Land Subsidence of Jakarta Metropolitan Area

Rochman DJAJA, Jacub RAIS, Hasanuddin Z ABIDIN and Kuntjoro WEDYANTO, Indonesia

Key words: spatial planning, land subsidence, groundwater

SUMMARY

Land subsidence is one of vertical deformation of the earth's crust as a consequence of crustal dynamics. Land subsidence changes the vertical position (height/elevation) of the ground control points as reference points for all engineering works, and which also influence the structure of all infrastructures and other related activities in the area.

The GPS land subsidence monitoring network was established in Jakarta metropolitan area and the observations were held in December 1997, June 1999, June 2000, June 2001 and October 2001 respectively. The rate of land subsidence at each location of GPS monitoring points shown the average variations from 7.5 cm to 32.8 cm within four years period. This means that the land subsidence is influenced by the characteristic of local area where the points are located. The heights obtained by GPS satellite observation periodically has been used to figure out the trend of land subsidence and shown the largest rate of 84 mm/year at Pantai Indah Kapuk (North Jakarta). Moreover, comparing the land subsidence trend and the groundwater level trend at the wells located close to GPS monitoring points, a positive correlation between the two phenomena is shown. This can be concluded that the land subsidence is also influenced by groundwater extraction.

Considering the land subsidence effect, the investigation of land subsidence in Jakarta metropolitan area and other cities is essential in support of spatial planning at present as well as in the future and of monitoring the established physical facilities. The availability of height data maintained periodically would be the input to figure the land subsidence out.

Land Subsidence of Jakarta Metropolitan Area

Rochman DJAJA, Jacub RAIS, Hasanuddin Z ABIDIN and Kuntjoro WEDYANTO, Indonesia

1. INTRODUCTION

1.1 Area and Population

Jakarta Metropolitan, as the capital city of the Republic of Indonesia, is situated on the northern coastal alluvial plane of Jawa which shares boundaries with West Jawa Province in the south and in the east, and with Banten Province in the west. The area of the capital city is about 652 km^2 and consist of 5 regions (Center Jakarta = 122.75 km^2, North Jakarta = 150.52 km^2, East Jakarta = 183.73 km^2, South Jakarta = 144.92 km^2 and West Jakarta = 130.76 km^2). The population of Jakarta was about 800,000 people when Indonesia proclaimed its independence in 1945 and increase to 8.2 million in 1990 as shown in Figure 1 and Figure 2 *(BAPPEDALDA,2003)*. An annual increase of 2.4% was calculated during the 1980-1990 period. In 2005 the population of Jakarta is estimated to be 12 million. Unlike other regions, over 75% of the population of Jakarta is in an urban setting. Most people who are working in Jakarta during the day are commuters and live in the three neighboring cities, Bogor and Bekasi (West Jawa Province) and Tangerang (Banten Province). That is why during the day the population of Jakarta may increase up to 10 to 11 million people. Land use in Jakarta is primarily for settlement areas, industrial estates, commercial and trade areas, and government's and non-governmental offices.

1.2 Geology and Hydrogeology

The Jakarta area is relatively flat with topographical slopes ranging between 0^o and 2^o in the northern and central part, and up to 5^o in the southern part. The southern area has an altitude of about 50 m above mean sea level. There are 13 natural and artificial rivers flowing through Jakarta, of which the main rivers are Ciliwung, Sunter, Pasanggrahan, Grogol and their tributaries, which forms the main drainage system of Jakarta. (*Abidin et al. 2001*). The geology of Jakarta is shown in Fig 3 (*Dinas Pertambangan DKI, 1996*).

Jakarta is located on a groundwater basin, known as the Jakarta Groundwater Basin. The base of the aquifer system is formed by impermeable Miocene sediments which also cropped out at the southern boundary of the basin. The basin fill consists of marine Pliocene and Quaternary sand and delta sediments of up to 300 meter 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 a very frequent component of these aquifers.

Quaternary deposits may be conveniently divided into three aquifer systems on the basis of the hydraulic characteristics and depths, these are: (1) Phreatic Aquifer System (0 – 40 m); (2) Upper Confined Aquifer System (40 – 140 m), and Lower Confined Aquifer System (>140 m).

Under natural conditions the recharge area of the deep aquifer system is located in the hilly area at elevations between 25 m - 200 m. Discharge from the confined aquifer to the natural base level in the flat coastal area occurred mainly by upward leakage, evapotranspiration and outflow to the surface water system. Today, recharge to the deep aquifer system, other than horizontal inflow, may occur throughout the city area by downward leakage, as head levels of the confined aquifer system have dropped regionally (2 – 4.6 m $year^{-1}$) to below the water table of the unconfined shallow aquifer system (*Sutrisno, 1999*).

Supplying the water to the user is considering a pressing problem in Jakarta. The volume of groundwater extraction carried out by some people and companies has increased. The groundwater is of considerable economic and social importance because almost 60%-70% of the Jakarta population and the majority of both industries and activities rely on this resource *(Adi,1994)*.

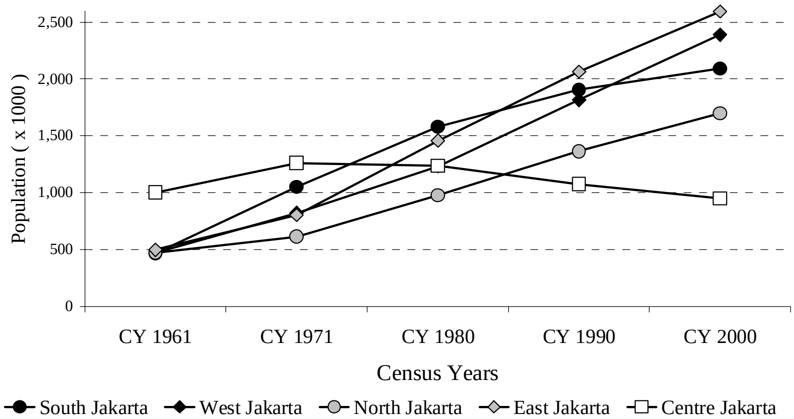


Figure 1: The Population of Jakarta

1.3 Land Subsidence

The surface of the earth, being part of the lithosphere, is dynamics and deformable. The deformation can be categorized into horizontal deformation and vertical deformation. The land subsidence is a vertical deforma-tion phenomena besides uplift or rebound. The rate of vertical deformation is quantified by the displacement of the vertical position of ground control points from two or more epochs of measurements.

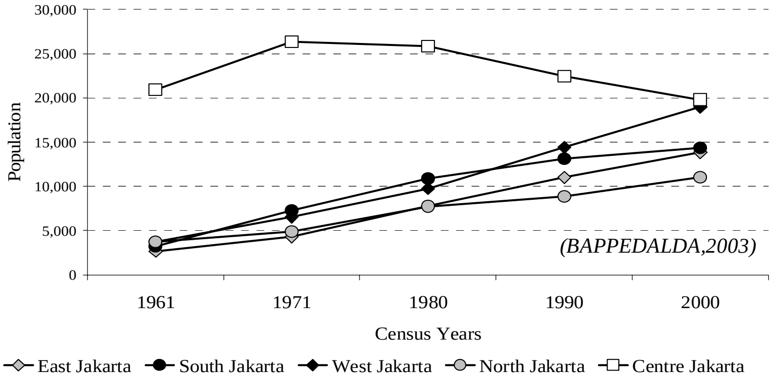


Figure 2: Population in Square Kilometres

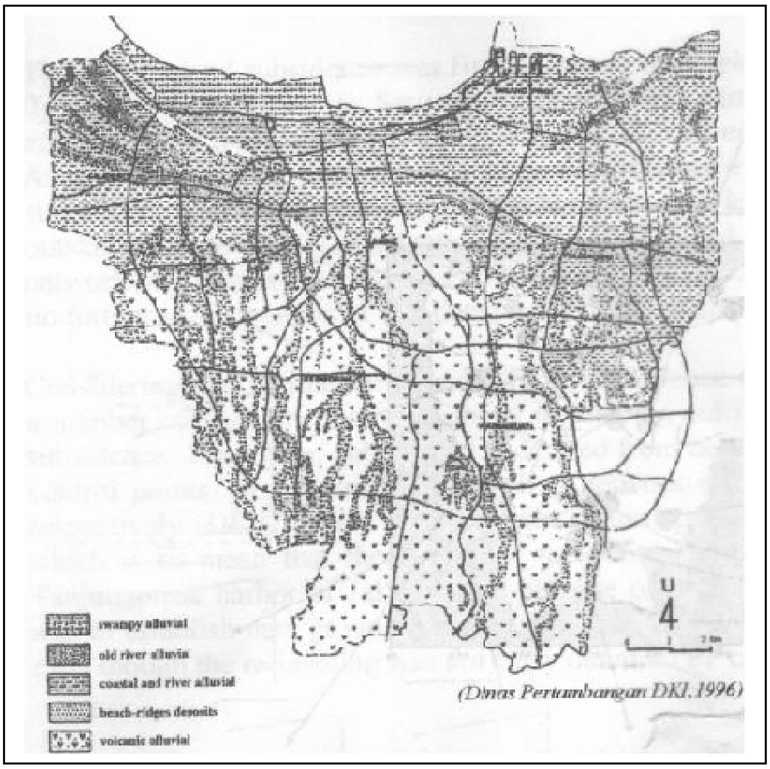


Figure 3: Geology of Jakarta

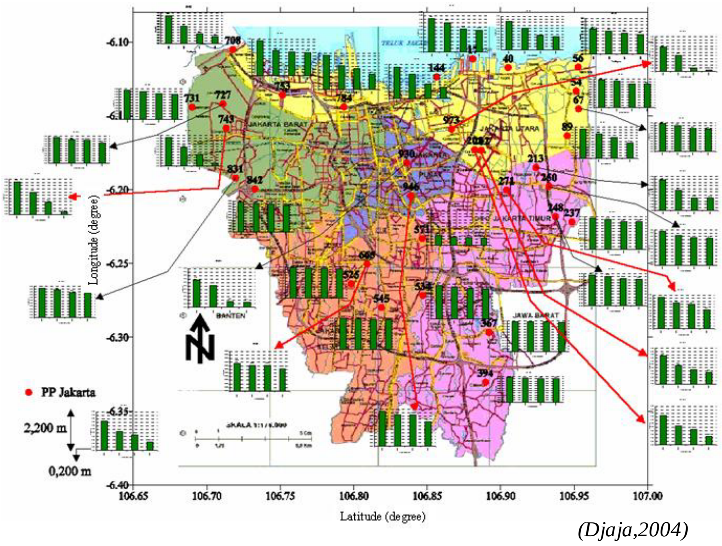
The Jakarta land subsidence was first known to researchers in 1978 when the buildings and a fly-over bridge, known as Sarinah bridge at M.H.Thamrin Avenue, in Jakarta Center, were cracked. Also flooding in Jakarta in that period covered a wider area (*Hutasoit et al. 1997*). As a matter of fact, land subsidence in Jakarta was ever observed in 1926, when a Dutch surveyor conducted re-measurements of the first order leveling network from Jatinegara in the outskirt of Jakarta to Tanjungpriok harbor, and found that the loop closure of the leveling network was higher that the established tolerances (*Suharto 1971*). Since then, there were no further investigations of this occurrence until the crack accident happened in 1978.

Considering the detrimental impact of land subsidence on buildings and other infrastructures, a number of researchers have interest in carrying out investigation on the cause and rate of subsidence. The rate of subsidence is derived from height difference measurements at ground control points of the first order leveling network in the years 1982, 1991, 1997 and 1999 respectively (*DPPT 1995*). These height control points are abbreviated as PP (Priok Peil), which is to mean that the height of the control points are referred to the tide gauge at Tanjungpriok harbor of Jakarta. The purpose of the releveling measurements as mentioned was to establish new ground control points and to relocate the lost of vertical control points, even though the re-leveling was not carry out at all PP control points.

2. THE PATTERN OF LAND SUBSIDENCE

2.1 The Vertical Movements

Although the purpose of the releveling of the PPs as mentioned above was not directed to investigate the land subsidence, but the data were a valuable asset. Most of the land subsidence investigation conducted over part of Jakarta territory. In this paper, a number of 32 PPs were measured in 4 epochs and the location of these control points is shown in Figure 4 *(DPPT 1995; Dinas Pertambangan 1999)*. The heights of control points in each epoch provide the trend of height change which prove the evidence of a land subsidence in Jakarta . The trend and rate of subsidence of each PP is characterized by the topography where the PPs are located.. Generally, in the northern part of Jakarta, the trend of heights is decreasing, which means a downward movement, compared to the southern part of the city. From the PP heights observed in the period of 1982 – 1991, the largest subsidence has taken place at PP 708 (at Cengkareng, North Jakarta) with a rate of 8.5 cm/year. In the period 1997 – 1999 the largest figure of subsidence is at PP 743 (at Daan Mogot, North-West Jakarta) with a rate of 31.9 cm/year. The increasing rate shows that land subsidence in Jakarta is continuing. Therefore, planners and engineers should take into account of the occurrence in their future planning and construction works.



(Djaja,2004)

Figure 4: The height of vertical control points for the year 1982,1991,1997 and 1999 as determined by precise leveling survey

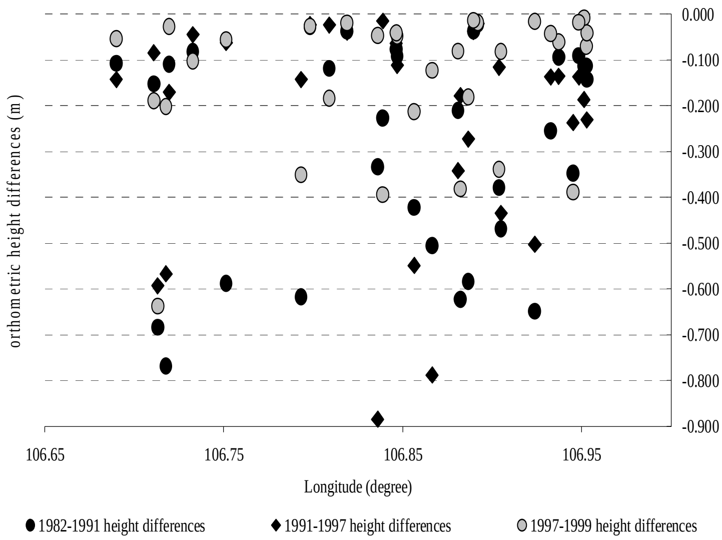


Figure 5: The PP height differences and longitude

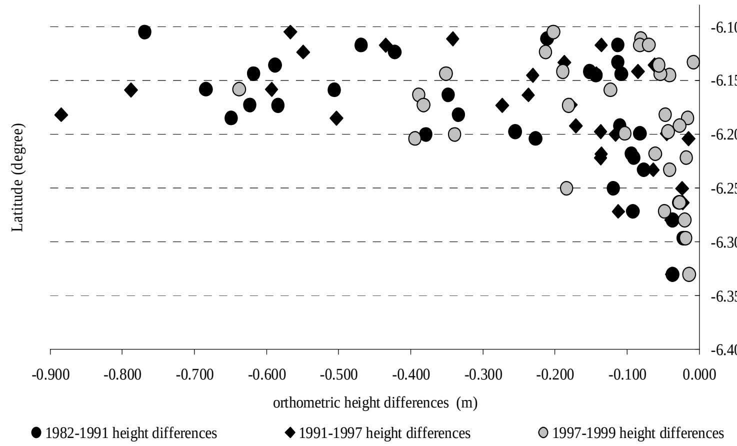


Figure 6: The PP height differences and latitude

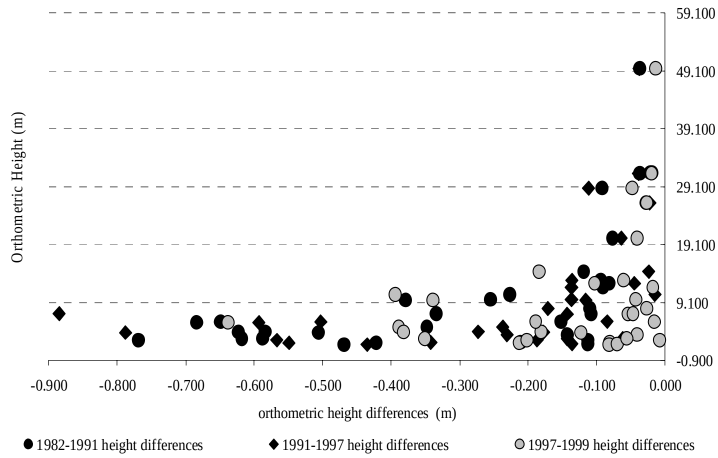


Figure 7: The PP height differences and elevation

Figure 5, 6 and 7, show the distribution of land subsidence (represented by the height difference of leveling control points of several epochs) based on the position of the geographic positions (latitude, longitude and height). The distributed points show a significant clustering between the height difference and the height or elevation of the points on PP height datum (Fig. 7), and also the height difference with respect to latitude (Fig.6). This means that land subsidence of Jakarta determined by periodic geodetic leveling provide a certain pattern of subsidence in the North-South direction and the rate of subsidence is likely influenced by the topography (elevation). In the East-West direction (longitude direction) it does not provide any information which means that the area in the East-West direction almost has a uniform characteristics (Fig. 5).

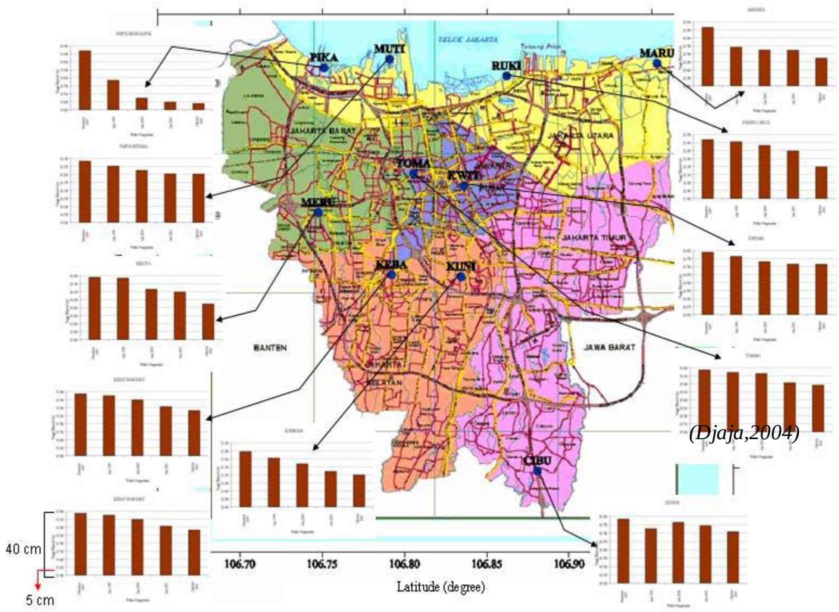


Figure 8: The orthometric height of the points as determined by GPS survey

In 1998, the method of GPS measurements was intro-duced in investigating land subsi-dence in Jakarta *(Abidin 1998; Abidin et al. 2001)*, and the GPS land subsidence monitoring network was then established. The network, radial in form with respect a fixed national GPS station at Cibinong, was extended by adding some monitoring points to the established network *(Djaja 2001)*. The land subsidence investigation deals with small movement within cm or mm range of height differences *(Arsjad 1993)*. Therefore the use of traditional leveling network or GPS observations would not make any difference. The GPS monitoring points of the network were measured in 5 epochs, as presented in Figure 8.

The distribution of land subsidence observed by GPS observations shows almost the same result as by conventional leveling. During the period of GPS observations carried out in December 1997 to June 1999, the largest figure of subsidence was found at Pantai Indah Kapuk, a settlement area in North Jakarta, and the rate of subsidence was 12.1 cm/year. Observations made in the period of June 1999 to June 2000, the largest figure of subsidence was again at Pantai Indah Kapuk with a rate of 11.3 cm/year. However, in the period of June 2000 to June 2001 the largest subsidence figure was found at Daan Mogot in North-West Jakarta. In the period of June 2001 to October 2001 the subsidence rate at Pulogadung Industrial Estate (Table 1), was 17.8 cm within 5 months or 3.5 cm/month (Table 1).

The distribution of GPS points along the longitude shows no significant orthometric height diffe-rences (Fig 9). The pattern is almost the same as in leveling measure-ment. (see Fig.5). Again, the coverage of Jakarta in the east-west direction shows no significant influence in orthometric height differences of the GPS points. The same pattern is also observed for control point along the latitude (Fig.10).

The dissemination of land subsidence as represented by ortho-metric high differen-ces shows a signifi-cant relationship bet-ween subsidence and the orthometric height of the points (Fig.

11), compare with Fig. 7. In conclusion, the subsidence in the northern part of Jakarta is much higher than in the southern part. This can be explained from geological structure of Jakarta, where the northern part as an alluvial plane has much higher compressi-bility than the southern part which is more stable.

2.2 The Land Subsidence Trend

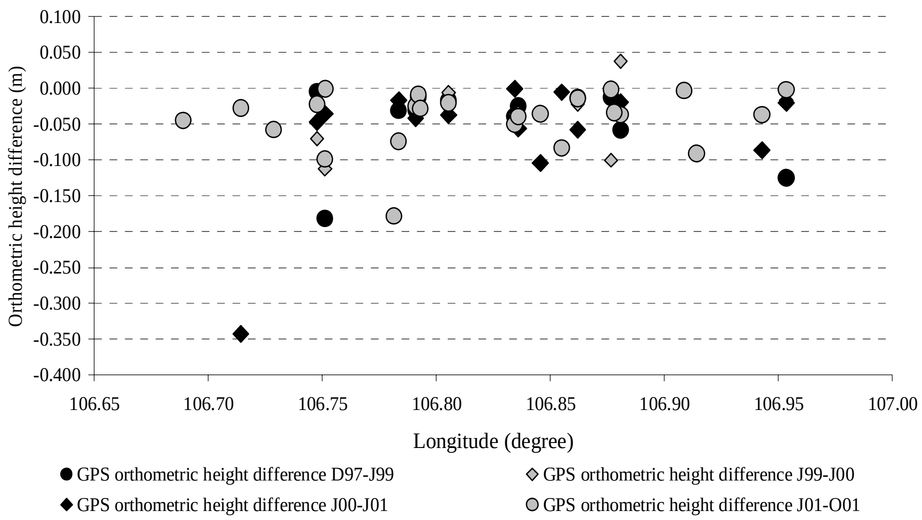


Figure 9: The orthometric height differences and longitude

The rate of land subsidence at one location is primarily influenced by local environmental factor, geological structure, soil layer properties and others.

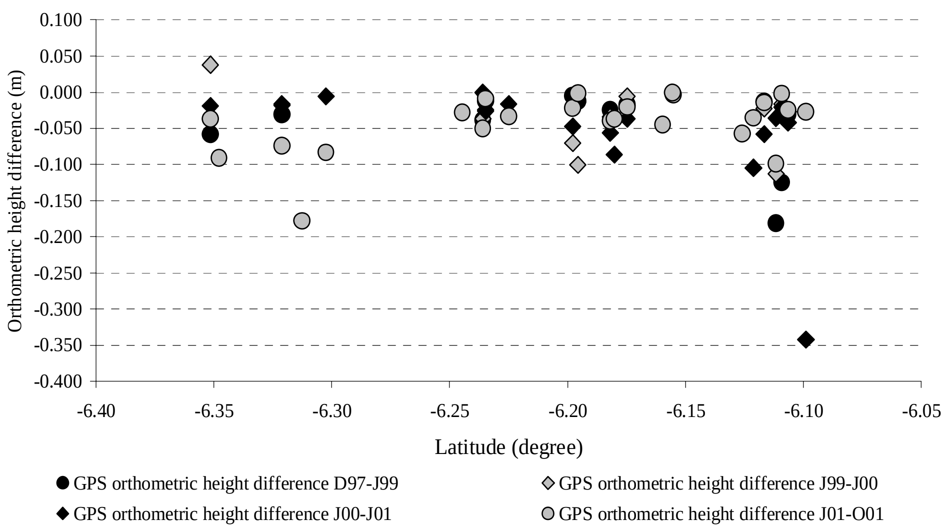


Figure 10: The orthometric height differences and latitude

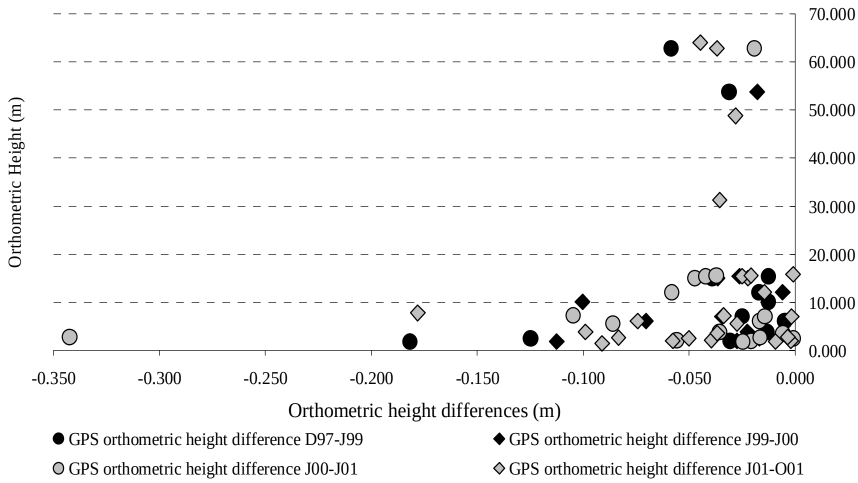


Figure 11: The orthometric height differences and orthometric height

The trend of subsidence is determined by evaluating the height changes observed from the period of observations. Modeling is important for prediction and analysis of the phenomena *(Rais 2003)*. Modeling the land subsidence trend is intended to predict the future trend of land subsidence *(Liu 1998)*. Moreover, the time factor is an important variable to be considered in defining the trend of subsidence. GPS and leveling both have the capability to provide the height difference data accurately, but only the GPS could provide the real time accuracy. The land subsidence trend provided by observed GPS height is more close to reality. The trend then is fitted through a suitable mathematical formulation, either logarithmic, exponential or polynomials. The suitable formula is based on the minimum value of squared residuals *(Adual 1994; Vega et al. 1984)*.

Remarkably, the most land subsidence trend in Jakarta is quadratic subsidence *(Djaja, 2004)*, but there are also some points indicated a linear trend. The curve line of land subsidence trend in Jakarta is more likely realistic if the local soil properties are taken into account.

Basically, the distribution of monitoring height points which is representing the characteristic of the area is also important. However, due to economic and efficiency reasons, the monitoring points area usually placed at certain location which represent the characteristic of the area. For practical purposes the establishment of land subsidence monitoring networks is considered important for reference of all engineering works in the respective areas.

3. GROUNDWATER EXTRACTION

The limited distribution of fresh water in Jakarta effects the people and the industries extract groundwater for their basic needs. This causes imbalances between discharge and recharge of groundwater that resulting in the lowering of the water table in the aquifers. In fact, reducing of the groundwater level (water table) makes getting water from wells more and more difficult, especially for ordinary people who used to get water from their own wells. Coincidentally, a number of groundwater monitoring wells are established in a number of places in Jakarta. Even though, the monitoring is basically intended to assess the availability

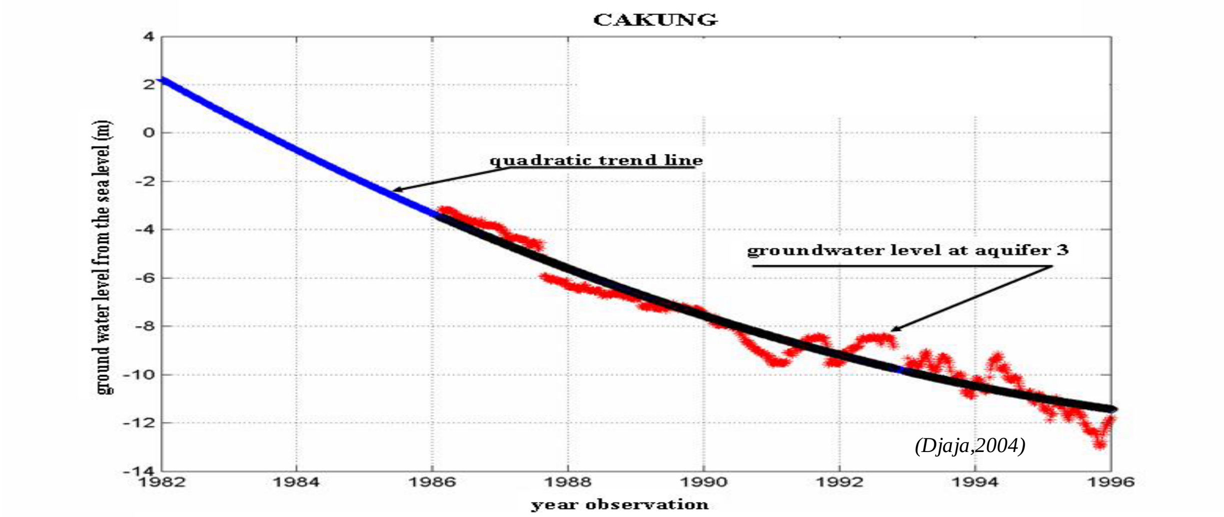


Figure 12: Groundwater level at Cakung Well

and the quality of the groundwater. And hence, that is not directed to monitor the subsidence. However, the trend of the groundwater table at Cakung Monitoring well is remarkably shown in Fig.12 *(Sumaryo 1997)* where the ground-water level lowered within 13 years. Figure 12 shows the trend of groundwater level at Cakung well which fits to quadratic equation.

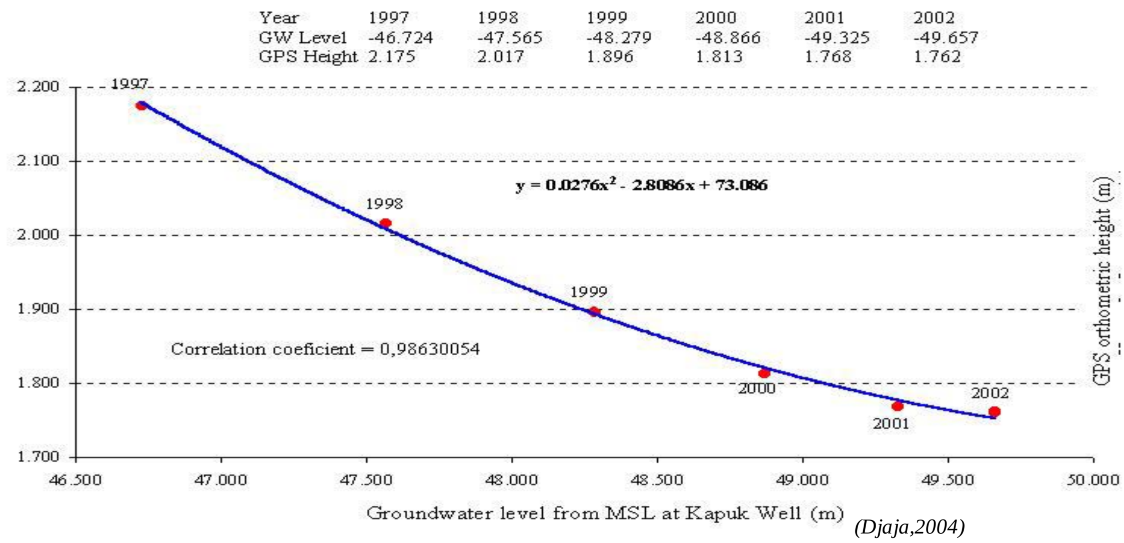


Figure 13: Trend of groundwater level at PIKA (GPS station at Pantai Indah Kapuk) and orthometric height

Those proved the principle that when the volume of groundwater decreases the level of land surface above the aquifer will be influenced. The compaction of the soil layers also supports the existence of land subsidence. Additionally, Figure 13 shows the correlation between the groundwater level trend and the trend of GPS orthometric heights.

4. CONCLUSIONS

Land subsidence has occurred in Jakarta as shown by cracking of the buildings, widenned-flooding area and stoppage of drainage system. These will influence the daily life of the city. Other cities laying in the northern coastal plain of Jawa are also influenced by land subsidence. The rate of land subsidence is at the range of cm or mm and this can only be detected by precise geodetic measurement methods. GPS satellite observation, --which provides real time and does not depend on the topography and distance from the reference point--, is an efficient and practical methods in monitoring land subsidence.

The largest rate of subsidence in Jakarta as shown by re-leveling the PP vertical control points is during the period 1997-1999 with a rate of 31.9 cm/year at PP 743 (Daan Mogot). In the period June 2000 - June 2001 the rate observed by GPS is 34.2 cm/year at Daan Mogot and in the period from June 2001 to October 2001 is 17.8 cm/year at Pulogadung. Although the rate is small but it will affect significantly for the area. This phenomena should be taken into account in the process of spatial planning.

The pattern and rate of subsidence in Jakarta has some correlation to the topography and the environment (population and activities). At location where the GPS subsidence monitoring point and groundwater monitoring well are close, the subsidence and the level of the groundwater table has some correlation. This will prove that subsidence is related to the extraction of groundwater.

Accuracy of height difference and time implementation on the survey is an important variable to determine and predict land subsidence. Since GPS observations provide real time result, this could provide the trend of subsidence more realistically. A land subsidence network is timely to be established at big cities in Indonesia.

REFERENCES

Abidin, H.Z. 1998. *Pemantauan penurunan tanah di wilayah Jakarta dengan metode survei GPS*, Laporan Akhir Program Penelitian Kejasama Pemda DKI - ITB, Tahun Anggaran 1997/1998, Jurusan Teknik Geodesi - ITB, Bandung.

Abidin, H.Z. et al. 2001. Land Subsidence of Jakarta (Indonesia) and its Geodetic Monitoring System. *Natural Hazards* **23** : 365-387, Kluwer Academic Publishers, Netherlands.

Adi,S.1994. *Estimasi pengambilan airtanah pada setiap kelompok akuifer cekungan Jakarta*. Makalah Ikatan Ahli Geologi Indonesia, Pertemuan Ilmiah Tahunan.

Aduol, F.W.O. 1994. *Robust Geodetic Parameter Estimation under Least Squares through Weighting on the Basis of the Mean Square Error*. www.uni-stuttgart.de/gi/research/schriftenreihe/quo_vadis/pdf/aduol.pdf

Arsjad, ABSM. 1993. Subsidence (terban) (Gerakan tanah vertikal kebawah), *Survey dan Pemetaan*, Vol. 10, No. 3, Juli 1993, 49-54,Cibinong.

BAPPEDALDA.2003. *Buku-II*. http://www.dki.go.id/bapedalda/Buku-II.

Dinas Pemetaan dan Pengukuran Tanah (DPPT) DKI Jakarta. 1995. *Buku Daftar Ketinggian Titik Tetap (Peil Priok) di Wilayah DKI Jakarta*.

Dinas Pertambangan DKI Jakarta,1996. *Rencana Tata Ruang Wilayah DKI Jakarta*.

Dinas Pertambangan DKI Jakarta. 1999. *Pemetaan resettlement akibat beban bangunan dan faktor teknis geologi.*

Djaja, R. 2001. Pemantauan Penurunan Tanah di Wilayah Jakarta, *Laporan Kemajuan (Tahap I) dan Kertas Kerja Riset Unggulan Terpadu, RUT. VIII*, Jakarta.

Djaja, R.2004. *Submiited Disertation*.

Hutasoit, L.M., Sunyoto, D. Murdhohardono. dan A. Handoyo. 1997. *Pengaruh Alami Geologi dan Berat Bangunan terhadap Penurunan Muka Tanah dan Terjadinya Genangan Air*. Seminar Sehari Geologi Pertambangan, Dinas Pertambangan Daerah Khusus Ibukota Jakarta, Jakarta, Indonesia.

Liu, Q. 998. *Time-dependent Models of Vertical Crustal Crustal Deformation from GPS-Leveling Data*. Surveying and Land Information Systems. Journal of the American Congress on Surveying and Mapping, Vol 58, No. 1.

Murdohardono, D. And H. Tirtomihardjo. 1993. Penurunan Tanah di Jakarta dan Rencana Pemantauannya.

Rais, J. 2003. *Pemodelan sebagai sarana riset*.Personal Communication.

Suharto, P. 1971. Waterpas teliti di Indonesia, *Risalah Ilmiah*,Geodesi ITB, Bandung.

Sumaryo. 1997. Hubungan penurunan muka air tanah dengan penurunan muka tanah di wilayah DKI Jakarta. *Program Studi Geografi, Jurusan Ilmu-ilmu Matematika dan Pengetahuan Alam*. Program Pasca Sarjana, Universitas Gajah Mada, Yogyakarta.

Soetrisno S. 1999. Groundwater Management Problems, a Jakarta and Bandung (Indonesia) Comparative City Case Studies. http://www.geocities.com/Eureka/Gold/1577/gw_manage.html.

Vega, G.F. and S. Yamamoto. 1984. Techniques for prediction of subsidence. *Guidebook to studies of land subsidence due to ground-water withdrawal, International HydrologicalProgramme*, Working Group 8.4, pp.89-116, the United Nations Educational, Scientific and Cultural Organization, 7, place de Fontenoy, 75700 Paris.

CONTACTS

Rochman Djaja, Jacub Rais, Hasanuddin Z Abidin, Wedyanto Kuntjoro
Geodetic Engineering Dept
Bandung Institute of Technology
Jl. Ganesa 10
Bandung 40132
INDONESIA
Email: wedyanto@gd.itb.ac.id

Table 1. GPS Orthometric Height of Jakarta

No.	GPS Point	Position		Orthometric Height (m)				
		Long (der)	Lat (der)	D1997	J1999	J2000	J2001	O2001
(1)	(2)	(3)		(4)				
1	CIBU	106.8808	-6.3515	62.957	62.899	62.937	62.917	62.881
2	CINE	106.7835	-6.3211	53.842	53.811	53.793		
3	MERU	106.7477	-6.1979	6.230	6.225	6.155	6.138	6.064
4	KUNI	106.8343	-6.2360	15.151	15.112	15.075	15.028	15.006
5	MARU	106.9534	-6.1092	2.615	2.490	2.473	2.472	2.422
6	MUTI	106.7909	-6.1066	2.009	1.978	1.951	1.930	1.928
7	KEBA	106.7921	-6.2349	15.474	15.461	15.435	15.393	15.368
8	PIKA	106.7512	-6.1117	2.091	1.910	1.797	1.773	1.763
9	RAWA	106.8766	-6.1956	10.170	10.157	10.057		
10	RUKI	106.8621	-6.1166	3.920	3.907	3.884	3.849	3.750
11	KWIT	106.8360	-6.1820	7.102	7.077	7.042	7.028	7.026
12	TOMA	106.8054	-6.1747	12.111	12.094	12.088	12.030	12.016
13	ANCL	106.8456	-6.1212			2.187	2.131	2.091
14	BSKI	106.8779	-6.2250			15.569	15.532	15.511
15	CNDT	106.8549	-6.3025			31.136	31.310	31.274
16	CLCN	106.9428	-6.1801			7.312	7.207	7.174
17	KAMR	106.7143	-6.0990			2.748	2.731	2.648
18	KLGD	106.9086	-6.1552			3.540	3.534	3.498
19	KLDR	106.6890	-6.1597			5.639	5.553	5.526
20	DNMG	106.7513	-6.1555			3.068	2.725	2.722
21	BMT1	106.9142	-6.3479				64.056	64.012
22	BMT2	106.7930	-6.2447				15.856	15.855
23	CEBA	106.7287	-6.1260				1.477	1.386
24	CINB	106.7814	-6.3126				48.800	48.772
25	DADP	106.7186	-6.0862				2.023	1.965
26	PLGD	106.9180	-6.2123				7.917	7.739