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Modelling for Groundwater Extraction Effect for Jakarta Land Subsidence

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Abstract: ***Subsidence has been a very disturbing issue as its endangered densely populated area at the north part of Jakarta as well as the infrastructure that existed along the coastline. Although there are several main cause of subsidence in Jakarta, discussion will be from the groundwater effect point of view. The subsidence has become a consideration for Jakarta to build a preventive infrastructure or any other infrastructure in Jakarta. Due to Subsidence process, there are some consequences has to be bare such as building damages and flooding that has become fidgety for people along the coastline. Today the sea level has become higher than houses along the shoreline. The research conducted in Sunter area that has been completed with sufficient geotechnical data with groundwater level measurements from 1985 and geodetic measurements since 1985. Based on the data, the rate of subsidence calculated as settlement and calibrated with Geodetic GPS measurements. As the result, the rate of subsidence for existing condition is not affected by the rate of groundwater level decreasing during 1985 to 2015 around 0.3 meters/year. Modelling continues using an extreme scenario that reaches 1.5 meters/year and the result is ground water has a significant effect on subsidence. The percentage of the groundwater effect of subsidence in normal condition is less than 5%, but in extreme condition is around 30%.***

Keywords: Subsidence; Settlement; Jakarta; Groundwater; Flood

1. Introduction

Subsidence is the motion of a surface (usually, the Earth's surface) as it shifts downward relative to a datum such as sea-level. The opposite of subsidence is uplifting, which results in an increase in elevation. Ground subsidence is of concern to geologists, geotechnical engineers, and surveyors. In Jakarta Subsidence has been a very hot issue due to a very densely populated area at the north part of Jakarta as well as the government infrastructure that existed along the coastline. The subsidence in Jakarta has become a consideration to build another infrastructure or any other infrastructure to prevent Jakarta from Subsidence. Flooding in deltas SEE Asia region have more significant impacts when the combination of several issues such as land subsidence, lowland reclamation, and sea level rise threaten in the same time [7].

A. Problem Definition

Due to Subsidence process, there are some consequences has to be bare such as building damages and flooding. Flood has become fidgety for people along the coastline yet the sea level has become higher than the land they live in. In this situation, the government has to take action for controlling the subsidence. In order to create some infrastructure to prevent subsidence or subsidence effect, there has to be a study that explains the subsidence mechanism in Jakarta. It is recommended for local government agencies to conduct better disaster management and relief fund management. Early warning system should be installed and executed by responsible local authorities [11].

B. Literature Survey

Several studies about subsidence have been done in several world strategic cities, such as Bangkok and Tokyo. The causes of subsidence in those areas, mainly due to excessive ground water abstraction. Jakarta is unique and might be different with those cities, in this case, the geological study conducted for consideration and determination. Land subsidence impacts in urban areas are quite numerous and can be categorized into infrastructural, environmental, economic and social impacts. Environmental impacts of subsidence are usually underestimated since it is indirect effect and its appearance usually is unseen and has a relatively longer time response than infrastructural impacts. For example, although land subsidence in urban areas contributes to inundation and flooding phenomena, however, land subsidence is usually forgotten in assessment and modeling of flooding and inundation in urban areas [12]

A geological study conducted based on the regional mapping from the previous researcher and interpreted as a requirement for subsidence study. Furthermore, the study conducted based on geotechnical data by using the drilling sample description and laboratory test for the geotechnical parameter and properties. The geotechnical parameter used as input parameter for consolidation modeling and the subsidence time period. Input parameters for the consolidation modeling consist of geotechnical properties and groundwater level time series. The model has to be fitted and calibrated with the actual field monitoring data acquired by serial Geodetic GPS Monitoring measurements. The geodetic GPS data used for geotechnical calibration and monitoring due to very limited data obtained from touch coring and laboratory test. The model located in Sunter area that has drilling and geotechnical properties. Along with the drilling data, in nearby location have observation well for three semi-confined aquifers and one dug well for unconfined aquifer data. The screen or piezometer tips are located at 173-177 m, 115-135 m, and 235-241 m. For that depth, the 115-135 m is considered as medium depth well aquifer and the 173-177m and 253-241 m depth is considered as a deep well aquifer.

The GPS monitoring data obtained from 1985 to 2015, and confirmed that have declining trends and considered as land subsidence. The GPS monitoring data obtained from terrestrial measurements using geodetic instruments. The base reference for the measurements is tied in Badan Informasi Geospasial (BIG; was Bakosurtanal) reference point. BIG has the real time base reference controlled by satellite and considered as unchanged or unmoved control point.

Besides the Geotechnical Analysis, there are also several other analysis methods. Analysis of land use changes / land cover can be done by creating a matrix of land use changes / land cover based on the results of GIS analysis of the observed or studied. Matrix of land cover changes can be seen vast changes that occur every year [14]. One way to increase the clay shear strenght ai the concrete injection using cement coloumn. Cement column reinforcement is a method of soil reinforcement used in the field to increase soil's shear strength and decrease soil's compressibility [15]. But this method is unaplucable due to the Jakarta condition and it will cost lots of money.

2. Methodology

There is some material that is used in this study. The material is included:
1) Borehole log data complete with the geotechnical laboratory test.
2) Groundwater Monitoring
3) Geodetic GPS Measurements

With reference to the calculation of groundwater levels and the effective voltage at a time of soil or rock, then do the next calculation such as the calculation of consolidation. Consolidation calculated on subsidence in Jakarta is a secondary consolidation because the deposition process has gone on for several thousand years ago.

Understanding the types of consolidation and the consolidation of the soil layers will be presented as follows:
Definition of consolidation is the process of reduced water content in the saturated clay layer with no change of water by air [9], [8]. According to [5], the reduction in volume that occurs during consolidation caused by one or a series of several factors:
1) Regrouping clay granules.
2) Deformation of the clay granules.
3) Deformation pore water and air.
4) The exit of the pore water and air.

Consolidation in the field measurements can be monitored by installing piezometer. This tool records the changes in pore water pressure along time. The magnitude of the decline can be measured by noting the height of a reference point corresponding to a structure or on the soil surface. In search of data decline, every opportunity must be taken, because only with the measurement accuracy of the method can theoretically be realized. There are two types of consolidation on the ground, namely the consolidation of primary and secondary consolidation. Understanding and explanation of the consolidation will be described below:

1) Primary Consolidation
The decline in consolidated primary is one process of decline that occurred in clay saturated fine-grained with coefficients and power speed small and depending on the time. This occurrence caused by the dissipation of pore water pressure and discharge the air in the cavity of the future of land [10], If the voltage that occurs beyond the capacity of the soil framework conditions specific void ratio, then the excess voltage will be entirely retained by pore water. With the decreased number of pores, the capacity of force between the grains of soil framework increases, which will further reduce the size of the pore water pressure. The next process will continue until there is a balance in which the pore water pressure will be equal to the voltage across the voltage hydrostatic and will be retained by the structure between the grains.

2) Secondary Consolidation
The exact definition of secondary consolidation settlement has not been fully defined clearly. The decline in the secondary is generally regarded as the decline due to changes in effective stress, even though it happened in full yet fully understood. Secondary consolidation settlement is void ratio changes resulting from the melting of the grain structure viscous ground [10].

Secondary consolidation settlement is a change in volume that continues over time, which began during the primary consolidation, although occur at a low speed at a constant effective voltage after all the pore water pressure has dissipated entirely [5]. Secondary consolidation settlement is characterized by the occurrence of creep (melting) of the clay structure due to the effective voltage constant [10] (Fig.1). Secondary consolidation theory is very extensive, very complex mathematical approach in which the parameters of the soil cannot be determined either by secondary consolidation discussions, therefore, remains controversial [10]

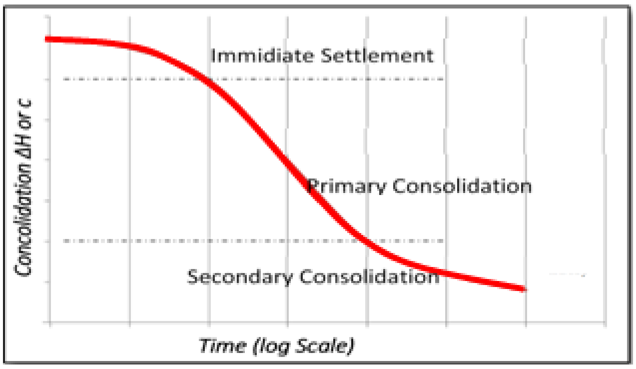

Figure 1: The correlation between ΔH and log t [6].

Although the model rheology has been developed by Gibson and Lo [10] component of the decline was the result of pressure that occurs in the bond between the particles of clay itself as well as the interaction between the particles-particles of soil with water where the effect on the size of the smallest yet completely understood. Other complicating factors occur on clay is difficult to separate between the decline in the secondary of the total reduction.

If the consolidation that occurs in a clay soil layer is thick enough, the part that is closer to the surface may be completely consolidated, but the part that is in the middle of the clay layer may still experience some consolidation primer. But both types of decline contributed to a decline in total on the surface. Therefore, some of the hypothesis is practicable to estimate the secondary decline would have been acceptable for the purpose of practical use in engineering practice.

Secondary consolidation resulting from decreasing with time curve, the curve of secondary consolidation can be grouped in three forms based on its behavior:

1) Type I curve, which has a concave shape which is good, secondary consolidation further decreases with time curve becomes horizontal when the maximum reduction was achieved.
2) Type II characteristic of the type II show, a straight section following the logarithmic approach to limit substantial time.
3) Type III Speed secondary pressure increases with subsequent continuous log time slowly until done. All types of secondary decline curve shown in Fig.1 [6]

Consolidation of clay Compared with sandy soil, clay has properties that are less favorable to the consolidation process. It can be noted in the table below:

Table 1: Soil and Sand consolidation comparison

No	Soil Type	Seepage	Rate consolidation
1	Clay	Low	Fast
2	Sand	Hugh	Slow

Concluded from several sources [9] [4] [3]

3. Result and Discussion

Several data are very useful in the analysis process. These data consist of groundwater measurements, subsidence measurements, and geotechnical bore log. Each and every data are useful for input and recalibrate the parameter for better interpretation. There are four analysis models established for the result. Alaysis started from the geological condition, groundwater, geodetic and geotechnical.

a) Geological Formation

Geological modeling is the basis of the calculation of subsidence in geotechnical and site identification subsidence. They based on data from the drilling log, both for ground water as well as geotechnical. Geological modeling uses linear interpolation by ROCKWORKS done with software that has the ability to interpolate and lithological interpretation of data into cross-sectional shape, both 2-dimensional and 3-D.

Before performing geological modeling, stratigraphic modeling first performed by the existing regional reference conditions. Stratigraphy modeling results in the area of Jakarta conducted by a proportionality description of the bore log with a description of the results of regional mapping, so we get the equality of lithology and conclusions drawn into the rock formations. The results of the lithology equalization can be concluded that in the area of Jakarta, there are 4 rock formations with two lithological units quaternary.

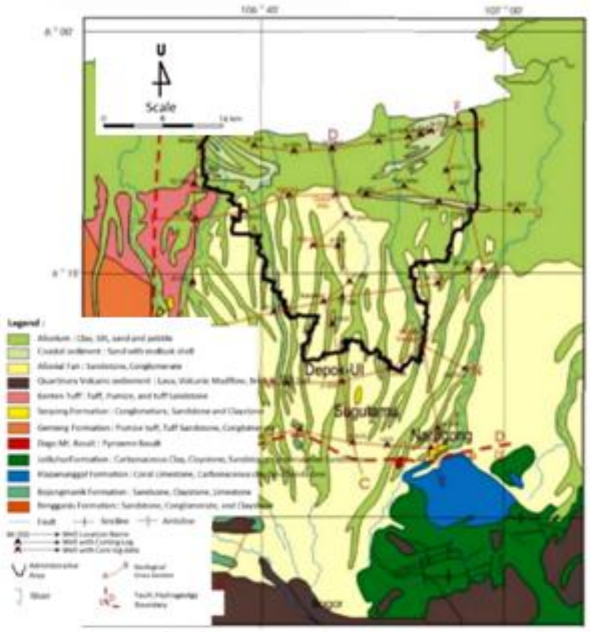

Figure 2: Geology map of Jakarta[13]

Formations, which are attached in the area of Jakarta (Fig.2.) which are (from old to young):
1. Subang Formation
2. Jatiluhur Formation
3. Klapanunggal Formation
4. Kaliwangu Formation

And the recent sediments (Quaternary) that can be identified are (from old to young):
1. Volcanic alluvial fan and
2. Coastal Development sediment

Based on geological conditions in Jakarta, there are 5 formations that can be identified. Formation identification is based on the description of the drill logs provided either in the form of cutting and core samples. The description of the results is shown in the form of models and display in 3D models (Fig.3.).

In the discussion of regional geology, the Kaliwangu formation is not aligned with volcanic fan one another. This indicates that the formation Kaliwangu already experienced compaction or compressed so that the possibility of the impact on the decrease topographic settlement or subsidence can't happen again. The possibility of a settlement influence on the occurrence of subsidence occurs only in the fan area Volcanic and coastal development. This shows that as measured by the GPS that already exist today, or the coastal area of North Jakarta which have the greatest degree of subsidence, while in the South Jakarta area did not experience a significant rate of subsidence.

Under these conditions, the geologic modeling is affected by subsidence due to the heavy load of overburden and groundwater influence is on the fan volcanic sediment and coastal development.

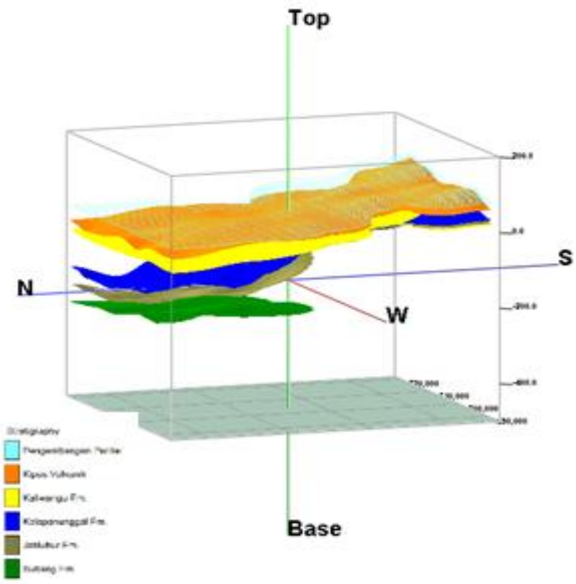

Figure 3: Jakarta Geological Formation layer result of modeling

b) Groundwater Elevation Analysis

The ground water elevation data already measured during several years. The data acquired from Badan Pengelolaan Lingkungan Hidup Daerah (BPLHD) DKI Jakarta province. The measurements were conducted from 1985 to 2015, with several years with blank data. As the measurements in nearby Sunter continues in good order, also the drilling bore log data conducted in Sunter, therefore the groundwater data in near Sunter is used as the reference. Another advantage is not far from the Sunter drilling location, also located a geodetic GPS measurement point. The groundwater elevation data are described as the graph below (Fig.4.).

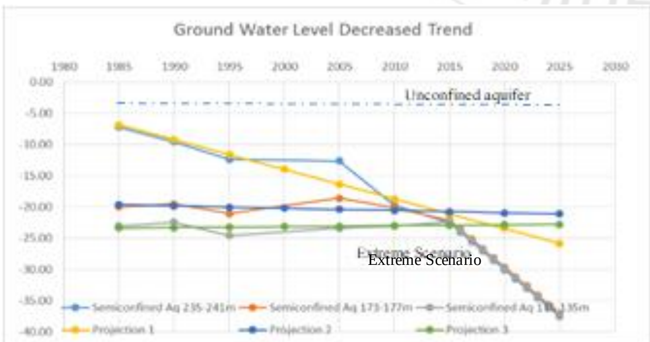

Figure 4: The ground water leveldecreases trend and projection

From the graph below, can be seen that the semi-confined aquifer 173-177 m depth screen has a linear projection towards horizontal line, and also with the semi-confined 115-135 m depth. The one decreasing is the semi-confined 235-241 meter that has quite a stiff angleto approximately reach 0.3m drawdown per year. From this graph can be seen more clearly than the first and second semi-confined aquifers are not having differential decreasing from 1985 to 2015. Somehow, in modeling purposes, the scenario is made to simulate the land subsidence rate due to groundwater level change, especially the decreasing ground water level. The unconfined aquifer in Sunter area has not been changed from 1985 to 2015 and only fluctuated around 2-4 meter from surface level due to a dry and rainy season.

One of the considerations for modeling purposes is the scenario created for the extreme condition that all the semi-confined aquifer has trended for 1.5-meter depth decreasing each year to the year 2025. This assumption is used to consider that there can be condition if there is no surface water supply for Jakarta area, and then Jakarta people start to use ground water as their raw water

c) Geodetic Subsidence Measurements Analysis

In order to measure the subsidence rate that occurred in Jakarta, terrestrial measurements performed in Jakarta. The data measured for ground elevation recording of subsidence are also not far from the drilling location. Measurements conducted terrestrial have recording time span from 1985 to 2015. Variations include measurement data obtained using a base reference point level and use GPS Geodetic. Advantages of the use of GPS Geodetic is ease of data acquisition, but very dependent ontechnology evolving conditions, their satellites and weather condition. Model results can be viewed on Fig.5, whereas some results can be seen as follows.

Subsidence that occurred in Jakarta has been monitored since 1978 to 2015. The data from the past several years arevaried because it uses different measurement methods and tool although based on the same datum. The datum is used the geodetic reference point in Bakosurtanal or BIG. The results of the modeling and interpretation of the data displayed based on data sources and methods of measurements. To give a better picture about land subsidence, geodetic-based monitoring systems utilizing leveling and GPS surveys have also been implemented [1].

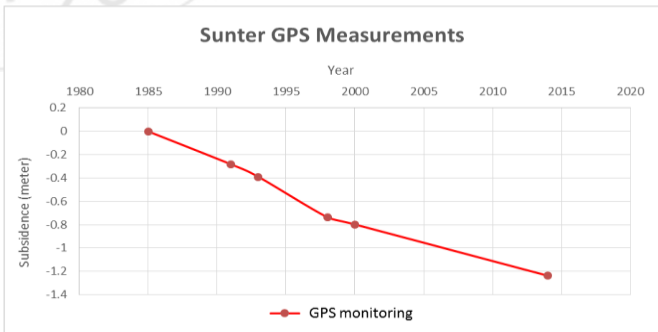

Figure 5: Graph of GPS measurements in Sunter Area

d) Geotechnical Bore log Analysis

Drilling lithology data required in the form of a type of rock or soil are in the area of research either in the form of sand, clay, silt and so forth and also by the depth of each lithology. Geotechnical data required in the form of the value of consolidation (Cv), the consolidation of the secondary (Ca), a specific gravity of normal (γn), heavy wet type (γwet), the value of the ratio of over-consolidated (OCR), the value of the ratio of reloading and swelling (RR) and consolidation ratio (CR). Geotechnical data required must come from each lithology in the same well with the base model wells that have previously been created. If the parameter is not derived directly from the results of laboratory tests, they do value approach using empirical formulas that have been widely spread. It is common for some of the parameters do not have laboratory test result.

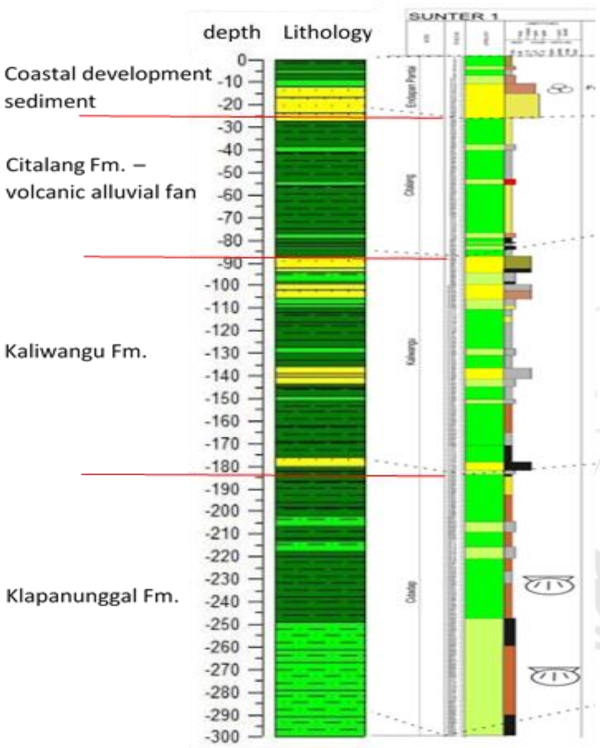

Figure 6: Sunter Log Bore (Sunter-01)

Based on the description there are three major geological formation units which are Coastal development sediment part of alluvial formation.

The parameter divided to several segment parameters depends on the soil properties. Segregation is considered and to be adjusted with the regional geology properties. From this consideration, there is three main formations forming this bore log that can be compared with the regional formation, as shown in Fig.6.

Alluvial fan a part of Citalang Formation, Kaliwangu Formation, and Klapanunggal Formation. Each and every formation has different soil properties and characterization to divide the calculation. The calculation based on the adjustment geotechnical parameter from the Geodetic GPS measurements shown in table III as follows:

Table II: Parameter for each lithology

Litologi	Parameter	Coastal development sediment	Citalang	Kaliwangu, Subang, Jatiluhur
Sand	Gamma n	17.22	19.80	20.20
	Gamma sat	22.15	24.30	23.45
	Cv	-	-	-
	OCR	1.28	1.34	1.41
	RR	0.07	0.06	0.06
	CR	0.21	0.20	0.18
	Ca	0.01	0.00	0.00
Clay	Gamma n	15.16	15.87	17.30
	Gamma sat	19.05	20.09	20.26
	Cv	0.00	0.00	0.00
	OCR	1.52	1.57	1.51
	RR	0.11	0.10	0.06
	CR	0.35	0.30	0.20
	Ca	0.01	0.01	0.00

From the result of adjustment parameters, the gamma-saturated value has a very high value, although it is still in the range. The value can occur as the weight of the sediment should be that heavy to accommodate the rate of settlement. Despite the value, there could be several other causes of the settlement or subsidence in Jakarta, for example, the tectonics factor.

e) Result

Settlement modeling analysis was performed using the software help D-Settle of Deltares. Using this software, it shows a decrease or subsidence rate. Input data consists of the drilling log data and the results of laboratory tests. The field data is the basic data used to calculate land subsidence and then adjusted with geodetic GPS monitoring data in the area of Jakarta. Modeling was done still refers to the drilling site with a comparison of GPS measurements located about 500 meters from the drilling location.

The result is, a parameter of lab calculation does not correspond to actual field conditions; there is a difference of 2.4 meters by using GPS geodetic observations. Under these conditions, then adjustments geotechnical parameters shown in color charts purple and light green color (Fig.7.). Those parameters are split between a decline due to a combination of tectonic and geotechnical factors to geotechnical conditions only. The result of the adjustment is then projected to the year 2035 so that obtained a massive decrease of 1.6 meters in 2035 due to geotechnical and tectonic and there was no significant difference between the tectonic factor or not. Magnitude is a total subsidence caused by geotechnical factors, namely settlement because of the load of the building, a natural consolidation, and groundwater.

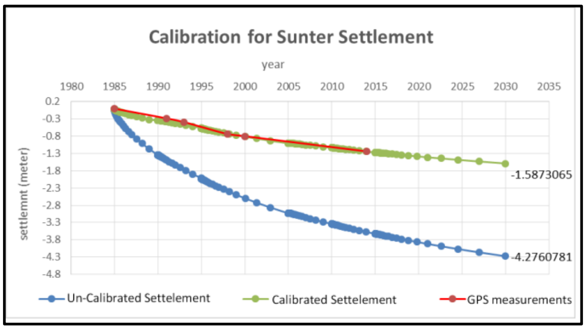

Figure 7: Subsidence graph with geological and geotechnical parameters in the wellbore Sunter

Calibration parameters required for the amount of subsidence to conform the actual conditions. Depth adapting for lithology types and weights can be done after calibration parameters of geotechnical parameters are obtained on each different layer. The modeling using multiple scenarios groundwater conditions can be done by using the calibrated parameter. The scenarios used to follow the data listed in Table III.

Table III: Scenario conditions of the groundwater table with linear projections until year 2100

Scenario		2015	2025	2050	2100
I	GWL (meter)	-22.52	-22.52	-22.52	-22.52
	Subsidence (meter)	-1.31968	-1.54223	-1.947	-2.41173
II	GWL (meter)	-22.52	-25.825	-25.825	-25.825
	Subsidence (meter)	-1.31968	-1.54223	-1.951	-2.45155
III	GWL (meter)	-22.52	-25.825	-37.71	-37.71
	Subsidence (meter)	-1.31968	-1.54223	-1.96017	-2.48381
IV	GWL (meter)	-22.52	-25.825	-37.71	-61.48
	Subsidence (meter)	-1.31968	-1.54223	-1.96017	-2.48381

In 2015, the existing condition in the groundwater in Jakarta in Sunter region is about a (-22.52) meter from the face of the local soil. Scenario assumptions used are:

1) Scenario 1, the groundwater in the area of Sunter can be set by regulation so that the amount of recharge and discharge are the same so that the ground water level until 2100 anyway.
2) Scenario 2, ground water by 2025 can be set by regulation so that the ground water is projected for 2025 is fixed at depth (-25.825) meter.
3) Scenario 3, the groundwater in 2025 can be set by regulation so that the ground water is projected for 2050 is fixed at depth (-37.71) meter.
4) Scenario 4, groundwater in 2025 can be set by regulation so that the ground water is projected for 2050 is fixed at depth (-61.84) meter.

The results of this scenario are the difference in the amount of reduction or subsidence is not significant, amounting to 0.471 meters, or about 47 cm of scenario 1 is equal -2.41173 meters of existing conditions and scenarios 4 of -2.48381 existing condition (Fig.8.).

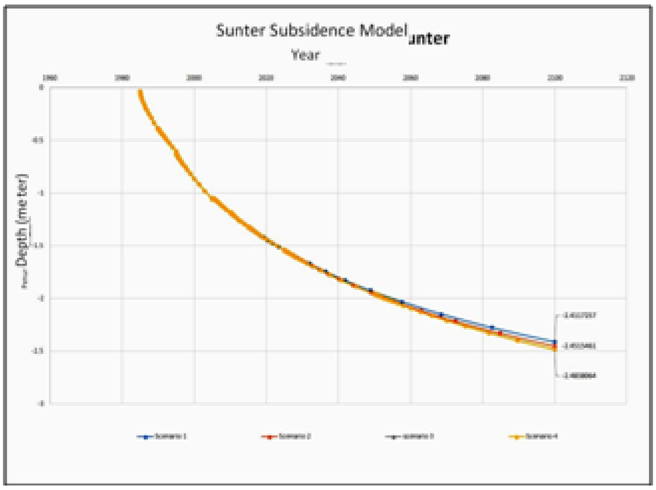

Figure 8: Subsidence graphic for 4 scenarios

The condition can occur due to the consolidation process contained in the Jakarta neighborhood very slowly. The consolidation process that occurs takes so that the water contained in the soil pores dissipated and experienced compression, causing subsidence.

Sensitivity analysis created for this model to find out whether or not the groundwater has affected the subsidence rate. The sensitivity analysis is using the assumption that the groundwater abstraction rise up five times the normal condition existing. The normal condition of the groundwater level decrease is around 0.3 m depth per year, but the extreme condition created up to 1.5 m meter depth per year. This scenario can happen if each and every person in Jakartaare using groundwater as their main source of daily needs, especially using deep well groundwater, as the unconfined water quality is not adequate for raw water.
As a result, the rate of subsidence has increased rapidly. The percentage of subsidence cannot be measured properly, but for approximately 100 years in the future, the subsidence level has difference 1.23-meter depth (Fig.9.).

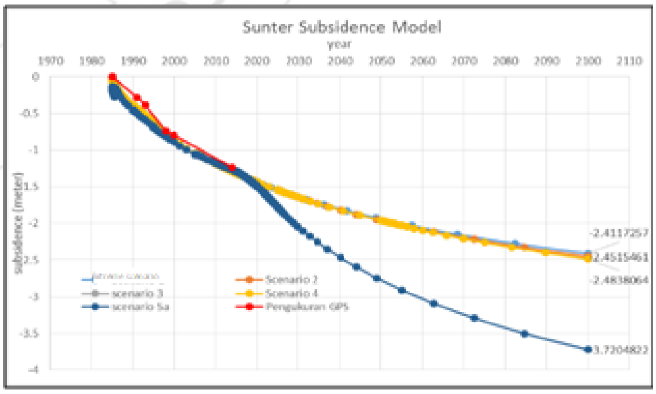

Figure 9: Subsidence graph with extreme scenario

As a processing result, the extreme ground water condition has increased the subsidence rate approximately about 30% for 5 times higher extraction to normal condition. Based on this assumption, if Jakarta citizen abstracted the groundwater excessively, then the result will be the increasing of subsidence rate, up to 30% higher than normal condition.

4. Conclusion

As a result, land subsidence in the area of North-Jakarta, Sunter, occurs as a natural consolidation. Groundwater level decrease occurs at the semi-confined aquifer layer deeper than 150 meters. Consolidation apparently has the same rate with release pore water pressure due to dissipation or groundwater pumping. Consolidation occurs more intensively in the uppermost layer intensively until a depth of about 30 meters Groundwater influence on subsidence at normal conditions less than 5%, while in extreme conditions to reach about 30%.

5. Future Scope

From this research there are hopefully improvement in Data Acuisistion in Jakarta, also this research is a basic principle for subsidence calculation based on settlement process.

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