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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" S latitude 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 means that 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 (Fig.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

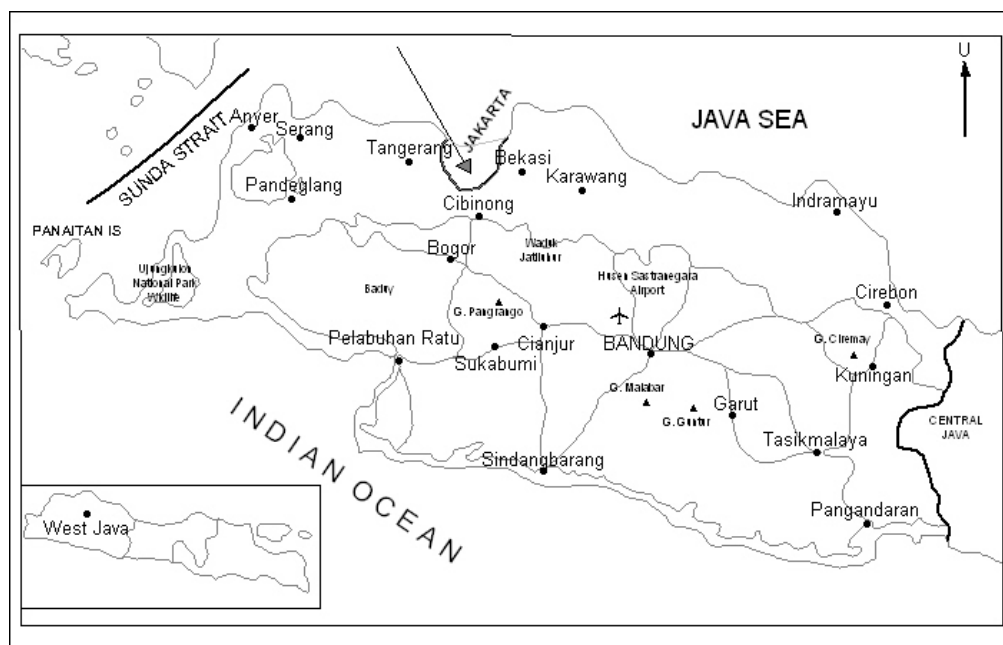


Fig. 1 Location map of the Greater Jakarta. It is the Capital City of Republic of Indonesia and located in the coastal area of Java Island.

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 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, Tangerang, 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/km ²)
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 Tangerang 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 (Fig. 2):

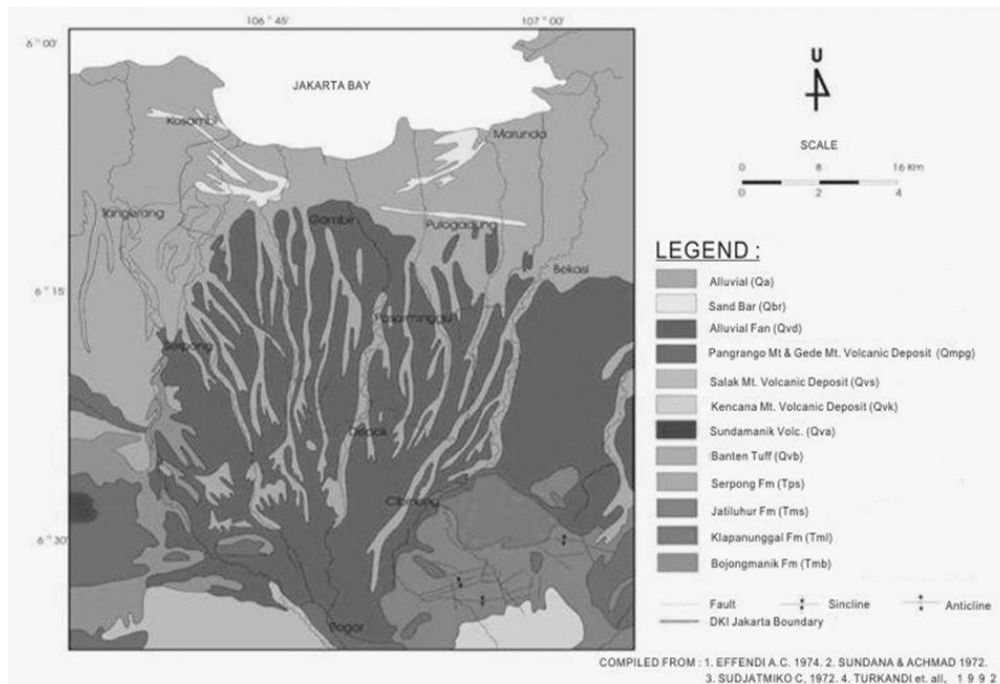


Fig. 2 Geological map of the Greater Jakarta and its surrounding area. At the surface, the lithology is dominated by coastal and deltaic deposits.

- 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**, interbedded of conglomerate, sandstone, marl, pumice conglomerate, and tuffaceous 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 to 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 area management 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 (Fig. 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

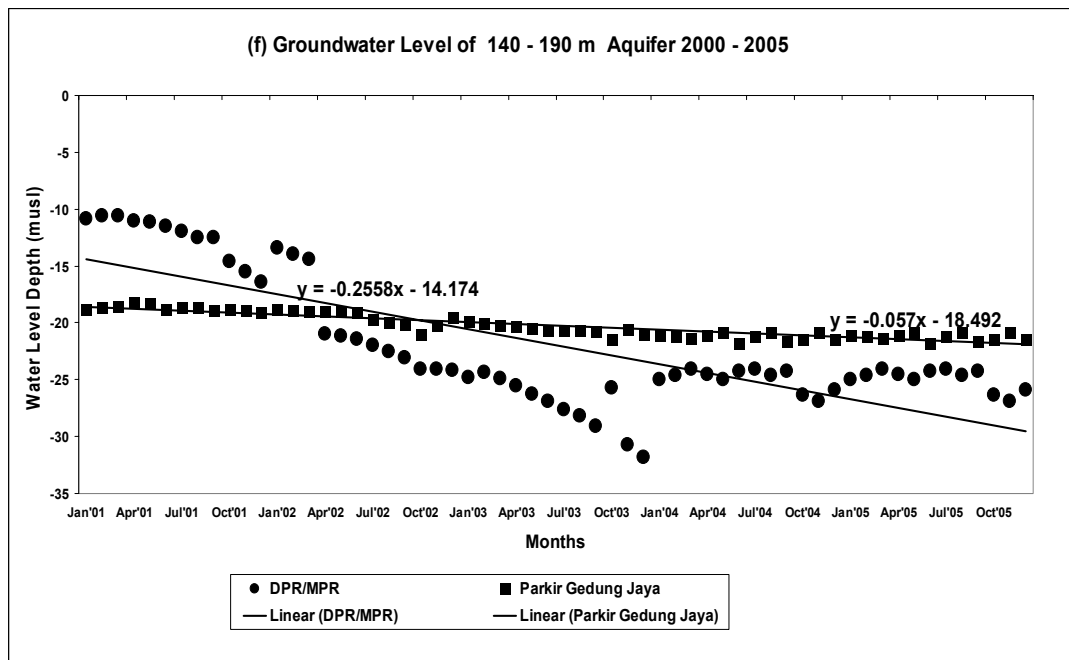


Fig. 3 Groundwater level fluctuations between of 2001- 2006 at some locations in Greater Jakarta area. It is showed that the groundwater tend to decrease.

measurements (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.

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.

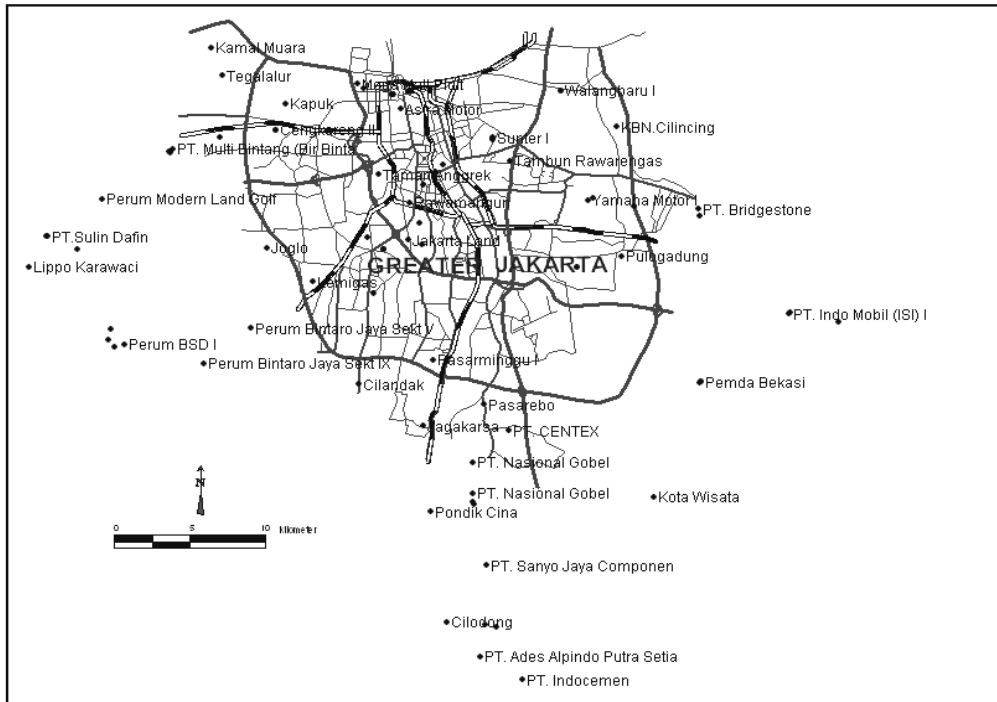


Fig. 4 Monitoring wells location in Greater Jakarta area and its surrounding area.

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 °C precision and the accuracy is ± 0.03 °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 (Fig. 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.

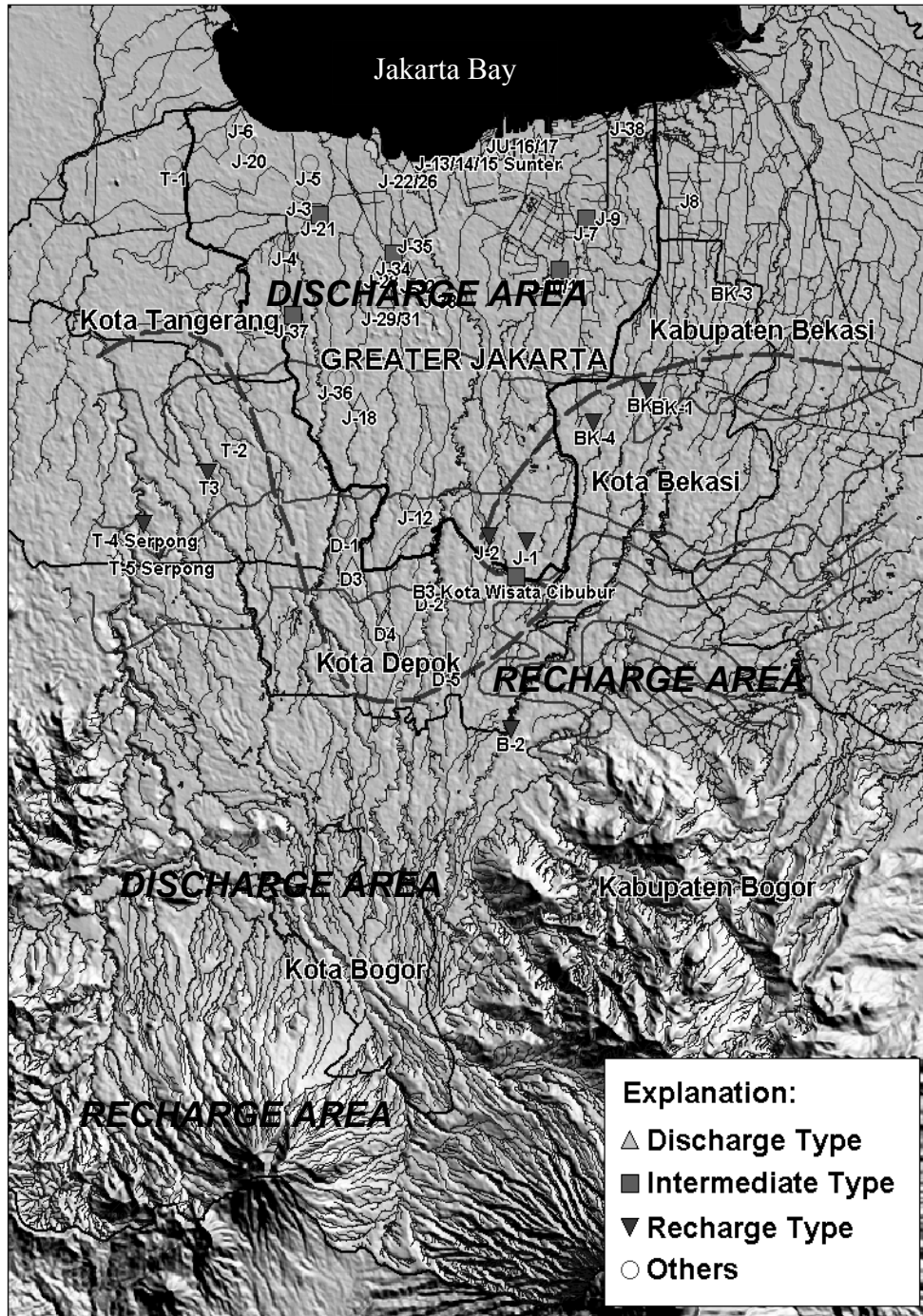


Fig. 5 Recharge and discharge area delineation using sub-surface temperature data analysis and direction of water flow inferred from the thermal properties.

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 Fig. 6.

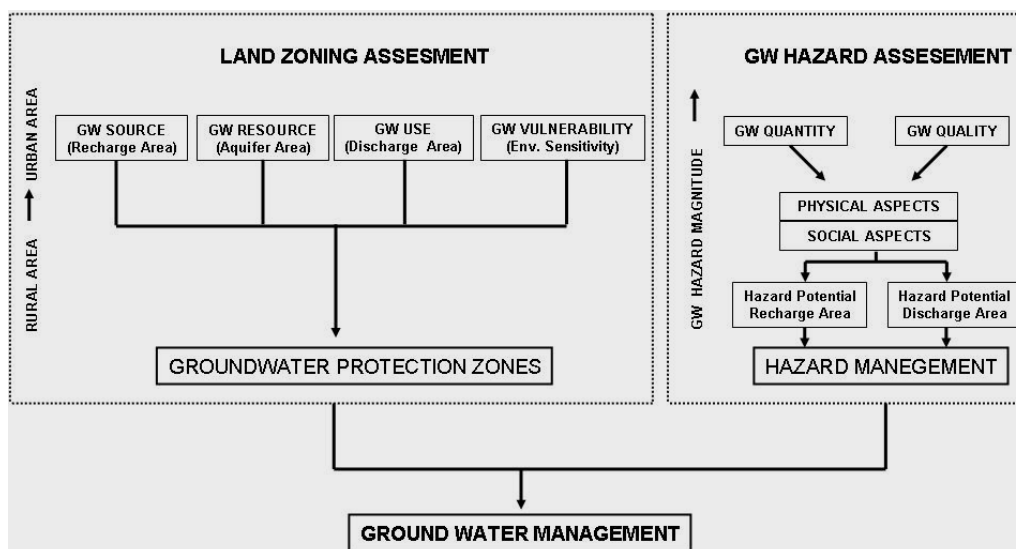


Fig. 6 Scheme of groundwater management in Greater Jakarta area.

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 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.
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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REFERENCES

- Abidin, H.Z., Kusuma, M.A., Meilano, I., Arief Nurdin, Darmawan, Dudi, Bintoro, Agus, and Kahar, J. (1998): Pemantauan Penurunan Tanah di Wilayah Jakarta dengan Metode Survey GPS, S&P, *Majalah Survey dan Pemetaan*, Ikatan Surveyor Indonesia, ISSN: 0125-8466, XII (3), 45-56.
- Abidin, H.Z., Andreas, H., Djaja, R., Darmawa, D. and Gamal, M. (2007): "Land subsidence characteristics of Jakarta between 1997 and 2005 as estimated using GPS surveys" *GPS Solutions*, Springer Berlin / Heidelberg, DOI: 10.1007/s10291-007-0061-0, Website: <http://dx.doi.org/10.1007/s10291-007-0061-0>
- Appelo, C.A.J., and Geirnaert, W. (1991): Processes Accompanying the Intrusion of Salt Water. *Hydrogeology of Salt Water Intrusion: A Selection of SWIM Papers, Theme 5: Hydrochemical and Soil-Physical Investigation*, International Association of Hydrogeologist (ed. by DE Breuck, W.).
- Assegaf, A.(1998): Hidrodinamika Airtanah Alamiah Cekungan Jakarta. Msc. Thesis Dep. Teknik Geologi ITB, Bandung, Indonesia.
- Bapedalda DKI Jakarta (2003): Buku II, <http://bps.jakarta.go.id/>
- Beck, A.E., Garven, G. and Stegena, L. (1987): *Hydrogeological Regimes and Their Subsurface Thermal Effects*. Geophysical Monograph, 47, IUGG Volume 2, American Geophysical Union, 158 p.
- Bemmelen, R.W. van (1949): *The Geology of Indonesia, Vol. Ia. General Geology*.

- Martinus Nijhoff, 732 p, The Hague.
- Beutler, G., Bock, H., Brockmann, E., Dach, R., Fridez, P., Gurtner, W., Hugentobler, U., Ineichen, D., Johnson, J., Meindl, M., Mervant, L., Rothacher, M., Schaer, S., Springer, T. and Weber (2001): Bernese GPS Software Version 4.2. In Hugentobler, U., Schaer, S., and Fridez, P. eds. Astronomical Institute, University of Berne.
- Boyle, J.M. and Saleem, Z.A., (1979): Determination of Recharge Rates using Temperature-Depth Profiles. *Water Resour. Res.* **15**, 1616-1622.
- Bredehoeft, J.D. and Papadopoulos, I.S., (1965): Rates of Vertical Groundwater Movement Estimated from Earth Thermal Profile. *Water Resour. Res.* **1**, 325 – 328.
- Carlston, C. W. (1963): An early American statement of the Badon Ghyben-Herzberg principle of static fresh-water-salt-water balance. *American Journal of Science*, **261**, 88-91.
- Cartwright, K. (1970): Groundwater Discharge in Illinois Basin as Suggested by Temperature Anomalies. *Water Resour. Res.* **6**, 912-918.
- Dim, J.R., Miyakoshi, A., Sakura, Y. and Fukami, K. (2000): Thermal Analysis for Groundwater Flow Assessment in a Sedimentary Basin of Japan. *Groundwater: Past Achievements and Future Challenges*, Balkema, Rotterdam, 131-134.
- Djaja, R. (2001): Pemantauan Penurunan Tanah di Wilayah Jakarta. Laporan Kemajuan (Tahap I) dan Kertas Kerja Riset Unggulan Terpadu, RUT. VIII, Jakarta.
- Djaja, R., Rais, J., Abidin, H.Z. and Wedyanto, K. (2004): Land Subsidence of Jakarta Metropolitan Area. *Proceeding 3rd IG Regional Conference*, Jakarta, Indonesia.
- Domenico, P.A. and Palciaukas, V.V. (1973): Theoretical Analysis of Forced Convective Heat Transfer in Regional Groundwater Flow. *Geological Society of America Bulletins*, **84**, 3803 – 3814.
- Domenico, P.A. and Schwartz, P. (1990): *Physical and Chemical Hydrogeology*. John Wiley & Sons, USA, 517 – 557.
- Drury, M.J. (1984): Perturbation to Temperature Gradients by Water Flow in Crystalline Rock Formations. *Tectonophysics*, **102**, 19-32.
- Engelen, G.B. and Kloosterman, F.H. (1996): *Hydrological System Analysis, Method, and Application*. Kluwer Academic Publisher, Dordrecht, The Netherlands, 140-144.
- Freeze, R.A. and Witherspoon, P.A. (1967): Theoretical Analysis of Regional Groundwater Flow, Effect of Water-table Configuration and Subsurface Permeability Variation. *Water Resour. Res.* **3**, 623 – 634.
- Freeze, R.A. and Cherry, J.A. (1979): *Groundwater*. Prentice Hall, Englewood Cliffs, NJ 07632. German Water Engineering, 1979, Factual Report : Hydrogeology. Vol 1/4 : Part III/III, Drilling Log, Bandung.
- Geyh, M.A. and Soefner, B. (1996): Groundwater mining study by simplified sample collection in the Jakarta Basin aquifer, Indonesia. *International Atomic Energy Agency, Proceedings Series*, 174-176.
- Gray, D. M. (1973): Editor in Chief, Handbook on the Principles of Hydrology, A General text with special emphasis on Canadian conditions, Saskatchewan, Canada.
- Hem, J.D. (1989): Study and Interpretation of the Chemical characteristics of Natural Water. *United State Geological Survey Water Supply Paper 2254*, 3rd Edition. 45 p.
- Jessop, A.M. (1990): *Thermal Geophysics*. Elsevier, Amsterdam, 306 p.
- Jobmann, M. and Clauser, C. (1994): Heat Advection versus Conduction at KTB:

- Possible Reasons for Vertical Variation in Heat Flow Density. *Geophys. J., Int.*, **119**, 44 – 68.
- Kilty, K. and Chapman, S. (1980): Convective Heat Transfer in Selected Geologic Situations. *Groundwater*, **4**, 386-394.
- Kukkonen, I.T. and Clauser, C. (1994): Simulation of Heat Transfer at the Kola Deep-hole site: Implications for Advection, Heat Refraction and Paleoclimate Effects. *Geophys. J., Int.*, **116**, 409-420
- Martodjojo, S. (1984): Evolusi Cekungan Jawa Barat. Doctor Dissertation, Bandung Institute of Technology, Bandung, Indonesia.
- Mazor, E. (1997): *Chemical and Isotopic Groundwater in Hydrology, The Applied Approach*. Marcel Dekker Inc.
- Parsons, M.L. (1970): Groundwater Thermal Regime in Glacial Complex. *Water Resour. Res.*, **6**, 1701 – 1720.
- Romijn, E., Groba, E., Fiedler, K., Laugier, R., Lohnert, E. and Garagunis, C. eds. (1985): *Geothermics Thermal-Mineral Waters and Hydrogeology*. Theophratus Publications S.A., Athens.
- Rybach, L. eds. (1985): Heat Flow and Geothermal Processes. *Proceedings of IUGG Inter-disciplinary Symposium No. 10*, Hamburg, Germany, August 1983, Journal of Geodynamics, Special Issue 4.
- Sakura, Y. (1978): Studies on Groundwater Circulation using Temperature Data. In *Studies on Water Balance in Japan*, Kokon Syoin, Tokyo, 344 p.
- Sakura, Y. (1993): Groundwater Flow Estimated from Temperature in the Yonezawa Basin, Northeast Japan. *IAHS Publ.*, No.215, 161-170.
- Sakura, Y., Uchida, Y. and Anderson, M.P. (1996): Effects of Groundwater Flow and Surface Warming on the Subsurface Thermal Regime in the Nobi Plain around Nagoya, Central Japan. *Eos Trans.*, AGU **77**, Suppl., S97.
- Satriyo, H. (2000): Konservasi Air Tanah Daerah Jakarta-Bogor, Direktorat Tata Lingkungan Geologi dan Kawasan Pertambangan. Technical Report, Bandung.
- Schmidt and Butkuss (2004): Groundwater Modeling in the Greater Jakarta Area, Indonesia. Symposium CCOP, Tsukuba, Japan.
- Schmidt, G., Haryadi, T. and Kohler, G. (1985): Jakarta Groundwater Study - Groundwater Modelling. Directorate of Environmental Geology (DEG), Report No. HAG 116, Bandung.
- Shimada, J., Kayane, I., Shimano, Y. and Taniguchi, M. (1993): Use of Several Environmental Tracers to Detect the Surface-Subsurface Water Interaction in an Alluvial Fan. *Tracer in Hydrology, Proceeding of the Yokohama Symposium, July 1993, IAHS Publ.*, No. 215.
- Soekardi, P. (1986): Peta Hidrogeologi Indonesia Skala 1:250.000, Lembar Jakarta. Directorate of Environmental Geology and Mining Area, Technical Report, Bandung., Indonesia.
- Sutrisno, S. (2001): Is Jakarta Free from Sea Water Intrusion? Awiligar, http://us.geocities.com/rayano8/jkt_intrusi_eng.html.
- Taniguchi, M., Shimada, J., Tanaka, T., Kayane, I., Sakura, Y., Shimano, Y., Dapaah-Siakwan, S., and Kawashima, S. (1999): Disturbance of Temperature-Depth Profiles Due to Surface Climate Change and Subsurface Water Flow : 1. An Effect of Linear Increase in Surface Temperature Caused By Global Warming and Urbanization in

- the Tokyo Metropolitan Area, Japan. *Water Resour. Res.* **35**, 1507-1517.
- Uchida, Y., Sakura, Y. and Anderson, M.P. (1999): Subsurface Temperature Field in the Nobi Plain, Central Japan. In Sakura, Y. and Tang, C., eds. *Proceeding of the International Symposium on Groundwater in Environmental Problems*, Chiba University, 43-46.
- Woodbury, A.D. and Smith, L. (1988): Simultaneous Inversion of Hydro-geologic and Thermal Data. 2. Incorporation of Thermal Data. *Water Resour. Res.* **24**, 356-372.
- A Reference Book for the Water-Well Industry (1980): Groundwater and Wells. Johnson Division, UOP Inc., Saint Paul, Minnesota, 55165.