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Sustainable energy development and water supply security in Kamojang Geothermal Field: The Energy-Water Nexus

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ABSTRACT

The Kamojang Geothermal Field (KGF) is a typical vapor dominated hydrothermal system in West Java, Indonesia. From 1983 to 2005, more than 160 million tons of steam have been exploited from the KGF and more than 30 million tons of water were injected into the reservoir system. Between 2009 and 2011, KGF has mass deficiency rate to maintain stable production.

Time lapse gravity monitoring can monitor mass balance in the reservoir system. Mass variation in the reservoir of KGF is estimated by this method. According to the calculation and history of production and injection, natural recharge to the KGF's reservoir is estimated at about 2.77 MT/year from 1999 to 2005 and 2.75 MT/year from 1999 to 2008.

Natural recharge, 50% of injected water, cooling system, drilling and other activities in KGF spend large amounts of fresh water. Water consumption for local people is about 0.055 MT/year. The water volume of KGF in dry season is 0.1 MT/month while in rainy season is about 4.6 MT/month. The water demands for sustainable geothermal production of KGF and local people's consumption will increase in the future. Integrated planning between the energy and water sectors in KGF therefore will be essential to meet rising demands for both resources.

1. INTRODUCTION

Energy demand is growing rapidly and is correlated to increasing population and industries in the world. The environmental impact of the energy industry development varies on different resources. Consumption of fossil fuel energy resources has a high environmental impact leads to global warming and climate change. Therefore, in recent years there has been a trend towards the increased commercialization of various renewable energy sources. According to fulfill energy demand and to cut environmental impact, we need the alternative energy sources. Energy generation also must consider water management and food production towards better sustainable environmental and energy usage. The geothermal energy is one of the renewable energy that has the potential as a good alternative in the country in the path of ring of fire.

Geothermal energy as a thermal energy generated and stored in the earth has some environmental consequences during its exploitation. The type of fluid of geothermal reservoir has different plant technologies and environmental impacts. Environmentally, vapor dominated of geothermal system has less impact than liquid dominated system. The effects of geothermal electricity production in an environmentally view are included land use, geological hazards, waste heat, atmospheric emissions, solid waste, emission to soil or water, water use, impact on biodiversity, noise and social impact (Bayer P., et al. (2013)). Sustainable production of geothermal energy resources is directly being affected by environmental impact supervision. In this present paper, we only consider the water use and consumption impact to the sustainable energy production.

Indonesia has a low electrification ratio due to growth of electricity demand is larger than generation capacity growth. Electricity generation from geothermal energy is only about 5 percent and plans to increase the use of renewable energy. Research shows that renewable energy sources can meet up to 35 percent of Indonesia's energy needs by 2035 (Leitmann J. (2009); Marpaung et al. (2012)). As first quarter of 2018 in EBTKE report, Indonesia has about 1.95 GWe installed capacity of geothermal power plant and in the last five years has a slightly slow growth rate (Figure 1). Geothermal power in particular can play a key role in shaping Indonesia's low carbon future. The geothermal potential in Indonesia is about 40% of the world potential, and can overcome the national electricity demand. In the environmental point of view, energy quality, and economic perspective, the sustainable of geothermal energy has a very important role in the future.

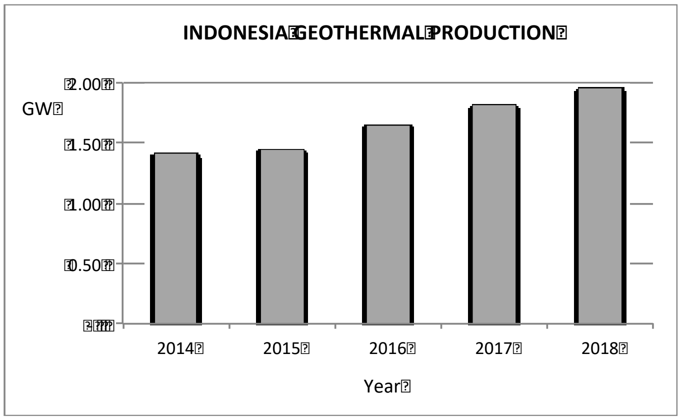

Figure 1: Indonesia Geothermal Production

Kamojang Geothermal Field (KGF), the oldest geothermal field in Indonesia, is located in Garut and Bandung area, West Java. The KGF is a vapor-dominated system with reservoir boundary covered an area of about 14 km^2 to 21 km^2 (Figure 2). The development in KGF increased gradually from 30 MWe since 1982 to 235 MWe in present. From 1983 to 2005, the production activity in KGF extracted more than 160 million tons of steam and increasing up to more than 270 million tons until 2015 (Table 1) (Directorate General EBTKE (2016)). During early production period from 1983 to 2005, they injected about 30 million tons the combine of condensed water, surface water and groundwater into the reservoir system. In order to keep up the large production rate, the geothermal industry continuously added some make-up wells in KGF. The amount rate of production is 8 to 13 MT/year, while injection rate to the reservoir has limited rate between 1.8 and 2 MT/year (Suryadarma et al. (2010)).

Tabel 1: Steam production in KGF (EBTKE (2016)

Periods	KGF Steam Production Mtons	Cummulative Steam Production Mtons
1983 – 2005	160.00	160.00
2006	8.10	168.10
2007	8.12	176.22
2008	12.10	188.32
2009	12.61	200.93
2010	12.45	213.38
2011	12.47	225.85
2012	10.88	236.72
2013	11.26	247.98
2014	10.49	258.47
2015	11.97	270.44

The large production and injection in more than a quarter century at KGF caused mass variation in geothermal reservoir, surface water and groundwater. The mass variation in the reservoir is largely controlled by production, injection, and natural recharge rate. The balanced supply of these three parameters will lead to sustainable development. This progressive development and increased production certainly transformed reservoir condition and the surrounding. We conducted the repeat gravity measurements in the geothermal field to monitor the sustainability and mass variation in the reservoir throughout exploitation.

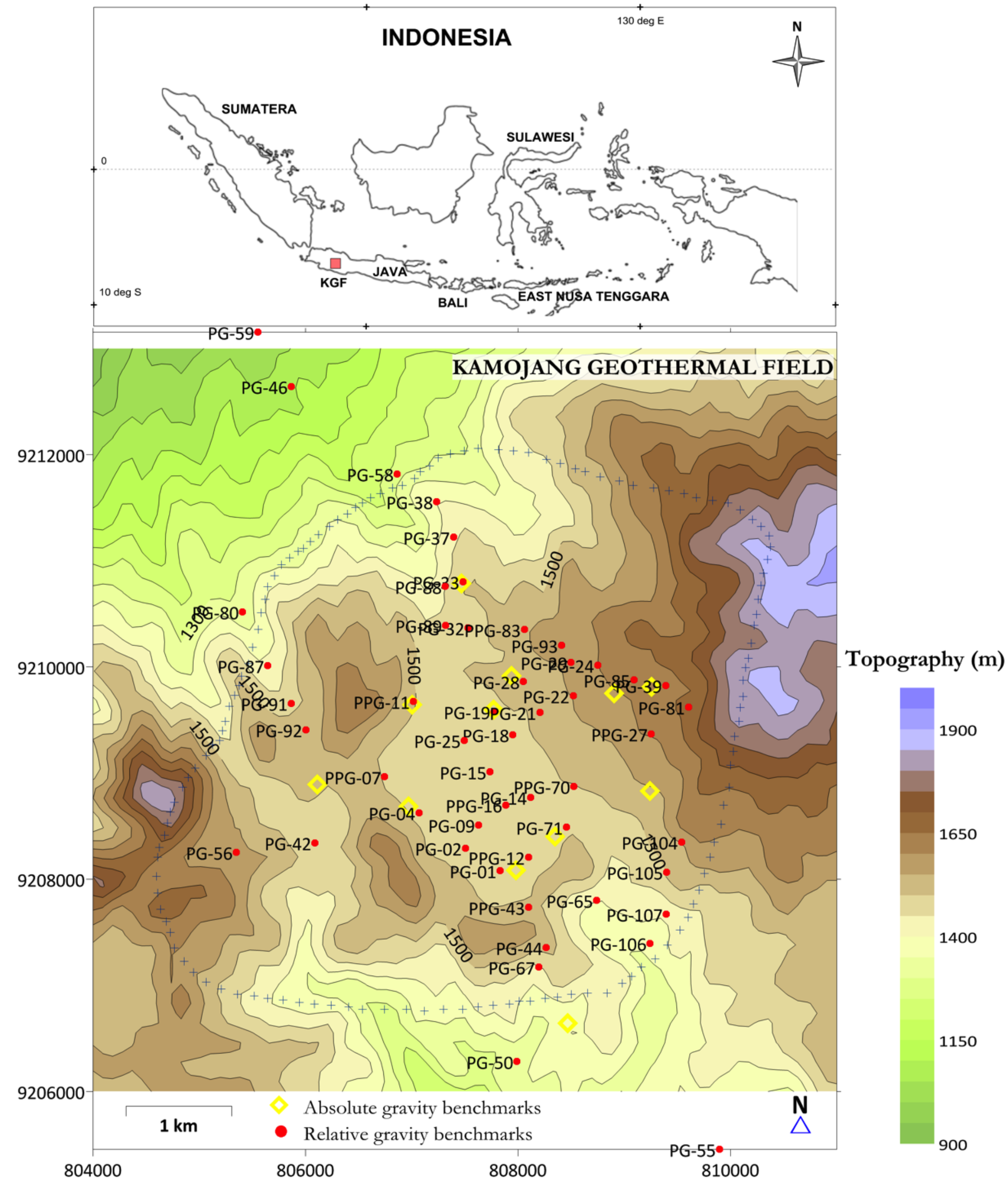

Figure 2: Kamojang Geothermal field with topographic contour, absolute gravity benchmarks (yellow diamond) and relative gravity benchmarks (red dot)

2. ENERGY-WATER NEXUS

Energy policy includes energy development, production, distribution, and consumption need some possible criteria of stable supply, economic efficiency and environmental compatibility. Water resource policy encompasses the collection, preparation, use and disposal of water need similar criteria to support human uses and protect environmental quality.

Energy and water are inseparably linked. Energy and water are the main living needs of people besides food. Some renewable energy, which is hydropower, geothermal, biomass, requires water to generate electricity. On the other hand, clean water production and consumption need some energy in their processes. Generally, hydropower, biomass or geothermal energy production will affect water consumption in the surrounding area and vice versa. The management between energy and water should consider availability and sustainability from these two factors.

2.1 Energy for Water

Clean water production requires energy. We use energy for lifting, moving, distributing, and treating water. Some water sources in the subsurface or deep groundwater reservoir need energy to pump water to the surface. Non-conventional water sources, such as reclaimed wastewater or desalinated seawater need a lot of energy. Energy intensities per cubic meters of clean water produced vary between different sources, e.g. about 0.37 kWh from locally produced surface water, 0.66–0.87 kWh from reclaimed wastewater and 2.6–4.36 kWh from desalinated seawater (Siebert et al., 2010; SEI, 2011).

Groundwater and especially deep groundwater generally need more energy intensive than river or lake water. Total energy use for water in some countries is dominant used for pumping groundwater. Water imports to dry areas or cities become more energy intensive as it raises the distance transportation from the water source. A lack of water security can lead to increased energy demand and vice versa.

2.2 Water for Energy

Energy industry needs water for most processes of development. The amount of water for the energy industry is about 8 percent of global water withdrawals (SEI, 2011). We use water for the extraction, mining, processing, refining, and residue disposal of fossil fuels, as well as for growing biofuels and for generating electricity. Biomass energy requires water for growing feedstock, which substantially needs more water than fossil fuels, requiring about 10,000–100,000 liters per Giga Joule (GJ) of energy. Oil and gas production need 1–10 liters of water per GJ of energy, oil sands about 100–1000 liters (GAO, 2010; Gerbens-Leenes et al., 2009; WEF, 2011; SEI, 2011). Hydropower needs water as an energy source to generate electricity. The produced energy from hydropower is depending to water flow.

Geothermal energy needs water as main production that comes from a reservoir. Water from surface, groundwater, other reservoirs or injection wells enter to geothermal reservoir. In Geothermal energy exploitation, large amounts of water are also needed for some energy exploitation processes. Electricity generation in the geothermal field consumes large water for the drilling of production and injection, construct and run the wells. Water injection to geothermal reservoir is the most consumed water for geothermal operation. Harto et al. (2013) explained the large water consumptions in the geothermal field come from drilling and construction, stimulation and circulation testing, and plant operation. There are two plant operations, which is above ground operational losses, such as for a cooling system, and below ground operational losses, such as injected water loss.

Sustainability in geothermal exploitation is defined as the ability to economically support the installed capacity in sustained for 100 to 300 years (Sanyal, 2005). The sustainable geothermal energy exploitation depends on the water availability and demand. The water demand of geothermal operation is likely going to increase due to time operation, increased installed capacity and some water loss. The water demand is also coming from local people, domestic needs, and some local industries around geothermal field.

3. ENERGY SECURITY

The United Nations has defined the energy security as "the access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses". On the other hand, the International Energy Agency has an energy security definition as "uninterrupted physical availability of energy at a price, which is affordable, while respecting environmental concerns". The stable supply, affordability in economics, and environment friendly are some limits in the energy security.

Renewable energy that maintains the long time production, or called as renewable-sustainable energy, is a main alternative energy. Geothermal energy, as one of the potential renewable-sustainable energy, will meet sustainable production with good monitoring. Geothermal monitoring is an important stage before and during production. Some monitoring methods are applied in the geothermal field with different goals. In this present study, we localized monitoring for sustainable energy development in Kamojang geothermal field, Indonesia.

In the early 20th century, Indonesia government started geothermal exploration in KGF and continued successfully with the first shallow test wells. They generated the first electrical power at Kamojang in 1978 when a small (mono block 250 kWe), a free exhaust-type turbine was installed and then the design of the first large-scale geothermal power plant was completed in 1979 (Hochstein and Sudarman (2008)). In late 1982, they installed a production capacity of 30 MWe (Unit I) in KGF. Development drilling continued with two 55 MWe units (Units II and III) in 1987, a 60 MWe (unit IV) in 2007, and a 35 MWe (Unit V) to complete a 235 MWe installed capacity, in 2015.

There are more than 66 wells of the active production wells, injection wells and monitoring wells. Pertamina has drilled more than 76 wells with bottom hole temperatures ranging from 115 to 245°C (Moeljanto (2004)). They use three to five deep unproductive wells in the center of the field as injection wells. The decline of the steam flow rate notably occurred at some production wells. Doddy et al. (2000) explained the decline rate of the production wells use the type curve matching in 1999 is about 7.43 %/year. We conducted the repeated gravity measurements to monitor the change in the geothermal reservoir throughout exploitation.

3.1 Gravity monitoring for mass balance estimation

The present monitoring study for mass balance estimation uses gravity and hydrology data. Gravity monitoring data estimate the mass variation of water in the geothermal reservoir. Repeat gravity measurement or microgravity techniques generally used to distinguish data in the range of 1 – 500 μGal from those in geophysical prospecting (Bouguer anomalies) which usually lie in the range 500-100,000 μGal (Hunt (2000)). This method is also applicable to investigate the dynamic processes in various types of volcanoes and geothermal field. Gravity changes characterize the subsurface processes: i.e., the mass of the intrusion or hydrothermal flow (Battaglia et al. (2003); Rymer et al. (1998)).

Gravity changes during the exploitation of the geothermal reservoir may show negative or positive variation. The temporal gravity changes can give insight into the mass variation and the location of places where net mass loss or gain occurred. Measurements of repeat gravity are pertinent to estimate the natural recharge into the reservoir and its increase in response to production-induced pressure decline (Hunt (1970); Geri et al. (1985); Allis and Hunt (1986); Nordquist et al. (2004)). We evaluate the gravity monitoring data to offer the mass balance model of the Kamojang geothermal system.

The relative gravity measurements in KGF 1999, 2005 and 2008 have been performed using LaCoste Romberg type G or Scintrex CG3 gravimeter. We assumed the quality data is similar with accuracy up to 10 μGal. These relative gravimeters have high accuracy and low residual drift. Relative gravimeter calibrates the value to the absolute gravity point. Gravity measurements in 2009, 2010 and 2011 used A10 absolute gravimeter, which is a portable absolute gravimeter. This has good precision and accuracy factor of 10 μGal. The A10 uses laser, interferometer, long period inertial isolation device and an atomic clock to measure the position of the test mass very accurately (Micro-g LaCoste Inc. (2006)).

We conducted the round measurement of gravity method, a close looping technique and a careful field measurement, covering an area of about 35 km^2 in KGF. The gravity measurement considers these procedures to get accurate data, cut the drift errors and uncertainty, and to find the shock-induced tares. Gravity monitoring in 1999 and 2005 which PG55 is reference benchmark, consists of a network of more than 51 relative gravity benchmarks and decreasing in 2008 is about 30 benchmarks due to some benchmarks were lost or broken. There are 12 absolute gravity benchmarks in 2009, 2010 and 2011 measurement. We select the available absolute gravity benchmarks around geothermal field. We need locations that have a flat surface, enough area for absolute gravity equipment, small noise and good contact with the ground. Absolute gravity measurements not refer a reference benchmark. The corrections and calibration were conducted in the data processing of the observed gravity data in KGF. We classify the correction factors of the gravity measurement into the correction of variations with position, variation with time and mass dynamics in the earth (Hunt (2000)). The correction factors of gravity monitoring are shown in Table 2. The earlier paper (Sofyan et al. (2011)) explained the detail gravity measurement and data processing in KGF. Absolute and relative gravity benchmarks in KGF are also shown in Figure 2.

We record the temporal residual gravity changes over benchmarks to check in terms of mass variation in subsurface. The smoothed contouring data of long wavelength have various gravity changes range as in Figure 3. The gravity changes helps to give a picture of the mass movements that have occurred as a result of the production and injection activities between years and natural recharge from outside of the reservoir.

Tabel 2: Correction of the gravity monitoring (Hunt, (2000))

Correction factors	*Difference*	*Correction types*	*At the KGF*
Variation with position	- The difference height above sea level (about 300 μgal /m) - The difference latitude position (about 0.8 μgal /m) - The difference longitude position (< 0.01 μgal /m)	Height and tide correction	calculated
Variation with time	Difference position of the sun and moon	Tide correction	calculated
Drift	The difference condition of gravimeter (Caused by the movement)	Drift correction	calculated
Topographic change/ Ground subsidence	The difference elevation of the station	Free air correction $\Delta g_v = \frac{dg}{dz}\Delta h$ (Telford, 1976)	calculated
Variation in shallow groundwater level	The difference of the shallow groundwater volume (the rainfall rate changes) (about 5-10 μgal (Goodkind, 1986))	$\Delta g_w = 2\pi G\rho\varphi(1-S)\Delta h$ (Hunt, 2000)	Negligible (The RGM in the similar season)
Variation in soil moisture	The difference in the saturation (The rainfall rate changes)	$\Delta g_a = 2\pi G\rho\varphi\Delta Sd$ (Hunt, 2000)	Negligible (The RGM in the similar season)
Atmospheric pressure variation	The changes of air pressure (< 5 hPa or about 2 μGal)	Air pressure correction	Negligible (It is too small)
Active volcanism	The emplacement of the magma at shallow depths	Volcanism correction	Negligible (No relation to KGF location)
Mining operation	The removal of mineral ore, rock and other mining from underground	Mass change correction	Negligible (No relation to KGF location)
Variation of the surrounding area	The difference surface topography of the terrain (such as construction etc.)	Terrain correction	Negligible (It is too small in the KGF)

Mass balance applies the mass conservation to the analysis of physical systems. We analyze and estimate the mass that enters or leaves the system through production, injection, and natural recharge. Gauss's theory (Hammer, 1945; Hunt, 2000) explains the mass variations as:

$$\Delta m = \frac{1}{2\pi G}\sum(\Delta g.\Delta A) \qquad (1)$$

where Δm = the mass changes (kg), Δg = the gravity changes (mGal), ΔA = Area concerned (km^2), G = the gravitational constant $6.672 x 10^{-11}$ Nm^2kg^{-2}. The gravity change Δg for each grid as calculated below:

$$1\Delta g = \frac{dg_{i,j}+ dg_{i+1,j},+dg_{i,j+1}+ dg_{i+1,j+1}}{4} \qquad (2)$$

where dg_i, $dg_{i+1,j}$, dgi_{j+1}, $dg_{i+1,j+1}$ are the gravity change at one grid square.

This method has advantages in the way of averaging gravity changes in each grid area. It means that these results will also averaging and reducing some uncertainty factors of these gravity data. In the simple error propagation analysis, uncertainty in some observed variables can be joined become the last result. The last result determines a smaller uncertainty than total error. Error propagation δR in general functions R is:

$$\delta R = \sqrt{\left(\frac{\partial R}{\partial X}\delta X\right)^2 + \left(\frac{\partial R}{\partial Y}\delta Y\right)^2 + \cdots} \qquad (3)$$

R is a function of variables X,Y and other variables (R(X,Y,…)).

In this mass variation analysis at KGF by applying the Gauss's potential theorem to gravity change data, we could not avoid "error in tailing off" and "error in gravity datum" (Hammer, 1945; Sugihara and Ishido, 1998). Gravity measurement at KGF could not cover the area, particularly in the NE and SW part. This is a remote area with the mountains and steep area and it is difficult for gravity monitoring. Previous gravity data covered small area only about 25 km^2. According to this analysis, we make an assumption to manage these problems. We expected that gravity change data in larger area would make a close loop of Gaussian method.

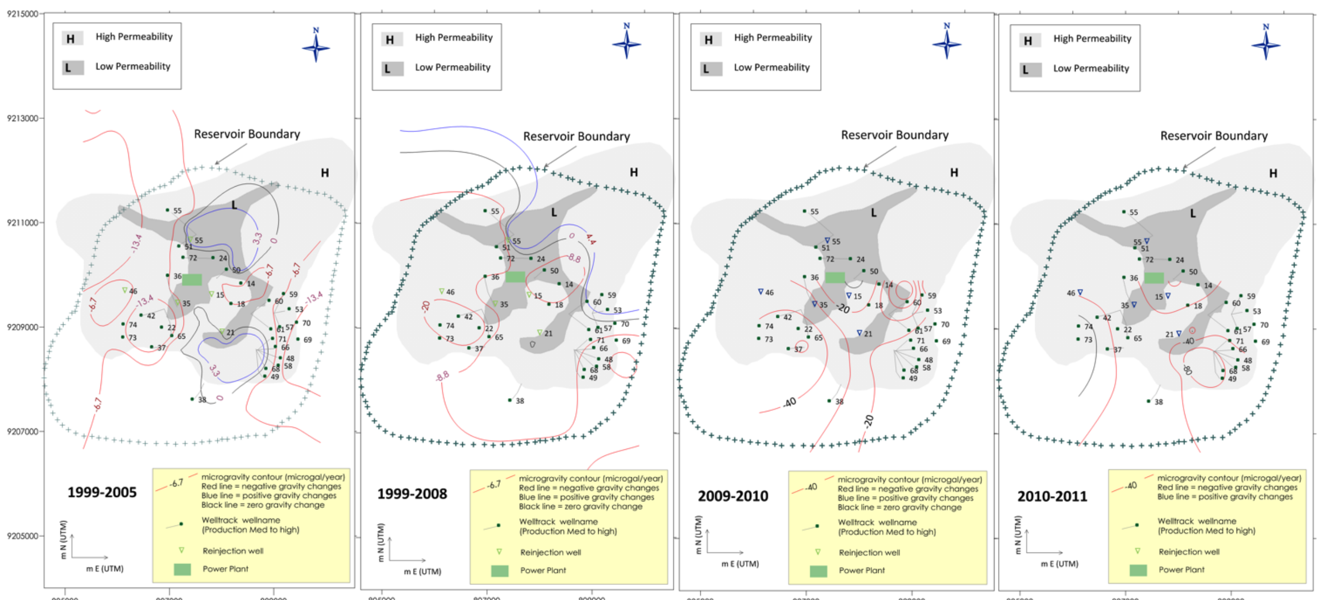

Figure 3: Gravity changes in KGF

We divide the corrected gravity change map into grids. The mass changes of the 1999-2005 show decrease about -20.07 million tons for 6 years period or equal to -3.34 MT/year. Since 1983 to 2005, more than 160 x 106 tons of steam have been exploited from KGF and more than 30 x 106 tons of water has been injected to KGF. More than 40 production wells supplied steam constantly (Sanyal et al. (2000)). The total production rate from the field has remained relatively constant. The average of the total production rate of the 1999 - 2005 is about 7.98 MT/ year. The average total injection rate of the 1999-2005 is about 1.87 MT/ year. The net produced mass (total produced mass – total injected mass) at the KGF during this period is about 6.11 MT/ year. Assuming all the injected water entered to the reservoir, the estimated total rate of the natural recharge of the Kamojang reservoir system is about 2.77 MT/year. The recharge rate to KGF of about 45% of the net produced mass has occurred from the natural flow and lateral aquifers.

During 1999 to 2008, the mass variation in KGF decreased to a -3.78 MT/year. In 2007, the Kamojang production capacity was improved during the increased install capacity of 200 MWe. More than 40 production wells supplied steam to the four generator units. The average of the 1999 – 2008 total production rates per year increased to about 8.35 MT/year. During this period, the injection rate slightly decreased to 1.82 MT/year (Pertamina (2008)). The net produced mass at KGF during this period is about 6.53 MT/year. The natural recharge to the Kamojang reservoir system in this period is about 2.75 MT/year if all injected water entered to the reservoir.

The gravity variations of the 2009 - 2010 period and 2010-2011 periods come from absolute gravity data. The recalculation of mass variation in KGF between 2009 and 2010 decreased to -7.1 MT/year. This present calculation is different from earlier published result (Sofyan et al., 2011) -8.2 MT/year because of the larger calculation area. The mass variation between 2010 and 2011 more decreased up to -7.4 MT. The average production and injection rate in this calculation are estimated from figures of the production - injection rate of KGF in published data (Pertamina (2008); Suryadarma et al. (2010)). We assumed the production and injection rate between 2010 and 2011 is not different from the previous year. We estimate the mass balance in KGF in Table 3.

Tabel 3: Mass balance in KGF

	Production* MT/year	Injection* MT/year	Mass change MT/year	Natural Recharge MT/year
1999-2005	7.98	1.87	-3.34	2.77
1999-2008	8.35	1.82	-3.78	2.75
2009-2010	12	2	-7.1	2.9
2010-2011	12	2	-7.4	2.6

Note: Production and injection rate were estimated from data figures (Pertamina, 2008; Suryadarma et al., 2010)

4. WATER SECURITY

Water security is defined as the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socioeconomic development, for ensuring protection against waterborne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability (UN-Water (2013)). Access to safe drinking water and sanitation have recently become a human right. While not part of the most water security definition yet, availability of and access to water for other human and ecosystem uses is also very important from a nexus perspective (Grey et al. (2007)). Water is a renewable resource, and globally there is enough water.

4.1 Water availability

The geothermal exploitation will influence water condition on the surface and in the subsurface. Menjoz and Sauty (1982) explained the general alteration in water resources during geothermal exploitation is a hydraulic effect or pressure change, thermal effect, and chemical effect. Some changes of water in quantity and quality through withdrawal, generating electricity, some evaporated and consumption. We assumed the water withdrawn is a condition when production water is returned through re-injection or other activities into original sources. There is merely a slightly altered state of the water resource. The water consumption is not only the consumed water by people or living creature, but we consider also the water, which is transformed into another state such that it cannot be later used for other purposes within the natural annual water cycle in the region, such as evaporation process.

Since 2008 in the increasing production, KGF needs steam from the geothermal reservoir about 1.08 million tons or more in one moth to generate 200 MW electricity. The water from injection wells and limited natural recharge enter to the geothermal reservoir as a water resource. If the steam production rate larger than injection and the natural recharge rate, some fluid mass in the reservoir will be vanish or negative mass variation.

In the geochemical studies, the reservoir in the KGF is originated from meteoric water and not from magnetic fluid. The natural recharges to the geothermal reservoir come from rainwater. From 30 years measurement, Aldrian E. (2003) explained the average rainfall rate of the region A of Indonesia (including the Java Island and KGF) is influenced by Australia monsoon. Region A has one peak and one-minimum and experiences strong influences of two monsoons. Those are the wet northwest monsoon from November to March and the dry southeast monsoon from May to September. The 33 years (1961-1993) monthly rainfall average in Indonesia can be seen in Figure 4.

Mock F.J. explained the water balance from precipitation factor, in 1973. The water to come from rainfall will transfer or out to the air by evaporation, enter to the subsurface by infiltration or become surface water flow like a river or base flow in the groundwater. Mock simply explained the precipitation (P) turns to Evapotranspiration (Ea), groundwater storage change (ΔGs), and total run-off (TRO) in the equation:

$$P = E_a + \Delta G_s + TRO \qquad (4)$$

The average precipitation trend around KGF also followed the region A of Indonesia precipitation trend. Rafa (2012) took data from one precipitation station (Leles station) near to KGF. Leles station is about 8 km from KGF. The average precipitation data at Leles station come from 10 years' data from 2001 to 2010. According to difficulty of direct measurement of evapotranspiration rate, which it is influenced by many factors, estimation methods are developed using meteorological data. Rafa (2012) uses Penman-Monteith Method to estimate the limited evapotranspiration monthly rate between 2001 and 2010. The largest evapotranspiration value of KGF average between 2001 and 2010 occurred in February, while the smallest value happened in May. Rafa (2012) also estimated the total run-off (TRO) data in KGF between 2001 and 2010. The total run off trend is similar to precipitation trend. October has the lowest of total run off, while March has the largest of total run-off.

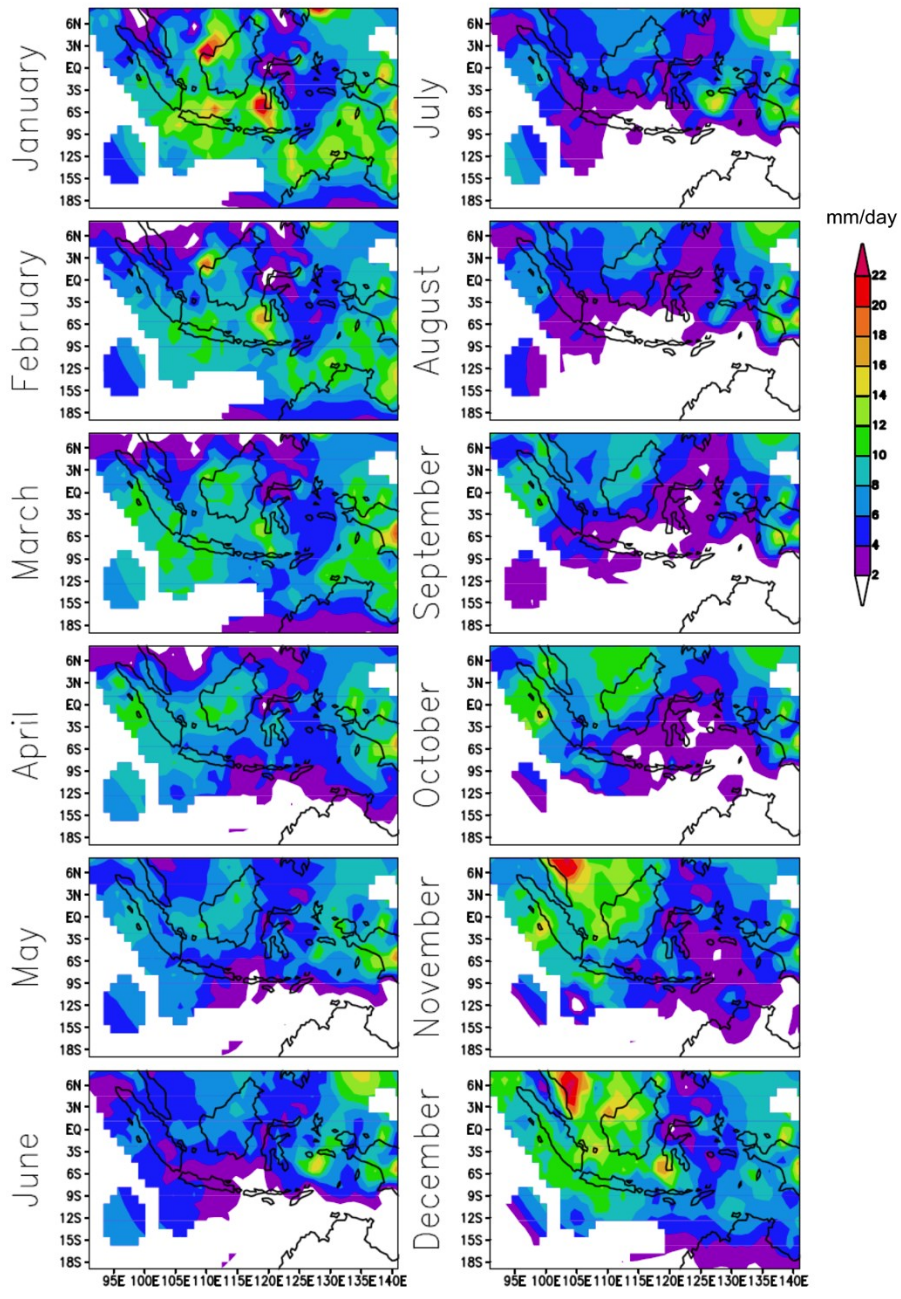

Figure 4: The 33 year (1961-1993) monthly rainfall average in Indonesia (Aldrian (2003))

The unit quantities in meteorological parameters of water balance, such as precipitation, evapotranspiration and total run-off, usually use unit in mm/year or mm/month given to a block with an area of 1 m^2. We multiply these parameters by reservoir area of KGF 14 km^2 to estimate the water volume. The earlier research (Saptadji MN and Artika Y, 2012) explained the average potential availability of surface water each month in KGF by water balance data between 2004 and 2008. The average value per month of water balance parameters in KGF can be seen in Figure 5.

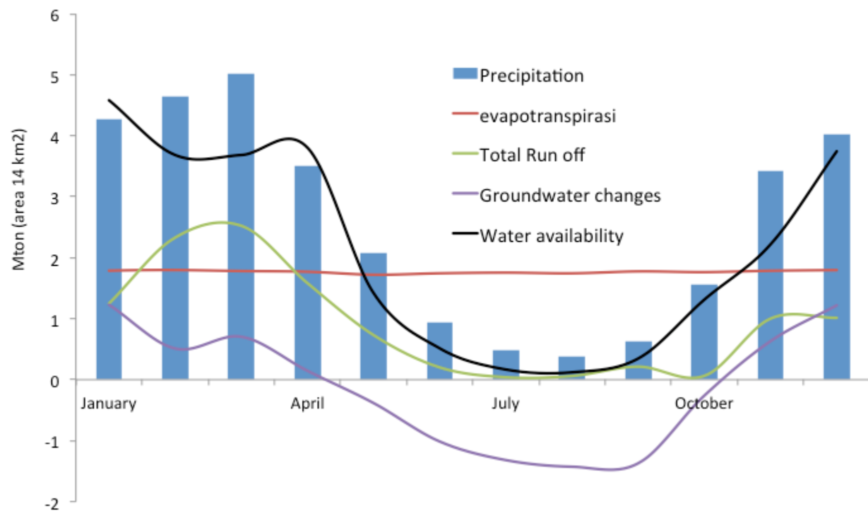

Figure 5: The average of water balance parameters in KGF (Saptadji MN and Artika Y (2012); Rafa M (2012))

4.2 Water demand

The water demand in KGF is coming from three sectors that are from the local people, from domestic or local industry, and from geothermal company. The area of water demand estimation is a little wider than reservoir boundary because natural recharge to geothermal reservoir also comes from surrounding. The area for water demand estimation is about 24.5 km^2.

KGF is located in Laksana village that about 8,000 people live in this village (information from local government). The number of local people who live in the water demand estimation area of KGF is about 900 residents (Rafa M., 2012). In the raw estimation, the number of people in this area will increase to about 1000 residents in the recent year. Local peoples who live inside of the geothermal area and around KGF need a water supply as one of the main daily needs. The average water, which is required for one resident in the village area, is about 100 to 150 liter/day (Indonesia National standard/ SNI (2002)). The main water resource is coming from groundwater and surface water. Through simple calculation, the largest water demand from local people is about 0.05475 MT/year.

Local peoples of KGF work as farmers, who growing vegetables like potatoes, cabbage, sweet potatoes, cassava and also who raise local goats. Some local peoples work in geothermal company and other jobs. Farmers need the amount of water significantly. The water needs of one goat are about 5 liter/day (SNI (2002)). If we assumed there are 200 goats in this area, the average required water in one year is about 0.365 kilo tons. There are some recreation areas, small hotels, school, mosque, local stores, and fish farms in this area, which also required an amount of water. Assumption of the total consumption of these local industries is about 0.0005 MT/year.

The geothermal company required a huge amount of water in its operation. The large water is consumed in the drilling of geothermal production and injection, constructing and operating the wells. Water injection to geothermal reservoir is the most consumed water for geothermal operation. About 50-60% of injection water are originally from condensed water of steam production and the rest is coming from surface water and groundwater (Rafa (2012)). The injection rate of KGF after increase production in 2008 is about 2 MT/year. We assumed the 40-50% of injection rate as consumed water is about 0.8 to 1 MT/year. The largest water demand comes from geothermal activity. The water demand from 2001 to 2010 in KGF is shown in Figure 6.

5. DISCUSSION

Groundwater conservation is an effort to keep the sustainable production of groundwater reservoir. The recharge into groundwater keep up the aquifer to supply the sufficient amount water to the geothermal reservoir as a natural recharge, without interfering supply to local people. Some artificial recharge to aquifer in KGF can be managed by collecting some run-off water and reforestation. Pertamina, the geothermal company who operated KGF, already has some reforestation program around geothermal area.

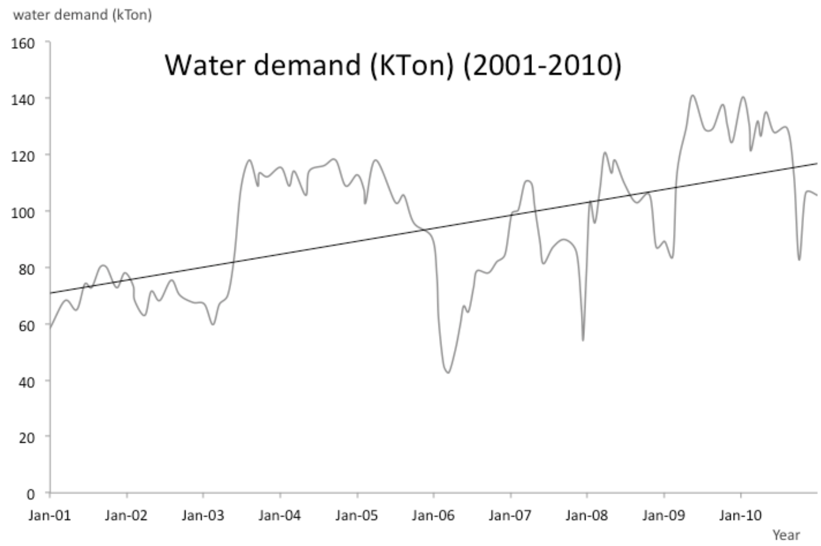

Figure 6: The water demand in KGF between 2001 and 2010 (Rafa M. (2012))

The challenge is the increasing of water demand of surface water and groundwater from all sectors in the future. The population of local people around KGF increasing follows to national population trend. The increasing of economic level of local people around KGF becomes another reason of increasing new residents. The geothermal production in KGF also has a plan to the next level stage with more capacity because of the escalation of national electrical demand. Refer to Figure 6, if the largest demand in 2010 is about 140ktons/month, the double water demand will take place in 2040. According to the increased water and energy demand in the future with limited water resources in KGF, the water management is required to keep a balance of water-energy nexus. The simple water management in geothermal field can be viewed in Figure 7.

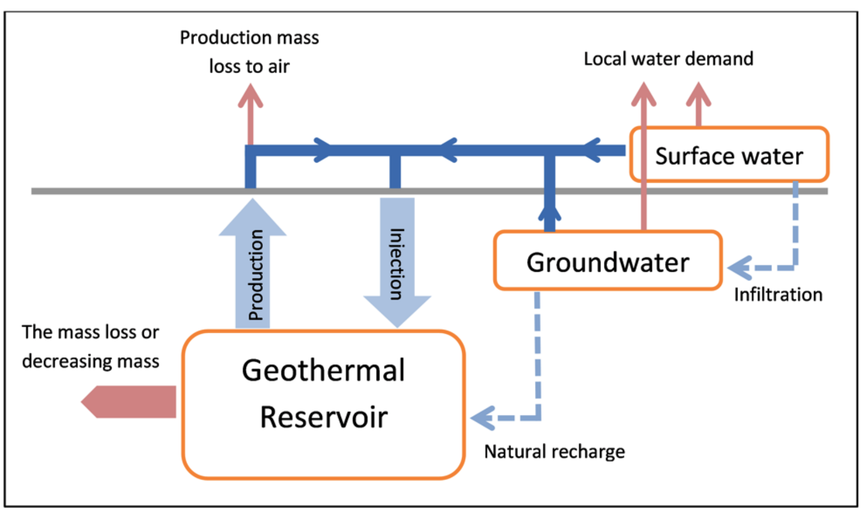

Figure 7: The simple water management in geothermal field

According to the average of water availability in KGF each month, the surface water has a potential water amount less than 1 MT/month during dry season between June and September. At the same time during the dry season May to October, it also has a decreased mass of groundwater in the KGF. The water balance in dry season must be more considered to monitor the water condition. The repeated gravity measurements in this research, which estimates the mass variation in geothermal reservoir, were conducted always during a dry season. The mass balance in geothermal reservoir showed the limited natural recharge, which enters to geothermal reservoir, is roughly 2.75 to 2.9 MT/year or average about 0.23 to 0.24 MT/month. According to this situation, during four months in the dry season between June and September, the water demand roughly will be about 1.31 MT, which is 0.33 MT for injection, 0.02 MT for local demand and 0.96 MT for natural recharge, while the surface water available is around 1.15 MT. This is a negative balance situation (Table 4).

The mass loss in geothermal reservoir after 200 MWe capacity of KGF is about -7.1 to -7.4 MT/year. This is a huge loss if it is compared to the limited natural recharge. One effective way to scale down this mass loss is to increase the injection rate. According to previous research (Sofyan et al., 2011), about 50% of the injection water will be taken from surface water and groundwater. The mass balance in the geothermal reservoir has a direct interest to water balance on the surface. If we consider the sustainable production of KGF, it is important to keep balance between input and output mass in the reservoir. In the steady condition, the production capacity forecast in KGF possibility will decrease in the future.

Tabel 4: Water balance in KGF during dry season between June and September

Water demand (June-September) (MT)			Water available (MT)
50% of Injection	Local demand	Natural recharge	Surface water
0.33	0.02	0.96	1.15

6. CONCLUSION

Mass variation in the reservoir of KGF from 1999 to 2005 is about −3.34 MT/year, while being about −3.78 MT/year from 1999 to 2008. According to the history of production and injection, we estimate the natural recharge to the KGF's reservoir is about 2.77 MT/year from 1999 to 2005 and 2.75 MT/year from 1999 to 2008. Between 2009 and 2010, the mass loss in the geothermal reservoir is about -7.1 MT/year and natural recharge is about 2.9 MT/year. The last period between 2010 and 2011 have mass loss about -7.4 MT/year and natural recharge about 2.6 MT/year. In order to maintain the 235 MWe sustainable production of KGF, the geothermal company should add some production make-up wells, increase the water injection rate and the water supply for natural recharge.

The abundant amount of water is required for sustainable geothermal energy production and the domestic water supply need. Based on Geochemical studies, the water in geothermal reservoir of KGF is originally coming from meteoric water. The precipitation in KGF has rainfall patterns followed the region A of an Indonesia precipitation trend that is influenced by the Australian monsoon. According to the reservoir area of 14 km^2, the available surface water in KGF is about 3.88 MT during six months of dry season and about 21.73 MT during six months of rainy season. The water balance has a correlation between precipitations, available surface water and variation of groundwater. Available surface water and groundwater will influence a natural recharge to geothermal reservoir. According to water balance estimation, during the dry season there is a negative trend when water discharge larger than precipitation recharge and a positive trend in the rainy season. The solution of this situation is the injection water in KGF should be conducted during the rainy season.

The water demand in KGF is come from three sectors, which are from the local people, domestic or local industry, and geothermal company. The water consumption of 1000 local people around KGF is about 0.055 MT/year, while the total consumption of local industries is estimated about 0.0005 MT/year. The geothermal company required a huge amount of water in its operation, especially for water injection. The 40-50% of injection rate as consumed water, which is come from surface water and groundwater, is about 0.8 to 1 MT/year. The water demand in KGF is increasing due to increase population and geothermal activity. The water demands for sustainable geothermal production of KGF and for local people's consumption will increase in the future. Integrated planning between the energy and water sectors in KGF therefore will be essential to meet rising demands for both resources.

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