Climate Change Impacts on the Management of Citarum Watershed

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1.1 Background

The Industrial Revolution that started in1840 began the use of fossil fuel, especially the consumption of coal; it is the major cause for the drastic increase of greenhouse effect gases volumes in the atmosphere. The main green-house gas produced by fossil fuel consumption is carbon dioxide (CO2). The greenhouse gas effect has significantly triggered the global temperature rise on earth year after year. This phenomenon is known as the global warming.

The global warming caused by the greenhouse gases has already and will always influence the world climate. Indonesian WWF and IPCC (1999) have reported that the yearly temperature in Indonesia has increased by 0.3 ^{0}C since 1990. A scenario of climate change (Indonesian WWF and IPCC, 1999) predicted that the temperature will increase between 1.3 ^{0}C to 4.6 ^{0}C in 2100 with the trend of 0.10^{0}C – 0.40^{0}C per year. Susandi (2006) projected that temperature rise in Indonesia will reach 3.5 0C in 2100, and earth's temperature will reach the maximum of 6.2 ^{0}C that year. The implications of the temperature rise will raise 100 cm of ocean's surface in 2100. The accumulation of these events will affect the infrastructures, buildings, and human activities in the present time and in the future.

One of the basic human needs affected by global warming is the water reserve. Water supply is an important issue related to the climate change. Vörösmarty et al. (2000) showed that the water supply became an issue as the result of earth's population growth which also increases the need of water. The increase of this demand will put pressure on the global water system that is highly related to the global warming. The population growth and the economy are the main factors that lead to the increase of water demand, while the water supply is influenced by the increased evaporation which resulted from temperature rise of the earth surface. The increased water supply demand is correlated with the need of the integrated management of water resources, and failing to do so, will damage the water resources physically, institutionally, and the implication will be on the socioeconomy.

Currently, the water management in Indonesia is generally considered as inadequate in the sense that at this point not everyone has the access to a sufficient amount of water to get on with their day-to-day lives. If there is no intervention for the water management, it will cause a problem. Half hearted approach or attempt to manage the water supply issue will not lead us to a comprehensive and sustainable solution. The decision makers and the authorities need to have a study that will bridge their lack of related educational background to manage water, so they can formulate a balanced and harmonic decision between the social function, environment, and the water resource economy.

This study attempts to analyze the climate change and its effect on the water reserve in riverside areas. This research provides answers to the need of climate change analysis related to temperature and rainfall, which will influence some variables, related to the water balance system and integrated water management. The study area is Citarum riverside, West Java.

The result will hopefully give a picture about water bodies' management affected by the climate change and also as a recommendation for the ongoing development plan.

1.2 Objectives

The objectives of the study are:

1. To analyse problems related to meteorology variables on climate change: the temperature and rainfall.

2. To assess water supply issue using meteorology variables (temperature and rainfall) and to create a map and spatial data which give a picture about river condition, as the implication of the climate change.

3. To include climate change issues in the river management plan, so a scientific document can be produced as the base for policy making and adaptation efforts for the decision makers and the government.

4. To analyze the possibility of floods and landslide occurrences, by studying the contour map and zoning.

5. To produce spatial map (space scale), a temporal map (time scale), the Citarum riverside data condition and its projection for 2020, as an implication of climate change.

6. In general, the purpose of the study is to develop an approach to analyse the issues and problems about water resource management in Indonesia, especially in Citarum riverside by including the climate change issues.

1.3 Scope of study

- The condition of Citarum riverside has grown very complex; therefore this research will focus more on the study of climate change at Citarum River that relates to the water availability and river management.
- The study assesses the climate change from the angle of meteorology (related to the temperature variable and rainfall) at Citarum River, and will not discuss the climate change that influences the quality of water or any other effects.

In this study, a comprehensive assessment is conducted about river body management which relates to the climate change. Citarum riverside in West Java at 107.182310 E - 107.537893 E and 6.235521 S - 6.869114 S will be the case study:

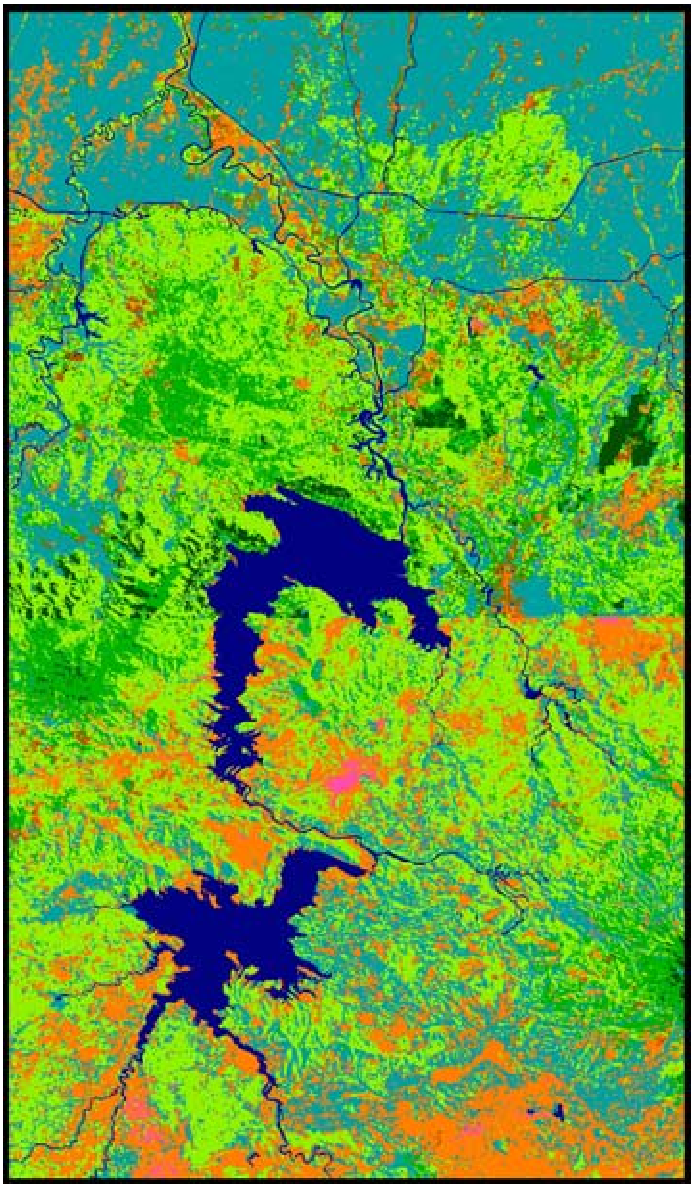

Figure 1. 1 Research area: Citarum riverside

2.1 The Benefit of the Research

The study produces a report about an assessment of the river body condition in Indonesia, with the aim of helping the decision makers and the authorities (the government) to make a comprehensive policy, related to the water management, especially in its relation to the climate change. This study also assesses the upriver area, where we will make an analysis about water balance. In the end, this research can contribute to the development planning in Indonesia, especially the water source management related to the climate change issue.

2.2 Previous Researches

Indonesia is located in the tropical climate zone (Köppen, 1900, in Puradimaja, 2006). This type of climate usually has a characteristic in the seasonal variation: high rainfall in the rainy season and very low rainfall in dry season. The condition makes it difficult to control the water in the rainy season and it is also difficult to get sufficient water in the long dry season. Thus, it's necessary to do a study about water source management that is related to the climate change because rainfall is one of the important factors in climate change.

GCM (global circulation model) MAGICC/SCENGEN is used for the global scale climate change projection. This model is used to produce global temperature projection, change of rainfall amount in the future, and ocean's surface level rise. The projection will be calculated until 2100 with ten years interval. Climate change projection in Indonesia has been done by two models of GCM simulation, ECHAM4 (Germany) and HadCM2 (UK). SRESS B2 Emission scenario has been selected to project the temperature and rainfall in Indonesia. B2 scenario is assumed as the reference scenario that creates maximum temperature projection of 1.4 ^{o}C in 2050 and will keep increasing until 2.6^{o}C in 2100. Next, the A2 scenario (signified by the increase of the population and low growth in economy) will produce the increase of the temperature in Indonesia and it will reach more than 3^{o}C in 2100. The change of the amount of rainfall occurs randomly with the change of deficit percentage 20 % and 12 % increase in 2100 compared to the rainfall data in 1990.

The study on the change of river debit as the result of the change in zoning has also been done by Sabar and Prasetiati in 2006 in Bandung basin area. The conclusion from the research is:

- There is a significant change, which are the decrease of the vegetation area and the increase of the developed area. These changes raise the tendency of runoff coefficient to increase, which links to the increase of river maximum debit and the decrease of river minimun debit. The next phenomenon that will also likely to happen often is the danger offlood in the rainy season and drought in the dry season.
- The water surface condition has also threatened the ground water reserve in the Bandung basin; this is indicated by the decreasing water surface and soil subsidence.

Suroso and Santoso (2006) also stated that zoning changes influence the increase of river debit. There is a change of zoning from 1759, 28 ha of paddy fields, 289.54 ha of cultivated lands, 1284.36 ha human settlements in 1995, to 1603.97 ha paddy fields, 283.32 ha cultivated lands, 1445.88 ha human settlements in 2001, which have caused the river debit to increase.

The calculation showed that climate change could also alter the water resource availability, and it will affect the growth of agriculture, industry, and urban development. Therefore climate changes will have a great effect on the water source management in some riverside areas (design, operation, and water usage system management).

Here are some of the runoff projection calculations with different climate change scenarios. If there is a 20 % decrease of rainfall and a 2°C increase of temperature, the yearly runoff will decrease 41 % from the present yearly runoff. If the rainfall remains the same, runoff will increase by 9%. But if there is a 10% rainfall increase and 2°C to 4°C temperature rise, it will result in a runoff increase from 4 to 12 % (Hailemariam, 1999).

Similar research has also been done to calculate the amount of direct runoff in Jakarta area to analyse the flood incident in 2005. After the calculation was processed for the flood case in January 17th-20th 2005 at Tangkapan Kali Angke area, Pesanggrahan, and Grogol, it produced a good result. The maximum direct runoff value in January 19th, 2005 reached 3.76 inches, the increase of DRO started in January 17th until January 18th, 2005, because there was a high rainfall in January 17th (2.23 inches). In January 19th, 2005, DRO reached maximum value (3.76 inches) when the prediction of rainfall is 4.11 inches. Then the amount started to decrease until it came to less than 1 inch in January 21th.

The highest DRO value in January 19th, 2005 correlated to the worst of flood which was also in January 19th, 2005. The amount of DRO in 19th January, 2005 was caused by the large amount of rainfall in January 19th, 2005, and worsened by the rainfall accumulation. The ground could not absorb more rain as it had become very saturated from the previous torrential rain that fell in the previous days consecutively. When again heavy rain fell in January 19th, the water from the rain just flowed on the surface and caused big DRO. The biggest DRO value was found in residential areas and the small DRO value was found at the green area such as fields, farm-yards, and paddy fields. It shows that the calculation of DRO with Soil Conservation Service methods is adequately reliable to be used in calculating the DRO, because it has included the variety of land/ground covers, type of ground, and soil moistness (Herlianti, 2007).

2.3 The Project Potentials

The studies regarding river bodies are parallel to the climate change. These studies proved to be useful for both the local government and the central government to help making more accurate decision regarding water resources conservation policies, especially on the demand and supply of water. These policies can then be used as the law for infrastructure developments to support the riverside area in adapting to the climate change. The method developed in this study will be applicable for other areas, making adjustments whenever necessary to meet the specific conditions in those other areas.

3.1 Climate Data Processing and Groundwater Calculation

There are several variables used in this study, and all the variables are also used in the calculation for the groundwater variables. Climate data used here are:

- Temperature (°C)
- Rainfall (mm)
- Surface Wind Speed (m/s)
- Duration of light exposure (hours)
- Average sun radiation (cal/m^2)

Those variables are processed into the following equations to determine the value evapotranspiration. Evapotranspiration refers to the amount of water vapor being released back to the atmosphere, both from evaporation and those released from other living beings (transpirations), such as from animals and plants. Equation used to determine the evapotranspiration value is the Penman Equation. There are three equations in the Penman methods. The first equation is:

$$E = \frac{AH + 0.27 E_a}{A + 0.27} \quad (3.1)$$

with:

E: Evapotranspiration

A: gradient of the saturated water vapor at a certain temperature

E_a: Evaporation

H: Second Equation

The second equation is:

$$H = R(1-r)(0.18 + 0.55S) - B(0.56 - 0.092\sqrt{e_d})(0.1 + 0.9S) \quad (3.2)$$

with:

R: Sun radiation on horizontal surface

r: reflection coefficient

S: Sun radiation (sunshine)

e_d: actual steam pressure

And the final equation from Penman methods:

$$E_a = 0.35(e_a - e_d)(k + 0.01 W_2) \quad (3.3)$$

with:

e_a : saturated steam pressure at average temperature k : roughness coefficient

W_2 : wind-speed at the altitude of 2 meters

The next step is to calculate the direct runoff and the base-flow. Basically, base-flows are the percolated waters that reach the ground water reservoir, and then supply the river as a ground water discharge. The Soil Conservation Service (SCS) is a method developed by the Agricultural Department of the United States since 1947. The SCS method is used to calculate the amount of direct runoff from a certain event of precipitation (USDA, 1986). The equation is:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (3.4)$$

Where, Q = Direct Run-off (inch)

P = Rainfall (inch)

S = Maximum retention (inch)

The value of S is parallel to the condition of the soil and land cover, shown in the Curve Number (CN). The CN value varies from 0 until 100.

$$S = \frac{1000}{CN} - 10 \quad (3.5)$$

To determine the amount of CN, there are a number of notable factors, i.e. the type of soil, land covers, hydrological condition, and the soil moistness.

On the other hand, base-flow is calculated by continuing the Penman method. Basically, runoff is the sum of the base-flow and the direct runoff. Using the SCS method we already acquire the values of direct runoff, then with available climate data, the value for variable runoff can be obtained Therefore, the value of the base-flow can be determined.

The output resulted from the above equations will be the crucial part on policy making regarding the riverside area management. The output will be updated according to changes of the most current river condition, so the policies made will always be compatible to the changes on the river's condition. One interesting point from this study is that the policies made for the riverside area management involves climate change, therefore the formulation can be considered as a river's strategic plan to adapt to the climate change. This policy not only involves the river biophysics factors, but also includes other factors such as variability of the climate and weather.

3.2 Projection Model of the Climate Change

In conducting the projection of the climate change parameters (the temperature and rainfall) it is necessary to have spatial observation data and field measurement data, The data used in this research are satellite data and climatological data for the temperature and rainfall around the

Citarum's riverside area. The earliest step is to collect climotological data and TRMM (Tropical Rainfall Measuring Mission) satellite data for the riverside area of Citarum for 10 years and climatological data such as rainfall and the monthly surface temperature. TRMM data are only used as a comparison data to the climatological data, spatially.

From the database, monthly data are extracted from each season every year. In this case, every year is divided into two periods, which are the rainy season (represented by January data) and the dry season (July).

Besides the two data above, it is necessary to have a digital map of the riverside area of Citarum River that includes location points of the meteorology obervation stations. Each observation points provide the value of rainfall and surface temperature, to find the plot that are within the range of Citarum's riverside area and its vicinity, it requires spatial interpolation. The interpolation used here is the Kriging method where this method is an interpolation that produced geostatical grids. The Kriging Point method estimated the value of each point in every grid, while also considering the value of each point that has a real value.

For the next step, the projection model of the climate change will be developed from the primary model of the last year of the observation period by developing non-linear equation on each climatological data spots. This equation will be extrapolated to obtain spatial and temporal projection for the rainfall and temperature of the observed area (Citarum riverside area). This model is used in this research to maximize the accuracy to the actual results and also because this model can be used in overlay with the spatial map of water resources in Citarum riverside area.

3.3 Image Processing

The images are obtained from Landsat TM for year 1991 and 2001. Both images consist of two different types of images, which are 3-band image and 8-band image. The Landsat 3-band image is used to identify the types of soil, and landsat 8-band is used to analize the vegetation index (NDVI - Normalized Difference Vegetation Index). NDVI is used to determine the condition of vegetation in certain area. Basically, NDVI calculates the amount of the sun radiation absorbed by plants, especially on leaf surfaces. The green plants absorb sun radiations on the parts called photosynthetically active radiation (PAR). The value of NDVI varies from -1.00 to +1.00. The following equation is used in calculating the NDVI:

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{3.6}$$

with:

NIR : Near Infrared spectrum

RED : Infrared spectrum

The processing of 3-band images resulted in land use map, and aided with soil type map, we can determine the value of direct runoff by using the SCS method. The entire image processing is mostly done using GIS software

3.4 Flowchart

The whole steps of this study are as in the following diagram:

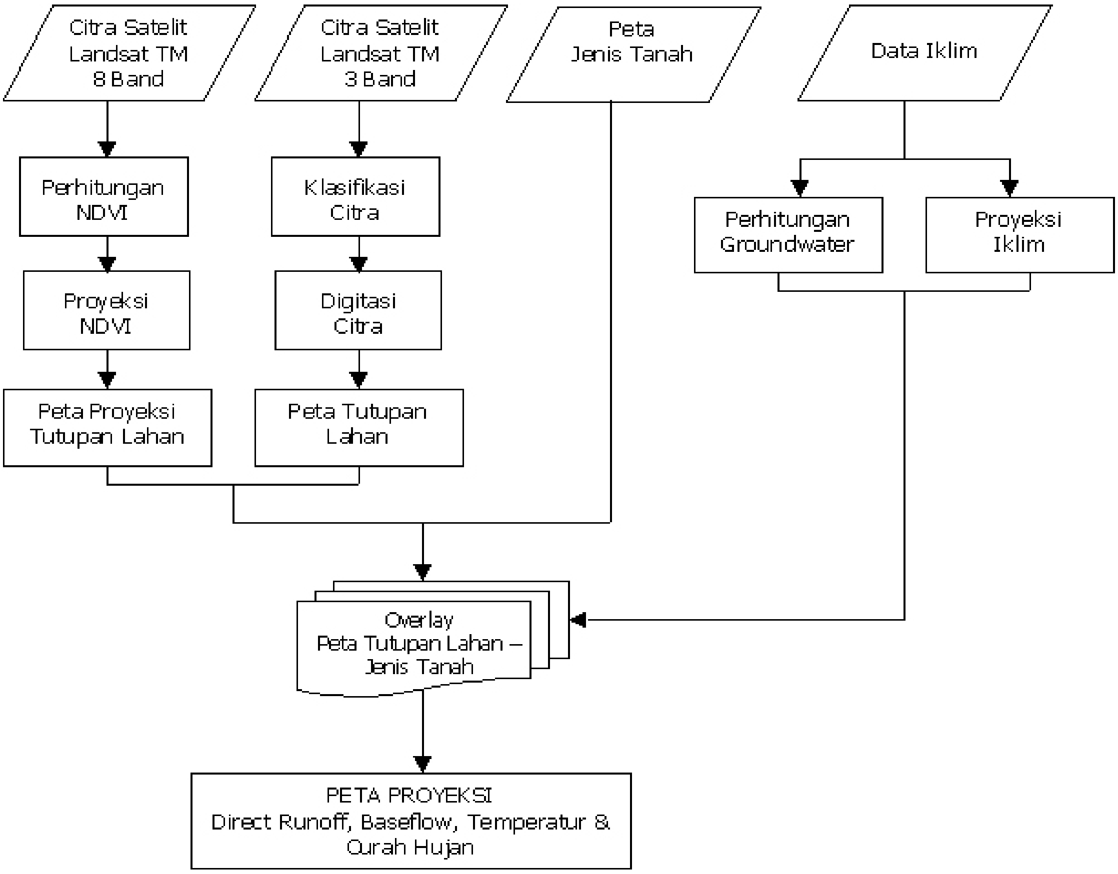

Figure 3.1 Flowchart of the research methodology

The hydrology cycle describes the movement of water on, in, and under the earth's surface. Because the hydrology cycle is actually a "cycle", and thus it is unclear where it begins or where it ends. Water can change forms from the liquid state, solid, and gaseous state at various stages in the cycle. This cycle also causes the recharge and discharge process at some reservoir of ground waters.

Base-flow and direct runoff are part of the hydrology cycle. Base-flow links with the discharging process for ground water, and direct runoff describes the amount of water that directly flows on the ground, in the case of precipitation. The value of direct runoff depends on a number of conditions, from the meteorology side, land covers and the soil types of an area or region. If the direct runoff and base-flow values are known, many important issues can also be predicted such as: the threat of floods, landslides, river and river debit, drought and groundwater reserve.

4.1 Rainfall and Temperature Projection Analysis

Climate change is indicated from the changes in two major meteorological factors, which are the temperature and the rainfall. These factors contribute to the rise of the sea level. The changes in temperature will cause changes on other variables in the atmosphere, which in the end causing changes on the rainfall. The change in the rainfall does not change the amount of the rainfall, but drastically altering the distribution pattern. This means that during the rainy season, certain area will receive more rains and during the dry season will receive fewer rains. This posed many problems to the mankind, because the impact of this change can be very dangerous, and even lethal. With the condition described previously, during the rainy season there is an increased occurence of various disasters, such as floods, landlides, and diseases epidemic through vectors. And during the dry season the disasters will continue with other type of disaster such as drought, which will lead to failing crops and the spread of various illnesses affecting the skin and digestive system, which will possibly lead to death.
Rainfall pattern in Indonesia is known as type-V pattern or monsoon type, or a rainfall with annual graph shaping like the letter "V". This means the number of precipitations in Indonesia will increase during December - February and it will decrease during June - August (see image 4.1). The periods of March - May and September - November are also known as transition periods. During this period, the rainfall and wind condition is constantly changing due to the monsoon wind, which is constantly shifting because of the heat source movement (wind pressure).

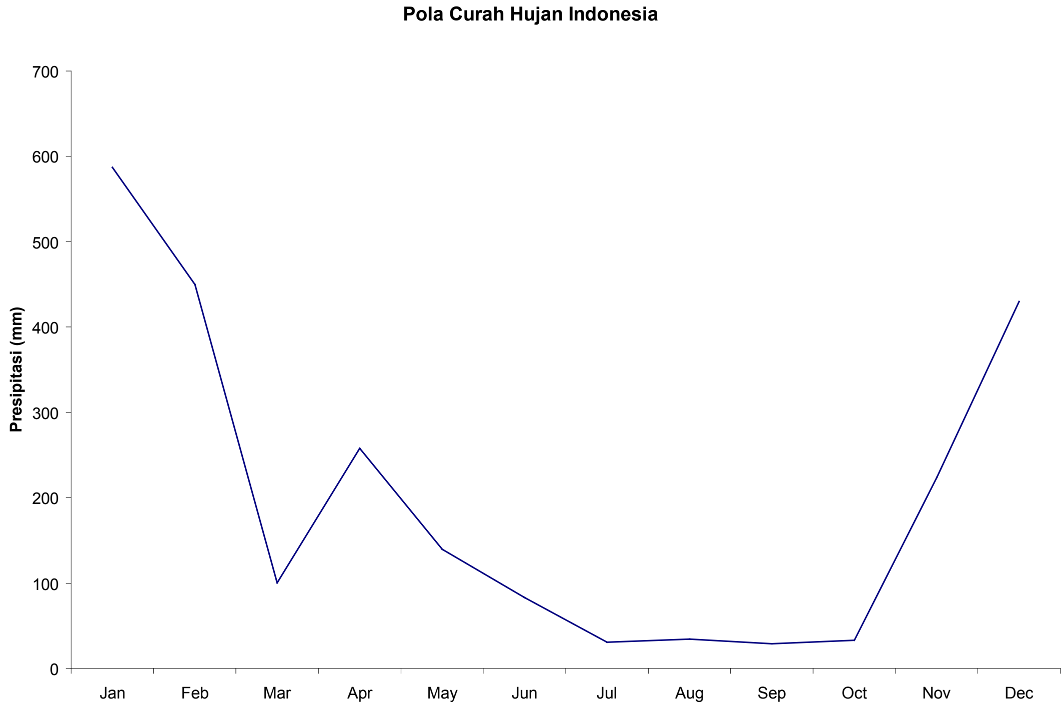

Figure 4.1. The general rainfall pattern in Indonesia.

The rainfall in the researched area also follows this pattern. From the climate data obtained in the researched area, the average rainfall of Januari is 362.4 mm (14.27 inches) and the average rainfall of February is 99.04 mm (3.91 inches). This means that the rainfall pattern in the observed area is the monsoon rainfall pattern (see Figure 4.2). With this pattern, it is clear that in January the water received from precipitation is abundant, which can cause disaster if it is not managed properly. But using appropriate approach, the excess water can be utilized for irrigation and saved in a reservoir during the dry season. The dry season represented by July showed huge difference on the number of the rainfall. This can lead to drought, failing crops, and scarcity of clean water during the dry season. These conditions will also affect the situation of the Citarum riverside. The abundant water during the rainy season could cause riverbanks overflow, which potentially leads to floods. But if managed properly, it could be used to increase the river debit, and make use of the dam in the Citarum riverside.

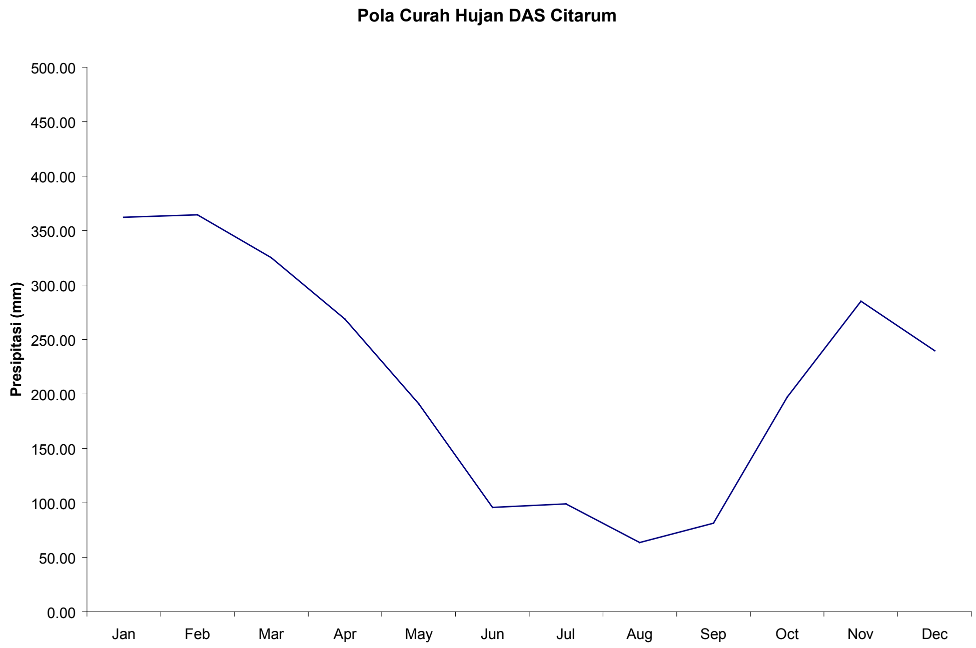

Figure 4.2. The rainfall pattern in Citarum riverside.

The average temperature of the observed region varies around 23°C - 27°C from 2001 to 2004. The annual temperature pattern here is constantly changing, due to the difference in "caloric capacity" between the land and sea. Therefore during the rainy season the temperature does not decrease, and during the dry season the temperature does not get any higher from the rainy season. The temperature on January 2001 in the observed area can be seen in Figure 4.3. The lowest temperature in January 2001 is 24.7°C and the highest is 27.1°C. The estimated temperatures of 2020 indicate significant change, marked by the increased heat of the southern part of observed area, and vice versa for the dry season (see Figure 4.4). This is caused by the change of land uses around the observed area (see Table 4.1). This change is indicated by the fading green vegetation in 2020. This condition is predicted from the NDVI projection of the image from landsat TM on 2001, projected for the year 2020. From this result, it is also predicted that the amount of ponds will decrease and there will be increased number of solid non vegetative objects in the observed area. This condition is assumed as a shift on land use from heavy forest or farm-yard into city or industrial area. The decreased number of wetlands (such as farmlands and swamps) is interpreted as the transformation of water yielding areas into cities/towns, industrial area, or even roads. The temperature changes will influence the rainfall, because the temperature changes will affect surface heat and air pressure which will lead to increased, or decreased number of convection.

Table 4.1 The change of land uses of 2001 and 2020 based on NDVI analysis.

Jenis Tanah	Landuse 2001	Landuse 2020
A	Hutan Lebat	Hutan Lebat
A	Hutan	Kebun

A	Kebun	Kota/industri
A	Kota	Kota/industri
A	Industri	Kota/industri
A	Lahan Kosong	Kota/industri
A	Sawah/Lahan Basah	
B	Hutan Lebat	Hutan Lebat
B	Hutan	Kebun
B	Kebun	Kota/industri
B	Kota	Kota/industri
B	Industri	Kota/industri
B	Lahan Kosong	Kota/industri
B	Sawah/Lahan Basah	
C	Hutan Lebat	Hutan Lebat
C	Hutan	Kebun
C	Kebun	Kota/industri
C	Kota	Kota/industri
C	Industri	Kota/industri
C	Lahan Kosong	Kota/industri
C	Sawah/Lahan Basah	
D	Hutan Lebat	Hutan Lebat
D	Hutan	
D	Kebun	Kebun
D	Kota	Kota/industri
D	Industri	Kota/industri
D	Lahan Kosong	Kota/industri
D	Sawah/Lahan Basah	

The temperature in July (dry season) 2020 (see Figure 4.4) changes siginificantly, that comes to as much as 2.8^{o}C. This phenomenon is common when interlaced with the change of the land use of the observed area. As the elevation in the south is higher than the northern side; the area will experience a more intense heat in July. An area with higher elevation receives more heat than the lower elevation. This would lead to significant temperature changes during the dry season; therefore it will need proper management and adaptation to anticipate the conditions projected to happen in year 2020.

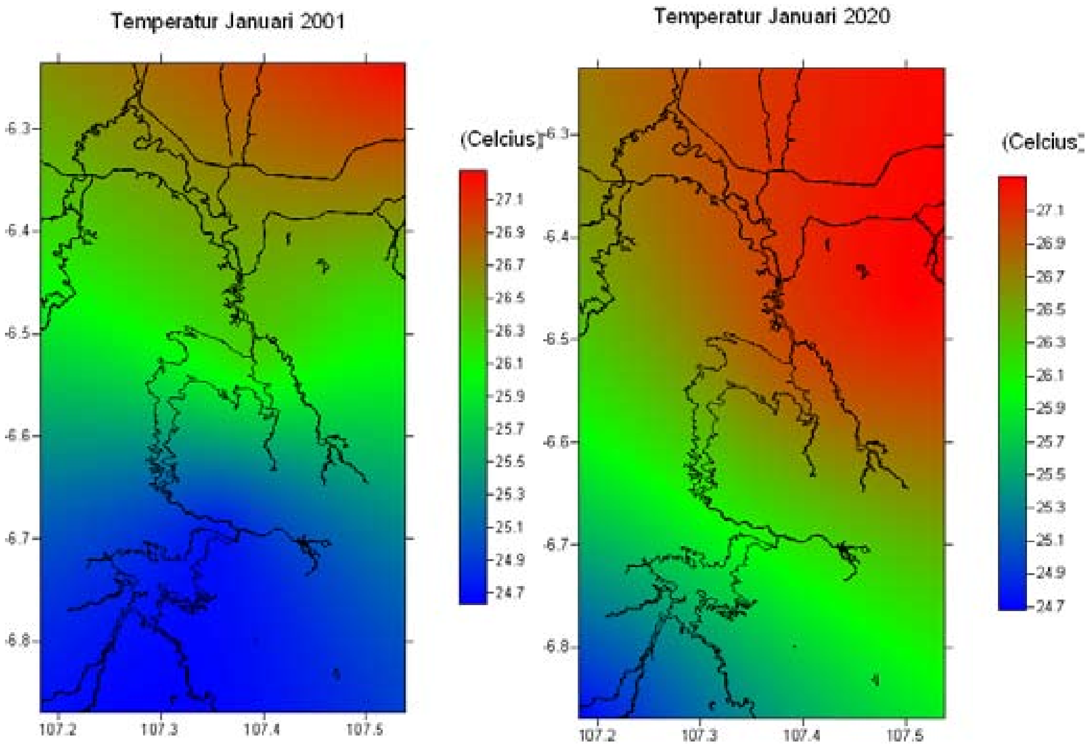

Figure 4.3. The temperature of January (rainy season) in the observed area.
The image on the left was taken in 2001 and on the right is the prediction for 2020.

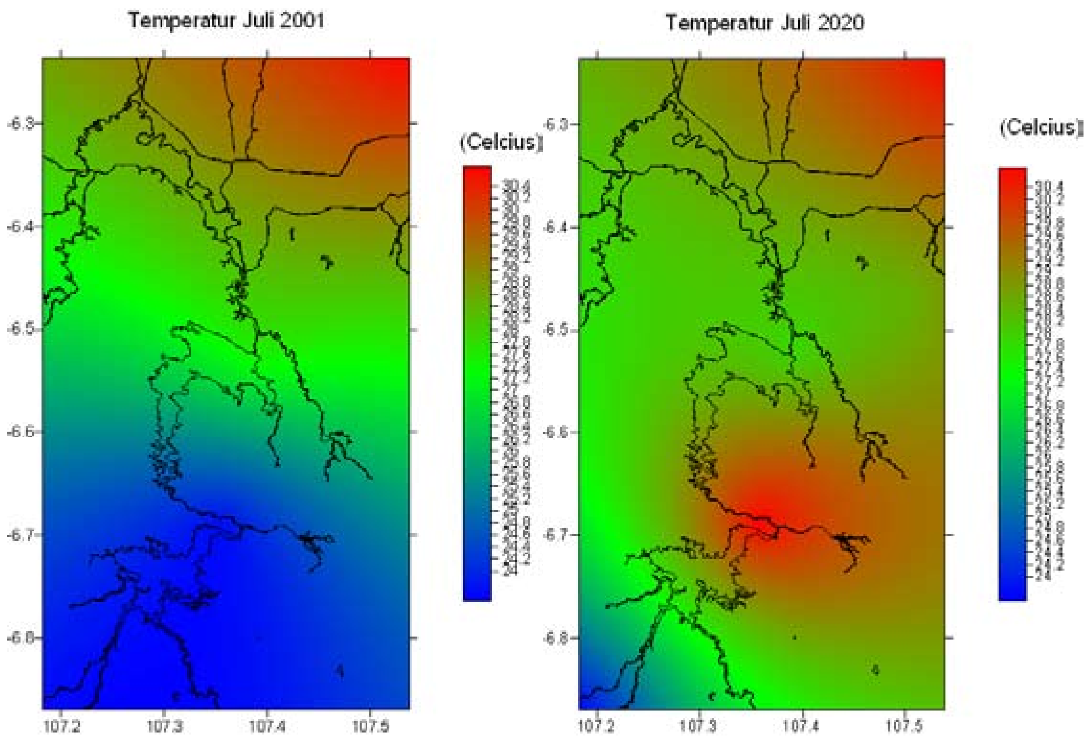

Figure 4.4. The temperature of July (dry season) over the observed area.
The image on the left was taken in 2001 and on the right is the prediction for 2020.

The rainfall pattern in the obeserved area is the monsoon type (see Figure 4.2). In January (rainy season) the rainfall is higher than in July (dry season). In January 2001 (see Figure 4.5) it shows that rainfall varies from 249.86 mm (9.837 inches) to 746.65 mm (29.396 inches). The rainfall amount could be advantageous or disastrous depending on the environmental management of the area. For the prediction for 2020 it shows the rainfall will vary from 239.33 mm (9.422 inches) to 1377.22 mm (54.221 inches). Table 4.2 depicts the rainfall prediction. The prediction for 2020 indicates the increased number of precipitation, and looking at the land use in 2020, this could bring more disasters than advantages.

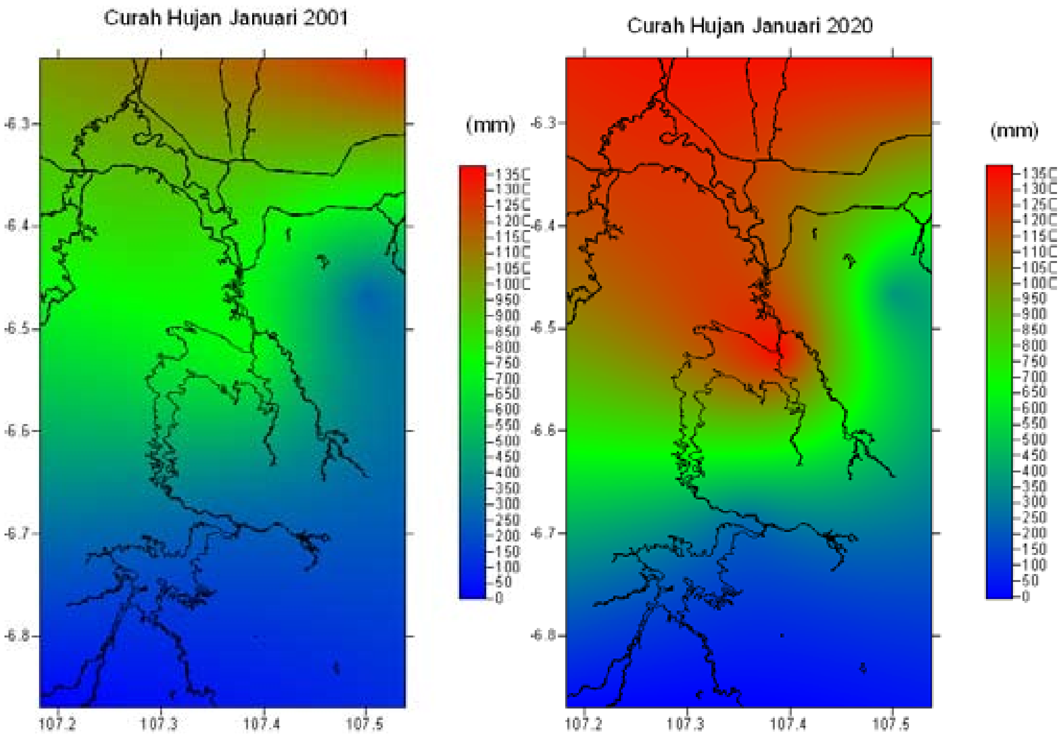

Figure 4.5 The rainfall in observed area during rainy season, represented by image taken in January. Image on left showed the rainfall in 2001, and the right is the prediction in 2020.

In Figure 4.5, it showed that in 2020 increased rainfall in the observed area will occur in places with lower elevation. The southern area has higher elevation while the north part has lower elevation. This will make the middle up to the northern part more prone to experience floods. This is caused by the flow of water moving from south to north. If appropriate steps are not taken to adapt to these changes, then the chances of flood ocurring will greatly increase.

Table 4.2 Amount of rainfall in the research area in 2001 and its prediction for 2020.

Stasiun	2001		2020	
	Jan	Jul	Jan	Jul
Cirata	249.86 mm	90.55 mm	239.33 mm	0.0025 mm
Jatiluhur	746.65 mm	1271.21 mm	1377.22 mm	1148 mm
Cikumpay	265.16 mm	388 mm	366.95 mm	125 mm

The rainfall in July (dry season) showed an interval between 90.55 mm (3.565 inches) to 1271.21

mm (50.048 inches) in 2001, and an interval between 0.0025 mm (0.000098 inches) to 1148 mm (45.197 inches) in 2020 (see Figuree 4.6). Based on 2020 prediction, almost all the observed area suffered lower rainfall. This will need proper attention especially in the nothern area, since the rainfall will significantly decreased in 2020. This could lead to lower supplies of clean water and also failing crops, or failed hatcheries around the dam, and other possible social problems.

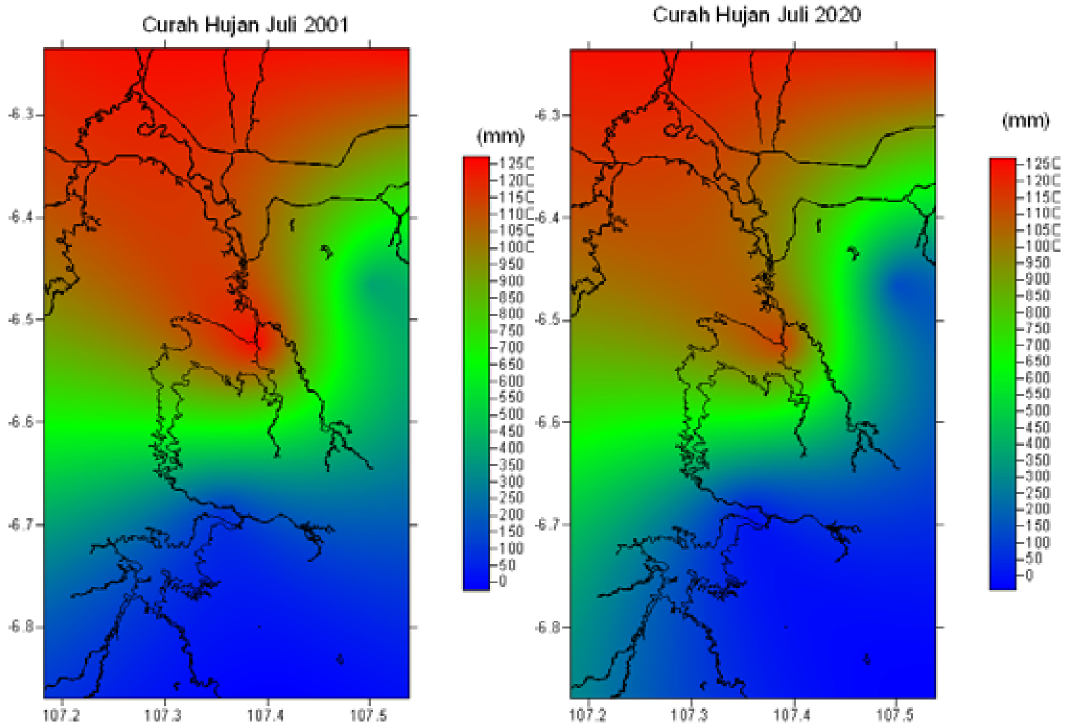

Figure 4.6 Rainfall in research area during the dry season represented by image taken in July. The image on the left showed the rainfall in 2001, and the image on right showed the prediction in 2020.

In general, during the rainy season the rainfall increased to as much as 240.61 mm (9.47 inches) and decreased as much as 158.95 mm (6.26 inches). The effect of climate change is very significant on the seasonal rain distribution. In the rainy season the number of precipitation is very high, but during the dry season it is very low and the rain is very infrequent. This will increase the chances of floods in rainy season and drought in dry season.

4.2 Analysis on Land Use Changes

One of the effective ways in identifying types of vegetation land use is to analyze the change in NDVI index. NDVI is an effective and simple way to identify the condition of vegetation in certain area, and this method proves to be useful and has often been used before to calculate the index of green plants canopy in the multi spectral remote sensing data. Using mathematical definitions, certain area with have thick vegetation will have a positive NDVI value, and in open waters the NDVI value will be negative.

In 2001 (see Figure 4.7) it shows that in the observed area, there are still a large number of green shaded areas around the Jatiluhur and Cirata Dam. The green shaded areas represent thick forest with trees in good conditions, meanwhile the areas shaded in orange and red represent the range of different land covers, from open land to wetland. The wetland is either farmlands or swamps. The large number of farmlands near the settlement area is considered normal, since most people there cultivate their own land to meet their daily needs by farming or farm-yarding.

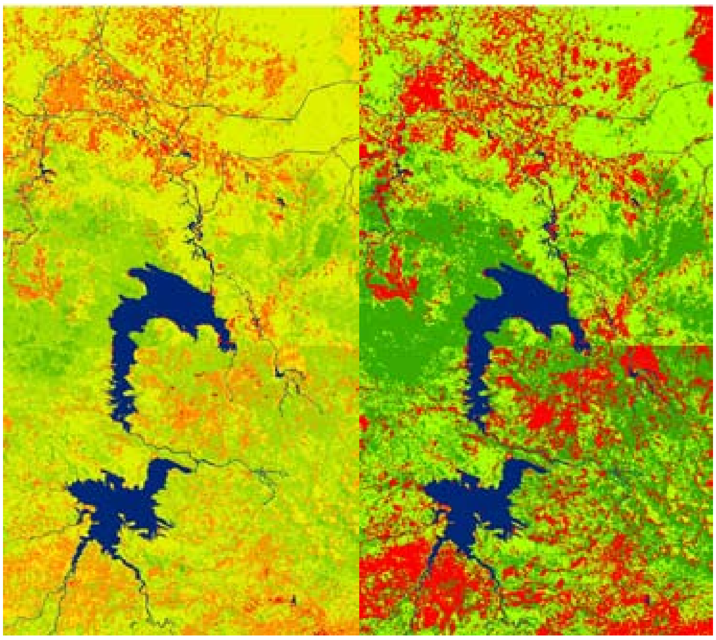

Figure 4.7 Land use in the observed area for 2001 (left) and its prediction in 2020 (right)

As for 2020, it shows that around Jatiluhur the color is significantly changing. This shows the forest degradation, being turned into farm-yards, or farm-yards into empty land, or farm-yards turned into housing areas. This condition is also visible in almost the entire study area. It can be interpreted as changes from natural land use (forests, farm-yards, empty lands) into housing area or even industrial area. This also includes the development of transportation infrastructure (roads, terminal, etc.). In general the land cover components remain the same as in 2001 (see Table 4.3), but the size of vegetation decreases, turning into non-vegetation land covers.

Table 4.3. Table of land use in observed area in 2001

No.	Land Covers	Size (km2)
1	River	183.054
2	Thick Forest	82.6854
3	Forest	718.769
4	Farm-yard	1133.77
5	City	136.764
6	Industrial area	8.06922
7	Empty lands	396.637
8	Paddy fields/ Wetlands/	109.89

The shift from vegetation area into non-vegetation area will affect the hidrology cycles of the observed area. Basically the volume of water on a certain cycle can be maintained (Puradimaja, 2006). However, the shift from vegetation into non-vegetation area is causing water catchments volume deficit, thus depleting the water supply. Besides, the DRO increases as infiltration decreases, followed by increased surplus of water on the surface. Assessments regarding base-flows and direct runoffs, using the data and calculation for projection in climate change will be explained in the following paragraphs.

4.3 Analysis and Projection of Direct Runoff

Value of the Direct Runoff (DRO) depends on the types of soil, land covers and the rainfall, therefore its value varies for different the soil types and land covers. According to the DRO map in January 2001 with rainfall of 16.56 inches (420.62 mm) the DRO varies between 0 to 16.31 inches (see Figure 4.8). The biggest DRO occurs in the city/town areas and clay soil type. This is caused by the inability city/town surfaces to absorb large amount of water; the surfaces in these areas are mostly covered by water-proof layers such as concrete and cement. Clay also affect the water catchments ability because of its small porosity, making it difficult/slow for water to be absorbed into the ground, hence causing more water to slip away on the surface as DRO. Clay with the D soil type has water absorbing rate of 0-1 mm/hour. This means when precipitation occurs with the level of 400 mm, the water will be on the surface for 400 hours (equivalent to 17 days).

The DRO value in January 2001 shows a high number, varies between 13.30 inches to 16.31 inches (337.82 mm - 414.27 mm). With the rainfall of 16.56 inches it means more than 70% of the rainfall will flow on the surface as a DRO. The high number of the DRO in January is caused by the rainy season occured at that time (high rainfall). Compared to DRO projection of January 2020, it is obvious that the DRO in January 2020 will increase to 26.03 inches (661.61 mm). The value of the DRO will also increase, reaching up to 25.66 inches (651.76 mm) and with the change on the overlay (increased number of city area), the number of areas with high DRO will increase compared to the one in January 2001. These conditions will increase the chance of disasters occurring in the observed area, such as flood, landslides, river overflowing, and failing crops. Therefore, proper adaptation will be needed to reduce these undesirable and disastrous effects. Therefore it is urgently imperative that the stakeholders, in this case the local government and other parties should develop policies to prevent future damages which might happen because of the climate changes.

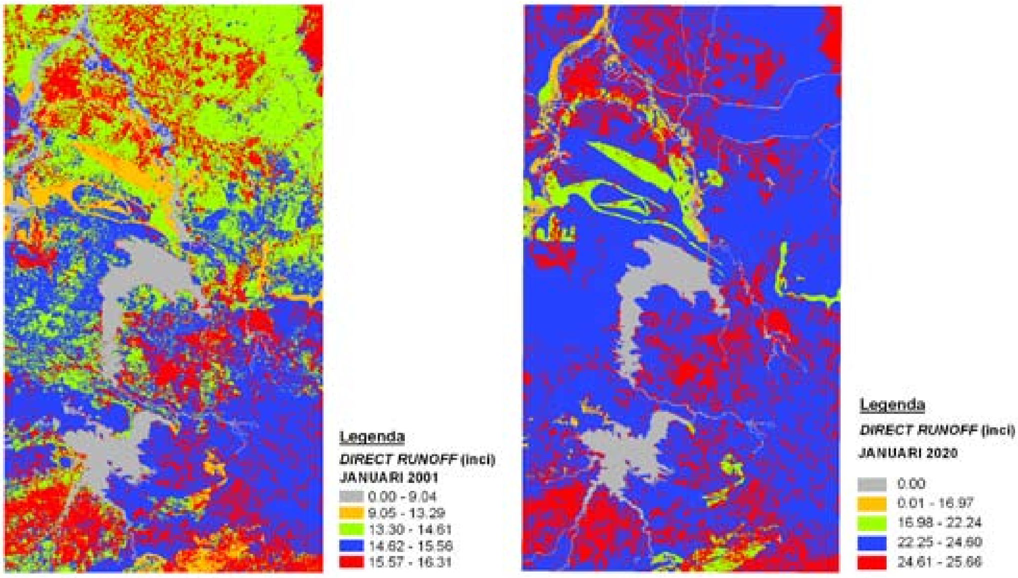

Figure 4.8 Direct runoff study area map for January (wet season) 2001 (left panel) and the projection for 2020 (right panel).

The DRO map of July 2001, which is a dry season, shows that only a few areas have high DRO (shown in blue and red shades), most of the DRO is relatively smaller than the maximum value (see figure 4.9). The projection of DRO for July 2020, areas with high DRO (compared to the maximum value) expand following the change in land covering (see table 4.1).

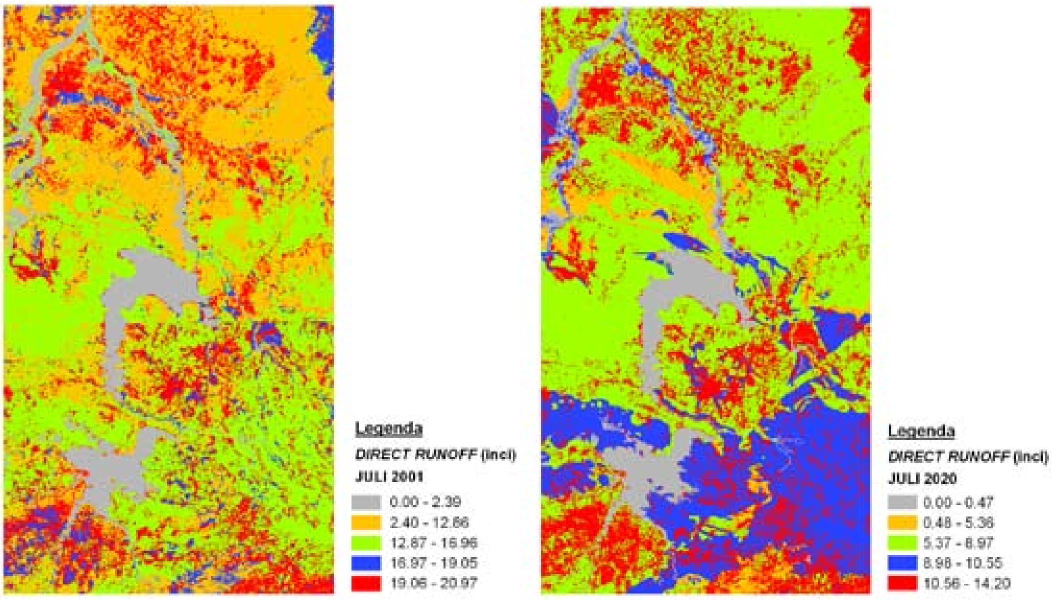

Figure 4.9 Direct runoff study area map for July (dry season) 2001 (left panel) and the projection for 2020 (right panel).

The conclusion is that DRO value is relatively proportional to the rainfall rate; if the rainfall is high the DRO will be high, and if the rainfall rate is low the DRO will be low as well. This concludes that the change in rainfall rate will greatly affect the volume of DRO of an area. Therefore the climate change, signified by increased of global temperature, has changed the local climate of some area. The change of temperature has also changed the rainfall level, and because the DRO corresponds proportionally to the rainfall rate, the climate change is then affecting the DRO.

4.4 Base-flow Analysis and the Projection

Base-flow in general shows the amount of water that reaches the underground water reservoir (recharge) and also water that goes out to the river or lake (discharge). But in this study, we are not going to discuss the discharge process. From Penman equation, which is used to determine the base flow rate, we can only analyze the amount of recharge that occurs in underground water reservoir in the study area. Base flow is directly affected by runoff and direct runoff; hence base flow is also affected by the amount of infiltration. The capacity of land or soil to absorb water determines the level of infiltration; therefore base flow is also determined by the type of soil and land cover in the area.

In this study, the base flow value is derived from the existing DRO level. For January 2001, base flow value interval is between 0.01 – 8.07 inch (0.254 – 204.978 mm). If we link this with the rainfall rate of the same month and the same year, which is 420.55 mm, the amount of water that actually recharges in the study area is less than 50% of the total rainfall. In Figure 4.9 we can see that the area with base flow of more than 4 inches only occurs in the A type soil, or the sandy soil type. While in the projection map of 2020, the base flow has changed drastically to the level between 0.01 – 6.05 inch. This means that the maximum base-flow value has lowered by 2.02 inci (51.31 mm) in areas with the type A soil. Based on the NDVI projection, the decrease is caused by the change of land use into something solid (and thus impermeable), such as housing, industrial areas or road networks. This will decrease the recharge of underground water, and thus the availability of water would diminish, the same would happen to the discharge process to the river. Prolonged decrease in the discharge process would result in a dry river. As a consequence many problems would start to arise such as drought, failed harvest, and other social problems related to the availability of water.

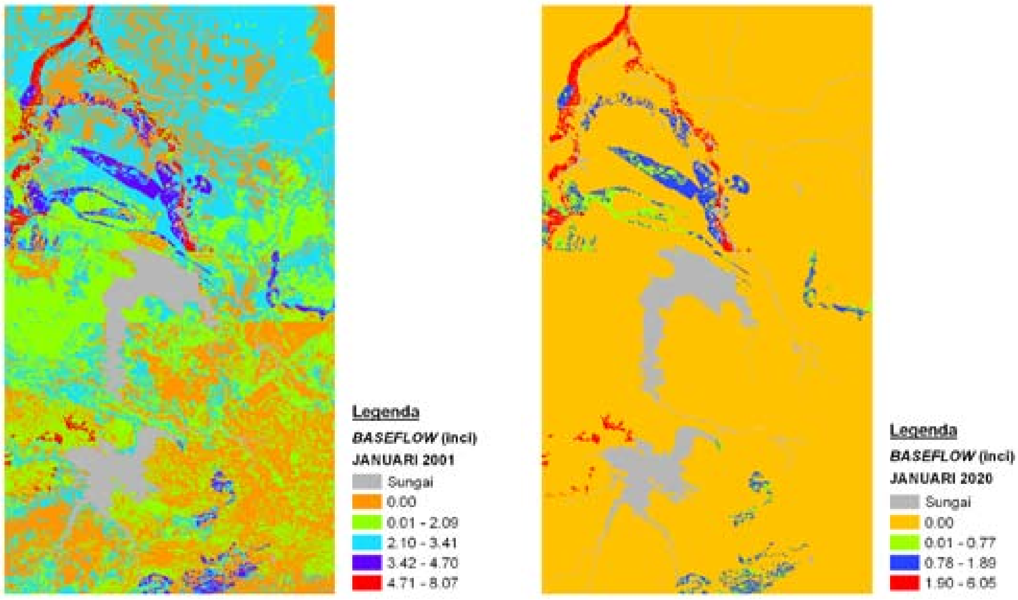

Figure 4.10 Base flow map for January 2001 (left) and the projection for 2020 (right).

In July (see Figure 4.11) the base flow in study area increased to 0.01 – 12.84 inch (0.254 – 326.14 mm) from the rainfall rate of 22.96 inches (583.18 mm). Even though the rainfall rate increased, the water volume that reaches the underground water reservoir is less than 50% from the total amount of rainfall rate. But the interesting point here is that the rainfall rate in July is higher than in January, this is because the data is recorded using the area's average rainfall. There are several monitoring stations that recorded some anomaly in the rate of July rainfall; the result is that the July rainfall is higher than January. But the calculation of the average rainfall recorded in all monitoring stations shows that the rainfall pattern is still that of the monsoon rainfall pattern (see Figure 4.2). The cause of anomaly is still unknown, and it will need further research to study the anomaly.

The result of base-flow projection in 2020 (see Figure 4.11 - right panel) shows just about the same result, between 0.01 – 12.15 inch (0.254 – 308.61 mm). This relates to the still high rainfall rate in July 2020, of about 16.72 inches (424.69 mm). This shows that infiltration rate is still low; please note that high base-flow value only occurs in a small number of areas (less than 20% of study area). Depleted by the change of land-use in the catchments area, this will cause further decrease of base flow. And this condition is certainly not good.

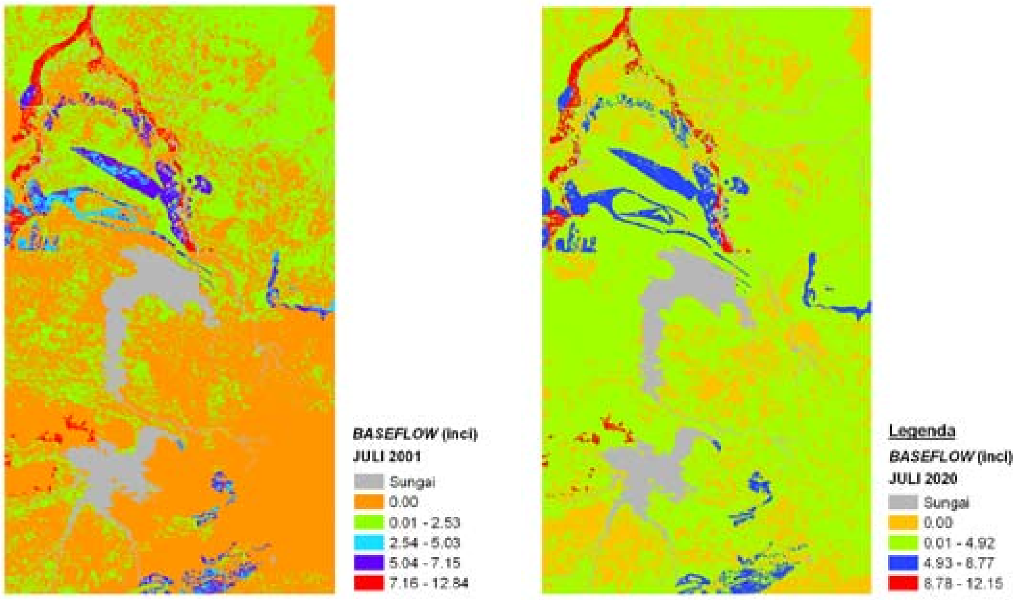

Figure 4.11 Base-flow map of July 2001 (left) and the projection for 2020 (right).

From the condition above, we can see that the base-flow value of an area is much related to the land cover and the type of soil. For this study area, the type C soil (runoff potential is medium to high) is dominating, hence the volume of water that percolates to reach the groundwater reservoir is relatively small compared to the amount of DRO. On other hand, the type A soil (runoff potential is really low) is very little, therefore even though some base flow values in the study area is more than 12 inches, the water catchments area is very small (less than 20% of total study area).

From the climate variable analyses, climate change and groundwater in the previous chapters, we can conclude that:

1. Based on the result of temperature variable projection, the temperature tends to increase until 2020, and will continue to rise in the future. The trend of gradual increase in temperature is an indication of a climate change in the research area.
2. From the perspective of seasonal distribution in the study area, the rising temperature changes the rainfall rate. In general the study area is wetter during the rainy season and drier in the dry season.
3. The change in rainfall distribution causes potential natural hazards triggered by increased rainfall rate such as: flood, landslide, river overflow, and the spread of epidemic diseases. On the other hand, decreasing rainfall can cause drought, failed harvest, lack of clean water, and social problems, such as monopoly of water supply.
4. Flood threat in the northern part of study area is higher because the elevation in this part is lower than the south, and in high rainfall period, this can cause big flood in the north because the south part is also steeper compared to the gradual slope in the north. The topographical profile of the area poses also the danger of river overflow and a giant accumulation of water forming around the riverside area in the north.
5. The area with potential landslide is in the steep slope between Cirata and Jatiluhur. The area west of Jatiluhur, also faces the same threat because it is a steep area with high DRO rate.
6. Based on the rainfall rate in wet and dry season, actually the volume of from rainfall can cover the water needs for the local communities in study area. A person would need 100 liter of water per day, the rainfall in 1 month (January 2001) is 348 million litter, and the population in Citarum riverside is 5.7 million. The rainfall could supply 20.4 liter/day for each person or 20% of the need. The river, lake, or even artesian water (well) can supply the remaining required water.
7. The current rain level is still sufficient to provide the water reserve needed to conserve the forest in the research area (the forest in the area needs $0,93x10^8$ liter/month while the volume of water in January 2001 is $3,48x10^8$ liter/month). Even with the assumption that the forest area decreases as the result of local development, the water volume projected for year 2020 is still enough to maintain this condition. But if in reality the level of development exceeds the estimated rate causing even less water catchments then this prediction might not be valid.
8. Based on the data of the average monthly debit between 1984 and 2005 at one point in the research area, the average daily debit in a year comes to 12.253.884 liter/day for every square kilometer. Therefore the average monthly debit is 367,616,520 liter/month. If this number is added to the rain level, the sum would be 7.15×10^8 liter of water/month. This would provide enough water for the demand of the communities in the riverside area and also for the forest (the total need of water for the communities and forest is $6,63x10^8$ liter/month).

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GLOSSARY

Base-flow

Water that reaches the groundwater reservoir which supplies the river.

Direct Runoff

The overflow of surface water. This happens when water directly flows over the ground surface because the soil can no longer absorb the rain.

Green House Effect

During the day time, when the sun radiates its energy to the earth, a large part of the radiation energy (45%) is reflected back to the sky. The green house gas layer in the atmosphere will absorb the reflected sun radiation. This phenomenon is often called the green house effect. Green house effect correlates with global temperature change. If there is no green house effect in atmosphere, the earth temperature will be below - 18°C.

Evaporation

The process of liquid turning into gas.

Evapotranspirasi

Water evaporation through direct evaporation of a wet surface and the release of vapors from vegetations.

Green House Gas

The gasses that absorb sun radiation and bounce it back to earth and causing the earth temperature to rise. Some of the green house gasses are: carbon dioxyde ($CO_{2)}$, Methane, Nitrous Oxyde, etc.

Groundwater

The water below the ground surface.

Infiltration

The process of water being absorbed by the soil or rocks.

Convection

The vertical air movement caused by heated ground surface.

Global Warming

The warming of the earth surface caused by green house gasses in the atmosphere.

Percolation

Water movement into the soil.

Precipitation

Various water particles (liquid and solid), that falls from the atmosphere and reach the ground.

Runoff
Sum of base-flow and direct runoff.

Hydrology Cycle
Natural water cycle of the earth, the transformation from liquid, solid, and gas.

Vapor Pressure
Pressure caused by the molecules of evaporated water in certain air volume.

Air Temperature
Degree of hotness and coldness of air measured by a thermometer.

Transpiration
Release of water vapor by plant into the atmosphere.

Water Catchment Volume
Capacity of soil to trap/retain water.

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