Results of land subsidence measurement using GPS method in the Jakarta groundwater basin in 2015-2019

F M Abdullah, H Andriyanto, J R Nababan, F Abdillah and R I H Sulistyawan

Groundwater Conservation Unit, Geological Agency, Ministry of Energy and Mineral Resource, Indonesia

E-mail : firmanmaliki@gmail.com, firman.abdullah@esdm.go.id

Abstract. The development of population and development activities in big cities in Indonesia, especially in the city of Jakarta and surrounding areas is very rapid. From several land subsidence studies, several factors have been identified that cause land subsidence, namely: excessive groundwater extraction, reduction due to building/infrastructure loads, subsidence due to natural consolidation of soft soil layers, and subsidence due to tectonic forces. At present the exploitation of ground water for industrial and residential needs is at a level that needs attention. Excessive pumping of groundwater will cause a decrease in the quantity of ground water, entry of seawater into the land (sea water intrusion) and land subsidence. Symptoms of the negative impact of land subsidence have been felt in several areas, especially in industrial areas located in the northern part of Jakarta. This land subsidence can be measured by GPS or satellite geodetic method, which have begun to develop in Indonesia in the past two decades. Measurements were made using the radial method at 53 GPS points in 2015 up to 100 measurement points in 2019 in Jakarta Groundwater Basin. The result of these campaign GPS surveys that is northern part of Jakarta relatively had higher subsidence rate than the southern. The largest subsidence almost reached 6.2 cm/year in Muara Baru in northern area which is southern area only suffered an average rate of 1.16 cm/year.

Key words : land subsidence, GPS survey method, Jakarta Groundwater Basin

1. Introduction

Jakarta is the capital city of Indonesia and considered to be the largest and densest population in the South East Asia. Jakarta is located at Jakarta Groundwater Basin which is consist of mainly young volcanic and sediment deposits. The Jakarta area is relatively flat in the norther part and slightly hilly in the southern part. Administratively, the Jakarta Groundwater Basin consists of DKI Jakarta itself, eastern part of Tangerang City and Regencies, Tangerang Selatan City, western part of Bekasi City and Bekasi Regencies, and northern part of Depok City and Bogor Regencies (Figure 1).
Figure 1. The location of Jakarta Groundwater Basin

Hydrogeologically, the base of aquifer system is formed by impermeable miocene sediments which also cropped at southern boundary of the basin. The basin mainly consist of quaternary alluvial volcanic fan deposit that formed from tuffaceous and conglomerate sandstone, young river deposit, swamp deposit, sand bar deposit, Banten Tuff, Serpong Formation, and Bojongmanik Formation. Fachri et all called quaternary alluvial volcanic fan deposit as Citalang Formation which is the main aquifer of Jakarta. 

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We used the term of Jakarta Groundwater Basin rather than Jakarta itself because of our main task and duty not only considering Jakarta but our main responsibility covered the whole of Jakarta Groundwater Basin. The objective of this research is to estimate the rate of land subsidence that has occurred from 2015 to 2019 by using GPS- satellite based positioning system- in the Jakarta Groundwater Basin, and therefore the results can be used as basic data or information in carrying out further planning and policy by the government or interested party.

2. Data and Methods
Land subsidence in Jakarta and its neighboring area had been reported in several scientific investigation reports. There are some scientific methods usually used for investigating or studying land subsidence phenomena such as GPS campaign survey, analysis of In Sar data, extensiometer analysis method, and so on. In this study we used GPS survey method which is relatively flexible and could cover wide area.

The method of GPS survey is re-measuring GPS points every year in the Jakarta Groundwater Basin. The GPS points that are measured annually must be the same points. After recording the GPS data from satellites for 6-8 hours, data will be processed later (post processing). The GPS surveys used dual frequency geodetic type GPS receivers, data was taken with interval 15-30 seconds, elevation mask 10-15°.

The GPS receiver used in these surveys was Trimble R7 (2015-2017) and Trimble R9 (2018-2019) and the processing software was Trimble Business Centre v 2.5 (2015-2017) and v 4.0. (2018-2019). The GPS data processed with the nearest reference station to the GPS points. Those reference stations which will be used as benchmark of measurement are managed by Geospatial Information Agency. Every baselines must be resolved to get the best results. Satellites with large standard deviations or have too many cycle slips when data was recorded must be edited or eliminated.

The results are ellipsoid heights in those points. More experience in processing data will generate better results. These results will be compared every year, and therefore can describe the ellipsoid heights differences from time to time at the same points. Every year we got ellipsoidal heights in all GPS points, then we got height differences on these points. Average results are the average changes per year in the year 2015 to 2019. The positive results indicated the ground surface level are up, and the negative results indicated ground surface level are down or subside. The location of the initial GPS points in 2015 can be seen in figure 2.
Figure 2. The initial GPS Points in 2015

GPS survey campaign first started in 2015 with 53 GPS points. In 2019 we measured up to 100 GPS points. The selected results will be showed in Table 1, which are only contain the results of GPS measurement (ellipsoid height) in northern area of Jakarta Groundwater Basin and Table 2 which had the results in southern basin1-12,14-15,17-20. The positive average changes mean the ground surface was up whereas negative average changes mean the land surface was subsided. There are no GPS survey conducted in 2017. We only selected the results with relative good accuracy.
Table 1. Ellipsoid height results in northern area

| GPS points                  | 2015    | 2016    | 2017    | 2018    | 2019    | Average changes (cm/year) |
|-----------------------------|---------|---------|---------|---------|---------|---------------------------|
| 12B, Cikokol                | 36.161  | 36.157  | 36.168  | 36.102  | 36.117  | -1.467                    |
| 15B, Joglo                  | 32.969  | 32.914  | 32.902  | 32.877  |         | -3.067                    |
| 17B, Duri Kosambi           | 25.046  | 25.054  | 25.024  | 24.898  | 24.807  | -5.975                    |
| 19B, Tongkol                | 19.389  | 19.371  | 19.327  | 19.273  | 19.249  | -3.500                    |
| 21B, Muara Baru             | 19.130  | 19.031  | 19.043  | 18.944  | 18.883  | -6.175                    |
| 23B, Latumenten             | 20.839  | 20.834  | 20.846  | 20.794  | 20.762  | -1.925                    |
| 24B, Gambir                 | 23.422  | 23.364  | 23.409  | 23.372  | 23.399  | -0.575                    |
| 26B, Dadap                  | 21.333  | 21.262  | 21.233  | 21.156  | 21.092  | -6.025                    |
| 28B, Kamal Muara            | 20.507  | 20.426  | 20.443  |         |         | -1.600                    |
| 30B, Kali Deres             | 21.473  | 21.432  | 21.362  |         |         | -2.775                    |
| 31B, PIK                    | 19.231  | 19.094  | 19.063  |         |         | -4.200                    |
| 35B, Muara Angke            | 18.756  | 18.724  | 18.638  |         |         | -2.950                    |
| 27C, Kayu Manis             | 28.898  | 28.884  | 28.877  | 28.915  |         | 0.567                     |
| 28C, Kлемент                | 29.116  | 29.185  | 28.977  | 28.986  |         | -4.333                    |
| 29C, Medan Satria           | 27.424  | 27.427  | 27.340  | 27.299  | 27.304  | -3.000                    |
| 31C, Babelan                | 22.080  | 22.071  | 22.067  | 21.977  | 21.940  | -3.500                    |
| 32C, Bumi Bhakti            | 21.539  | 21.537  | -       | 21.525  | 21.525  | -0.267                    |
| 33C, Penggilingan           | 30.166  | 30.135  | 30.261  | 30.171  | 30.189  | 0.575                     |
| 35C, Kemayoran              | 20.578  | 20.555  | 20.468  | 20.561  |         | -0.567                    |
| 36C, Tj. Priok              | 20.271  | 20.263  | 20.266  | 20.240  | 20.235  | -0.900                    |
| 38C, Cakung                 | 26.932  | 26.939  | 27.030  | 26.972  |         | 1.333                     |
| 40C, Marunda                | 22.142  | 22.070  | 21.978  | 22.032  | 22.033  | -3.633                    |
| 41C, Tarumajaya             | 21.455  | 21.349  | 21.332  | 21.320  | 21.284  | -5.700                    |
| 44C, Pulomas 2              | 21.973  | 21.903  | 21.844  |         |         | -4.300                    |

Table 2. Ellipsoid height results in southern area

| GPS points                  | 2015    | 2016    | 2017    | 2018    | 2019    | Average changes (cm/year) |
|-----------------------------|---------|---------|---------|---------|---------|---------------------------|
| 01A, Fatmawati              | 56.316  | 36.168  | 36.102  | 56.266  |         | -1.150                    |
| 04A, Alam Sutera            | 43.494  | 43.477  | 43.423  | 43.499  |         | 0.125                     |
| 08A, Cinere                 | 70.961  | 70.963  | 70.931  |         |         | -1.000                    |
| 09A, Cinangka               | 95.088  | 95.082  | 95.100  | 95.094  |         | -0.150                    |
| 10A, Pamulang               | 74.515  | 74.457  | 74.458  | 74.444  |         | -1.775                    |
| 11A, Rempoa                 | 59.773  | 59.744  | 59.652  | 59.712  |         | -1.525                    |
| 42D, Cibubur                | 83.599  | 83.559  | 83.445  | 83.437  |         | -4.050                    |
| 44D, Halim                  | 37.204  | 37.210  | 37.158  | 37.161  |         | -1.075                    |
| 45D, Jati Sumpurna          | 90.317  |         | 90.287  | 90.247  |         | -1.750                    |
| 46D, Pondok Melati          | 59.895  | 59.877  | 59.888  | 59.887  |         | -0.200                    |
| 50D, Margonda               | 104.155 |         | 104.102 | 104.064 |         | -3.033                    |
| 51D, Kebagusan              | 54.286  |         | 54.309  | 54.294  |         | 0.200                     |
| 53D, Pondok Cina            | 85.743  | 85.735  | 85.752  |         |         | 0.300                     |
3. Conclusion and Discussions

It appears from the results of the GPS measurements survey the northern part is relatively have higher rate subsidence than the southern part, and then can be said that the subsidence is heterogenous in time and place. There is no land subsidence more than 10 cm/year in the period of 2015-2019 using GPS survey method. The largest subsidence almost reached 6.2 cm/year in Muara Baru in northern area which is southern area only suffered an average rate of 1.16 cm/year.

What is interesting is, there are some GPS points in the southern part of the Jakarta Groundwater Basin which have decreased up to several cm, namely the measurement points in Cibubur (42D) and Margonda (50D), but still need further research to confirm this condition. Implementing a continuously GPS network may be useful because of possibly large temporal variations in the rates of subsidence which is difficult to observed by episodic GPS measurements. However the GPS survey method is not the only way to study or investigate land subsidence phenomena. Other researchers can use extensiometer method and/or InSAR data to estimates the rate of land subsidence.

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