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The contribution of human activities to subsurface environment degradation in Greater Jakarta Area, Indonesia

Robert M. Delinom[a,*], *Abdurrahman Assegaf*[b], *Hasanuddin Z. Abidin*[c], *Makoto Taniguchi*[d], *Dadan Suherman*[a], *Rachmat Fajar Lubis*[e], *Eko Yulianto*[a]

[a]*Research Centre for Geotechnology, Indonesian Institute of Sciences, Jln. Cisitu - Sangkuriang, Bandung 40135, Indonesia*
[b]*Geological Department, Trisakti University, Jln. Kyai Tapa No. 1, Jakarta 11440, Indonesia*
[c]*Geodesy Research Division, Faculty of Civil and Environmental Engineering, Institute of Technology Bandung, Jln. Ganesha 10, Bandung 40132, Indonesia*
[d]*Research Institute for Humanity and Nature, 457-4 Motoyama, Kamigamo, Kitaku, Kyoto 603-8047, Japan*
[e]*Graduate School of Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba 263-8522, Japan*

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ABSTRACT

This study examines the factors of human activities causing environmental stresses on the subsurface environments in the urban settings of Jakarta. A major objective of this study is to identify the basin geometry and estimate how critical is the degradation of the subsurface environment within the basin, and it covered micro-palaeontology and chemical analyses, the decrease of water level, and GPS data. New data on shallow groundwater quality is provided and the results indicate strong evidence for human activities have influenced the degradation of the Jakarta subsurface environment.

1. Introduction

In 2001, the UNEP (United Nations Environment Program) produced its third UNEP Global Environment Outlook, Geo 3 (UNEP Website, 2002). It draws attention to the fact that the availability and quality of fresh water is rapidly becoming one of the most critical environmental and developmental issues of the twenty first century. The use of groundwater resources is becoming more important as it is a very easy abstract. Despite its importance, groundwater is often misused, usually poorly understood and rarely well-managed.

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 a 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 sufficient time to devise an effective strategy for sustainable management.

Most global environmental studies have focused on the environmental issues above ground surface such as air and water pollution, global warming, seawater pollution, and decrease in biodiversity. Subsurface environmental issues are also important for human life in the present and future, but they have been largely ignored because of the invisibility of the phenomena and difficulty of the evaluations. Change in

* *Corresponding author*. Tel.: +62 22 250 3654; fax: +62 22 250 4593.
E-mail addresses: rm.delinom@geotek.lipi.go.id, delinom2002@yahoo.com (R.M. Delinom).

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reliable water resources between groundwater and surface water are occurring in many Asian cities depending on the development stage of urbanization. Although surface water is relatively easy to evaluate, changes in regional groundwater storage remain a difficult task. Subsurface environmental problems such as subsidence due to excessive pumping and groundwater contamination have occurred repeatedly in Asian major cities (Foster and Chlton, 2003) with a time lag depending on the character of urbanization.

Under the RIHN project on "Human Impacts of Urban Subsurface Environment, this project will focus on the subsurface environment of the entire Jakarta Basin. It is at this basin scale that subsurface water, heat, and material transport are interconnected. Sub-theme 1 (Development stage of the Asian city and subsurface environments) will focus on identifying the factors in human activities causing the environmental stresses on the subsurface environments in the urban settings. It will identify the different development stages and describe the major causalities with respect to urbanization and changes in subsurface environment over a long-term perspective.

A major objective of this study is to identify the basin geometry and estimate how critical is the degradation of the subsurface environment within the Jakarta Basin due to human activities. Groundwater over-abstraction has become a common issue along the coastal area where good quality groundwater is available.

This study presents the results of the following activities:

1. micro-palaeontology analysis using 3 drilling cores for setting down the basin geometry,
2. chemical analyses from 17 water samples from springs located in the southern part of Jakarta, 51 water samples from monitoring wells inside Jakarta groundwater basin, and 42 water samples from shallow groundwater around Jakarta Area,
3. an analysis of the decrease of water level in 51 monitoring wells and 50 dug-drilled wells of 5 years period records,
4. and GPS data from 27 networks station.

This study examines the basin geometry and the impact of groundwater pumpage and soil layer compaction on the subsurface environment.

2. Study area

2.1. General View

The Greater Jakarta is the capital of the Republic of Indonesia and occupies the coastal plain area which borders the Java Sea to the North (Fig. 1). The elevations of this plain vary from 0 to 1000 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″ S latitude covering an area of about 652 km^2. It has a humid tropical climate with annual rainfall varying between 1500 and 2500 mm and influenced by the monsoons. Land use in Greater Jakarta mostly comprises housing, industry and commerce whilst some agriculture is practiced in the urban fringe areas.

The population of Jakarta at present is around 8.3 millions (Jakarta Local Government Website, 2007). It represents the official number of population that actually lives in the Greater Jakarta Area. The population can be expected to increase in the near future by both natural increase and net in immigration as many people have been attracted to come to this city to pursue a better life. 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 opening 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. According to the Statistical Local Office of Greater Jakarta (2003), the highest population density of Jakarta Area was found in Central Jakarta (18,746 people/km^2) and were followed by West Jakarta (12,426 people/km^2), South Jakarta (11,676 people/km^2), East of Jakarta (11,157 people/km^2), North Jakarta (8,267 people/km^2), and Seribu Island (1616 people/km^2).

It is obvious that urbanization has increased the water demand in this area. As the drinking water which is supplied by surface water covers only 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-pumping as it is taking place at the present time in Jakarta. Over-pumping can also decrease the volume of groundwater and produce subsidence of the land surface. The subsurface layer compaction has led to 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.

2.2. Geological Setting

According to Engelen and Kloosterman (1996), structurally, the Jakarta 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. Regionally, Jakarta Area is occupied by lowland area that has five main landforms (Rimbaman and Suparan, 1999) that consists of:

1. volcanic and alluvial landforms, that are found in southern part of the basin,
2. marine origin landforms, which are occupied the northern area adjacent to the coastline,
3. beach ridge landforms, which are discovered along the coast with east–west direction,
4. swamp and mangrove area landforms, which are encountered in the coastal fringe,
5. paleo-channels, which run perpendicular to the coastline.

Geologically, the study area is dominated by quaternary sediment and, unconformably, the base of the basin is formed

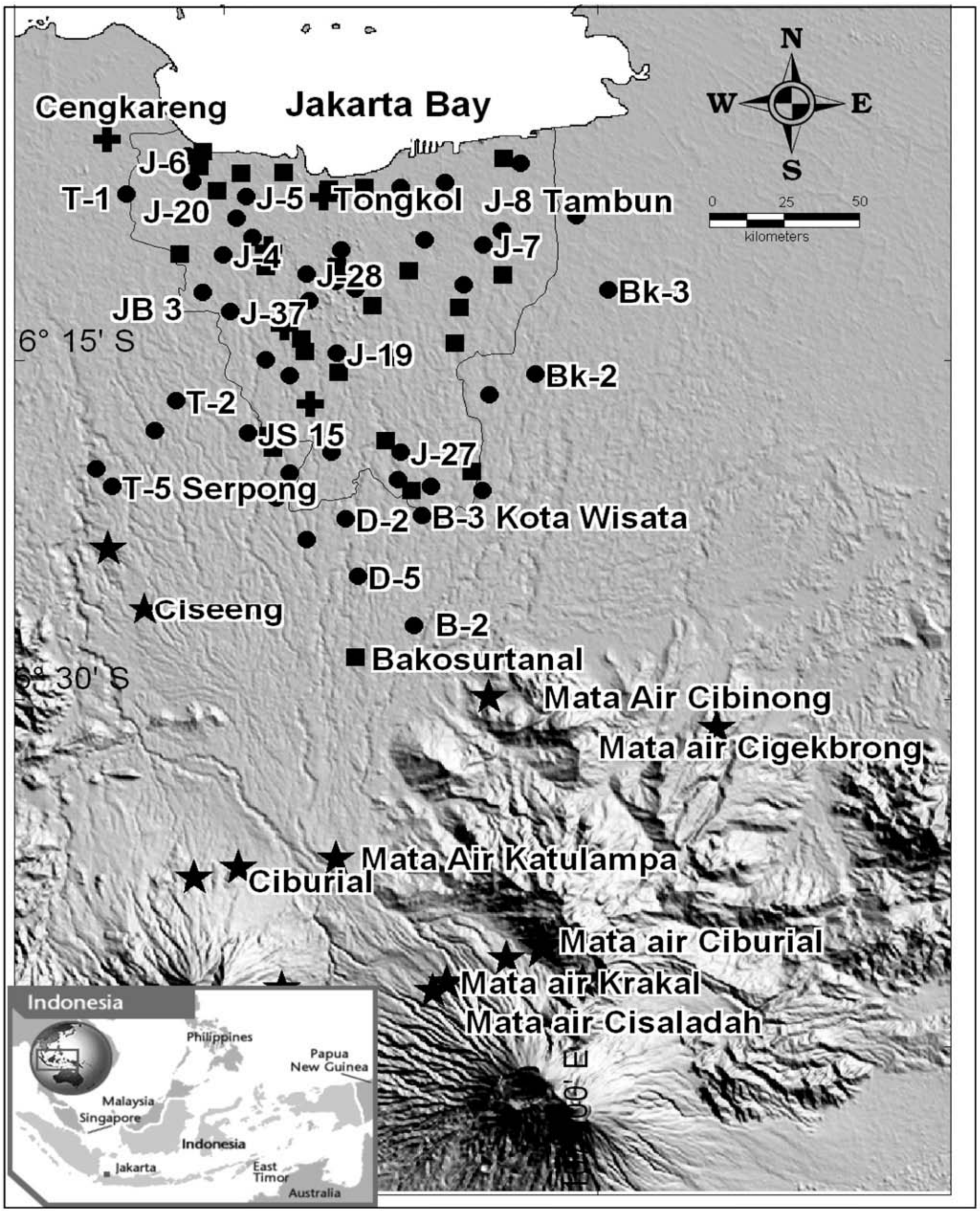

Fig. 1 – Location of study area and sampling sites. The Greater Jakarta is located in theIsland of Java. The clove symbol is marked for micropaleontology sampling site, star symbol for springs hydrochemistry sample site, circle symbol for monitoring well site where the hydrochemistry samples were collected and groundwater level were monitored, and square symbol is marked for GPS measurement sites.

by impermeable Miocene limestone sediments cropping out at the southern area, which were known as Bojongmanik and Klapanunggal Formation. 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 (Martodjodjo, 1984; Asseggaf, 1998), and the sand layers were connected to each other (Fachri et al., 2003). This conclusion was based on stratigraphic cross correlation of South–North direction from core and cutting evaluation of 20 boreholes around Jakarta Basin. The geological map of this area is presented on Figure 2.

3. Sampling and methods

3.1. *Micro-paleontology*

The knowledge of basin geometry is important as it will give information about the environment of the area we deal with. Many approaches can be used to analysis the geometry. In this paper, micropaleontology analysis, pollen and spores contents, was used as a tool to get the information. Samples for micro-palaeontology analysis were taken from five cores namely Cengkareng, Babakan, Blok-M, Tongkol and Meruya cores (Fig. 1). Four samples collected from Blok-M core at

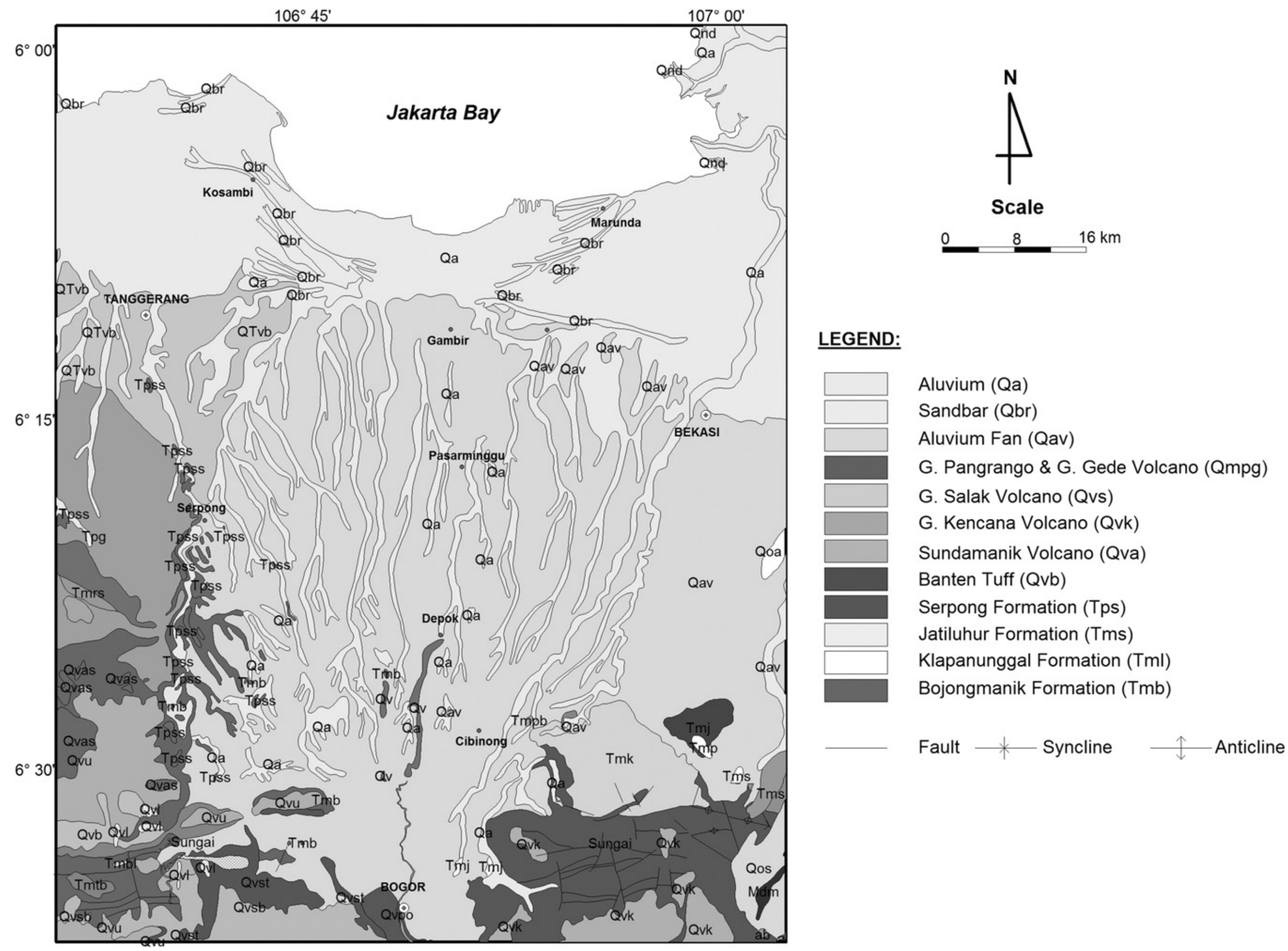

Fig. 2 – The Geological Map of Greater Jakarta and its Surrounding Area. The study area is dominated by quaternary sediment which was dominated by coastal and deltaic deposits. The impermeable Miocene formation is acted as the base of the basin. (Effendi, 1974; Sudjatmiko, 1972; Turkandi et al., 1992).

162.5–162.55 m, 153.45–153.5 m, 152.3–152.35 m and 36.6–36.65 m depths; seven samples from Tongkol core at 116.2–116.25 m, 124.4–124.45 m, 143.5–143.52 m, 159.8–159.82 m, 174–174.02 m, 188.6–188.62 m and 234.6–234.65 m; six samples from Meruya core at 48–48.02 m, 68–68.02 m, 117–117.45 m, 134–134.35 m, 136.3–136.35 m and 147.8–147.85 m. Those levels were defined because the stratigraphic profile of the cores the Plio-Pleistocene boundary was predicted to stand within the range of those levels.

Samples were then treated with 10% KOH, swirling technique to remove sand, mix of HCl and HNO_3, treated with 40% HF. Heavy minerals were removed by using $ZnCl_2$ e.g. 2.2 prior to acetolysis treatment. All pollen and spore grains were counted. Ages of samples are deducted based on the fossil index. Frequencies for all pollen and spore types were calculated on the total counts of pollen grain and presented in pollen diagrams.

Foraminifera data were obtained from the report of Dinas Pertambangan DKI Jakarta (LPM-ITB, 1997) and LGPN-LIPI team (Hehanussa and Djoehanah, 1983). These two reports provide un-analyzed planktonic foraminifera data. These data will be reviewed to determine sample ages and Plio-Pleistocene boundaries.

3.2. *Hydrochemistry*

Serious problems of salt water intrusion have affected some coastal cities in Indonesia, including Jakarta, Medan, Surabaya, and Semarang. The size and extent of the intrusion is very much dependent on the manner of groundwater usage. An initial model was developed by Ghyben in 1888 and by Herzberg (1901) (the Ghyben–Herzberg model) which describes the hydrostatic balance between fresh and saline water (cited from Carlston, 1963). Beside that, the nitrate content in groundwater can be an evident of human activities to groundwater condition as nitrate concentration at a certain area is always connected with the input of domestic waste which is influenced by the density of septic tank (Hammer and MacKichan, 1981). Domestic waste produced ammonia (NH_3), and then it is changed to be nitrate by bacteria via nitrification reaction as below:

$$\underset{\text{Ammonia}}{2NH_3} + 3O_2 \xrightarrow[\text{nitrite bacteria}]{\text{NItrosomonas/Nitrosococcus}} \underset{\text{(nitrit acid)}}{2HNO_2} + 2H_2O + 158\ \text{kilo calorie}$$

$$2\ HNO_2 + O_2\ \underline{\text{Nitrobacter}} \rightarrow \underset{\text{(nitrate acid)}}{2HNO_3} + 36\ \text{kilo}\ \underline{\text{calorie}}$$

Nitrate acid, then, formed nitrate ion by ionization process.

The nitrate concentration level is also influenced by the stage of city development and the older is the higher nitrate content (Appleyard, 1995). In groundwater, nitrate contaminant will always be found at groundwater level zone.

In order to obtain an overview of the groundwater condition in the Jakarta Basin, 17 springs located in the hilly area south of Jakarta, 47 shallow drilled wells, and 32 monitoring wells distributed throughout Jakarta were collected (Fig. 1). Water laboratory analysis used the following techniques: ion chromatography (Shimadzu) for NO_3–N, SiO_2, Cl^- and SO4 $^{2-}$; inductively couple plasma (ICPS-1000 III C, Shimadzu) for Na^+, K^+, Mg^{2+}, Ca^{2+}; titration (pH 4.8 alkalinity) for HCO_3^-; while electrical conductivity (EC), pH, water temperature, and groundwater depth were measure in-situ.

3.3. *Groundwater level*

Groundwater level monitoring, either of shallow or deep groundwater, was conducted between 2001 and 2005. There are 50 wells for monitoring the shallow ground water level which were located on the area of 50 elementary schools and 51 wells for monitoring deep groundwater level which were randomly distributed within the Jakarta Basin area (Fig. 1). Among the 51 monitoring wells for deep groundwater level, only 30 wells were equipped with automatic water level recorders (AWLR). There is no AWLR available for shallow groundwater monitoring wells.

Generally, the shallow groundwater monitoring wells were constructed using 4 inch diameter pipes reaching 12 to 20 meter depth. No data of screen positions were available and the wells are open-ended. The water level measurements were carried out once a month during the 2002 to 2005 period. Those wells were located on the Bogor Alluvial Fan with an unconfined aquifer. The deep monitoring wells were constructed using 5 in. diameter pipes reaching 200 m deep and the screens were located on the target aquifers depth. The wells were drilled exclusively to monitor groundwater level and land subsidence caused by groundwater withdrawal.

3.4. *Global Positioning System (GPS) Measurement*

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 are a function of the condition of the point where the equipments are located.

In view of the higher cost saving and speed of simultaneous data collection of GPS surveys compared to levelling, the Department of Geodetic Engineering, Institute of Technology Bandung (ITB) decided to establish a 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 1. Station BAKO is the southern most 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). The use of GPS satellite-based positioning system to systematically establish geodetic control points over the Jakarta Area was firstly 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.

Seven GPS surveys have been conducted during December 1997, June 1999, June 2000, June 2001, October 2001, July 2002, and December 2002 to September 2005 (Fig. 5). These surveys did not always occupy the same stations. The first survey started with 13 stations. The network then expanded to 27 stations. At certain times, 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 and 11 h. The data were collected with a 30 s interval using an elevation mask of 15°. The data were processed using the software Bernese 4.2 (Beutler et al., 2001). Since the present study was mostly interested in relative heights with respect to a stable point, the radial processing mode was used instead of network adjustment mode. In this case the relative ellipsoidal heights of all stations were determined relative to the BAKO station.

Considering the length of the baselines of 40 to 50 km, a precise ephemeris was used instead of the broadcast ephemeris. The effects of tropospheric and ionospheric biases were 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 modelling was implemented. The algorithms for the tropospheric parameter estimation and local ionospheric modelling can be found in Beutler et al. (2001). In processing baselines, most of cycle ambiguities of the phase observations were successfully resolved.

4. Result and Discussion

4.1. *Micro-palaeontology*

In general pollen and spores contents in the samples do not refer to a definite level of the Plio-Pleistocene boundary. The Plio-Pleistocene boundary is characterized by last appearance of *Stenochlaniidites papuanus* and first appearance of *Dacrycarpus/Podocarpus imbricatus* (Rahardjo et al., 1994). Accordingly, the presences of *S. papuanus* and *Dacrycarpus/P. imbricatus* in sample 68 m of the Meruya core indicate that the Plio-Pleistocene boundary is at 68 m depth.

The presence of *S. papuanus* only in sample 162.5–162.55 m of the Block-M core and high value of Gramineae in sample 162.5–162.55 m and 153.45–153.5 m indicate that the Plio-Pleistocene boundary lies on ca. 162 m depth in this core. The absence of *S. papuanus* from samples 153.45–153.5 m, 152.3–152.35 m and 36.6–36.65 m indicate that it might have disappeared after sample 162.5–162.55 m deposited. Moreover, last appearance of *S. papuanus* associated with Gramineae abundance is a characteristic of the Plio-Pleistocene Boundary in Java. Therefore, the Plio-Pleistocene boundary may fall within 153–163 m level. Single specimen of *S. papuanus* indicates that it may be a reworked-fossil. If it is a reworked-fossil, the Plio-Pleistocene boundary would stand at a level deeper than 162 m in this core.

Abundant mangrove pollen in samples of 162.5–162.55 m, 153.45–153.5 m, and 152.3–152.35 m indicates a mangrove depositional environment. Accordingly, sea level was at about 150–160 m lower than present level when the samples were deposited. This confirms the position of Plio-Pleistocene boundary at about 150–160 m in the Blok-M core because global sea level was in its lowest position during the Plio-Pleistocene.

The occurrence of *Gs. obliquus* in TKL 227–228 m, Situ Babakan 79.7 m, Cengkareng 105–106 m and Cengkareng 108–109 m indicate that the ages of these samples are not younger than Early Pliocene in respect to Bolli et al. (1985). The presences of *Gs. obliquus* and *Gs. ruber* in sample 105–106 m of the Cengkareng core indicate that this sample was deposited in the Early Pliocene. Accordingly, the Plio-Pleistocene boundary is at a depth shallower than 105 m in the Cengkareng core. *Gs. obliquus* and *G. cf. venezuelana* which are present in sample 79.7 m of the Situ Babakan core indicate Middle Pliocene age. By this reason, Plio-Pleistocene boundary is at a depth shallower than 79.7 m in the Situ Babakan core. Based on the presence of *Gs. obliquus* in sample 227 m, it is evident that the Plio-Pleistocene boundary is at a depth shallower than 227 m in Tongkol core.

Pollen and foraminifera data show us that the Plio-Pleistocene boundary in Jakarta is not placed on a similar level. It varies in depth from place to place rather than simply sloping in a particular direction. Structure configuration in which Jakarta and its surrounding areas have been evident to be in low and high structures shows that the basement configuration might have controlled in some parts to this undulation.

Considering the position of the cores, a north–south section puts the cores respectively as follows: Cengkareng core, Tongkol core, Meruya core, Blok M core, and Babakan core. Reconstruction of the Plio-Pleistocene boundary along this section allows recognizing two low and two high structures. The Babakan and Meruya cores stand on low structures while Blok M and possibly Tongkol and Cengkareng cores stand on high structures (Fig. 3). The Plio-Pleistocene boundary is at a level shallower than 300 m depth in all cores. This contradicts the argument that the

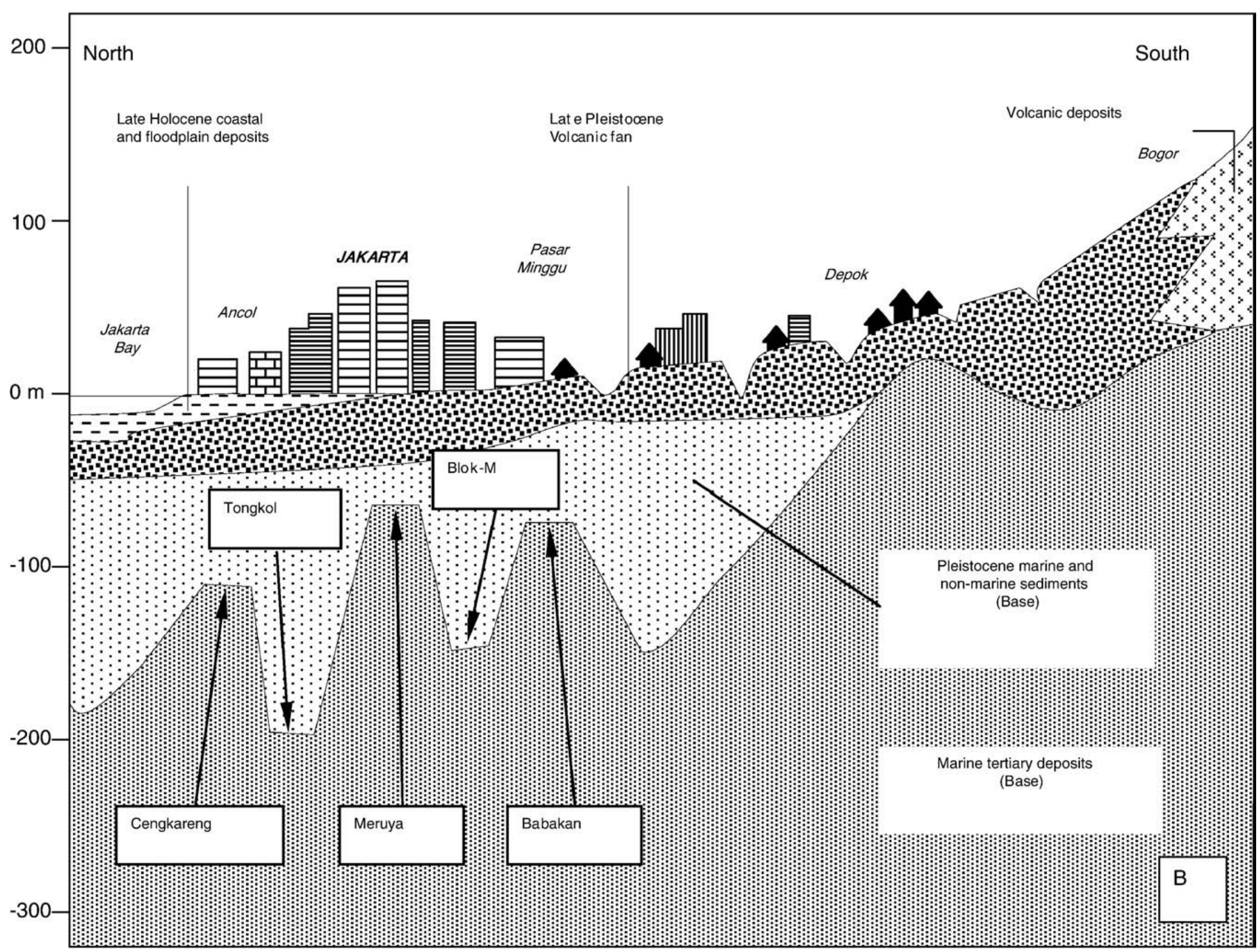

Fig. 3 – The geometry of Greater Jakarta Basin which was delineated by Micropaleontology Analysis. This reconstruction showed that the Quaternary sediment is thin. The Tertiary sediment in the southern part of the basin is very shallow and cropped out in some places.

boundary in general lies at depths more than 250 m and locally more than 300 m as argued by Soekardi and Koesmono (1973). It also rejects the previous argument that the Plio-Pleistocene boundary in Jakarta sloping and deepening to the north (Soekardi and Purbohadiwidjojo, 1979).

Although the basement configuration may be the main factor in the boundary undulation, quaternary tectonic also seems to contribute some influences. The presence of wood fossil dated 38,000 yr BP in the river terrace sediment about 25 m above the modern river surface at Depok and some marine terraces (LPM-ITB, 1997) indicate quaternary tectonic uplift. Some seismicity in the last decades might have also influenced the boundary by fault reactivation. In contrast, compaction and sediment consolidation due to over pumping of ground water and loading by surface construction might have been the other considerable factor.

4.2. Hydrochemistry

As groundwater moves along its flow paths in the saturated zone, increases of total dissolved solids and most of major ions normally occur (Freeze and Cherry, 1979). The concentration of different chemical elements in groundwater provides evidence of their chemical evolution. Prior to water chemistry analyses in laboratory, physic-chemical measurements of electrical conductivity and pH were measured in the field just after water sampling. For geochemical graphic analytical methods, piper and stiff diagrams have been widely used in groundwater studies to characterize a large number of water chemical data. By plotting the chemical data onto such diagrams, the differences of the chemical composition of the water could be clearly classified. The distribution of ground water types based on a stiff diagram plotted data is shown on Figure 4.

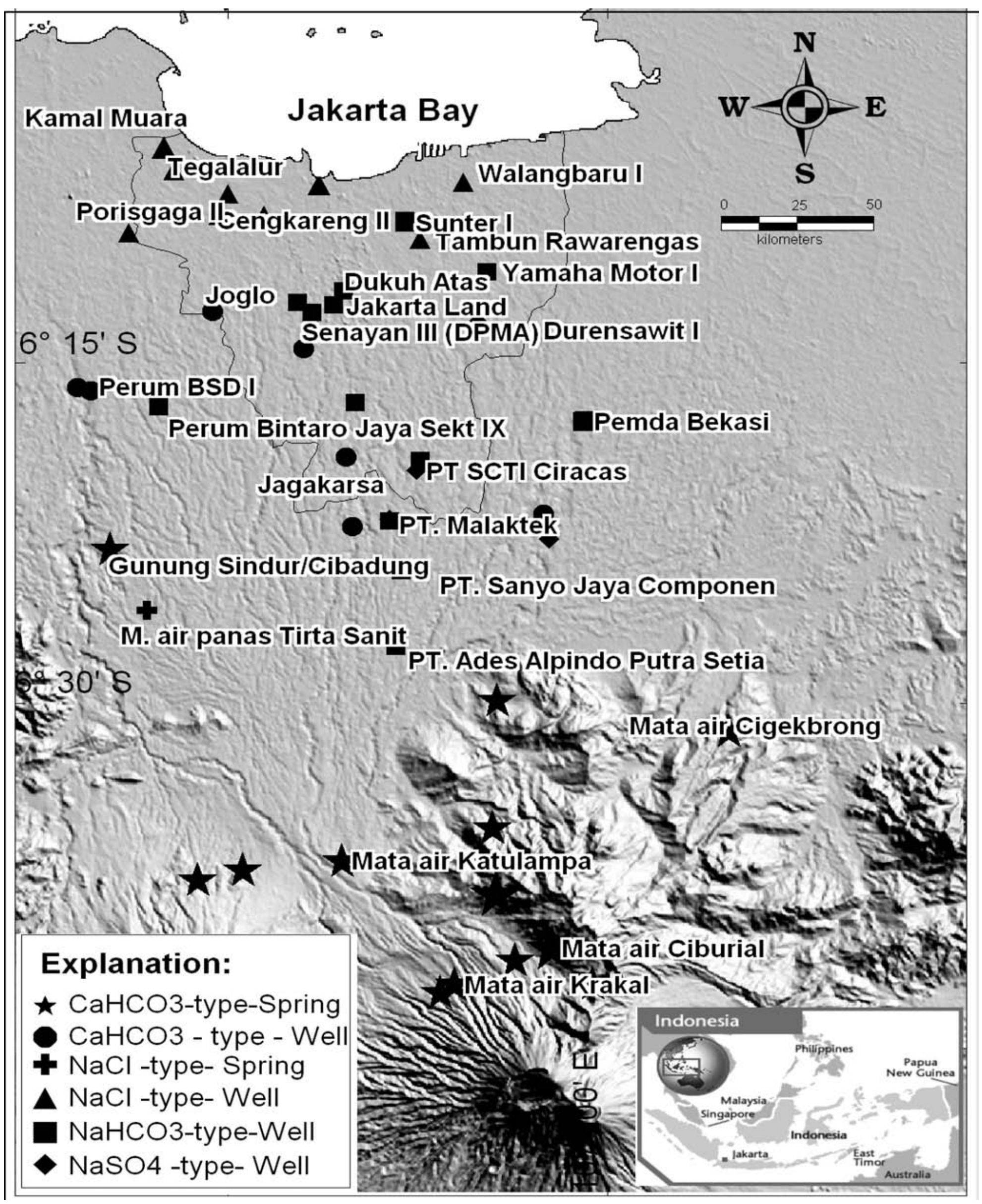

Fig. 4 – Groundwater and spring water type based on Stiff Diagram. One sample from the spring belong to NaCl type, some works on this phenomenon argue that this is due to structural geology control, which allowed fossil water from older formations to emerge in this area. Along the coast, some deep groundwater also belongs to NaCl type, but the condition of groundwater is still questionable.

The sample from the Ciseeng hot spring belongs to the NaCl water type. Based on geological condition, this phenomenon is due to structural geology control which allowed fossil water (brine) from older formations to emerge in this area. Along the coast, west to east, all groundwater samples belong to the NaCl-type water as the content of sodium chloride is high. But, it can not be assumed as a result of sea water intrusion as all monitoring wells are deep. Therefore, high sodium chloride content can be an influence of brine from old formation. It needs further analysis, such as C_{14} isotope study, to confirm it.

Major pollutants in groundwater associated with human activities are the nutrients, nitrate-N (NO_3^-–N), nitrite (NO_2^-), and phosphate (PO_4^{3-}). Nitrate and nitrite are mainly related with domestic waste, while phosphate is linked with agricultural activity (Hammer and MacKichan, 1981). Before collecting water samples, based on the geological condition, it is assumed that only the shallow groundwater (0–40 m depth) has been polluted by human activities waste (Fig. 5). Therefore, only the samples from these unconfined aquifers were analyzed for nitrate-N, nitrite-N, and phosphate contents. Nitrate-N may enter the shallow groundwater from natural leaching of nitrates, nitrogenous fertilizer runoff, human organic waste, and industrial waste.

In the dense population areas of Jakarta, i.e., Central and West Jakarta, the nitrate-N content are high (Table 1), even excess nitrate-N maximum contaminant level (MCL) which are allowed by the Indonesian Government, this limit value is similar with the limit of some other countries such as Australia i.e., 10 mg/l, and no nitrite contents are in excess of MCL. Infants below the age of six months who drink water containing nitrate-N in excess of 10 mg/l could become seriously ill (methaemoglobinaemia). Concentration of up to 23 mg/l may be acceptable if not used for infant (Hart, 1974). Nitrite content is still very low as it is rapidly oxidized to nitrates. Phosphate was found in the area where agricultural activities still exist, i.e., South, East, and West Jakarta. Phosphate may enter the surface and groundwater from decomposition of organic matters in industrial waste and fertilizer. The content of phosphate is rarely remaining in the waters as they are used by plants as nutrient sources. The fertilizer that is used in this area is mostly phosphate type fertilizer.

4.3. *Groundwater Level*

Based on the water level measurement data of the 2002–2005 periods, it was shown that in general the shallow groundwater level has a negative trend, it was decreasing. This is shown on Figure 6.

The deep groundwater monitoring wells have been constructed within the period of 1994 to 2000. Total of the monitoring well is 51 wells and only 30 wells were equipped with automatic water level recording (AWLR) of which 1 (one)

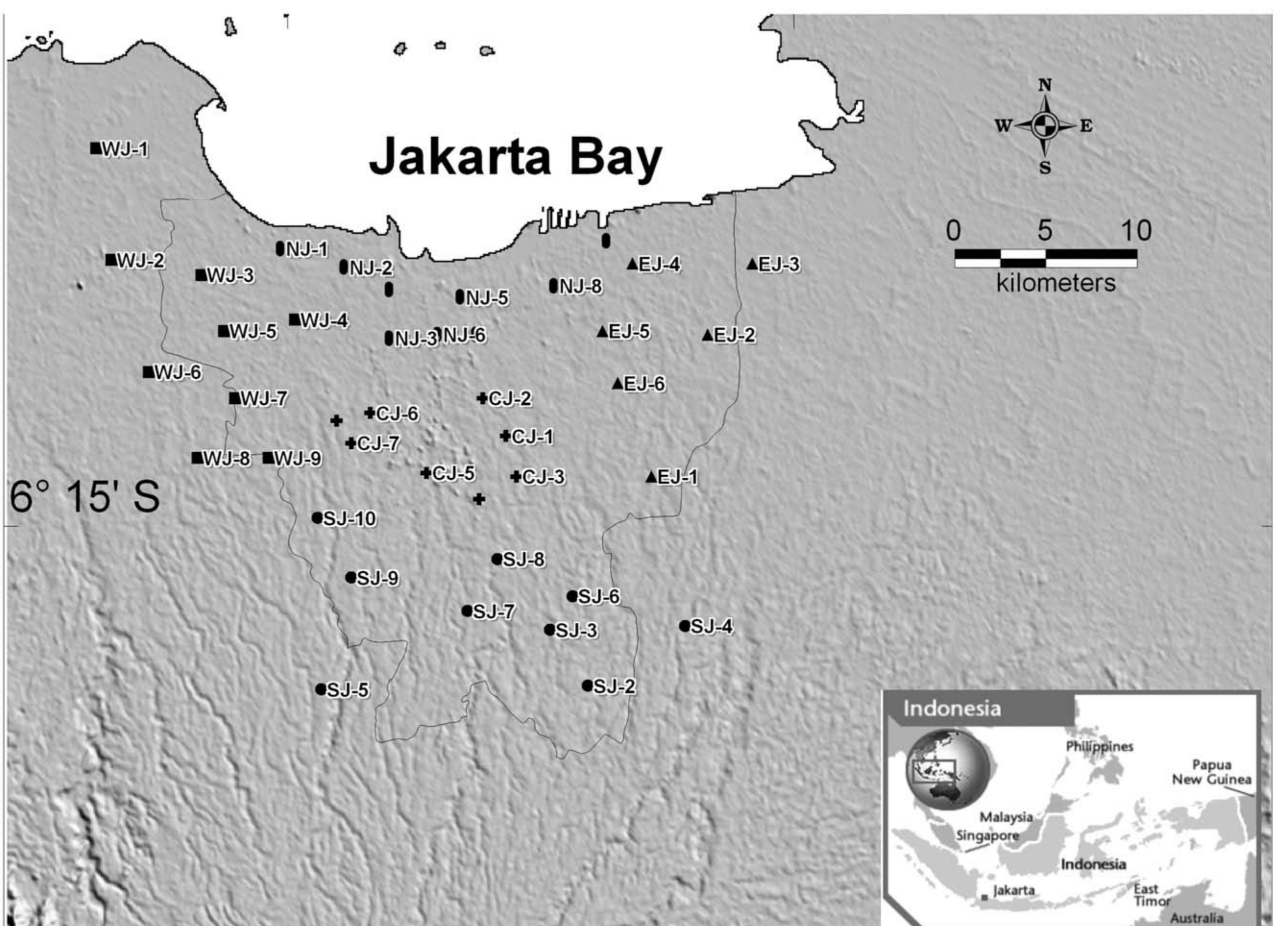

Fig. 5 – Shallow Groundwater Sampling Site. 42 sampling sites were visited during the field work.

Table 1 – Major element nitrate-N, nitrite-N, and Phosphate content in shallow groundwater (unconfined aquifer) samples in Greater Jakarta Area.

Sample site	pH	Ca^{2+} (mg/l)	Mg_2^+ (mg/l)	K^+ (mg/l)	Na^+ (mg/l)	HCO_3^- (mg/l)	Cl (mg/l)	SO_4^2 (mg/l)	$N–NO_3^-$ (mg/l)	$N–NO_2^-$ (mg/l)	PO_4^{3-} (mg/l)
South Jakarta											
SJ 1	6.96	1.20	0.39	0.08	1.83	2.03	0.85	0.32	1.34	0.54	1.1
SJ 2	5.50	0.33	0.77	0.03	0.09	0.25	0.81	0.18	1.14	0.00	0.5
SJ 3	6.47	1.34	0.79	0.03	0.70	1.27	0.94	0.25	5.68	0.00	0.6
SJ 4	6.19	0.53	0.79	0.04	0.87	1.16	1.04	0.22	1,28	0.00	1.7
SJ 5	7.61	4.36	1.59	0.21	2.26	6.86	1.37	0.75	0.94	0.15	1.7
SJ 6	4.87	0.67	0.57	0.03	1.04	0.58	1.13	0.36	6.68	0.02	0.1
SJ 7	6.96	1.07	1.06	0.05	0.48	1.54	0.52	0.50	0.20	0.04	0.2
SJ 8	6.58	1.07	1.06	0.05	1.28	1.16	1.70	0.49	3.84	0.05	0.0
SJ 9	6.96	2.55	0.53	0.03	0.97	1.58	1.42	0.63	9.72*	0.02	0.0
SJ 10	7.76	1.34	0.92	0.09	1.39	2.47	0.94	0.54	0.28	0.03	0.8
East Jakarta											
EJ 1	7.70	1.20	0.79	0.12	1.35	2.800	0.47	0.13	0.08	0.02	1.0
EJ 2	5.95	1.20	1.46	0.05	0.97	1.56	1.32	0.08	0.18	0.00	1.0
EJ 3	5.75	0.94	1.59	0.05	2.53	0.87	3.07	0.47	15.16*	0.08	1.1
EJ 4	4.79	0.40	0.26	0.38	1.39	0.48	0.94	0.24	6.72	0.00	0.6
EJ 5	5.60	0.53	0.98	0.26	0.87	0.49	1.23	0.38	6.26	0.01	0.4
EJ 6	7.00	3.09	0.53	0.14	2.01	3.56	0.94	0.39	2.46	0.03	0.8
West Jakarta											
WJ 1	7.13	4.16	1.33	0.08	2.61	5.08	0.62	1.27	9.72*	0.30	1.1
WJ 2	6.58	1.93	3.74	0.76	13.57	6.59	5.89	6.35	0.23	0.01	0.6
WJ 3	5.94	0.42	0.74	0.13	3.39	1.36	1.97	1.29	0.09	0.01	0.6
WJ 4	6.51	1.43	1.38	0.79	9.13	4.78	2.25	4.07	0.16	0.00	0.2
WJ 5	7.20	4.46	6.39	0.92	36.15	13.53	24.43	8.41	1.43	0.54	0.1
WJ 6	6.29	18.72	10.42	0.35	19.14	3.36	37.04	8.08	0.28	0.01	0.59
WJ 7	6.58	1.12	1.12	0.56	9.35	2.91	4.97	4.48	19.23*	0.01	0.6
WJ 8	6.89	6.43	6.68	0.84	5.96	9.04	2.54	5.86	12.57*	0.00	0.3
WJ 9	7.22	3.81	6.97	0.68	22.61	14.23	14.36	3.82	1.02	0.14	1.5
Central Jakarta											
CJ 1	7.37	2.28	1.46	0.08	1.74	3.59	0.32	1.27	2.08	0.06	1.1
CJ 2	7.58	5.11	2.26	1.03	4.47	10.17	1.27	0.56	1.60	0.90	0.06
CJ 3	7.19	1.36	1.16	0.18	3.36	3.36	0.52	1.77	14.00*	0.00	0.60
CJ 4	7.01	2.37	3.42	0.28	7.30	9.37	4.76	0.14	16.10*	0.00	0.30
CJ 5	6.86	5.15	2.59	0.64	5.46	6.85	4.42	1.64	12.03*	0.00	0.2
CJ 6	7.00	2.75	0.45	0.28	2.70	2.10	1.13	2.35	3.00	0.00	0.5
CJ 7	7.63	1.08	3.15	0.89	29.58	11.64	19.11	2.59	1.89	0.00	0.0
CJ 8	7.36	3.14	2.44	0.38	8.09	5.09	5.12	2.02	18.40*	0.00	0.6
North Jakarta											
NJ 1	7.40	2.25	3.45	0.40	16.44	12.47	7.15	1.42	1.27	0.24	0.3
NJ 2	4.04	2.86	3.84	0.52	5.05	11.91	0.76	0.29	1.98	0.00	0.1
NJ 3	6.91	4.72	2.85	1.23	21.53	14.38	11.37	2.28	1.43	0.07	0.1
NJ 4	8.01	0.44	0.26	0.19	12.41	8.86	1.79	0.38	12.50*	0.00	0.2
NJ 5	7.05	4.31	2.21	0.52	4.02	7.69	1.92	0.28	11.45 8	0.00	0.2
NJ 6	6.86	5.85	1.89	0.64	7.97	7.57	6.95	1.01	1.79	0.24	0.2
NJ 7	6.83	5.67	5.98	0.64	6.96	10.59	4.15	2.78	2.35	0.00	0,4
NJ 8	7.07	2.37	1.98	0.25	6.79	7.94	2.73	0.45	2.02	0.00	0.1
NJ 9	6.94	2.43	3.32	0.56	8.27	8.32	4.70	1.58	2.81	0.00	0.1

Note: * marks are for high nitrate contents samples which were taken from dense populated area. All samples were taken from shallow groundwater (unconfined aquifers).

was defect and could not be used even manually. At the end of 2005, only 48 wells still existed and only 22 AWLR were still working. Based on the range of screen depths, which was assumed to be identical with the aquifer position, those 50 wells could be grouped into 5 clusters i.e. 0–40 m, 40–95 m, 95–140 m, 140–190 m, and 190–250 m.

- Cluster 0–40 meter Aquifers. This cluster consists of 5 monitoring wells with water level fluctuated between −2.18 and −32.68 m below sea level (b.s.l.). Most of those wells are located on the Bogor Alluvial Fan. Based on water level data of those wells, 1 well showed a positive trend (Bapedalda, Central of Jakarta), 1 well with a negative trend (Senayan, Central of Jakarta), and 3 wells just fluctuated as the season changed i.e., Pasar Rebo and Cilandak (South of Jakarta), Tongkol (North of Jakarta).
- Cluster 40–95 meter Aquifers. This cluster comprises 7 monitoring wells with water level ranging between −4.12 and −25.80 m b.s.l. The seasonal fluctuating water level could only be observed at the Duren Sawit monitoring well

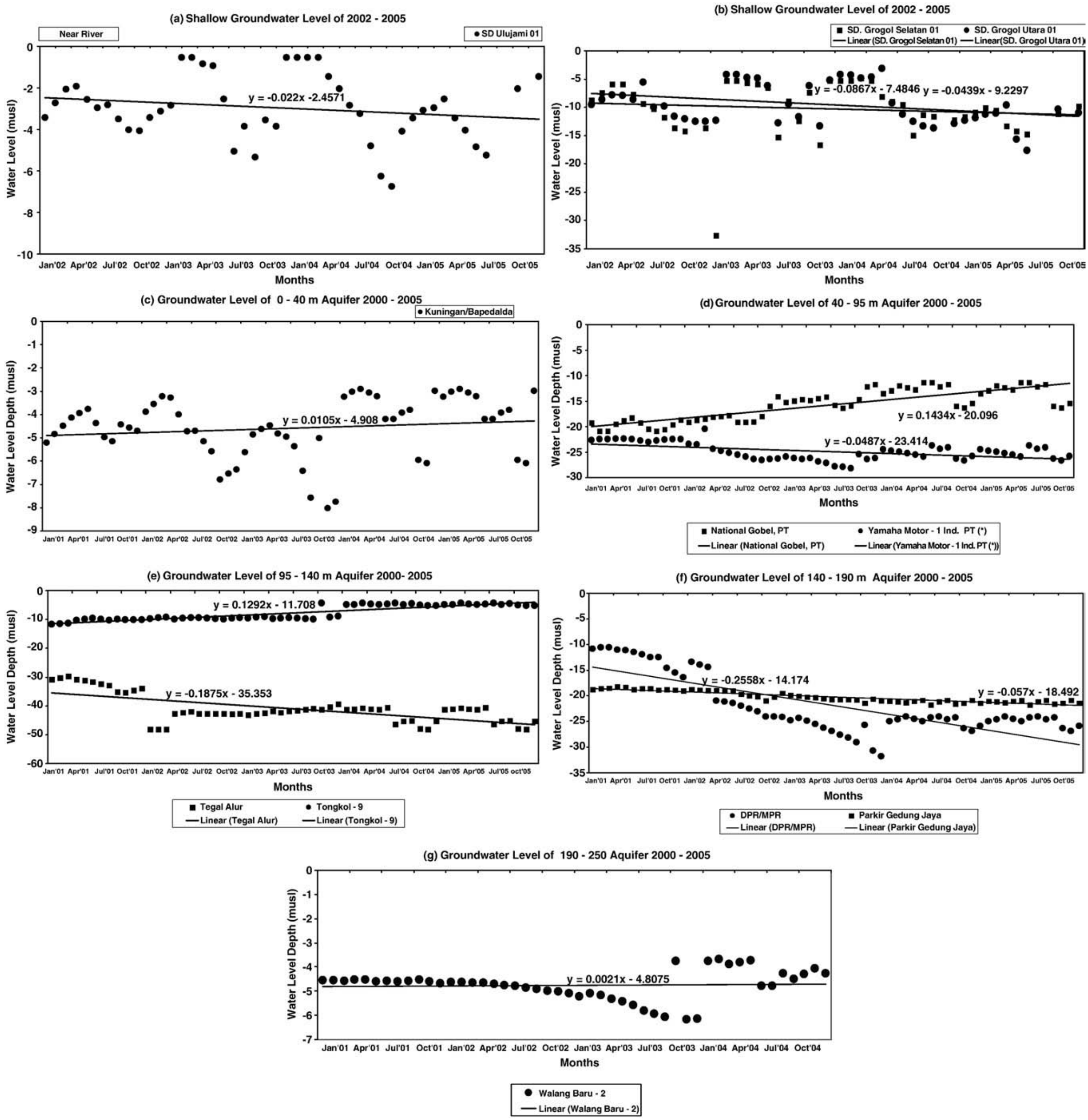

Fig. 6 – Groundwater Level Fluctuation of January 2002 to December 2005. This figure showed that groundwater in most Jakarta is declining slightly, but it can be identified.

in the eastern part of Jakarta. The wells located on the southern part of Jakarta (Jagakarsa, PT SCTI, and National Gobel) showed a positive trend, while all wells located in the central and northern part of Jakarta (Tongkol, Senayan, and Yamaha Motor), showed a negative trend. Generally, this cluster is relatively balanced between negative and positive trends.

- Cluster 95–140 m Aquifers. This cluster consists of 10 monitoring wells with water levels ranging between −1.34 and −51.05 m b.s.l. The water levels in the north-western part of Jakarta (Sunter, Kapuk and Jelambar) mostly show seasonal fluctuation. In the eastern part of Jakarta (Sinar Sostro), the water level is relatively stable. A positive trend was observed in the northern part of Jakarta (Walangbaru and Tongkol) while a negative trend was observed in south and central Jakarta (Dharmawangsa, Joglo, Tegal Alur and Jakarta Land).
- Cluster 140–190 m Aquifers. Five monitoring wells belong to this cluster. The water level ranged between −10.56 and −31.82 m b.s.l. In the eastern part (Tambun Rengas), the water level tended to be positive, while the other four wells which are located in the central part (DPR/MPR and Gedung Jaya) and in the northern part (Kamal Muara and Sunter) of

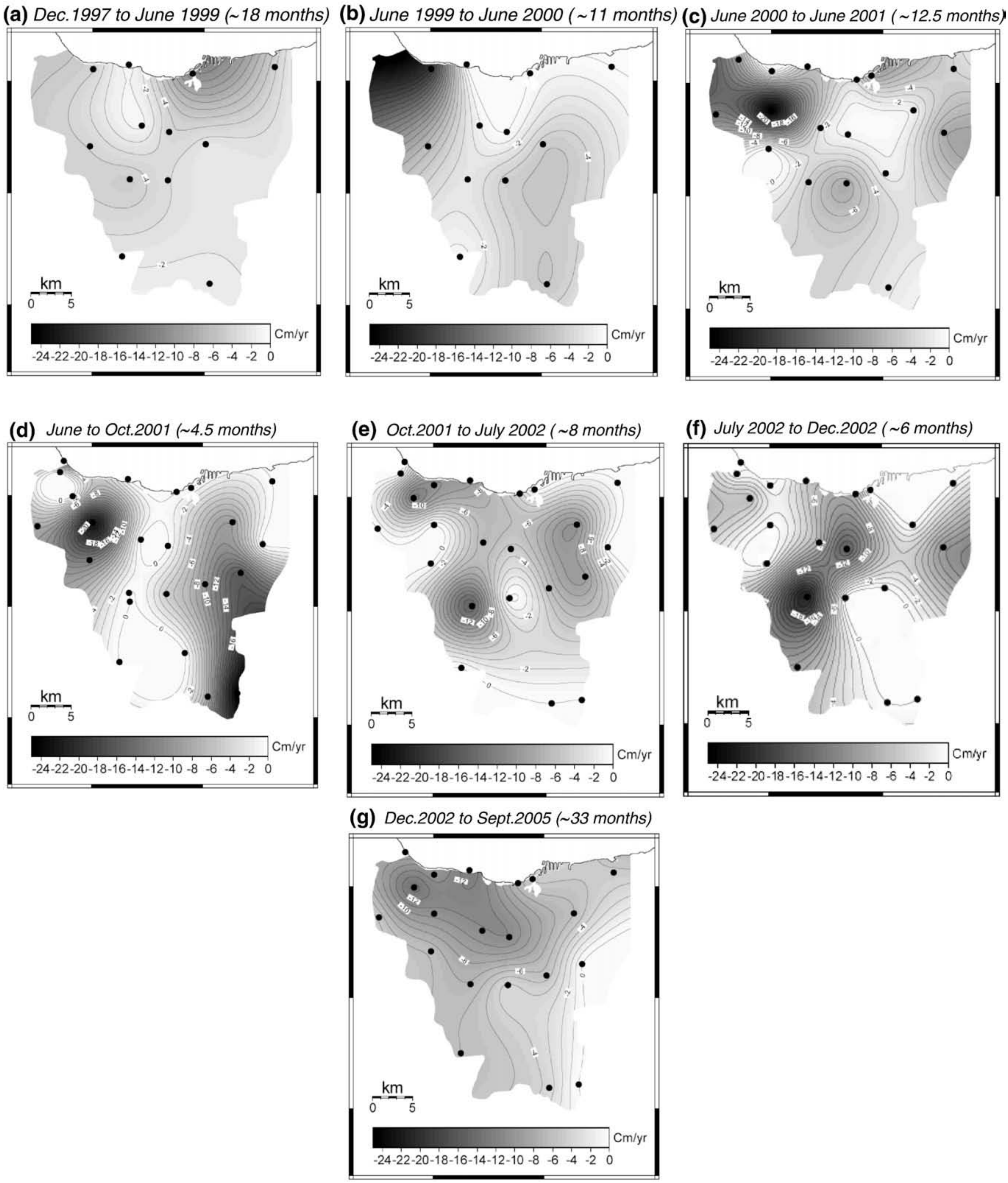

Fig. 7 – Rates of Land Subsidence (cm/year) in Jakarta Area. The GPS measurements showed that some land subsidence had occurred in Jakarta Area. The measurements were carried out during the period of December 1997 to September 2005. The darkest symbol represented the highest subsidence rate. It showed that subsidence rate in a certain area was not the same year by year.

Jakarta show a negative trend. Therefore, for this cluster, generally, the water levels are decreasing.

- Cluster 190–250 m Aquifers. Within this deepest aquifer, 6 monitoring wells were drilled. Only one well (Walang Baru in northern part of Jakarta), showed a positive water level trend. The other 5 wells, Cakung (north-east), DPRD DKI (central), Pasar Minggu (south), Sunter (north-west), and Tongkol (north), showed a

Table 2 – Matrix of Subsurface Condition in the Jakarta Area.

	West Region	East Region	Central Region	North Region	South Region
Water Quality	−3	0	−5	−5	0
Shallow GW	−3	−1	−5	−5	0
0–40 Aquifer	−3	−1	−3	−5	−3
40–95 Aquifer	−3	−3	−3	−5	−3
95–140 Aquifer	−5	−3	−3	−3	−3
140–190 m Aquifer	−3	−3	−3	−3	−3
190–250 m Aquifer	−3	−3	−3	−3	−3
Land Subsidence	−3	−3	−5	−5	0
Total Score	−26	−17	−30	−34	−12

The value of the matrix is ranged between 0 (zero) and −5 (minus five) and it depends on the condition of each substance that will scored. Zero means the substance still in a good condition while −5 means the worst condition.

negative trend. Generally, the water level of this aquifer is decreasing.

4.4. *Global Positioning System (GPS)*

The estimated subsidence rates during the period Dec. 1997 to Sept. 2005 are 1 to 10 cm/yr and reach 15–20 cm/yr, as shown on Figure 7. The highest rates of land subsidence occur in north-western Jakarta. The central and north-eastern parts sometimes also show quite high rates of subsidence. This figure 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/semi-annual signal bias that plagues all GPS temporal measurements.

The measurement result suggests 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. More detailed results on GPS-derived subsidence in Jakarta basin can be found in Abidin et al. (2007).

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. Therefore, planners and engineers should take into account this condition for their planning and construction works.

5. Conclusion

In order to acquire a comprehensive view based on the above data, a matrix method (Table 2) has been utilized. The value of the matrix is ranged between zero and minus five and it depends on the condition of each substance that will score. Zero means the substance is still in a good condition while −5 means the worst condition. The results show that the worst subsurface conditions were found in north, central and west parts of Jakarta.

In the northern part of Jakarta the population density is lesser than in any other part of Jakarta Area, but the scores are the highest and many factories were built in the northern area of Jakarta. This is unavoidable as the seaport and the airport are located in these areas, resulting in the highest ground water yield (highest extraction rate) and most extensive build-up area. In the central part of Jakarta, as a central activities area and the densest area, there are many government and offices and many skyscrapers have been built. The heavy buildings erected on a surface of loose material together with groundwater harvesting, undoubtedly, it will trigger a compaction process which might cause land-subsidence in the area.

Comparing with the density population of each area and Table 2, it is obvious that in the Jakarta Area, human activities have influenced the subsurface environment condition of Jakarta, and the relationship of a densely populated area and environment alteration is recognizable. So far, not many subsurface environment studies have been carried out in this area. Hence, the chance for detecting new phenomena in this basin is quite plausible.

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