Climatological and land use evaluation to maintain water supply in Pulai reservoir, Bintan island - Indonesia

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Abstract: Pulai reservoir with an area of 49.9 ha and maximum depth of 12 m, serves as clean water resources for Tanjung Pinang city, Bintan island. The objective of this research was to evaluate the fluctuation of water level on reservoir, related to the climatological and land use conditions. Water level in January 2009 was 400 cm and continued to decrease to 105 cm in August 2009 that ceased the water supply. The rainfall during ten months study period (January – October 2009) was 1,968 mm, below of its average level of 2,447 mm. The dry spell reduced the water supply input to reservoir for about 2.5 million m³ or equivalent to four months of clean water supply. Mean monthly air temperature was also increased by 1 °C compared to the last 29 years. A similar trend was observed for humidity, where its mean value of 85.9% decreased to 83.3%. Initially, the catchment area was 474.12 ha, covered by protected forest (98%). However, in 2009 the remaining forest area was only 8.15%. It suggested the decreasing of water storage capacity. It could be explained that the climate change and uncontrolled land use may contribute to the water crisis of Pulai reservoir.

1. Introduction
Watershed is a stretch of area which is limited by topographic boundaries (ridge), which if the rain is to be accommodated, flowed through the tributaries and out on the main river and then to the sea. This changes rainwater into the river flow and flow into the sea through a long process in the watershed. Therefore, the watershed can be assumed as a hydrological system, where rain is an input and the characteristics of water product (quality, quantity and distribution of water) flows into the sea as an output. If the process is still running well, the surface water fluctuations and sediment content are relatively smaller [1].

The process is influenced by hydrological, geomorphological, geological, topographic, climatological, soil and land use factors. These factors are interrelated with each other and land use is a factor that is rapidly changing in accordance with the development of population and socio-economic level of the community.

Land use change has a linear relationship with an increase in built area. In forests, the soil surface is mostly filled with litter that hold rainwater flows, slowing down surface flow and can further increase soil organic matter, so that the soil is looser, microorganisms thrive, all of which will increase infiltration capacity and permeability of soil. In addition, plant roots also increase infiltration capacity and water permeability.

In the conservation context of natural resources, according to [2] plants have many functions. Plants intercept rainwater which reduce rainwater energy (splash erosion) and reduce the runoff, decrease the
runoff velocity, decrease soil displacement, increase soil aggregation and porosity, increase biological activity in soil and soil moisture and also increase storage capacity.

Land use changes affect the infiltration capacity and surface water storage or a combination from both, and the subsequent effect is to cause changes in surface flow [3]. The decrease in infiltration capacity has more influence on the volume of surface flow, while the surface reservoir has more influence on the slowing (delay) of the surface flow to flow up to the outlet watershed.

In addition, for land use factors, rainfall is a very important factor in the watershed hydrological system. Rainfall patterns affect the processes that occur in the watershed. If the characteristics of the rain change, the yield of the water coming out in the watershed will also change. Global climate change causes a shift in the season, where the dry season will last longer resulting in a prolonged drought.

According to [4] the impacts of global climate change, increases of extreme events, such as huge rainfall, high air temperatures and storms, could also cause water scarcity. This water scarcity has a much greater intensity and impact on small islands. In small islands, the river flow is short, the catchment area is small, thus water reserves both on the surface and below the ground are very limited. When there is only a small disturbance to rainfall, the impact on water reserves is strongly observed.

Indonesia is the largest archipelagic country in the world which consists of 17,508 islands that have a very high level of vulnerability to disasters and climate change. Climate change exacerbates and increases the complexity of problems in small islands such as the availability of clean water, sea water intrusion, sea water abrasion and ecosystem degradation.

Bintan Island is one of 111 outermost small islands that have been set by the government based on Presidential Decree No. 6 of 2017 concerning the determination of the outermost small islands. Bintan Island is a specific national strategic region, with natural resources and environmental services. It also has a strategic role in maintaining the sovereignty of the state. Bintan Island, Batam and Karimun are planned as a development area for Special Economic Zones (SEZ) through collaboration with the government of Singapore. This SEZ is a node of the centre of superior economic activity, supported by excellent service facilities and the capacity of infrastructure that is internationally competitive. The development of this special economic zone certainly requires large amounts of water but on the other hand, the availability of water is very limited. In the future, pressures on water resources will increase, both from the impact of economic development, such as land conversion, pollution and over exploitation; and the impact of global climate change, such as an increase in extreme rain.

Pulai Reservoir lies in Bintan Island as a water supply for Tanjung Pinang city. Based on the interpretation of the 2007 SPOT image, the reservoir area is approximately 49.9 ha. The maximum depth of the Pulai reservoir is around 12 m with a relatively flat reservoir. This reservoir is elongated with four rivers flowing into the reservoir and has a spill way at a height of 11.75 m.

In 2009 Tanjung Pinang city, experienced a water crisis, which was caused by the occurrence of extreme dry season. Pulai reservoir, which is the main source of raw water for PDAM (national drinking water company) Tirta Janggi, experienced a significant deficit, almost three months from June to August that influenced the operational PDAM. Therefore, the objective of this research was to evaluate the fluctuation of water levels in the Pulai reservoir, related to climatological and land use conditions, and how to increase the capacity of the Pulai reservoir.

2. Materials and methods
The data in this study was obtained from secondary data and observations in the field. Secondary data, such as rainfall and meteorological data was obtained from Tanjung Pinang meteorological station which is located at an altitude of 37.5 m above sea level [5]. Reservoir water level and intake discharge data, as well as water production capacity were collected from PDAM Tirta Janggi Tanjung Pinang, and the protected forest area map was obtained from the Tanjung Pinang forestry service, as well as data and information related to the Pulai reservoir from the Riau Islands government [6]. Data on land use types was obtained from the interpretation of satellite images and field ground check.
2.1. Processing and analysis of data

Physical data processing of study areas related to aspects of space were analysed by Geographic Information System (GIS), including distribution of land use, topographic distribution and determination of the catchment area of the Pulai Reservoir. Meteorological data processing was carried out with weather-parameter statistical analysis of data series for the past 30 years (1980 - 2009).

The availability of water in the Pulai Reservoir was based on the calculation of monthly flow derived from the catchment using the Thornthwaite and Matter water balance methods. This method requires input of monthly rainfall data, temperature, astronomical location, land use map, land map and average height of watershed. Land use maps and land maps were used to calculate "Water Holding Capacity (WHC)", which is influenced by soil texture and root zone. Based on the analysis of these two param, the WHC value of the study area was estimated at 150.

The distribution and accumulation of monthly flows from catchment were used for the analysis of reservoir water balance. Cumulative flow was analysed using the "Simple Mass Curve" approach. The mass flow rate of the incoming flow can be used to determine the amount of water available that is safe to be used throughout the year. The amount of availability of water was determined based on the cumulative flow debit slope [7]. The water balance of the Pulai Reservoir was calculated by considering the incoming water from both surface flow and rainfall that flows directly on the reservoir; and the water taken for the interests of PDAM and evaporation directly from the reservoir.

3. Results and discussion

Analysis of reservoir water level data from 2008 to 2009 showed that during 2008, water fluctuations ranged from 270 to 400 cm (the height of the PDAM intake at the position of 0 cm). In the first week of January 2009, the reservoir water level was in the position of 400 cm, but the second week immediately fell 100 cm, to 300 cm and dropped continuously to -1.05 cm (fourth week of August). In the third week of September the water level was at 68 cm and increased steadily, in November the reservoir water level was already 205 cm (figure 1). During the 3 months (June-July-Aug) 2009 the supply of water to the PDAM was severely disrupted, so that the supply of clean water to the city of Tanjung Pinang was reduced by around 50%. The lack of raw water supply in the future is increasing considering the increase in PDAM intake, in 2006 the average volume of water per month was 510,986 m³, in 2007 it was 541,771 m³ and 2008 was 573,613 m³ [8].

![Figure 1. Water level fluctuation at Pulai reservoir.](image-url)
3.1. Climatological analysis
Rainfall and evaporation are factors that influence the dynamics of water resources in a watershed. This evaluation focused on the current state of water crisis in Pulai reservoir in 2009 and compared to the average conditions during the last 29 years, using data sourced from [5].

Rainfall data shows that the average annual rainfall from the last 29 years (1980 - 2008) was 3,216 mm. Over the last 29 years, there has been a dry year twice, where the annual rainfall was well below the annual average, which amounted for 2,417 mm and 2,396 mm for 1997 and 2000, respectively. The condition during the water crisis in 2009 was a repetition of the phenomenon of dry years. Meanwhile, precipitation during rainy days in the study area recorded fairly large amount, with the average of 196 days per year. This condition can increase the moisture, so it can reduce the rate of evaporation either of the reservoir and the water catchment area of Pulai reservoir.

Rainfall in 2009 was smaller compared to the average of the last 29 years (figure 2). During the period of January to July 2009, the amount of monthly rainfall was smaller than the average during the years 1980 to 2008 (except February), even in January amounted to only 42 mm, whereas the average of the last 29 years amounted to 301 mm. Similarly, the amount of rainfall during 2009 was 2,563 mm, below the average in the last 29 years, which was 3,216 mm. The decreased rainfall of 653 mm reduced the supply of water to the reservoir for about 20 percent of the average rainfall during normal conditions.

![Figure 2. Comparison of rainfall in 2009 with the mean values of 1980-2008.](image)

Climatological elements that affect evaporation consist of wind speed, humidity, solar radiation and air temperature. In 2009, air temperature was higher than the average for 29 years (1980-2008) and on average, it increased by around 1 °C. The decrease in water content in the air (humidity) occurred in almost all months in 2009 compared to the average of the last 29 years, except in February, it was slightly smaller (80.7% to 81.1%). Air humidity decreased over the year from 85.9% (in 1980 - 2008) to 83.3% (in 2009).

Based on the conditions of the two elements (air temperature and humidity), in 2009 the Pulai reservoir and its catchment area experienced an increase in the amount of water "lost" through evaporation. Meanwhile, the rate of evaporation was relatively disturbed by solar radiation and wind speed. Overall, solar radiation in 2009 decreased compared to the average of 1980 - 2008, from 46.5% in 1980 - 2008 to 39.5% in 2009. The declining pattern of wind speed was also observed, which was from 7 knots in 1980 - 2008 to 6.8 knots in 2009 [8].
3.2. Land use analysis
Land use is a rapidly changing factor in accordance with the development of population and socio-economic level of a community. This land change affects the hydrological balance of a watershed.

The water catchment area of the Pulai reservoir (530.4 ha) was actually legally protected, because almost all (98%) of the reservoir water catchment area was covered by the protected forest area (figure 3). This Protected Forest Area has been set since 1987 (Minister of Forestry Decree No. 424 / Kpts-II / 1987, December 28, 1987) when Tanjung Pinang region was still relatively undeveloped. On the other hand, the development of city and population influenced land use and reduced forest condition.

![Figure 3. Catchment area of Pulai reservoir.](image)

Land use in the Pulai reservoir watershed based on the data series of 1990, 2003 and 2007 is presented in figure 4. In 2007 the forest area remained only 8.15% and the other in the form of shrubs 50.8%, plantations 36.7%, mixed gardens 3.5% and settlement 0.8%.

Forest area decreased drastically between 1990 and 2003, from 65.97% to 4.65%, although in 2007 the forest area increased to 9.15% but not significant. Meanwhile, on forest land, the surface of the soil was mostly filled with litter which hold the raindrop, slowing down the surface flow, this process further increase soil organic matter, thus the soil became looser, microorganisms thrive, all of which increase the infiltration capacity as well as soil permeability. In addition, plant roots also increase infiltration capacity and water permeability.

Deforestation and changed forest into open land until 2003 was recorded at 52% of the total land area of the Pulai watershed and changed into shrubs in 2007 (51%). The area of shrubs which covered more than half of the Pulai watershed were potentially turn into agricultural land or other uses. Considering that all of these water catchment areas are included in the Protected Forest area, it is very possible that this stretch of shrub can be reforested in order to increase the carrying capacity of the land for the sustainability of the Pulai reservoir. Forest land clearing was related to the development of plantation areas, where in 1990 was only 18.52% of the total area of the Pulai watershed and increased to 41.66% in 2003 [9].

Land use in the water catchment area of Pulai reservoir in the form of shrubs was more than half. Reforestation will increase the water reserves in the reservoir catchments. According to [10] coefficient runoff on shrub (0.07) was two times higher than its forest (0.03), indicating more surface runoff in shrub. Also, it could be explained that infiltration capacity in forest was larger than that in shrub.
The percentage of rainwater that seeps into the soil is very important in the conservation of water resources. Rainwater that seeps into the soil can then flow into the part that is saturated with water as groundwater supply. During dry season, the saturated water also stabilizes the river water flow, as a base flow at a small discharge [11].

Forests function as an effective rainwater catchment area. The soil layer is very rich with organic materials, so the infiltration capacity becomes higher. The greater percentage of rainwater that seeps at the surface of the ground, it will reduce the risk of flooding, drought and sedimentation, and decrease soil erosion [12].

Figure 4. Land use of Pulai reservoir catchment area.

3.3. Water supply condition at Pulai reservoir
The availability of water in the Pulai reservoir was calculated as flow, derived from the catchment using the Thornthwaite and Matter water balance methods. Flow distribution and accumulation were used to analyse reservoir water balance. Cumulative flow was analysed using the "Simple Mass Curve" approach. The mass flow rate of the incoming flow can be used to determine the amount of water available that is safe to be used throughout the year. The amount of water availability was determined based on the cumulative flow rate slope. The accumulation of flow that occurred from the catchment area of the Pulai reservoir is shown in figure 5. The figure shows the water discharge limit for PDAMs with a monthly volume of up to 475,000 m³ without changing the water level in the reservoir. If the intake of water is greater than the discharge, it will reduce the volume of water in the reservoir. In addition, if the rainfall is lower than normal, the water volume will continue to decrease to a level lower than the intake point, as happened in 2009.
3.4. Alternative for capacity building for Pulai reservoir

Some alternatives were arranged in order to increase reservoir capacity to supply PDAM with raw water. The alternative was based on the calculation of reservoir water balance to determine the maximum amount of water that can be taken based on the incoming water, evaporation, and safe retrieval limits related to the intake and spillway positions. Alternative I, was the intake at the current position and the safe limit on the volume of the 3,000,000 m$^3$ reservoir or reservoir water level of 1 meter above the intake. This alternative has been done. Alternative II, was the intake placed at 9 m or below 5 m from the current position with a safe limit volume of 2,500,000 m$^3$. Alternative III was the same as the second condition but the spillway position was raised by 1 meter.

The calculation results in alternative I showed that the change in storage has a negative value in January to April, and July to October 2009. It suggested that the direct inflow and rainfall were smaller than the discharge and evaporation from the surface of the reservoir. Assuming that the reservoir was fully filled in early January, then the lowest volume above the safe collection limit will occur in November. The maximum amount of water that can be taken was 590,000 m$^3$ per month (figure 6).

**Figure 5.** Water flow and water availability at Pulai reservoir catchment.

**Figure 6.** Volume of reservoir, safety limit and maximum volume intake on alternative I.
Alternative II showed that changes in storage have a negative value in January to April, and June to October 2009 (figure 7). This means that the direct inflow and rain fall were smaller than the intake discharge and evaporation from the surface of the reservoir. The maximum amount of water that can be taken was 640,000 m³ per month. Assuming that the reservoir was fully filled in early January, then the lowest reservoir volume above the safe collection limit will occur in November. Safe volume is intended as a backup if there is a rain condition that is lower than normal conditions.

**Figure 7.** Volume of reservoir, safety limit and maximum volume intake on alternative II and III.

Alternative III showed that the maximum amount of water that can be taken to maintain the volume of the reservoir above the safe limit was 694,000 m³. The amount of intake discharge resulted in negative storage changes from January to October 2009. This means that the direct inflow and rain fall were smaller than the discharge and evaporation from the surface of the reservoir. Assuming that the reservoir was fully filled in early January, then the lowest reservoir volume above the safe collection limit will occur in November (figure 7). In alternative III, the maximum amount of water that can be taken for PDAMs rose by 7.8% compared to alternative II and increased by 16.9% compared to the current condition (alternative 1).

**4. Conclusion**

Rainfall in 2009 (2,563 mm) which was far below the average of the last 29 years (3,216 mm) was the main factor that caused the water crisis and this condition was exacerbated by the conversion of 52% of the forest into shrubs and oil palm plantations in the Pulai reservoir watershed. A very large area of shrubs has the potential to be reforested, considering that this site as a protected forested area based on formal jurisdiction, so that it will increase water reserves. Meanwhile, the increase in air temperature above the average also contributed to the increase of water evaporation.

The current water supply capacity from the Pulai Reservoir to the PDAM is 590,000 m³ per month with reservoir water reserves of 3 million m³. If the intake position is lowered by 5 m and reservoir water reserves are 2.5 million m³, the water extraction capacity will increase to 640,000 m³/month and if added to increasing the spill way 1 m height can increase the water withdrawal capacity to 690,000 m³/month.
5. References

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