) joint collaboration and with financial assistance from USAID has partnered with BAKOSURTANAL to install 10 tide gauges using GTS. The capability of stations will be upgraded gradually to use BGAN communication.

- **GeoForschung Zentrum Potsdam, Germany**

  In view of the Earthquake and Tsunami of 26 December 2004, BAKOSURTANAL and GFZ have been involved in The German - Indonesia

TEWS (GITEWS) Programme. There are installed 10 sea level stations and 10 continuous GPS stations. Each tide gauge station consists of continuous GPS monitoring, a ground meteorological sensor and multiple communication capabilities such as GTS, BGAN/Inmarsat, and PASTI.

- **The Geodynamics department, DNSC Copenhagen, Denmark**

  BAKOSURTANAL in co-operation with the Geodynamics Division, DTU Space, Denmark Technical University, undertakes a joint campaign for regional airborne gravity in Indonesia. The aim of this cooperation is to provide the good coverage of gravity data for geoid mapping in Indonesia as well as to contribute for the improvement of the global Earth Gravity Model (EGM).
  The main objective of this project is to undertake an airborne gravity survey over parts of Indonesia to provide data for precise geoid model for the area and to provide data for the Earth Geo potential Models (EGM'S). To integrate the collected airborne data with BAKOSURTANAL existing surface data and to use the terrain elevation model from SRTM in order to compile the best possible geoid for the area.

- **Institute Geographique National (IGN), France**

  BAKOSURTANAL in cooperation with IGN has establishe a DORIS beacon in BAKOSURTAL's Base in Cibinong.

- **Kyoto University. Japan**

  The scope of cooperation between BAKOSURTANAL and Kyoto University are as follows:
  - Establishment of Absolute Gravity Network in the Indonesian archipelago as a part of the Absolute Gravity Standard Station Network in Asia and Oceania,
  - Studying the time dependent behavior of the gravity field in East Asia and Southeast Asia,
  - Studying the influence of the environmental parameters on the absolute gravity measurements,
  - To conduct research and development in data processing and explanation of the problems on the geodynamics and on the physics of the interior of the earth,
  - To determine accurately the tidal parameters to study the geodynamical problems of the nearly diurnal free wobble of the Earth's core, seismic core modes, core undertones, the Earth's rotation and the polar motion.

## 3. Future Cooperation

The future geodetic activities will continue the cooperation with International Institutions. There are some new proposed activities:

- PROTECS (Project for Training, Education and Consultancy)

  After succesfully GI-TEWS (German Indonesia Tsunami Warning System)-project, GFZ-BAKOSURTANAL and BMKG agree to continue with a new project, it is called PROTECS. This project start on June 1, 2011 for the next three years.

- New MoU with GFZ

  A new MoU between BAKOSURTANAL and GFZ will be signed the next few month. Cooperative activities carried out under this MoU may include scientific research into the following areas of interest:

  1. Operation, data sharing and maintenance of the GITEWS GPS-controlled tide gauges
  2. Sharing data and expertise for GPS analyses in the frame of the IGS TIGA project
  3. Satellite altimetry calibration/validation;
  4. Specific research topics exploiting altimetry data and gravity data;
  5. Sharing software for tide gauge data processing;
  6. Sharing databases; and
  7. other areas of interest to be mutually agreed upon by the Parties.

# Real Time Coastal Sea Level Network Supporting Indonesian Tsunami Early Warning System

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## Introduction

The demand for high rate sea level data transmission enabling a tsunami warning issuance in both Indian Ocean and the Indonesian Internal Sea Waters has been increasing after the tragedy of the 2004 Sumatra Tsunami. As it is known, the tsunami was the most catastrophic in recorded history, causing great loss of lives with more than 120,000 fatalities in Indonesia and thousands more over 9 countries in Asia. If an early warning system were available in the region, many lives could have been saved.

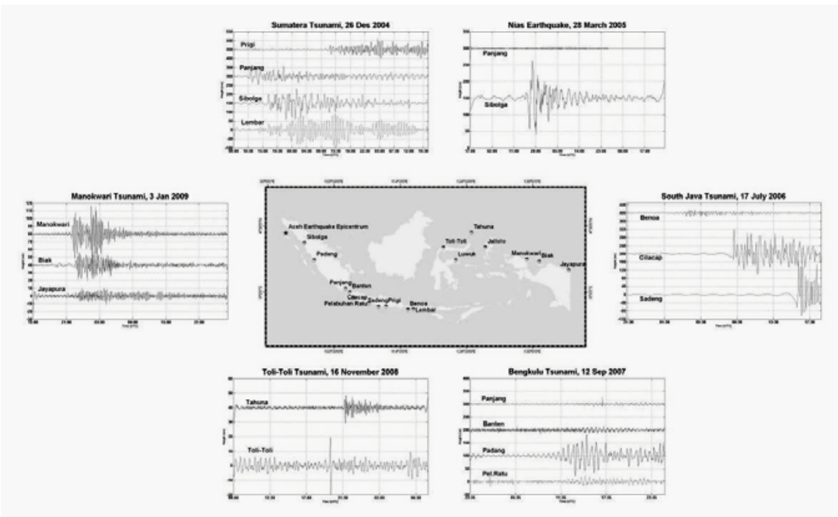


Figure 1. Tsunami occurrences at least once in a year since 2004

Realising the great loss in the tragedy and in support of the early warning system in both Indian Ocean and internal waters of Indonesia, Indonesia has allocated national funding for establishing the Indonesian Tsunami Early Warning System (IdnTEWS). This can be claimed as a turning point in the development of real time coastal sea level monitoring network in Indonesia. Unexpectedly, the tsunami events occurred at least once in a year starting from the devastating tsunami to date and these have been triggering the efforts to speed up the progress development of the warning system in the region. More important, the distribution of earthquakes generating tsunamis, as can be seen in Figure 1, shows that the threat is not only found along the coastlines facing the Indian Ocean, but also in both the Internal Waters and Indonesia that facing Pacific Ocean. Therefore the needs to distribute more stations to the Eastern parts of Indonesia should be carried out and this of course requires more investment.

This paper reports the station distribution of the existing network, a description on technology applied, GPS technology added in the network, and data availability.

**Station Map Distribution**

The Permanent Sea Level Monitoring Network of Indonesia is fully centralised under the responsibility of BAKOSURTANAL in terms of budgeting, maintenance and data processing. However, the contribution of the local port authorities is considerable by assigning at least one of their staff to operate the station on a daily basis.

The network is aimed at functioning as reference stations serving for multi purpose as such as from practical application to research. The network distribution is still far than adequate for representing tidal characteristics along the entire country coast line.

Assuming that one tidal station represents a tidal regime of about 100 km of coast line length, an ideal number of permanent tidal stations, classified as reference stations, for the whole country should be about 810 stations. Therefore, the network is still gradually expanding in number of stations with support not only from the tsunami warning program, but also from support of inter department for densification of the network until it possibly reach the idealistic station distribution.

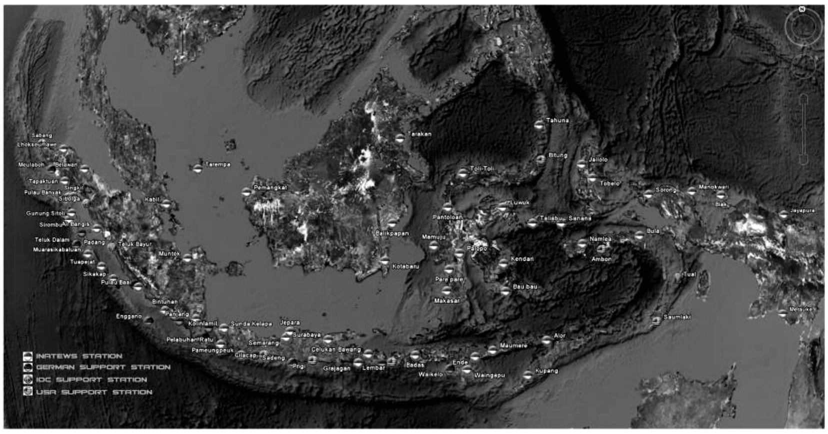


Figure 2. Distribution map of the Indonesian Sea Level Monitoring Network

Support for development of the sea level component of InaTEWS is derived from mainly four sources of funding available at present that have contributed to the upgrade and installation of tide gauge stations. The support and number of the installed of agreed stations are as follows:

- The German - Indonesia TEWS (GITEWS) Programme has installed 7 out of 10 agreed sea level stations and the remaining will be completed by the end of 2009. Each station consists of continuous GPS monitoring, a ground meteorological sensor and multiple communication capabilities such as GTS, BGAN/Inmarsat, and PASTI.
- USA Government under NOAA/University of Hawaii Sea Level Centre (UHSLC) joint collaboration and with financial assistance from USAID has partnered with BAKOSURTANAL to install 7 out of 10 agreed stations using GTS. The capability of stations will be upgraded gradually to use BGAN communication and continuous GPS monitoring planed to take place by May 2009.
- The IOC has provided funding for 3 tide gauge station upgrades. UHSLC and BAKOSURTANAL partnered to install all the agreed stations. The work completed by the early of 2008. The capability of stations will also be upgraded gradually to use the BGAN communication and continuous GPS monitoring expected to start by May 2009.
- Indonesian government under the InaTEWS Programme supports funding has completed to install 40 out of 60 agreed stations using GSM and VSAT platforms. However, the completion of the remaining stations is still subject to funding availability.


(a) (b)

Figure 3 Adopting local art and culture in the tidal hut outlook **(a).** Poster for explaining to public about the importance of sea level stations in supporting tsunami warnings **(b)**

The progress of new developments of Indonesia Coastal Seal Level Monitoring Network has been achieving in total 90 stations with the following summary, namely:

- **First Order Sea Level Network** consisting of 57 out 80 planned real time stations supporting both IOTWS and InaTEWS. This is designed to use multiple-use platforms and various communication tools for back up as such as GTS, BGAN, PASTI (Indonesian Satellite-based Communication provider), VSAT and GSM data.
- **Second Order Sea Level Network** consisting of 25 float gauge digital stations using GSM data connections. This order is mainly distributed in the internal water of Indonesia which is relatively not prone to tsunami threats.
- **Third Order Sea Level Network** consisting of 8 operational analogue (graphical chart) stations. Since the cost for operational is higher than that of digital, this type will be gradually replaced with digital in the next few years.

Efforts to adopt local arts and culture impression on the outlook of the tidal huts have been made allowing participations from the local people to keep the stations from destructions and vandalism, as shown in Figure 3(a).

The UNESCO Jakarta under JTIC programme has generously provided a poster explaining to public living in tsunami at risk about the importance of sea level stations in supporting tsunami warnings, as shown in Figure 3(b).

*Tide Gauge Technology*

The stations supporting tsunami warnings consist of multiple-use platforms using higher data sampling rate which provide the range, durability and sampling capability to monitor tsunami signals including stability and accuracy to measure long term sea level trend and its variations. The stations dedicated to non-hazard monitoring are adequately equipped with single type of sensor with float gauge or pressure.

The sensor basic configuration for natural hazard monitoring capability should use combination of the three different types of sensors consisting of pressure, float gauge and radar. The three types of sensors should be capable of operating independently and have a 0.5 millimetre height resolution over a range of 0 to 15 meters. This will ensure to provide back-up and redundancy, continuous observations during extreme water levels and long term satisfactory performance for at least 12 months. The common specification of three types level sensors are as follows:

- **Radar gauge tidal recording** with 10 second data sampling rate enabling monitoring of sea level with high time resolution recording. This should be a primary sensor in supporting the warning system by having the advantage of ease of operation and maintenance since a direct contact to the sea water is at the very minimum level and the stilling well is no longer necessary

- **Pressure gauge digital recording** with one minute data sampling rate and high capability in detecting quick changes of water pressure caused by tsunami and this is also adequate to fill any short gaps which may occur in the radar type. The installations of this type have been showing more widespread use including in the future plan of network densification in particular for practical applications.
- **Float gauge digital recording** with one minute data sampling rate, allowing real time monitoring that can cover extreme sea level changes for relatively short time durations. In some current areas it is found not possible to install a well in the installations request a considerable amount of costly engineering work.

Both of the GITEWS and Indonesia support stations are equipped with sensors manufactured by the same company while those supported by NOAA/UHLSC use those of different manufacturers and then customised them in one system using data loggers supporting the GTS transmission. It is found that some problems related to firm ware could not be fixed on site and this should only be handled by manufacturer for commercial reasons. Therefore, number of spare units of data loggers and sensors should be available allowing to a quick recovery and subsequently this will keep an optimal data recording.

Communication is one of the main bottlenecks in the development of an early warning system in terms of maintenance and airtime cost. The operational demands driving the data communications system requirements are: i) Reliable real time data streaming (every minute), ii) system stability, iii) system versatility and two-way communication capability, iv) ability to expand usage, and iv) affordable cost. The demands would only be fulfilled by using different communication channels such as VSAT, GTS/Meteosat, BGAN, and GSM data, which are all running independently, if possible. This provides a more robust system to ensure that the system is able to receive data during emergencies. The use of satellite based data communication with solar cell for a self-supporting power supply should be the most reliable option for the vast archipelagic region.

In a normal situation when the required data transmission rate is not that high, use of Meteosat or Japanese geostationary satellites and GTS provides the most reliable option for data transmission. This approach allows for data transmissions every 15 minutes, the satellite link modem consumes low energy, and the transmission air time is free access due to the generous support of WMO. However, Indonesia is located in the potential tsunami risk front lines where the time needed for tsunami waves to reach the nearest coastline is 15 minutes on average. This communications option is not meant for facilitating an extreme mode with faster data transmission requirements, such as one minute transmission rates when a tsunami occurs. This high transmission rate often requires that the system trigger the stations, located close to the tsunami source, to continuously transmit data in the event of a major earthquake. This allows the experts on duty at the Indonesia Tsunami Early Warning Centre to make a decision to evacuate or not to evacuate.

Problem of providing a sufficient power supply is mostly encountered in high rate data transmission using satellite unlike that of using GSM/GPRS of which range of distance for transmission is shorter compare to the former. A worse condition will occur when orientation of the antenna is not correctly pointing to the assigned satellite. Several types of satellite communication used namely GTS; Inmarsat/BGAN, Iridium and Indonesia Satellite PASTI. The 15 minute interval data transmission with GTS is found relatively very stable and reliable as indicated mostly over 90% data record availability. The one minute data transmission interval capability with BGAN is added later in the system fulfilling a higher rate transmission for coastal zone of Indonesia classified tsunami at risk. It is found that the performance is reliable though modems of some stations should need to be repaired. In fact, the transmission is not set to a constant one minute transmission rate but it is set to capability of one minute transmission which is triggered during a tsunami mode.

The use of VSAT in the Indonesian support stations is the high priority option since this is the best solution at present for real time data communication. It is becoming more cost effective and reliable for a vast area such as Indonesia with an archipelagic condition where mostly very minimal terrestrial communication infrastructure is available. The VSAT instrumentation should have a high standard technical specification, such as all connectors should be hermetically sealed to protect the electronics from water, dust and particularly high salinity in outdoor and marine environments. Problem of power supply is still unavoidable due to the consumption of power is higher compare with other communication platforms.

In the year 2009, it has been initiated to use the Iridium communication as it has been used by the Agency for the Assessment and Application of Technology (BPPT) in the development of Indonesia support buoys.

The use of the terrestrial based transmission using a wireless communication should be a better option since the area coverage of GSM/GPRS facilitated by numbers of providers is significantly improving in the country. Although it is susceptible to a local earthquake but it is found that providers show more reliable capacity for a quick recovery. Again, the density of station distribution could compensate failure of the neighbouring stations allowing monitoring the propagation of tsunami in the region at risk. As some GSM/GPRS providers are now facilitating a monthly based subscription with a more affordable cost, BAKOSURTANAL has initiated to start a real time transmission at some stations and this will be expanded covering the whole network if the signal coverage is available.

The stations mostly rely on batteries charged by solar panels for power since local power is not an appropriate option at many remote areas and more importantly that local power is vulnerable to failure in the event of earthquake or tsunami run off.

However, despite that high intensity of sun shine but both high humidity and cloud are factors greatly reducing an optimal capacity of solar power in the equatorial region. Considering the factors, several batteries, mostly those of maintenance free, should be available more than required for back up enabling to maintain power in a worse condition where sun shine availability resulting from high rainfall and cloud is not sufficient to recharge the batteries for at least four days.

Optimal sea level observations still require local operators to routinely check and maintain the station. BAKOSURTANAL assigns in total 120 local operators, recruited from the local port authority office where the stations are located. The operators play a very significant role in maintaining the stations to ensure the full operation of the instruments. This is because the recording instruments used in the network still require a regular maintenance and more important, the stations are mostly located in busy ports which are prone to damage by traffic in the harbour and vandalism. A minimum weekly monitoring contact carried out by a staff on duty in BAKOSURTANAL office to the operators. It is now possible since most of the operators could afford to have mobile phones unlike in the past when contact with operators were difficult since contact can only be done with fixed line and some with letters. Training workshops for improving the operator's skill on station maintenance have been conducted regularly. The results of the regular monitoring and training have been encouraging, as indicated by a significant improvement in data quality and data return from an average of 60 to 95%.

## GPS Technology

The first initiative to incorporate continuous GPS measurements in the sea level monitoring system in Indonesia carried out under the GITEWS programme. This is a significant improvement for both determination of geocentric position of the stations and separation of thermal expansion from the sea level variation records. Considering the locations of the coastal stations are mostly in harbour with geological formation of alluvial sediments, the variations are partly caused by ground layer compaction and subsidence. The high accuracy of height derived GPS time series is also significant to show indication of instability occurred with the jetty piers of which this could also affect the sea level records.

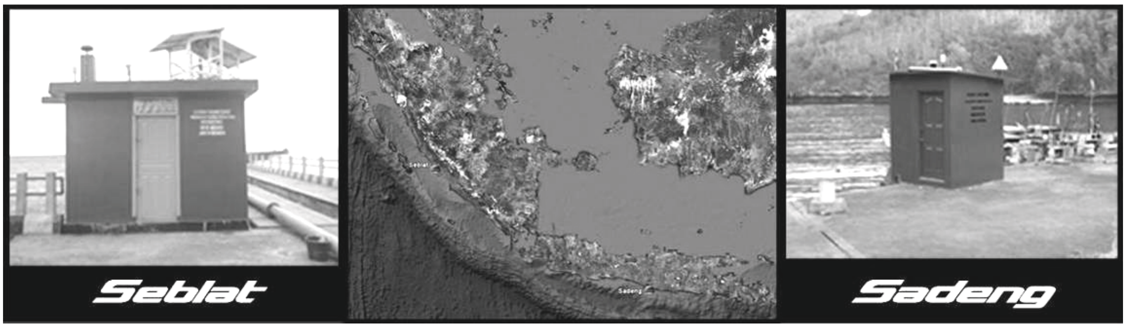


Figure 4. The tidal huts with GPS antenna on top located in Seblat (Sumatra) and Sadeng (Java).

Stations supported under the GITEWS program are all equipped with geodetic type GPS receivers together with ground meteorological sensors enabling for the computation of more high accurate atmospheric corrections required for the determination of precise height component. The additional sensor is also useful for other applications as such as GPS meteorology. In term of tsunami warnings, the station with atmospheric measurement capabilities is also of great importance to ensure that the extreme sea level change indicated during the tsunami alert mode is not caused by a positive surge and vice versa.

Table 1. The existing and planned continuous GPS observations at the sea level monitoring stations. The sea level data is free accessible from the UNESCO/IOC website.

| No | Tide Station | LAT | LONG | GPS Availability | Data Communication |
|---|---|---|---|---|---|
| 1 | Ambon | -3.683 | 128.183 | Planned | GTS |
| 2 | Benoa | -8.767 | 115.217 | Planned | GTS |
| 3 | Bitung | 1.450 | 125.200 | Planned | GTS |
| 4 | Cilacap | -7.750 | 109.000 | Planned | GTS |
| 5 | Enggano | -5.346 | 102.271 | Yes | GTS & BGAN |
| 6 | Lembar | -8.733 | 116.083 | Planned | GTS |
| 7 | Meulaboh | 4.127 | 96.130 | Yes | GTS & BGAN |
| 8 | Padang | -0.950 | 100.367 | Planned | GTS |
| 9 | prigi | -8.283 | 111.733 | Planned | GTS |
| 10 | Sabang | 5.833 | 95.333 | Planned | GTS |
| 11 | Sadeng | -8.300 | 110.567 | Yes | GTS & BGAN |
| 12 | Saumlaki | -7.984 | 131.291 | Planned | GTS |
| 13 | Seblat | -3.222 | 101.602 | Yes | GTS & BGAN |
| 14 | Sibolga | 1.750 | 98.767 | Planned | GTS |
| 15 | Tanjung Lesung | -6.478 | 105.658 | Yes | GTS & BGAN |
| 16 | Teluk Dalam | -0.553 | 97.822 | Yes | GTS & BGAN |
| 17 | Waikelo | -9.390 | 119.219 | Yes | GTS & BGAN |

More importantly, the coastal gauge GPS stations are also of importance to provide formation of baselines used for ambiguity resolutions to the nearest GPS buoys located offshore. The data is transmitted hourly using Inmarsat/BGAN to BAKOSURTANAL and German Research Centre for Geosciences (GFZ) servers and the system has a capacity to trigger the transmission in higher rate during the tsunami mode.  Figure 4 shows the tidal hut located in Sadeng (Western tip of Java) and Seblat (Western coast of Sumatra) with the GPS antennas at the roof top.

Another initiative will be carried out at several of the ten existing coastal sea level stations supported by both NOAA/UHSLC and UNESCO.  The installation is planned to start by early May 2009.  Table 1 shows the existing and planned continuous GPS observations at the sea level monitoring stations supported under GITEWS, IOC, and NOAA/UHSLC.  In total there will be at least 20 continuous GPS capable sea level stations in the Sea Level Monitoring Network of Indonesia.

### Data Availability

The percentage of data record per year is improving greatly after the era of digital sensors together with reliable communication tools enabling remote monitoring of the sensor performances.  The availability of mobile phone owned by most operators nowadays also enables to facilitate troubleshooting and quick recovery by the local operators via a remote help by the engineer on duty at the BAKOSURTANAL office. This is hardly possible to carry out in the past.

In supporting the tsunami warnings, the real time sea level data from the BAKOSURTANAL Sea Level Centre's computer server should flow continuously to that of the National Tsunami Warning Centre (NTWC) via a dedicated internet connection.  The data streaming is displayed on web-based and this be incorporated to the Decision Support System (DSS) in NTWC by the end of year 2009.  The web-based display of the real time sea level transmitted to the Warning Centre is shown in Figure 6.

Indonesia with supports of the partners has also been contributing a free access real time data from 17 stations with the list of station as shown in Table 1.  The data is displayed in the UNESCO/IOC website with the address as [http://www.ioc-sealevelmonitoring.org/](http://www.ioc-sealevelmonitoring.org/).  The data is made available in accordance with the IOC Oceanographic Data Exchange Policy as adopted by the 22nd session of IOC Assembly in Resolution 6.

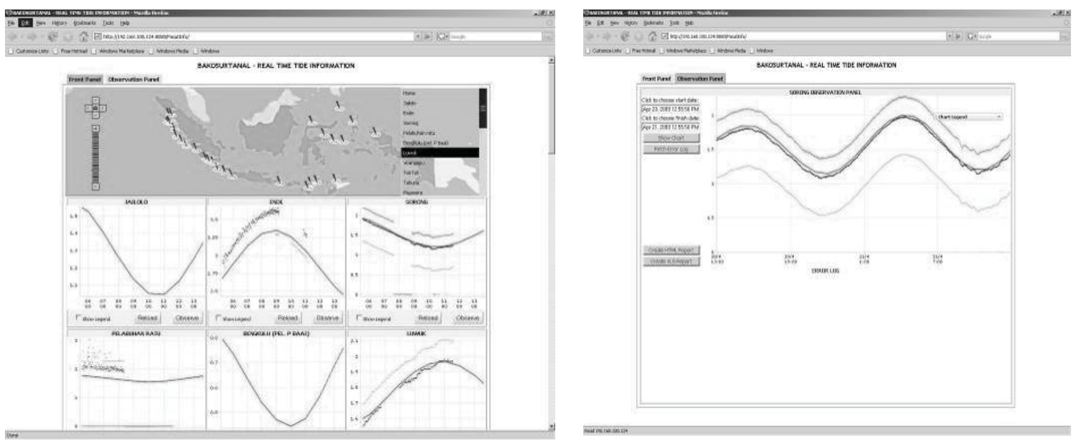

Figure 5. Real time sea level data flow from the Indonesia sea level centre (BAKOSURTANAL) to the Tsunami Warning Centre (BMKG) transmitted through a dedicated line.

## Conclusion

The development of the Indonesian Real Time Coastal Sea Level Network is progressing significantly in support for both InaTEWS and IOTWS. There are 57 of 80 planned stations already in place and the total number of stations in the network consists of 90, as of May 2009. Ongoing attempts to complete the deployment of the remaining stations and the data display including a quality control capability which have been pursued.

The extensive network uses different communication channels such as VSAT, Meteosat/GTS, BGAN, PASTI and GSM data, which are all running independently, if possible. As Indonesia coastlines are close to tsunamigenic areas, the communication system should be capable of operating in an extreme tsunami mode where data transmission fast rate from the stations is required.

The significant addition of new real time sea level stations is a great opportunity to improve an operational ocean observing system covering the whole Indonesia region with a better distribution.

The deployment of GPS receivers and meteorological sensors at sea level stations will greatly contributing to both the high precision vertical control supporting tsunami and climate research.

## Acknowledgements

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# Present Status of Indonesian Sea Level Monitoring Network

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## Introduction

Since 1984, National Coordinating Agency for Surveys and Mapping of Indonesia (BAKOSURTANAL) has been developing and operating the National Permanent Sea Level Monitoring Network. Initially, the equipments were developed using graphic/analog system and it is intended to support the determination of vertical datum for surveying and mapping purposes, navigation and coastal management that do not require data in real time. The number of tide gauges is increased from year to year in line with the increasing needs of reference vertical datum for levelling networks to support surveying and mapping activities. The early implementation was started by BAKOSURTANAL with 8 analogue stations. The number of new stations increased by about 2 per year, except for a significant increase of 25 digital stations in 1998 to support the bathymetric mapping of the exclusive economic zone and sea line passages in Indonesian waters. The Indonesian Sea Level Monitoring Network before the 2004 Sumatra Tsunami consisted of 60 stations, of which 35 stations were using analogue graphical chart recorders and 25 stations were using digital recorders with Public Switch Telephone Node (PSTN) data connection.

Figure 1. National Sea Level Monitoring Network of Indonesia, operational before the 2004 Sumatra Tsunami (Manurung, 2007)

The demand for permanent sea level monitoring has been increasing after the tragedy of the 2004 Sumatra Tsunami. The tsunami was the most catastrophic in recorded history, causing great loss of lives with more than 120,000 fatalities in Indonesia and thousands more over 9 countries in Asia. If an early warning system were available in the region, many lives could have been saved.

Realizing the great loss in the tragedy and in support of the early warning system in Indian Ocean initiated by the United Nations, Indonesia has allocated national funding for establishing the Indonesian Tsunami Early Warning System (InaTEWS). As sea level monitoring is an important component of TEWS with its role for confirming the arrival time and height of the waves. Indonesia in joint efforts with international partners under the coordination of IOC/UNESCO has established real or near real time sea level monitoring stations.

Current status (April 2011), BAKOSURTANAL manage 113 stations comprising:

- 10 tide gauges in cooperation with Germany
- 10 tide gauges in cooperation with IOC/UHSLC
- 93 tide gauges purely financed by Indonesian Government

## 2. Present Status of BAKOSURTANAL Sea Level Monitoring

The 26th December 2004 Sumatra Tsunami, which devastated the coastal area of Aceh and the surrounding countries in the Indian Ocean, can be claimed as a turning point in the development of sea level monitoring in Indonesia. Since then, the appreciation of the importance of sea level monitoring has been increasing, resulting in funding by the Indonesian Government for 2006 - 2008 fiscal years for modernizing the network with new instrumentation and real time communication tools. In fiscal year 2010, BAKOSURTANAL got an additional funding to built 20 stations, and further three tide gauges are installed on March 2011.

The current status (April 2011), BAKOSURTANAL maintain in total 93 tide gauges purely finance by Indonesian Government.

### *New 20 Tide Gauges in 2010*

Grand design of Indonesia Tsunami Early Warning System (InaTEWS) is to build 80 tide gauges in real time in Indonesian waters. Until the end of 2009, BAKOSURTANAL maintains 60 real time tide gauges, therefore BAKOSURTANAL for Expenditure Budget Amendment (APBN-P) in 2010 proposed to build new 20 real time tide gauges to complete the grand design. The works are completed at the end of 2010 and operate at begin of 2011. The distribution of the new 20 tide gauges is shown in figure 2.


Figure 2. Distribution of the new 20 tide gauges

The purposes of the new tide gauge installations are as follows:

- To complete the grand design InaTEWS for supporting Indonesia Tsunami Early Warning System (InaTEWS),
- To determine mean sea level, Lowest Astronomical Tide and Highest Water Level for Surveys and Mapping,
- To monitor the effect of Global Climate Changes into Indonesian waters,
- As fundamental data for the development of National Spatial Data Infrastructure (NSDI)

To provide back-up and redundancy, each field unit consists of three types of water level sensors capable of providing continuous observations during extreme water levels and long term satisfactory performance for at least 12 months. The three types of level sensors are as follows:

- Float gauge digital recording with one minute data sampling rate, allowing real time monitoring that can cover extreme sea level changes for relatively short time durations.
- Pressure gauge digital recording with one minute data sampling rate and high capability in detecting quick changes of water pressure caused by tsunami.
- Radar gauge tidal recording with 10 second data sampling rate enabling monitoring of sea level with high time resolution recording.
- The three types of sensors should be capable of operating independently and have a 0.5 millimeter height resolution over a range of 0 to 15 meters.

*New 3 Tide Gauges in 2011*

Besides the construction of 20 new tide gauges financed through Expenditure Budget Amendment in fiscal year 2010, BAKOSURTANAL build also 4 buildings for tidal stations, one building for German-Indonesia tide gauge in Rote, and the other three are in Tuban, Jambi and Dumai. The last three stations are not dedicated for InaTEWS but for other purposes like Monitoring Sea Level Rise, and Surveys/Mapping. The equipments are installed on March 2011. Figure 3 shows the distribution of the Stations.


Figure 3. Distribution of new tide gauges installed on March 2011

*Pushing Raw Data to Decision Support System of InaTEWS*

BAKOSURTANAL provides Web-Display to Decision Support System of InaTEWS. The system can display the raw data from BAKOSURTANAL'S Tidal Database in real time. In addition the raw numerical data from 24 tide gauges are directly pushed into DSS of InaTEWS, i.e.:

1. Bengkulu
2. Bintan
3. Binuangen
4. Ende
5. Gunung Sitoli
6. Jailolo
7. Kota Jawa
8. Krui
9. Maumere
10. Nusa Penida
11. Pamempeuk
12. Pelabuhan Ratu
13. Pulau Banyak
14. Sanana
15. Singkil
16. Tahuna
17. Tua Pejat
18. Waingapu
19. Sikakap
20. Muara Sekabaluan
21. Kota Agung
22. Sarmi
23. Raja Ampat
24. Jayapura

**GITEWS Sea Level Monitoring**

German-Indonesia Tsunami Early Warning System (GITEWS) program supports 10 sea level stations. Each station consists of continuous GPS monitoring, a ground meteorological sensor and VSAT communication. In February 2006, Geoforschung Zentrum (GFZ) carried out site surveys to plan the construction of tide gauges. The first installation is in Sadeng Gunungkidul, Yogyakarta that is equipped with sea level, GPS and ground meteorological sensors, installed on September 2006. At present, all of the 10 planned tide gauges are installed. The last construction is in Rote installed on

February 2011. Data communication for tide gauge in Sadeng is facilitated with VSAT, on the other tide gauges are with Meteosat, BGAN and PASTI, enabling data stream in real time mode to InaTEWS. All of the GITEWS raw numerical data are pushed to DSS of InaTEWS.

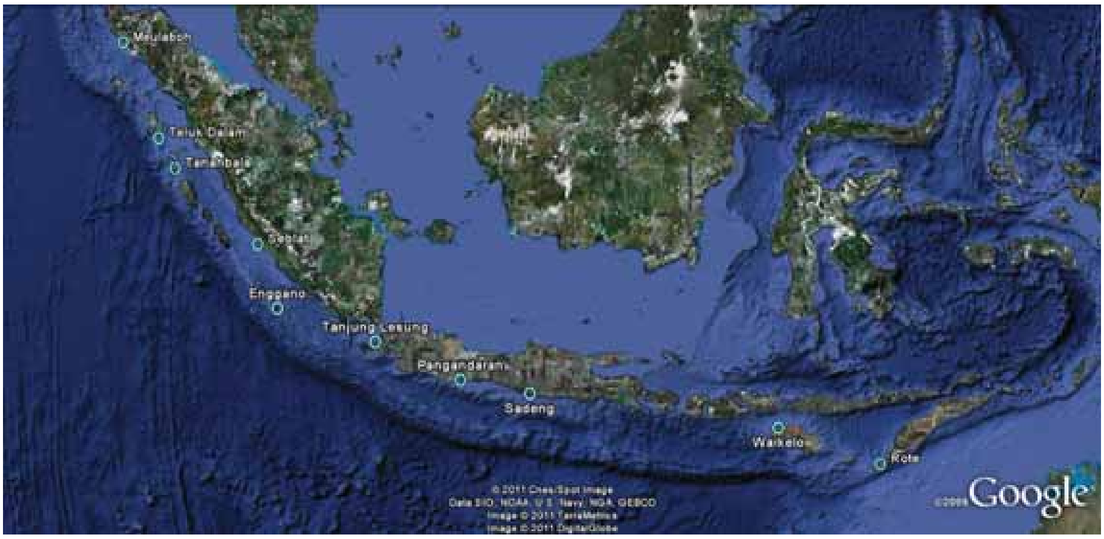


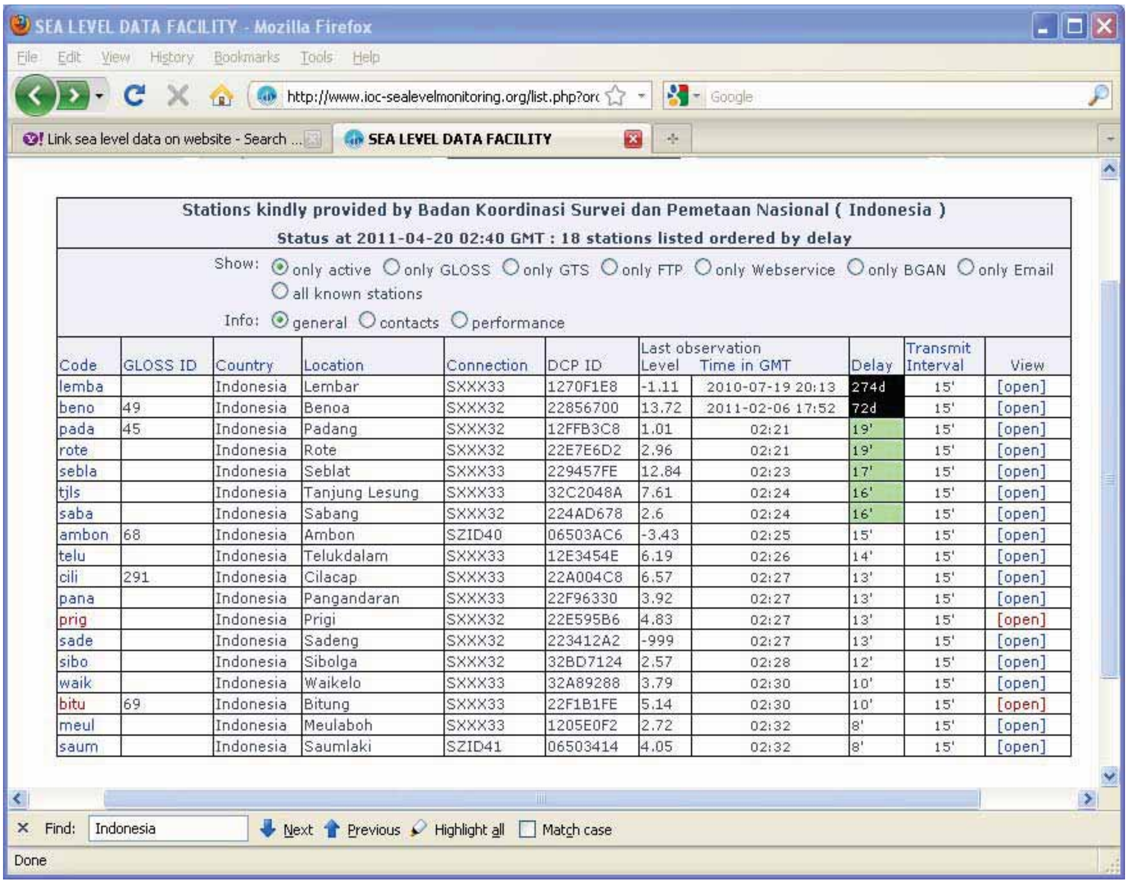

Figure 4. Distribution of GITEWS Sea Level Monitoring

**USA-Indonesia Sea Level Monitoring Networks**

BAKOSURTANAL and the UHSLC, with financial support from the IOC and USAID, have installed 7 real time tide gauges facing to Indian Ocean and 3 tide gauges around Banda Sea. The first installation was built in April 2005 in Sibolga on the western coast of North Sumatra Province. The next installation was carried out in Sabang and Padang on December 2005. The installations were continued in January 2006 at Benoa (Bali) and further in early February 2007 the tide gauges in Cilacap and Prigi were installed. Four additional stations, i.e. Lembar, Bitung, Ambon and Saumlaki were installed in 2008. All the stations are equipped for 15 minute data transmission using GTS/Meteosat. Later, BGAN communication capability will be added to the stations. The data can be accessed via http://www.ioc-sealevelmonitoring.org/

InaTEWS doesn't receive the raw data from these tide gauges in real time, therefore the use of these data for supporting Tsunami Early Warning is carried out manually through the website of IOC's Sea Level Monitoring. In the future, it could be better if the raw data can be pushed to InaTEWS.

Recent status on April 2011, the tide gauges in Benoa, Lembar and Ambon are defect and will be repaired on May 2011.




Stations kindly provided by Badan Koordinasi Survei dan Pemetaan Nasional ( Indonesia )

Status at 2011-04-20 02:40 GMT : 18 stations listed ordered by delay

Show: only active, only GLOSS, only GTS, only FTP, only Webservice, only BGAN, only Email, all known stations

Info: general, contacts, performance

| Code | GLOSS ID | Country | Location | Connection | DCP ID | Last observation Level | Time in GMT | Delay | Transmit Interval | View |
|---|---|---|---|---|---|---|---|---|---|---|
| lemba | | Indonesia | Lembar | SXXX33 | 1270F1E8 | -1.11 | 2010-07-19 20:13 | 274d | 15' | [open] |
| beno | 49 | Indonesia | Benoa | SXXX32 | 22856700 | 13.72 | 2011-02-06 17:52 | 72d | 15' | [open] |
| pada | 45 | Indonesia | Padang | SXXX32 | 12FFB3C8 | 1.01 | 02:21 | 19' | 15' | [open] |
| rote | | Indonesia | Rote | SXXX32 | 22E7E6D2 | 2.96 | 02:21 | 19' | 15' | [open] |
| sebla | | Indonesia | Seblat | SXXX33 | 229457FE | 12.84 | 02:23 | 17' | 15' | [open] |
| tjls | | Indonesia | Tanjung Lesung | SXXX33 | 32C2048A | 7.61 | 02:24 | 16' | 15' | [open] |
| saba | | Indonesia | Sabang | SXXX32 | 224AD678 | 2.6 | 02:24 | 16' | 15' | [open] |
| ambon | 68 | Indonesia | Ambon | SZID40 | 06503AC6 | -3.43 | 02:25 | 15' | 15' | [open] |
| telu | | Indonesia | Telukdalam | SXXX33 | 12E3454E | 6.19 | 02:26 | 14' | 15' | [open] |
| cili | 291 | Indonesia | Cilacap | SXXX33 | 22A004C8 | 6.57 | 02:27 | 13' | 15' | [open] |
| pana | | Indonesia | Pangandaran | SXXX33 | 22F96330 | 3.92 | 02:27 | 13' | 15' | [open] |
| prig | | Indonesia | Prigi | SXXX32 | 22E595B6 | 4.83 | 02:27 | 13' | 15' | [open] |
| sade | | Indonesia | Sadeng | SXXX32 | 223412A2 | -999 | 02:27 | 13' | 15' | [open] |
| sibo | | Indonesia | Sibolga | SXXX32 | 32BD7124 | 2.57 | 02:28 | 12' | 15' | [open] |
| waik | | Indonesia | Waikelo | SXXX33 | 32A89288 | 3.79 | 02:30 | 10' | 15' | [open] |
| bitu | 69 | Indonesia | Bitung | SXXX33 | 22F1B1FE | 5.14 | 02:30 | 10' | 15' | [open] |
| meul | | Indonesia | Meulaboh | SXXX33 | 1205E0F2 | 2.72 | 02:32 | 8' | 15' | [open] |
| saum | | Indonesia | Saumlaki | SZID41 | 06503414 | 4.05 | 02:32 | 8' | 15' | [open] |

Figure 5. Website to access USA-Indonesia Sea Level Data in near real time

## Summary

The progress on development of the Indonesian Indonesia Sea Level Network is completed in total 113 stations where 6 tide gauges are still analog system. The purposes are not only for Tsunami Early Warning, but also for other purposes. Up to 2014 it is not planned to build some new stations, so the activities will be focused to maintain the tide gauges. At this moment, raw numerical data from 34 tide gauges are pushed to Decision Support System in BMKG for supporting both InaTEWS and IOTWS.

Table 1. National Sea Level Monitoring Network up to April 2011

| Source | <2005 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | Total |
|---|---|---|---|---|---|---|---|---|---|
| USA/NOAA/UHSLC | - | - | - | 3 | 4 | - | - | - | 7 |
| IOC/Unesco | - | 2 | 1 | - | - | - | - | - | 3 |
| Germany | - | - | 2 | 2 | 3 | 1 | 1 | 1 | 10 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Indonesia | 53 | - | 2 | 14 | - | 1 | 20 | 3 | 93 |
| Total | 53 | 2 | 5 | 19 | 7 | 2 | 21 | 4 | **113** |

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# The Airborne Gravity Survey for Regional Geoid Mapping

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The earth gravity measurements can be conducted by land, marine and air borne surveys or using space borne mode. Both land and marine surveys give 'in situ' gravity values but very time consuming and difficult to perform in rough terrain or shallow water (coastal areas). On the other hand the space borne mode, i.e., measuring the earth gravity from satellite gives a quick globally dataset but the high resolution of the gravity field is attenuated due to high orbit. The airborne gravity survey which measures the gravity from an aircraft offers the best technique to cover inaccessible areas such as mountainous and coastal region in a short time and provides a seamless dataset with better resolution than the space borne technique or accuracy comparable to land survey.

The implementation of the satellite based height system requires a high precision geoid. To create such geoid, a good coverage and quality of gravity data is needed. The main constraint to produce the precise geoid for this country is the deficiency of gravity data, especially in mountainous and coastal areas where access for terrestrial measurements are limited.

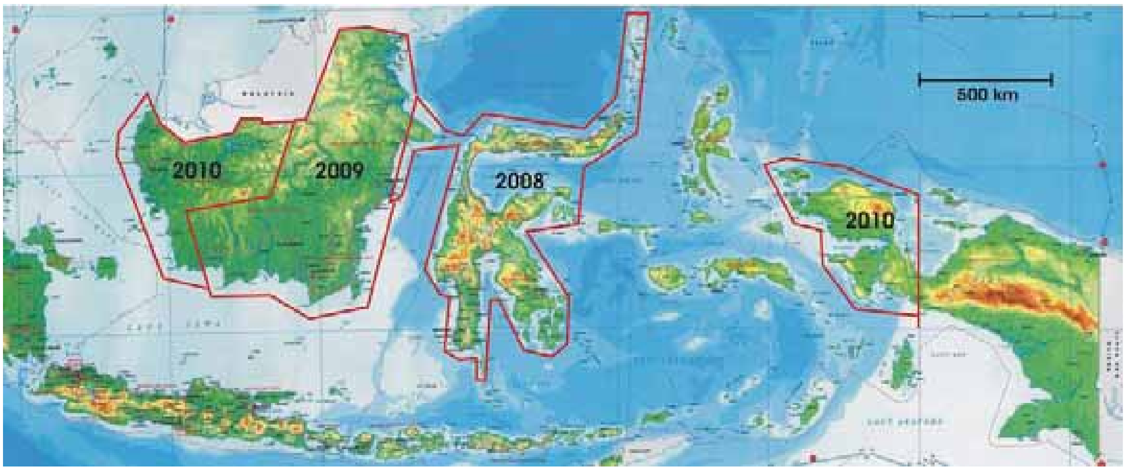


Figure 1. The 2008-2010 Airborne Gravity Survey Areas

BAKOSURTANAL in co-operation with the Geodynamics Division, DTU Space, Denmark Technical University, undertakes a joint campaign for regional airborne gravity in Indonesia. The aim of this cooperation is to provide the good coverage of gravity data for geoid mapping in Indonesia as well as to contribute for the improvement of the global Earth Gravity Model (EGM).

The main objective of this project is to undertake an airborne gravity survey over parts of Indonesia to provide data for precise geoid model for the area and to provide data for the Earth Geo potential Models (EGM'S). To integrate the collected airborne data with BAKOSURTANAL existing surface data and to use the terrain elevation model from SRTM in order to compile the best possible geoid for the area.

The joint airborne gravity surveys have been carried out since 2008 covering major islands of Sulawesi, Kalimantan and Papua. The total numbers of about 510 flights hours have been completed during 2008 – 2010 field work, measuring 145,000 Km lines flown at 10 nautical miles track intervals. It is planned to continue the surveys to cover the rest of the areas where gravity data is unavailable.


Figure 2. BAKOS chairman, Dr. Asep Karsidi in front of the survey aircraft

**Airborne gravity measurements**

The metodology of the surveys are :

a. Gravity measurements will be made with a modified LaCosta & Romberg airborne/seaborne gravimeter (s/n S-99 or S-38), augmented with inertial component. A highly damped, zero-length spring type gravity sensor mounted on a stabilized platform with the following specifications:
   - Range : 12,000 mGal
   - Drift : 3.0 mGal per month or less
   - Operating temperature : 0° C to 40° C
   - Power requirements : less than 300 Watt
   - Accuracy : better than 2 mGal

b. The instrument will be installed in a locally chartered aircraft Cessna 208B Grand Caravan and DASH 6 or similar aircraft has proven to be a reliable platform for gravity measurements with the following conditions:
   i). The aircraft must have an auto-pilot system for smooth navigation.
   ii). The aircraft should be small size, to get good phugoid motion characteristics and high stability at low speeds.
   iii). Performance:

- Cruise speed : less than 160 knot
- Range : more than 1,300 km
- Service ceiling : more than 5,000 m
- Payload with full fuel : more than 400 kg

iv). Accommodation : 2 (two) flight crews and 3 (three) passengers

v). Access to aircraft power : 28 Volt DC or 110/220 Volt AC.

c. The resulting data will provide high-accuracy gravity data given in an international reference frame (called: IGSN71 and WGS-84). The area will be surveyed along flight lines with a spacing of 10 nautical miles, at flight elevations adapted to local topography. Data will subsequently be downward continued to a common surface. The gravity data collected from these surveys shall be accurate to 2mGal internally at an along-track resolution of 6-8 km.

d. The Global Positioning System (GPS) are used for vertical and horizontal positioning control. Geodetic type GPS receivers are required both for installing in the aircraft and for GPS reference stations, with the following conditions:

i). Minimum 4 (four) GPS units must be used for measurements (two as rover in aircraft and two on ground for differential reduction). As an alternative, permanent GPS stations can be used as reference station for positioning.

ii). Tracking L1 C/A code, L1/L2 full-cycle carrier and fully operational during P-code encryption

iii). Accuracy for horizontal ± 20 cm + 1 ppm and for vertical ± 20 cm + 1 ppm.

**Overview Survey**

The activity of airborne gravity survey is carried out since 2008, with coverage area as follows:

*Year 2008*

| | |
|---|---|
| Area | : Sulawesi |
| Survey Period | : 21 September – 4 November |
| Number of Flights | : 36 |
| Airboorne Time (hours) | : 158 |
| Kilometers flown | : 44,000 |

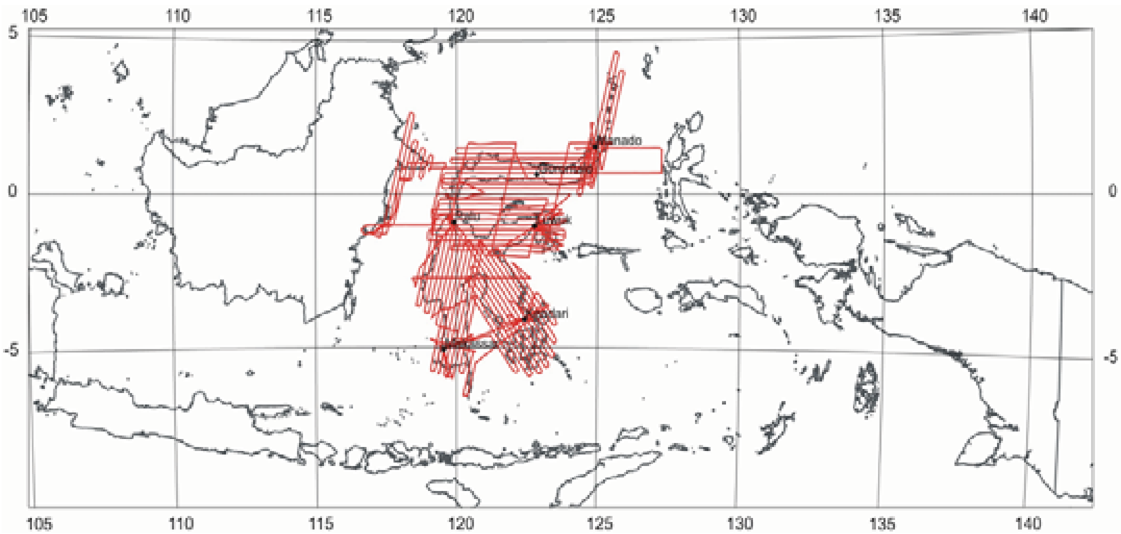


Figure 3. Airborne Gravity Survey Coverage for Year 2008

### *Year 2009*

| | |
|---|---|
| Area | : South and East Kalimantan |
| Survey Period | : 23 October – 26 November |
| Number of Flights | : 37 |
| Airboorne Time (hours) | : 162 |
| Kilometers flown | : 45,000 |

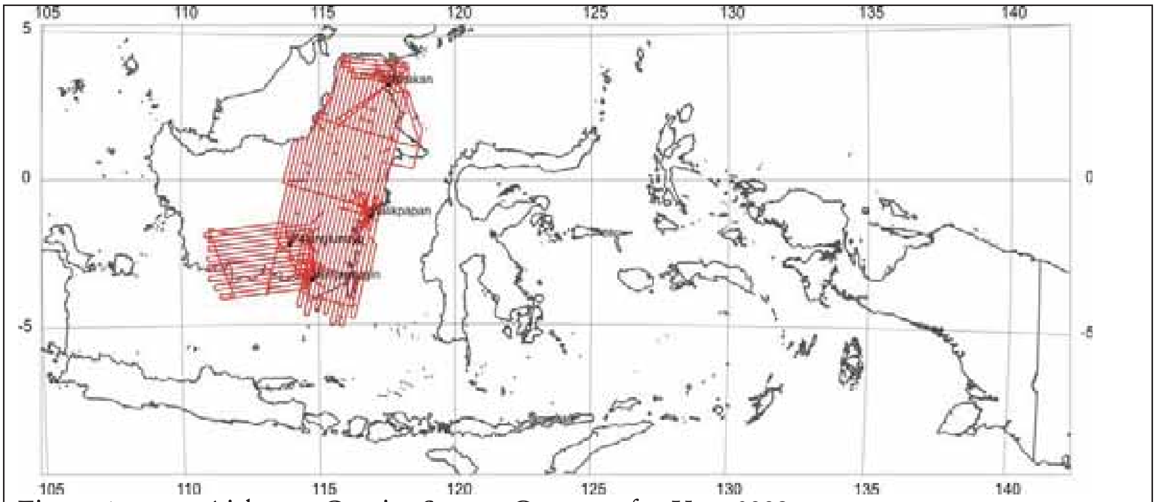


Figure 4. Airborne Gravity Survey Coverage for Year 2009

*Year 2010*

| | |
|---|---|
| Area | : Western Kalimantan and Western Papua |
| Survey Period | : 9 July – 26 August |
| Number of Flights | : 41 |
| Airboorne Time (hours) | : 190 |
| Kilometers flown | : 56,000 |

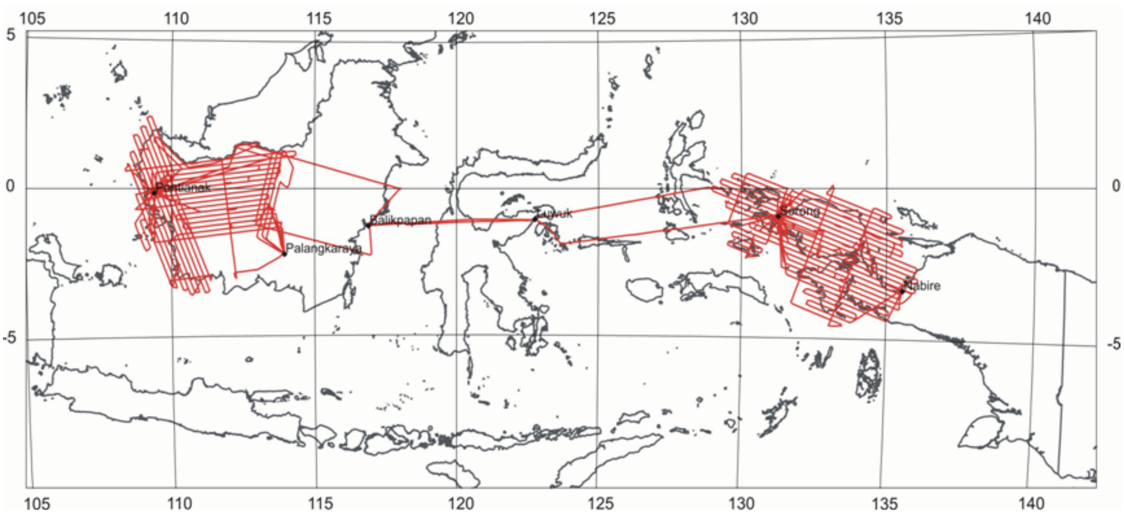


Figure 5. Airborne Gravity Survey Coverage for Year 2010

*Year 2011*

This year, airborne gravity survey is planned to cover the rest of wesrtern Papua as shown in Figure 6.

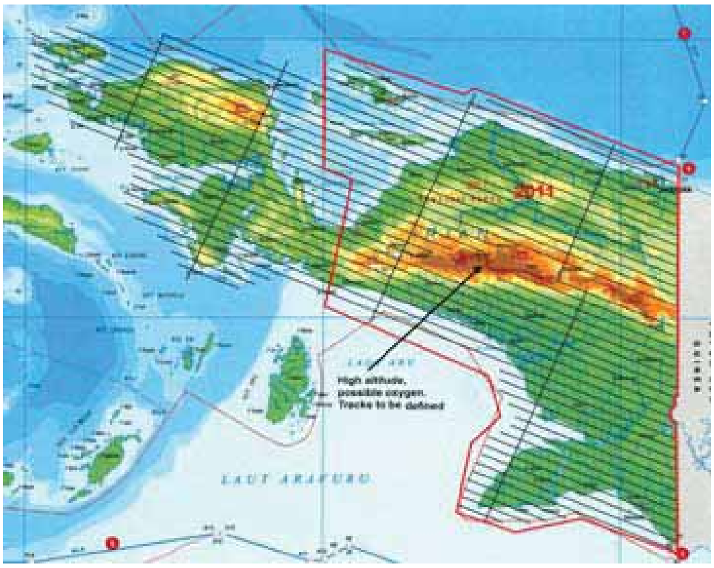


Figure 6. Airborne Gravity Survey Coverage for Year 2010

## Closing remarks

The airborne gravity survey conducted since year 2008 has yielded a set of GPS kinematics position and Free-air gravity anomaly data along the flight strips. This set of data then be gridded into 6' interval data. This preliminary result has need to be completed by GPS kinematics processing using the precise orbit and tying the gravity value into the reference (GBU). It will give the standard/absolute value of gravity data based on IGSN71 standard.

To build Geoid Map, the next activities should be done are:

- Data merging for water regime using DNSC08 model
- Upward continuation process for ground data
- Downward continuation process to surface for merged data
- Gravimetric geoid computation
- Quality control of geoid computation

The regional airborne gravity survey has been successfully completed over Sulawesi and Kalimantan islands while data collections over Papua need to be continued. The end goal for the activities is to establish a geoid model for the area that will meet the requirement for GNSS surveying. Initial assessment of the accuracy of the airborne gravity data indicates a noise level around 2.4 mGal which implies that a geoid accuracy of around 5 to 10 cm should be achievable for the area.

# Studying Land Subsidence in Semarang (Indonesia) Using Geodetic Methods

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## Summary

Semarang is the capital of Central Java province, located in the northern coast of Java island, Indonesia, with an area of about 374 $km^2$ and population of about 1.4 million. It has been reported for some time that locations in Semarang are subsiding at different rates. This subsidence is mainly due to natural consolidation of alluvial, coupled with excessive groundwater extraction and load of constructions. During the high tide periods, these subsiding areas used to experience flooding. Land subsidence phenomena in Semarang has been studied using several geodetic monitoring methods, i.e. levelling surveys, InSAR (interferometric Synthetic Aperture Radar) technique, GPS surveys, and microgravity surveys. Based on the levelling, InSAR and microgravity data, the subsidence with maximum rate of up to about 15 cm/year were observed during the period of 1979 up to 2006. Largest subsidence occurred at areas along the coast. This paper mainly describes and discusses the results obtained by GPS surveys that have been conducted in 2008 and 2009, and InSAR using ALOS/PALSAR images of 2007 and 2008. Paper is sum up with some concluding remarks.

*Key words*: Semarang, Land Subsidence, GPS , InSAR, Levelling, Microgravity

## Introduction

Semarang is the capital of Central Java province, located in the northern coast of Java island, Indonesia (see Figure 1). It is centred at the coordinates of about -6°58' (latitude) and +110°25' (longitude), and covers an area of about 37,366.8 hectares or 373.7 km2, with the population of about 1.43 million people in 2006 [Semarang City, 2009].

Topographically, Semarang consisted of two major landscapes, namely lowland INDONESIA and coastal area in the north and hilly area in the south. The northern part, where the city centre, harbour, airport and railway stations are located, is relatively flat with topographical slopes ranging between 0 and 2°, and altitude between 0 and 3.5 m; while the southern part have slopes up to 45° and altitude up to about 350 m above sea level.

The northern part has relatively higher population density and also has more industrial and business areas compared to the southern part. The land use of southern part is usually consisted of residential, office, retail, public use and open space areas.

Two rivers run through the city, one on the east side and another on the west which essentially dividing the city into three parts.

Geologically, Semarang has three main lithologies, namely, volcanic rock, sedimentary rock, and alluvial deposits. According to Sukhyar (2003), the basement of Semarang consists of Tertiary Claystone of the Kalibiuk Formation. Overlying this Formation is the Notopuro Formation which consists of Quaternary volcanic material. The two formations crop out in the southern part of the Semarang area. The northern part of the Semarang area is covered by Kali Garang deltaic alluvium up to a depth of 80 to 100 m in the coastal area. Aquifers are found at depths ranging from 30 to 80 m in this alluvium.

The northern part of Semarang is composed by very young alluvium with high compressibility. Several researches [Van Bemmelen, 1949; Marfai et.al. 2008] reported that the shoreline of Semarang progresses relatively quick toward the sea, namely about 2 km in 2.5 centuries or about 8 m/year. Therefore it can be expected that natural consolidation process still occurred until now, causing land subsidence in the northern part of Semarang.


Figure 1. Geographical location of Semarang.

Increases in the population and urban development in the area, has accelerated land subsidence through excessive groundwater extraction, and load of building and construction.

Land subsidence is not a new phenomenon for Semarang, which has experienced it since more than 100 years. The impact of land subsidence in Semarang can be seen in several forms, such as the wider expansion of (coastal) flooding areas, cracking of buildings and infrastructure, and increased inland sea water intrusion. It also badly influences the quality of living environment and life (e.g. health and sanitation condition) in the affected areas.

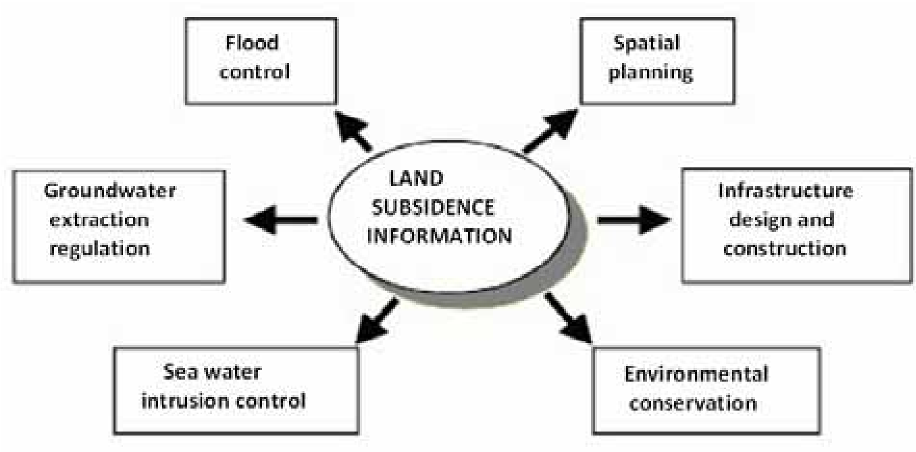



Figure 2. The importance of land subsidence information.

In the case of Semarang, comprehensive information on the characteristics of land subsidence is applicable to several important planning and mitigation efforts (see Figure 2), such as effective control of coastal flood and seawater intrusion, spatial-based groundwater extraction regulation, environmental conservation, design and construction of infrastructure, and spatial development planning. Considering the importance of land subsidence information for supporting development activities in the Semarang area, monitoring and studying the characteristics of this subsidence phenomenon becomes more valuable.

Some subsidence study has been conducted in Semarang city using several geodetic methods, such as Levelling [Sutanta et al., 2005; Marfai and King, 2007], GPS surveys, Gravity [Sarkowi et al., 2005; Fukuda et al., 2008] and InSAR [Murdohardono et al., 2009; BGR, 2009]. This paper describes and discusses the results obtained by GPS surveys that have been conducted in 2008 and 2009.

## Land Subsidence In Semarang

Land subsidence in Semarang has been widely reported and its impacts can be seen already in daily life. It can be seen in the forms of coastal flooding (it is called rob by the locals) that its coverage tends to enlarge by times. Figure 3 shows the severity of coastal flooding in coastal areas of Semarang. This frequent and severe rob not just deteriorate the function of building and infrastructures. It also badly influences the quality of living environment and life (e.g. health and sanitation condition) in the affected areas (see Figure 4). Cracking of buildings and infrastructure, and increased inland sea water intrusion, are also other impacts of land subsidence.

The economic losses caused by land subsidence in Semarang are enormous; since many buildings and infrastructures in the industrial zone of Semarang are severely affected by land subsidence and its collateral coastal flooding disasters.

Many houses, public utilities and a large number of populations are also exposed to this silent disaster. The correspondingmaintenance cost is increasing by year. Provincial government and communities are required to frequently raise ground surface for keeping roads and buildings dry. The living conditions of population affected by the land subsidence are in general decreasing. Based on the levelling surveys conducted by the Centre of Environmental Geology from 1999 to 2003 it was found that the relatively large subsidence were detected at around Semarang Harbor, Pondok Hasanuddin, Bandar Harjo and around Semarang Tawang Railway station, with the rates ranging from 1 to 17 cm/year [Tobing and Murdohardono, 2004; Murdohardono et al., 2007].

Figure 3. Coastal flooding in Semarang on mid April 2009; courtesy of Kompas photo, 2 July 2009.

Levelling derived subsidence zones in Semarang is given in Figure 5. The zoning is derived based on the height changes of 29 levelling points. It should be noted in this case that the zoning is highly generalized and maybe in accurate in detail. This Figure shows that the northern coastal areas of Semarang are subsiding with the rates larger than 8 cm/year. These areas are generally composed by swamp deposit of soft clay soil.

The estimation based on the PS InSAR technique also revealed that the areas close to shoreline have subsidence rates of more than 8 cm/year [Murdohardono et al., 2009; Kuehn et al., 2009], as shown in Figure 6. The contour lines in this Figure are based on the PS InSAR based velocity data derived from 28 ERS-2 and ENVISAT-ASAR radar scenes recorded between 27 November 2002 and 23 August 2006.

Figure 4. Examples of subsidence impacts in Semarang.

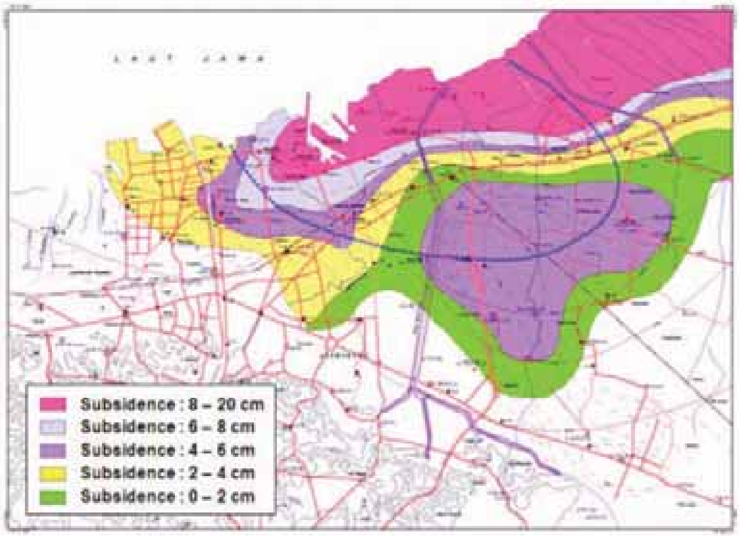



Figure 5. Levelling derived subsidence in Semarang in the period of 2000 to 2001; courtesy of Geological Agency Bandung, after [Murdahardono et al., 2007].

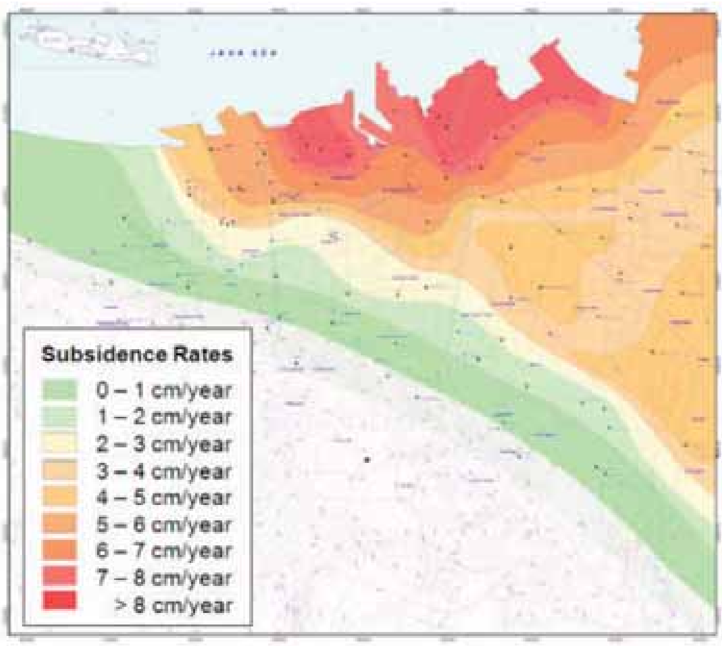



Figure 6. PS InSAR derived subsidence rates in Semarang; courtesy of Geological Agency Bandung, after [Murdahardono et al., 2009; Kuehn et al., 2009].

Subsidence in Semarang has also been studied using the microgravity method since 2002 by the research group from the Department of Geophysics of ITB. Based on this method, it is found that during September 2002 to November 2005, a maximum subsidence of about 48 cm occurred in the northern region of Semarang (see Figure 7). It corresponds to a maximum rate of about 15 cm/year.

Based on the results from Levelling, PS InSAR and Microgravity methods, shown in Figures 5 to 7, suggested that during the period between 2000 and 2006, subsidence process in Semarang is going on with the rates that can be up to about 15 cm/year. The higher subsidence rates always occur in the northern coastal areas and getting generally smaller to the south direction.

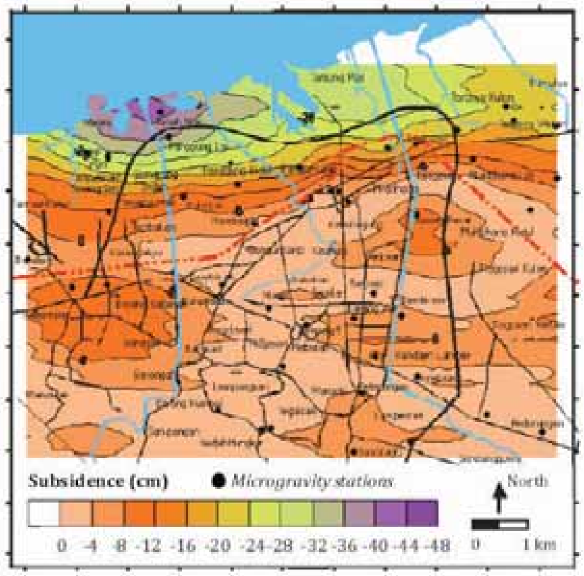



Figure 7. Microgravity derived subsidence in Semarang from Sept. 2002 to Nov. 2005; after [*Supriyadi,* 2008].

Since 2008, the Geodesy Research Division of ITB started to study land subsidence in Semarang by using GPS surveys and InSAR methods. The results are presented in the following sections.

**Land Subsidence Measured By GPS**

GPS (Global Positioning System) is a passive, all-weather, satellite-based navigation and positioning system, which is designed to provide precise three-dimensional position and velocity, as well as time information on a continuous worldwide basis [Wells et al., 1986; Hofmann-Wellenhof et al., 2007; Abidin, 2007].

With GPS survey method several monuments, which are placed on the ground covering the Bandung Basin and its surroundings, are accurately positioned relative to a certain reference (stable) point, using the GPS survey technique. The precise coordinates of the monuments are periodically determined using repeated GPS surveys at certain time intervals. By studying the characteristics and rate of change in the height components of the coordinates from survey to survey, the land subsidence characteristics can be derived.

For monitoring land subsidence, when the expected subsidence is of very small magnitude, the ideal positioning accuracy to be achieved is at the mm level. In order to achieve this level of accuracy the GPS static survey method based on dual-frequency carrier phase data processing should be implemented, with stringent measurement and data processing strategies [Abidin et al., 2002; Leick, 2004].

GPS surveys for studying land subsidence in Semarang have been conducted on 7-13 July 2008 and 5-11 June 2009. The number of observed points was 48 at first survey and 52 points at second survey. The location and distribution of the points are shown in Figure 8. Station SMG1 is the southernmost point in the network and considering its relatively stable location is used as the reference point for this subsidence study.

The GPS surveys exclusively used dual-frequency geodetic-type GPS receivers. The length of surveying sessions was in general between 9 to 11 hours. The data were collected with a 30 second interval using an elevation mask of 150. The surveys were mainly carried out by the staffs and students from the Department of Geodesy and Geomatics Engineering of ITB (Institute of Technology Bandung). Example of some GPS stations is shown in Figure 9.

The data were processed using the software Bernese 5.0 [Beutler etFigure 8. GPS network for studying al., 2007]. Since we are mostlyland subsidence in Semarang. interested in the relative heights with respect to a stable point, the radial processing mode was used instead of a network adjustment mode. In this case, the relative ellipsoidal heights of all stations are determined relative to SMG1 station. For data processing, a precise ephemeris was used instead of the broadcast ephemeris. The effects of tropospheric and ionospheric biases are mainly reduced by the differencing process and the use of dual-frequency observations. The residual tropospheric bias parameters for individual stations are estimated to further reduce the tropospheric effects. The algorithms forthe tropospheric parameter estimation can be found in

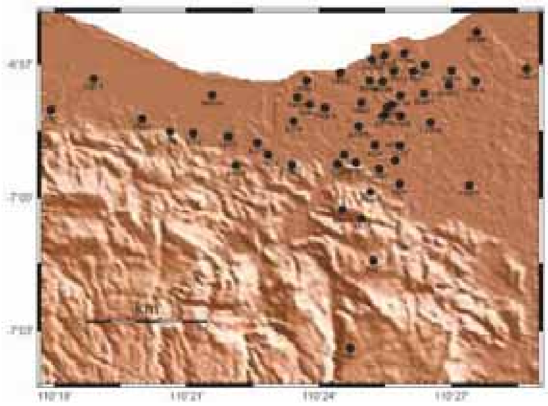


Figure 8. GPS network for studying land subsidence in Semarang.


Figure 9. Example of GPS stations for monitoring land subsidence in

Beutler et al. (2007). In processing baselines, most of the cycle ambiguities of the phase observations were successfully resolved.

The standard deviations of GPS - derived relative ellipsoidal heights from all surveys were in general better than 1-2 mm (see Figure 10). A few points have slightly larger standard deviations, due to the lack of observed data caused by the signal obstruction.

Semarang.

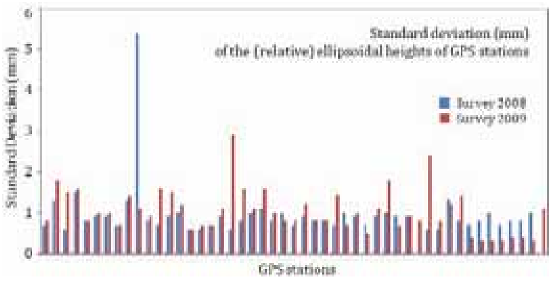



Figure 10. Standard deviations of GPS - derived relative heights in mm.

In using GPS surveys method, the height change $\Delta dhij$ and its rate $v\Delta dh_{ij}$ at each station are derived using the following relation:

$$\Delta dh_{ij} = dh(t_j) - dh(t_i) \quad (1)$$

$$v\Delta dhij = \Delta d_{hij} / (t_j - t_i) \quad (2)$$

where $dh(t_j)$ and $dh(t_i)$ are the relative ellipsoidal heights with respect to SMG1, obtained from the *i*th and *j*th GPS surveys. Subsidence is represented by a negative value of $\Delta dh_{ij}$ .

In order to statistically check the significance of the estimated subsidence values, we apply the general linear hypothesis test [Leick, 2004] to the estimated height parameter. The null hypothesis of the test is that the estimated relative ellipsoid heights at epoch *j* equal the estimated value of the previous epoch *i*., i.e. there is no subsidence has occurred. Therefore,

null hypothesis $H_o : \Delta dh_{ij} = 0$ (3)

alternative hypothesis $H_a : \Delta dh_{ij} \neq 0$ (4)

The test statistics for this test is

$$t = \frac{\Delta dh_{ij}}{\hat{\sigma}\ \Delta dh_{ij}} \quad (5)$$

which has the customary Student's t-distribution if $H_o$ is true. The null hypothesis is rejected if

$$|t| > t_{df,\alpha/2} \quad (6)$$

where df is the degrees of freedom and α is the significance level. In our case the degree of freedom is very large since the GPS baselines were derived using 8 to 10 hours of observations at 30 seconds interval. A t-distribution with infinite degree of freedom is identical to a normal distribution. At a confidence level of 99% (i.e. α=1%), the critical value is $t_{\infty,0.005} = 2.576$ .

Based on the results given in Figure 11, it could be statistically concluded that with 99% confidence level there were significant ellipsoidal changes observed by GPS surveys at all the stations during the period between July 2008 and June 2009, except for a few stations, namely KOP8, PAMU, PBR1, SMKN and T374. The GPS -derived ellipsoidal height changes and their rates that have passed the statistical testing are shown in Table 1.

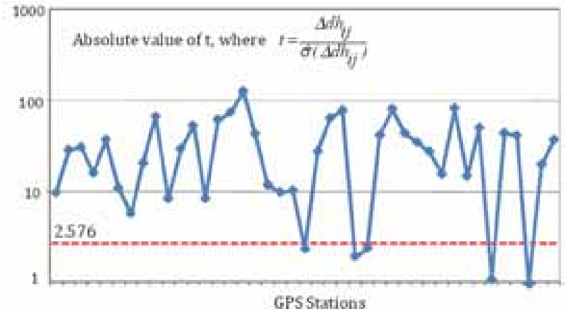



Figure 11. Summary of congruency test of GPS derived land subsidence results.

Table 1. GPS-derived subsidence results in Semarang, based on GPS surveys of July 2008 and June 2009.

| GPS Station | Subsidence (cm) | | Subsidence rate (cm/yr) | |
|---|---|---|---|---|
| | $\Delta dh_{12}$ | $\sigma(\Delta dh_{12})$ | $v\Delta dh_{12}$ | $\sigma(v\Delta dh_{12})$ |
| 0259 | -1.0 | 0.1 | -1.1 | 0.1 |
| 1106 | -6.2 | 0.2 | -6.8 | 0.2 |
| 1114 | -4.8 | 0.2 | -5.3 | 0.2 |
| 1124 | -3.4 | 0.2 | -3.7 | 0.2 |
| 1125 | -4.1 | 0.1 | -4.5 | 0.1 |
| 1303 | -0.8 | 0.1 | -0.8 | 0.1 |
| AY15 | -2.0 | 0.1 | -2.2 | 0.1 |
| BM01 | -12.4 | 0.2 | -13.5 | 0.2 |
| BM05 | -4.5 | 0.6 | -4.9 | 0.6 |
| BM11 | -3.5 | 0.1 | -3.8 | 0.1 |
| BM16 | -9.4 | 0.2 | -10.3 | 0.2 |
| BM30 | -1.5 | 0.2 | -1.6 | 0.2 |
| BTBR | -8.0 | 0.1 | -8.8 | 0.1 |

| | | | | |
|---|---|---|---|---|
| CTRM | -6.1 | 0.1 | -6.7 | 0.1 |
| ISLA | -11.3 | 0.1 | -12.3 | 0.1 |
| JOHR | -4.4 | 0.1 | -4.9 | 0.1 |
| K371 | -3.0 | 0.3 | -3.3 | 0.3 |
| KO16 | -1.8 | 0.2 | -2.0 | 0.2 |
| MP69 | -4.7 | 0.2 | -5.1 | 0.2 |
| MSJD | -7.9 | 0.1 | -8.7 | 0.1 |
| MTIM | -8.6 | 0.1 | -9.4 | 0.1 |
| PMAS | -4.9 | 0.1 | -5.3 | 0.1 |
| PRPP | -8.3 | 0.1 | -9.1 | 0.1 |
| SD01 | -7.3 | 0.2 | -8.0 | 0.2 |
| SD02 | -3.9 | 0.1 | -4.2 | 0.1 |
| SFCP | -3.6 | 0.1 | -3.9 | 0.1 |

Results from GPS show that land subsidence in Semarang has spatial variations, ranging from 0.8 to 13.5 cm/year with the mean of 5.9 cm/year (see Table 1 and Figures 12). Northern region of Semarang city exhibits higher rates of subsidence compare to its southern region, as shown in Figures 13 and 14.

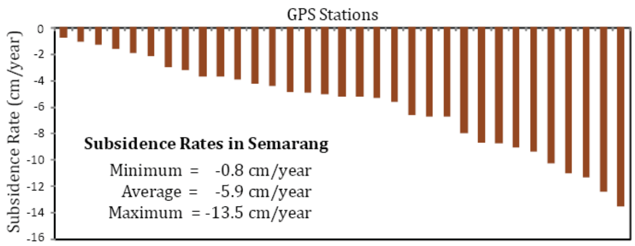
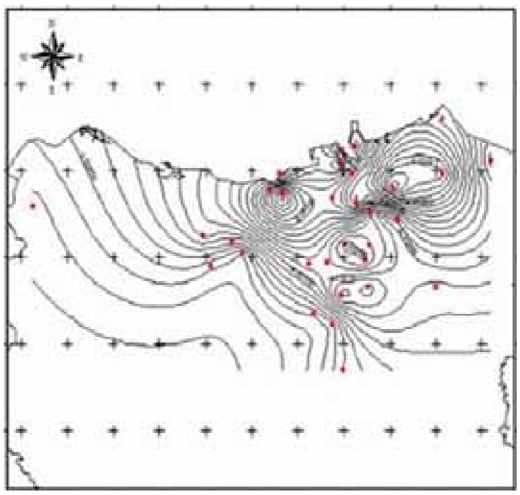



Figure 12. GPS-derived subsidence rates in Semarang



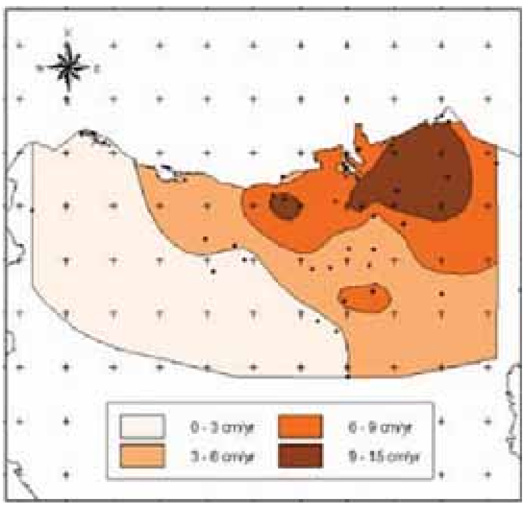


Figure 13. GPS derived contours of

subsidence rates in Semarang

Figure 14. GPS derived zones of subsidence rates in Semarang.

The GPS derived subsidence results show more or less the same rates and pattern of subsidence as derived by Levelling, PS InSAR and Microgravity methods. GPS results also indicate that subsidence process is still going on until recently (i.e. June 2009) in Semarang.

**Land Subsidence Measured By InSAR**

Geodesy Research Division of ITB has also used InSAR method to study land subsidence in Semarang using data from the ALOS/PALSAR satellite, which was launched in January 2006 as a successor of JERS-1/SAR. There are three ALOS PALSAR images were processed in this case (see Table 2). They were acquired in Fine Beam Single Polarization mode (HH polarization) with off-nadir angle of 41.5 degrees. InSAR processing has been performed using Level 1.1 products (SLC: Single Look Complex).

There are two pairs of images were processed (see Table 3). The first pair is between 24 October 2007 (071024) and 11 December 2008 (081211), and the other is between 9 December 2007 (071209) and 11 December 2008 (081211). The baselines of image pairs are about 684 m and 849 m, respectively. In this case, the subsidence is derived using two pass differential method, and SRTM data was used for generating the DEM for the area. The final results of subsidence are shown in Figure 15.

Table 2. ALOS/PALSAR images used for studying land subsidence in Semarang city

| Date | Looking direction |
|---|---|
| 24 October 2007 | Ascending |
| 09 December 2007 | Ascending |
| 11 December 2008 | Ascending |

Table 3. Image pair of data

| Image Pair | Baseline (Perpendicular) |
|---|---|
| 071024_081211 | 683.877 meter |
| 071209_081211 | 848.753 meter |

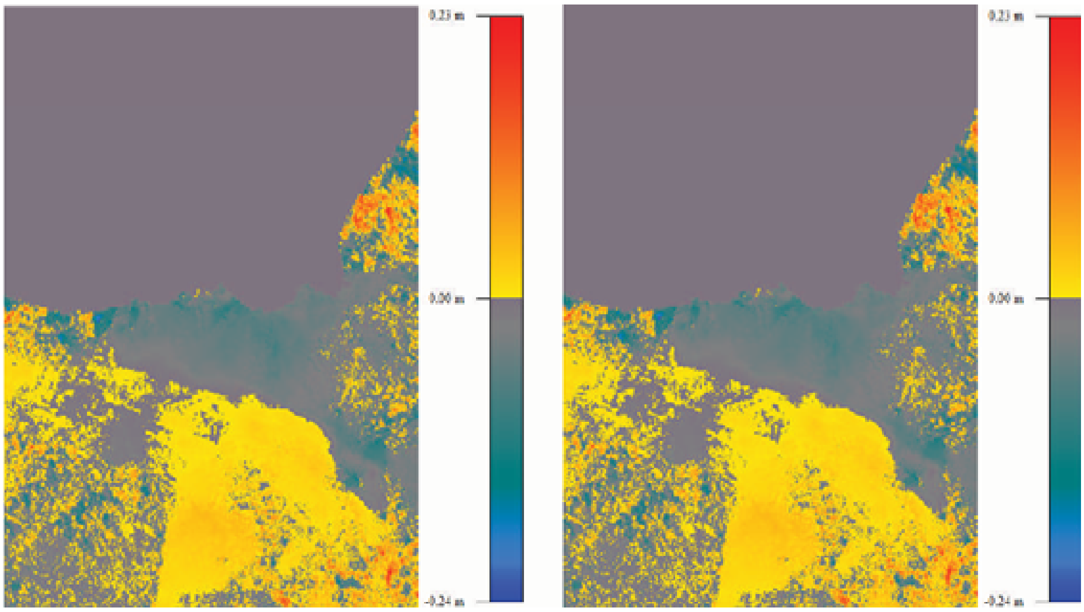



Figure 15. ALOS/PALSAR InSAR derived subsidence in Semarang city, from (071024_081211) pair (left), and (071209_081211) pair (right)

Results shown in Figures 15 show that subsidence in Semarang city is generally occuring in the northern part of the city, with the maximum rates of about 15 cm/year. These results are more or less similar with the aforementioned results derived by other methods.

It should be noted in this case that, the uplift presence in Figure 15 is mostly caused by the very low correlation of images, and the uplift presence in this Figure should not be considered as a 'real' uplift [*Sidiq*, 2009].

## Closing Remarks

Land subsidence in northern part of Semarang is believed to be caused by the combination of natural consolidation of young alluvium soil, groundwater extraction and load of buildings and constructions. Due to this coastal land subsidence, part of the north coast area of Semarang city has been showing a growth of sea water inundation since almost the last three decade.

Groundwater abstraction in Semarang city is increasing sharply since early 1990s, especially in industrial area (see Figure 16). According to [*Marsudi*, 2001], the number of registered wells in 1900 is 16; becomes 94 wells in 1974, 178 wells 1981, 350 wells in 1989, 600 wells in 1990, 950 wells in 1996, and 1050 wells in 2000. The registered groundwater abstraction is increasing from about 0.4 million m3/year in 1900, to 0.9 million m3/year in 1974, 1.8 million m3/year in 1981, 8.8 million m3/year in 1989, 16.9 million m3/year in 1990, 32.8 million m3/year in 1996 and 38 million m3/year in 2000.

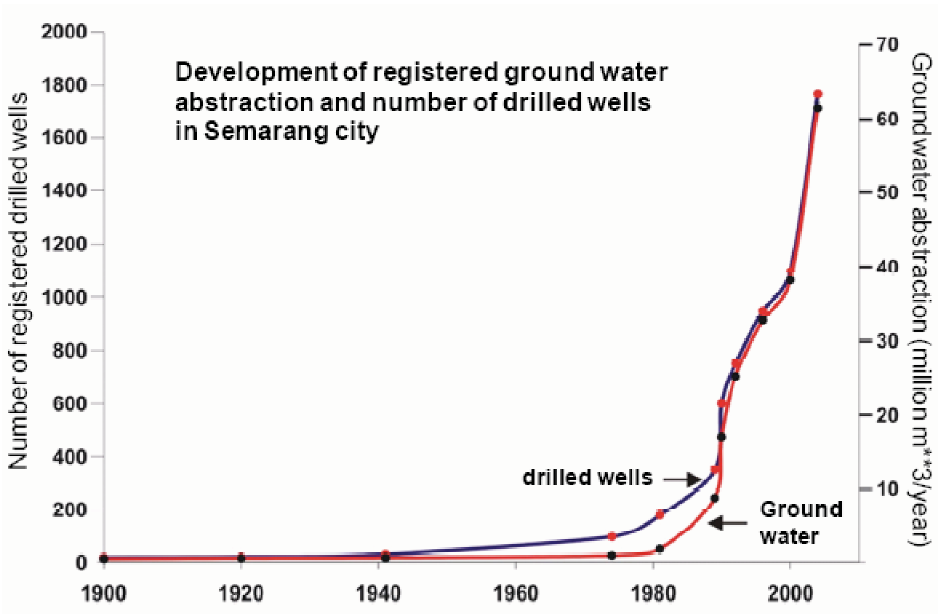



Figure 16. Development of ground water abstraction and registered drilled wells in Semarang, after [*Murdohardono et al*, 2007].

Due to excessive groundwater abstraction, the groundwater level in Semarang during the period of 1980 and 1996 is lowering with the rates of about 1.2 to 2.2 m/year [*Marsudi*, 2001]. This will then introduce land subsidence above it.

More data and further investigations are required to understand the intricacies of the relationship between land subsidence and natural consolidation and groundwater extraction in Semarang area. Additional causes of subsidence, e.g. load of buildings and construction, and tectonic movements, should also investigated and taken into account.

Finally it should be noted that in the coastal areas of Semarang, the combined effects of land subsidence and sea level rise will make worse the tidal flooding phenomena which already experienced by Semarang during the high tide periods. The adaptation measures to reduce the impacts of this hazard therefore should be developed as soon as possible.

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# Land Subsidence and Urban Development in Jakarta (Indonesia)

Hasanuddin Z. Abidin, Heri Andreas, Irwan Gumilar And Mohammad Gamal,
Yoichi Fukuda And T. Deguchi

## Summary

Jakarta is the capital city of Indonesia with a population of about 9 people, inhabiting an area of about 660 square-km. In the last three decades, urban development of Jakarta has grown very rapidly in the sectors of industry, trade, transportation, real estate and many others. This exponentially increase urban development introduce several environmental problems. Land subsidence is one of them. The resulted land subsidence will also then affect the urban development plan and process. It has been reported for many years that several places in Jakarta are subsiding at different rates. Over the period of 1982–1997, subsidence ranging from 20 to 200 cm is evident in several places in Jakarta. In general the land subsidence exhibits spatial and temporal variations, with the rates of about 1 to 15 cm/year. A few locations can have the subsidence rates up to about 20-25 cm/year. There are four different types of land subsidence that can be expected to occur in the Jakarta basin, namely: subsidence due to groundwater extraction, subsidence induced by the load of constructions (i.e., settlement of high compressibility soil), subsidence caused by natural consolidation of alluvial soil and tectonic subsidence. It was found that the spatial and temporal variations of land subsidence depend on the corresponding variations of groundwater extraction, coupled with the characteristics of sedimentary layers and building loads above it. This paper discusses the relation between land subsidence and urban development activities in Jakarta.

*Key words:* Jakarta, Land Subsidence, Urban Development, Leveling, GPS , InSAR

## Introduction

The city of Jakarta has a population of about 9 million people [*BPS Jakarta,* 2007], inhabiting an area of about 661.52 km2. During the day, the population can increase to about 13 million. Jakarta is centered at the coordinates of about -6° 15' (latitude) and +106° 50' (longitude) and, located on the lowland of the northern coast of the West Java province, as shown in Figure 1.

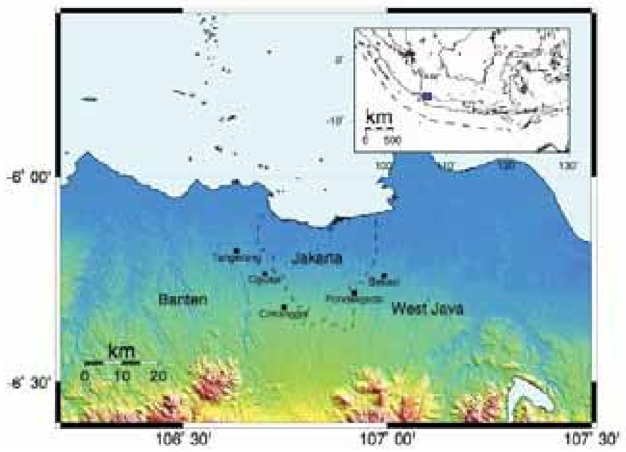



Figure 1. Jakarta and its surrounding areas

The area is relatively flat, with the topographical slopes ranging between 0° and 2° in the northern and central parts, and between 0° and 5° in the southern part. The southernmost area of Jakarta has an altitude of about 50 m above mean sea level (MSL).

Regionally speaking, Jakarta is a lowland area which has five main landforms, namely [*Rimbaman and Suparan*, 1999; *Sampurno,* 2001]: (1) Volcanic alluvial fan landforms, which are located in the southern part; (2) Landforms of marine-origin, which are found in the northern part adjacent to the coastline; (3) Beach ridge landforms, which are located in the northwest and northeast parts; (4) Swamp and mangrove swamp landforms, which are encountered in the coastal fringe; and (5) Former channels, which run perpendicular to the coastline. There also 13 natural and artificial rivers flowing through Jakarta, namely Cisadane, Citarum, Ciliung, Angke, Krukut, Sunter, Bekasi, Cakung, Karawang, Cikarang, Ciranjang, Cimancuri and Cidurian.

In terms of geological and hydrological settings, according to *Yong et al.* (1995), the Jakarta basin consists of a 200 to 300 m thick sequence of Quaternary deposits which overlies Tertiary sediments. The top sequence is thought to be the base of the groundwater basin. The Quaternary sequence can be further subdivided into three major units, which, in ascending order are: a sequence of Pleistocene marine and non-marine sediments, a late Pleistocene volcanic fan deposit, and Holocene marine and floodplain deposits. Three aquifers are recognized inside a 250 m thick sequence of quaternary sediment of the Jakarta basin, namely [*Soetrisno et al.*,1997; *Hadipurwo,*1999] : the Upper Aquifer, an unconfined aquifer, occurs at a depth of less than 40 m; the Middle Aquifer, a confined aquifer, occurs at a depth between 40 and 140 m; and the Lower Aquifer, a confined aquifer, occurs at a depth between 140 and 250 m. Inside those aquifers, the groundwater generally flows from south to the north [*Lubis et al.,* 2008]. Below a depth of 250 m, an aquifer in the tertiary sediment was also found. But according to *Murdohardono and Tirtomihardjo* (1993), it is less productive and its water quality is relatively poor.

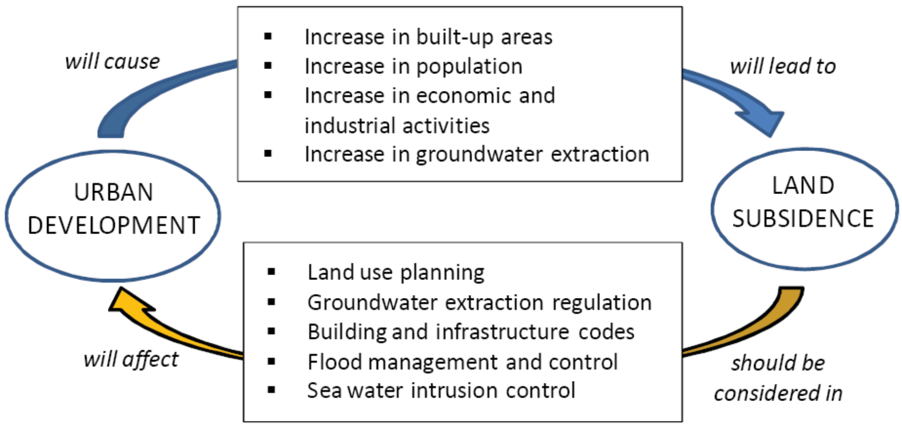



Figure 2. Urban development and land subsidence relation in Jakarta

In the last three decades, urban development of Jakarta and its surrounding areas has grown very rapidly in the sectors of industry, trade, transportation, real estate and many others. This exponentially increase urban development introduce several environmental problems. According to [*Firman and Dharmapatni*, 1994], this rapid urban development has caused several negative externalities, namely : (1) extensive conversion of prime agricultural areas into residential and industrial areas, (2) significant disturbance to main ecological function of the upland of Jakarta area as a water recharge area for Jakarta city, (3) increase in groundwater extraction due to development of industrial activities and the high population increase, (4) high concentrations of BOD and COD in most of the rivers flowing through the Jakarta area as a result of domestic, agricultural and industrial waste disposal, (5) solid waste disposal is now felt as a pressing problem, and (6) the air pollution in Jakarta city has reached a critical point reflected in more evident acid rain. The first three negative impacts will contribute to land subsidence phenomena in several places in Jakarta. The resulted land subsidence will also then affect the urban development plan and process. Figure 2 illustrates the possible relation between land subsidence and urban development in Jakarta.

Land subsidence is a real phenomenon in Jakarta. Over the period of 1982–1997, subsidence ranging from 20 to 200 cm is evident in several places in Jakarta. In general the land subsidence exhibits spatial and temporal variations, with the rates of about 1 to 15 cm/year. A few locations can have the subsidence rates up to about 20-25 cm/year. It was found that the spatial and temporal variations of land subsidence depend on the corresponding variations of groundwater extraction, coupled with the characteristics of sedimentary layers and building loads above it. In the following sub-chapters, the relation between land subsidence and urban development activities in Jakarta will be discussed and analyzed.

## Land Subsidence In Jakarta

Land subsidence is not a new phenomenon for Jakarta, the capital city of Indonesia. It has been reported for many years that several places in Jakarta are subsiding at different rates [*Murdohardono & Tirtomihardjo,* 1993; *Murdohardono & Sudarsono,* 1998; *Rajiyowiryono,* 1999]. The impact of land subsidence in Jakarta could be seen in several forms, such as cracking of permanent constructions and roads, changes in river canal and drain flow systems, wider expansion of flooding areas, malfunction of drainage system, increased inland sea water intrusion and increased tidal flooding coverage. Based on several studies [*Murdohardono and Sudarsono,* 1998; *Rismianto and Mak,* 1993; *Harsolumakso,* 2001; *Hutasoit,* 2001], there are four different types of land subsidence that can be expected to occur in the Jakarta basin, namely: subsidence due to groundwater extraction, subsidence induced by the load of constructions (i.e. settlement of high compressibility soil), subsidence caused by natural consolidation of alluvium soil, and geotectonic subsidence. The first three are thought to be the dominant types of land subsidence in Jakarta basin.

In the case of Jakarta, the comprehensive information on the characteristics of land
subsidence is important for several tasks (see Figure 3), such as spatial-based groundwater extraction regulation, effective control of flood and seawater intrusion, conservation of environment, design and construction of infrastructures, and spatial development planning.

Considering the importance of land subsidence information for supporting the development activities in Jakarta area, monitoring and studying the characteristics of subsidence phenomena becomes necessary.

Since the early 1980's, the land subsidence in several places of Jakarta has been measured using several measurement techniques, e.g. leveling surveys, extensometer measurements, ground water level observations, GPS surveys, and InSAR technique [*Abidin,* 2005; *Abidin et al.,* 2001, 2004, 2008a, 2008b]. The prediction of ground subsidence, based on certain models incorporating geological and hydrological parameters of Jakarta, has also been investigated [*Murdohardono and Tirtomihardjo,* 1993; *Yong et al.,* 1995; *Purnomo etal.,* 1999].

The results obtained from leveling surveys, GPS surveys and InSAR technique over the period between 1982 and 2008 show that land subsidence in Jakarta has spatial and temporal variations. In general the observed subsidence rates are about 1 to 15 cm/year, and can be up to 20-25 cm/year at certain location and certain period. The summary of subsidence rates in Jakarta is given in Table 1. The more comprehensive results can be seen in *Abidin et al.* (2001, 2008a, 2008b).

Table 1. Observed subsidence rates in Jakarta; the rates vary both spatially and temporally.

| Method | Period | Subsidence Rates (cm/year) |
|---|---|---|
| Leveling surveys | 1982 - 1991 | 0 - 9 |
| | 1991 - 1997 | 0 - 25 |
| GPS surveys | 1997 - 2008 | 0 - 25 |
| InSAR | 2006 - 2007 | 0 - 12 |

**Urban Development And Land Subsidence**

Land subsidence in Jakarta can be caused by four factors, namely: excessive groundwater extraction, load of buildings and constructions, natural consolidation of alluvium soil, and tectonic activities. Up to now, there is no information yet about the contribution of each factor on the subsidence at each location and their spatial (contribution) variation. In case of Jakarta, tectonic activities seem to be the least dominant factor, while excessive groundwater extraction is considered to be one of dominant factor. The first three factors will have close relation with urban development activities in Jakarta and its surrounding areas.

***Increase in Population and Built-up Areas***

Urban development in Jakarta is going-on rapidly. According to [*Firman and Dharmapatni*, 1994], Jakarta has been the most attractive area in Indonesia for domestic and direct foreign investment because of its better infrastructure, high concentration and access to mass markets, pool of skilled labour and entrepreneurs and high access to the decision makers.


The economic activities in the region have grown very rapidly, especially in industry, trade, transportation, real-estate, and many other sectors; and have also spilled over into the adjacent areas, such as Bogor, Tangerang, Depok and Bekasi. It then increases the urbanization rates into Jakarta and surrounding areas, and population of Jakarta growth rapidly. Consequently, coverage of the built-up areas is increased and the green areas are decreased. Nowadays, most areas of Jakarta are built-up areas, as shown in Figure 3.

Figure 3. Built-up areas of Jakarta in 2008, which cover about 90% of the region.

According to [*Lo and Yeung*, 1995], in 1948 the population of Jakarta was about 2 million, with a built-up area of 20,000 ha, including Kebayoran Baru, a new town in the south. In 1965 the population of Jakarta was about 4 million, with a built-up area of 35,000 ha. By 1980, Jakarta occupied 65,400 ha with a population of 6.5 million, and it was by this time that the influence of the city on the region (rather than simply on its fringes) was clearly demonstrated. The 1990 Population Census showed that Jakarta had 8.2 million inhabitants. The population growth of Jakarta is shown in Table 2. In 2006, the population density has reached about 13,500 peoples/km2, which make Jakarta the densest region in Indonesia.

Table 2. Population growth of Jakarta [*Lo and Yeung*, 1995; *BPS Jakarta*, 2007]

| Year | Population ('000) | Year | Population ('000) |
|---|---|---|---|
| 1948 | ≈ 2,000 | 2002 | 8,379 |
| 1961 | 2,973 | 2003 | 8,603 |
| 1971 | 4,579 | 2004 | 8,725 |
| 1980 | 6,503 | 2005 | 8,864 |
| 1990 | 8,259 | 2006 | 8,961 |

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 135 are star (classified) hotels; and 1955 large and medium manufacturing companies in Jakarta [*BPS Jakarta*, 2007].

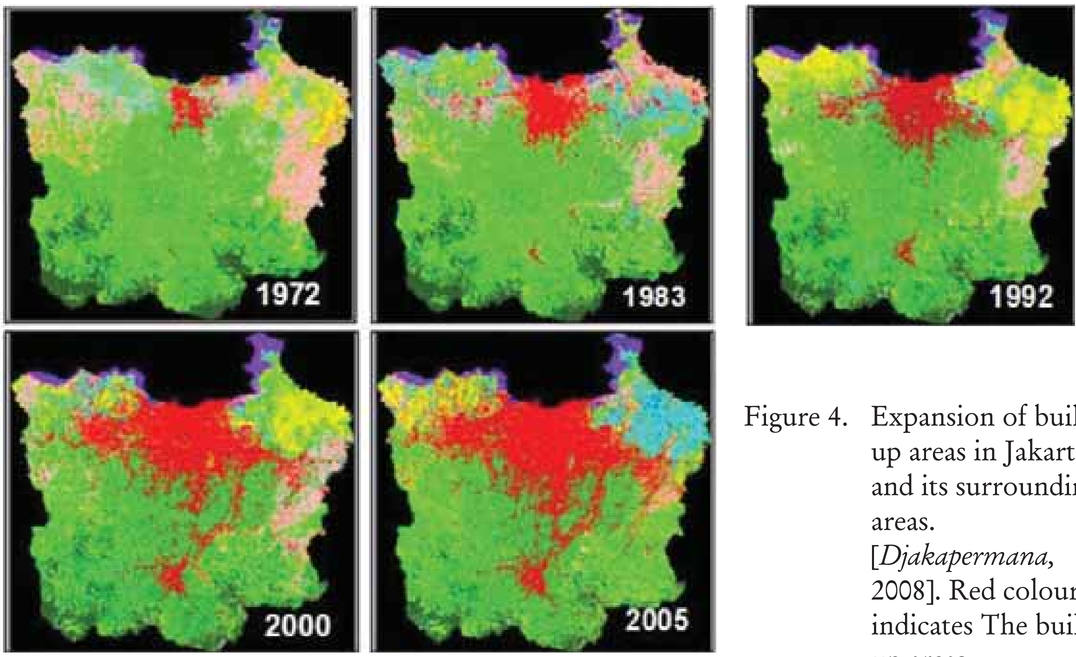



Figure 4. Expansion of built-up areas in Jakarta and its surrounding areas. [*Djakapermana*, 2008]. Red colour indicates The built-up areas.

Unfortunately, these developments mostly occupied the available green areas in Jakarta. In 1965, the green areas made up more than 35 percent of the Jakarta's area and currently account for only 9.3 percent of the area [*Rukmana*, 2008]. Several new towns have also been developed along the perimeter of Jakarta and its surrounding areas which also increase the coverage of built-up areas in the region. Figure 4 shows the sharp increase in coverage of built-up areas in Jakarta since 1972 to 2005.

This increase in built-up areas directly affect the water recharge areas and rechargeability of withdrawn groundwater in Jakarta and its surrounding areas. Coupled with the increase consumption of groundwater due to increase in population and economic and industrial activities, the (ground and surface) water system in Jakarta and its surrounding areas are severely affected. In turn it will contributes to occurance of land subsidence phenomena in several locations inside Jakarta, as will be explained in the following section.

*Excessive Use of Groundwater*

The population growth and increase in economic activities in Jakarta and its surrounding region lead to the increase in water need. Unfortunately most of water consumption in Jakarta is fulfilled by groundwater extraction. This over discharging of groundwater would deepen the piezometric water level inside the middle and lower aquifers and in turn would cause land subsidence above it.
The groundwater extraction in Jakarta could be categorized into shallow (< 40 m) and

deep (> 40 m) extraction. Shallow extraction is through dug wells or driven wells, operated with buckets, hand pumps or small electrical pumps; whereas the deep extraction is mostly from drilled wells. Shallow extraction is mostly done by the population. It is well spread over the area, but its extraction rate per well is relatively low. Deep extraction is usually conducted by industry. It is usually more concentrated, and has a relatively high extraction rate per well. According to *Sudibyo* (1999), the number of registered drilled wells in Jakarta was 3626 wells in 1998. Based on the studies done by *Murdohardono and Tirtomihardjo* (1993), from the sample of 197-drilled wells in Jakarta, out of 2800 registered drilled wells at that time, 156 wells (79%) are extracting groundwater from depths between 40 m and 140 m, and 41 wells (21%) are extracting from depths between 140 m and 250 m.

The registered groundwater extraction in Jakarta varies from just 3 Qabs (million m3) in 1900 up to maximum of 33.8 Qabs in 1994, and then down to 16.9 Qabs in 1998. It should pointed out here that, these numbers may not reflect the real groundwater extraction in Jakarta basin. According to *Soetrisno* (1997) the unregistered deep groundwater extraction in Jakarta can be as high as 50% or even more. This excessive groundwater pumping will usually lead to the deepening of the piezometric water level inside the middle and lower aquifers. According to *Soetrisno, et al*. (1997), the piezometric level in North Jakarta has changed from 12.5 m above sea level in 1910 to about sea level in 1970's, and then deepened significantly to 30-50 m below sea level in 1990's.

The subsidence rate is closely related to the rate of piezometric water level (head) deepening in the middle and lower aquifers. In the case of Jakarta, the increases in both population and industry, which require a lot of groundwater, could explain the above declining trend of piezometric heads, as shown in Figure 5.

The corelation between land subsidence and excessive groundwater taking in Jakarta can be illustrated using the subsidence results obtained from leveling surveys. Figure 9 shows the observed land subsidence during the period of 1982-1991 and 1991-97. Maximum subsidence during the period of 1982-1991 is about 80 cm, while for the period of 1991-97 is about 160 cm. In general the subsidence rates in Jakarta area during this period is about 1-5 cm/year and can reach 26 cm/year at several locations. During the period between 1982 and 1991, the maximum rate of subsidence is about -8 cm/year, while during the period between 1991 and 1997 it is about -26 cm/year. More comprehensive results on leveling-based subsidence in Jakarta can be seen in *Abidin et al.* (2001).

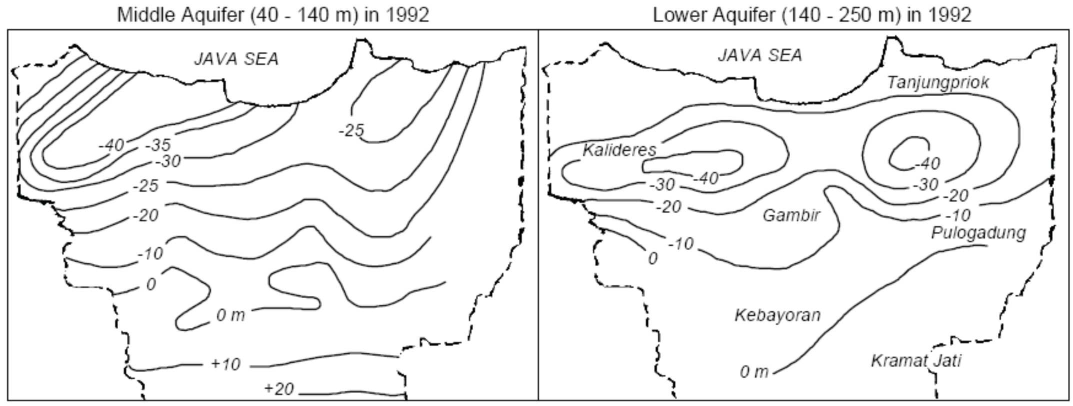



Figure 5. Piezometric water level contours (in metres) inside Middle and Lower Aquifers of Jakarta in 1992; adapted from [*Murdohardono and Tirtomihardjo*, 1993].

If we compare Figures 5 and 6 it can be realized that the cones of piezometric level depressions inside the middle and lower aquifers more or less coincide with the cones of largest land subsidence measured by the leveling. It should also be noted here that in those areas of subsidence cones, due to their high soil compressibility the situation could be worse with the settlement caused by the load of constructions.

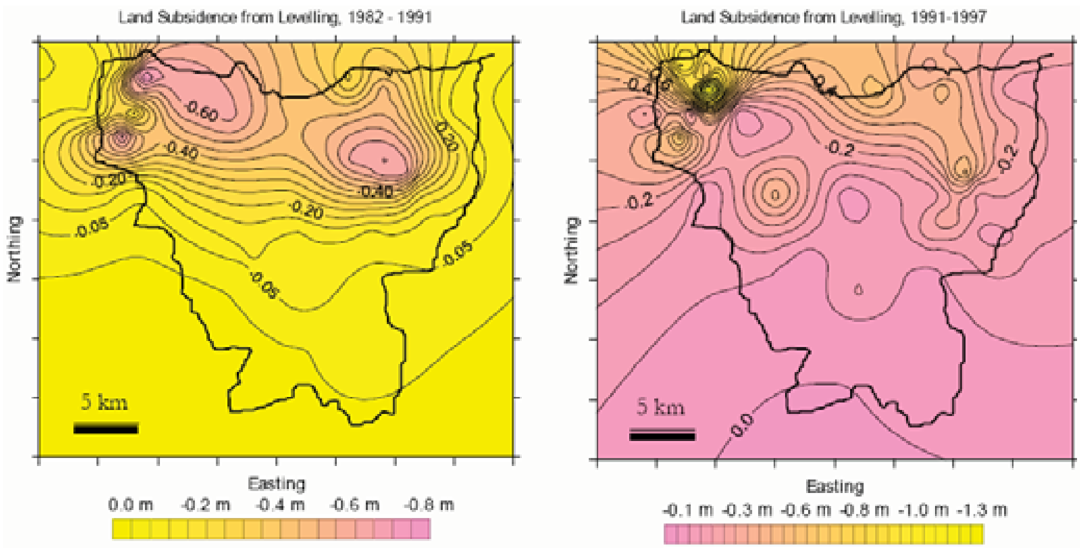



Figure 6. Land subsidence in Jakarta measured from leveling surveys (in metres), Over the periods of 1982 – 1991 (left) and 1991 – 1997 (right) [Abidin et al, 2001].

The groundwater level inside the middle and lower at several locations in Jakarta are seems still decreasing up to now. The groundwater level are decreasing with the rates of about 0.2 to 2 m/year over the period of 2002 to 2007 [*Abidin et al.*, 2008b]. In comparison with GPS derived subsidences, it can be seen that the large subsidences are usually associated with the realtively high rates of groundwater level change rates. A more detail explanation on GPS derived subsidence and its relation with groundwater extraction is given in [*Abidin et al* 2008a; 2008b].

### *Coastal Development*

Coastal area of Jakarta has also experienced extensive urban development. Many establish-ments take places in this coastal region, such as sea port, coastal resort, golf course, residential areas, industries, condominiums, malls, hotels, and commercials and office buildings. Some areas haev also been reclaimed to accomodate more coastal development initiatives. It should be pointed out, that the observed land subsidences along the coastal areas of Jakarta are relatively have larger rates. Therefore it will somehow affect the coastal development of Jakarta.

Figure 7. Part of coastal areas of Jakarta.

Figure 8 shows land subsidence in northern part of Jakarta detected by InSAR over the period of June 2006 to February 2007. This Figure shows that subsidence along the coastal zone of Jakarta has a spatial variation, with subsidence rates can reach about 12 cm/year. Please note in this Figure, that one cone of deepest subsidence is located in Pantai Mutiara housing complex, which is actually a land reclamation area. The GPS derived subsidence result (see Figure 9) also show the relatively higher subsidence rates in the western and central parts of Jakarta coastal areas, during the period of Sept. 2007 to August 2008.

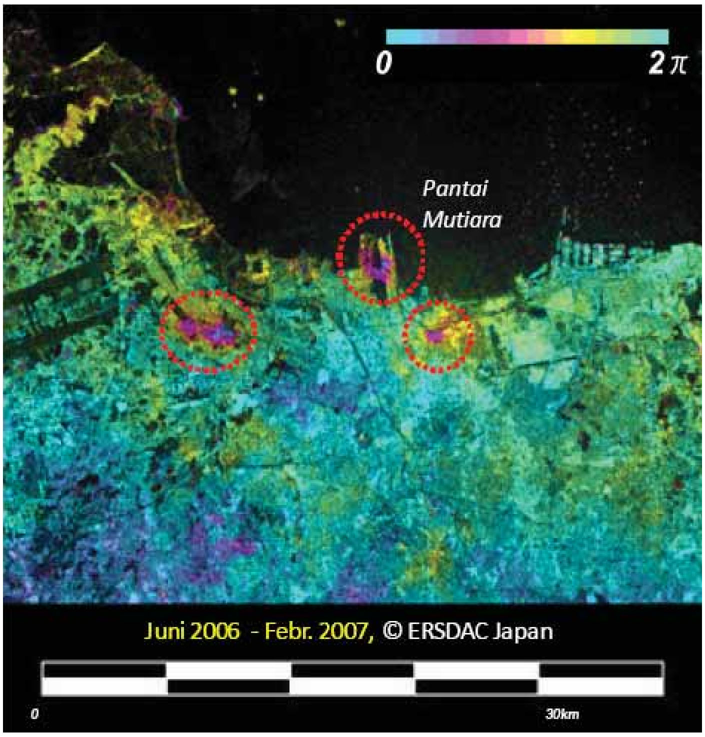



Figure 8. InSAR-derived subsidence in the northern part of Jakarta using ALOS PALSAR data.

Considering the sea level rise phenomena, coastal subsidence in Jakarta will certainly affect coastal development in Jakarta. Considering the relatively flat nature (i.e. 0-2 m above MSL) of most coastal areas of in Jakarta, this combined effect of land subsidence and sea level rise will certainly be have disastrous consequences for habitation, industry, and fresh groundwater supplies from costal aquifers. During high tides, tidal flooding is already affecting some of these coastal areas. The extent and magnitude of subsidence related flooding will worsen with the likely

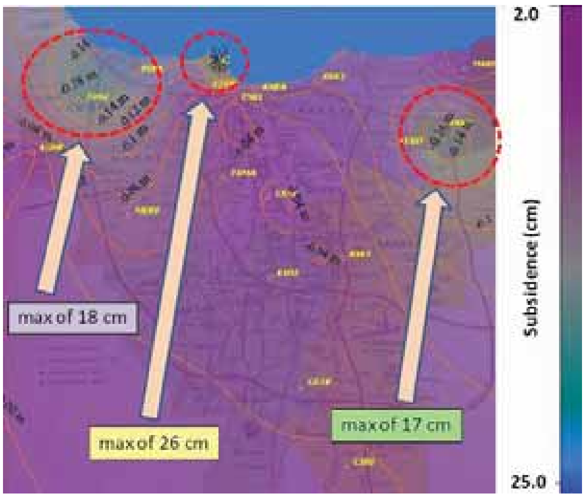
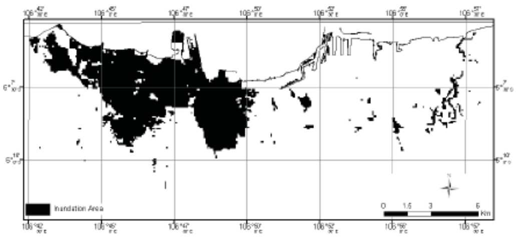



Figure 9. GPS derived subsidence during the period of Sept. 2007 to August

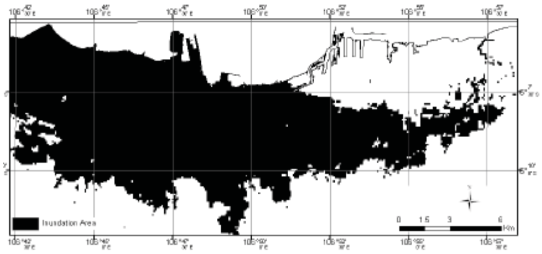
continuation of sea level rise along the coastal area of Jakarta, which is bordered by the Java sea.

2008.

By utilizing the InSAR derived subsidence as shown in Figure 8 and the sea level rise rate of 2 mm/year [*Gornitz*, 1995; *IPCC*, 2007], the possible inundated areas can be estimated as shown in Figure 10.



Inundation areas in 2020 (in black); covering about 5,146.80 hectares



Inundation areas in 2050 (in black); covering about 16,237.87 hectares

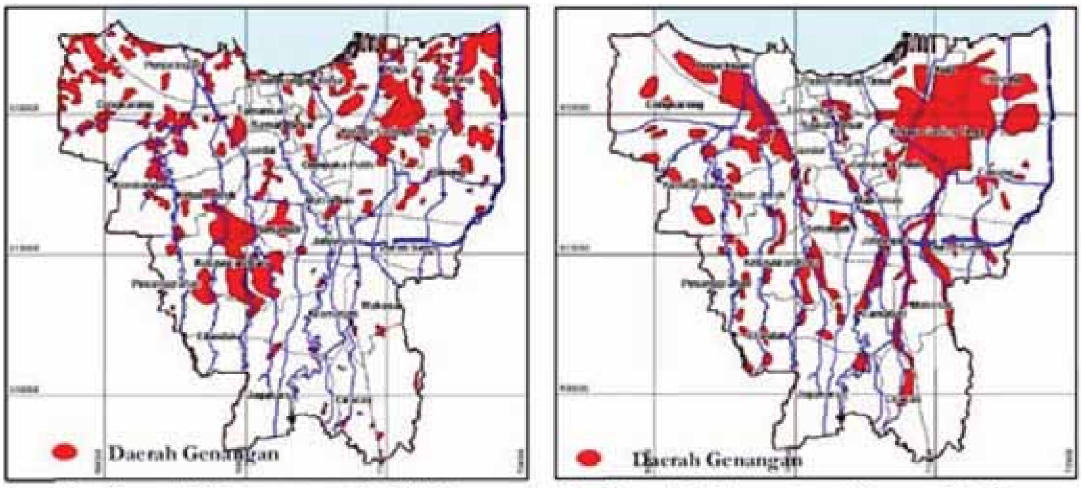
Figure 10. Possible inundation areas in the coastal areas of Jakarta; with the assumption of spatially different subsidence rates along the coast and sea level rise rate of 2 mm/year.

### *Impacts of Subsidence to Urban Development*

Impacts caused by land subsidence to urban development in Jakarta can be seen in several forms. The differential subsidence nature in Jakarta basin my introduce the cracking and damage in buildings and infrastructure and may change the flow pattern of surface water. Subsidence may also enlarge the (tidal) flooding inundation areas, and in general will deteriorate their environmental quality. Subsidence along several coastal areas of Jakarta also makes them more vulnerable toward sea level rise phenomena. Figure 11 shows several indications of land subsidence phenomena in Jakarta.

In case of Jakarta, which is actually prone toward flooding, subsidence phenomena has to be fully understood for flood management system. During the period between 1993 and 2007, at least there are four big floods in Jakarta, namely on 9-10 January 1993, February 1996, 26 January - 1 February 2002, and 4 – 14 February 2007. Figure 12 shows in general the flood inundation areas of the 2002 and 2007 flooding.

Figure 11. Several indication and impact of land subsidence in Jakarta *Wirakusumah,* 2008]. A and B are locations in Kamal Muara; C and D are locations along the highway to the airport (Cengkareng).




Flooding of 2002, courtesy of LAPAN

Flooding of 2007, courtesy of Kompas (10 February)

Figure 12. Flooding inundation areas in Jakarta.

If the flooding inundation areas in Figure 12 are compared with the previous subsidence information as derived by Leveling, GPS and InSAR techniques; the correlation between land subsidence and flooding inundation can be seen in the western and eastern parts of North Jakarta region. In other areas however, the correlation is quite weak, and in this case the inundation areas are mainly located along the flooded rivers.

## Closing Remarks

The results obtained from leveling surveys, GPS surveys and InSAR technique over the period between 1982 and 2008 show that land subsidence in Jakarta has spatial and temporal variations. In general the observed subsidence rates are about 1 to 15 cm/year, and can be up to 20-25 cm/year at certain location and certain period. There is a strong indication that land subsidence in Jakarta area is governed by the excessive groundwater extraction from the middle and lower aquifers, besides also by building/construction load and natural consolidation of sedimentary layers. The excessive groundwater extraction causes the rapid decrease in groundwater level inside the aquifers, and in turn cause the land subsidence above it. However, the relation between land subsidence and groundwater level decrease inside the acquifers in certain location will not always be a direct and simple relation.

Land subsidence in Jakarta has a strong linkage with urban development process. Urban development in Jakarta causes increases in built-up areas, population, economic and industrial activities, and also groundwater extraction. These increases can then lead to land subsidence phenomena. In other side, the existing land subsidence phenomena will affect and should be considered in urban development process itself. In this case, land use planning, groundwater extraction regulation, building and infrastructure codes, flood management and control, and seawater intrusion control; are examples of several urban development aspects that will be related with land subsidence phenomena.

Finally it can be concluded that more data and further investigation is required to understand the detail and comprehensive relationship between land subsidence and urban development in the Jakarta basin. Additional causes of subsidence, e.g. load of buildings and construction, natural consolidation of alluvium soil, and tectonic movements, should also investigated and taken into account. Further research on the impacts of land subsidence in Jakarta should also be systematically conducted, especially in relation with the flooding inundation areas; and also with the coastal flooding in relation with sea level rise phenomena.

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# Land subsidence characteristics of Jakarta between 1997 and 2005, as estimated using GPS surveys

Hasanuddin Z. Abidin, H. Andreas, Rochman Djaja, Dudy Darmawan, M. Gamal

## Abstract

Jakarta is the capital city of Indonesia with a population of about 12 million people, inhabiting an area of about 625 km2. It is well known that several areas in Jakarta are subsiding rapidly. There are four different types of land subsidence that can be expected to occur in the Jakarta basin, namely: subsidence due to groundwater extraction, subsidence induced by the load of constructions (i.e., settlement of high compressibility soil), subsidence caused by natural consolidation of alluvial soil and tectonic subsidence. In addition to the leveling method, Global Positioning System (GPS) survey methods have been used to study land subsidence in Jakarta. In this paper, we characterize subsidence in the Jakarta basin using eight episodic/campaign GPS surveys between 1997 and 2005. The estimated subsidence rates are 1–10 cm/year. The observed subsidence rates in several locations show a positive correlation with known abstraction volumes of groundwater extraction. These basin-wide series of GPS measurements show how this type of measurement can play an important role in multiple public policy decision making in this rapidly growing area.

*Keywords*: Jakarta, Land subsidence, GPS , Groundwater

## Introduction

Jakarta's population is about 10 million people, covering an area of about 650 km2. Jakarta is centered at about 6°15′S and +106°50′E and located on the lowland of the northern coast of the West Java province, as shown in Figure 1. The area is relatively flat, with topographical slopes ranging between 0° and 2° in the northern and central parts, and between 0° and 5° in the southern part. The southernmost area of Jakarta has an altitude of about 50 m above mean sea level.

Jakarta is a lowland area with five main landforms (Rimbama and Suparan 1999): (1) alluvial landforms (southern part). (2) Landforms of marine-origin (northern part adjacent to the coastline). (3) Beach ridge landforms (northwest and northeast parts). (4) Swamp and mangrove swamp landforms (coastal fringe). (5) Former channels (perpendicular to the coastline). There are about 13 natural and artificial rivers flowing through Jakarta, of which the main rivers, such as Ciliwung, Sunter, Pesanggrahan, Grogol and their tributaries, form the main drainage system of Jakarta.

Land subsidence is not a new phenomenon for Jakarta. The occurrence of land subsidence was recognized in 1926. Evidence for subsidence was based on repeated leveling measurements conducted in the northern part of Jakarta (Schepers 1926; Suharto 1971). Unfortunately, the investigation of land subsidence using leveling was not repeated for 50 years until 1978. Starting in 1978, the impact of land subsidence in Jakarta could be seen in several ways, such as the cracking of permanent constructions located around the center of the Jakarta area (along Thamrin Street), the wider expansion of flooding areas, the lowering of the groundwater level and increased inland seawater intrusion. According to the Local Mines Agency, over the period of 1982–1997, subsidence ranging from 20 to 200 cm is evident in several places in Jakarta.

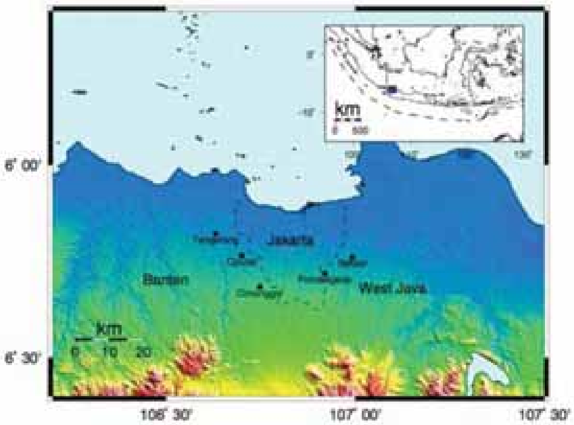


Figure 1 Jakarta basin

It has been reported for many years that several places are subsiding at different rates (Murdohardono and Tirtomihardjo 1993; Murdohardono and Sudarsono 1998; Rajiyowiryono 1999; Abidin et al. 2001). Considering this significant amount of subsidence and its wide impact on many developmental and environmental aspects, a systematic and continuous monitoring of land subsidence in Jakarta is obviously needed and is critical to the welfare of the city.

In the case of Jakarta, the comprehensive information on the characteristics of land subsidence is important for several tasks (see Figure 2), such as spatial-based groundwater extraction regulation, effective control of flood and seawater intrusion, conservation of environment, design and construction of infrastructures and spatial development planning.

According to Murdohardono and Sudarsono (1998) and Rismianto and Mak (1993), there are four different types of land subsidence that can be expected to occur in the Jakarta basin, namely, subsidence due to groundwater extraction, subsidence induced by the load of constructions (i.e., settlement of high compressibility soil), subsidence caused by natural consolidation of alluvial soil and geotectonic subsidence. From those types of subsidence, the main spectrum of land subsidence in Jakarta is thought to be caused by groundwater extraction. Excessive groundwater extraction will lead to the deepening of groundwater level (piezometric head), which in turn will cause land subsidence and also seawater intrusion (Soekardi et al. 1986).

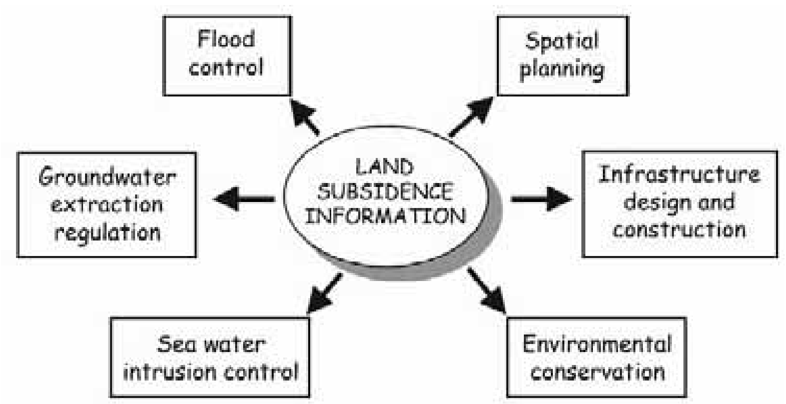


Figure 2 The importance of land subsidence information

Since the early 1980s, land subsidence in several places of Jakarta has been measured using several measurement techniques, e.g., leveling surveys, extensometer measurements, groundwater level observations and Global Positioning System (GPS) surveys (Abidin et al. 2004). The prediction of ground subsidence, based on certain models incorporating geological and hydrological parameters of Jakarta, has also been investigated (Murdohardono and Tirtomihardjo 1993; Yong et al. 1995; Purnomo et al. 1999).

This paper describes the characteristics of land subsidence in Jakarta basin during the period of 1997–2005, as observed by GPS surveys.

## GPS surveys for land subsidence study in Jakarta

The use of GPS satellite-based positioning system to systematically establish geodetic control points over the Jakarta area was first conducted in 1994 by the National Land Agency (BPN). This GPS network is aimed at supporting cadastral mapping, and its design was not intended to monitor land subsidence.

Considering the higher cost saving and speed of simultaneous data collection of GPS surveys compared to leveling, the Department of Geodetic Engineering, Institute of Technology Bandung (ITB) decided to establish the new GPS network for monitoring land subsidence in the Jakarta basin, with some stations occupying points of the existing BPN network. The configuration of this GPS monitoring network is shown in Figure 3. Most of the stations (see Table 1) have reinforced concrete monuments with depths of about 1–2 m below the ground surface and were established between 1993 and 1995.

Station BAKO is the southernmost point in the network and is also the Indonesian zero order geodetic point. It is used as the reference point. BAKO is an IGS [International Global Navigation Satellite Systems (GNSS) Service] station, operated by the National Coordinating Agency for Survey and Mapping (BAKOSURTANAL).

Based on IGS daily solutions of BAKO data from 2000 to 2006, as computed by the Jet Propulsion Laboratory (JPL 2007), the global velocities of BAKO during that period are –7.63 ± 0.04 mm/year in latitude, 25.38 ± 0.13 mm/year in longitude and 2.13 ± 0.23 mm/year in height. These velocities represent the global crustal motion of the Sunda Shelf block, where the BAKO station and the Jakarta basin are located. Using yearly GPS campaign data from 1991 to 1997 and 2001, Bock et al. (2003) estimated the horizontal velocity of the block as 6 ± 3 mm/year in SE direction relative to the Eurasian plate. Since BAKO and the Jakarta basin are located in the Sunda Shelf block, all GPS subsidence monitoring stations in the Jakarta basin will experience the same crustal motion velocities. This crustal motion is taking into account when defining the coordinates of BAKO. In this study, ITRF2000 is used as the reference frame for BAKO coordinates. Moreover, since BAKO is located in the southern part of the Jakarta basin, which is geologically located on more stable volcanic deposits (Yong et al. 1995; Rismianto and Mak 1993), it can be safely assumed for the purpose of this subsidence study that it is a relatively stable station. The monument of the BAKO station (see Figure 4) was built in 1981. It is made of reinforced concrete, 2 m depth, with an underground foundation of about 1.5 · 1.5 m. It is erected 50 cm above the ground with a width of about 40 x 40 cm.

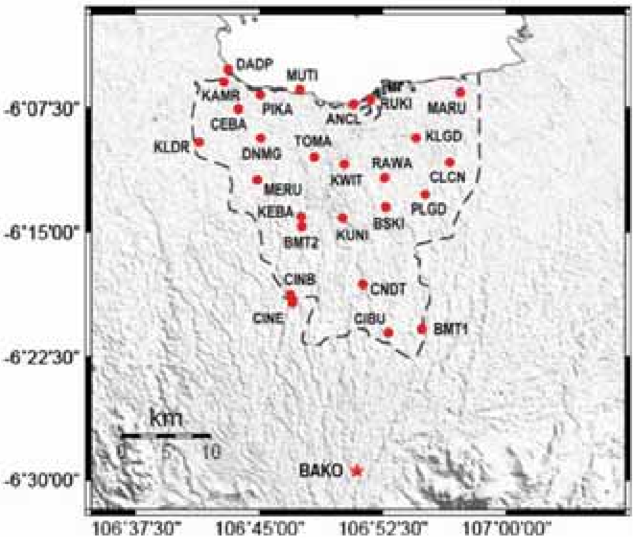


Figure 3 GPS network for monitoring land subsidence in Jakarta

The eight GPS surveys were conducted during December 1997, June 1999, June 2000, June 2001, October 2001, July 2002, December 2002 and September 2005. These surveys did not always occupy the same stations. The first survey started with 13 stations. The network then expanded subsequently to 27 stations. At certain epochs, some stations could not be observed due to the destruction of monuments or severe signal obstruction caused by growing trees and/or new construction.

The GPS surveys exclusively used dual-frequency geodetic- type GPS receivers. The length of the sessions was in general between 9 and11 h (see Table 1). The data were collected at 30 s intervals using an elevation mask of 15_. The data were processed using the software Bernese 4.2 (Beutler et al. 2001). Since we are mostly interested in the relative heights with respect to a stable point, the radial processing mode was used instead of a network adjustment mode. In this case, the relative ellipsoidal heights of all stations are determined relative to BAKO station.

Considering the length of the baselines of 40–50 km, a precise ephemeris was used instead of the broadcast ephemeris. The effects of tropospheric and ionospheric biases are mainly reduced by the differencing process and the use of dual-frequency observations. The residual tropospheric bias parameters for individual stations are estimated to further reduce the tropospheric effects. In the case of the residual ionospheric delay reduction, a local ionospheric modeling is implemented. The algorithms for the tropospheric parameter estimation and local ionospheric modeling can be found in Beutler et al. (2001). In processing baselines, most of the cycle ambiguities of the phase observations were successfully resolved.

The standard deviations of GPS -derived relative ellipsoidal heights from all surveys were in general better than 1 cm (see Figure 5). A few points have slightly larger standard deviations, due to the lack of observed data caused by the signal obstruction.

## GPS-derived land subsidence in Jakarta

In using GPS surveys method, the height change Ddhij and its rate mDdhij at each station are derived using the following relation:

$$\Delta dh_{ij} = dh(t_j) - dh(t_i) \tag{1}$$

$$v\Delta dh_{ij} = \Delta dh_{ij} \ / \ (t_j - t_j) \tag{2}$$

where $dh(t_i)$ and $dh(t_j)$ are the relative ellipsoidal heights with respect to BAKO, obtained from the $i$th and $j$th GPS surveys. Subsidence is represented by a negative value of $\Delta dh_{ij}$. All GPS -derived ellipsoidal height changes and their rates, as obtained from GPS data collected by eight GPS surveys, are given in Tables 2 and 3.

In order to statistically check the significance of the subsidence values, we apply the general linear hypothesis test (Leick 2004) to the estimated height parameter. The null hypothesis of the test is that the estimated relative ellipsoid heights at epoch j equal the estimated value of the previous epoch i., i.e., no subsidence has occurred. Therefore,

| | | |
|---|---|---|
| null hypothesis | $H_o: \ \Delta dh_{ij} = 0$ | (3) |
| alternative hypothesis | $H_a: \ \Delta dh_{ij} \neq 0$ | (4) |

The test statistics for this test is

$$t = \frac{\Delta dh_{ij}}{\hat{\sigma}\,\Delta dh_{ij}} \tag{5}$$

which has the customary Student's $t$ distribution if $H_o$ is true. The null hypothesis is rejected if

$$|t| > t_{df,\alpha/2} \tag{6}$$

where $df$ is the degrees of freedom and $\alpha$ is the significance level. In our case the degree of freedom is very large since the GPS baselines were derived using 8 to 10 hours of observations at 30 seconds interval. A $t$-distribution with infinite degree of freedom is identical to a normal distribution. At a confidence level of 99% (i.e. $\alpha = 1\%$), the critical value is $t_{\infty,0.005} = 2.576$ .

Examples of GPS -derived land subsidence at several observing stations are shown in Figs. 6 and 7. In about seven years, i.e., December 1997–September 2005, the accumulated subsidence at several GPS stations is about 25–50 cm (see Figure 6). At other stations the subsidence ranges from 25 to 70 cm in five years, i.e., June 2001–September 2005 (see Figure 7). Based on the results shown in Figs. 6 and 7, it can be concluded that land subsidence rates in the Jakarta basin have both a spatial and a temporal variation. This indicates that the sources of land subsidence in Jakarta also differ spatially.

The estimated subsidence rates during the time December1997–September 2005 are 1–10 cm/year and reach 15–20 cm/year, as shown in Figure 8. The highest rates of land subsidence occur in northwestern Jakarta. The central and northeastern parts sometimes also show quite high rates of subsidence. Figure 8 shows more clearly the nature of spatial and temporal variation of land subsidence rates in the basin. These vertical temporal variations, however, may still be contaminated by annual/semiannual signal bias that plagues all GPS temporal measurements. Joint contributions from surface mass redistribution (atmosphere, ocean, snow and soil moisture) are the primary causes of the observed annual vertical variations of GPS -derived site positions (Dong et al. 2002; Blewitt and Lavallee 2002). By using long-term (~5 years) time-series of daily GPS solutions at eight stations, Ding et al. (2005) obtained the annual and semi-annual variations in height components with the weighted means of amplitudes of about 3.6 and 2.0 mm, respectively.

Table 1 GPS stations and observation times

| GPS stations/pillars | | | | | Times of observation (h) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Name | A* | B* | C* (m) | S-1** | S-2** | S-3** | S-4** | S-5** | S-6** | S-7** | S-8** |
| 1 | BAKO | 1981 | RC | 2 | Continuous observation | | | | | | | |
| 2 | CIBU | 1993 | RC | 1.5 | 09.9 | 09.9 | 20.6 | 10.2 | 10.4 | 10.0 | 10.0 | 09.1 |
| 3 | CINE | 1994 | RC | 1 | 20.8 | 07.8 | 09.3 | n.o. | n.o. | n.o. | n.o. | n.o. |
| 4 | KEBA | 1994 | RC | 1 | 19.8 | 11.0 | 10.0 | 11.3 | 10.3 | 10.3 | 10.2 | 10.0 |
| 5 | KUNI | 1994 | RC | 1 | 10.4 | 11.4 | 10.9 | 10.5 | 10.0 | 11.0 | 10.4 | 08.6 |
| 6 | KWIT | 1993 | RC | 1.5 | 19.2 | 10.7 | 10.2 | 10.6 | 10.0 | 09.9 | 10.1 | 10.7 |
| 7 | MARU | 1993 | RC | 1.5 | 10.2 | 10.0 | 10.1 | 10.1 | 10.0 | 09.3 | 10.0 | 09.6 |
| 8 | MERU | 1994 | RC | 1 | 10.7 | 11.5 | 10.2 | 09.9 | 10.0 | 10.1 | 10.1 | 10.0 |
| 9 | MUTI | 1994 | RC | 1 | 19.6 | 10.9 | 10.1 | 10.7 | 10.6 | 10.0 | 10.2 | 06.9 |
| 10 | PIKA | 1994 | RC | 1 | 10.0 | 10.0 | 10.1 | 09.7 | 10.3 | 10.1 | 10.1 | 08.8 |
| 11 | RAWA | 1994 | RC | 1 | 10.0 | 10.3 | 11.0 | n.o. | n.o. | n.o. | n.o. | n.o. |
| 12 | RUKI | 1993 | RC | 1.5 | 19.4 | 10.0. | 10.3 | 11.3 | 10.3 | 10.2 | 10.1 | 09.7 |
| 13 | TOMA | 1993 | RC (on the roof) | 0.5 | 11.1 | 09.3 | 10.4 | 10.3 | 10.1 | 10.0 | 10.8 | 08.0 |
| 14 | ANCL | 1994 | RC | 1 | n.o. | n.o. | 10.3 | 12.9 | 10.3 | 10.0 | 10.0 | 10.1 |
| 15 | BSKI | 1994 | RC | 1 | n.o. | n.o. | 10.3 | 10.3 | 10.4 | 11.1 | 10.8 | 09.5 |
| 16 | CLCN | 1994 | RC | 1 | n.o. | n.o. | 11.6 | 04.8 | 09.8 | 12.1 | 10.4 | n.o. |
| 17 | CNDT | 1993 | RC | 1.5 | n.o. | n.o. | 10.2 | 10.0 | 09.9 | n.o. | n.o. | n.o. |
| 18 | DNMG | 1994 | RC | 1 | n.o. | n.o. | 10.1 | 09.6 | 10.0 | 09.9 | 10.2 | 10.8 |
| 19 | KAMR | 1994 | RC | 1 | n.o. | n.o. | 10.2 | 09.6 | 10.0 | 10.6 | 10.3 | n.o. |
| 20 | KLDR | 1994 | RC | 1 | n.o. | n.o. | 10.0 | 10.1 | 10.0 | 10.0 | 10.1 | 09.8 |
| 21 | KLGD | 1994 | RC | 1 | n.o. | n.o. | 10.2 | 09.9 | 10.0 | 10.5 | 10.2 | 06.7 |
| 22 | BMT1 | 1997 | RC | down to bedrock | n.o. | n.o. | n.o. | 10.2 | 13.0 | 10.5 | 10.0 | 10.3 |
| 23 | BMT2 | 1997 | RC | down to bedrock | n.o. | n.o. | n.o. | 11.3 | 09.6 | 10.0 | 10.2 | 09.0 |
| 24 | CEBA | 1994 | RC | 1 | n.o. | n.o. | n.o. | 10.1 | 10.1 | 10.0 | 10.0 | 09.6 |
| 25 | DADP | 1994 | RC | 1 | n.o. | n.o. | n.o. | 10.1 | 10.0 | 10.0 | 10.0 | 03.6 |
| 26 | PLGD | 1994 | RC | 1 | n.o. | n.o. | n.o. | 10.0 | 10.0 | 10.0 | 10.0 | 09.9 |
| 27 | CINB | 1994 | RC | 1 | n.o. | n.o. | n.o. | 10.1 | 10.1 | 10.0 | 10.3 | 08.3 |

* A establishment year, B monument type (RC = reinforced concrete), C depth of monument below the surface

** S-1–S-8 denote Survey-1–Survey-8, and they were conducted in the periods 24–26 December 1997, 29 and 30 June 1999, 31 May–3 June 2000, 14–19 June 2001, 26–31 October 2001, 2–7 July 2002, 21–26 December 2002 and 21–25 September 2005, respectively

*** n.o No observation was made


Figure 4 Monument of BAKO station

Figures 6, 7 and 8 suggest that the subsidence rates of stations over a certain observation period can slow down, accelerate or be relatively steady in comparison with the rates from the previous period. It indicates that the subsidence in the Jakarta basin is not homogeneous. The variability is due to a number of causal mechanisms, including excessive groundwater extraction, building load, sediment compaction and tectonic activities.

Our data set does not allow us to identify which of these causal mechanisms is most important or determine their spatial relationship across the basin.

## Land subsidence and groundwater extraction

The GPS surveys show that land subsidence in Jakarta exhibits spatial and temporal variations. Excessive groundwater extraction from the middle and lower aquifers of the Jakarta basin by individuals and by industry is hypothesized to be the main factor that causes land subsidence. In this hypothesis, the spatial and temporal variations of land subsidence will strongly depend on the corresponding variations of groundwater extraction, coupled with the characteristics of sedimentary layers and building loads above it. However, the detail and relation between land subsidence and excessive groundwater extraction in the whole Jakarta basin is not yet understood.

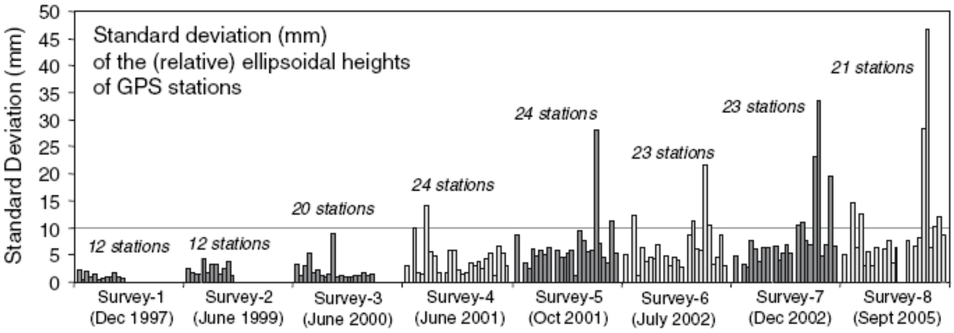


Figure 5 Standard deviations of GPS -derived relative heights in mm

Table 2 GPS-derived ellipsoidal height changes from eight surveys, in WGS84

| No | Station | $\Delta dh_{12}$ | $\Delta dh_{23}$ | $\Delta dh_{34}$ | $\Delta dh_{45}$ | $\Delta dh_{56}$ | $\Delta dh_{67}$ | $\Delta dh_{78}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | CIBU | −2.4 ± 0.3 | −4.6 ± 0.4 | −2.3 ± 0.4 | −2.9 ± 0.9 | −1.3 ± 1.0 | −0.2 ± 0.7 | −9.6 ± 0.7 |
| 2 | CINE | −3.5 ± 0.2 | −0.6 ± 0.2 | | | | | |
| 3 | KEBA | −6.9 ± 0.3 | −2.2 ± 0.3 | −4.4 ± 1.0 | −1.5 ± 1.1 | u.r. | −10.7 ± 1.3 | −19.1 ± 1.5 |
| 4 | KUNI | −4.7 ± 0.2 | −4.0 ± 0.6 | −7.9 ± 0.6 | −1.6 ± 0.3 | 0.0 ± 0.3 | −0.1 ± 0.3 | −10.6 ± 0.7 |
| 5 | KWIT | −5.7 ± 0.5 | −1.0 ± 0.5 | −0.9 ± 0.2 | −0.6 ± 0.6 | −3.0 ± 0.9 | −7.6 ± 1.0 | −29.9 ± 1.5 |
| 6 | MARU | −6.4 ± 0.2 | −0.4 ± 0.3 | −4.3 ± 1.4 | −0.1 ± 1.5 | −0.8 ± 0.6 | −0.2 ± 0.7 | −13.2 ± 0.7 |
| 7 | MERU | −5.8 ± 0.3 | −5.9 ± 0.4 | −0.3 ± 0.6 | −4.6 ± 0.8 | −1.4 ± 0.7 | −1.1 ± 0.6 | −17.2 ± 0.7 |
| 8 | MUTI | −1.2 ± 0.4 | −0.5 ± 0.4 | −5.5 ± 0.5 | −0.5 ± 0.7 | −6.1 ± 0.7 | −2.4 ± 0.8 | −34.4 ± 0.7 |
| 9 | PIKA | −6.1 ± 0.2 | −17.6 ± 0.2 | −0.4 ± 0.2 | u.r. | −6.9 ± 0.9 | −2.1 ± 0.9 | −28.0 ± 0.9 |
| 10 | RAWA | −3.8 ± 0.3 | −4.2 ± 0.9 | | | | | |
| 11 | RUKI | −16.1 ± 0.4 | −0.4 ± 0.4 | −8.5 ± 0.2 | −1.4 ± 0.6 | 0.0 ± 0.8 | 0.3 ± 0.8 | −13.4 ± 0.9 |
| 12 | TOMA | −1.2 ± 0.1 | −1.1 ± 0.2 | −2.9 ± 0.6 | −0.5 ± 0.7 | −4.4 ± 0.5 | −3.4 ± 0.5 | −29.6 ± 0.9 |
| 13 | ANCL | | | −3.4 ± 0.6 | −0.3 ± 0.7 | −2.3 ± 0.7 | −3.2 ± 0.7 | −17.8 ± 0.6 |
| 14 | BSKI | | | −1.5 ± 0.2 | −3.6 ± 0.6 | −3.9 ± 0.7 | 0.0 ± 0.8 | −15.1 ± 0.9 |
| 15 | CLCN | | | −8.1 ± 0.2 | −0.2 ± 0.6 | 0.2 ± 0.6 | −4.7 ± 0.6 | |
| 16 | CNDT | | | u.r. | −0.3 ± 0.2 | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 17 | DNMG | –25.8 ± 0.4 | –8.5 ± 1.0 | –1.8 ± 1.3 | –1.0 ± 1.4 | –28.7 ± 1.3 |
| 18 | KAMR | –9.4 ± 0.3 | –1.6 ± 0.8 | –2.9 ± 1.4 | 0.0 ± 1.6 | |
| 19 | KLDR | –13.0 ± 0.4 | –2.8 ± 0.7 | –0.4 ± 0.8 | –2.6 ± 1.0 | –14.6 ± 1.0 |
| 20 | KLGD | –1.4 ± 0.3 | –3.3 ± 0.6 | –6.7 ± 0.8 | –0.1 ± 0.9 | –16.4 ± 1.1 |
| 21 | BMT1 | | –9.2 ± 2.8 | –1.4 ± 3.5 | 0.3 ± 3.2 | 4.2 ± 3.7 |
| 22 | BMT2 | | –2.3 ± 0.9 | –9.8 ± 1.3 | u.r | u.r. |
| 23 | CEBA | | –1.1 ± 0.5 | –8.3 ± 0.6 | –2.8 ± 0.6 | –36.6 ± 0.8 |
| 24 | DADP | | –5.4 ± 0.8 | –0.7 ± 0.6 | –0.4 ± 0.8 | –21.3 ± 1.2 |
| 25 | PLGD | | –5.8 ± 1.3 | –6.1 ± 1.4 | –34.9 ± 2.1 | 2.9 ± 2.3 |
| 26 | CINB | | –1.2 ± 0.6 | –0.5 ± 0.6 | –4.3 ± 0.7 | –16.6 ± 1.1 |

The unit is (cm)

u.r. Indicates unreliable result caused by severe signal obstruction and too many cycle slips in the data

In the context of groundwater extraction, it should be noted that three aquifers are recognized inside a 250 m thick sequence of quaternary sediment of the Jakarta basin, namely, (Hadipurwo 1999) the upper aquifer, an unconfined aquifer, which occurs at a depth of less than 40 m; the middle aquifer, which is a confined aquifer and occurs at a depth between 40 and 140 m; and the lower aquifer, which is confined and occurs at a depth between 140 and 250 m. Inside these aquifers, the groundwater generally flows from south to the north. An aquifer was also found in the tertiary sediment below a depth of 250 m.

The groundwater extraction in Jakarta can be categorized into shallow (< 40 m) and deep (> 40 m) extraction. Shallow extraction is via dug or driven wells, operated with buckets, hand pumps or small electrical pumps; whereas, deep extraction is mostly from drilled wells. Shallow extraction is mostly done by individuals and the wells are generally evenly distributed across the basin and their extraction rate per well is relatively low. Deep extraction is usually conducted by industry and is localized and has a high extraction rate. The land subsidence observed in the coastal, west and northeastern parts of Jakarta are thoughtto be caused by this deep groundwater extraction, whichreduces the water pressure in the aquifer (piezometric level) (Rismianto and Mak 1993). According to Soetrisno et al. (1997), the piezometric level in north Jakarta has changed from 12.5 m above sea level in 1910 to about sea level in the 1970s, and then deepened significantly to 30–50 m below sea level in the 1990s. Figure 9 shows the piezometric levels inside the middle and lower aquifers in 1992.

Table 3 GPS-derived rates of ellipsoidal height changes from eight surveys, in WGS84

| No | Station | $v\Delta dh_{12}$ | $v\Delta dh_{23}$ | $v\Delta dh_{34}$ | $v\Delta dh_{45}$ | $v\Delta dh_{56}$ | $v\Delta dh_{67}$ | $v\Delta dh_{78}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | CIBU | –1.6 ± 0.2 | –5.0 ± 0.5 | –2.2 ± 0.4 | –7.7 ± 2.5 | –2.0 ± 1.5 | –0.4 ± 1.4 | –3.5 ± 0.3 |
| 2 | CINE | –2.3 ± 0.1 | –0.7 ± 0.2 | | | | | |
| 3 | KEBA | –4.6 ± 0.2 | –2.4 ± 0.4 | –4.2 ± 1.0 | –4.1 ± 2.8 | u.r. | –21.4 ± 2.6 | –6.9 ± 0.5 |
| 4 | KUNI | –3.1 ± 0.1 | –4.3 ± 0.6 | –7.6 ± 0.5 | –4.2 ± 0.8 | 0.0 ± 0.4 | –0.1 ± 0.6 | –3.8 ± 0.3 |
| 5 | KWIT | –3.8 ± 0.3 | –1.1 ± 0.5 | –0.8 ± 0.2 | –1.6 ± 1.6 | –4.5 ± 1.3 | –15.2 ± 2.0 | –10.9 ± 0.5 |
| 6 | MARU | –4.3 ± 0.1 | –0.5 ± 0.3 | –4.1 ± 1.4 | –0.3 ± 3.9 | –1.2 ± 0.9 | –0.4 ± 1.4 | –4.8 ± 0.2 |
| 7 | MERU | –3.9 ± 0.2 | –6.5 ± 0.4 | –0.3 ± 0.6 | –12.2 ± 2.2 | –2.0 ± 1.1 | –2.1 ± 1.2 | –6.3 ± 0.2 |
| 8 | MUTI | –0.8 ± 0.2 | –0.5 ± 0.4 | –5.3 ± 0.5 | –1.2 ± 1.9 | –9.2 ± 1.0 | –4.9 ± 1.5 | –12.5 ± 0.2 |
| 9 | PIKA | –4.1 ± 0.1 | –19.2 ± 0.2 | –0.4 ± 0.2 | u.r. | –10.3 ± 1.4 | –4.1 ± 1.9 | –10.2 ± 0.3 |
| 10 | RAWA | –2.5 ± 0.2 | –4.6 ± 1.0 | | | | | |
| 11 | RUKI | –10.8 ± 0.3 | –0.4 ± 0.4 | –8.2 ± 0.2 | –3.8 ± 1.6 | 0.0 ± 1.1 | 0.6 ± 1.6 | –4.9 ± 0.3 |
| 12 | TOMA | –0.8 ± 0.1 | –1.2 ± 0.2 | –2.8 ± 0.6 | –1.4 ± 2.0 | –6.6 ± 0.8 | –6.7 ± 1.0 | –10.8 ± 0.3 |
| 13 | ANCL | | | –3.3 ± 0.6 | –0.7 ± 2.0 | –3.5 ± 1.0 | –6.3 ± 1.4 | –6.5 ± 0.2 |
| 14 | BSKI | | | –1.5 ± 0.2 | –9.5 ± 1.5 | –5.9 ± 1.0 | –0.1 ± 1.6 | –5.5 ± 0.3 |
| 15 | CLCN | | | –7.7 ± 0.2 | –0.6 ± 1.6 | 0.3 ± 1.0 | –9.5 ± 1.2 | |
| 16 | CNDT | | | u.r. | –0.7 ± 0.5 | | | |
| 17 | DNMG | | | –24.8 ± 0.4 | –22.6 ± 2.7 | –2.7 ± 1.9 | –1.9 ± 2.7 | –10.4 ± 0.5 |
| 18 | KAMR | | | –9.0 ± 0.3 | –4.3 ± 2.2 | –4.3 ± 2.0 | 0.0 ± 3.2 | |
| 19 | KLDR | | | –12.4 ± 0.4 | –7.6 ± 1.8 | –0.6 ± 1.2 | –5.2 ± 1.9 | –5.3 ± 0.4 |
| 20 | KLGD | | | –1.3 ± 0.3 | –8.8 ± 1.6 | –10.0 ± 1.2 | –0.1 ± 1.8 | –6.0 ± 0.4 |
| 21 | BMT1 | | | | –24.6 ± 7.5 | –2.2 ± 5.3 | 0.6 ± 6.4 | 1.5 ± 1.3 |
| 22 | BMT2 | | | | –6.2 ± 2.4 | –14.8 ± 1.9 | u.r. | u.r. |
| 23 | CEBA | | | | –3.0 ± 1.3 | –12.4 ± 0.8 | –5.7 ± 1.2 | –13.3 ± 0.3 |
| 24 | DADP | | | | –14.4 ± 2.0 | –1.1 ± 0.9 | –0.8 ± 1.6 | –7.8 ± 0.4 |
| 25 | PLGD | | | | –15.4 ± 3.3 | –9.2 ± 2.1 | –69.8 ± 4.3 | 1.0 ± 0.8 |
| 26 | CINB | | | | –3.1 ± 1.6 | –0.8 ± 0.9 | –8.6 ± 1.4 | –6.0 ± 0.4 |

The unit is (cm/year)

u.r. indicates unreliable result caused by severe signal obstruction and too many cycle slips in the data

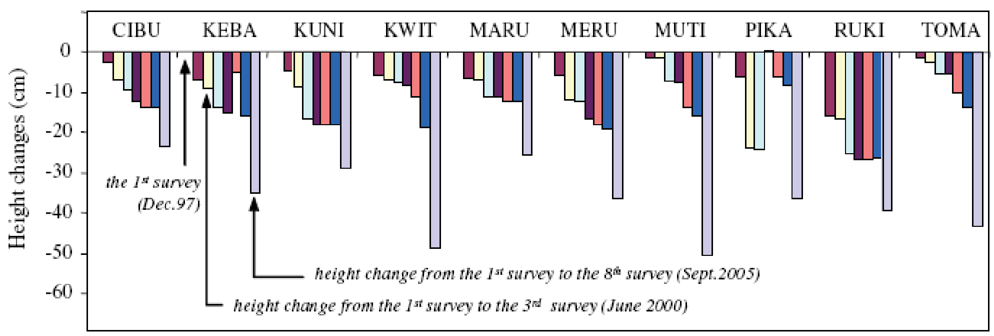


Figure 6 Accumulated GPS derived subsidence (cm) during the period of December 1997–September 2005

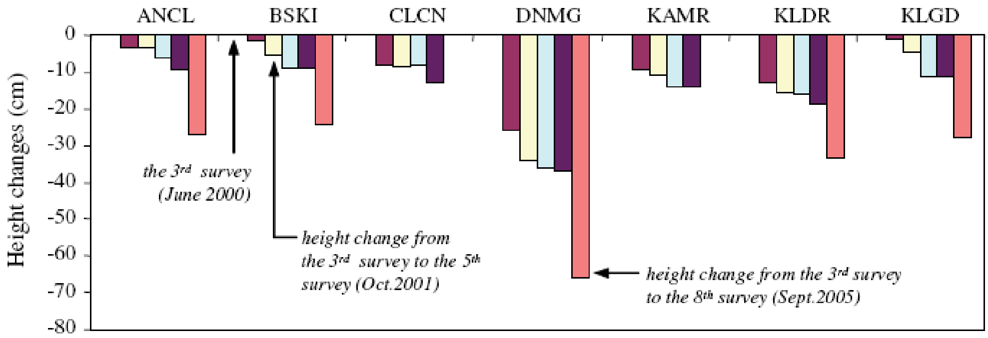


Figure 7 Accumulated GPS derived subsidence (cm) during the period of June 2001–September 2005

The measured subsidence rates established using GPS is closely related to the rate of piezometric water level (head) deepening in the middle and lower aquifers. According to Hadipurwo (1999), the maximum depth of the piezometric head inside the middle and lower aquifers tends to deepen with time. An example is shown in Figure 10. The increase in population and industry in Jakarta, which requires a lot of groundwater, could explain the declining trend of the piezometric heads. The deepening of piezometric heads in turn contributes to land subsidence in the basin.

Figure 9 shows the piezometric water level contours in 1992. If this figure is compared with the GPS -derived land subsidence rates between 1997 and 2005 shown in Figure 8, the correlation between land subsidence and excessive groundwater extraction can be seen, especially in northwestern Jakarta.

More data and further investigation are required to understand the complete relationship between land subsidence and excessive groundwater extraction in the basin. Additional causes of subsidence, e.g., load of buildings, natural consolidation of alluvial soil and tectonic movements, should also be investigated and taken into account.

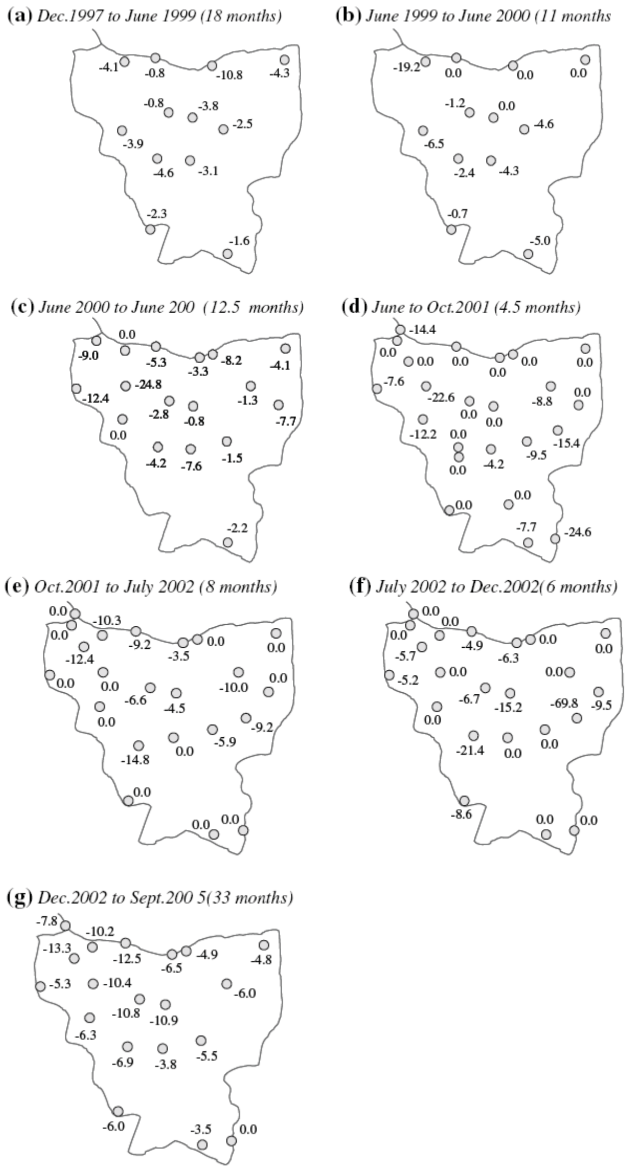


Figure 8 Rates of land subsidence (cm/year) in several places in Jakarta basin, as estimated by GPS surveys. The statistically insignificant rates (with a confidence level of 99%) are denoted with the values of 0.0 cm/year

## Closing remarks

GPS surveys are a robust method for studying and monitoring land subsidence in Jakarta. There are several advantages of using GPS : (1) GPS provides a three-dimensional displacement vector with two horizontal and one vertical component; so it provides not only land subsidence information, but also horizontal motions. (2) GPS provides the displacement vectors in a well-defined coordinate reference system, which makes it possible to effectively monitor land subsidence over large areas. (3) GPS can yield displacement vectors with a precision of several millimeters in the temporal and spatial domain. (4) GPS is available continuously, day and night, and independent of weather conditions. This makes field operations flexible.

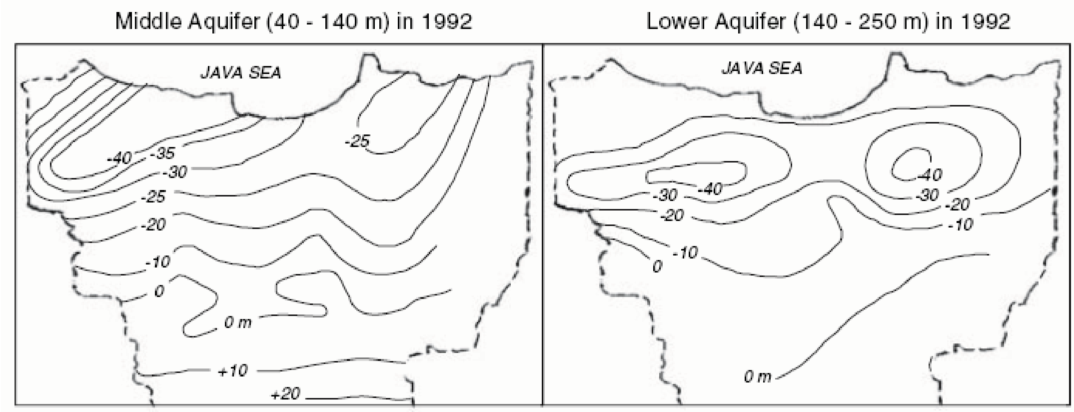


Figure 9 Piezometric water level contours (in mm) inside middle and lower aquifers of Jakarta in 1992, adapted from (Murdohardono and Tirtomihardjo 1993)

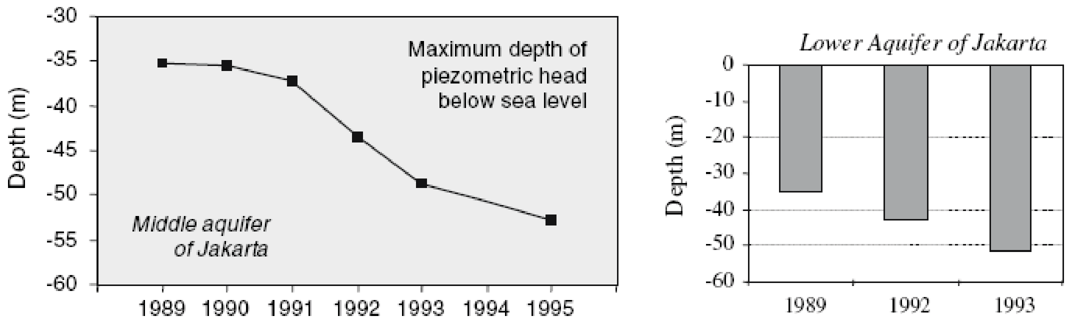


Figure 10 Example of the deepening of the piezometric head inside the middle and lower aquifers of Jakarta, drawn from the data given in Hadipurwo (1999)

Based on our experience, the main constraint for using GPS in studying land subsidence in a large city like Jakarta is signal obstruction and multipath caused by high rise buildings, trees, billboards, etc. For this reason, GPS stations cannot always be established in a desired location. Another problem is due to active development activities inside urban areas, which sometimes destroy or alter observation monuments. It should also be noted that the detection of land subsidence at the level of a couple of millimeters requires dual-frequency geodetic type receivers, good project planning, stringent observation strategy and data processing strategy available only in scientific software. Expertise in GPS data acquisition and precise data processing is therefore required.

Implementing a continuously operating GPS network in the Jakarta basin may be useful, because of the possibly large temporal variations in the rates of subsidence. These temporal variations may be difficult to observe with episodic GPS measurements. A fundamental limitation of GPS methods is that the measurements are limited to specific points with no spatial continuity. To overcome this limitation, the Interferometric Synthetic Aperture Radar (InSAR) technique (Massonnet and Feigl 1998) should be considered. InSAR provides complete spatial coverage, but is only a relative technique that requires a tie to GPS to transform it to an absolute one.

In order to achieve an even better understanding and modeling of land subsidence in the Jakarta basin, the variations derived from GPS surveys should be integrated with land subsidence information obtained from leveling and INSAR, and also with information from geohydrological and geotechnical measurements (e.g., using automatic water level recorder, piezometer, extensometer, drilling, etc.).

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# Land subsidence characteristics of the Bandung Basin, Indonesia, as estimated from GPS and InSAR

H. Z. Abidin, H. Andreas, M. Gamal, A. D. Wirakusumah, D. Darmawan, T. Deguchi and Y. Maruyama

## Abstract

The Bandung Basin is a large intramontane basin surrounded by volcanic highlands, in western Java, Indonesia, inhabited by more than five million people. Based on the results of five GPS surveys conducted in February 2000, November 2001, July 2002, June 2003, and June 2005, it can be concluded that for the period of 2000 to 2005 several locations in the Bandung Basin have experienced land subsidence. Over this 5-year period land subsidence in a few locations reached a magnitude of about 70 cm, with a subsidence speed of about 1–2 cm/month. A similar rate of subsidence was also detected by the InSAR (Interferometric Synthetic Aperture Radar) technique during the period between June 2006 and March 2007.

The statistical testing showed no strong correlation between GPS -derived land subsidence and registered groundwater extraction during the period of February 2000 to July 2002. The InSAR technique, however, detected significant subsidence in the textile industry area, which very large volumes of groundwater are usually extracted.

**Keywords.** Subsidence, GPS , InSAR, Bandung, groundwater.

## Introduction

Bandung is the capital of the West Java province, Indonesia (Figure 1). The city is surrounded by several medium-sized towns, which together form Greater Bandung area. A highland plateau lies in the catchment area of the upper Citarum River. It is surrounded by a range of hills and volcanoes, some of which are still active, and form the intra-montane basin known as the Bandung Basin.

The basin has an area of about 2300 km2 and encompasses three administrative units: the Bandung municipality, the surrounding Bandung regency (district) and part of the Sumedang regency. The central part of the basin, mostly comprising urban and industrial areas, is a plain measuring about 40 km east-west and about 30 km north-south, with an altitude of about 650 to 700 m. In 1995 the Bandung municipality had a population of about 2.5 million, and today the Bandung Basin has more than 5 million inhabitants.

There are several types of land subsidence that can be expected to occur in the Bandung Basin, namely subsidence due to groundwater extraction, subsidence induced by the load of manmade constructions (i.e. settlement of highly compressible soil), subsidence caused by natural consolidation of alluvium soil, and geotectonic subsidence. The detailed characteristics and mechanisms of land subsidence are still relatively unknown.

Since information on land subsidence characteristics will be useful for managing many developmental and environmental aspects (Figure 2), systematic and continuous monitoring of land subsidence in Bandung is obviously needed, and critical to the welfare of the city. Comprehensive information on land subsidence characteristics would be important for several tasks, such as spatial-based groundwater extraction regulation, e¤ective control of floods, conservation of environment, design and construction of infrastructure, and spatial development planning in general.

In principle, the land subsidence phenomenon can be studied using several methods, such as hydrogeology methods, e.g. ground water level observation, extensometer measurement and piezometer measurement, as well as by geodetic methods such as levelling surveys, GPS surveys and InSAR (Interferometric Synthetic Aperture Radar); see Sneed et al. (2001), Bell et al. (2002), Ge et al. (2007). In this paper the use of GPS survey and InSAR techniques (Massonnet and Feigl 1998) for studying land subsidence in Bandung will be discussed. The discussion will be based on results obtained from five GPS surveys that have been conducted in February 2000, November 2001, July 2002, June 2003 and June 2005; and InSAR results from the period between June 2006 and March 2007.

## Bandung basin and its hydrogeologic features

The Bandung Basin is a large intra-montane basin surrounded by volcanic highlands (Figure 3). The central part of the basin has an altitude of about 665 m and is surrounded by up to 2400 m high Late Tertiary and Quaternary volcanic terrain (Dam et al. 1996). The catchment area of the basin and surrounding mountains covers approximately 2300 km2, and the Citarum River with its tributaries forms the main drainage system of the basin catchment. Deposits in the basin comprise of coarse volcaniclastics, fluvial sediments and notably a thick series of lacustrine deposits. A more detailed explanation of the geologic and morphologic setting of the Bandung Basin can be found in Dam et al. (1996).


Figure 1. Location of Bandung, Indonesia.

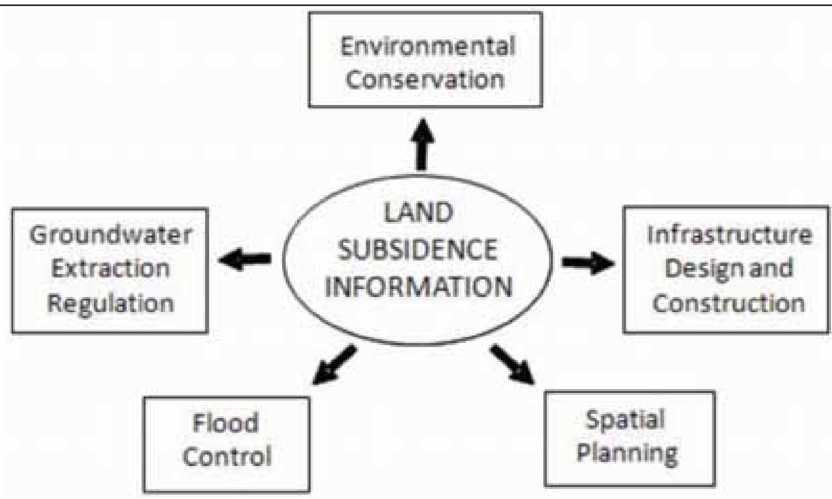


Figure 2: Benefit of land subsidence information.

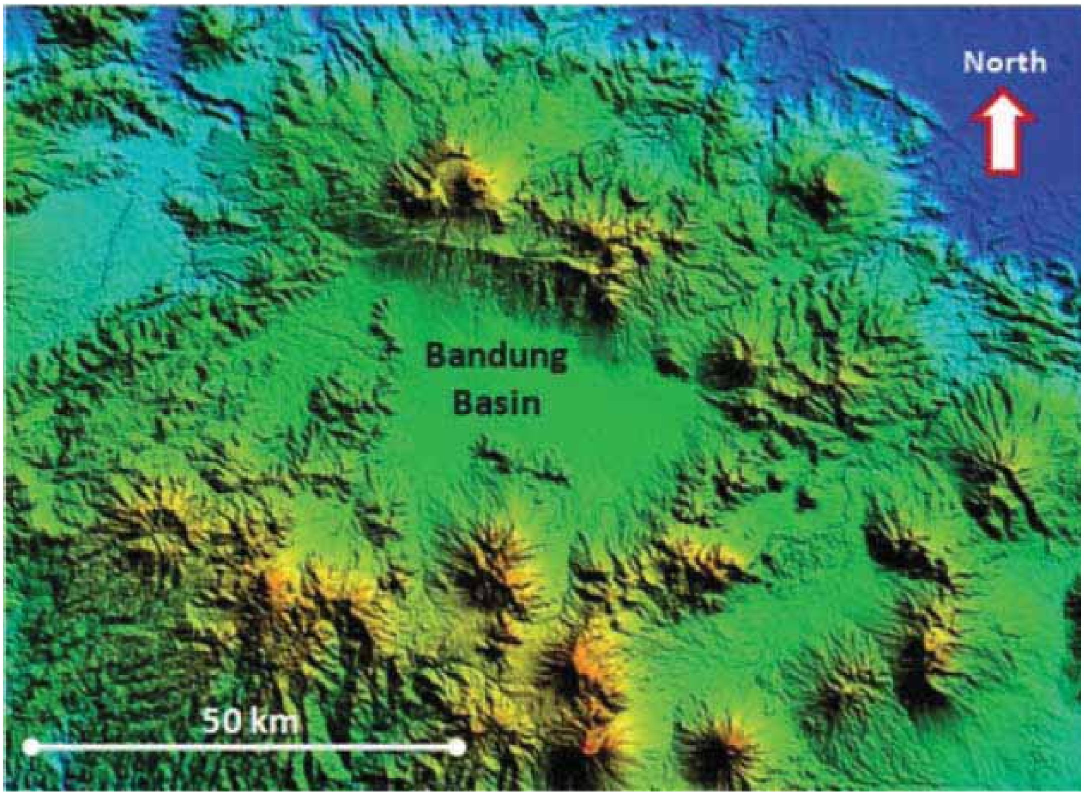


Figure 3. Bandung Basin and its surroundings.

The Bandung Basin encompasses three administrative units: the Bandung municipality, an urban area 81 km2 in size perched against the northern mountain range; the surrounding Bandung regency; and part of the Sumedang regency (Braadbaart and Braadbaart 1997). The population of the Bandung municipality increased from less than 40 000 in 1906 to nearly one million in 1961, and had grown to about two and half million by 1995. In addition, with expansion of manufacturing and textile industries in the Bandung Basin, urbanisation increased and in 2005 more than 7 million people inhabited the basin. This increase in both population and industrial activity in turn increased the degree of groundwater withdrawal from the aquifers in the Bandung Basin, as illustrated in Figure 4. According to Wirakusumah (2006), about 60% of the total clean water required in the Greater Bandung area (i.e. about 512 million cubicmetres) are supplied by groundwater; and the industry relies nearly 100% on groundwater resources.

On the basis of its hydraulic characteristics and its depth, the multi-layer aquifer configuration of the Bandung Basin may be simplified into two systems (Soetrisno 1996): shallow aquifers (a few metres to around 40 m below the surface) and deep aquifers (more than 40 m to 250 m below the surface). These aquifers are composed of volcanic products from the volcanic complexes that bordered this basin, and lake sediments that were deposited when the central part of the basin was a lake. The lake was fully formed about 50 000 years ago, and was drained away about 16 000 years ago (Dam et al. 1996).

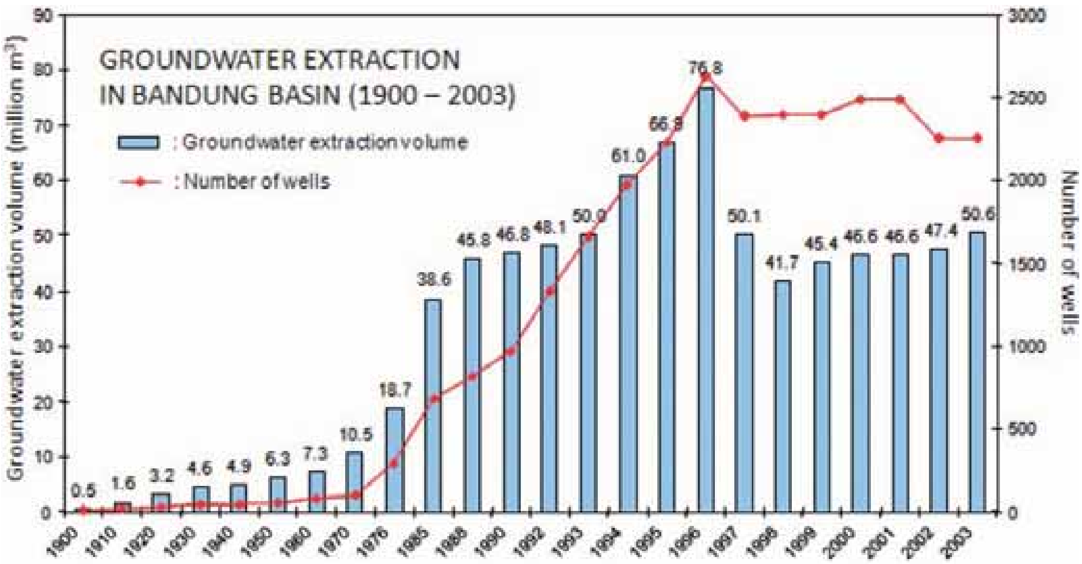


Figure 4. Registered groundwater extraction in Greater Bandung (1900–2003) from the deep aquifers, adapted from Ruchijat (2006).

Table 1. Groundwater level decreases in several locations in the Bandung Basin (Wirakusumah 2006).

| No. | Location | 1980 | 2004 |
|---|---|---|---|
| 1. | Cimahi | +15 m | –86 m |
| 2. | Kebon Kawung | +22 m | –36 m |
| 3. | Rancaekek | +1 m | –39 m |
| 4. | Lanud Sulaeman | +7 m | –14 m |
| 5. | Dayeuh Kolot | +2 m | –55 m |
| 6. | Banjaran | +2 m | –20 m |
| 7. | Majalaya | +3 m | –41 m |

Increased groundwater extraction has led to a rapid sinking of water tables on the plain (Table 1), which in turn can cause land subsidence. During the 1980s, the average annual drop in water tables in the basin was one metre, and in the most heavily extracted areas annual drops of up to 2.5 metres were recorded (Soetrisno 1991). From 1980 to 2004, i.e. over about 24 years, the groundwater level in the Bandung Basin has dropped by about 20 to 100 m, as shown in Table 1. This drop in groundwater level has both spatial and temporal variations. Increased groundwater extraction will also decrease well productivity, and has led to drastic changes in the time and direction of travel of underground water (Braadbaart and Braadbaart 1997). Continuous lowering of the groundwater level in the industrial areas has considerably changed the flow characteristics of the groundwater system, in which vertical downward leakage occurs almost in the entire Bandung Basin (Soetrisno 1996).

## GPS surveys in the Bandung basin

GPS (Global Positioning System) is a passive, allweather, satellite-based navigation and positioning system, which is designed to provide precise threedimensional position and velocity, as well as time information on a continuous worldwide basis (Wells et al. 1986, Hofmann-Wellenhof et al. 2007). For monitoring land subsidence, when the expected subsidence is of very small magnitude, the ideal positioning accuracy to be achieved is at the mm level. In order to achieve this level of accuracy the GPS static survey method based on dual-frequency carrier phase data processing should be implemented, with stringent measurement and data processing strategies (Leick 2004). Considering the fact that the achievable GPS accuracy and precision is becoming higher and higher, it could be expected that the role of GPS for monitoring land subsidence will become more and more important in the near future.

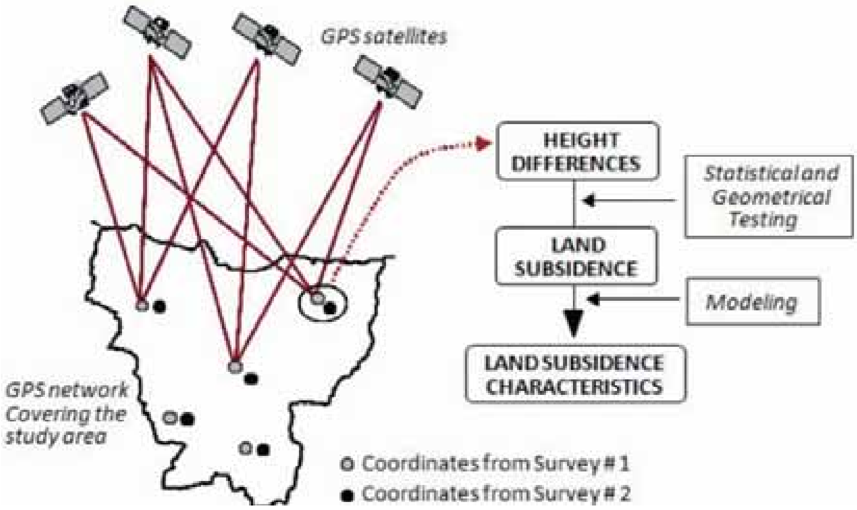


Figure 5. Principle of land subsidence monitoring using the repeated GPS survey method.

The principle of land subsidence monitoring using repeated GPS surveys is depicted in Figure 5. Using this method several monuments, which are placed on the ground covering the Bandung basin and its surroundings, are accurately positioned relative to a certain reference (stable) point, using the GPS survey technique. The precise coordinates of the monuments are periodically determined using repeated GPS surveys at certain time intervals. By studying the characteristics and rate of change in the height components of the coordinates from survey to survey, the land subsidence characteristics can be derived.

In order to study the land subsidence phenomena in the Bandung Basin, five GPS surveys have been conducted in February 2000, November 2001, July 2002, June 2003 and June 2005 (Table 2).

Table 2: GPS surveys for land subsidence monitoring in the Bandung Basin.

| | | |
|---|---|---|
| Survey-1 | 21–24 Feb. 2000 | PSCA, BNJR, BJNS, CMHI, DYHK, MJL1, RCK1, RCK2, UJBR |
| Survey-2 | 21–30 Nov. 2001 | PSCA, BRGA, BNJR, BJNS, CMHI, CPRY, DYHK, GDBG, KPO1, KPO2, MJL1, MJL2, RCK1, RCK2, UJBR |
| Survey-3 | 11–14 July 2002 | PSCA, BRGA, BNJR, BJNS, CMHI, CPRY, DYHK, GDBG, KPO1, KPO2, MJL1, MJL2, RCK1, RCK2, UJBR, BM9L, BM13L, BM18L, BM19L, BM30X, BM30L |
| Survey-4 | 1–3 June 2003 | Same as in Survey-3, except BRGA (monument was damaged) |
| Survey-5 | 24–27 June 2005 | Same as in Survey-4, except BM9L, BM19L, BM30X (monuments were missing or destroyed) |

The surveys at all stations were carried out using dual-frequency geodetic-type GPS receivers. In this case the PSCA station located inside the Institute of Technology Bandung (ITB) campus was used as the reference point with known coordinates. For all GPS surveys, except for the first survey, the length of sessions was between 10 to 12 hours. In the first GPS survey the length of sessions was about 5 to 6 hours.
The data were collected with a 30-second interval, and the elevation mask was set to 15_ for all stations. The surveys were carried out by the Geodesy Research Division of ITB, in cooperation with the Centre of Volcanology and Geological Hazard Mitigation, Ministry of Energy and Mineral Resources. The configuration of the GPS monitoring network is shown in Figure 6.

## GPS survey data processing and results

GPS data processing is carried out using the SKIPro version 2.1 commercial software. Processing is done in radial mode from the PSCA station. Since the baseline lengths are relatively short, ranging from 3 to about 23 km, scientific GPS software was not used for data processing. The PSCA station is assumed to be stable for the subsidence study, and its coordinates were computed relative to an Indonesian IGS station located in the BAKOSURTANAL area, Cibinong, Bogor, approximately 110 km away. For all computations, precise ephemerides and the Saastamoinen tropospheric model were used. The final coordinates were estimated using the ionosphere-free linear combination after fixing the integer ambiguities of the L1 and L2 signals.

For land subsidence monitoring only the ellipsoidal height components are used. Subsidence at a certain GPS station is obtained by simply di¤erencing the ellipsoidal heights of the station as estimated from two consecutive GPS surveys (see Figure 5). The standard deviations of GPS -derived relative ellipsoidal heights from five surveys that have been conducted in the Bandung Basin are depicted in Figure 7. This figure shows that in the first survey the obtained precision level of relative ellipsoidal heighting was 1–3 cm, while for the other surveys it was at the several mm level. The precision of the first survey results is inferior to the following surveys due to the shorter session lengths that were observed. It should be noted here that usually commercial software such as SKIPro gives over optimistic estimates of standard deviations.

## Estimated land subsidence

Based on the estimated ellipsoidal heights obtained from GPS processing, the height di¤erences between two consecutive survey epochs can be calculated. The height di¤erences based on five GPS surveys are given in Table 3, along with their standard deviations. In this table possible subsidence is indicated by negative values of height differences.

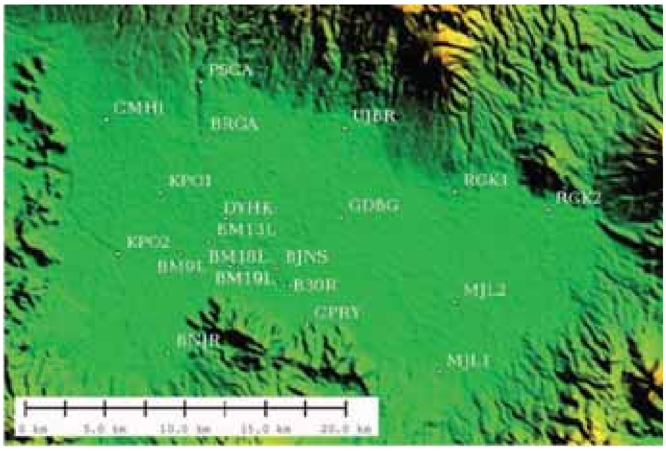


Figure 6. Distribution of GPS points for studying land subsidence in the Bandung Basin. The PSCA reference station is the northern most point in the figure.

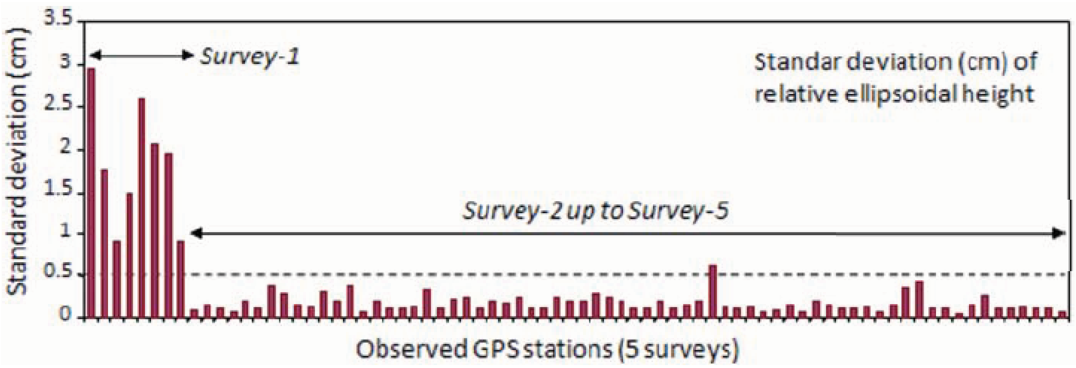


Figure 7. Standard deviations of the estimated coordinates of GPS stations from 5 surveys.

Table 3. Ellipsoidal height di¤erences (relative to PSCA) from five GPS surveys (cms).

| No. | Station | dh12 | $\sigma_{dh12}$ | dh23 | $\sigma_{dh23}$ | dh34 | $\sigma_{dh34}$ | dh45 | $\sigma_{dh45}$ |
|---|---|---|---|---|---|---|---|---|---|
| 1. | BNJR | −15.2 | 2.9 | −2.7 | 0.2 | −2.9 | 0.2 | −14.2 | 0.1 |
| 2. | BJNS | −16.1 | 1.7 | −3.0 | 0.2 | −2.6 | 0.2 | – | – |
| 3. | CMHI | −39.9 | 0.9 | −12.5 | 0.2 | −13.7 | 0.3 | −9.0 | 0.4 |
| 4. | DYHK | −32.9 | 1.5 | −12.9 | 0.2 | −3.6 | 0.2 | −16.8 | 0.2 |
| 5. | MJL1 | −14.1 | 2.6 | −1.8 | 0.2 | −7.2 | 0.2 | 5.9* | 0.2 |
| 6. | RCK1 | −21.1 | 2.1 | −3.8 | 0.3 | 13.1* | 0.3 | −6.6 | 0.1 |
| 7. | RCK2 | −31.5 | 2.0 | −10.5 | 0.4 | −0.7 | 0.2 | −14.3 | 0.1 |
| 8. | UJBR | −5.4 | 1.0 | −1.2 | 0.1 | −5.3 | 0.2 | 14.3* | 0.2 |
| 9. | BRGA | – | – | −8.4 | 0.2 | – | – | – | – |
| 10. | CPRY | – | – | −2.1 | 0.4 | 9.1* | 0.3 | 3.1* | 0.4 |
| 11. | GDBG | – | – | −0.8 | 0.4 | −14.7 | 0.3 | −8.2 | 16.3 |
| 12. | KPO1 | – | – | 0.2* | 0.4 | −6.1 | 0.7 | −2.7 | 0.6 |
| 13. | KPO2 | – | – | −0.1 | 0.2 | −5.3 | 0.2 | −10.5 | 0.1 |
| 14. | MJL2 | – | – | 3.1* | 0.4 | −3.0 | 0.2 | −7.6 | 0.3 |
| 15. | BM9L | – | – | – | – | −16.7 | 0.3 | – | – |
| 16. | BM13L | – | – | – | – | −5.0 | 0.3 | −21.2 | 0.2 |
| 17. | BM18L | – | – | – | – | −13.9 | 0.3 | −20.7 | 0.2 |
| 18. | BM19L | – | – | – | – | −4.9 | 0.3 | – | – |
| 19. | BM30X | – | – | – | – | 19.8* | 0.3 | – | – |
| 20. | BM30L | – | – | – | – | −8.9 | 0.3 | 3.5 | 0.2 |

* uplift

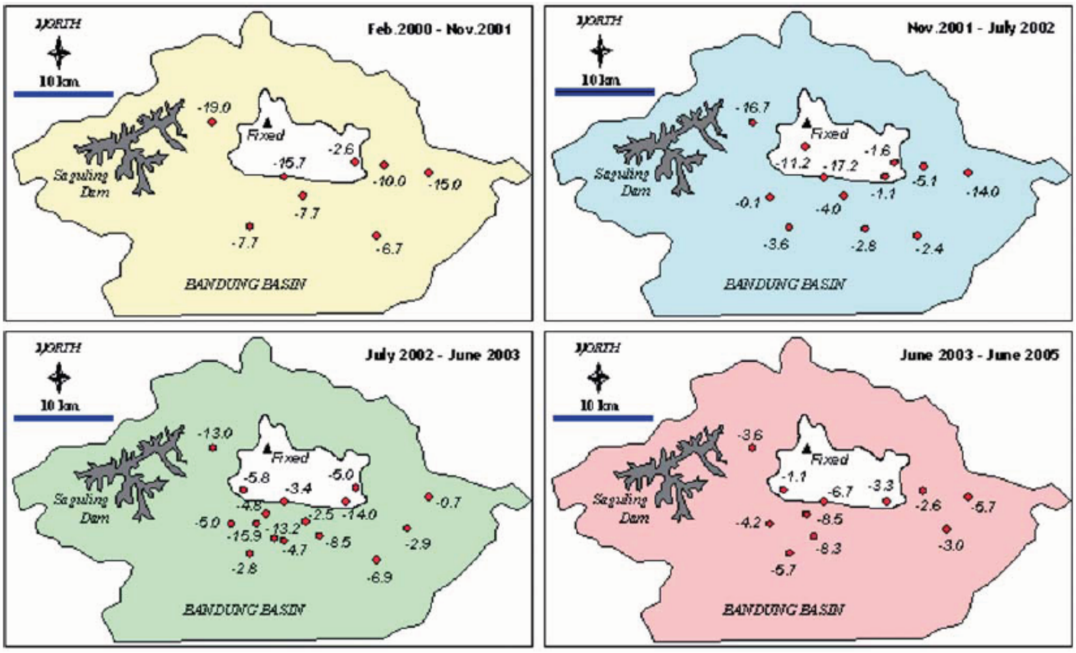


Figure 8. Temporal and spatial variation of subsidence rates (mm/month) in the Bandung Basin during the period 2000 to 2005.

In order to statistically check the significance of the subsidence values measured by GPS surveys, the congruency test (Caspary 1987) was performed. The null hypothesis of the test is that the relative ellipsoid heights of two consecutive epochs (e.g. i and j ) are stable, i.e. there is no subsidence. Therefore:

null hypothesis $H_o : \ \Delta dh_{ij} = 0$ (1)

alternative hypothesis $H_a : \ \Delta dh_{ij} \neq 0$ (2)

The test statistics for this test is

$$t = \frac{\Delta dh_{ij}}{\hat{\sigma}\ \Delta dh_{ij}} \qquad (3)$$

which has the customary Student's $t$ distribution if $H_o$ is true. The region where the null hypothesis is rejected is (Wolf and Ghilani 1997):

$$|t| > t_{df,\alpha/2} \qquad (4)$$

where $df$ is the degree of freedom and α is the significance level used for the test. In our case, for baselines derived using 10 to 12 hours of GPS data a 30-second data interval, then $df \rightarrow \infty$. Note that a $t$-distribution with infinite degree of freedom is identical to a normal distribution. If a confidence level of 99% (i.e. $\alpha = 1\%$) is used, then the critical value $t_{\infty,0.005} = 2.576$ (Wolf and Ghilani 1997). If these values are adopted for the congruency test, then significant subsidence is found in all the stations in all four observed periods, except for stations GDBG and KPO2 in the second observed period (i.e. November 2001–July 2002), and GDBG in the fourth period (i.e. June 2003–June 2005). The statistical test was only applied to the negative values of height differences. Therefore in the fourth period uplifted stations MJL1, UJBR and CPRY were not tested.

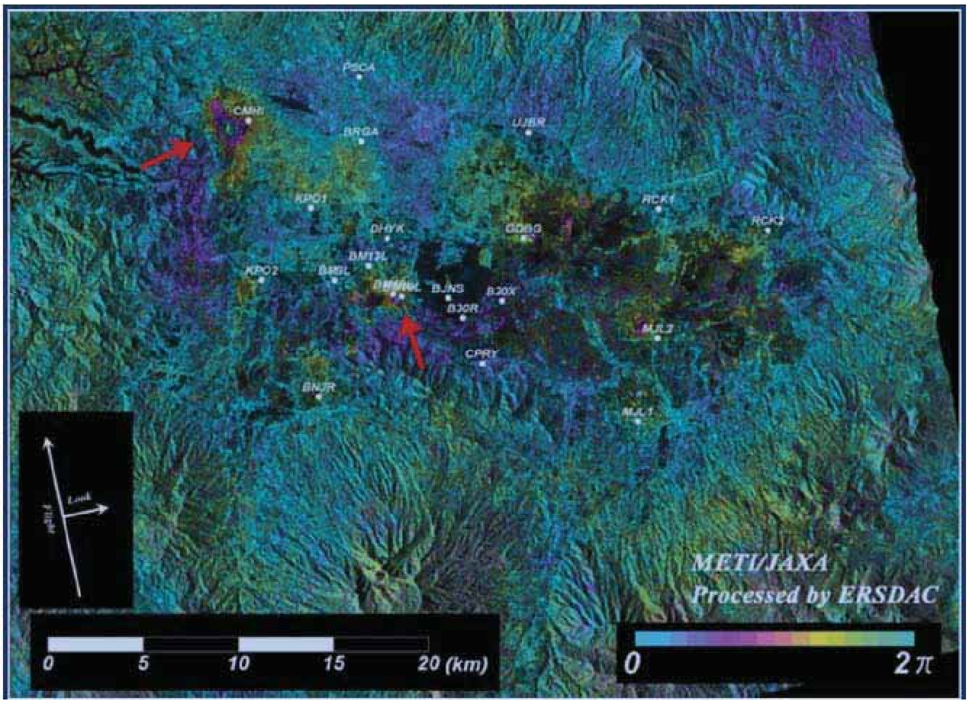


Figure 9. InSAR-derived subsidence in the Bandung Basin during the period 3 June 2006 to 6 March 2007 (about 9 months).

Based on the testing results, it can be statistically concluded that with 99% confidence level there was subsidence observed by GPS surveys at most of the stations during the four observed periods. Land subsidence in Bandung has both temporal and spatial variations as indicated by Figure 8. In general, rates of subsidence are about 2–20 mm/month, or 2–24 cm/year. Several stations, e.g. CMHI, DYHK, RCK2, GDBG, BM9L and BM18L (see Figure 6), have higher subsidence rates compared to others, namely around 1–2 cm/month or 12–24 cm/year. Stations CMHI, DYHK, RCK2 and GDBG are located in the textile industry areas, where excessive groundwater extraction is expected to occur; while BM9L and BM18L stations are located on the bank of the Citarum River. The results in Figure 8 also show that subsidence rates are not always linear. Several stations show a slowing down of subsidence, while others do not. These results indicate that the mechanism of land subsidence in the Bandung Basin is not simple and may be caused by several factors, such as excessive groundwater extraction, building load, sediment compaction, and tectonic activities. The underlying process responsible for the uplift observed in some cases is still unknown, and investigations are still to be carried out to understand this phenomenon.

## Land subsidence from InSAR

Subsidence in the Bandung Basin seems to be continuing to the present day. Based on the results obtained from InSAR (Interferometric Synthetic Aperture Radar) using ALOS/PALSAR data, subsidence of over 12 cm occurred during the period between June 2006 and March 2007, near GPS stations CMHI, BM18L and BM19L (Figure 9). The InSAR technique applied to the Bandung Basin uses data from the ALOS/PALSAR satellite, which was launched in January 2006 as a successor of JERS-1/SAR. Figure 9 was generated from SAR data observed on 3 June 2006 and 6 March 2007. The images were acquired in Fine Beam Single Polarisation mode (HH polarisation) with an o¤-nadir angle of 41.5_. InSAR processing was performed using Level 1.1 products (SLC: Single Look Complex) distributed to the public by ERSDAC. The processing software for InSAR was developed by Deguchi (2005) and Deguchi et al. (2006). From the results obtained using PALSAR data some clear phase anomalies were detected around Bandung (CMHI, BM18L, BM19L and others). The colour pattern from blue to red (blue-yellow-red) indicates that the surface has deformed away from the SAR sensor position. One cycle of phase corresponds to approximately 11.8 cm (half the wavelength of the L-band). From this image, around the CMHI station the phase anomalies imply land subsidence during the 276 days that is equivalent to 15 cm (1.3 cm/ month) in the look direction of the SAR sensor. If a conversion of look direction into ellipsoidal normal is made, then this rate of subsidence around the CMHI station is in agreement with the previous rates obtained from GPS surveys, which is about 1–2 cm/month.

## Representation of subsidence in the field

The results obtained by the GPS surveys and InSAR show that land subsidence is indeed real and have been occurring in several places in the Bandung Basin with maximum rates of about 1–2 cm per month. Furthermore, subsidence in the Bandung Basin has spatial and temporal variation. Its representation in the field can be observed in the form of ground lowering or fracturing, and other structural deformation around the subsidence areas, as shown in Figure 10.


Figure 10. Examples of subsidence features in the field. A and B: ground lowering and hanging wall in the Leuwigajah area (around CMHI GPS station); C: di¤erential subsidence around GDBG GPS station; D: structural cracking around DYHK GPS station.

## Land subsidence and groundwater extraction

A hypothesis has been proposed by several studies (Soetrisno 1991, Braadbaart and Braadbaart 1997, IGES 2006) that land subsidence observed in several locations in the Bandung Basin has been caused by excessive groundwater extraction. The two primary categories of groundwater withdrawers in the basin are shallow well pumps and deep well pumps. The majority of shallow wells are used for domestic purposes, while deep wells are operated by the regional water company or by private firms such as textile industries, manufacturing companies and hotels (Braadbaart and Braadbaart 1997).

The above hypothesis is however not always true, as indicated by the example shown in Figure 11. This figure shows example of observed land subsidence on several GPS points and the registered groundwater extraction rates around the corresponding GPS points (i.e. inside 1 km radius). During the two observed periods, the Figure shows that in general there is no correlation between subsidence and registered groundwater extraction rate, except for the CMHI station. In order to gain more insight into a possible correlation between land subsidence and groundwater extraction variables, Spearman's rank correlation coefficients ($R$) are computed for the two observed periods. The coefficient is a non-parametric (distribution-free) rank statistic proposed by Spearman in 1904 as a measure of the strength of the associations between two variables (Lehmann and D'Abrera 1998). The coefficient can be computed using the following relation (Mulholland and Jones 1981):

$$R = 1 - \frac{6\sum d^2}{n(n^2-1)} \qquad (5)$$

where d is the di¤erence between the ranks of both variables and n is the number of pairs being correlated. The computed rank coefficient correlations for the (Feb. 2000–Nov. 2001) and (Nov. 2001–July 2002) periods are 0.643 and 0.827, respectively.

In order to statistically check the significance of correlation between land subsidence and ground water extraction, a statistical test was performed using a computed rank coefficient R as the test statistic. The hypotheses used for the test were:

$H_0$: there is no correlation between the ranked pairs; and
$H_a$: ranked pairs are correlated:

The rejection region for the null hypothesis is (Mendenhall and Sincich 1989):

$$R \geq R_0\ (n,\alpha)\,, \qquad (6)$$

where α is the significance level used for the test. The values of $R_0(n,\alpha)$ for $4 < n < 31$ and $\alpha$ = *(0.05, 0.025, 0.01 and 0.005)* can be found in Mendenhall and Sincich (1989). The results of statistical testing with a 99% confidence level (i.e. $\alpha = 0.01$) are shown in Table 4.

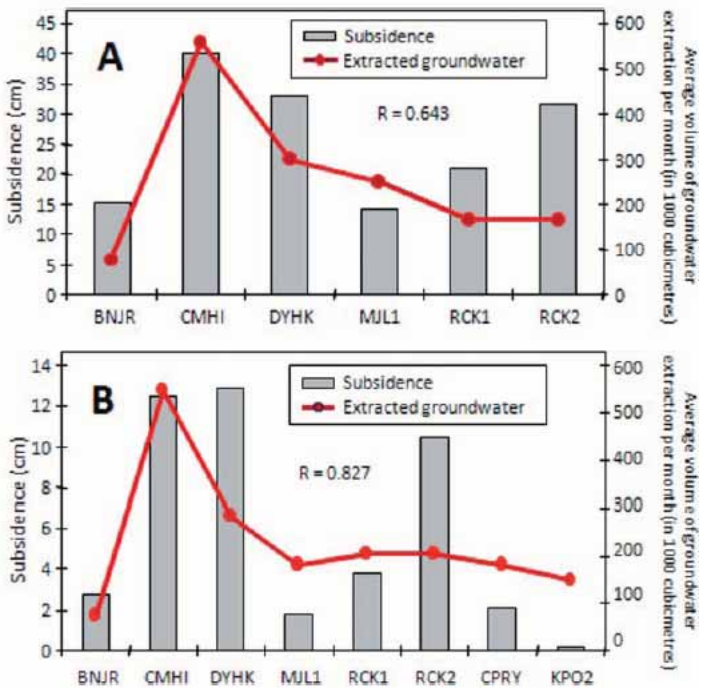

Figure 11. Example of land subsidence at several GPS stations and the registered volume of groundwater extraction in the area around GPS stations. A is for (February 2000–November 2001) period and B is for (November 2001–July 2002) period. In this Figure, R is Spearman's rank correlation coefficient.

Table 4. Results of Spearman's non-parametric test for rank correlation.

| Period | $R$ | $n$ | $\alpha$ | $R_0(n, \alpha)$ | $H_0$ is rejected? |
|---|---|---|---|---|---|
| Feb. 2000–Nov. 2001 | 0.643 | 6 | 0.01 | 0.943 | no |
| Nov. 2001–July 2002 | 0.827 | 8 | 0.01 | 0.833 | no |

Based on the above test results, it can be statistically concluded that with 99% confidence level there was no significant correlation between the GPS -observed land subsidence and the registered groundwater extraction rates during the period February 2000 to July 2002.

This fact could imply two things; firstly the registered groundwater extraction volume does not reflect the real groundwater use, and secondly the amount of land subsidence is also influenced by other factors, such as the di¤erent geological structures and soil compressibility at the observed locations. In the case of the Bandung Basin both reasons may be valid.

Although statistically there is no strong correlation, in reality subsidence in the Bandung Basin seems to be strongly a¤ected by excessive groundwater extraction. According to Hutasoit (2008), the registered groundwater extraction volume is just about 30% of the actual amount. In 1995, the illegal extraction of groundwater was estimated to be 120% of the registered volume (Soetrisno 1996). Moreover, from evidence found in the field, the significant InSARobserved subsidence shown in Figure 9 is located in the textile industry area. It is known that the textile industry usually extracts very large volumes of groundwater.

Excessive groundwater extraction will generally lower the groundwater level in the corresponding area. Therefore it can be expected that subsidence of certain areas will have a positive correlation with the lowering of the groundwater level. Examples in Figure 12 and 13 show that this correlation does exist in the Rancaekek area.

However, further research is needed to clarify the real correlation pattern between land subsidence, groundwater extraction volume and groundwater level in the Bandung Basin. More geodetic and hydrogeological data are needed in order to gain greater insight into subsidence characteristics in the Bandung Basin.

## Closing remarks

Based on the results obtained from land subsidence monitoring in the Bandung Basin, it can be concluded that the GPS survey technique is a reliable method for studying and monitoring land subsidence phenomena. The method is capable of detecting a land subsidence signal that has a relatively small magnitude (of the order of a few cm, or even several mm), although achieving this level of accuracy is not an easy task. In this case the use of dual-frequency geodetic-type receivers is essential, along with good survey planning, a stringent observation strategy, and careful data processing. Although for relatively short baselines (e.g. less than 30 km) the use of commercial GPS software is sufficient for land subsidence studies, for longer baselines use of a scientific software is preferable.

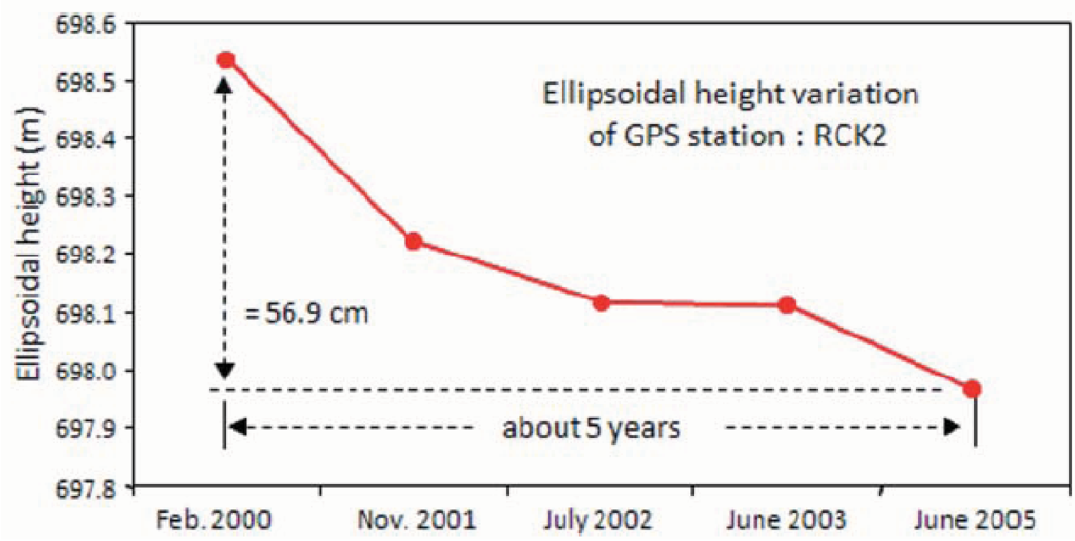


Figure 12. Subsidence of the RCK2 station located in the Rancaekek area.

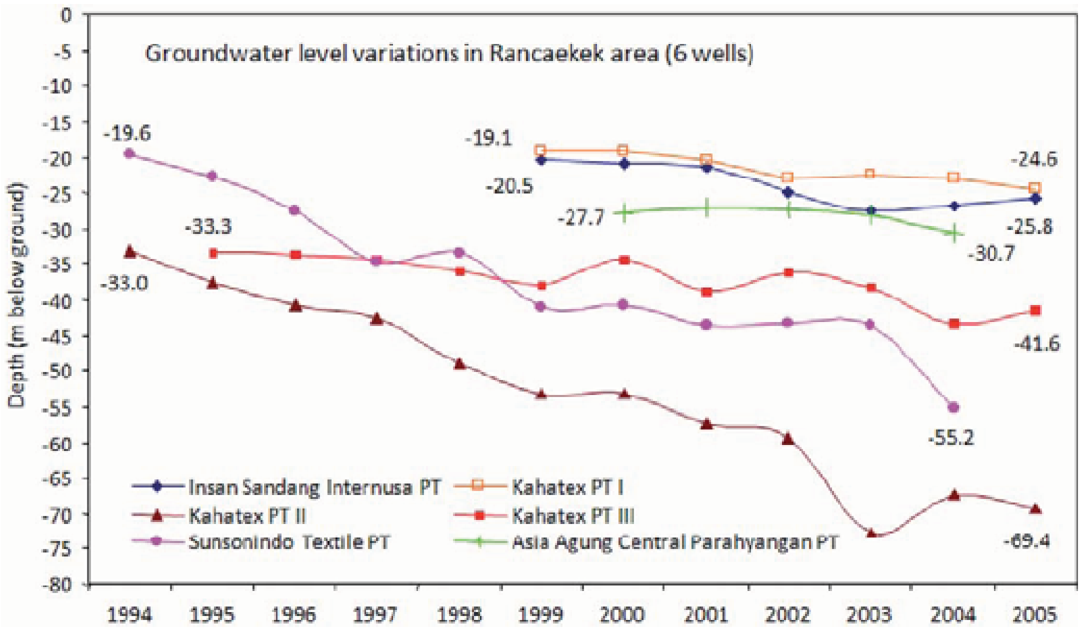


Figure 13. Indication of groundwater level fall in the Rancaekek area, adapted from Wirakusumah (2006).

In comparison with GPS techniques which give the subsidence information just on the observation points, InSAR can provide accurate subsidence information on a more continuous spatial domain with a few cm accuracy level. However, time frames for studying land subsidence will be dictated by the passing times of radar satellites over the studied area. Moreover, in the context of data processing, the relatively dense vegetation of urban areas in Indonesia, its relatively rapid environmental changes and its relatively dynamic atmospheric conditions need careful attention and treatment.

This study shows that a combination of GPS surveys and InSAR results are useful for studying and monitoring land subsidence phenomena. Besides complementing each other, both spatially and temporally, they can also be used to check against one another for quality assurance purposes.

In the case of land subsidence in the Bandung Basin, excessive groundwater extraction is hypothesized as being the main cause of land subsidence. The comparison between GPS -derived subsidence rates and the registered groundwater extraction volume for the period February 2000 to July 2002, however indicates that this hypothesis is not always true. This can be due to the large volume of unregistered groundwater extraction as well as other factors such as construction load, natural consolidation and geotectonic phenomena. The InSAR technique did however detect that significant subsidence occurred in the textile industry area, where very large volumes of groundwater are usually extracted. This InSAR result supports the hypothesis that excessive ground water extraction has led to subsidence in the corresponding area. However, further research is still needed to clarify the real mechanism and pattern of land subsidence in the Bandung Basin. In this regard, besides carefully considering all possible factors influencing subsidence in the Bandung Basin, the GPS and InSAR derived results should also be integrated with results obtained by other monitoring techniques such as levelling and automatic water level recorders. Comparison between incident rainfall with time and observed land subsidence, and the delay between rainfall and water entering the water table should also be studied in order to gain a better insight of the land subsidence characteristics in the Bandung Basin.

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# Crustal Deformation Studies In Java (Indonesia) Using GPS

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## Abstract

Along the Java trench the Australian–Oceanic plate is moving and pushing onto and subducting beneath the Java continental crust at a relative motion of about 70mm/yr in NNE direction. This subduction-zone process imposed tectonic stresses on the forearc region offshore and on the land of Java, thus causing the formation of earthquake fault zones to accommodate the plate movement. Historically, several large earthquakes happened in Java, including West Java. This research use GPS surveys method to study the inter-seismic deformation of three active faults in West Java region (i.e. Cimandiri, Lembang and Baribis faults), and the co-seismic and post-seismic deformation related to the May 2006 Yogyakarta and the July 2006 South Java earthquakes.

Based on GPS surveys results it was found that the area around Cimandiri, Lembang and Baribis fault zones have the horizontal displacements of about 1 to 2 cm/yr or less. Further research is however still needed to extract the real inter-seismic deformation of the faults from those GPS -derived displacements. GPS surveys have also estimated that the May 2006 Yogyakarta earthquake was caused by the sinistral movement of the (Opak) fault with horizontal co-seismic deformation that generally was less than 10 cm. The post-seismic horizontal deformation of the July 2006 South Java tsunami earthquake has also been estimated using GPS surveys data. In the first year after the earthquake (2006 to 2007), the post-seismic deformation is generally less than 5 cm; and it becomes generally less than 3 cm in the second year (2007 to 2008).

*Keywords*: Crustal deformation; Java.

## Introduction

Along the Java trench the Australian–Oceanic plate is moving and pushing on to and subducting beneath the Java continental crust at a relative motion of about 70mm/yr in NNE direction. According to Natawidjaya [2006], this subduction-zone process imposes tectonic stresses on the fore-arc region offshore and on land of Java, thus causes the formation of earthquake fault zones to accommodate the plate movement. Historically, several large earthquakes happened in Java, as reported by Newcomb and McCann [1987].

This research uses GPS surveys method to study the activities of three active faults in West Java region. These faults are the Cimandiri, Lembang and Baribis faults (see Figure 1). The study of co-seismic and post-seismic deformation related to the May 2006 Yogyakarta and the July 2006 South Java earthquake are also the concern of this crustal deformation study. Several GPS campaigns have been conducted (see Table 1). GPS monitoring networks used in this study are shown in Figure 2.

All GPS data processing were carried out using Bernese 5.0 scientific processing software [Beutler *et al.*, 2007]. The IGS (International GNSS Service) precise ephemeris was used, and the coordinate reference system was established by connecting to 20 IGS stations around Indonesia, namely ALIC, BAHR, BAKO, CEDU, COCO, DARW, DGAR, GUAM, IISC, KARR, KIT3, KUNM, LHAZ, MATE, PIMO, TID2, TOW2, TSKB, WUHN, YAR2 [IGS, 2008].

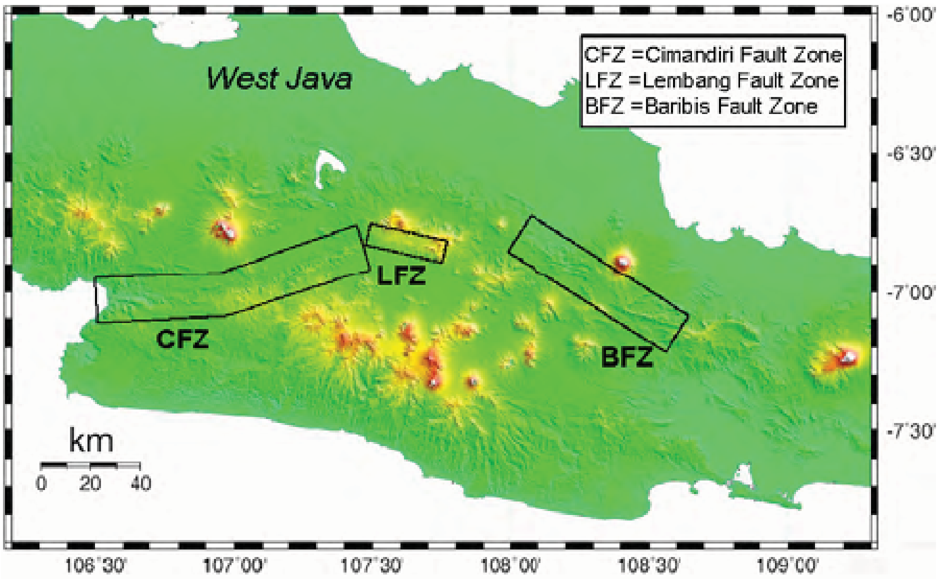

Figure 1. Active faults in the West Java region.

Table 1. GPS Surveys that have been conducted.

| Faults or Earthquake Area | Time of GPS Surveys |
|---|---|
| Cimandiri Fault | 1–4 Dec. 2006; 20–23 Aug. 2007; and 8–12 Aug. 2008 |
| Lembang Fault | 22–24 June 2006; 09–13 Nov. 2006; 16–19 Aug. 2007; and 13–16 Aug. 2008 |
| Baribis Fault | 1–4 May 2007; and 3–6 Nov. 2007 |
| Pangandaran (July 2006 South Java earthquake) | 23–30 July 2006; 9–15 Aug. 2007; and 1–5 Aug. 2008 |
| Yogyakarta (May 2006 Yogyakarta earthquake) | 4–8 June 2006 and 21–26 June 2008 |

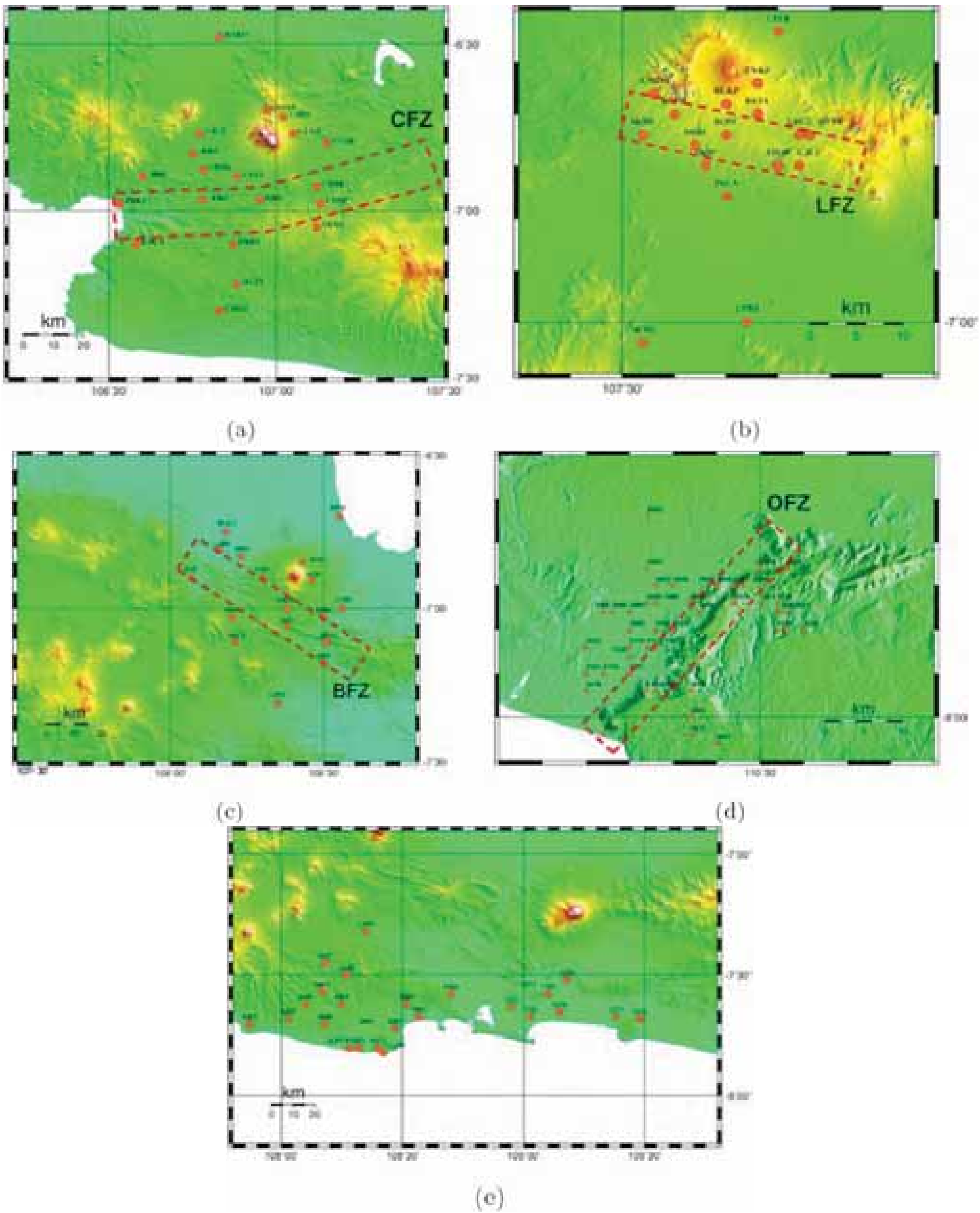


Figure 2. GPS monitoring networks for studying inter-seismic deformation in Cimandiri

fault (a), Lembang fault (b), Baribis fault (c); post-seismic deformation of the 2006 Yogyakarta earthquake (d); and post-seismic deformation of the 2006 South Java earthquake (e). In this picture CFZ, LFZ, BFZ and OFZ are Cimandiri, Lembang, Baribis and Opak Fault Zones, respectively.

## Inter-Seismic Deformation of the Lembang, Cimandiri and Baribis Faults

*Lembang fault* is topographically and geologically remarkable and runs about 10 km north of Bandung in the EW direction as shown in Figure 1. According to the Directorate of Environmental Geology, the Lembang fault has an earthquake cycle of about 500 years [Pikiran Rakyat, 2004]. Relatively large population is living around the fault area, e.g. city of Bandung and town of Lembang. *Cimandiri fault* is an active fault in Sukabumi area (West Java), which runs in the direction from Pelabuhan Ratu, passing Sukabumi, Cianjur and Padalarang as shown in Figure 1. According to Darji *et al.* [1994], Cimandiri is a sinistral strike-slip fault. Several previous earthquakes such as Pelabuhanratu earthquake [1900], Cibadak earthquake [1973], Gandasoli earthquake [1982], Padalarang earthquake [1910], Tanjungsari earthquake [1972], Conggeang earthquake [1948], and Sukabumi earthquake [2001], occurred along the Cimandiri fault. *Baribis fault* is a thrust fault in the region of Subang–Majalengka–Kuningan, in the eastern part of West Java. Its existence is first proposed by van Bemmelen [1949], based on the name of hilly region of Baribis, located southwest of Majalengka and west of Ciremai volcano. Baribis fault can be considered as an active fault, since there have been several earthquakes occurring in the region along this fault.

Inter-seismic deformation of Lembang, Cimandiri and Baribis faults are derived from the position displacements as estimated from consecutive GPS surveys. If more than two campaigns have been conducted, then the average displacement rates were estimated. The horizontal displacements around Lembang, Cimandiri and Baribis faults as obtained from GPS surveys are shown in Figs. 3–5. The reference frame of the displacement vectors is ITRF 2000.

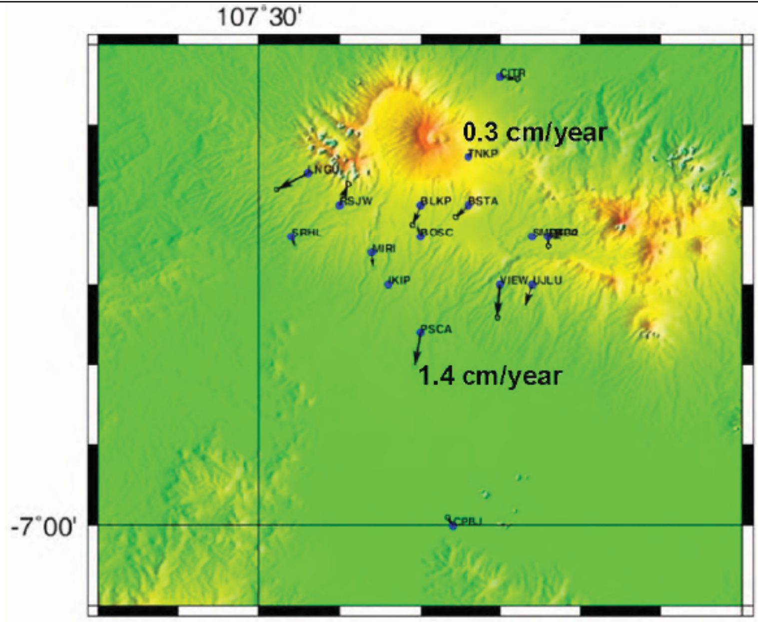


Figure 3. Average horizontal displacement rates of the area around Lembang fault, as estimated from GPS surveys on June 2006, August 2007 and August 2008. The rates vary spatially between 0.3 to 1.4cm/yr.

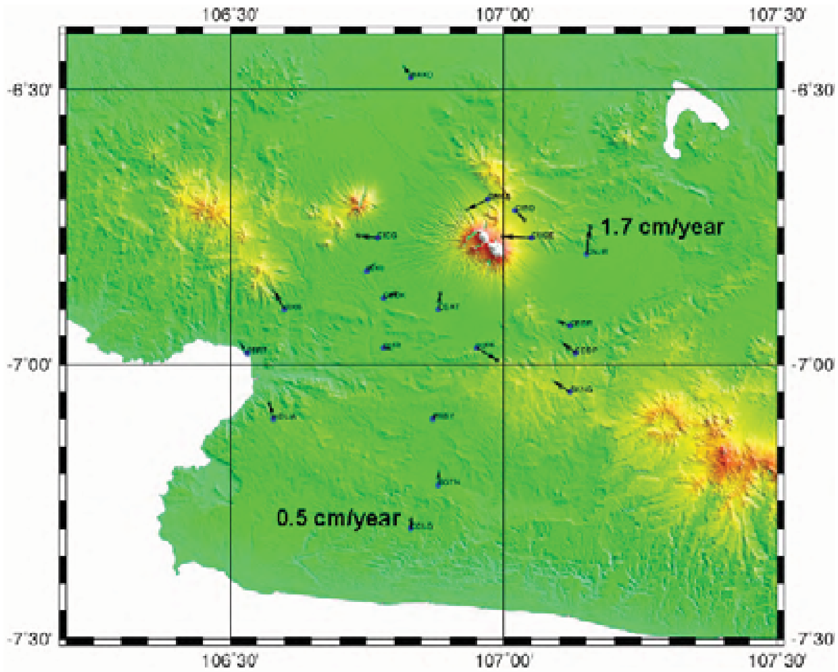


Figure 4. Average horizontal displacement rates of the area around Cimandiri fault, as estimated from GPS surveys on December 2006, August 2007 and August 2008. The rates vary spatially between 0.5 to 1.7 cm/yr.

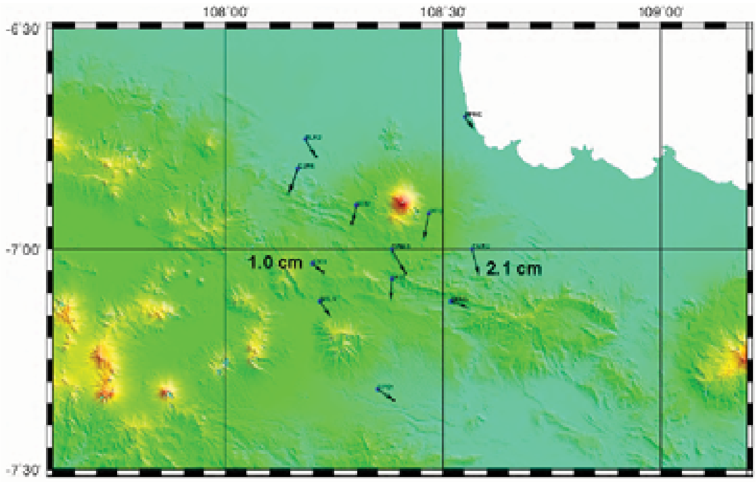


Figure 5. Horizontal displacements of the area around Baribis fault, as estimated from GPS surveys on June 2007 and November 2007. The displacements vary spatially between 1.0 to 2.1 cm.

Inter-seismic horizontal displacement rates around the Lembang fault area, as estimated from GPS surveys conducted on June 2006, August 2007 and August 2008, are shown in Figure 3. The displacement due to the Sunda block motion, with the rate of about 2.7 cm/yr with the south-east direction [Bock *et al.*, 2003] has been removed. However, the horizontal displacement rates between 0.3 to 1.4 cm/yr, are still apparent. Since the northern and southern parts of the Lembang fault are moving with relatively the same direction, this displacement should not be fully related to the activity of the Lembang fault.

These apparent horizontal displacements may be due to co-seismic deformation of the Indramayu earthquake (7.5Mw, depth of 290km) that occurred on Thursday, August 09, 2007 at 12:04:58 a.m. with its epicenter located at about 115km north of the Lembang fault [USGS, 2007]. This earthquake occurred about a week before the last GPS campaign in Lembang fault, i.e. 16–19 August 2007. Therefore, the displacements shown in Figure 5 may also contain the initial part of post-seismic deformation. However, more research and analysis should be performed to clarify this hypothesis.

Related to the Cimandiri fault, the horizontal displacement rates as estimated from GPS surveys conducted on December 2006, August 2007 and August 2008 are shown in Figure 4. The displacements due to the Sunda block motion have been removed from the solution. From Figure 4 it can be realized that the area around Cimandiri fault moves with different rates and directions, with the rates vary spatially between 0.5 to 1.7 cm/yr. In order to verify whether these motions are due to the fault activity or not, more GPS surveys should be conducted.

The estimated inter-seismic horizontal displacements in the Baribis fault area as obtained from GPS surveys conducted on May and November 2007, after a removal of the Sunda block motion, is shown in Figure 5. During this period, the displacements vary spatially between 1.0 to 2.1 cm.

Since the northern and southern parts of the Baribis fault are moving with relatively the same direction, this displacement should not be fully related to the activity of Baribis fault. As in the case of the Lembang fault, these apparent horizontal displacements may also contain the post-seismic deformation signal of the Indramayu earthquake of 9 August 2007, with its epicenter located about 150 km north-west of Baribis fault [USGS, 2007]. However, more research and analysis should be performed to clarify this hypothesis.

It should be mentioned that in the above Figs. 3–5, the 95% error ellipses are plotted at the tip of the displacement arrows. The same scales are used for both displacements and error elipses. Since they are very small, they are difficult to recognize in the figures.

## Co-Seismic Deformation of the 2006 Yogyakarta Earthquake

The 27 May 2006 earthquake hit the Provinces of Yogyakarta and Central Java of Indonesia at 5:54 a.m. local time, with its epicenter estimated around 25km south-southwest of the Indonesian city of Yogyakarta and about 10 km below the sea bed [USGS, 2006a]. The USGS-estimated magnitude of first earthquake is Mw 6.3. Subsequently, about 750 aftershocks have been reported, with the largest intensity recorded at Mw 5.2. The 2006 Jogyakarta earthquake occurred along the active Opak fault, which runs about NE from the Parang Tritis area to the Bantul area then continue northward to the Klaten region (see Figure 6). In this case, the principle earthquake fault movement along the Opak fault might also trigger some movements along the Dengkeng fault.

A week after the earthquake, i.e. 4 to 8 June 2006, a GPS survey was conducted on 48 GPS points belonging to the 2nd order GPS network around Jogyakarta and Central Java, that was firstly observed in 1998. GPS surveys were conducted using 14 geodetic-type dual-frequency GPS receivers. Each point is observed for about 8 to 10 hours, while the reference point located in the UGM Boulevard Jogyakarta is observed continuously.

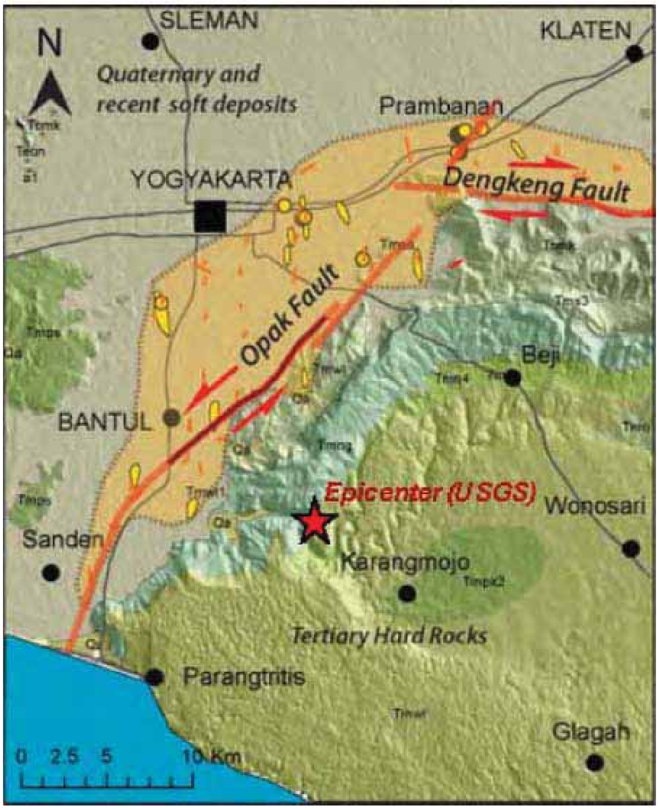


Figure 6. Opak Fault and Dengkeng Fault; courtesy of Danny H. Natawidjaja.

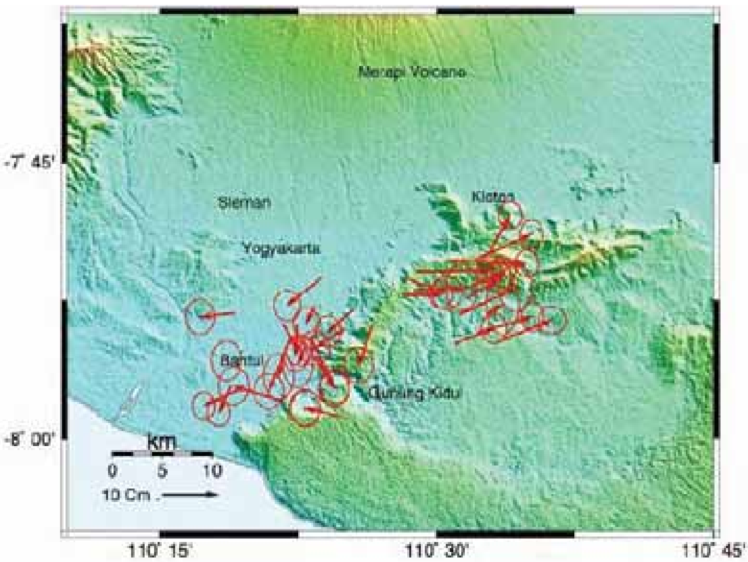


Figure 7. Co-seismic horizontal displacements of the Yogyakarta 2006 earthquake.

GPS results in Figure 7 show that horizontal co-seismic displacement around Bantul and Jogyakarta are mostly less than 10 cm, with mostly south and south-west directions (see Figure 7). By using the Okada model [Okada, 1985] and genetic algorithm, these derived-GPS displacements are then used to estimate the fault geometry. The estimation results indicated the existence

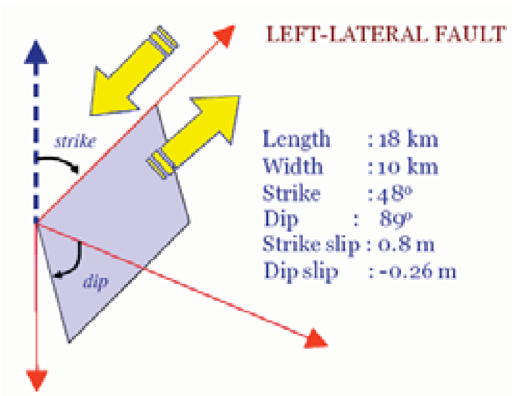


Figure 8. The estimated fault geometry causing the 2006 Yogyakarta earthquake.

of left-lateral fault with a strike of 48° and a dip of 89° (see Figure 8). This fault is located slightly to the east of the Opak fault as indicated in Figure 6. Based on the USGS Moment Tensor Solution, the dip and strike of the fault causing the Yogyakarta 2006 earthquake are 85° and 59°; and according to the Harvard Moment Tensor Solution are 90° and 51° [USGS, 2006a]. GPS -derived dip and strike, i.e. 89° and 41°, are closer to those given by the Harvard Moment Tensor Solution.

## Post-Seismic Deformation of the 2006 South Java Earthquake

The July 17th 2006 South Java earthquake (Mb6.1, Ms7.7 and Mw7.7, Harvard global CMT) occurred about 200 km south of western Java Island (see Figure 7). It occurred on Monday, July 17, 2006, at 3:19:28 p.m. local time (8:19:28 UTC). The USGS recorded at least 22 aftershocks south of Java ranging between magnitude 4.6 and 6.1. Two largest aftershocks measured 6.0 and 6.1 Mw [USGS, 2006b].

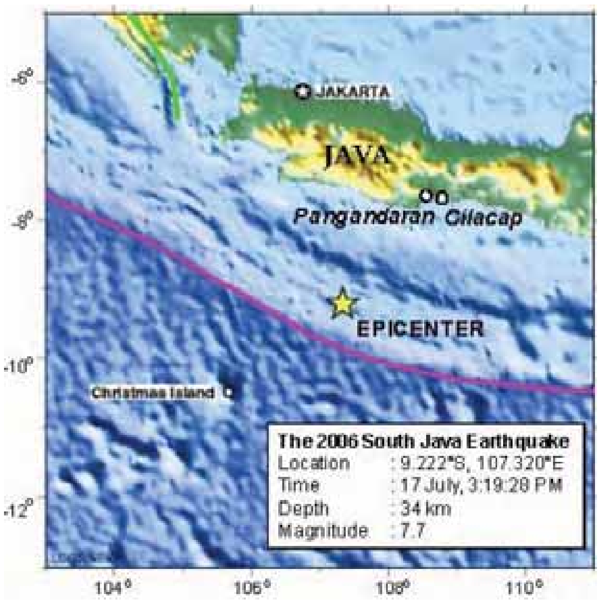


Figure 9. Earthquake location; after [USGS, 2006b].

The July 17th 2006 South Java earthquake (Mb6.1, Ms7.7 and Mw7.7, Harvard global CMT) occurred about 200 km south of western Java Island (see Figure 9). It occurred on Monday, July 17, 2006, at 3:19:28 p.m. local time (8:19:28 UTC). The USGS recorded at least 22 aftershocks south of Java ranging between magnitude 4.6 and 6.1. Two largest aftershocks measured 6.0 and 6.1 Mw [USGS, 2006b].

In order to study the post-seismic deformation of the earthquake, three GPS surveys were conducted on July 2006, August 2007 and August 2008, by the researchers from ITB, LIPI, Nagoya University and Tokyo University. About thirty GPS points along approximately 200 km coastline were observed.

The observation length at each site is more than 18 hours. The dual-frequency geodetic type receivers were used for the observation. The GPS data were processed using Bernese 5.0 GPS processing software [Beutler *et al.*, 2007]. In this case, the ITRF 2005 was used as a reference frame, and 23 IGS stations were involved in the processing along with all observation sites.

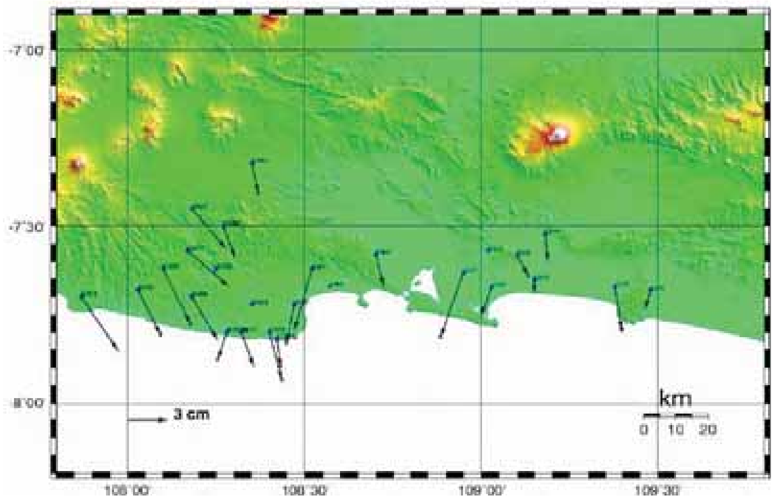

Figure 10. Post-seismic horizontal deformation of the 2006 South Java earthquake, as estimated from GPS surveys on July 2006 and August 2007. The displacements are in general less than 5 cm.

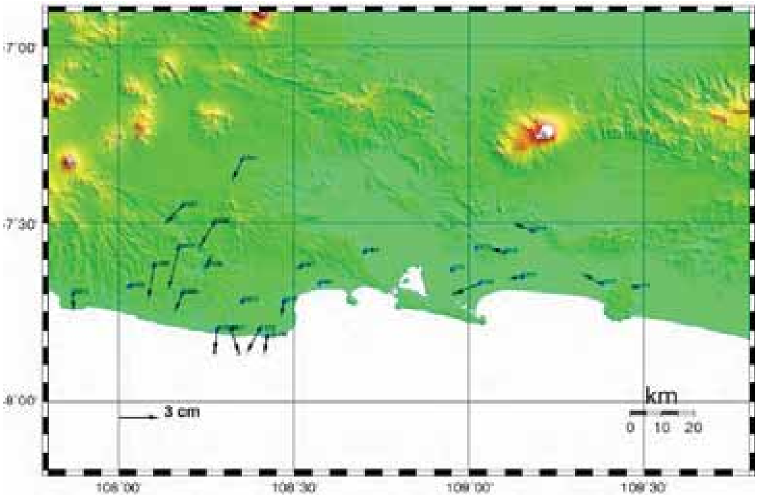


Figure 11. Post-seismic horizontal deformation of the 2006 South Java earthquake, as estimated from GPS surveys on August 2007 and August 2008. The displacements are in general less than 3 cm.

The estimated post-seismic horizontal deformation is shown in Figs. 10 and 11. It can be seen that the magnitude of post-seismic deformation between July 2006 and August 2007 is in general less than 5 cm, with increasing magnitudes toward the west direction, i.e. decreasing distances toward the epicenter. The post-seismic deformation is getting smaller with time, and between August 2007 and August 2008, its magnitudes are in general less than 3 cm. The physical reasons on the spatial variation in post-seismic deformation direction as indicated in Figs. 10 and 11 are still under investigation.

## Closing Remarks

Based on GPS survey results it was found that the area around Cimandiri, Lembang and Baribis fault zones have the horizontal displacements of about 1 to 2 cm/yr. Further research is however still needed to extract the real inter-seismic deformation of the faults from those GPS -derived displacements. GPS surveys have also estimated that the May 2006 Yogyakarta earthquake was caused by the sinistral movement of the (Opak) fault with horizontal co-seismic deformation that was generally less than 10 cm. The post-seismic horizontal deformation of the July 2006 South Java tsunami earthquake has also been estimated using GPS surveys data. In the first year after the earthquake (2006 to 2007), the post-seismic deformation is generally less than 5 cm; and it becomes generally less than 3 cm in the second year (2007 to 2008).

Considering the vulnerability of Java Island toward the future earthquakes and its relatively dense population, these crustal deformation studies using GPS surveys will be continued. In the future, data from newly established continuous GPS stations will be incorporated in the analysis, and possibility of InSAR-based deformation study [Massonnet and Feigl, 1998] will also be explored and implemented.

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# The Applications of GPS CORS in Indonesia: Status, Prospect and Limitation

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**Summary**

The use of GPS for positioning, surveying and mapping applications in Indonesia is systematically started at the end of 1980s. In this case, static surveying and real time (absolute and differential) positioning are the two most positioning modes being used. The GPS CORS in Indonesia were firstly established by the Indonesian National Coordinating Agency forSurveys and Mapping (Bakosurtanal) with three stations, i.e. in Cibinong (West Java), Medan (North Sumatra) and Parepare (South Sulawesi). In October 2009 the GPS CORS of Bakosurtanal consists of 51 continuously operating GPS reference stations. Several clusters of local GPS CORS have also been established by other governmental agencies and universities. GPS CORS prospect in Indonesia is very promising especially for maintaining the national spatial reference system to support various applications of positioning, surveying and mapping, such as in land administration, mining and transportation sectors. Observing several natural hazard phenomena in Indonesia, e.g. earthquake, tsunami volcanic eruption, land subsidence and landslide, will also be greatly improved. GPS based mapping of tropospheric water vapor and ionospheric TEC over Indonesia region will also benefit from the enormous data provided by GPS CORS. The current results of GPS CORS in Indonesia will be presented in this paper, especially those related to maintenance of the national spatial reference system, tectonic deformation monitoring and TEC mapping over Indonesia region. Potential application for land administration will be discussed. Possible limiting factors for sustainable operation of GPS CORS in Indonesia will also be critically reviewed.

*Key Words:* GPS , Positioning, Cors, Indonesia, Reference Frame

## Introduction

GPS is started to be used in Indonesia at the end of 1980s especially for surveying and mapping related purposes. Afterward the applications are started to increase encompassing various fields of application, from geodynamics study and deformation monitoring to land administration, transportation and recreation applications. In this case, static surveying and real time (absolute and differential) positioning are the two most positioning modes being used. Since 1992, the Indonesian National Coordinating Agency for Surveys and Mapping (Bakosurtanal) has also systematically conducted precise GPS surveys for refining and densifying the national geodetic control network of Indonesia [*Subarya,* 2004]. In this case, Bakosurtanal is responsible for establishing the 0th and 1st order national geodetic network. At present, these networks consisted of more than 950 GPS stations all over Indonesia, defined in the ITRF2005 reference frame. Since 1994, the National Land Agency (BPN) has also started using GPS surveys for establishing the cadastral control networks of Indonesia [*Abidin et al., 1998*]. These cadastral networks are the considered as the 2nd and 3rd order national geodetic networks, and are connected to the 0th and 1st geodetic networks maintained by Bakosurtanal. Since 1993, the Indonesian Ministry of Forestry has also started to use GPS surveys for establishing the control network for forest surveying, mapping and management [*Soetardjo,* 1999]. This forestry control network is connected to the national geodetic control networks. GPS based local geodetic networks were also established sporadically by the govermental agencies and private sectors (e.g. deformation monitoring, mining and energy, real estates, and construction of public utilities ), mainly to serve their specific needs. The GPS CORS (Continuously Operating Reference Stations) in Indonesia were firstly operated by Bakosurtanal since 1996, consisting of three stations in Cibinong,West Java (BAKO station), in Medan, North Sumatra (SAMP station), and Parepare, South Sulawesi (PARE station) [*Matindas and Subarya*, 2009]. Afterward, Bakosurtanal expanded this GPS CORS network, and by October 2009 the network has consisted of 51 stations. Other national agencies, such as the Indonesian Institute of Sciences (LIPI) and BPN have also started establishing their own GPS CORS network. LIPI, in collaboration with the California Institute of Technology (Caltech) and the Earth Observatory of Singapore (EOS), has established the SUGAR (Sumatera GPS Array) [*Caltech,* 2010; EOS, 2010]. This CORS network is mainly aimed to study the nature of large earthquakes in the subduction zones of the Sumatra Island. Recently, BPN has also tested the possibility of using GPS CORS stations for speeding up the land administration process in Indonesia [*Adiyanto et al.,* 2009]. Several smaller and localized GPS CORS networks in Indonesia are also established by the private sectors and universities [*Sunantyo,* 2009].

## The National GPS Cors Of Indonesia

In principle, the national GPS CORS network of Indonesia, is officially the one that is established by Bakosurtanal [*Subarya,* 2004; *Matindas and Subarya,* 2009]. This network is usually termed as the Indonesian Permanent GPS Station Network (IPGSN). The primary purpose of the IPGSN is to maintain an accurate and precise geodetic reference frame over Indonesian region, and also to support a wide range of scientific and practical applications such as geodynamics and deformation monitoring, meteorological and ionospheric studies, sea level monitoring, intelligent transportation systems, and real-time based surveying and mapping applications. The establishment of IPGSN network was initiated in 1996 which is started with three stations in Cibinong (West Java), Sampali Medan (North Sumatra) and Parepare (South Sulawesi). The network was afterward systematically strengthened with more stations, and after the

Sumatra-Andaman earthquake and tsunami of 26 December 2004, the IPGSN network was rapidly developed. This rapid development is part of the development of the Indonesian Tsunami Early Warning System (InaTEWS). Afterward, Bakosurtanal expanded this GPS CORS network, and by October 2009 the network has consisted of 51 stations. The current status of IPGSN is depicted in Figure 1.

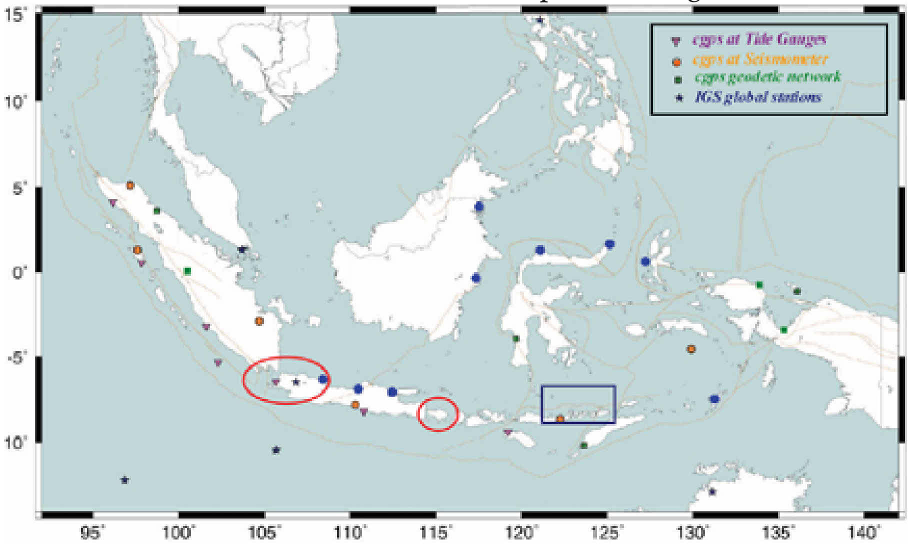


Figure 1. The current status of the Indonesian Permanent GPS Stations Network (IPGSN). It consists of 14 stations located around the Sunda Strait and West Java and 7 stations in the eastern end of Java and Bali Island (inside open red ellipses); 10 stations are located along Flores thrust-fault (inside open blue square); 7 stations near seismometer stations (orange circles); 7 stations near or on tide gauge stations (reverse triangles); 7 geodetic (old) stations (green squares); and 10 stations will be install in 2010 (blue circle). After *Matindas and Subarya* (2009).

(a) (b) (c)

Figure 2. The IPGSN geodetic monument types: (a) on the top of concrete roof, (b) concrete pillar, (c) stainless-steel rod, and (d) on a tide gauge station. Photos are taken by Cecep Subarya.

*(d)*

All stations of IPGSN use the high precision L1/L2 geodetic type GPS receivers (i.e. Ashtech UZ-12, Leica GRX1200 family, Topcon GB-1000 and Net G3, and Septrentio PolarX2) with choke ring antennas and radomes, and most of the GPS receivers equipped with meteorological (temperature, pressure and humidity) sensors [*Subarya et al.*, 2010]. Besides GPS receiver, the station also equipped with a radio or VPN-IP modem for data communication, sufficient batteries and solar panels to charge the batteries. GPS data is recorded at 1Hz rate and streamed in real time or near real time of 1 hour latency to the data processing center at Bakosurtanal office in Cibinong, West Java. Considering the stringent geodetic requirements for the IPGSN, stable geodetic monuments are constructed at all locations with various types of geodetic monuments as shown in Figure 2.

## Status Of Other GPS Cors In Indonesia

Besides the national GPS CORS established and maintained by Bakosurtanal, other national agencies, such as the Indonesian Institute of Sciences (LIPI) and BPN have also started establishing their own GPS CORS network. LIPI, in collaboration with the California Institute of Technology (Caltech) and the Earth Observatory of Singapore (EOS), has established the SUGAR (Sumatera GPS Array) network, consisting of 32 continuous stations [*Natawidjaja*, 2010]. The location and distribution of these stations are shown in Figure 3. The location and distribution of these stations are shown in Figure 3. All stations are equipped with the dual-frequency geodetic type receivers, with choke ring antennas and radomes; and record the data with 1 Hz data rate. The data collected by this CORS network has been used to study the deformation related characteristics of large earthquakes in the subduction zones of the Sumatra island.

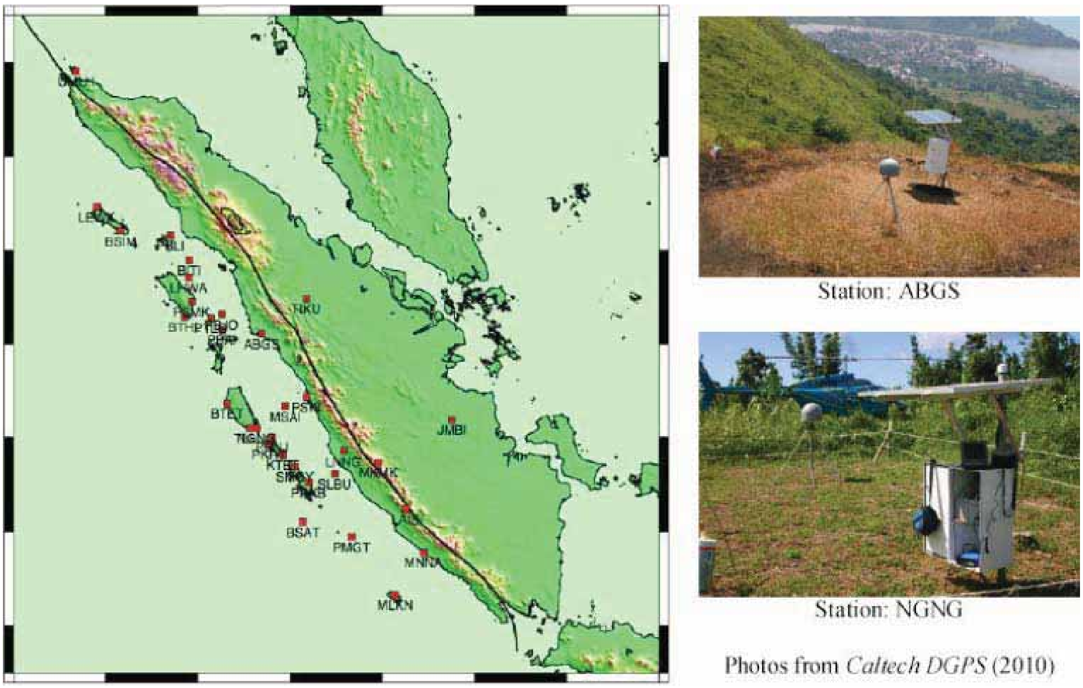


Figure 3. The location and distribution of 32 SUGAR stations.

In order to speed up the land administration process in Indonesia, BPN has also started to establish GPS CORS, consisting of Class-A and Class-B type stations (see Figure 4). Three stations around the capital city of Jakarta, i.e. Tangerang, Bekasi and Bogor, have been established and tested [*Adiyanto et al.*, 2009]. In 2010, other 33 CORS stations will be established in Java and Bali and other strategic areas outside Java and Bali.


Figure 4. Planned location and distribution of BPN GPS CORS station in Java [*Adiyanto and Wibisono*, 2009]. Class-A and Class-B stations are denoted with red and yellow circles respectively.

All of the BPN CORS stations will be equipped with dual-frequency geodetic-type GPS receivers. The Class-A type stations will be established on the ground and planned to have specification and performance comparable to the IPGSN stations maintained by Bakosurtanal. The Class-B type stations will usually installed on the building, preferably in the land office building in the corresponding areas, as shown in Figure 5.


Figure 5. The first three BPN CORS stations; from *Adiyanto et al.* (2009).

Several universities, namely Institute of Technology Bandung (ITB) in Bandung, University of Gajah Mada (UGM) in Yogyakarta and Institute of Technology 10 November (ITS) in Surabaya have also established GPS CORS stations in their campuses. In this case, the Geodesy Research Division of ITB, in cooperation with GSI Japan, ERI University of Tokyo, and Bakosurtanal, has established 5 GPS CORS stations as shown in Figure 6. The main aim of this CORS network is to study the inter-seismic deformation of active faults in West Java, e.g. Cimandiri, Lembang and Baribis faults [*Abidin et al*, 2009].

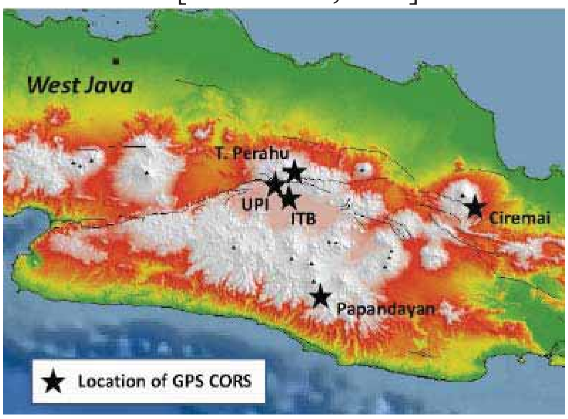



Figure 6. GPS CORS maintained by Geodesy ITB in West Java

## Applications Of GPS Cors In Indonesia

GPS CORS in Indonesia will be useful for various existing applications in Indonesia and also will create more innovative applications, both in real-time and post-processing modes, as shown in Table 1. The existence of GPS CORS networks will be very useful for Indonesia, a vast archipelago consisting of more than 17.000 islands and has population of more than 200 millions. GPS CORS stations will be useful as the reference stations for various GPS -based positioning, surveying and mapping applications. Differential based GPS positioning for various applications, such as for topographic and thematic mapping, marine surveying, photogrammetry, oil and gas exploration and exploitation, cadastral surveying, construction surveys, forestry and agriculture mapping, and for boundary demarcation; will be benefitted by GPS CORS stations.

Table 1. Existing and potential utilization and function of GPS CORS.

| Utilization and Function of GPS CORS | |
|---|---|
| **Real-time mode** | **Post-processing mode** |
| Early warning system for various natural hazards in Indonesia | The coordinate reference frame for various positioning, surveying and mapping applications in Indonesia. |
| The Network-RTK system for surveying and mapping applications. | The coordinate reference frame for monitoring andstudying natural hazard phenomena in Indonesia |
| The reference stations for supporting various navigation and transportation applications (land, marine, air). | The monitoring network for geodynamics and tectonic studies in Indonesian region. |
| Integration, checking and validation for various coordination reference systems | Studying and mapping the characteristics of troposphere and ionosphere above Indonesian territory. |

GPS CORS will also have significant impact for natural hazard mitigation applications. The Indonesian archipelago located at the junction of the Eurasia, Australia, Pacific, and Philippine Sea plates, resulting in wide spectrum topography, frequent earthquakes, and volcanism [Hamilton, 1979]. In the west, the Australia plate subducts beneath the Eurasia plate along the Java trench while to the east, the continental part to the east, the continental part of the Australia plate collides with the Banda arc and the Pacific-oceanic plate. Indonesian region is therefore prone to earthquakes, tsunamis and volcanic eruptions. Considering is rugged topography and usually heavy rainfall, landslide and flooding are also other prominent natural hazards that continuously affecting Indonesia. Land subsidence moreover also affecting some large cities in Indonesia. Up to now since about 1992, GPS surveys have been extensively used to study the characteristics and aspects of several natural hazard phenomena, namely earthquake [e.g. Bock et al., 2003; Subarya et al., 2006; Abidin et al., 2009], volcanic eruption [e.g. Abidin et al., 2004; 2005; 2008c], land subsidence [e.g.

Abidin et al., 2008a; 2008b], and landslide [e.g. Abidin et al., 2007]. By also using continuous GPS data from GPS CORS stations, then more detail characteristics of natural hazard phenomena can be studied, as shown by the examples in Figure 7. These results based on GPS continuous data are related to the 13 September 2007 Bengkulu earthquake [Meilano et al., 2009] and the eruption of Papandayan volcano on 20 November 2002 [Abidin et al., 2005]. Based on the examples shown in Figure 7 it can be realized that by locating GPS CORS stations on specific areas on and around subduction zones, active faults and active volcanoes, the CORS system may also function as the early warning system for earthquake and volcano eruption. However, in order to realize it, this potential use of GPS CORS for the early warning systems have to be supported by the reliable real-time data communication andpowerful and sophisticated real-time GPS data processing.

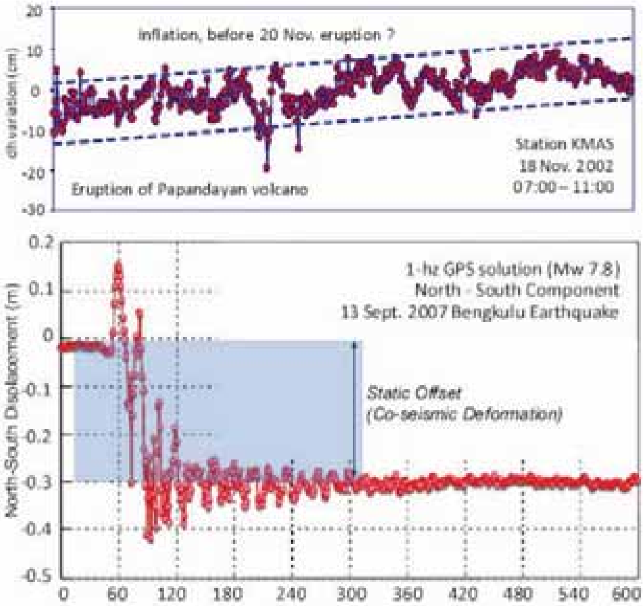


Figure 7. The potential applications of GPS continuous data for studying the characteristics of deformation related to the eruption of Papandayan volcano on 20 Nov. 2002 (above) and the 13 Sept. 2002 Bengkulu earthquake (below)

The existence of dense and reliable GPS CORS stations in Indonesia will actually be beneficial not only for natural hazard mitigation; but it will also important for supporting surveying and mapping applications, GPS -based meteorology, and Intelligent Transport System (ITS) of Indonesia. In order to support the transportation sectors, the CORS should also have a functional capability of being as regular DGPS (Differential GPS ) system. In the case of surveying and mapping, GPS CORS will have tremendous impacts in Indonesia, mainly for cadastral, construction and public utility, and mining surveying and positioning related activities. In the case of transportation sector, land and marine sectors will be most benefitted. The potential use of GPS continuous data for mapping of Total Electron Content (TEC) over Indonesian region is indicated by the results shown in Figure 8. These monthly TEC models were derived using data from 10 GPS CORS data in and around Indonesia, i.e.

from 6 IPGSN stations (SAMP, BAKO, KOEP, TOLI, PARN and BIKL) and 4 IGS stations (NTUS, COCO, DARW, and PIMO). More detail and comprehensive results on this ionospheric study can be seen in *Muslim* (2009). As in the case of GPS derived coordinate variation, the GPS derived TEC values have also the potential to be used as a kind of early warning for large earthquake, as shown by example given in Figure 9. In this case, it can be seen that a few days prior to the 26 December 2004 mega thrust Sumatra-Andaman earthquake, the ionospheric anomalies can be seen in GPS derived TEC using SAMP, NTUS and IISC continuous GPS data [*Muslim*, 2009]. However more research is still needed to clarify this pre-seismic GPS derived ionospheric anomaly.

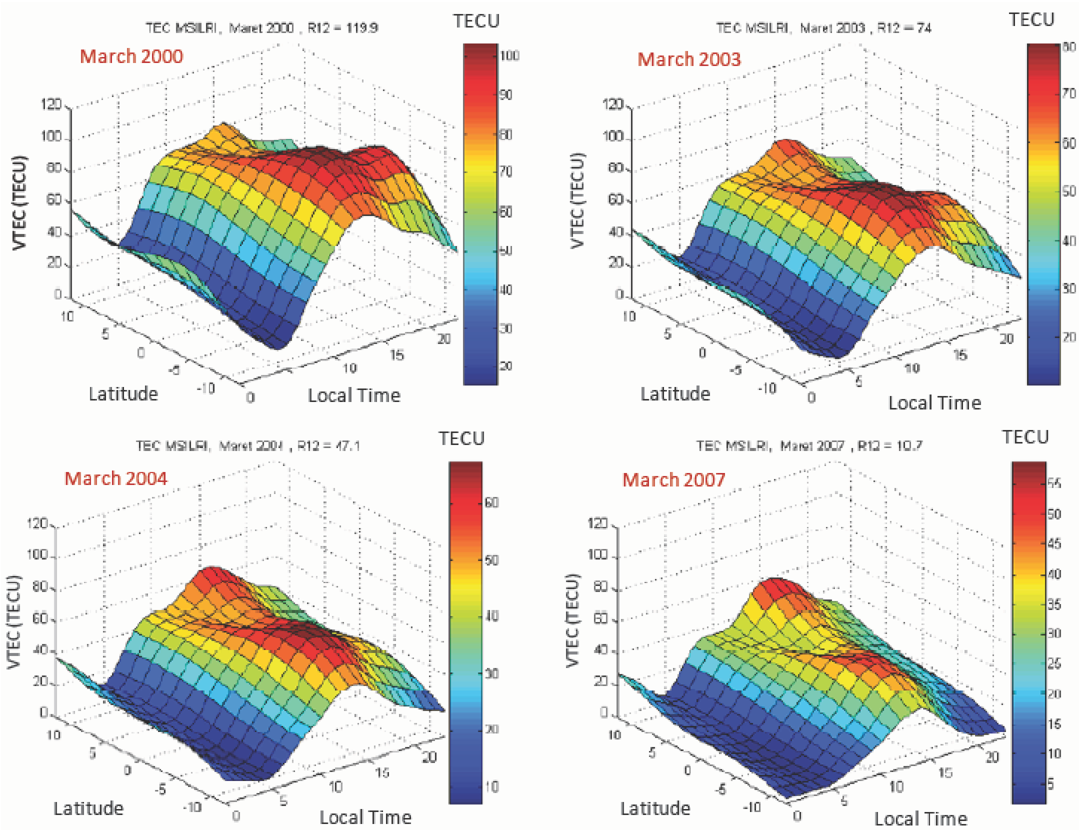


Figure 8. Example of Monthly TEC Model for Indonesia from GPS Continuous Data [*Muslim*, 2009].

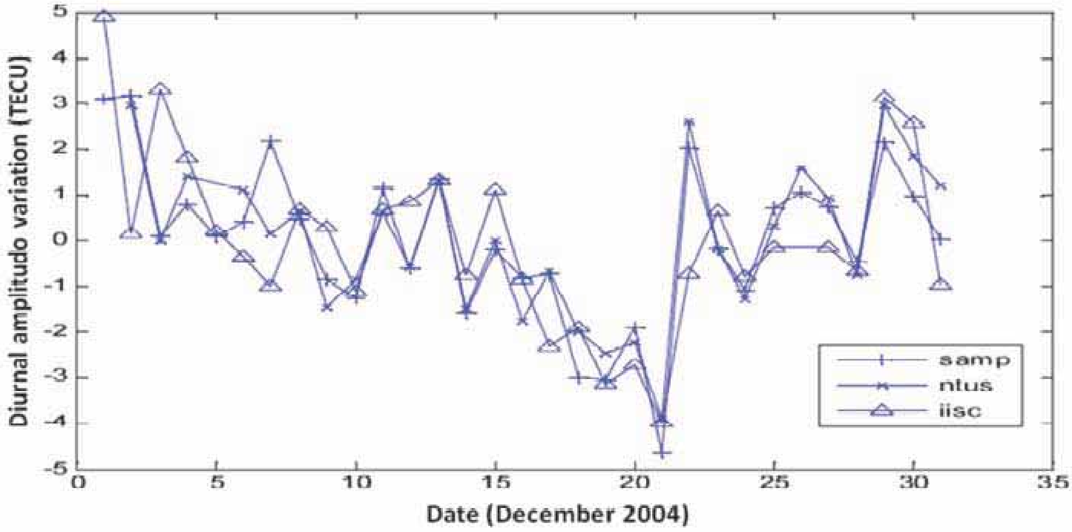


Figure 9. Ionospheric TEC anomalies prior to the 26 December 2004 Earthquake ? [*Muslim*, 2009].

Several National GPS CORS (IPGSN) stations can also become part of the Indonesian Tsunami Early Warning System (ITEWS) which is now in the process of establishment by the Indonesian government. The sensors of the ITEWS comprise seismometers, GPS instruments, tide gauges and buoys as well as ocean bottom pressure sensors as shown in Figure 10.

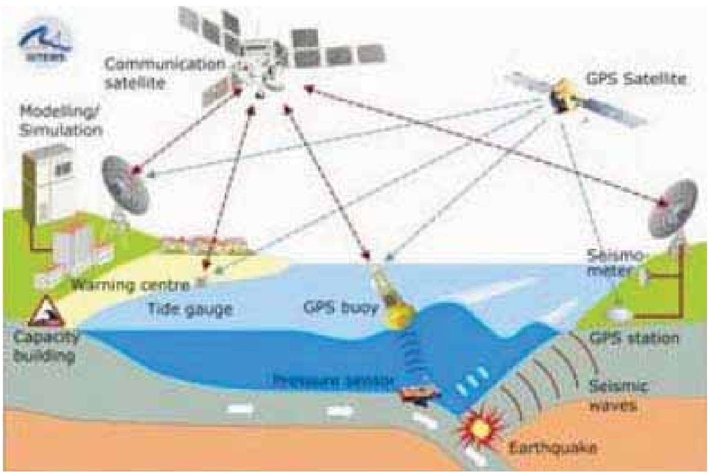


Figure 10. The Indonesian Tsunamy Early Warning Systems[*GITEWS*, 2010]

## Challenges And Limitations

In establishing, operating and maintaining the good and reliable GPS CORS network covering all region of Indonesia, there are several challenges and limitations that have to be properly taken into consideration. These factors have both structural and cultural natures, and can be summarized as in the following points. 1. The reliability of the GPS CORS will strongly depend on good and reliable communication links between the continuous GPS stations and its data processing centre. In the case of IPGSN which is maintained by Bakosurtanal, its locations are located all over

Indonesia, and the data processing centre at Bakosurtanal, Cibinong in West Java. Considering the vast area being cover, the archipelagic nature of Indonesia, relatively high spatial divide in the communication infrastructure inside the Indonesian region, and the remoteness of most of continuous GPS stations, the internet and satellite-based communication link seem to be the most effective solution for IPGSN. However, this mode of communication is relatively expensive; and in the case of internet connection, the 100% integrity and reliability cannot always be achieved, even in Java island region which has a relatively best communication infrastructure. 2. In order to have good, reliable and continuous mode of operation, all remote continuous GPS stations will also require proper and continuous maintenance and caring. Each station will therefore need proper resources all year long, e.g. electrical power supply, related hardware and software resources, and human resources for checking and taking care the station site and equipments. The difficulty in operating and maintaining the GPS CORS station in Indonesia will vary and usually getting more difficult when its location getting farther away from Java island and/or from the urban areas. The financial support for the daily operation and maintenance of GPS CORS stations therefore should always be considered, preferably in the long term basis. In the case of national GPS CORS such as IPGSN, the political will and continuous support from the central government is indeed necessary. 3. Maintenance and operation of the relatively large scale GPS CORS networks in Indonesia, such as those presently maintained by Bakosurtanal and in future also by BPN; will require also conducive and professional working culture, and also good support from dedicated and professional human resources. This human capital, is not needed just to operate and maintain the whole system, but also to process the collected data and analyze the obtain results for various applications and interests. At present times, the working culture in the government offices are not always compatible and suitable with the working culture needed for maintaining and operating the good and reliable GPS CORS networks. The number of qualified and dedicated persons for maintaining and operating GPS CORS should also be increased and provided with proper reward and remuneration. In this case, outsourcing part of the operational and maintenance activities of GPS CORS network to the private company may also be considered. 4. Since the large scale GPS CORS network covering Indonesian region will require substantial amount of qualified human capital, the related human resource development program should also be systematically planned by the related institutions (e.g. Bakosurtanal and BPN). In terms of high learning institutions, at present times in Indonesia there are four state universities (ITB Bandung, UGM Yogyakarta, ITS Surabaya, and Undip Semarang) and three private universities (Itenas Bandung, ITN Malang, University of Pakuan Bogor) that have study programs on surveying, geodesy and/or geomatics engineering. In the context of GPS CORS related capacity building in related institution, those high learning institutions, besides supplying their graduates can also offer various Continuing Education Programs (CEP) for enhancing the competency of human resources belonging to various agencies related to the GPS

CORS programs. 5. Since the development of good and reliable national GPS CORS network (e.g. IPGSN) will absorb a lot of money and efforts, the use of the system is preferably not just only for supporting one specific sector such as positioning, surveying and mapping. Instead it should also support other national needs and interests, such as natural hazard mitigation and intelligent support system. Since each application usually will have their own specification on data requirement and management, then the GPS CORS system should beadaptively designed and operated to fully support those various applications.

## Closing Remarks

World-wide development of GPS CORS is increasing rapidly, due to increasing availability, accuracy, reliability and integrity of GPS systems; and also to advancements in electronics, instrumentation and control fields. The applications of GPS CORS in Indonesia has also steadily growing and has good opportunity to serve various national, regional and local needs and interests. The existence of good and reliable GPS CORS network covering the Indonesian archipelago would greatly increase our ability of observing the Earth system dynamics and phenomena in the region; and at the same time increasing the accuracy and reability of the national spatial (geodetic) reference system for supporting various applications and needs related to positioning, navigation, surveying and mapping in the Indonesian region. The advancements of GPS CORS networks in Indonesia should also be supported by proper legal infrastructures and qualified human resources. The support and endorsements from central government, parliament, related governmental agencies and high learning institutions will therefore also be important for suistainable development of GPS CORS in Indonesia. Finally, it should be emphasized that some of GPS CORS applications in Indonesia (e.g. positioning, surveying and mapping and also intelligent transportation systems), if professionally managed can generate a substantial amount of revenue for government and also private sector. Therefore if is considered suitable, the business prospects and plan of the national GPS CORS system of Indonesia should also be taken into consideration and systematically be prepared.

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**Biographical Notes**

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# Land Subsidence Characteristics of the Jakarta Basin (Indonesia) and its Relation with Groundwater Extraction and Sea Level Rise

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## Abstract

Jakarta is the capital city of Indonesia with a population of about 9 million people, inhabiting an area of about 660 km2. It has been reported for many years that several places in Jakarta are subsiding at different rates. Over the period of 1982–1997, subsidence ranging from 20 to 200 cm is evident in several places in Jakarta. There are four different types of land subsidence that can be expected to occur in the Jakarta basin, namely: subsidence due to groundwater extraction, subsidence induced by the load of constructions (i.e., settlement of high compressibility soil), subsidence caused by natural consolidation of alluvial soil and tectonic subsidence. In addition to the levelling surveys, GPS survey methods and InSAR measurements have been used to study land subsidence in Jakarta. This paper describes the characteristics of subsidence in Jakarta over the period of 1982 to 2007 as observed by the three methods. In general land subsidence in Jakarta exhibits spatial and temporal variations, with rates of about 1 to 15 cm/year. A few locations can have subsidence rates up to about 20-25 cm/year. It was found that the spatial and temporal variations in land subsidence correlate with variations in groundwater extraction, coupled with the characteristics of sedimentary layers and building loads above it. The observed subsidence rates in several locations show a positive correlation with known volumes of groundwater extraction. However, the relative magnitude and spatial variability of the effect of groundwater extraction on land subsidence in the whole Jakarta basin is not yet fully understood. In the coastal areas of Jakarta, the combined effects of land subsidence and sea level rise also introduce other collateral hazards, namely the tidal flooding phenomena.

*Keywords:* Jakarta, Land subsidence, Levelling, GPS , InSAR, Groundwater, Sea Level Rise

## Introduction

Land subsidence is not a new phenomenon for Jakarta, the capital city of Indonesia. It has been reported for many years that several areas of Jakarta are subsiding at different rates [*Murdohardono &Tirtomihardjo*, 1993; *Murdohardono & Sudarsono*, 1998; *Rajiyowiryono,* 1999]. The impact of land subsidence in Jakarta is observed in several forms, such as cracking of permanent constructions and roads, wider expansion of flooding areas, malfunction of drainage systems, and increased inland seawater intrusion. Based on several studies [*Murdohardono and Sudarsono,* 1998; *Rismianto and Mak,* 1993; *Harsolumakso,* 2001; *Hutasoit*, 2001], there are four different types of land subsidence that can be expected to occur in the Jakarta basin, namely: subsidence due to groundwater extraction, subsidence induced by the load of constructions (i.e. settlement of high compressibility soil), subsidence caused by natural consolidation of alluvial soil, and geotectonic subsidence. The first three are thought to be the dominant types of land subsidence in Jakarta basin. In the case of Jakarta, comprehensive information on the characteristics of land subsidence is applicable to several important planning and mitigation efforts (see Figure 1), such as spatial-based groundwater extraction regulation, effective control of flood and seawater intrusion, environmental conservation, design and construction of infrastructure, and spatial development planning. Considering the importance of land subsidence information for supporting development activities in the Jakarta area, monitoring and studying the characteristics of this subsidence phenomenon becomes morevaluable.

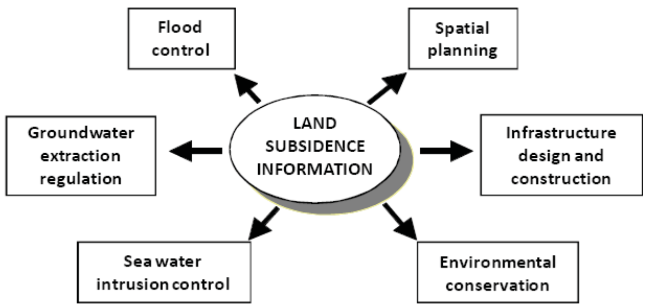



Figure 1. The importance of land subsidence information.

Since the early 1980's, land subsidence in several areas of Jakarta has been measured using a variety of measurement techniques including levelling surveys, extensometer measurements, groundwater level observations, GPS (Global Positioning System) surveys, and INSAR (*Interferometric Synthetic Aperture Radar*) [*Abidin,* 2005; *Abidin et al.*, 2001, 2004, 2008]. The prediction of ground subsidence, based on models incorporating geological and hydrological parameters of Jakarta, has also been investigated [*Murdohardono and Tirtomihardjo,* 1993; *Yong et al.*, 1995; *Purnomo et al.*, 1999]. This paper describes the characteristics of land subsidence in the Jakarta basin during the period of 1982 to

2007, as observed by levelling surveys, GPS surveys and InSAR. Theoretically, groundwater extraction that exceeds aquifer recharge could lead to a decline in groundwater levels (piezometric head), reducing the hydrostatic pressures supporting the aquifer material and causing land subsidence. Therefore the correlation between the observed subsidence and groundwater extraction volumes in the Jakarta area will also be studied.

## Jakarta and its characteristics

The city of Jakarta has a population of about 9 million people [*BPS Jakarta*, 2007], inhabiting an area of about 661.52 km2. Jakarta is located on the lowland of the northern coast of the West Java province (centred at coordinates of about -6o15' latitude and +106o50' longitude), as shown in Figure 2. The area is relatively flat, with topographical slopes ranging between 0o and 2o in the northern and central parts, and between 0o and 5o in the southern part. The southernmost area of Jakarta has an altitude of about 50 m above mean sea level (MSL). The average annual rainfall in the Jakarta area is about 2000 mm/year, with the maximum monthly average occurring in January and the minimum occurring in September.

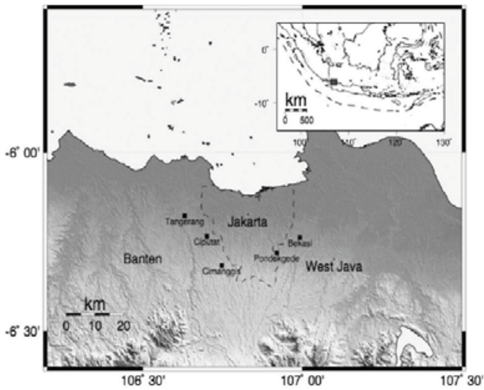



Figure 2. Jakarta and its surrounding areas.

Regionally speaking, Jakarta is a lowland area which has five main landforms, namely: (1) volcanic alluvial fan landforms, which are located in the southern part; (2) landforms of marine-origin, which are found in the northern part adjacent to the coastline; (3) beach ridge landforms, which are located in the northwest and northeast parts; (4) swamp and mangrove-swamp landforms, which are encountered in the coastal fringe; and (5) former river channels, which run perpendicular to the coastline [*Rimbaman and Suparan*, 1999; *Sampurno,* 2001]. It should also be noted that there are about 13 natural and artificial rivers flowing through Jakarta, of which the main rivers, such as Ciliwung, Sunter, Pesanggrahan, Grogol and their tributaries, form the main drainage system of Jakarta. In terms of geological and hydrological settings, according to *Yong et al.* (1995), the Jakarta basin consists of a 200 to 250 m thick sequence of Quaternary deposits which overlies Tertiary sediments. The base of the Quaternary deposits has been defined as the lower boundary of the groundwater basin. The Quaternary sequence can be further subdivided into three major units, which, in ascending order are: a sequence of Pleistocene marine and non-marine sediments, a late

Pleistocene volcanic fan deposit, and Holocene marine and floodplain deposits. Three aquifers are recognized within the 250 m thick sequence of Quaternary sediment of the Jakarta basin, namely: the Upper Aquifer, an unconfined aquifer, occurs at a depth of less than 40 m; the Middle Aquifer, a confined aquifer, occurs at a depth between 40 and 140 m; and the Lower Aquifer, a confined aquifer, occurs at a depth between 140 and 250 m [*Soetrisno et al.*,1997; *Hadipurwo,*1999]. The geologic materials confining these aquifers are silt and clay. Inside those aquifers, the groundwater generally flows from south to the north [*Lubis et al.,* 2008]. Below a depth of 250 m, an aquifer in the Tertiary sediments also has been identified. But according to *Murdohardono and Tirtomihardjo* (1993), it is less productive and its water quality is relatively poor.

**Land subsidence as observed by levelling surveys**

The first reliable information about subsidence in Jakarta came from results of levelling surveys. The systematic levelling surveys covering much of the Jakarta area were conducted in 1978, 1982, 1991, 1993, and 1997. Except for the last survey, which was performed by the Local Mines Agency of Jakarta, the levelling surveys were done by the Local Surveying and Mapping Agency of Jakarta. The levelling surveys were done using Wild N3, Zeiss Ni002, and Wild NAK precise levelling instruments. Each levelling line was measured in double-standing mode, and each levelling session was measured forward and backward to provide survey closure and to verify accuracy. The levelling line for each session is about 1 km in length. The tolerance for the difference between the forward and backward height-difference measurements is set to be $4\sqrt{D}$ mm, where D is the length of levelling line in km.

After applying relatively strict quality assurance criteria, only three surveys were considered sufficiently accurate for investigating the land subsidence in Jakarta; those conducted in 1982, 1991, and 1997. Moreover, only the results from specific levelling points in the network, which are considered the most reliable, are used for investigating land subsidence. In this case, repeatability of the heights obtained from different surveys and different loops, and stability of the monument with respect to its local environment, are used as the main criteria for selecting the points. The distribution of these levelling points is shown in

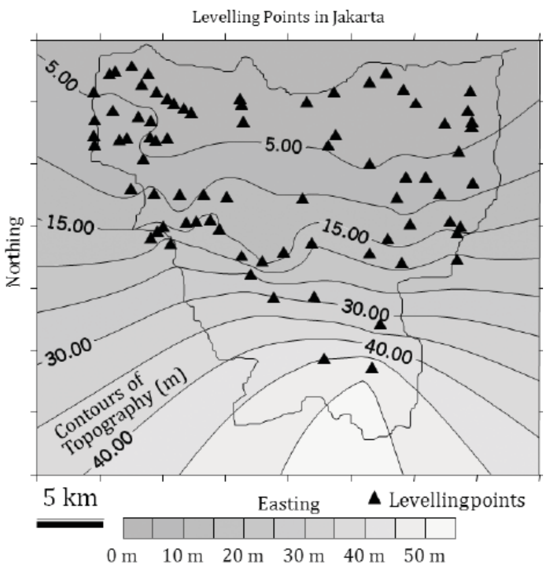



Figure 3. Levelling network in Jakarta.

Figure 3. The network consists of about 80 points distributed across Jakarta. The magnitude of land subsidence was estimated using 45 selected points from the levelling networks of 1982, 1991, and 1997.

Based on those levelling surveys, over the 15-year period of 1982 to 1997, subsidence ranging from 20 cm to 200 cm is evident at several places in Jakarta. Figure 4 shows that the maximum land subsidence observed by the levelling surveys during the period of 1991-97 is about 160 cm, while for the period of 1982-91 it is about 80 cm. The rates of land subsidence during the period of 1991-97 are also, in general, larger than those during the 1982-91 period, as indicated by the box-and-whisker plot shown in Figure 5. In general the subsidence rates in Jakarta area during this period are about 1-5 cm/year and can reach 25 cm/year at several locations (see Figure 5). From Figure 4 it can be seen that land subsidence in the northern part of Jakarta, which is close to the sea, is larger than in the southern part of Jakarta. In this case, three regions, namely two in the northwestern part (Cengkareng and Kalideres districts) and one in the northeastern part of Jakarta (Kemayoran-Sunter district), show the largest subsidence compared to the other regions. More comprehensive results on levelling-based subsidence in Jakarta can be seen in *Abidin et al.* (2001).

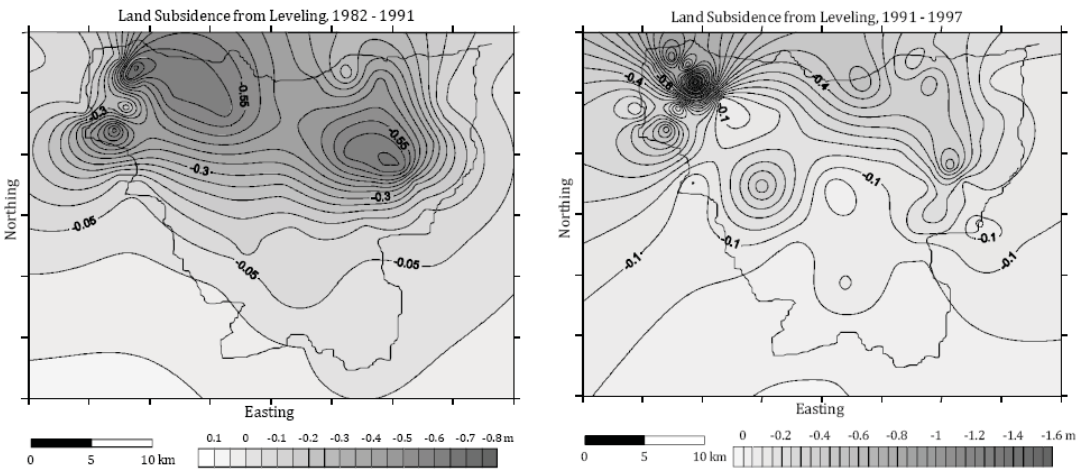



Figure 4. Land subsidence in Jakarta measured from levelling surveys (in metres), Over the periods of 1982 – 1991 (left) and 1991 – 1997 (right).

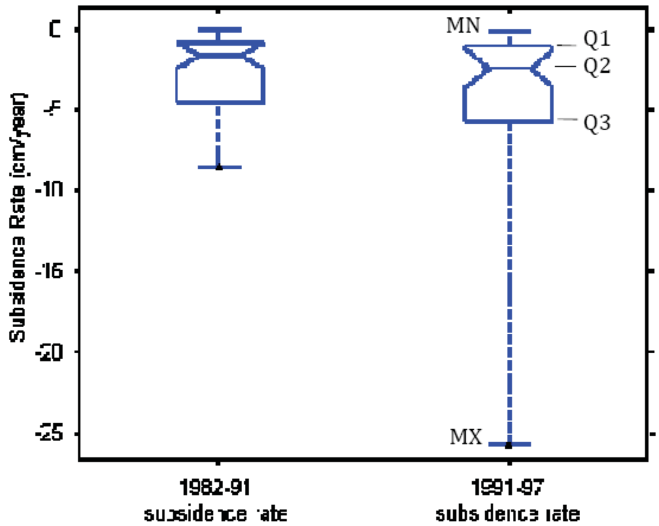



Figure 5. Box-and-Whisker plots of levelling-derived land subsidence rates in Jakarta. In this Figure: MN = sample minimum, Q1 = lower quartile (25th percentile), Q2 = median (50$^{th}$ percentile), Q3 = upper quartile (75th percentile), and MX = sample maximum.

**Land subsidence as observed by GPS surveys**

Besides using levelling surveys, land subsidence in Jakarta has also been studied using GPS survey methods [*Abidin et al*, 2002; *Leick,* 2003; *Abidin*, 2007]. The GPS -based land-subsidence study has been conducted by the Geodesy Research Division of ITB since December 1997. Up to now, ten GPS surveys has been conducted, namely on: 24 - 26 December 1997, 29 - 30 June 1999, 31 May - 3 June 2000, 14 - 19 June 2001, 26 - 31 October 2001, 02 - 07 July 2002, 21 - 26 December 2002, 21 – 25 September 2005, 10-14 July 2006 and 3-7 September 2007. The configuration of this GPS monitoring network is shown in Figure 6. These surveys did not always occupy the same stations. The first survey started with 13 stations, and the network then expanded subsequently to 27 stations. At certain epochs, some stations could not be observed due to the destruction of monuments, or severe signal obstruction caused by growing trees and/or new construction. Station BAKO is the southernmost point in the network and is also the Indonesian zero order geodetic point. It is used as the reference point. In this case the relative ellipsoidal heights of all stations are determined relative to BAKO station. BAKO is an IGS station, operated by the National Coordinating Agency for Survey and Mapping of Indonesia.

The GPS surveys exclusively used dual-frequency geodetictype GPS receivers. The length of surveying sessions was in general between 9 to 11 hours. The data were collected with a 30 second interval using an elevation mask of 150. The data were processed using the software Bernese 4.2 [*Beutler et al.,* 2001]. Since we are mostly interested with the relative heights with respect to a stable point, the radial processing mode was used instead of network adjustment mode. The standard deviations of GPS -derived relative ellipsoidal heights from all surveys were in general better than 1 cm [*Abidin et al., 2008*].

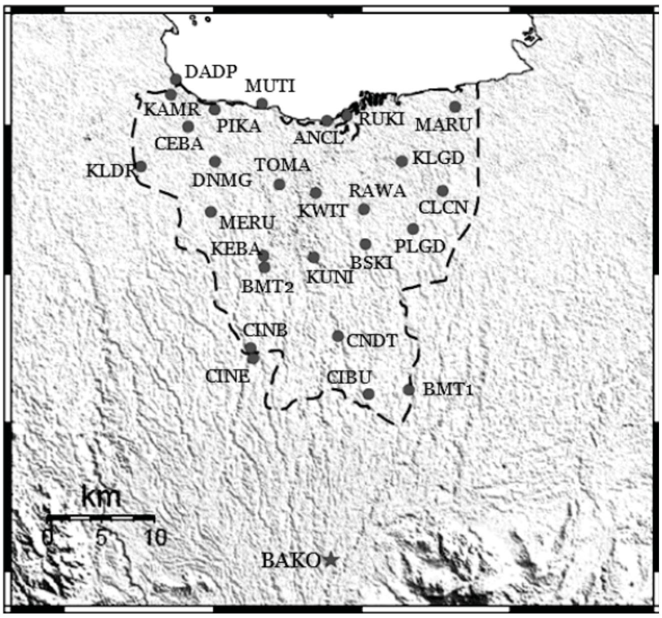



Figure 6. GPS network for monitoring subsidence in Jakarta.

Examples of GPS -derived land subsidence at several observing stations are shown in Figures 7, 8 and 9. On these Figures, the first measurement at each point established the baseline elevation for that site and, therefore, is shown as zero elevation change. The different color codes for the individual bars in these figures indicate that they were estimated from different GPS surveys. In about ten years, i.e. Dec. 1997 to Sept. 2007, the accumulated subsidence at several GPS stations can reach about 80-90 cm. In general the GPS observed subsidence rates during the period between December 1997 and September 2007 are about 1-15 cm/year. It is also found that land subsidence rates in the Jakarta basin have both a spatial and a temporal variation. This indicates that the causes of land subsidence in Jakarta also differ spatially. A more comprehensive review of GPS -derived land subsidence in Jakarta can be found in *Abidin* (2005) and *Abidin et al.* (2001, 2008).

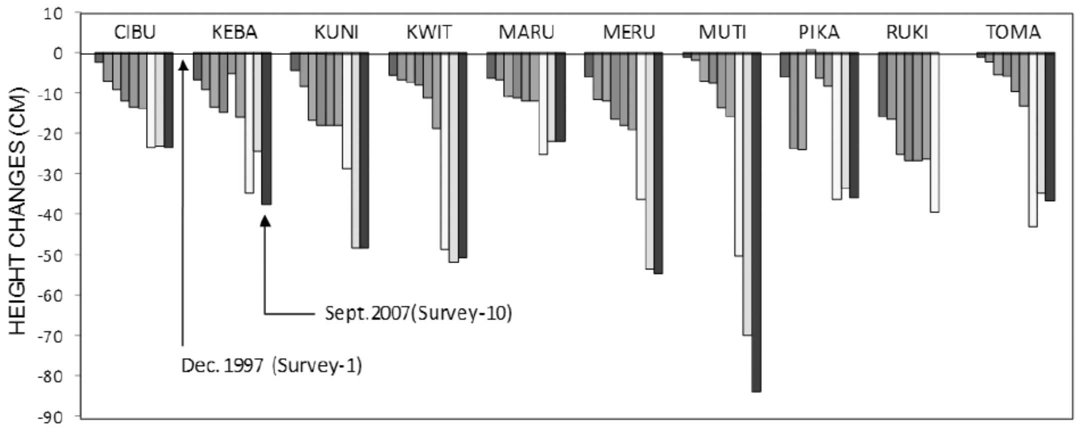



Figure 7. Accumulated GPS derived subsidence (cm) during the period of Dec. 1997 to Sept. 2007. The baseline elevations are those from GPS Survey-1 (Dec.1999).

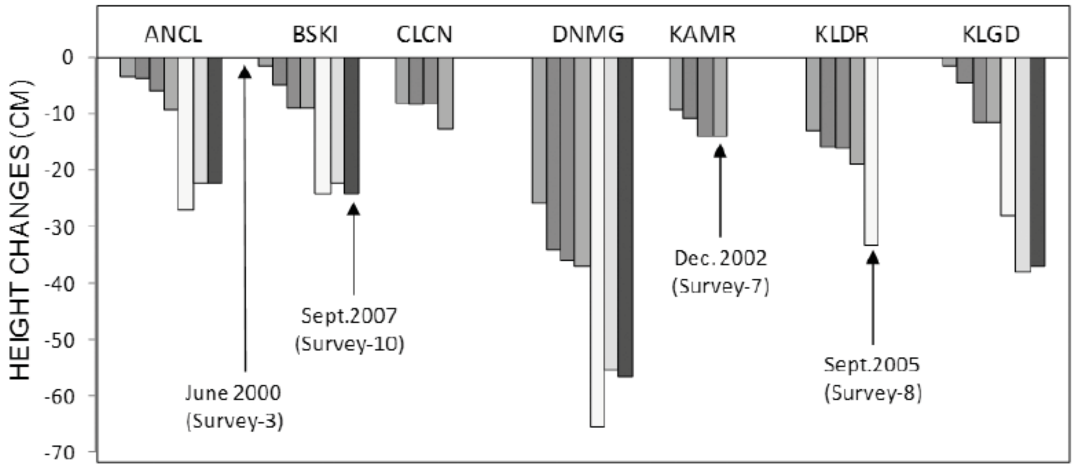



Figure 8. Accumulated GPS derived subsidence (cm) during the period of June 2000 to Sept. 2007. The baseline elevations are those from GPS Survey-3 (June 2000).

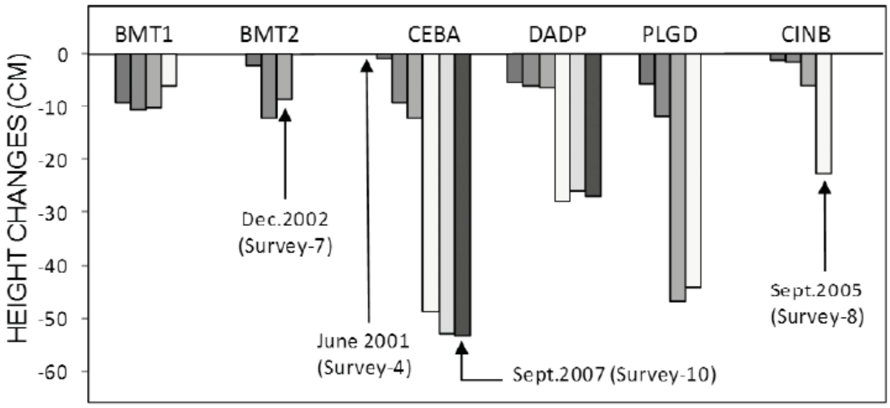



Figure 9. Accumulated GPS derived subsidence (cm) during the period of June 2001 to Sept. 2007. The baseline elevations are those from GPS Survey-4 (June 2001).

## Land subsidence as observed by InSAR

Since 2004, subsidence phenomena in Jakarta also have been studied using InSAR (*Interferometric Synthetic Aperture Radar*) techniques [*Schreier*, 1993; *Massonnet, and Feigl*, 1998]. The initial results are provided in *Abidin et al.* (2004). Recently, InSAR techniques were applied to study land subsidence in the Jakarta area using data from the ALOS/PALSAR satellite, which was launched in January 2006 as a successor of JERS-1/SAR. The SAR data observed during June 2006 and February 2007 were used. They were acquired in Fine Beam Single Polarization mode (HH polarization) with off-nadir angle of 41.5 degrees. InSAR processing has been performed using Level 1.1 products (SLC: Single Look Complex) distributed to the public by ERSDAC (Earth Remote Sensing Data Analysis Center) in Japan. The processing software for InSAR was developed by *Deguchi* (2005) and *Deguchi et al.* (2006).

Figure 10 shows land subsidence in northern part of Jakarta detected by InSAR over the period of June 2006 to February 2007. In this Figure, subsidence is calculated by multiplying the number of colour fringes by 11.8 cm. This Figure shows that subsidence along the coastal zone of Jakarta has a spatial variation. After correlation with GPS results, it was found that the maximum InSAR-derived subsidence rates for the eight month period between InSAR measurements reached about 12 cm/year, as shown in Figure 11. This subsidence rate is comparable with the rate observed by the GPS and levelling surveys. Please note in Figure 10, that of the area showing the largest land subsidence is located in Pantai Mutiara housing complex. The GPS station MUTI is located in this area and, as shown in Figure 7, this station

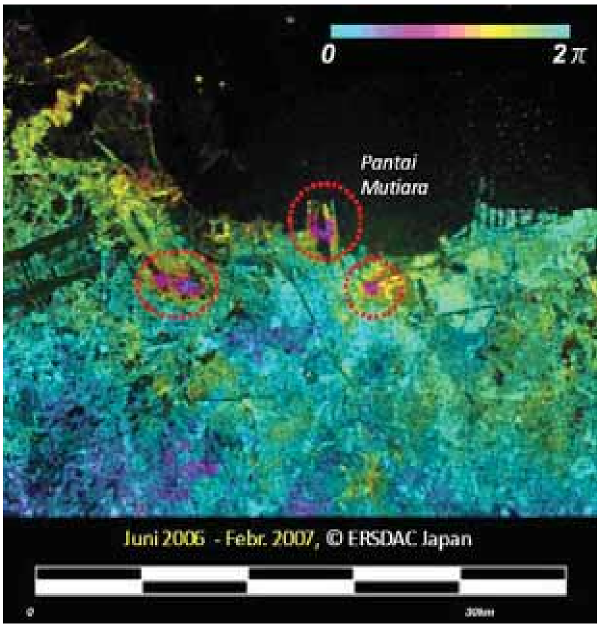



Figure 10. InSAR-derived subsidence in the northern partof Jakarta using ALOS PALSAR data.

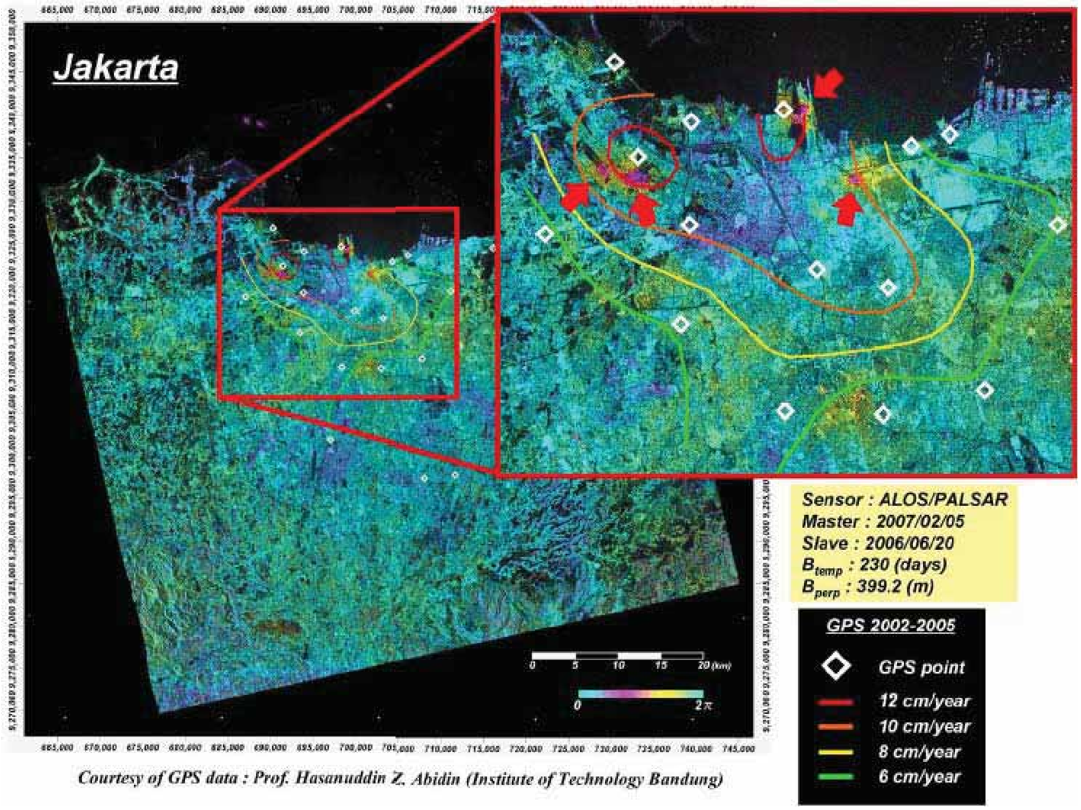



Figure 11. InSAR-derived subsidence rate in the northern part of Jakarta using ALOS PALSAR data. The red arrows are pointing toward the relatively large subsidence areas.

## Land subsidence and groundwater extraction

Land subsidence in Jakarta is thought to be caused by four factors, namely: groundwater extraction, loading of buildings and other constructions, natural consolidation of alluvial soil, and tectonic movement. Up to now, there has been no information about the relative contribution of each factor to localized subsidence or their spatial distribution. In the case of Jakarta, tectonic movement is thought to be the least dominant factor for progressive subsidence, while groundwater extraction is considered to be one of dominant factors. In the context of groundwater extraction, if the spatial distribution of land-surface subsidence in the period between 1982 and 1991 (Figure 4) is compared with changes in the elevation of the groundwater piezometric surface (Figure 12), it can be seen that a correlation exists. From this comparison it is suggested that the cones of depression within the piezometric surface inside the middle and lower aquifers more or less coincide with the cones of largest land subsidence measured by the levelling. In addition, each of the areas with the largest amount of land subsidence are situated in the areas consisting of sand bar and beach-river deposits; sediments that have high compressibility [*Murdohardono and Sudarsono,* 1998].

Currently, these areas are industrial areas with relatively highdensity settlement, both of which consume a lot of groundwater. This intensive groundwater abstraction appears to have deepened the piezometric water level inside the middle and lower aquifers and in turn caused land-surface subsidence above it. The subsidence rate is closely related to the rate of piezometric water level (head) deepening in the middle and lower aquifers. According to *Hadipurwo* (1999), the maximum depth of the piezometric head inside the middle and lower aquifers of Jakarta tends to deepen with time, as shown in Figure 13. In the case of Jakarta, the increases in both population and industry, which require a lot of groundwater, likely explain the declining trend of piezometric heads. This ever increasing demand on the groundwater resource appears to accelerate the deepening of piezometric head and, in a way, explains the higher maximum rate of subsidence in the period of 1991-1997 compared to those in 1982 to 1991 as observed by the levelling surveys (see Figure 5). Moreover, *Hadipurwo* (1999) also observed that up to 1995 the depression cones of the piezometric heads tend to widen with time. This may explain the aforementioned increase in the number of subsidence cones in the period of 1991-1997 compared to those in 1982-1991 (see Figure 4).

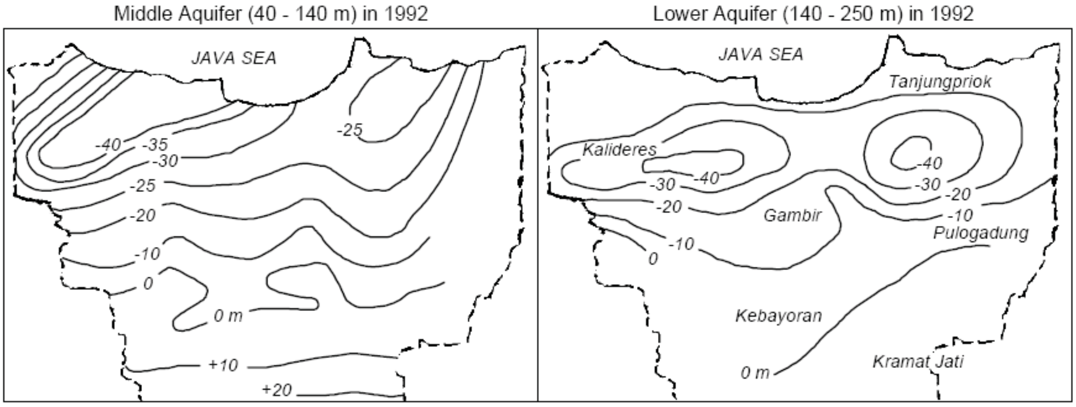



Figure 12. Piezometric water level contours relative to MSL (in metres) inside Middle and Lower Aquifers of Jakarta in 1992; adapted from [*Murdohardono and Tirtomihardjo*, 1993].

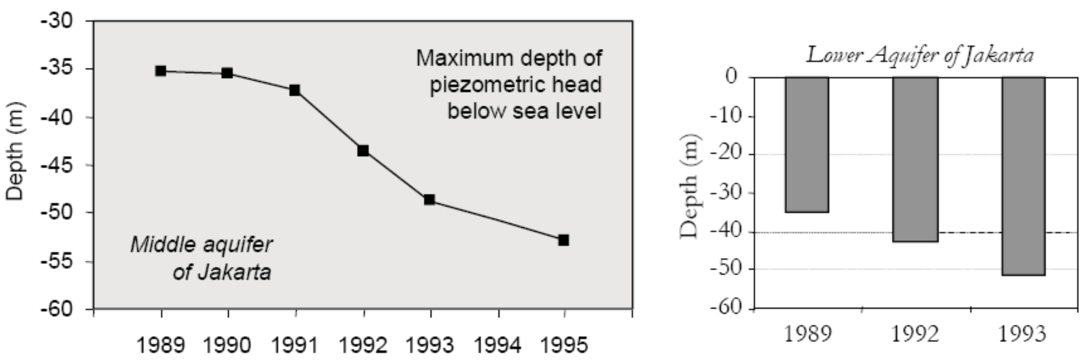


Figure 13. The deepening of the piezometric head inside the middle and lower aquifers of Jakarta; drawn from the data given in *Hadipurwo* (1999).

The groundwater level inside the Middle and Lower aquifers at several locations in Jakarta continue to decline. Figure 14 shows that the groundwater levels are decreasing with rates of about 0.2 to 2 m/year over the period of 2002 to 2007. In comparison with GPS -derived subsidences shown in Figure 7, 8 and 9, it can be seen that the large subsidences are usually associated with the relatively high rates of groundwater level change rates.

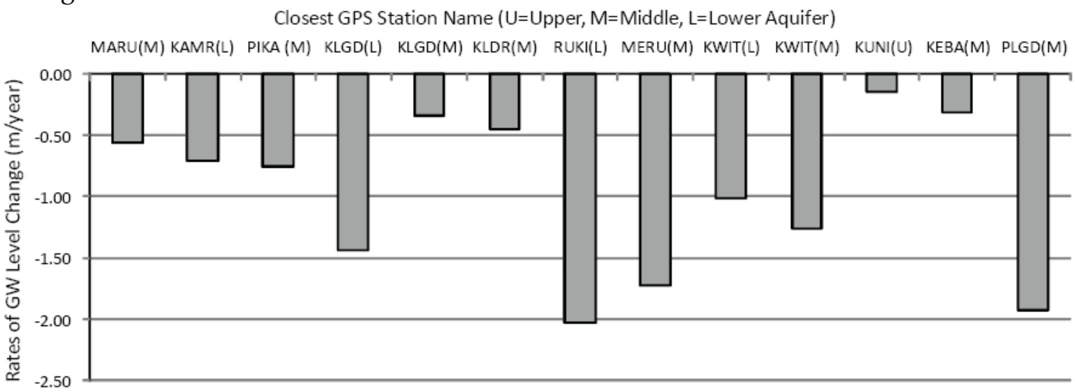



Figure 14. Groundwater level change rates at several monitoring wells around certain GPS stations in Jakarta during the period of 2002 and 2007.

It should be realized however that in the shorter time scale, the groundwater level changes inside the Jakarta aquifers are quite dynamic, as shown by an example given in Table 1. These groundwater levels can go up and down up from several decimeters to a few meters in a year. The effect of this short-term variation in groundwater level inside the aquifers on the long-term subsidence phenomena in the Jakarta area and its spatial variations are not yet fully understood. More research is needed to study and clarify this matter.

Table 1. Example of variation in depth to groundwater for selected monitoring stations in Jakarta from 2002 to 2007.

| **Location** | **Closest GPS station** | **Aquife r** | **Groundwater level depths (m)** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
| Cilincing ( KBN ) | MARU | Middle | -4.16 | -3.42 | -3.26 | -3.94 | - | -7.00 |
| Kamal Muara | KAMR | Lower | -23.50 | -23.36 | -23.72 | -25.62 | - | - |
| Kapuk | PIKA, | CEBA | Middle | -49.66 | -49.82 | -49.67 | -50.73 | - |
| Sunter – 1 | KLGD | Lower | -11.11 | -11.95 | -12.57 | -12.93 | -11.75 | -18.30 |
| Sunter – 3 | KLGD | Middle | -21.38 | -20.80 | -20.82 | -21.41 | -21.08 | -23.10 |
| Tegal Alur | KLDR | Middle | -41.38 | -39.47 | -38.11 | -41.98 | -38.44 | -43.65 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tongkol – 5 | RUKI | Upper | -4.71 | -3.30 | -3.29 | -10.20 | -4.19 | - |
| Tongkol – 7 | RUKI | Lower | -25.13 | -23.67 | -22.47 | -17.56 | -23.54 | -35.26 |
| Tongkol – 8 | RUKI | Lower | -24.50 | -23.67 | -23.35 | -27.67 | -24.24 | -28.85 |
| Tongkol – 9 | RUKI | Middle | -8.73 | -5.73 | -6.21 | -5.14 | -7.12 | -6.11 |
| Joglo | MERU | Middle | -18.28 | -20.15 | -20.14 | -24.48 | -20.21 | -26.92 |
| Parkir Gd. Jaya | KWIT | Lower | -20.20 | -20.60 | -20.88 | -21.86 | - | - |
| Atrium, Senen | KWIT | Middle | -12.26 | -21.36 | -21.66 | -12.66 | - | - |
| Bapedalda Kngn | KUNI | Upper | -5.57 | -5.42 | -5.77 | -4.56 | -4.94 | - |
| Dharmawangsa | KEBA | 92-125 | -31.95 | -33.29 | -33.75 | -32.26 | - | - |
| PT. YamahaM-2 | PLGD | Middle | -16.29 | -12.51 | -12.50 | -13.54 | - | -25.91 |
| Pulogadung | PLGD | Middle | -28.13 | -28.30 | -29.46 | -28.40 | -28.47 | -28.66 |

## Land subsidence and sea level rise in northern coast of Jakarta

The levelling, GPS and InSAR derived results show that the coastal areas of Jakarta are affected by subsidence phenomena with rates of about 1 to 15 cm/year. During high tides, tidal flooding is already affecting some of these coastal areas. The extent and magnitude of subsidence related flooding will worsen with the likely continuation of sea level rise along the coastal area of Jakarta, which is bordered by the Java sea. Figure 15 shows the tide gauge data from Tanjung Priok station located close to the Jakarta harbour. The sea level rise trend is apparent in this tide gauge record from 1984 to 2004, with the rate of about 9 mm/year. This trend is also shown by the satellite altimetry results (see Figure 16), with the slightly higher rate of about 15 mm/year. Based on these two data sets, it can be hypothesized that there is a sea level rise trend of about 1 cm/year in the coastal area of Jakarta. This sea level rise rate is much less than the subsidence rates of the coastal land area of Jakarta. The combined effects of land subsidence and sea level rise in the coastal areas of Jakarta should be considered in vulnerability assessments of the areas to the tidal flooding phenomena. Table 2 shows two possible scenarios of future tidal flooding conditions, the first being a conservative estimate (most probable case) and the second being a pessimistic (worst case) scenario.

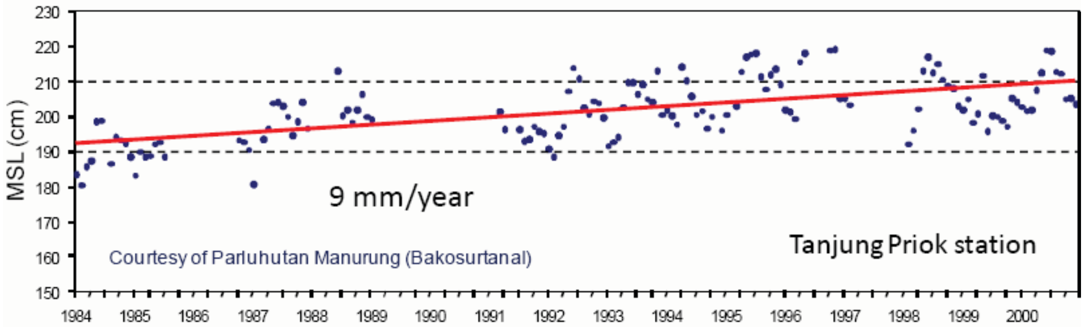



Figure 15. Trend of sea level rise in the coastal area of Jakarta, as derived from tide gauge data; courtesy of Dr. Parluhutan Manurung, Bakosurtanal, Indonesia. The coefficient of determination (R2)
is about 0.85.

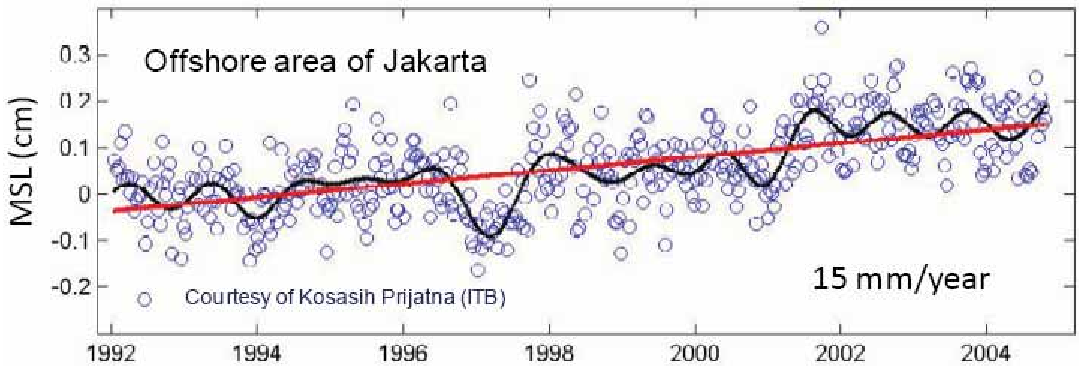
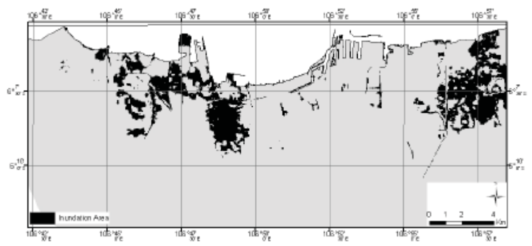



Figure 16. Trend of sea level rise in the offshore area of Jakarta, as derived from satellite altimetry data (TOPEX/Poseidon and JAS-1), courtesy of Ir. Kosasih Prijatna MSc, KK Geodesy ITB, Indonesia. The coefficient of determination (R2) is about 0.86.

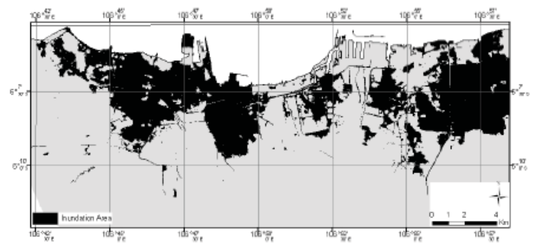
In the conservative scenario, a subsidence rate of about 2.5 cm/year and a minimum global sea level rise rate of about 2-3 mm/year [*Gornitz,* 1995; *IPCC,* 2007] are used. In the pessimistic scenario, a subsidence rate of about 10 cm/year and a local sea level rise rate of about 1 cm/year (as information from the tide gauge and satellite altimetry data) are used. In the conservative scenario, the possible rise in sea level relative to the coastal areas of Jakarta could be up to 0.3 m in 2020 and 1.1 m in 2050, compared to its reference condition in the beginning of 2008. In the pessimistic scenario, these values would be a 1.3 m rise in 2020 and a 4.6 m rise in 2050. Considering the relatively flat nature (i.e. 0-2 m above MSL) of most coastal areas of in Jakarta, this combined effect of land subsidence and sea level rise will certainly have disastrous consequences for habitation, industry, and fresh groundwater supplies from the coastal aquifers. Figure 17 shows the possible inundated areas estimated using the scenarios given in Table 2.

Table 2. Possible combined effect of land subsidence and sea level rise in the coastal area of Jakarta.

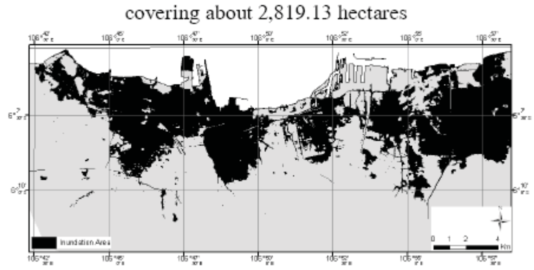
| CONSERVATIVE SCENARIO | |
|---|---|
| Land subsidence rate | 2.5 cm/year |
| Sea level (MSL) rise rate | 0.2 cm/year |
| Separation rate between MSL and land surface | 2.7 cm/year |
| Possible increase of sea level inundation in the coastal areas of Jakarta in 2020 (since beginning of 2008) | 0.3 m |
| Possible increase of sea level inundation in the coastal areas of Jakarta in 2050 (since beginning of 2008) | 1.1 m |
| **PESIMISTIC SCENARIO** | |
| Land subsidence rate | 10 cm/year |
| Sea level (MSL) rise rate | 1 cm/year |
| Separation rate between MSL and land surface | 11 cm/year |
| Possible increase of sea level inundation in the coastal areas of Jakarta in 2020 (since beginning of 2008) | 1.3 m |
| Possible increase of sea level inundation in the coastal areas of Jakarta in 2050 (since beginning of 2008) | 4.6 m |



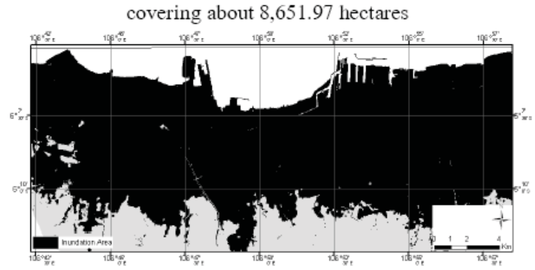
Inundation areas in 2020 (conservative scenario); covering about 2,819.13 hectares



Inundation areas in 2050 (conservative scenario); covering about 8,651.97 hectares



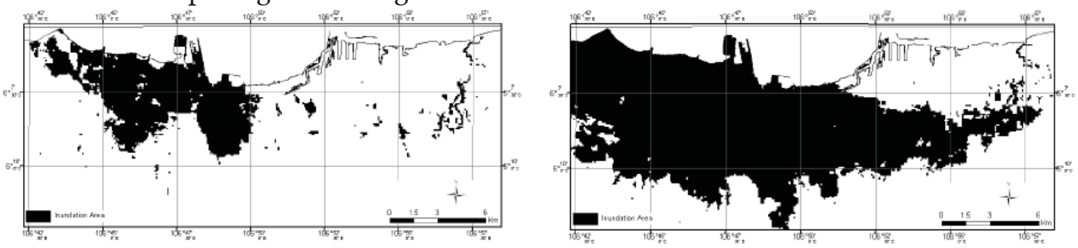
Inundation areas in 2020 (pesimistic scenario); covering about 9,989.02 hectares



Inundation areas in 2050 (pesimistic scenario); covering about 25,029.52 hectares

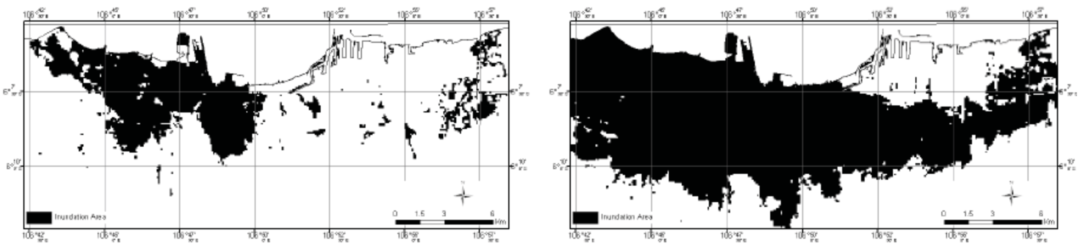
Figure 17. Possible inundation areas (in black) in the coastal areas of Jakarta; with the assumption of homogeneous subsidence rates along the coast.

It should be noted however that the land subsidence rate is not uniform over the entire coastal area of Jakarta, as shown in the previous Figures 4,7,8,9,10 and 11. These Figures show some coastal areas are more susceptible to tidal flooding than the others. If the spatially different rates of subsidences as derived by InSAR (see Figure 11) are integrated with the scenarios of sea level rise rates given in Table 2, then the possible inundation maps as given in Figure 18 are obtained.



Inundation areas in 2020 (conservative scenario of sea level rise rate); covering about 5,146.80 hectares

Inundation areas in 2050 (conservative scenario of sea level rise rate); covering about 16,237.87 hectares



Inundation areas in 2020 (pesimistic scenario of sea level rise rate); covering about 5,910.04 hectares

Inundation areas in 2050 (pesimistic scenario of sea level rise rate); covering about 18,108.61 hectares

Figure 18. Possible inundation areas (in black) in the coastal areas of Jakarta; with the assumption of spatially different subsidence rates along the coast.

## Closing Remarks

The results obtained from levelling surveys, GPS surveys and the InSAR technique over the period between 1982 and 2007 show that land subsidence in Jakarta has spatial and temporal variations. In general, the observed subsidence rates are about 1 to 15 cm/year, and can be up to 20-25 cm/year at certain locations and for certain time periods. There is a strong indication that land subsidence in the Jakarta area is related to the high volume of groundwater extraction from the middle and lower aquifers, with secondary contributions by building/construction loading and natural consolidation of sedimentary layers. The large volume of groundwater extraction causes a rapid decrease in groundwater levels inside the aquifers reducing the hydrostatic pressures on aquifer material, and in turn, causing the land surface above it to subside. However, the relation between land subsidence and localized groundwater level decrease will not always be a direct and simple relation, as indicated by example given in Figures 19 and 20. It may be due to variations in the amount of groundwater being pumped over time. Therefore, if the amount of groundwater pumping is available, then it will be interesting to compare the correlation between the variations in pumping rates with the change in land subsidence.

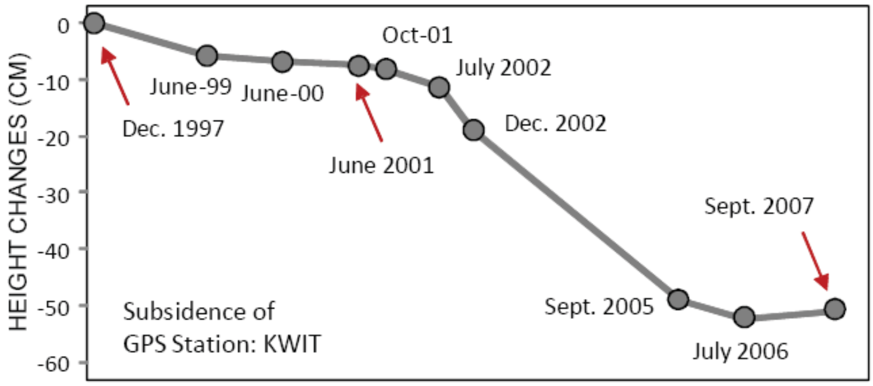



Fig. 19. GPS-derived ellipsoidal height changes of GPS station: KWIT.

Figure 19. GPS-derived ellipsoidal height changes of GPS station: KWIT.

Based on the data collected by the Provincial Mining Agency of Jakarta, it can be inferred that the groundwater level changes inside the aquifers of the Jakarta basin have rates of about a few dm/year up to a few m/year. Although most of the documented changes show a decline in the piezometric surface, some locations for specific aquifers and certain time periods also show groundwater level increases. In other words, short term variations in groundwater level also exist inside the aquifers of Jakarta basin. In studying the land subsidence phenomena in the Jakarta basin it would be interesting to investigate the effect of this short-term variation in groundwater pumping volumes and groundwater level on the long-term subsidence phenomena and its spatial variations.

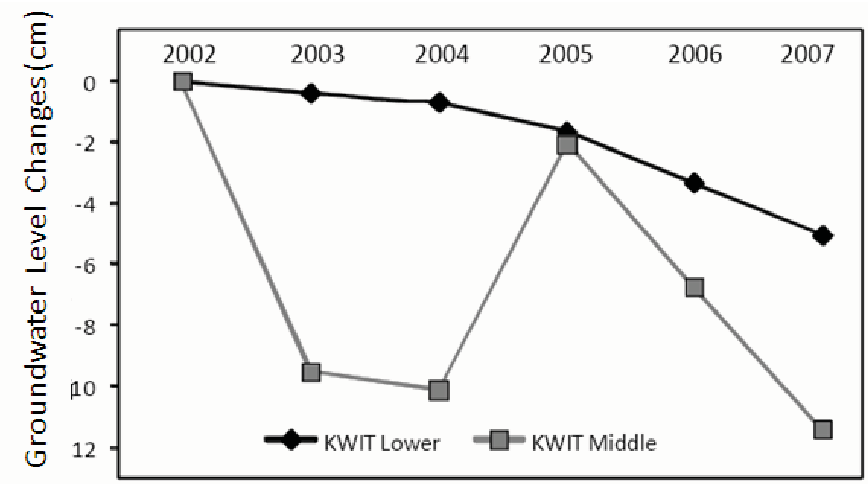


Figure 20. Groundwater level changes observed at the monitoring wells around the KWIT GPS stations.

More data and further investigations are required to understand the intricacies of the relationship between land subsidence and groundwater extraction in the Jakarta basin. Additional causes of subsidence, e.g. load of buildings and construction, natural consolidation of alluvial soils, and tectonic movements, should also investigated and taken into account. Finally it should be noted that in the coastal areas of Jakarta, the combined effects of land subsidence and sea level rise will introduce other collateral hazards, namely the tidal flooding phenomena. Several areas along the coast of Jakarta already have experienced tidal flooding during high tide periods. The adaptation measures to reduce the impacts of this phenomenon therefore should be developed as soon as possible.

## Acknowledgements

The GPS surveys has been conducted using research grants from the Ministry of Science and Technology of Indonesia, Ministry of National Education of Indonesia, ITB Research Grant 2005, and Kyoto University, Japan. The GPS surveys were conducted mainly by the staffs of Geodesy Research Division of ITB, and students of the Department of Geodesy and Geomatics Engineering of ITB. Ir. Bungaran Purba MM from the Provincial Mining Agency of DKI Jakarta is thanked for the information on groundwater level changes inside the aquifers of Jakarta basin.

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# Development of New Seismic Hazard Maps of the Indonesian Region

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**Summary**

The technical meeting for updating the Indonesian National Standard (SNI) seismic hazard maps 03-1726-2002 on 30 November 2009 in Jakarta that was arranged by the Ministry of Public Works of the Republic of Indonesia and supported by various government agencies, universities, and professional associations decided to revise the current Indonesian seismic map in the SNI 03-1726-2002. The Department of Public Works then established a team to revise the seismic hazard maps of Indonesia. This report summarizes research works on seismic hazard analysis conducted by the team in developing new spectral hazard maps of Indonesia. The maps were developed based on the total probability theorem by using a three-dimensional seismic source model and by considering the latest available geological and seismological data.

The seismic hazard analysis was performed using the following procedure: (i) conducting literature review on geology, geophysics and seismology to identify the activity of seismic sources in and around the Indonesian region, (ii) collecting and processing recorded earthquake data for the entire Indonesian region, (iii) modeling seismic source zones based on the advanced models appropriate with the USGS software, (iv) determining seismic parameters which include a and b values, maximum magnitudes, and slip rates, (v) calculating the spectral acceleration based on the total probability theorem, (vi) mapping the spectral hazard that includes the peak ground acceleration (PGA) and short period (0.2 sec) and 1.0 sec period spectra values.

The seismic hazard parameters used in this study were derived from published journals, proceedings, previous works conducted by the team members, and the latest information obtained during this study. In this study we have compiled and integrated previous and current studies. Earthquake source parameters were determined based on earthquake catalog, and geological and seismological information of active faults. The earthquake catalog covers the period from 1900 to 2009, and the area from 90°E to 145°E and from 15°S to 15°N.

Seismic sources were devided into subduction, fault, and background zones by considering the recurrence relationship that includes a truncated exponential model, a pure characteristic model, and both models. The geometry of fault and subduction was represented by three-dimensional (3-D) models based on the result of seismic tomography and the slip rates of faults were determined by considering the results of GPS measurements. Background source zones were modeled by using gridded models based on spatially smoothed earthquake rates. Several well-known attenuation functions were selected in accordance with the mechanism of seismic source including the Next Generation Attenuation (NGA) attenuation function. The logic tree was also applied to account for epistemic uncertainty including the recurrence model, maximum magnitude, and several attenuation functions.

Three hazard levels were calculated to represent 10% probability of exceedance (PE) in 50 years (475 years earthquake), 2% PE in 50 years (2,475 years earthquake), and 10% PE in 100 years (950 years earthquake) for ground motions at the base rock. Contours of PGA, short period (0.2 sec) and 1.0 sec spectra values for each hazard level were constructed.

The following figures are some examples of our new maps i.e. the PGA, the 0.2 and 1.0 sec spectral acceleration for the Indonesian region for the10% probability of exceedance in 50 years, respectively.

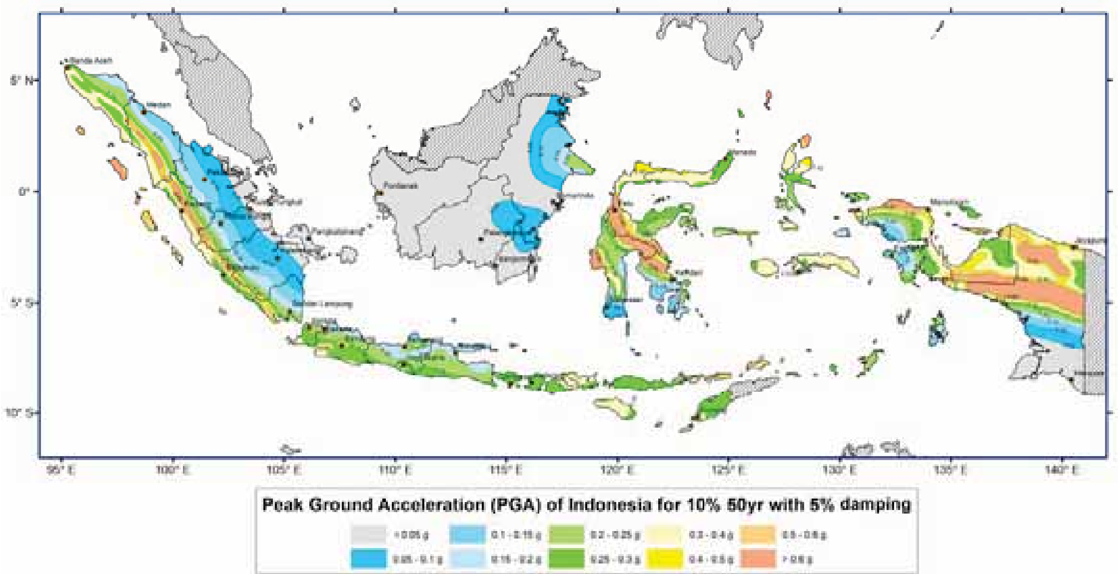


Figure 1. Map of the Peak Ground Acceleration (PGA) for the Indonesian region for the10% probability of exceedance in 50 years.

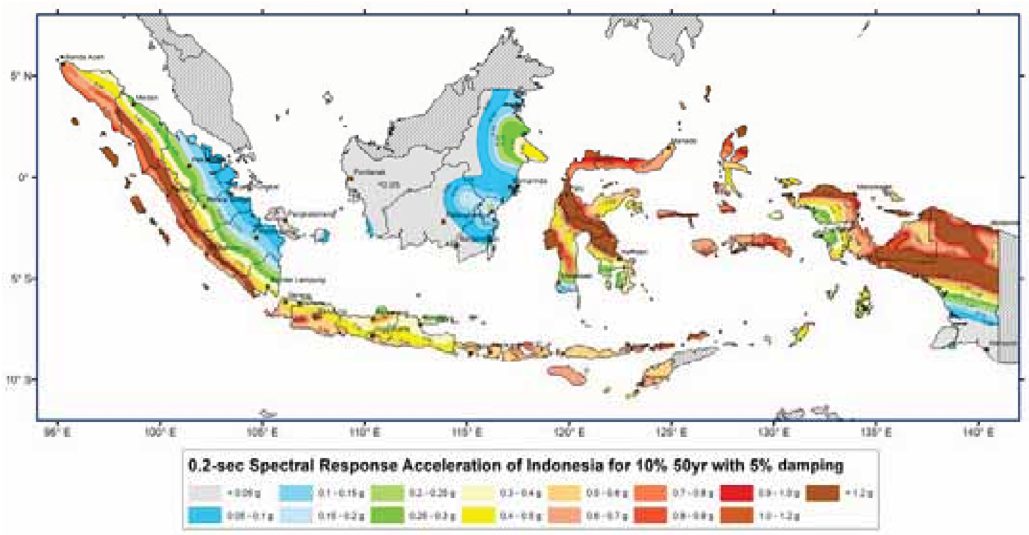


Figure 2. Map of the 0.2 sec spectral acceleration for the Indonesian region for the 10% probability of exceedance in 50 years.

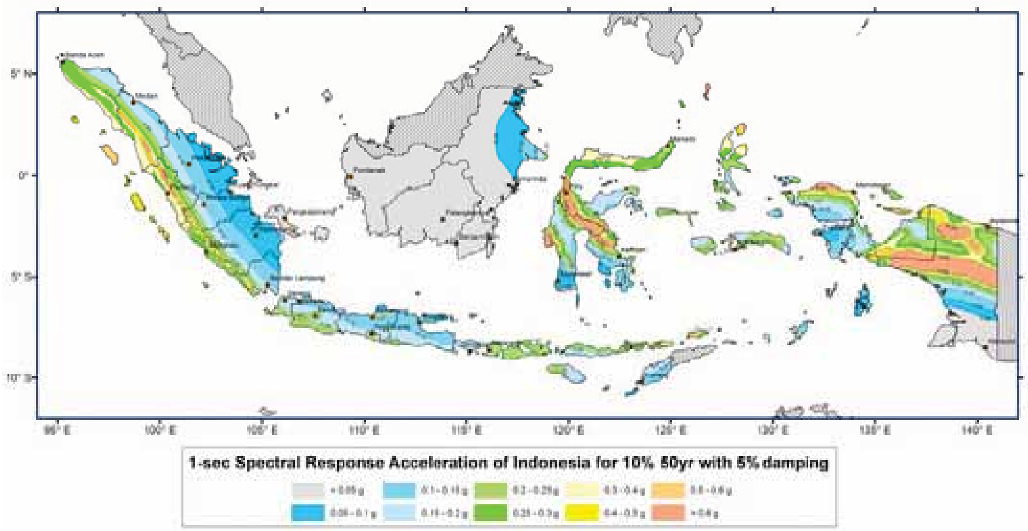


Figure 3. Map of the 1.0 sec spectral acceleration for the Indonesian region for the 10% probability of exceedance in 50 years.

See also http://www.pu.go.id/satminkal/balitbang/sni.

The new maps have been used to update the Indonesian Building Codes for the planning and design basis of earthquake-resistant infrastructures/buildings. With our new National Standard Building Codes, we hope that the earthquake disaster risk in Indonesia can be minimized.

We gratefully acknowledge the support from the Ministry of Public Works (PU) of the Republic of Indonesia, the National Disaster Management Agency (BNPB) and Australia-Indonesia Facility for Disaster Reduction (AIFDR), the Ministry of Research and Technology, and the Unites States Geological Survey (USGS) for their supports and assistance during this study.

## Volcanic Activity In Indonesia During Period of 2008-2011

Ministry of Energy and Mineral Resources
Geological Agency
Center for Volcanology and Geological Hazard Mitigation

**Background**

As an archipelago country, Indonesia is a meeting point of several tectonic plates. The Indo-Australia oceanic plate subducts beneath the Eurasian continental plate formed the volcanic arc in western Indonesia.The Indo-Australia, Phillipines, Pasific and some minor/small plates meet to form volcanic arc in eastern Indonesia. Volcanic arcs extends from Sumatera Island going east to Java, Bali, Nusa Tenggara, Sulawesi, Halmahera, Banda until Molucca Island. Along the volcanic arcs, there are 129 active volcanoes, which 69 of them are very active and hazardous. This situation causes Indonesia has high risk of natural disaster such as eruption, earthquakes, tsunami and landslide.

Based on regulation and legislation in Indonesia, Ministry of Energy and Mineral Resources conducting a national policy rule for geological hazard mitigations, with operated by Center for Volcanology and Geological Hazard Mitigation, Geological Agency. Main tasks of CVGHM are to conduct research, investigate and service of volcanology and geological hazard mitigation (volcanic eruption, earthquake, tsunami, landslide), issue an early warning for volcanic activities and landslide, disseminate geological hazard knowledge to local government and communities who live in the geological hazard zone, produce the geological hazard map for spatial planning, geological hazard mitigation and education, give technical recommendation to the local government to do geological hazard mitigation efforts and evaluate research, investigate and service of volcanology and geological hazard mitigation.

The volcano mitigation has conducted monitoring such as seismic and deformation on active volcano in understanding the stage of its activities to provide a volcano early warning system. Instrumentation and methods of monitoring are always developed. In addition, volcano hazard zone mapping and inventory of potential location for volcano tourism were also done.

Earthquake and tsunami mitigation has conducted quick responses on earthquake and tsunami disaster, mapping of earthquake and tsunami susceptibility, monitoring of earthquake from internet and other mass media, determination of active fault, mapping of ground amplification, tsunamigenic research, and also establishment of database of destructive earthquake in Indonesia.

The landslide program has conducted quick responses on landslide disaster, mapping of landslide susceptibility, monitoring of landslide on the vital area, survey of landslide and slope stability on the vital road lane, landslide early warning system and also establishment of database of destructive landslide in Indonesia.

## 2 Annual Review of Volcanic Activities

Observation and analysis of seismic data from the analog recording with one vertical seismometer from Volcano Observatory has currently done in Sorik Marapi, Tandikat, Kerinci, Kaba, Dempo, Galunggung, Papandayan, Ciremai, Slamet, Sundoro, Sumbing, Lamongan, Arjuno Welirang, Raung, Agung, Tambora, Rinjani, Lewotobi, Inelika, Ili Boleng, Anak Ranakah, Egon, Sangeangapi, Ebulobo, Batu Tara, Wurlali, Rokatenda, Sirung, Colo, Karangetang, Soputan, Awu, Bandaapi, Ibu, Dukono, Gamkonora, Kie Besi, Gamalama, volcanoes. Some volcanoes have been monitored by using more than 1 seismometer such as in Sinabung, Marapi,Talang, Krakatau, Gede, Salak, Tangkuban Perahu, Guntur, Dieng, Merapi, Kelut, Semeru, Ijen, Batur, Lokon volcanoes. In addition, continuous deformation survey has been applied in Sinabung, Papandayan, Guntur, Merapi, Semeru, Bromo, Lokon and Batur volcanoes. The purpose of monitoring is to understand the volcanic activities related to the volcano early warning system.

During the period of 2008-2011,four volcanoes erupted causing more than 200 persons died, hundreds injured and more than 300.000 persons evacuated (see Table 1 ).

Table 1. The volcano eruption during the period of 2008-2011

| No | Time | | Name of Volcano | Location | Explanation |
|---|---|---|---|---|---|
| | Year | Month | | | |
| 1 | 2008 | | | | No eruption occur; until the end of 2008: 14 volcanoes in Level II of alert level, 2 volcanoes in Level III |
| | | May 29 - 13 June | Dukono | West Halmahera | Erupted, no victim |
| | | 6 June - 21 October | Soputan | North Sulawesi | Erupted, evacuated, no victim |
| | | 21 May – 5 June | Semeru | East Java | Erupted, no victim |
| | | 15 April - 12 May | Egon | East | Erupted, no victim |

| No | Time | | Name of Volcano | Location | Explanation |
|---|---|---|---|---|---|
| | Year | Month | | | |
| | | | | Nusatenggara | |
| | | 21 April - now | Ibu | West Halmahera | Erupted, no victim |
| | | December 2 | Karangetang | North Sulawesi | Erupted, no victim |
| 2 | 2009 | | | | 7 volcanoes erupted; until the end of 2009: 15 volcanoes in Level II of alert level,3 volcanoes in Level III |
| | | January 1 | Dempo | South Sumatera | Erupted, no victim |
| | | January 15 -22 | Slamet | Central Java | Erupted, no victim |
| | | May 2 | Rinjani | West Nusatenggara | Erupted, no victim |
| | | 6 May- now | Anak Krakatau | Lampung | Erupted, no victim |
| | | 31 May - 9 June | Karangetang | North Sulawesi | Erupted, no victim |
| | | 16 July - 5 August | Ibu | West Halmahera | Erupted, no victim |
| 3 | 2010 | | | | 4 volcanoes erupted; until the end of 2010: 12 volcanoes in Level II of alert level, 2 volcanoes in Level III, |
| | | August 29 - September 7 | Sinabung | North Sumatera | Erupted, 30.000 persons evacuated, 1 victim |
| | | 6 August - September | Karangetang | North Sulawesi | Erupted, 4 persons victims |
| | | October 25 - November | Merapi | Central Java | Erupted, 300.000 persons evacuated, more than 200 victims |
| | | November 23 - May 2011 | Bromo | East Java | Erupted, no victim |

| No | Time | | Name of Volcano | Location | Explanation |
|---|---|---|---|---|---|
| | Year | Month | | | |
| 4 | 2011 (until June) | | | | 2 volcanoes erupted, 17 volcanoes in Level II of alert level, 3 volcanoes in Level III, 3 volcanoes in Level IV |
| | | March 11-24 | Karangetang | North Sulawesi | Erupted, 582 persons evacuated, no victim |

Survey and mapping of volcano includes;

- Volcano Hazard Zone Mapping on Wurlali, Sinabung volcanoes.
- Volcano Hazard Assesment on Papandayan volcano.
- Volcano Geological Mapping on Wurlali, Sinabung, volcano.
- Study of Gravity method on Batur volcanoes,
- Study of Geomagnet method on Galunggung, Dieng, Gamalama, Egon (2008), Kelut,
- Study of Chemical Water and Gas on Sorik Marapi, Papandayan, Tangkuban Perahu, Dempo, Rinjani, Lamongan, Guntur, Salak volcanoes.
- Study of Rock Chemical on Bromo volcanoes.
- Volcano Geological Mapping for B-type volcanoes, such as Bukit Daun, Pusuk Bukit, Karang, Sumbing (Jambi), Belirang-Beriti, Wilis, Sibual-buali, Kunyit
- Volcano Geological Hazard Mapping for B-type volcanoes, such as Rajabasa, Ungaran, Sumbing, Talaga bodas, Pusuk Bukit.

Improvement of volcano monitoring instrumentation such as the application of microprocessor technology for the development of volcano monitoring, $CO_2$ gas sampling and mapping methods was done at Dieng Plateau.

## 3. Cooperation

Cooperation research with other institutions on volcano and geological hazards mitigation as follows:

- Sakurajima Volcano Observatory (Kyoto University), DPRI. The collaboration study with Japan, through Sakurajima Volcano Research Center (SVRC), DPRI, Kyoto University has been set up for more than 18 years.

- o Volcano monitoring in Guntur (West Java) and Semeru (East Java) volcanoes.
- o Through JICA/JST project on the Multi-disciplinary Hazard Reduction from Earthquakes and Volcanoes in Indonesia (2008-2012):
  1. Volcano monitoring in Sinabung (North Sumatera), Talang (West Sumatera), Bromo (East Java), Merapi (Central Java).
  2. Study on tectonic activity at Bandung basin and around Guntur, Papandayan and Galunggung volcanoes (West Java) in relation to volcanic activities.
  3. Evaluation of volcanic activity at Merapi (Central Java) and Kelut (East Java) volcanoes.
- o Exchanges of volcano experts to share and developing the capabilities of CVGHM personel.

- Through JICA/JST – Japan project on the Multi-disciplinary Hazard Reduction from Earthquakes and Volcanoes in Indonesia (2008-2012):
  - o Study on caldera eruption have also been done at Bromo, Batur, Rinjani and Tambora volcanoes.
  - o Deformation monitoring by using ALOS images.
- Universite Libre de Bruxelles, Belgium

  The cooperation started in 2006 and ended in 2009. The project was related to risk and disaster mitigation of eruption. The target areas were Kelut, Rinjani, Sirung, Dempo, Krakatau and Papandayan volcanoes.
- Australian government, through Bureau of Meteorology-Volcanic Ash Advisory Center (BoM-VAAC Darwin).

  The cooperation is focused on developing volcano monitoring network in East Nusa Tenggara volcanoes. The installation of monitoring instrument has been done in 2009.
- Through European Commision, the MIAVITA project has been started in 2008. The target areas are Kelut and Merapi volcanoes.
- France government. The project was focused to develop volcano monitoring system for mitigation efforts purposes. The target areas were Semeru, Batur, Ijen, Merapi volcanoes.
- United State of Geological Survey, US
  - o Development of North Sulawesi Regional Volcano Monitoring Center. The purpose of the project is to further develop the Regional Volcano Monitoring Center of North Sulawesi, located at Kakaskasen-Menado, with existing observatory and upgrading of volcano monitoring system in North Sulawesi, which include undertaking on : seismic stations and telemetry,

geodetic, SO2 emission monitoring, equipment cache and data management and to conduct geologic evaluations. The project has already started since 2006.

   - Development of monitoring system at Ijen and Raung volcanoes by adding seismic stations. Other work is geological study at Ijen and Raung volcanoes to investigate deposits of past eruptions. The aim of this work is to reconstruct the volcano eruptive history of Ijen caldera (included Raung volcano). The project has already started since 2011.

- Earth Observatory of Singapore, Nanyang Technology of University

  The Improvement of Monitoring System at Gede and Salak volcanoes. The aim of the project is to study past magmatic and eruptive processes and to upgrade monitoring system (seismic, geodetic, geochemical, and hydrologic monitoring), to anticipate the next eruption of either volcano and, in the meantime, document processes of intrusions that fail to erupt. This study also seeks to understand why Gede and Salak are prone to sector collapse. The project has already started in March 2011.

- Local Government

  Cooperation between CVGHM and local government, before, during and after the occurrences of geological disaster is focused on technical recommendation and socialization of geological hazard mitigation.

## 3. Proposed Future Activities

The future volcano hazard mitigation programs of CVGHM will be focused on increasing the cooperation of research and investigation in monitoring volcano activity with:

- Kyoto University, Disaster Prevention Research Institute (cq Sakurajima volcano observatory & Kyoto University) on Sinabung, Talang, Guntur, Papandayan, Semeru and Bromo volcanoes.
- United State of Geological Survey, US on North Sulawesi volcanoes, Ijen and Raung volcanoes.
- France government on Ibu, Gamkonora, Dukono, Gamalama and Kie Besi volcanoes.
- Earth Observatory of Singapore, Nanyang Technology of University on Gede and Salak volcanoes.

# Research and development of space weather model and observation method in Indonesia during 2008-2010

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During the period of 2008 to 2010, the Space Science Center of LAPAN Indonesia has conducted the research and development of space weather model and observation method. Briefly the results of these activities are as follows:

1. Test results of the model prediction of x-ray flare show that the accuration of the model is about 75%. Statistical analysis using the 702 flare data from January 2000 to June 2008 have been obtained that 536 (76.35%) data is associated with the geomagntic storm. The time interval from the appearance of type II radio bursts up to the minimum Dst is about 53 to 65 hours with 95% confidence interval. The position of the solar active region where a source of bursts of radio plays an important role in relation to the occurrence of geomagnetic storms. Active region around the zero meridian and the active region in the western hemisphere of the sun is more strongly associated with the appearance of geomagnetif storm compared with an active area in the eastern of the sun. Statistical analysis also produces a correlation between time of the shock wave propagation and time difference between the initial radio bursts and the minimum peak of Dst satisfy a linear relationship with correlation coefficient of about 0.81. Informations of events of type II solar radio bursts, position of the active region, direction of interplanetary magnetic field and intensity of X-ray blast can be used to predict the probability of geomagnetic storm. The results of the analysis also showed that the single bursts events is more accurate than the bursts of events that occur sequentially in a few days.

2. Development of flare forecasting model.

   The model is based on an analysis of long-term sunspot data for two solar cycles from 1987 until 2010. The model is combined with the simulation results of magneto-hydro-dynamic (MHD) that can provide information about the evolution of sunspots. Forecasting models of flare events have been validated by using GOES satellite data and provide a conclusion that the flare forecasting model can be used for large flares forecasting for a few days to a week ahead. The application of this forecasting model can support space weather services in Indonesia.

3. Diagnostics model of space environment.

The diagnostics model of space environment is built based on data of satellites anomalies and space weather parameters. Bu using the model, users can know the potential of satellite operational disruption resulted by changes of space environment. This model can identify cases of satellite anomalies that are not reported. This model can be integrated with the model of Solar Particle Events (SPEs).

4. CME Detection Method Based On Satellite Observation Data.

This method uses the identification of satellite anomalies associated with the coronal mass ejections (CMEs). The identification technique is using data of CME halo (full and partial), Solar Proton Events (SPEs) and large geomagnetic storms (Dst <-100nT) as well as satellite anomalies accessed from www.sat-index.co.uk and some literature. Based on the analysis of the timing (epoch analysis) created a database containing satellite anomalies that occur and geomagnetic storm, SPE, and the CME associated with these anomalies during the solar cycle-23.

5. The method of determining solar geoeffective of CME activity based on its position in the sun.

Solar activity is primary source of space weather conditions. Solar storms that can cause geomagnetic storm are a flare, CME, filament eruption and flow of high-speed particles from coronal holes. Based on data analysis of SOHO, GOES and Dst, and the CME events have been identified CME Danger Zone, namely N21-S21, E30-W50, where if the CME source region within this region, the geomagnetic storm will be significant (<-100nT) or large solar geoeffectivenes of CME activity. If the source region of CME is located outside the danger zone, the solar geoeffectiveness of CME is small.

6. Research on Geomagnetic disturbances prediction model.

Based on analysis of prediction accuracy of Lund Dst model we obtanined that the Lund Dst model can be used for prediction of the daily variation of H component especially at Biak station, and generally at stations in Indonesia.

The short-term prediction of the daily variation of component of H by using Neural Network with the inputs of solar wind parameters (real-time satellite dataBz, V, and n) are valid for one to three hours ahead and have 90 – 95 % agreement wth the data observation from Biak station during year of 2000.

7. Analysis of earthquake precursors from ULF signal.

From the results of many studies have found the signs of ULF signal anomalies prior to large-scale earthquake. To prove the truth of the phenomenon and to explain the relationship between electromagnetic phenomena and physical mechanisms that may be related, data analysis of geomagnetic data at Kototabang have been carried out in its relation to the Sumatra earthquake. A case study has been conducted to observe the ULF signal anomalies associated with Aceh earthquake occurred on December 26, 2004 and the Nias earthquake which occurred on March 28, 2005 by using Wavelet Transform Modulus Maxima (WTMM). The results obtained showed a decrease in the parameter $A_{min}$ few weeks before the earthquake in Aceh, December 26, 2004 and the Nias earthquake, March 28, 2005, while the parameter Amax and A(fmax) showed no significant change. Fmax parameters, W, and Δ (delta) showed an increase which is not too significant a few weeks before the earthquake occurrence. However, this may indicate the occurrence of the process of self organizing criticality (SOC) in the lithosphere which is the beginning of an increase in seismic activity before the earthquake.

8. Development of Global Ionospheric Slab Thickness Model (GIST Model)

The GIST Model is model conversion of the TEC into the ionosphere F2 layer critical frequency (foF2). Given this model of HF radio frequency predictions can be given for one day ahead by using a global ionospheric map (GIM) as a input.

9. Propagation Model of E-Layer (M-ProE)

M-ProE model serves as a means of prediction of the probability of success of the information provider communication radios HF / VHF low. M-ProE program package has been enhanced in the accuracy and ability. Improved accuracy is done by modifying the coefficients in the Hagreaveas Hunsucker model based on data observation from Tanjungsari ionsonde. Improved accuracy is also performed by utilizing and implementing a data base of Es layer occurrence probability from Tanjungsari ionosonde as one of the output of the program package of M-ProE.

10. Determination Method T Regional Index.

The method is to determine the regional T index as a input for ASAPS prediction of HF propagation over Indonesian region.

11. Package Real Time Channel Evaluation Program (EKRT)

EKRT programs utilized in the evaluation of the frequency channels based on real time ionospheric data.

12. Development of The Ionospheric TEC regional model.

GPS signals used for positioning have propagation error when passing through the ionosphere in the form of additional time propagation. Additional time propagation depends on the total electron content (TEC) and the frequency of the GPS signal. TEC model can be used to reduce the propagation error. With near real time TEC regional over Indonesia the single-frequency GPS point positioning will be done quickly with accuracy levels up to cm-dm. The TEC regional model can also be used to estimate foF2 for the same area using relationship model of foF2 and TEC (foF2TEC model). The TEC model is developed by using near real time GPS data from 8 IGS stations: XMIS, PIMO, DARW, GUAM, IISC, NTUS, KARR and DGAR.

13. Development of the atmosphere and ionosphere observation equipment.

LAPAN has developed a VHF radar antenna at 150 MHz designed for atmospheric turbulence and 1-meter scale ionospheric irregularity observation. Further development of 150 MHz VHF radar is still needed to beused for observations of space weather phenomena, especially the ionospheric irregularity at 1-meter scale.

For observation of ionospheric TEC and scintillation, the GNU Radio Beacon Receiver (GRBR) have been installed in Indonesian region. This system combines two phase differences 150MHz (VHF) and 400MHz (UHF) that are transmitted by satellite in LEO orbit and received by a digital receiver. This system is much cheaper and simpler than other receivers on the system. The results of observation obtained still have an accuracy of about 80%.

# Impact of Climate Change on Water Resources In Java Island

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## Background

Indonesia has abundant water resources almost in every region. At present it is estimated 4 million MCM per year or equal to 2110 mm/year. More than 80% of the present water resources are used for agriculture. The average annual availability of water is 14.000 cubic meters per capita is large at first glance adequate for all country's needs. But things are very different on a regional basis. It is about 90 major river basins, more than 20 face critical water shortages. Furthermore catchment's degradation threatens food security and rural prosperity. This condition is likely to be attributed to degradation of the environmental condition and, consequently, changes in hydrological cycle, as indicated by:

- Degradation of carrying capacity of the upstream areas of the water catchments as a result of uncontrolled clearing of forests
- Uncontrolled land clearing within flooding areas, water catchment's areas and river banks that had resulted in reduced infiltration capacity, changes in river morphology, reduced carrying capacity of streams thus expanding the risk and increasing the frequency of flooding
- Degradation of riverbeds in Java, Bali and West Nusa Tenggara due to exploitation of sand that causes infrastructure and structural damage along the rivers.

The problems rose caused by decreasing water supply that appeared particularly on the islands of Java, Bali, Nusa Tenggara Timur where demand for water is higher than available water supply. Issues associated with these problems are population growth, industrialized, urbanization, groundwater overuse and inadequate supply in some regions.

## Purpose and Goal

Purpose: Adaptation and mitigation of climate change impacts on water

availability is done based on planning regarding research results instead of spontaneous adaptation.
Goal: Establishing cooperation and collaboration among institutions in Indonesia to get more understanding and increasing skill about climate change impact to water resources especially water availability for irrigation.

## Present Situation

*The Impact of Global Warming on Water Resources in Indonesia*

The global climate is a very complex system and global warming will interact with many other influences, but in Indonesia, it will make many of our existing climatic problems worse. For this reason, most Indonesian sources are already subject to many climatic-related hazards, including floods, droughts, storm and landslides (Figure 1 and Figure 2). Now these will become more frequent or more severe.

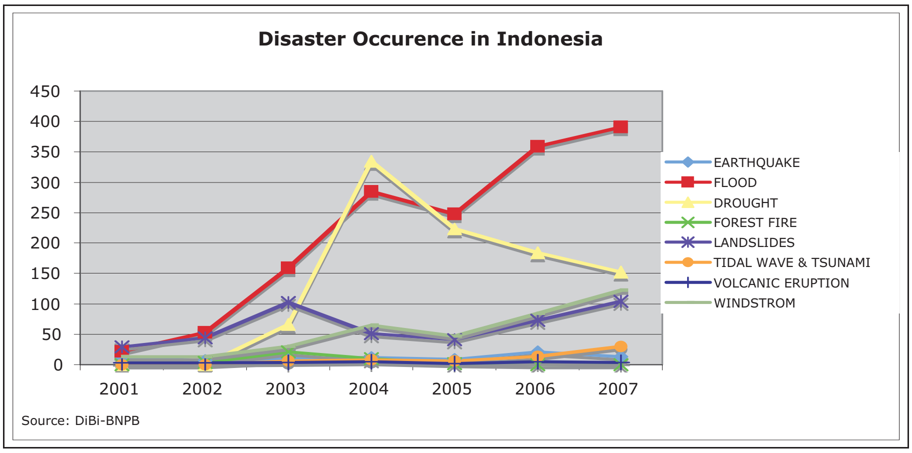



Figure 1. Disaster Occurrence in Indonesia

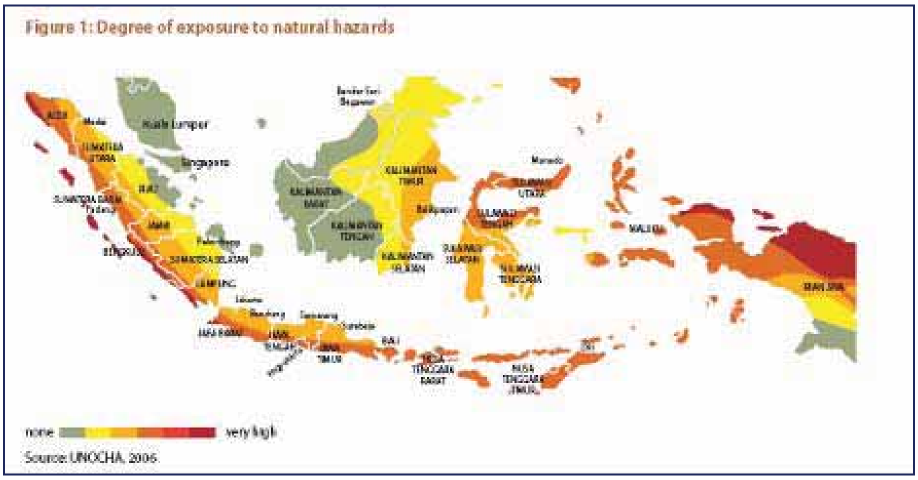



Figure 2. Degree of Exposure to Natural Hazards

### *Trends of Rainfall*

Impact of climate change to flooding is represented by significant positive trend of annual maximum daily rainfall. Temporal rainfall analysis based on 2500 stations annual maximum daily rainfall data from 1916-2004 has been carried out. To identify the climatic trend in the area, test of absence of trends by using Mann-Kendall test with 95% confidence interval were performed for the whole Java (Adidarma et al., 2009a). The significant positive and negative trends are figured out in spatial trend using iso-line of the value of the Tau Kendall coefficients. The study showed that significant positive trends (blue color) were found in some part of the areas (Figure 3). Figure 3 gives illustration about positive trend of annual maximum daily rainfall which occurs in some parts in Java Island such as in Jakarta area and Madiun area. The Madiun area is one of sub-catchments in Solo River Basin. These areas indicate that rainfall intensity is increase in the future. This condition can be used as a warning for flood occurrence. The study showed that significant negative trends for wet and dry season were found in most of the areas and only a few number of time series data indicated positive trends. (Figure 4 and Figure 5). The dominant of negative trends occur in Central & East Java.

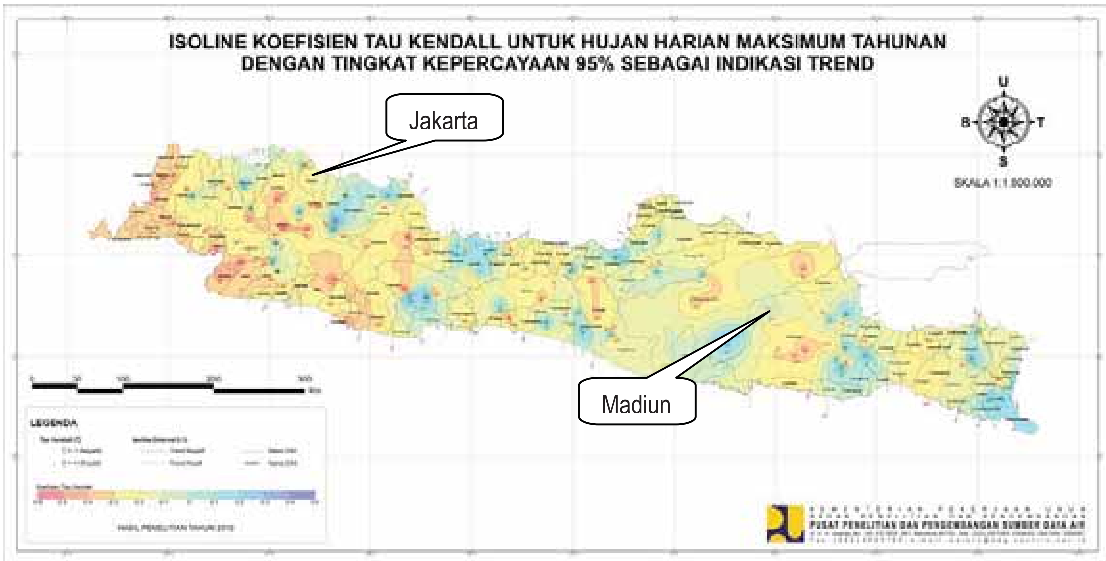



Figure 3. Significant trend in Java Island bases on Tau Kendall Coefficient using more than 2500 Annual Maximum Daily Rainfall Data from 1916 - 2004

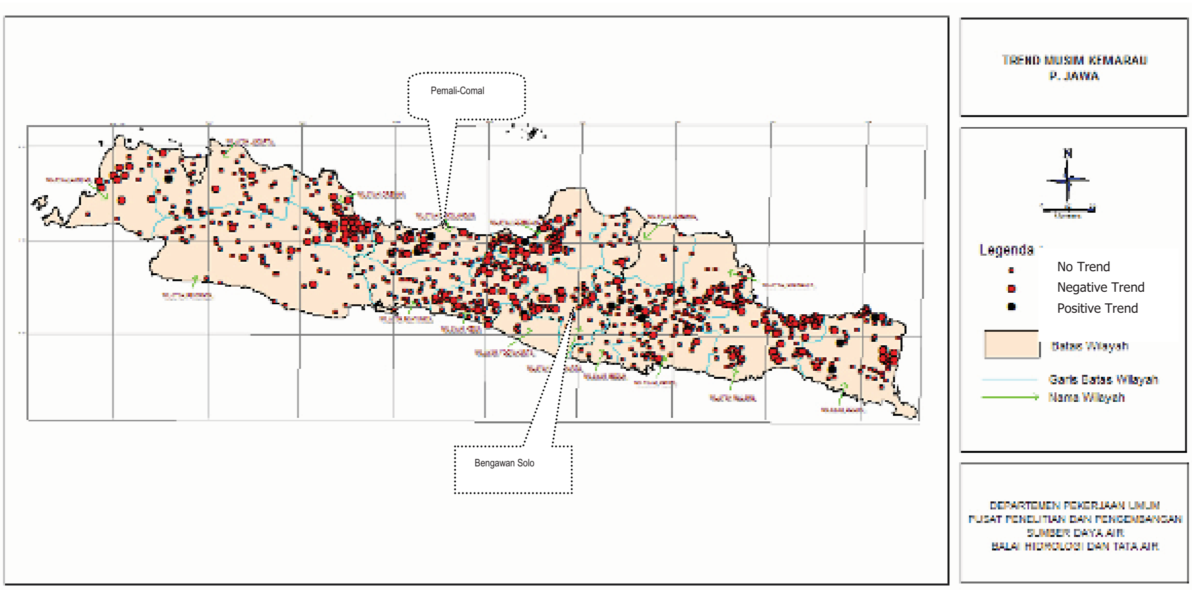



Figure 4. Significant Trend of Dry Season Rainfall in Java (Adidarma et al, 2009a)

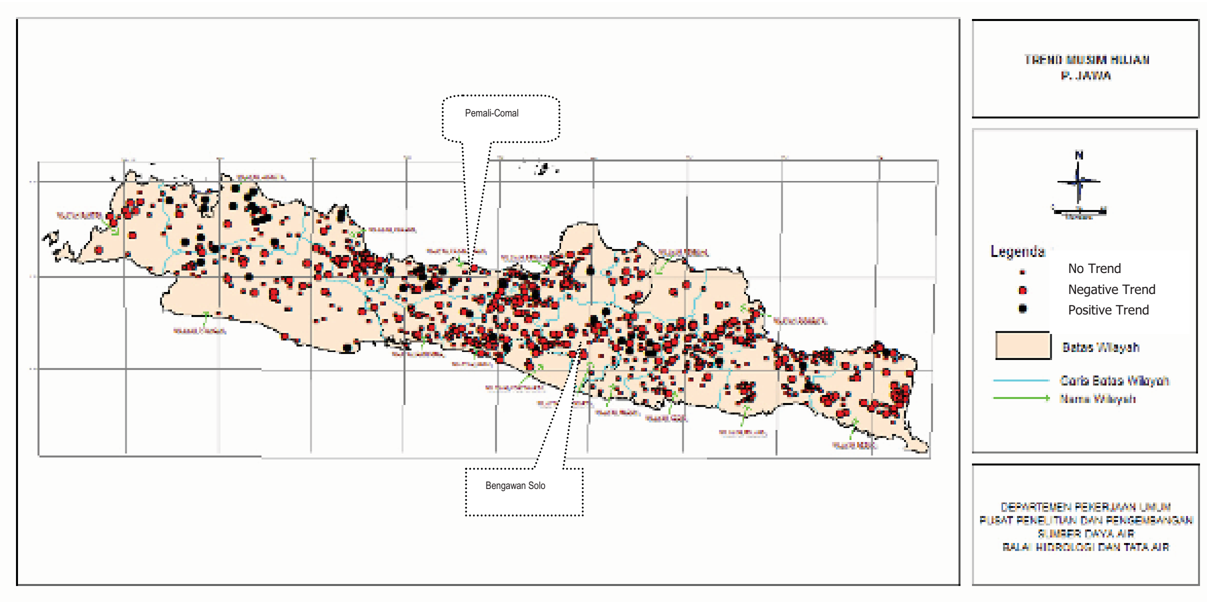
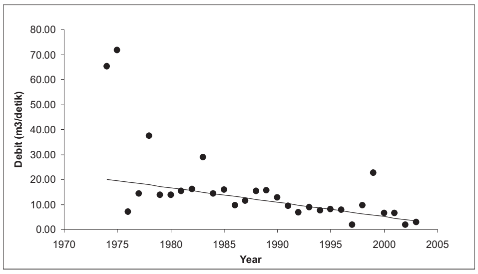


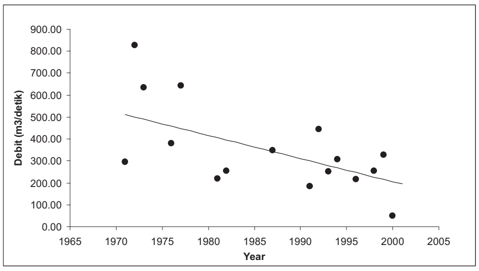

Figure 5. Significant Trend of Rainy Season Rainfall in Java (Adidarma et al., 2009a)

### *Trend of Stream flow*

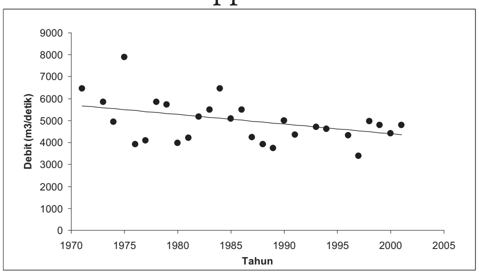
Character of annual runoff hydrographs in rivers mainly depends on land use land cover changes besides climate change as seen in Figure 6. Based on the results of the test of existence of trend on annual stream flow series in upper, middle and lower catchments on eight main rivers in Java showed that all the rivers in the study area had a tendency to decrease. It meant that that stream flow became less and the trend becomes more significant. The more downstream the river flows the bigger the decreasing of linier trend will be (Sutopo, 2009).

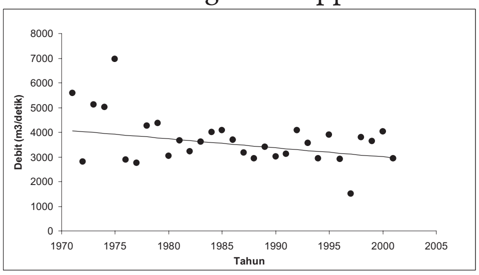



a) At Padas in Upper Solo River




b) At Nambangan in Upper Solo River



c) At Napel in Lower Solo River d) At Babad in Lower Solo River

Figure 6. Annual Runoff in the Upper and Lower Solo River, Source: Sutopo, 2009

Decreasing of trends in the downstream areas may be caused by some factors such as: a) withdrawal water in the middle catchments for irrigation requirement (Pawitan *et al*., 2000), b) decreasing annual rainfall in the downstream areas for example in Brantas River Basin during period 1955-2000 (Aldrian dan Djamil, 2008; Pawitan, 2004), c) the effect of the water allocation from dams in the upper areas (Humborg *et al*.,1997; Admiral *et al*., 1990; Bennekom *et al*., 1981; Conley *et al*., 1993); d)the decrease of base flows in the upper catchments

## Effect and Result

### *Impact on Water Resources*

Water resources and the hydrologic cycle are largely controlled by climatic factors including precipitation, humidity, temperature, wind speed, and solar radiation. Therefore, any change in any of these climate variables may affect the quantity, quality and spatial distribution of water on land. The scenarios for future climate change indicate the possibility of sharpening of extremes (e.g. droughts, floods etc.) and changes in seasonal and area distribution of water resources (Arnell et al., 2001).

If the changes are defined as a division between annual runoff after and before considering impact of climate change so 80% annual runoff changes means after climate change is figured out runoff becomes less with magnitude about 0.8 times annual runoff before climate changes. Through Continuous Rainfall Runoff Model and the usage of monthly hydrological data from 8 catchments, it is predicted that annual runoff with various rainfall and evapotranspiration changes so that the relationship amongst them are produced as shown in Figure 7. A 10% change in precipitation (decreasing) over a basin would result in 84% change in runoff, assuming no change in evaporation (Pusat Penelitian dan Pengembangan Sumber Daya Air, 2008).

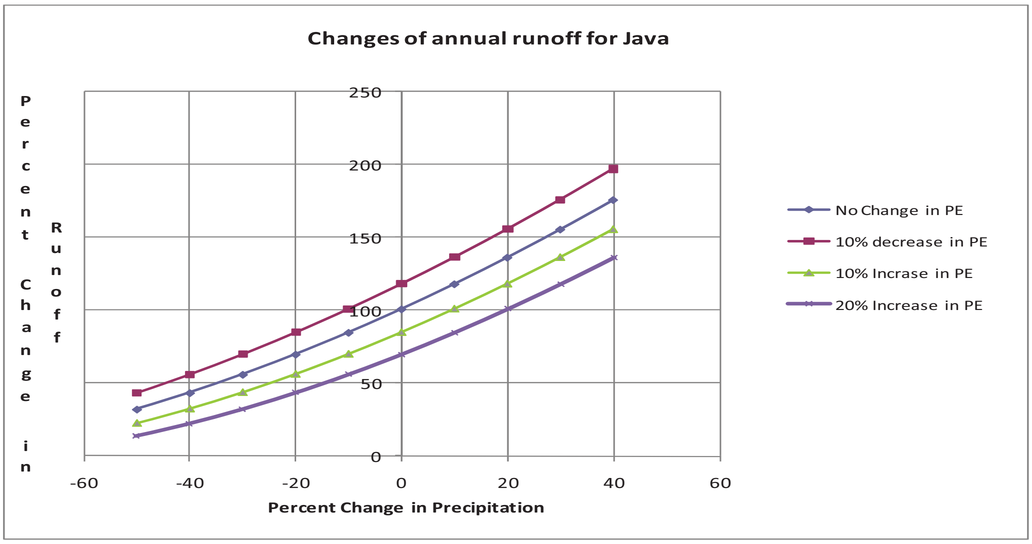



Figure 7. Changes in Stream flow as a Results of Changes in Precipitation and Evapotranspiration (Puslitbang Air, 2008)

*Impact on Drought*

By using amount of rainfall stations in each region, drought intensity was examined. The data used in this study was obtained from 69 rainfall stations recorded from 1916 to 1999 in Cirebon Region, 23 rainfall stations with period of 1916-2004 in Kedu Region and 34 stations from. 1916-2002 in Pekalongan Region (Adidarma et al., 2009b; Adidarma et al., 2009c).

The result showed that the intensity of drought becomes more severe in the latest decade as shown in Figure 8 and 9. Meteorological Drought in Pemali-Comal River Basin which consists of 12 sub-catchments is greater than 1.5 (category severe and extreme), its frequency increases mainly in the last period, see Figure 8. Spatially, area with high drought intensity enlarges in Cirebon, Kedu and Pekalongan Region, significant increases happen in Kedu and Pekalongan Region as seen in Figure 9.

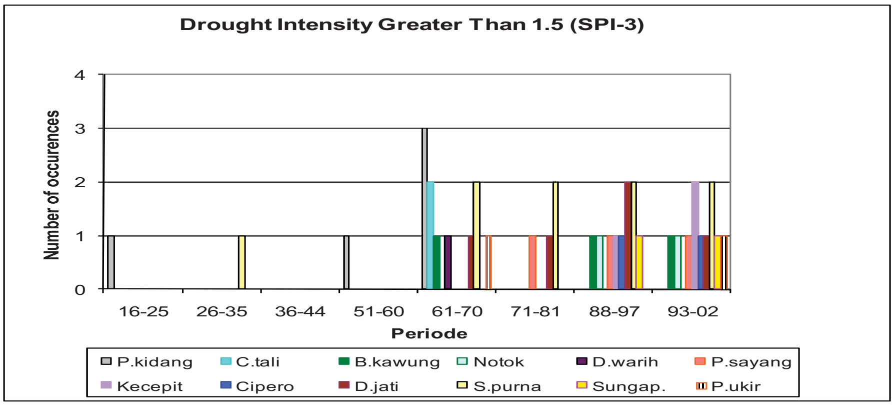



Figure 8. Number of Occurrence of Drought Intensity Greater Than 1.5 (Adidarma et al, 2009b)

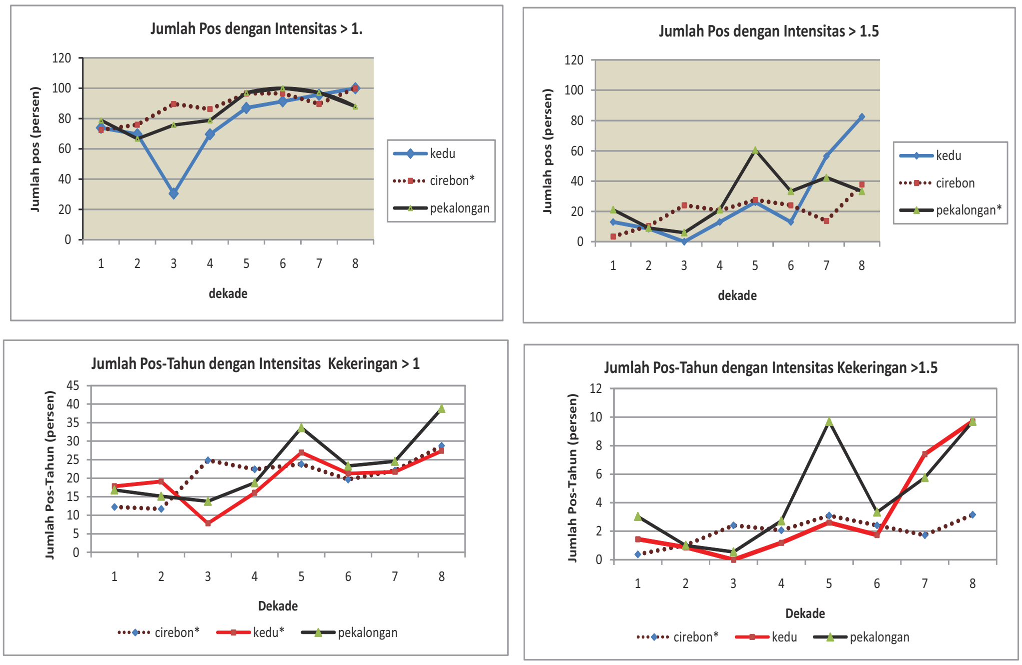



Figure 9. Percent Number of Rainfall Stations with Drought Intensity Greater Than 1 or 1.5 in Kedu, Pekalongan dan Cirebon Region. (Adidarma et al., 2009c)

### *Impact on Water Availability*

The water availability for irrigation can be categorized into the three scenarios described below:

a) The water availability is sufficient to meet the irrigation water requirement, but water shortages do occur when the flow is low during dry season of the year and during dry years

b) The water availability is plentiful as compared to the irrigation water requirement even during dry season, but water shortages do occur in dry years.
c) The water availability is always much greater than the irrigation water requirement over the irrigation season. Therefore, there is no a problem for the irrigation system as regards water availability

Reservoir formed by building a dam cross the river, so water can be stored in it. Usually, reservoirs in Java Island were built for multipurpose with main purpose for irrigation water supply. It is reported that water shortages in reservoir occurs almost every year during dry season, this condition may caused by decreasing the volume of rainfall and decreasing of runoff as an inflow to the reservoir, and also increasing the intensity of drought.

*Impact on Flood Events*

Causes of flooding can be divided into three categories these are natural causes, climate change causes, and man made. Deforestation is getting worse after 1945 especially in Java (Figure 10). This condition will give big impact to magnitude and frequency of flooding. Urbanization categorized as man made causes, is one of problems that give big impact to flooding. Figure 11 shows that urban development in Jakarta area is getting worse in year of 2025 (Brikman, 2007).

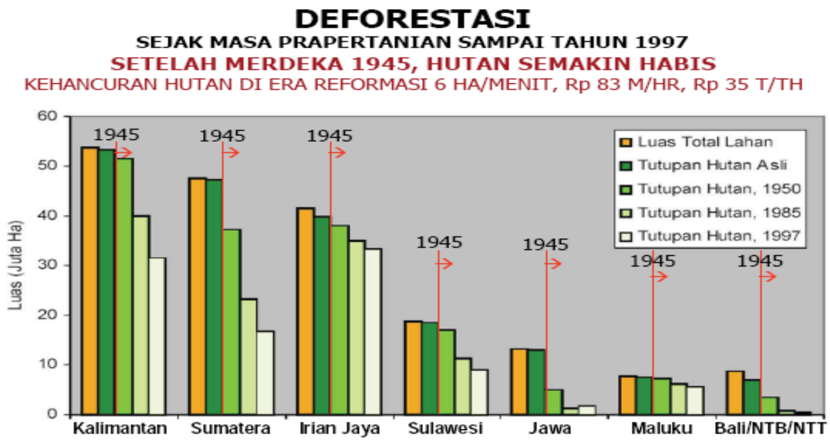



Figure 10. Deforestation in Indonesia (Forest Watch Indonesia& Global Forest Watch 2003)

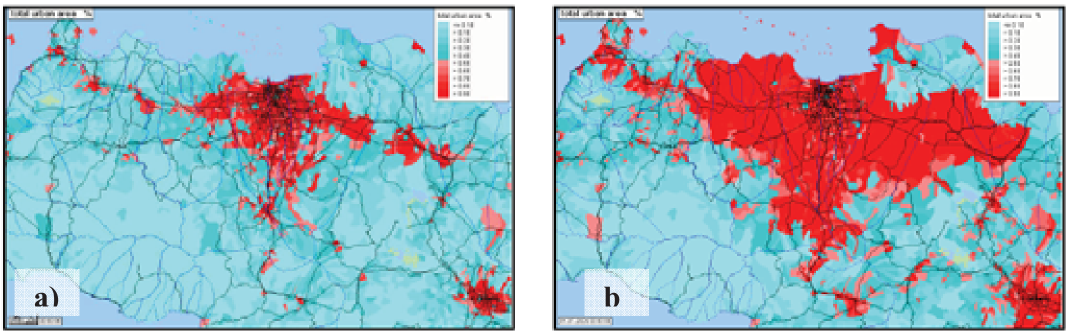



Figure 11. (a) Urban Development in 2000 (b) Urban Development in 2025

From the flood study in some causes of flooding in Jakarta, Bogor, Depok, Tanggerang, Bekasi (Jabodetabek) can be described as follows:

a) External: by inundation from the macro drainage, caused by heavy precipitation, deforestation, land use changing in the upstream areas
b) Internal: by inundation from the micro drainage system and land subsidence
c) Tidal: by inundation from high tidal levels and land subsidence condition
d) A combination of events is worse

In Jakarta flood area, land subsidence is dominant as a cause of flooding compare to sea level rise because climate change. Figure 12 illustrates that land subsidence in Pasar ikan (one location close by ocean) from 1989 to 2007 is about 40 -60 cm, on the other hand sea level rise is only 5 cm. Its mean that land subsidence is greater than sea level rise.

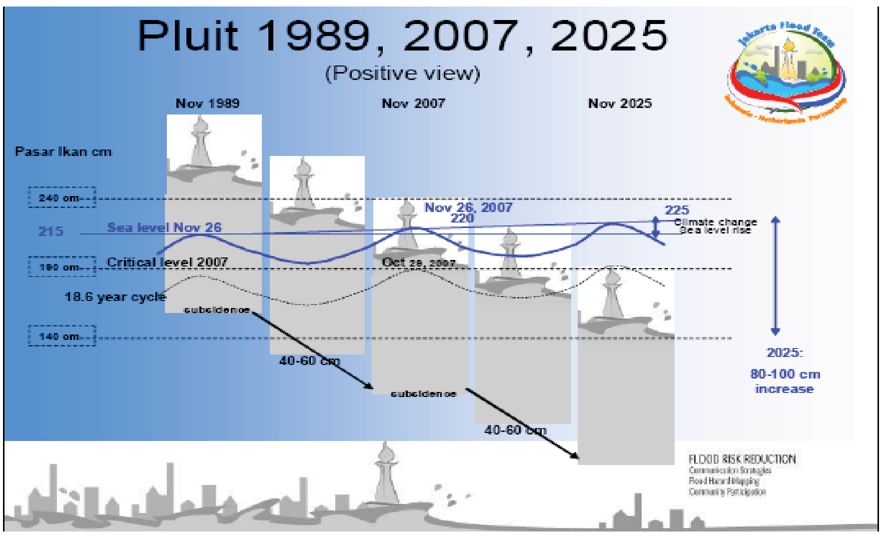



Figure 12 Comparison between land subsidence and sea level rise (Source; Brikman, 2007)

## Land use impact to Flooding

Annual maximum daily rainfall represented storm event for Bengawan Solo River Basin derived from series of daily rainfall from 1960 to 2007. The river basin was divided into three sub-catchments in Upper Solo River Basin, Madiun River Basin and Lower Solo River Basin. From series of daily basin rainfall for the three catchments, series of annual maximum were obtained. A significant trends was found in Madiun River Basin as depicted in Figure 6 (Adidarma et al, 2010). This phenomenon is also shown in Figure 3, in Madiun area is indicated having significant positive trend of annual maximum daily rainfall,

By using HEC-HMS Model the changes in percent of peak discharge and flood volume were computed from 2008 land use map and 1964 land use map If the influence was figured out so the differences will be appeared much bigger .The results show that impact of climate change to flooding (peak and volume) is smaller (26% and 20%) compare to land use changing, but when land use changing combine with Climate change, the impact to flooding is worse (102% and 90%) (Table 1).

Table 1 Changes (%) of the Peak Discharge and Flood Volume (land use 2008 compare to land use 1964 condition)

| Scenario | Upper Solo | | Madiun | | Lower Solo | |
|---|---|---|---|---|---|---|
| | Peak | Volume | Peak | Volume | Peak | Volume |
| 2008 w/o cc | 69 | 64 | 58 | 50 | 48 | 41 |
| 1964w/o cc | 67 | 63 | 56 | 49 | 48 | 42 |
| Changing (%) | | | | | | |
| 1964 w cc | | | 26 | 20 | | |
| 2008 w cc | | | 102 | 90 | | |

Note: w/o: without, w: with, cc: climate change (source: Adidarma, 2010)

### *Effect of ENSO Phenomenon*

El-Nino Southern Oscillation (ENSO) phenomenon has been found to be one of important factors that affect rainfall variability in Indonesia. Recent studies indicated that Indian Ocean Dipole Mode (IODM) also has significant influence on rainfall variability in Indonesia. Yamagata et al. (2001) and Kumar et al. (1999) stated that if IODM occurred at the same time with El-Nino (IODM is strongly positive and SOI strongly positive), it would counteract the reducing effect of El-Nino on rainfall. Analysis of averaged drought index for sub-catchment's Madiun in Bengawan Solo River Basin suggested that this type of relationship were true only for dry season rainfall in monsoonal type region (Figure 8).

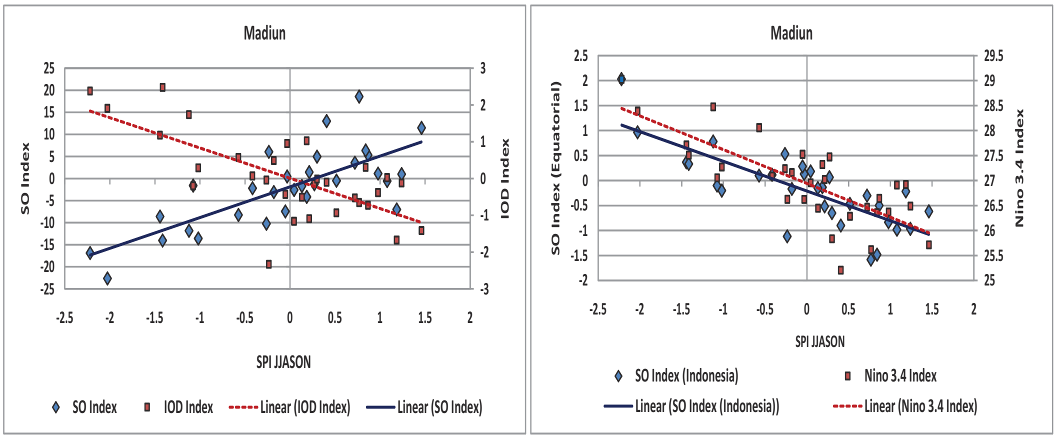



Figure 13. Relationship Between Drought Index (SPI JJASON) and SOI or IOD (Adidarma., 2009d)

The coefficient of correlation between SOI or IOD and dry season drought index could reach level more than 0.7 (strong correlation) for sub-catchment's Madiun in Bengawan Solo River Basin, Central Java and East Java (Figure 13 ).

When there is an El-Nino, Indonesia usually, have more droughts. When there is a La Nina, Indonesia have more floods. Over the period 1844-2006, out of 43 droughts, 37 were associated with an El Nino. The ENSO with South Oscillation Index (SOI) is also one of the main factors in the creation of larger frequency and greater magnitude of drought intensity for the whole River Basin Pemali-Comal and for several Sub-basins in Bengawan Solo River Basin. It has been proven by the existence of strong correlation between Drought Index and SOI in Pemali-Comal River Basin (Figure 14 and Figure 15).

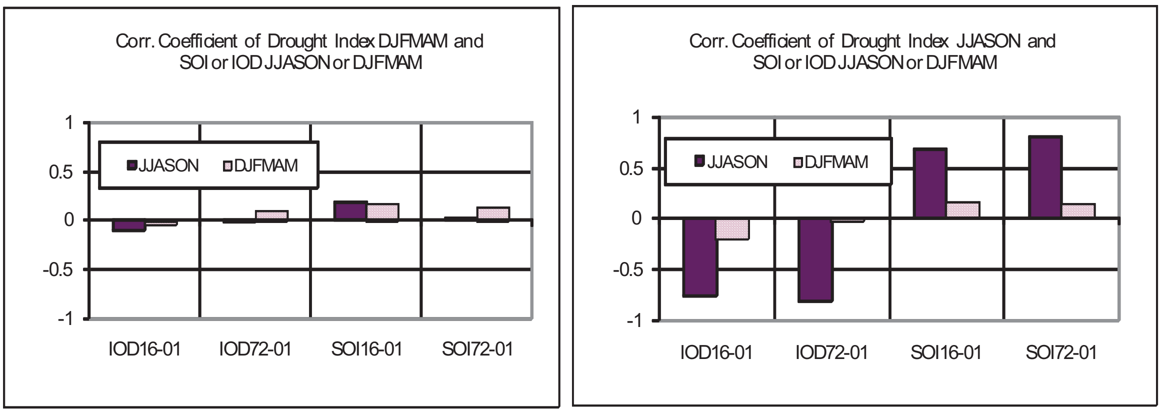



Figure 14. Correlation Coefficient of Drought Index (dry season: JJASON; wet season : DJFMAM) and SOI and IOD (Adidarma . 2009 d)

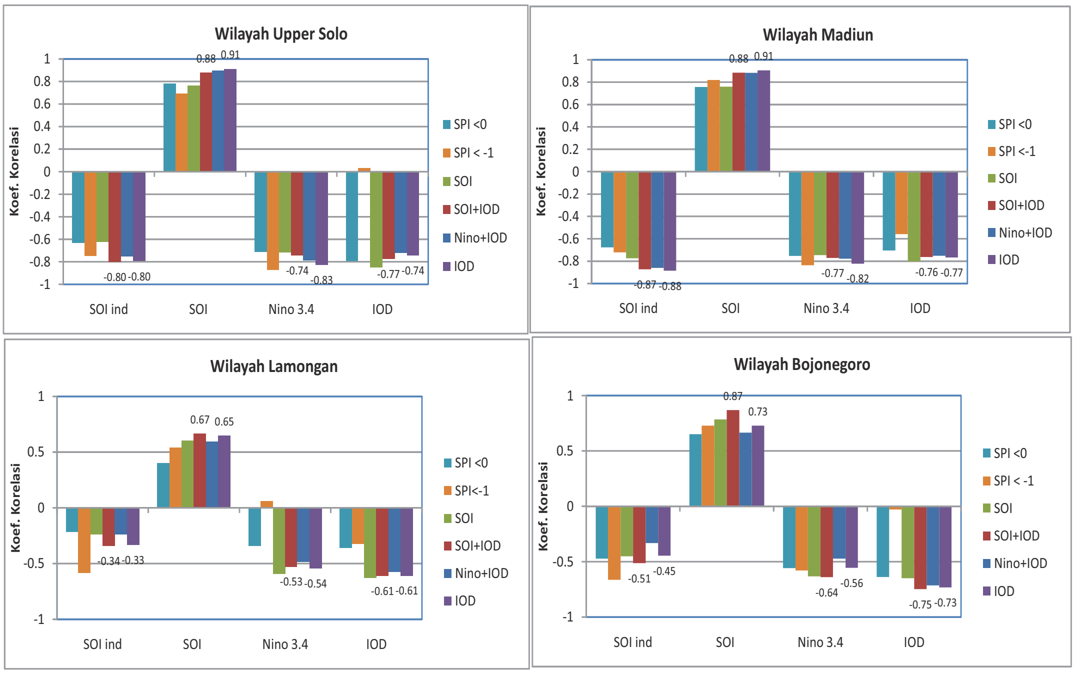



Figure 15. Coefficient Correlation of Drought Index (dry season: June July August September October November) and SOI and IOD for Sub-Catachments in Bengawan Solo River Basin (Adidarma, 2009d)

Relationship between global climate forcing factors (SOI and IODM) and rainfall variability in the four stations (Jakarta, Kupang, Meulaboh and Ambon) was assessed using regression analysis, (Lasco et al., 2006). The correlations between IODM and dry season were not as strong as those between SOI and dry season rainfall and in a few stations the correlations were not significant (Boer and Faqih, 2005). In equatorial type (Meulaboh), these two global climate forcing factors showed no significant correlation with the rainfall variability of all seasons, while in Ambon (local type) only SOI showed significant correlation with April-September rainfall (Adidarma., 2009d).

## *Keys for success*

### i) Assessing the Impacts of, and Vulnerability and Adaptation to Climate Change

To understand the climate better and thus be able to predict local climate change, Indonesia must have adequate operational national systematic observing networks, and access to the data available from other global and regional networks (UNFCC, 2007). Observations and data availability still need to be improved for the quantity and also the quality in Indonesia; especially systematic observation networks still are inadequate because there is a lack of stations and lack of maintenance. A sure knowledge base from systematic observation and forecasting services is essential to monitor climate;

detect and attribute climate change; improve the understanding of the dynamics of the climate system and its natural variability; provide input for climate models; and thus plan adaptation options.

Such kind of procedure included in planned adaptation category is the process of public policy making and preparation that is based on an awareness of the existing condition and vulnerabilities, the attributes that will change and the actions required to minimize loss or optimize benefits. Another adaptation, spontaneous adaptation is often referred to in the context of business adapting to change, usually triggered by markets or welfare changes and societal preferences. Those who favour deploying ''concrete" adaptation measures, such as the creation of reservoirs or development of irrigation systems, have sometimes been reluctant to adopt "softer" adaptation methods such as education, extension services, regulations, penalties and other incentives (Bergkamp et al., 2003).

In response to Indonesian climate change that are still in position of spontaneous adaptation by doing concrete adaptation measures. In the short time the efforts led to planned adaptation begin to appear. This needs cooperation between government institution and technical assistance from abroad.

Key points or requirements for success

- Understanding of climate change phenomena to predict local climate change should be improved by local training and or international training
- Increasing the long period of data recorded and Increasing the density of hydrological observation as well as meteorological observation is needed
- Increasing level of predictive skill for climate change phenomena is done by setting up MOU between RCWR, BMKG (Bureau of Geophysics, Meteorology and Climatology), Indonesia and Deltares & KNMI Nederland to transfer data and knowledge.
- Cooperation and collaboration among government institution and between institution other countries.
- Adaptation assessment should be based more on planned adaptation than on spontaneous adaptation that needs the improvement systematic observation network.

**ii) Dissemination**

Indonesia has 31 River Basin Organization (RBOs) in the major river basin which started their operations in 2007 in line with the Water Law 7/2004. The RBOs is an implementation unit under the Directorate General of Water Resources, Ministry of Public Works. RCWR have a program is call Dissemination Unit of Water Resources and Technology (DUWRMT) supported by JICA. The overall goal of the DUWRMT is increasing the capacity of RBOs related to implementation of practical water resources management. Through this program, RCWR disseminate the research results about climate change, especially which gives impact to water availability to all RBOs. This dissemination is done by some programs as follows:

a) Training, workshop, discussion,

b) Composing guidelines and manuals
c) Mechanism of Counseling to RBOs of water resources management

Other ways to disseminate the climate change impact is done by write a paper in national journal and news paper and also give presentation in national seminar which is held by other institutions.

Key points or requirements for success

- Studies and research activities in Research Centre for Water Resources has been supported and budgeted by government. Results and products are used to support government policies in coping with climate change mitigation and adaptation.
- Training to RBOs staff is done every year and when they have a technical problem, RCWR staff will give technical advices as a home doctor.
- Ministry of Public Works has set up teamwork that RCWR is a member to cope with climate change, this teamwork is formed as cooperation among division in Ministry of Public Works for National Action Plan for Mitigation and Adaptation of Climate Change.
- The research results should be used as base of adaptation for RBOs such as: reviewing reservoir operation rule curve for water allocation with the major supply for irrigation.

*Keys findings from failure*

1. Indonesia is a very vulnerable country towards natural hazards such as landslides, flood, droughts, and heavy precipitation events.
2. Various studies have proved that annual runoff become less and less, intensity of drought Increase, and more often heavy precipitation happen.
3. Phenomenon of South Oscillation Index and Indian Ocean Dipole Mode influence some part of Indonesian Region very much.
4. In Java, impact of climate change on water resources showed that changes in precipitation and evapotranspiration always have an amplified effect on runoff.
5. The RBOs as implementation unit for climate change adaptation for water resources has limited human resources for this field.

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# Groundwater management issues in the Greater Jakarta area, Indonesia

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## Abstract

The Greater Jakarta occupies the northern zone of Java Island and the elevations of this plain vary from 0 to 1,000 m above sea level. It is one of the most developed basins in Indonesia and is located between 106° 33'-107° E longitude and 5° 48' 30"- 6° 10' 30" Slatitude covering an area of about 652 km². The population of Jakarta at present is around 7.5 millions. As the water which is supplied by surface water only covers 30% of water demand, people are harvesting the available groundwater in the basin, which has already caused a negative impact on these resources itself both quantity and quality. The changing environment as consequence of the development has also brought undesirable effects to the quantity of groundwater. Therefore, the proper groundwater management of this area should be identified

*Keyword:* Jakarta groundwater basin, environment, water quality, water quantity, groundwater management issues

## Introduction

Since the beginning of the 20th century, groundwater from the Greater Jakarta Basin has been used for drinking water and other water resources purposes. Unfortunately, groundwater use is increasing year by year and some problems are threatening this fragile aquifer system. It has influenced either quality or quantity of groundwater. In the field, it is identified by groundwater level decline and the occurrence water intrusion in some parts of the basin.

The dependency of industry on groundwater is one of the constraints faced by groundwater management. This dependency is associated with the lack of infrastructure provided by the government. According to the most recent data, the amount of clean surface water that supplied to the industrial sector was only about 3.5 million m3 in 2003, which is just 1% of the volume required by industry. This meansthat almost all water required by the industrial sector comes from groundwater.

Another factor influencing the scarcity of groundwater is the condition of groundwater recharge area. Groundwater recharge can be interpreted as the addition to the groundwater from an external area to the saturated water column. Generally, groundwater is replenished from rainfall, rivers and human intervention such as an artificial recharge well or lake. One of the main factors influencing groundwater depletion is significant changes of the land cover from natural terrain to the developed areas, especially in the recharge area.

The groundwater management problem in the Jakarta Basin has many dimensions, one of them is to provide alternative source of water for industrial use. Looking at the groundwater control mechanism in the Jakarta Basin, licensing is still considered the main tool for controlling groundwater abstraction. This mechanism would not work with the bare minimum awareness of the stakeholders about the importance of groundwater conservation and weak law enforcement and monitoring. The fact is that in the Jakarta Basin, many unregistered deep wells still have been found. There are no incentives such as tax compensation for industries that recycle water. The result is that many industries are not interested in water conservation, making it extremely difficult to control groundwater extraction in the Jakarta Basin. The failure of water utilities to supply raw water and to extend the coverage area has also become a trigger for the groundwater problems. Industry still depends on groundwater, and since industries are self-regulating, groundwater control becomes difficult. The future challenge for groundwater management is to alter the mechanism of water provision that currently applies.

The increase of groundwater exploitation in Jakarta Groundwater Basin has already caused a negative impact on these resources itself both quantity and quality. In addition the changing environment as consequence of the development has also brought undesirable effects to the quantity of groundwater. In order to manage the groundwater potential in its optimal capacity, it is important to identify exactly where the recharge area take place and which quantities are involved.

## The Study Area

The Greater Jakarta is the capital city of Republic of Indonesia. It occupies the northern zone of Java Island that comprises low hilly areas of folded Tertiary strata, and Quaternary coastal lowlands bordering the Java Sea (Figure.1). Two quaternary formations and three young tertiary formations act as groundwater aquifers zone and one quaternary formation act as an aquitard. Some older formations present as basement of the basin. The elevations of this plain vary from 0 to 1,000 m above sea level.

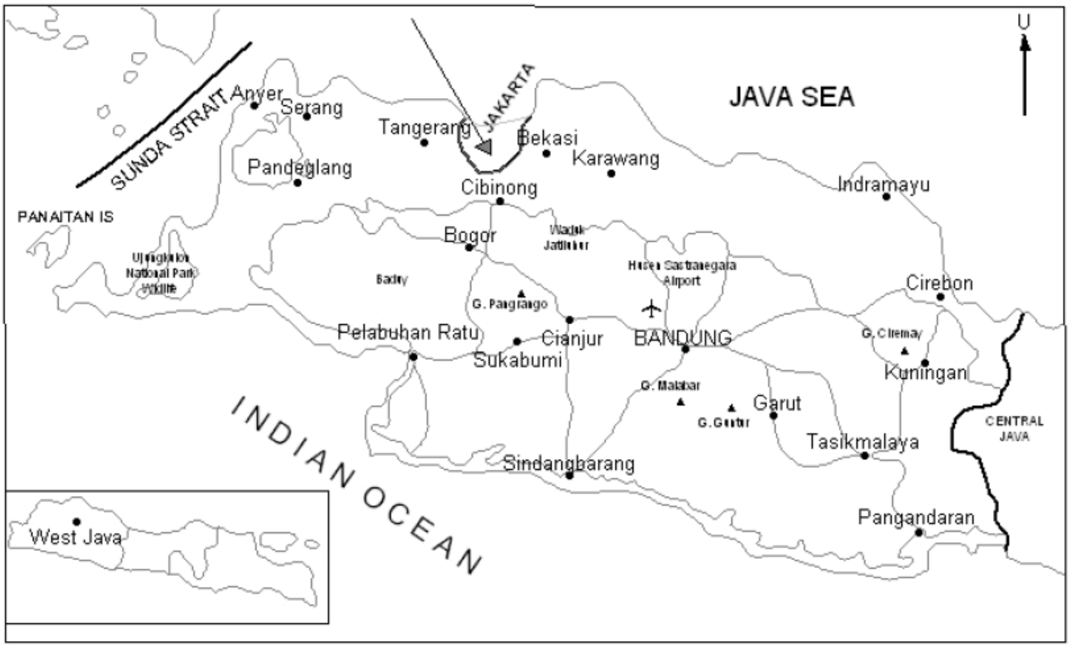


Figure. 1 Location map of the Greater Jakarta. It is the Capital City of Republic of Indonesia and located in the coastal area of Java Island.

It is one of the most developed basins in Indonesia and is located between 106°33'-107° E longitude and 5° 48' 30"-6° 10' 30" S latitude covering an area of about 652 km². It has a humid tropical climate with annual rainfall varying between 1,500 -2,500 mm and is influenced by the monsoons.

The population of Jakarta at present is around 7.5 millions (Jakarta Local Government Website, 2007) and the population density is presented on Table 1. It represents the official number of population actually living in the Greater Jakarta area. The reality which is faced by Jakarta is that many people who are working in Jakarta during the daytime are living in the adjacent cities i.e., Bogor, Depok, Tanggerang, and Bekasi (Bodetabek Area). Since the operation of the Jakarta - Bandung Highway, some people living in the cities of Purwakarta and Bandung have also become commuters. This circumstance has caused the population of Jakarta to increase up to 10 or 11 millions during the weekdays. It is obvious that urbanization has increased the water demand in this area. As the drinking water which is supplied by surface water only covers 30% of water demand, people are harvesting the available groundwater in the basin. In Jakarta Groundwater Basin, the use of groundwater has greatly accelerated conforming to the rise in its population and the development of industrial sector, which consume a relatively huge amount of water.

Table 1. Population density in Jakarta area.

| District of identified area | Population density (people/km2) |
|---|---|
| South of Jakarta | 11,676 |
| East of Jakarta | 11,157 |
| Central of Jakarta | 18,746 |
| West of Jakarta | 12,426 |
| North of Jakarta | 8,267 |
| Seribu Island | 1,616 |
| **Population density average** | **11,272** |

Source: Statistical Local Office of Greater Jakarta, 2003.

## Geological Setting

According to Engelen and Kloosterman (1996), structurally, the Jakarta groundwater basin is part of the so called a Northern Zone comprising the low hilly areas of folded Tertiary strata, and coastal lowlands bordering the Java Sea.

Geologically, the study area is dominated by quaternary sediment and, unconformably, the base of the aquifer system is formed by impermeable Miocene sediments which are cropping out at the southern boundary, which were known as Tanggerang High in the west, Depok High in the middle and Rengasdengklok High in the east. They acted as the southern basin boundary. The basin fill, which consist of marine Pliocene and quaternary sand and delta sediments, is up to 300 m thick. Individual sand horizons are typically 1 - 5 m thick and comprise only 20% of the total fill deposits. Silts and clays separate these horizons. Fine sand and silt are very frequent components of these aquifers (Martodjojo, 1984 ; Assegaf, 1998).

In detail, Sudjatmiko et al. (1972), Sundana and Ahmad (1972), Effendi et al. (1974) and Turkandi (1992) differentiated the lithology in this area into some formations and explained as follows (Figure. 2):

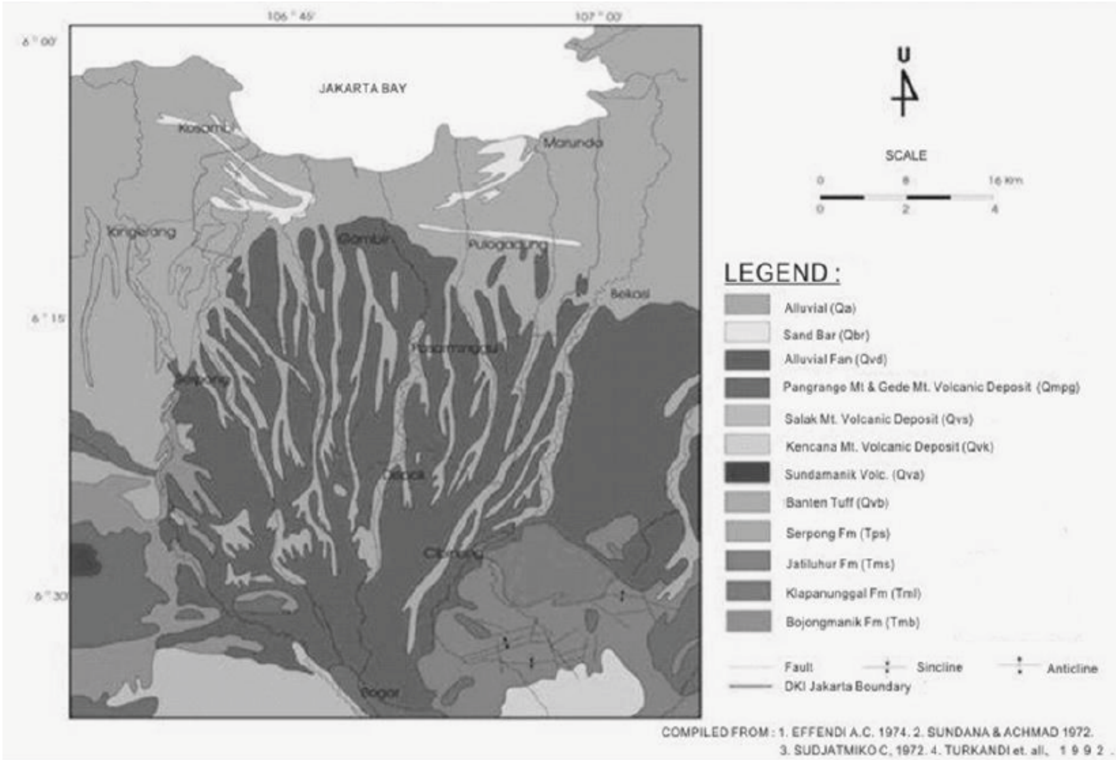


Figure. 2 Geological map of the Greater Jakarta and its surrounding area. At the surface, the lithology is dominated by coastal and deltaic deposits.

a. **Rengganis Formation** consists of fine sandstones and clay stone outcropped in the area of Parungpanjang, Bogor. Un-conformably, this formation is covered by coral limestone, marl, and quartz sandstone.
b. **Bojongmanik Formation** consists of interbedded of sandstone and clay stone, with intercalated limestone.
c. **Genteng Formation** consists of volcanic eruption material such as andesitic breccias and intercalated tuffaceous limestone.
d. **Serpong Formation**, intebedded of conglomerate, sandstone, marl, pumice conglomerate, and tuffacueous pumice.
e. **Coral Limestone**, Holocene age and found in Seribu Island Complex in Jakarta Bay, consist of coral colony, coral fragment, and mollusk shell.

Beside those above lithology, there are found Banten Tuff, young volcanic eruptive material, fan deposits, paleo and recent beach ridge deposits which are deposited parallel to recent coastal line.

## Megacity Groundwater Properties

There are 5 main factors that influences the groundwater resources in a mega city as Jakarta i.e., global climate change, population pressure, urbanization, agricultural and industrial activities. It is known that global climate change phenomena have increased the sea water level. It influenced the position of shorelines in some parts of the world, including northern part of Jakarta area that has border with the Java Sea. Like many other cities that located on coastal area, sea water encroached into the land and influenced either surface of groundwater resources. Total of population, urbanization and industrial activities created a pressure to the groundwater resources due to groundwater over-abstraction activity to fulfil their daily needs. The urbanization can also increase the impervious cover, drains, utility lines, backfilled areas, surface flow, point sources for recharge and contamination. The potential impacts of urbanization on groundwater resources are the resources availability and quality degradation. Some impacts of groundwater use on urbanization are infrastructure damage that is caused by the occurrence of land subsidence and infrastructure drainage and uplifted problems. Agricultural has a reciprocal relationship with the groundwater resources as it needs some groundwater resources for growing plants and in the other side, plants can act as the water recharge instrument. Public health condition is very much depending on the groundwater condition as people in Jakarta Area fulfil their water daily need from groundwater. The worse groundwater quality condition the worse public health of the area.

The groundwater in urban area is abstracted from aquifers through dug or drilling wells. Together with surface water, they are used o supply domestic, industrial, and agricultural activities. The waste water from those activities then are treated and used for irrigation or injected back to the aquifers. The urban groundwater quantity is depend on the aquifers direct and in-direct recharge, impermeable covers, artificial replenishment to increase aquifers recharge.

## The Groundwater Management

The main threats to groundwater sustainability arise from the steady increase in demand for water and from the increasing use and disposal of chemicals to the land surface. Management is required to avoid serious degradation and there needs to be increased awareness of groundwater at the planning stage, to ensure equity for all stakeholders and most important of all to match water quality to end use. Despite the threats from potentially polluting activities, groundwater is often surprisingly resilient, and water quality over large area of the world remains good. A vital aid to good groundwater management is a well-conceived and properly supported monitoring and surveillance system. For this reason monitoring systems should be periodically reassessed to make sure that they remain capable of informing management decisions so as to afford early warning of degradation and provide valuable time to devise an effective strategy for sustainable management.

Some alternatives to increase the water resources are: increase surface storage; improve groundwater management; water utilization efficiency; and large-scale inter basin water transfers. To improve the groundwater management, the sustainable groundwater management strategy should be employed. This strategy covers long term groundwater resources conservation, groundwater quality protection; change the groundwater resources management paradigm to groundwater as a non renewable resource.

It was recognised that the groundwater problems in recharge area is different with the groundwater problems in discharge area. The main groundwater problem in recharge area is the decreased of groundwater recharge which is caused by land use degradation. This substance can initiate the runoff increased and groundwater storage decreased, and creates flood and drought disasters. Therefore, the recharge areamanagement should be employed appropriately. The main problem in discharge area is the increased groundwater usage for human activities. It causes groundwater table descent and groundwater storage reduction and creates land subsidence, groundwater pollution, and drought disasters. Those problems then lead to flood disaster and groundwater resources crisis. In the discharge area, the things that should be executed are groundwater abstraction management. It is known that for doing the groundwater management, the basin geometry and the cover of recharge and discharge area should be defined first.

## Jakarta Groundwater Management

### *Jakarta Groundwater Present Condition*

Overexploitation of groundwater has become a common issue along the coastal area where good quality groundwater is available. Consequently, many coastal regions in the world experience extensive saltwater intrusion. It is obvious that urbanization has increased the water demand in this area. As the drinking water which is supplied by surface water only covers 30% of water demand, people are harvesting the available groundwater in the basin. In the Jakarta Groundwater Basin, the use of groundwater has greatly accelerated conforming to the rise of its population and the development of the industrial sector, which consumes a relatively huge amount of water. According to the Ghyben-Herzberg model, the natural hydrostatic equilibrium between salt and fresh water can change when a change occurs in the fresh groundwater head pressure. It can occur due to groundwater over- pumpage as it is taking place at the present time in Jakarta. Over-pumpage can also decrease the volume of groundwater and land surface subsidence occurred. The subsurface layer compaction also supports the existence of land subsidence. Geyh and Soefner (1996) reported on the salt water intrusion phenomena in the Jakarta Area. Djaja et.al. (2004) recognized land subsidence phenomenon occurring in some parts of the Jakarta Metropolitan Area. Serious problems of salt water intrusion have affected some coastal cities in Indonesia, including Jakarta. Medan, Surabaya, and Semarang and the size and extent of the intrusion very much depend on the manner of groundwater usage. The initial model was developed by Ghyben in 1888 and Herzberg (1901) and it is known as the Ghyben-Herzberg model which forms the base of the hydrostatic balance between fresh and saline water in a U-shaped tube.

Based on groundwater monitored data of 51 monitoring wells around Jakarta area, it can be concluded that most of water level in Jakarta area of 5 clusters aquifers i.e. 0 - 40 meters, 40 - 95 meters, 95 - 140 meters, 140 - 190 meters, and 190 - 250 meters, were decreased (Figure. 3).

Considering the detrimental impact of land subsidence on building and other infrastructures, a number of researchers carried out investigations on the cause and the rate of subsidence. Most of the land subsidence investigations have been conducted over part of the Jakarta territory. The trend and rate of subsidence is characterized by the condition of the point where the equipments are located.

The estimated subsidence rates during the period Dec.1997 to Sept.2005 are 1 to 10 cm/yr and reach 15-20 cm/yr. The highest rates of land subsidence occur in northwestern Jakarta. The central and north-eastern parts sometimes also show quite high rates of subsidence. These vertical temporal variations however, may still be contaminated by annual/semiannual signal bias that plagues all GPS temporal measurements (Abidin et al., 2007).

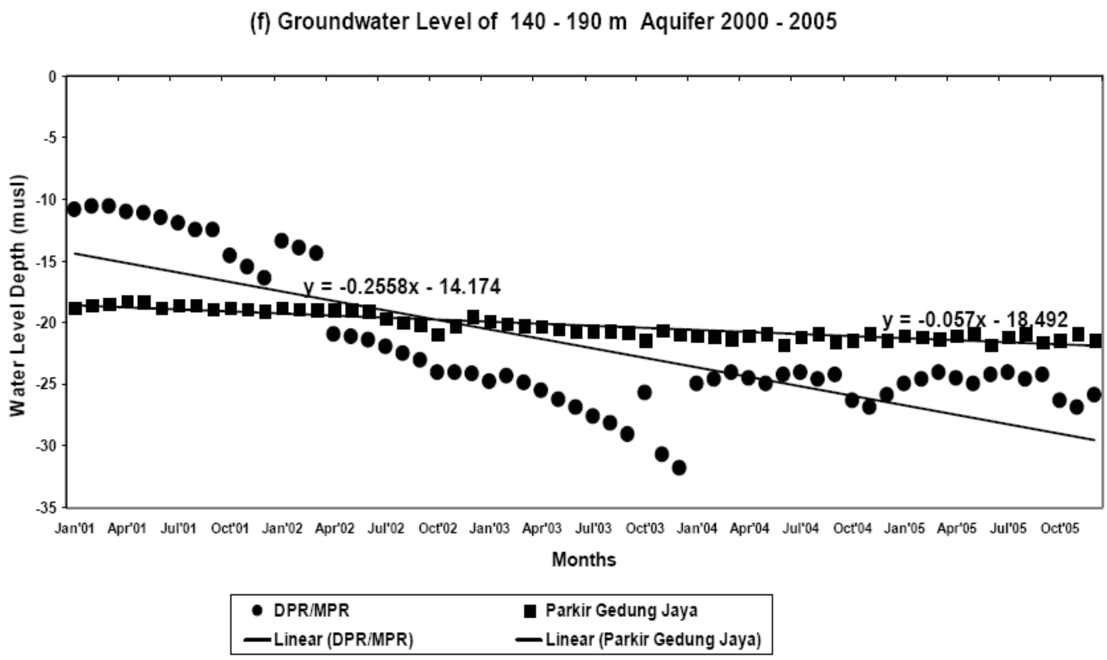


Figure. 3 Groundwater level fluctuations between of 2001- 2006 at some locations in Greater Jakarta area. It is showed that the groundwater tend to decrease.

From the observation period 1982 - 1991, the highest subsidence occurred at Cengkareng (North Jakarta) with a rate of 8.5 cm/year. In the period 1997 -1999, the highest subsidence occurred at Daan Mogot (North-West Jakarta) with a rate of 31.9 cm/year. The rate increase shows that the land subsidence in Jakarta is continuing.

### *Determination of Recharge and Discharge Area*

It is known that the hydrogeology of the Jakarta Basin is a very complex phenomenon. Until now, a good understanding of the hydrogeology of the basin on a regional scale is still not possible, due to lack of systematically sufficient drilling, testing and monitoring data. A collection of the drilling data of additional monitoring boreholes, to establish a closer monitoring network, has made it possible to develop a better understanding of the shallow groundwater flow systems. A chemical analysis of the monitoring well's water samples will assist in recognizing the water quality decrease and interaction between fresh and salt water. Groundwater level monitoring of boreholes will be required to develop an improved understanding of the water table fluctuations, the regional and local impacts of groundwater abstraction and dewatering related to groundwater yield.

Jakarta recharge and discharge area was determined using drainage pattern analysis, wet land area delineation, geological condition, and sub-surface temperature profile. The first three analyses showed the circumstance of Jakarta Basin geometry. It is shown very clearly that the Jakarta Groundwater Basin is not as wide as it is estimated before. The sub-surface temperature data analysis identified the Jakarta groundwater recharge area and direction of water flow inferred from the thermal properties.

There are some studies (Cartwright, 1970; Sakura, 1978 and 1993; and Dim et al, 2000), where temperature data were used to understand the groundwater flow system in a basin. The basic theory is that heat can be transported in a porous medium by way of three processes: conduction, convection, and radiation. The most important groundwater movement process in an aquifer is the convection process, as the convective alteration can cause the groundwater geothermal to increase with increasing depth in the recharge area and decrease in the discharge area (Domenico and Palciauskas, 1973). If it is assumed that the groundwater temperature in the well is equal to the surrounding subsurface temperature, we can get a one-dimensional view of the groundwater distribution by profiling the water temperature in the well. This is most important point for water temperature analysis when compared to other physically based measurements or tracer techniques.

The thermal disturbance that is caused by the advection of subsurface water flow makes thermal analyses suitable for groundwater studies. A number of previous authors (Cartwright, 1970; Parsons, 1970; Boyle and Saleem, 1979; Kilty and Chapman, 1980; Drury, 1984; Woodbury and Smith, 1988; Jobmann and Clauser,

1994) found that thermal signatures of groundwater underscore the fact that various conditions in a flow system can distort isotherms. Subsurface temperature analyses have proven that they can be quite appropriate in tracing and differentiation of the groundwater flow path. Temperature is the best and most reliable tool to establish the depth of groundwater circulation (Mazor, 1997).

The interaction of water with its surroundings generates various natural process, products, and conditions. Flow systems, on the other hand, function as mechanisms of transport and distribution of those effects into regular spatial patterns within the basinal flow domain. One of the results of these natural processes is that water moving through the subsurface can transport matter and heat. Heat transport by moving groundwater is one of the most visible and most well understood geologic processes in the subsurface (Beck et al., 1987; Romijn et al., 1985; Rybach, 1985; Smith and Chapman, 1983). Water can contain and transport heat because of its specific heat capacity.

Subsurface temperature distribution is affected by heat conduction and heat advection due to groundwater flow. There are some hydrological studies in which the groundwater flow system is estimated from subsurface temperature distribution in basins or plains (Uchida et al., 1999; and Sakura, 1993). Based on the results of these studies, it could be concluded that the subsurface temperature in the recharge area is much lower than in the discharge area at the same elevation. Temperature profiles measured in wells show a decreasing temperature gradient with depth in the recharge area and increasing temperature gradient with depth in the discharge area (Taniguchi et al., 1999). The geothermal zone is marked by temperature profile is not subject to seasonal variations and ground water flow perturbs the geothermal gradient by infiltration of relatively cool water in recharge areas and upward flow of relatively warm water in discharge areas which is causing concave upward profiles in recharge areas and convex upward profiles in discharge areas.

Without groundwater flow, the temperature-depth profile has a constant gradient with depth and a stratified thermal regime. Domenico and Palciauskas (1973) analyzed the two dimensional groundwater temperature distributions under condition of regional groundwater flow and found a concave shape for recharge areas where the downward water flux dominates and a convex shape for discharge areas where the upward groundwater flux dominates.

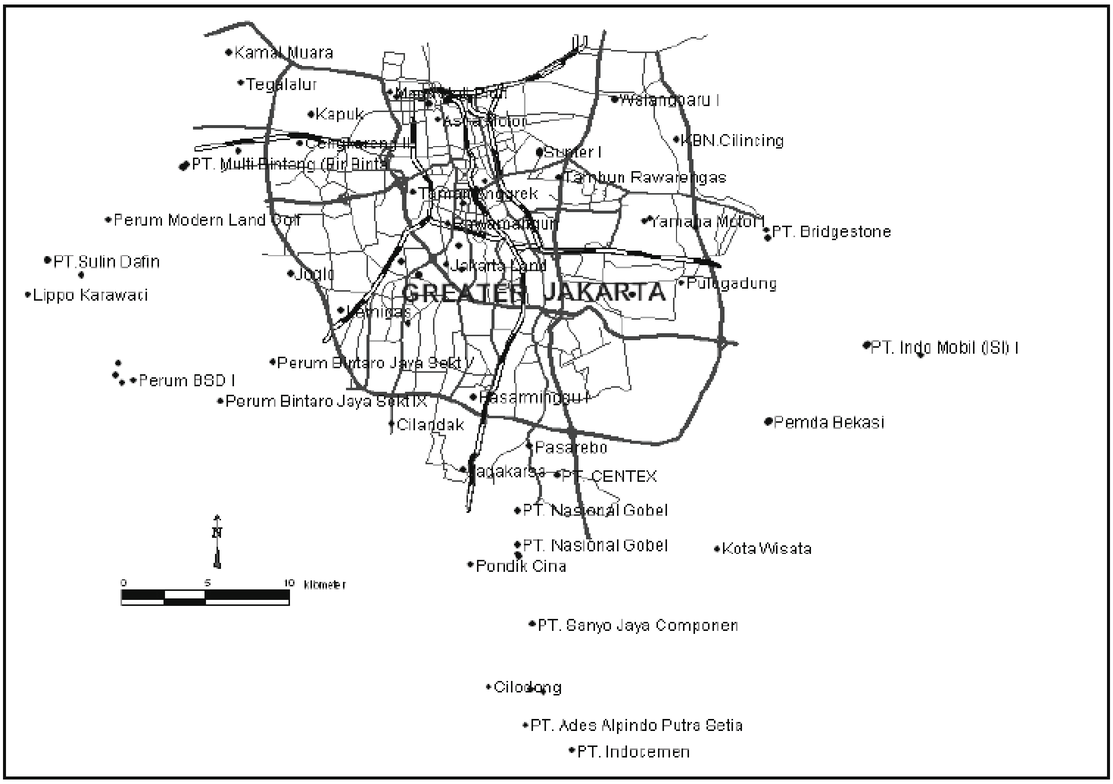


Figure. 4 Monitoring wells location in Greater Jakarta area and its surrounding area.

For this study, the thermal profiles in 51 monitoring wells of various depths (20 – 200 m) around Greater Jakarta area were measured. Measurements were carried out using a digital thermistor thermometer of 0.01 oC precision and the accuracy is ± 0.03 o C which was attached to a 300 m long cable measured the subsurface temperature at 2 m intervals from the static water level to the bottom of the hole. The wells were drilled exclusively to monitor groundwater level and subsidence caused by groundwater withdrawal. They are therefore ideal for thermal studies as they had attained a steady-state thermal condition as the time elapsed since their construction was quite a long period. The groundwater temperature data measurement analysis was plotted on the map and the detailed recharge and discharge area of Jakarta Basin was determined (Figure. 5). It showed that mostly Greater Jakarta Area is occupied by discharge area, while the recharge area located just in the southern part of this area. Facing this reality, the groundwater management in this area must be more concerned to the problems that are discovered within discharge area.

The recharge area of the aquifer at a depth of 40 m below surface is located at the southern part of Jakarta Basin itself, and the water from Bogor area is discharged at the south boundary of Jakarta basin as it is blocked by the Bojongmanik Formation (Depok High). The recharge of the aquifer at a depth of 95 m below surface comes from the S-E and S-W area of the basin, the recharge area of the aquifer at a depth of

140 m below surface is located at the S-E area, while the deepest aquifer is supplied by water from the east.

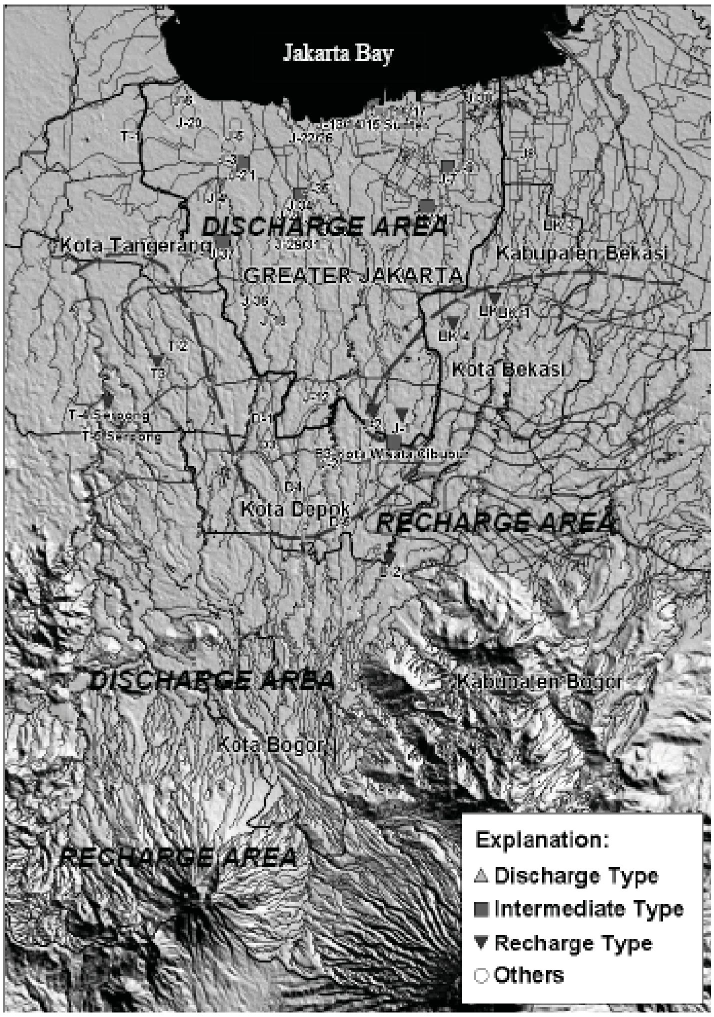


**Figure. 5** Recharge and discharge area delineation using sub-surface temperature data analysis and direction of water flow inferred from the thermal properties.

## The Groundwater Management in Greater Jakarta Area

Based on the groundwater hazard assessment in Greater Jakarta Area, as the discharge area, the quality hazards that were found are mostly the water pollution of domestic waste and industrial activities. Quantitatively, when groundwater level and reserve decreased, the land-subsidence, flooding and drought disasters, and sea water intrusion were discovered. In the recharge area, southern part of Jakarta, the domestic waste and agricultural activities influenced the groundwater quality condition. The decline of water recharged and groundwater reserve, the increasing run off and reduced of springs debit were encountered in this area. It is recognized that qualitatively the groundwater in Jakarta Area had been disturbed since the recharge area. Therefore, the condition of recharge area must be managed simultaneously with the discharge area. The groundwater management should cover the two important aspects, i.e., physical and technical aspects, and social and non technical aspects. Physically and technically, for managing groundwater quality, water treatment, waste management, wells monitoring, and groundwater quality modelling should be executed both in Jakarta Greater Area and in recharge area. Groundwater quantity management in recharge area will cover land rehabilitation, re-forestation, springs conservation, artificial recharge and injection wells construction, and recharge area broadening. In Jakarta Area, it will cover wells monitoring, groundwater maximum depletion and abstraction, sustainable groundwater yield determination, groundwater balance and local flow modelling, and water canals construction.

Socially, the groundwater quality management in recharge area and discharge area, Greater Jakarta Area, should cover control of groundwater source conservation zone; socialization of dangerous and environmental friendly substances utilization, groundwater quality basic knowledge. The groundwater quantity management in recharge area will cover the groundwater basic knowledge socialization, built area control, groundwater source conservation zone control, recharge area plan control, and law enforcement. While in discharge area, the discharge area plan control, groundwater abstraction tax, groundwater abstraction control, groundwater condition change monitoring, groundwater basic knowledge and sanitary system socialization, and law enforcement. Scheme of the whole groundwater management issues in Greater Jakarta are presented on Figure. 6.

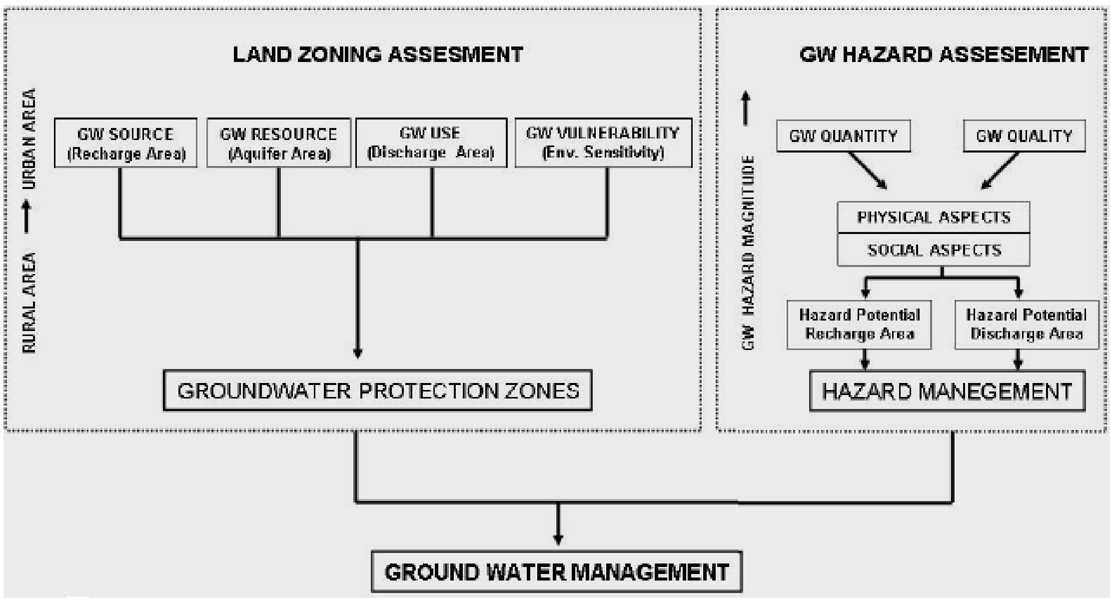


Figure. 6 Scheme of groundwater management in Greater Jakarta area.

## Concluding Remarks

Some remarks concerning the water management in Greater Jakarta area can be indicated, among others are:

1. To improve the groundwater management, the sustainable groundwater management strategy should be employed. This strategy covers long term groundwater resources conservation, groundwater quality protection; change the groundwater resources management paradigm to groundwater as a non renewable resource.
2. Greater Jakarta aea is occupied by discharge area, while the recharge area located just in the southern part of this area. Facing this reality, the groundwater management in this area must be more concerned to the problems that are discovered within discharge area.
3. Based on the groundwater hazard assessment in Greater Jakarta area, as the discharge area, the quality hazards that were found are mostly the water pollution of domestic waste and industrial activities.
4. It is recognized that qualitatively the groundwater in Jakarta area had been disturbed since the recharge area. Therefore, the condition of recharge area must be managed simultaneously with the discharge area.
5. The groundwater management should cover the two important aspects, i.e., physical and technical aspects, and social and non technical aspects.

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