CONTRIBUTION OF GROUNDWATER ABSTRACTION TO LANDSUBSIDENCE AT THE NORTH COAST OF SEMARANG

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ABSTRACT

Banyak kota-kota di Indonesia terletak di kawasan pantai atau dataran banjir yang terbentuk dari endapan alluvialr. Ketika kota berkembang permasalahan penurunan muka tanah muncul akibat penambamhan beban bangunan yang meningkat yang diperparah oleh pengambilan air tanah yang berlebihan. Tulisan ini membahas dampak pengambilan air tanah yang berlebihan dan peningkatan beban bangunan terhadap penurunan muka tanah di Kota Semarang. Berdasarkan kecenderungan pengambilan air tanah dan penambahan beban bangunan, potensi penurunan muka tanah ke depan dapat diprediksikan. Hasil prediksi menunjukkan laju penurunan yang cukup akurat dibandingkan dengan hasil pengukuran. Penurunan muka air tanah mempunyai pengaruh yang lebih dominan dibandingkan dengan penambahan beban pemabangunan terhadap penurunana muka tanah.

Kata kunci **:** *groundwater abstraction, uverburden load, land subsdeince*

BACKGROUND

Land subsidence resulting from groundwater over-abstraction and un-controlled development is a serious hazard which has affected many cities in the world. It causes extensive and costly damage to urban drainage, infra-structure and buildings, and other operational problems. The land subsidence is occurring beneath several major cities in Indonesia and develop slowly, silent, and unknowingly.

The land subsidence is also causing costly damage in many big cities. However, it is difficult to measure convincingly so that there has often been a prolonged debate and resistance to control groundwater pumping before taking any action. The study, therefore, has also an objective to prevent the land subsidence from occurring. An example on the handling of land subsidence is taken in Tokyo, Shanghai, and Bangkok where groundwater pumping were controlled and consequently, the soil settlement rates were also reduced.

It is therefore very important and critical for any development in an area, especially in the area sited on the alluvial deposits such as at the North Coast of Semarang, to be aware of any land subsidence occurrences. Early long-term anticipation to control and prevent land-subsidence from occurring is the key issue to be addressed appropriately.

The study is aimed to analyse the effect of groundwater abstraction and the development scale to land subsidence.

DESCRIPTION OF STUDY AREA

Semarang, the capital city of Central Java,is situated on the North Coast of Java, at Southern Latitude 6°56'08" to 7°06'57", Eastern Longitude 110°16'17" to 110°30'31". (Figure 1). The city covers an area of 373.73 sq. kilometers, and acts as a center for regional government, industries, trade,

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education and tourism. The population of the Semarang City at the year of 2000 is 1,309,667 people, with the annual growth of 1.51 %.

The north coastal plain is characterized by delta sediment deposit composed of very soft clay, soft clay, soft to me

dium sandy silt, and mixed of sand and loss to rigid small shells. All sediment materials are originated from Garang River.

The alluvial deltaic sediments that underline most of the coastal plain aquifer, are a thick sequence of clays. However, at shallow depth within the clays there are sandy layers forming a minor semi unconfined aquifer that is widely used for water supply by means of dug wells. Groundwater within the shallow aquifer is generally brackish or saline, but there is a broad zone with fresher water alongside the Kaligarang-Semarang, where it flows through the city (PPLH, 1996).

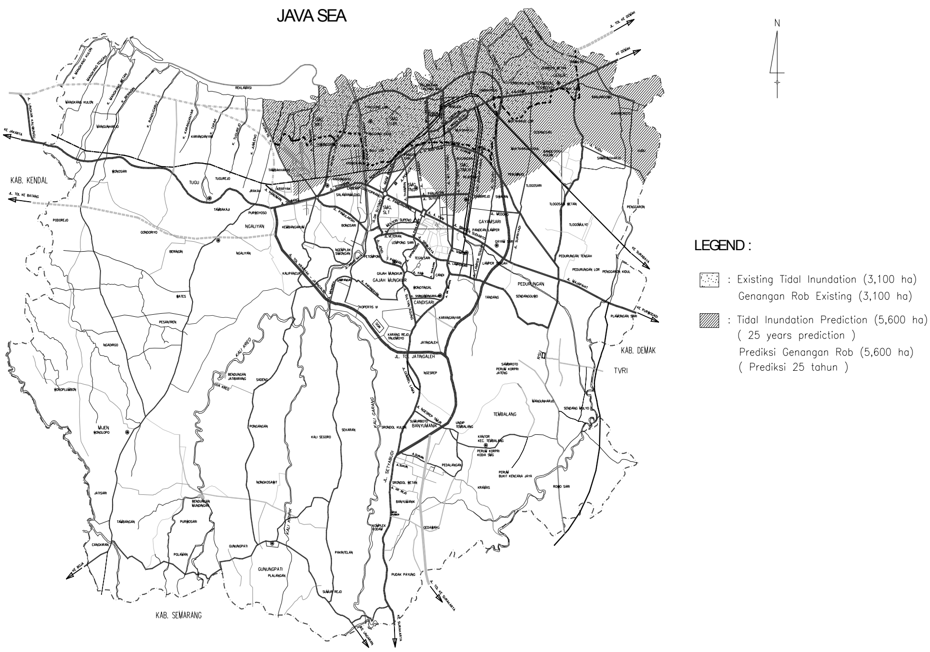

Figure 1. Study Area

Nevertheless, in general the groundwater is not potable due to its high salinity. Many local inhabitants in these areas still use dug wells for general sanitation but buy their drinking water, as the total urban population served by the system under PDAM in 1995 was estimated only 40% by direct connection and 10% by public standpipe. The shallow aquifer, in general, is contaminated by domestic wastewater and it is also vulnerable to pollution from industrial wastewater or leachates. Thus, the shallow semi-unconfined aquifer of the coastal plain is not suitable for water supply.

LITERATURE REVIEW

In general, land subsidence or settlement can occurred as a result from various causes such as (1) *Normal or natural consolidation* of recent clayey sediments under their own weight. This process is usually very slow and may takes a few decades after deposition, (2) *Earthquake vibrations*, which are mainly have influence on fine sands and silts, (3) *Compaction* by rollers, for example, to strengthen the foundation beneath an embankmenT, (4) *Dessication* or drying out of soils due to the water table drops, probably as a result of deep drainage canals and mainly affecting soft organic clays and peats, (5) *Hydrocompaction*, (6)*Dewatering* by pumping to lower the water table in foundation excavation or by electro-osmosis in silty clays, and (7) *Groundwater pumping*.

In all of these processes, the compaction or consolidation of the soil increases its density and reduces its pore spaces. Soils are elastic material to only a limited extends. Soil compaction which beyond the elastic deformation, i.e., become a plastic deformation will results in the ground surface remains deformed and will not rebound even if the causes of that compaction is removed.

Land subsidence due to groundwater abstraction has to be differentiated from other consolidation processes, i.e., from global eustatic effects and from rainy season flooding. An eustatic sea level rise, such as from global warming, will be much slower than the consolidation processes due to groundwater abstraction. Storm flooding, caused by poor drainage and the blockage of canals, is a problem on coastlines with rapid sedimentation.

The process that will be pursued in this study is the interaction on the susceptibility of land subsidence due to groundwater abstraction and the increase in the development scale in the study area. These groundwater abstraction and increase the development have resulted in an increase load to the soil. These processes have been very common phenomenon occurring in all continents. To emphasize the important of the proposed study, it is relevant to describe the overall dynamic interaction between groundwater abstraction, the increase in future development, land subsidence, and other environmental impacts.

Land subsidence is a subject within the scope of both geology and soil mechanics. However, the scope of the study within which the groundwater abstraction and the development master plan are the primary contributing factors have attracted the water resources, groundwater, and environmental specialist to be involved intensively.

The settlement resulted from increase in overburden can be estimated based on the following formula:

$$S = \frac{C_c H}{1+e_o} log\left[\frac{(P_o + \Delta P)}{P_o}\right] \quad \text{..................(1)}$$

where:

- S = the settlement (cm),
- C_c = coefficient of soil compressibility,
- H = soil thickness layer (cm),
- e_o = pore number,
- P_o = the initial effective overburden pressure (kg/cm^2),
- ΔP = the change in effective overburden pressure caused by increase in overburden load from the development (kg/cm^2).

Total settlement that will result from the increase in effective pressure, i.e., either due to the groundwater abstraction or the increase load from the development is calculated from the following formulae.

$$S = \frac{(\Delta P.h)}{M} \quad \text{....................................(2)}$$

where :

- S = the total settlement in mm,
- h = the individual layer thickness in meters.

Meanwhile, the rate of consolidation depends on the consolidation coefficient, C_v, and can be calculated through the following expression.

$$t = \frac{\left(T.H^2\right)}{C_v} \quad \text{......................................} (3)$$

where :

t = the total time in years for the whole settlement to occur,

T = dimensionless time factor for various degrees of consolidation,

H = the total thickness of the clay deposits.

The value of C_v is calculated from the following expression.

$$C_v = \frac{k}{\gamma_w m_v} \quad \text{......................................} (4)$$

Equivalently, the value of Cv can also be estimated as a function of Liquid Limit (Lambe and Whitman, 1969). The magnitude and the rate of aquifer settlement due to well pumping can be evaluated based on the following equation (Lohman, 1972):

$$S_u = \Delta\overline{\sigma}\left(\frac{S_c}{\gamma_w} - D_a n \beta_w\right) \quad \text{...............} (5)$$

if the water compressibility, β_w is neglected, then

$$S_u = \Delta\overline{\sigma}\frac{S_c}{\gamma_w} \quad \text{.................................} (6)$$

where:

S_c = coefficient of storage of an aquifer,

γ_w = unit weight of water,

D_a = depth of aquitard, n is porosity,

β_w = water compressibility.

ANALYSIS AND DISCUSSION

The recharge at the Ungaran aquifer can be estimated by various methods as the data is available. Those are:

Water recharge

Precipitation Percentage : with the average recharge area rainfall is 2885 mm/year, total recharge area is 110.9 km^2, and the infiltration factor 35%, the recharge calculated is then 2.885 x 110.9 x 10^6 x 35% = 112,000,000 m^3/year or 307,000 m^3/day.

Base flow Analysis of Garang River: Based on available data for 1986 – 1995 at Panjangan, the mean annual discharge of the river is 9.6m^3/s and the base flow is 2.72m^3/s. The direct abstraction from tub wells and spring piped by PDAM to Semarang and Ungaran cities is 0.73m^3/sec, thus total actual base flow is then 3.45m^3/sec, or 298.000m^3/day.

Soil Moisture Balance : The calculated total river flow is found to be 10.8 m^3/sec, and the estimate Ungaran recharge is 5.25 m^3/sec, or 450,000 m^3/day.

The above analysis indicates that the recharge in Gunung Ungaran averages some 300,000 m^3/day to 400,000 m^3/day although the infiltration occurs during November to April, and is released through the year from the underground reservoir. This recharge is calculated for an average year but the reliable yield has to base on a dry year so that the usable groundwater resource may be only about 60% of the recharge, say 210,000 m^3/day to 240,000 m^3/day.

Water Supply

The population of Semarang City increased from 1,232,931 people in 1995 to 1,309,667 people in 2000. It means that the annual growth is 1.21%. The projected population in 2005, and 2010, and 2025 is consecutively 1,376,627; 1,417,167; and 1,443,803 people.

The present water supply system of Semarang City is originated from various sources; spring, deep wells, and surface water. Total production is 1.853 lt/s, composed of 951 lt/s (51,32%) surface water and 902 lt/s (48,68%) groundwater.

The total urban population served by the system under PDAM in 1995 was estimated only 40% by direct connection and 10% by public standpipe. The remaining inhabitants are relying on dug or drilled private wells and public water taps supplied by water trucks.

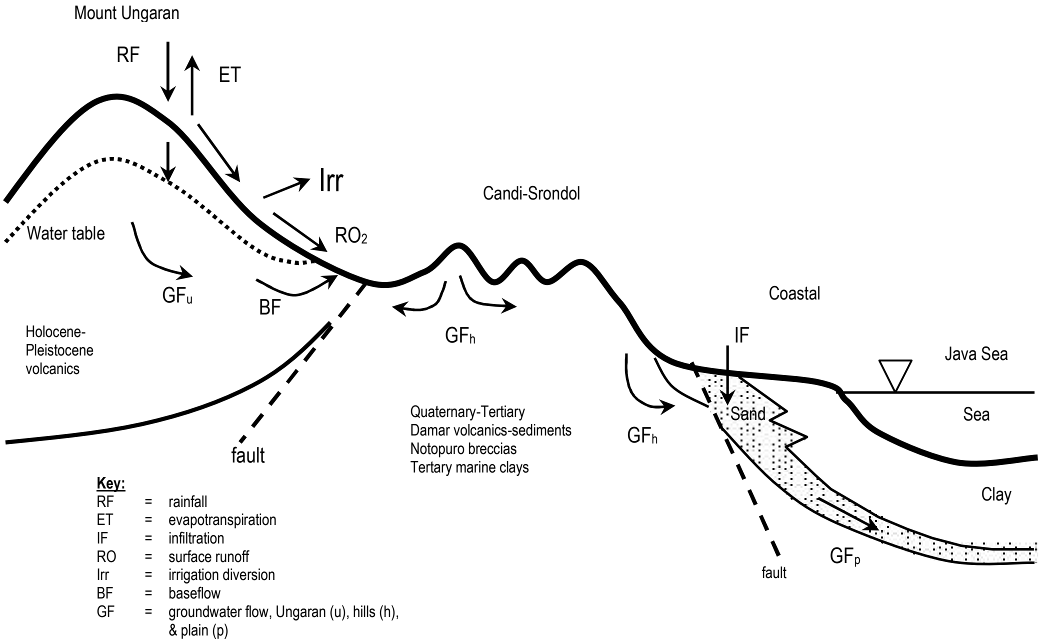

Figure 2. Schematic Hydrological section at Semarang

The water demand of Semarang City for municipal and industrial use is increasing in line with the rapid population growth and industrial development in Central Java. Considering to the population growth, and increasing water use percapita, water for industry, as well as for other purposes, it is predicted that the water demand will have to increase 3.374 m^3/s (106,402,464 m^3/year) in 2010, 3.077 m^3/s (125,418,672 m^3/year) in 2015, and 5.183 m^3/s (163,451,088 m^3/year) in 2025.

The current available water supply of 0.276m^3/s will have to be increased to 5.426m^3/s by the year 2025. If the surface potential water source, i.e.: Garang River (1.000 l/s), Babon River (50 l/s), and Kudu (2.250 l/s) have been fully developed, the water demand in Semarang City would be supplied sufficiently until the year 2025. However, the fact shows that the PDAM production was always far below the demand, and so far the deficit of water demand was fulfilled from groundwater, particularly that was pumped from deep aquifer.

Groundwater Abstraction

Groundwater is difficult aspect to control in Indonesia because of many private tubewell operated. The discharge may be small but the cumulatively is very big, specialize for a large city like Semarang as study area. The monitoring of groundwater abstraction is fundamental analysis in this research. This is related with water sources supply and soil properties characteristic especially land subsidence in the study area. The other research support this statement that decrease of groundwater elevation impacted to the land subsidence in Semarang about 0,6 cm/year until 1,2 cm/year (Mineral Technology Faculty of ITB, 1995).

Both number tube wells and discharge of groundwater abstraction in Semarang City is increased markedly, from 127 tube wells in 1982 to 776 tube wells in 1998, with the discharge of 13.49 million cubic meter in 1982 to 35.64 million cubic meter in 1997 (Table 1).

Table 1. Increasing number on discharge of tube wells in Semarang City between 1900 and 1998

No	Year	Number of tube wells	Volume of abstraction	
			m^3/day	million m^3/year
1	1900	16	1.300	0,47
2	1910	18	1.310	0,47
3	1920	18	1.400	0,50
4	1932	28	1.610	0,58
5	1982	127	37.460	13,49
6	1985	150	44.064	15,86
7	1990	260	61.570	22,17
8	1995	316	74.130	26,69
9	1996	659	80.954	29,14
10	1997	745	96.798	34,85
11	1998	776	98.998	35,64

Source: Sukrisno – DGTL (1999). Konservasi Air Tanah Daerah Semarang-Demak dan Sekirtarnya. (1999).

Land Subsidence

Land subsidence in the study area is presuming to be caused by soil consolidation and groundwater pumping. Measurement of Land Subsidence the indicator base on the leveling ground, as mentioned above.

Based on the compilation of the data, measurement carried out between 1984 and 2000), it was identified that there were only 7 (seven) stations (bench marks) which were always measured, while the other stations were intermittently measured. The data is combined with the latest measurement, which was carried out in this study (October 2002). Analysis of those data found that the rate of land subsidence varies from 0.79 cm/year at the Elizabeth Hospital (upper area) to 5.07 cm/year at DTK 135 located at Jl. Imam Bonjol. In general, there land subsidence rate tends to be higher at the coastal region then at the upper area.

Considering to the topographic and geological situation, the study area can be divided into three regions; lower, middle, and upper or hilly area. Land subsidence in the lower area is highest than the others. The average land subsidence in the lower area is three to four times at the upper area, and four to six times in the middle area (see Table 2).

Table 2. Average Land Subsidence in Semarang City

Type Area	Average Land Subsidence (cm/year)	Location study (Station)
Hilly	1.17	Sultan Angung (Akpol)
Middle	0.90	Kalisari/Dr. Sutomo Street
Lower	3.3-5.07	Tugu Muda,Pelabuhan

Land subsidence due to consolidation process

There are two kinds of consolidation: primary consolidation, and secondary consolidation. The primary consolidation is occurred in a certain duration time. It is depended on the various factors, such as; overburden on the top of the consolidated soil, the thickness and the number of soft soil layers, effective soil stress due to load, and contact area between load and consolidated soil. The value of primary consolidation can be estimated based on equation (1), where the overburden is equal to the land filling thickness. The secondary consolidation is occurred slowly, and it is usually neglected is the calculation.

Based on the available soil data, and the increasing overburden due to land filling, the rate of land subsidence due to overburden can be calculated. Some of constants say Cc=0.3-0.8, $\gamma = 1.7$-1.8 t/m^3 , eo = 1.6 - 1.8, and the upper and lower clay layer thickness are consecutively 23.2 and 9.60 meters. It can be shown that the land subsidence increases with increasing overburden. The increasing land subsidence is power function of the overburden with the power of 2.5. It is exactly fit until overburden thickness of 8 meters (Figure 4).

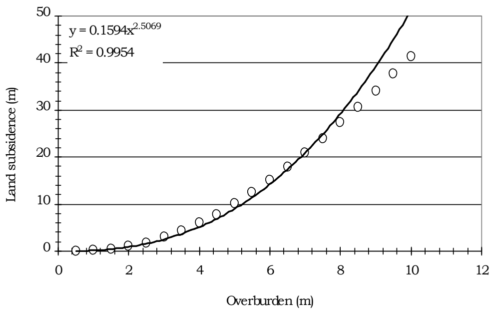

Figure 3. Correlation between overburden and land subsidence

Land Subsidence due to Groundwater Abstraction

As stated by ITB (1995) that over pumping in Semarang caused ground water drop and land subsidence. By implementing the same equation for the land subsidence due to overburden (eqn 1), the rate of land subsidence due to ground water drop can be estimated. In this case, the increasing overburden is generated by decreasing ground water level. Therefore the analysis consists of two steps; first estimate the ground water drop against ground water pumping, and then estimate the land subsidence against ground water drop.

The overburden generated by ground water drop can be estimated by using equations (5) or (6). The results are presented in Figure 5. There is simple correlation between ground water drop and overburden, i.e.:

$$H_w = 3.436 S_w^{0.2589} \quad \text{.........................(7)}$$

where:
H_w = overburden (m),
S_w = ground water drop (m).

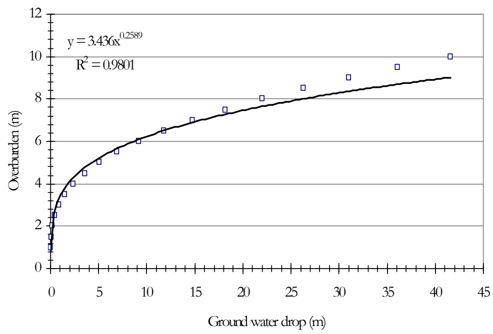

Figure 4. Correlation between aquifer settlement (groundwater drop) and overburden in Semarang City

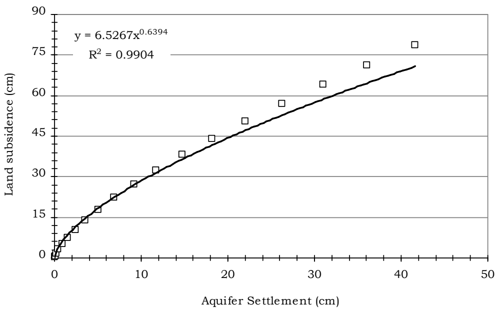

Figure 5. Correlation between Aquifer Settlement and Land Subsidence

As the correlation between groundwater drop and overburden has been found, the land subsidence generated by groundwater could also be estimated. The results are presented in Table 3. The correlation between aquifer settlement and land subsidence then could be generated in the form of:

$$S = 6.5267 Su^{0.6394} \quad \text{..........................(8)}$$

where S is land subsidence in centimetre, and Su is aquifer settlement in centimetre.

Total Land Subsidence

Total land subsidence, combination between consolidation process, and land subsidence due to ground water drop, then could be estimated by using Figure 6. As examples, Table 3 shows the comparison between land subsidence obtained from direct ground level measurement and analysis for some station within Semarang.

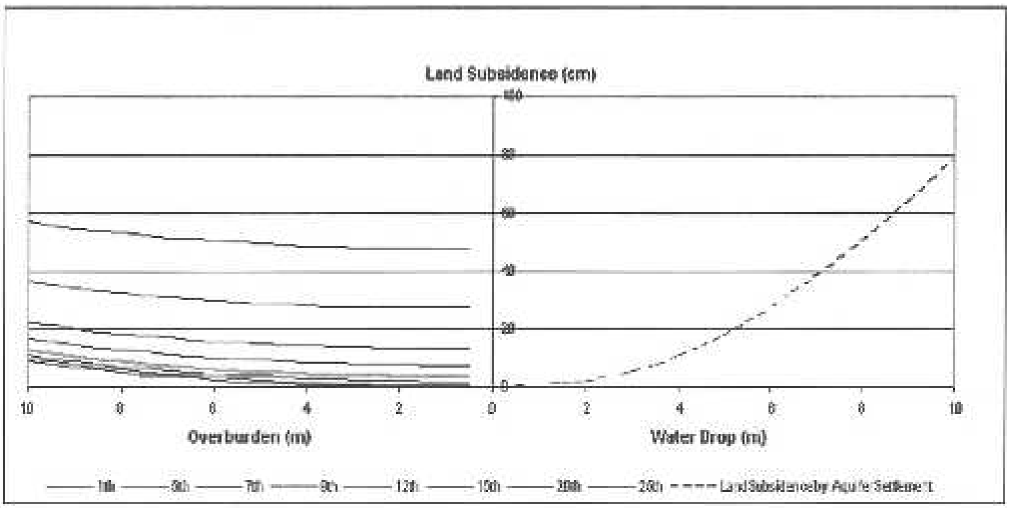

Figure 6. Total land subsidence, combination between consolidation process and land subsidence due to ground water drp

Table 3. Comparison between measured and estimated and subsidence of some stations in Semarang

lo	Station	Address	Measured Land subsidence Oct97-Dec98 (cm/year)	Estimated land susidence due to (cm)		
				Overburden	Groundwater drop	Total
1	TG 447	SPBU Kaliwiru	0.00	0	0.260	0.260
2	TK 341	Akpol	1.17	0	0.807	0.807
3	TK 340	Rs. Elizabeth	0.79	0	0.807	0.807
4	TK 009	Ps. Bunga, Jl. Dr. Sutomo	0.90	0	1.765	1.765
5	TG 446	Tugu Muda	2.30	0	5.110	5.110
6	TK 135	JL. Imam Bonjol	5.07	0.02	3.189	3.209
7	)TK019	Jembatan Banjir kanal Barat	3.30	0.46	5.110	5.570
8	)TK368	Madukoro Street	4.27	0.46	5.110	5.570

CONCLUSION AND RECOMMENDATION

Conclusion

1). Land subsidence occured in Semarang City composed of two processes: consolidation of soft soil layer due to overburden, and land subsidence due to ground water pumping. The rate of land subsidence varies spatially depended on the overburden load, ground water pumping and the geological characteristics. In general the rate is higher in the lower (coastal) area than in the upper area. Maksimum land subsidence occurred in Tanjung Mas Harbor, about 4 – 5 cm/year.

2). Land filling and reclamation on the coastal region contributed to the land subsidence. It increases overburden load. The higher the land filling, the higher the rate of land subsidence tend to be.

3). Groundwater pumping tends to increases continuously, as the water supply production from PDAM does not meet the water demand. The ground water pumping increases markedly in line with the increasing water supply deficit. Ground water pumping is already higher than the natural groundwater recharge.

Recommendation

1). The centre of development in the Semarang City should be moved from low land area at the north to the hilly area at the south. It is aimed to maintain or even reduce overburden load as well ground water pumping at the coastal area. To maintain groundwater balance, many efforts have to be carrout to increase groundwater recharge, such as maintain recharge area, and develop artificial recharge.

2). Increasing overburden load, due to either land filling and buildings, increasing land subsidence rate. Land filling, therefore, is not the answer to solve the tidal inundation problem in the low land-soft soil area.

3). The existing deep wells have to be strickly controled and monitored, to ensure that meterings are installed on the all wells, and the pumping rate is not over the permitted discharge (safe yield).

4). Application of additional new deepwells should be strickly limited for a very urgent only, while PDAM should fasten its development to meet the water demand, whithout this efford limitation of ground water pumping would be ineffectrive.

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REFERENCES

Andersen, L. J., 1983. *Sampling Techniques for Groundwater From Waterwells*. In Proc. UNESCO-TNO Int. Symp. MIIGS, p. 521-527.

Barber, C. and Davis, G. B., 1987. *Representative Sampling of Ground Water from Short-Screened Boreholes*. In Ground Water 25, p. 581-587.

Barcelona, M. J., Gibb, J. P., Helfrich, J. A., and Garske, E. E., 1985. *Practical Guide for Groundwater Sampling*. Illinois State Water Survey Contract Report 374.

Bemmelen, R. W. van, 1969. *The Geology of Indonesia*, Government Printing House, the Hague.

BGS, BBV, and BAPEDAL, 1998. *Groundwater Development Constraints in Layered Coastal Aquifers*. In Proceedings of the Seminar/ Workshop on Groundwater Quality Monitoring and Aquifer Control in Indonesia, March 1998.

Binnie and Partners, 1984. *Guideline BP 11 Groundwater Evaluation for Water Resource Projects*. Direktorat Bina Program, Ditjen Pengairan DPU.

Cambell, M.D., and Lehr, J. M., 1973. *Water Well Technology*. McGraw Hill, New York.

Davis, J.C., 1986. *Statistics and Data Analysis in Geology*. Wiley and Sons., New York.

DHV Consultant Engineers, et al., 1989. *Bali Water Resources Management Study*. Dit Bina Program, Ditjen Pengairan, DPU.

Dit. Geologi Tata Lingkungan, 1981. *Penilaian Umum Aspek Geologi Teknik Sehubungan dengan Rencana Pertambangan Kota Semarang*. Ditjen Geologi, Dept. Pertambangan.

Grantham, G., and Lucas, J. L., 1985. *Monitoring of the Unsaturated Zone as an Aid in Aquifer Protection*. Proc. IAH 18th Congress on Hydrogeology in the Service of Man., Cambridge, UK, pp. 70-83.

Lambe, T. W. and Whitman, R. V., 1969. *Soil Mechanics*. John Wiley and Sons.

Hasil Survey/Pengukuran Elevasi dalam Rangka Pengamatan Penurunan Tanah di Pelabuhan Tanjung Emas Semarang. (1998). CV MITRA REKAYASA – PT. (PERSERO) PELABUHAN INDONESIA III CABANG TG EMAS.

The Master Plan on Water Resources Development and Feasibility Study for Urgent Flood Control and Urban Drainage in Semarang City and Suburbs. (1992). JICA-MINTRY OF PUBLIC WORKS.

The Detailed Design of Flood Control, Urban Drainage and Water Resources Development in Semarang in the Republic of Indonesia. (1998). JICA-DGWRD.

Groundwater Monitoring and Control. (1998). BINNIE BLACK & VEATCH – BAPEDALDA.

Studi Penentuan Penurunan Permukaan Tanah di Semarang Bagian Bawah. (1997). Muhrozi, Cs – FT UNDIP.

Konservasi Air Tanah Daerah Semarang-Demak dan Sekirtarnya. (1999). Sukrisno – DGTL

Peta Cekungan Air Tanah Pulau Jawa dan Pulau Madura. (2001). Hendri Setiadi, dkk. – DGTL.

Sistem Pemantauan Kualitas Air Tanah & Perlindungan Akifer di Indonesia. Seminar dan Lokakarya (1998). BINNIE BLACK & VEATCH – BAPEDALDA.

Kashef, Abdul-Aziz Ismail, 1986, GROUNDWATER ENGINEERING,McGraw-Hill Book Company,USA.