Chapter 3
Hydrologic Balance of Citarum Watershed under Current and Future Climate

Rizaldi Boer, Bambang Dwi Dasanto, Perdinan and Delon Marthinus

Abstract As the biggest watershed in West Java, Citarum plays an important role in supplying water for many districts in the province. The Citarum watershed supplies approximately 7,650 million cubic metres of water per year ($m^3\ a^{-1}$). Currently, approximately 78% of the extracted water is used for irrigation, 14% for industrial activities and electricity generation, and 8% for domestic consumption. Analysis of this watershed found it to be very vulnerable to climate change. It was found that all of the sub-districts already experience water deficit problems (i.e. not enough supply to meet their demands), particularly in the lower areas such as Kerawang, Bekasi and Purwakarta, even without a changing climate and if the level of water extraction from the streamflow was limited to 10% of the mean annual flow. In 2080, the water deficit for most of the sub-districts in this lower area would be even more severe. Increasing water extraction to 20% of the mean annual flow would not change the water status of these sub-districts. Consequently, conflicts among water users may be a serious problem for these regions in the future.

Keywords Climate change · Hydrology balance · Citarum watershed

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R. Boer (✉) · B. D. Dasanto · Perdinan · D. Marthinus
Laboratory of Climatology, Department of Geophysics and Meteorology
Faculty of Mathematics and Natural Sciences, Bogor Agricultural University,
Gedung FMIPA Level 4 Wing 19 Kampus IPB Darmaga, Bogor, 16680, Indonesia
e-mail: rizaldiboer@gmail.com

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Introduction

Citarum watershed is an important watershed in West Java, Indonesia. Water supply from this watershed is used for many purposes, including electricity generation, domestic consumption, irrigation water for agricultural uses and flushing Jakarta canals. The watershed supplies approximately 7,650 million cubic metres of water per year ($m^3\ a^{-1}$); approximately 5,750 million $m^3\ a^{-1}$ (75%) comes from Citarum watershed dams (Saguling, Cirata and Jatiluhur) and 1,950 million $m^3\ a^{-1}$ (25%) comes from other rivers (Perum Jasa Tirta II 2003). Currently, approximately 78% of the water is used for irrigation, 14% for industrial activities and electricity generation and 8% for domestic consumption. Water is not only supplied for irrigating districts within the watershed area, but also for districts outside the watershed. For example, Jakarta, the capital of Indonesia, receives clean water from Jatiluhur dam. The dam also supplies water for other districts outside the Citarum watershed such as Indramayu and Sukamandi (the main rice production centres of West Java).

Extreme climate events, climate change, and land use and land use cover (LULUC) change such as forest degradation, are expected to significantly impact the Citarum watershed by decreasing the water supply. During drought years associated with the El Niño phase of the El Niño Southern Oscillation Index (ENSO), irrigation supply from a great portion of the watershed decreased significantly causing widespread drought in irrigated rice paddies, particularly in the tail-end of the irrigation area. In West Java, the average area (over the period 1989–2004) suffering from drought during normal years was approximately 7,800 ha, while during ENSO years, this area increased sharply to 290,000 ha (Directorate of Plant Protection 2000).

It is very likely that due to the increasing demand for water supply, conflicts between water users may be a serious problem in the future. It is predicted that after 2010, the Citarum watershed might not be able to meet the water demand of its users (Hernowo 2001). Observations using historical data from 1896 to 1991 have shown that annual rainfall over the Citarum catchments and the corresponding water discharge have decreased by about 10 and 3.1 mm annually. The output of the ECHAM model suggests that rainfall in this region would continue to decrease in the future.

This study aims to assess the vulnerability of the watershed to current climate variability and to evaluate the status of the water balance of the watershed under the current and future climate using a number of climate change scenarios.

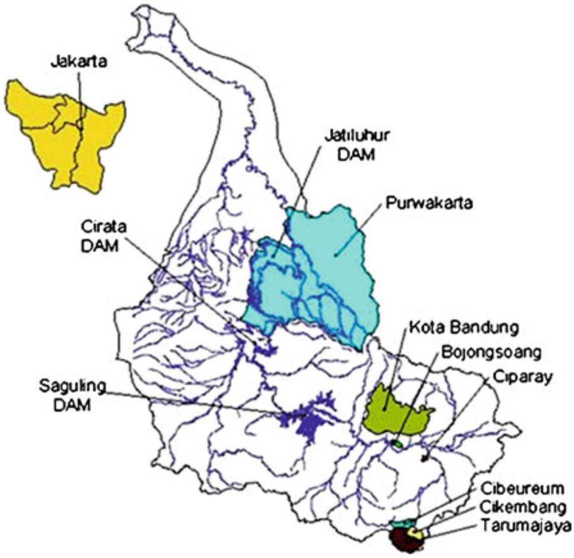


Fig. 1 Geographic characteristics of Citarum watershed

Methodology

Study Area

Citarum watershed is situated in West Java province, Indonesia. The catchment area is approximately 6,867 km^2 with a length of about 269 km. The highest geographic peak is approximately 1,700 m above sea level (ASL) and the lowest point is 0 m ASL. There are three dams in the watershed: Saguling in the upper part, Cirata in the middle, and Jatiluhur or Juanda in the lower part, as well as nine hydrological observation stations (Fig. 1). The main city is Bandung, which has a population of approximately 2.5 million people.

The annual rainfall is about 2,580 mm divided over two seasons–a rainy season (from November to April) that receives approximately 1,840 mm and a dry season (from May to October) that receives approximately 740 mm. The rainy season peaks around January. The average streamflow of Citarum river is 173 m^3 s^{-1}. The Saguling and Cirata Dams are mainly used for electricity generation while the Jatiluhur Dam is mainly used for agriculture. Perum Jasa Tirta II (2003) predicted that the water demand by allocation in 2005 would be approximately 5,519 million m^3 a^{-1} (75%) for irrigation, 672 million m^3 a^{-1} (9%) for drinking water, 473 million m^3 a^{-1} (6%) for industry, 315 million m^3 a^{-1} (4%) for fisheries, 315 million m^3 a^{-1} (4%) for flushing Jakarta canals, and 100 million m^3 a^{-1} (1%) for electricity generation.

The three dams (Saguling, Cirata, and Jatiluhur) are interconnected. Outflow from Saguling Dam goes to Cirata Dam, outflow from Cirata Dam goes to Jatiluhur Dam, and outflow from Jatiluhur is used for the many purposes as described above and then finally flows out to the Java sea (Fig. 1). Inflow from other local rivers also supplies the three dams.

Streamflow Analysis

ENSO events are one of dominant factors that cause extreme climate conditions in Indonesia such as drought (ADPC 2000; Yoshino et al. 2000; Kirono and Partridge 2002; D'Arrigo and Wilson 2008). Water inflow into the reservoirs decreased significantly as a result of decreased rainfall during ENSO-related drought events. The behaviour of streamflow during these events was assessed using a simple correlation analysis between the Southern Oscillation Index (SOI) and streamflow data from one hydrology station (Cigulung-Maribaya station) with a long historical record (1953–2002). The five SOI phases from Stone et al. (1996) were used in the analysis. These phases are consistently negative (Phase 1), consistently positive (Phase 2), rapidly falling (Phase 3), rapidly rising (Phase 4), and neutral (Phase 5). The SOI values can be downloaded from http://www.dpi.qld.gov.au. When SOI falls rapidly and then remains negative, it indicates that an El Niño event is likely, which normally reduces rainfall in Indonesia, particularly in parts of South Sumatra, Java, and the eastern part of Indonesia. Conversely, when SOI increases rapidly and then remains positive, it indicates that La Niña is likely, which normally increases rainfall.

A graphical analysis showing the change in streamflow mean between normal, El Niño and La Niña years was also conducted. Total inflows from local rivers to each dam from 1986 to 2002 were obtained from Perum Jasa Tirta II were used in the analysis. This record covered five El Niño years (1987, 1991, 1994, 1997 and 2002), two La Niña years (1989 and 1998), and ten normal years.

Hydrology Balance Analysis

The purpose of the hydrology balance analysis is to assess the status of hydrology water balance at Citarum watershed under current and future climate. The analysis was conducted down to the sub-district level.

Hydrology balance is expressed in the following equation:

$$\mathbf{Supply} = \mathbf{Demand} + \mathbf{Surplus}$$

If the demand is higher than supply, the surplus becomes negative and vice versa (if supply is higher than demand, the surplus becomes positive).

Water Supply

In the water supply analysis, the annual water supply (i.e. surface flow or discharge) of the watersheds was calculated using a simple linear regression between annual surface flow as dependent variable and annual precipitation as independent variable. This approach has been applied by previous work that assessed hydrologic balance in Indonesia (Pawitan 1996). The equation used for this study is expressed below,

$$\mathbf{V_Q = aP - b}$$

where $\mathbf{V_Q}$ represents annual surface flow or streamflow (in mm), **P** represents annual precipitation (in mm), and ***a*** and ***b*** are constants. In this analysis, the Citarum watershed is divided into three regions–upper, middle and lower–with areas of 1,874 km^2, 2,477 km^2, and 2,517 km^2, respectively. The relationship between annual streamflow of local rivers and annual rainfall for each region was developed using the above regression equation. Because Cirata Dam receives water outflow from Saguling Dam, and Jatiluhur Dam receives water outflow from Cirata Dam (refer back to Fig. 1), the water supply equation for these two dams is:

$$\mathbf{V_Q = aP + b - I}$$

where **I** represents the water outflow from the respective dams. As the streamflow data is in m^3 s^{-1}, these units were converted into annual streamflow measured as depth over the catchment (in mm). The calculation was conducted as follows:

$$\mathbf{V_Q = [I * (365 * 24 * 60 * 60)/A] * 1000}$$

where **I** represents the average of annual inflow or outflow (m^3 s^{-1}) and **A** represents the area of the corresponding sub-watersheds (m^2). The rainfall data used in the analysis is taken from 26 stations (8 stations in the upper region, 7 stations in the middle region, and 11 stations in the lower region).

This analysis assumed that the maximum annual streamflow (*VQ*) that can be used as water supply should not be more than the minimum inflow. Based on 15-year data, it was found that the minimum inflows to the Saguling, Cirata, and Jatiluhur dams were approximately 21, 23 and 22%, respectively. As such, this study used two water supply scenarios equal to 10 and 20% of the annual streamflow (discharge).

Water Demand

Demand for water comes from three sectors: domestic use (urban and rural), industry, and agriculture. Water demand for domestic use was estimated by multiplying population size by water consumption per capita. Bina Program Cipta

Table 1 Freshwater use per capita in Indonesia

Population size according to city category	Water demand (l/cap/day)			Loss	Total
	Household use	Drinking water	Non-household		
>1,000,000	190	30	60	75	280
500,000–1,000,000	170	30	40	55	230
100,000–500,000	150	30	30	50	200
20,000–100,000	130	30	20	40	165
<20,000	100	30	10	30	125

Source: Bina Program Cipta Karya 1991

Karya (1991) stated that the level of water consumption could be categorized based on the population size of the city. The higher the population is, the higher the demand per capita (Table 1). Thus, water demand projections will follow population projections, assuming no changes in the patterns or management of demand.

For the industrial sector, water demand is estimated based on the size of each industrial area. The two water demand categories used by Bappenas (1991) were 0.55 $\mathrm{l\ s^{-1}\ ha^{-1}}$ (minimum) and 0.75 $\mathrm{l\ s^{-1}\ ha^{-1}}$ (maximum). The analysis in this paper used a water demand value of 0.65 $\mathrm{l\ s^{-1}\ ha^{-1}}$. Because precise data on the size of industrial areas was unavailable, this analysis assumed that the industrial area of each sub-district follows the proportion of the sub-district relative to the total area of the watershed. Using this approach, the industrial area of the Citarum watershed was estimated to be approximately 49,615 ha (0.3% of the total watershed).

For the agriculture sector, the dominant water use is for irrigation (for rice cultivation, specifically). The length of the irrigation season for rice in the two watersheds is between 90 and 150 days. The amount of water required is between 140 and 150 mm per month, equivalent to between 4,500 and 7,000 $\mathrm{m^3\ ha^{-1}}$ per season. Thus, the total annual water demand for irrigation was estimated by multiplying the annual planting area by the demand. The annual planting data of irrigated rice was obtained from the Dinas Pertanian Propinsi Jawa Barat (Department of Agriculture for West Java Province) website (http://www.diperta-jabar.go.id).

Water Supply Scenarios

As the annual water supply is predicted using annual rainfall data, the scenario for water supply will follow rainfall scenarios. The rainfall scenarios were developed based on General Circulation Model (GCM) outputs under two emission scenarios, SRESA2 and SRESB2. Changes in rainfall under global warming varied considerably between GCMs. Two GCM models, CCSR and CSIRO, suggested that the seasonal rainfall would increase consistently over the period from 2020 to 2080

Table 2 Percent change of seasonal precipitation of wet season (DJF) and dry season (JJA) from current rainfall in 2080 under the SRESA2 and SRESB2 scenarios

Scenarios	Months	CGCM2	CSIRO-MK2	CSM-1.3	ECHAM4	GFDL-R15b	MRI2	CCSR/NIES2	DOE-PCM	HadCM3
A2	DJF	-9.16	5.09	-0.23	-7.3	52.21	10.69	10.62	2.18	3.65
A2	JJA	-8.28	12.54	-12.63	-44.92	-23.83	5.61	-5.08	10.04	-27.38
B2	DJF	-6.52	-2.82	-7.56	4.02	-2.05	7.44	-0.25	-2.8	10.72
B2	JJA	-15.72	12.68	-10.01	-13.82	-41.68	7.85	-15.74	19.05	-14.51

Source: Unpublished data (Xianfu 2002)

under both scenarios, except for September–October–November (SON) rainfall. Analysis from the ECHAM4 and CGCM1 GCMs projected that the rainfall would decrease consistently. The HadCM3 GCM did not produce a consistent impact. HadCM3 suggested that December–January–February (DJF) rainfall might not change up to 2020, but would increase up to 2.5% from the baseline in 2050 and then decrease by 2% from the baseline in 2080. The two most interesting findings are (i) the SON rainfall might not change more than 5% from the baseline under the two emission scenarios, and (ii) rainfall during other seasons would increase or decrease up to 15% from the baseline in 2080. Analysis prepared by Xian Fu (2002) also found similar features (Table 2). Because the impact of global warming on Indonesian rainfall is not consistent among GCMs, hypothetical climate scenarios were used. The five rainfall scenarios adopted by this study were -20, -10, 0, +10 and +20% change from the mean rainfall value.

Water Demand Scenarios

Three scenarios were used for water demand. The first scenario is called the baseline scenario (a scenario developed based on data of historical trend and taking into consideration long-term government plan for 2025) and the other two scenarios were developed based on assumptions used in SRESA2 and SRESB2. Therefore, the rate of population growth at each sub-district for the latter two scenarios followed from the population growth rates used in the SRESA2 and SRESB2. Similarly, the development of industrial areas under the other two scenarios was assumed to follow the pattern of GDP growth rate under SRESA2 and SRESB2. Meanwhile, the development of agriculture area was assumed to be the same as that under the baseline scenario. This assumption was used because of the limited land available for the development of agriculture area. The historical data suggested that irrigated paddy area has decreased at a rate of approximately 0.5% per year. Hereafter, the other two scenarios used are referred to as SRESA2 and SRESB2. The result of projections for population growth rate, rice planting area and industry area are presented in Tables 3, 4 and 5, respectively.

Table 3 Projected population growth rate within Citarum watershed under baseline, SRESA2, and SRESB2 scenarios from 2005 to 2080

Scenario	Population growth rate (% per year)				
	2000–2005	2006–2010	2011–2020	2021–2050	2051–2080
Baseline1/	1.67	1.52	1.40	1.21	0.88
SRESA22/	1.40	1.48	0.82	0.52	0.45
SRESB22/	1.30	1.38	0.76	0.45	0.34

(1) Average values over a number of districts in Citarum watershed

(2) Growth rates under these scenarios were developed based on growth rates used in IPCC scenarios (IPCC 2000). It was assumed that the maximum population density is 20,000 people per km^2 in a city (urban area), and 5,000 people per km^2 in rural areas

Table 4 Projected rice planting area within Citarum watershed from 2000 to 2080

District name	Rice planting area (ha/year)					
	2000	2005	2010	2020	2050	2080
Bandung City	4,465	3,422	1,992	500	500	500
Bandung	105,524	108,243	109,348	112,000	120,000	120,000
Bogor	88,185	92,010	95,280	102,000	120,000	120,000
Cianjur	114,415	99,687	88,707	80,000	60,000	60,000
Sukabumi	124,545	107,111	101,171	90,000	70,000	70,000
Subang	167,059	159,166	147,241	125,000	125,000	125,000
Sumedang	69,168	72,625	73,114	75,000	77,000	77,000
Garut	110,746	119,941	128,066	150,000	190,000	190,000
Purwakarta	28,886	33,565	36,820	45,000	63,000	63,000
Karawang	185,147	199,085	208,730	228,000	228,000	228,000
Bekasi	101,964	115,243	124,023	125,000	125,000	125,000

Source: Dinas Pertanian Jawa Barat 2002

Table 5 Projected industrial area within Citarum watershed under baseline, SRESA2 and SRESB2 scenarios from 2000 to 2080

Scenario	Industrial area (ha)					
	2000	2005	2010	2020	2050	2080
Baseline1/	19,440	23,000	27,000	35,000	50,000	60,000
SRESA22/	19,440	23,000	28,000	38,000	52,000	65,000
SRESB22/	19,440	23,000	30,000	40,000	55,000	70,000

(1) Perum Jasa Tirta II 2003

(2) Growth rates under these scenarios were developed based on growth rates from IPCC scenarios (IPCC 2000)

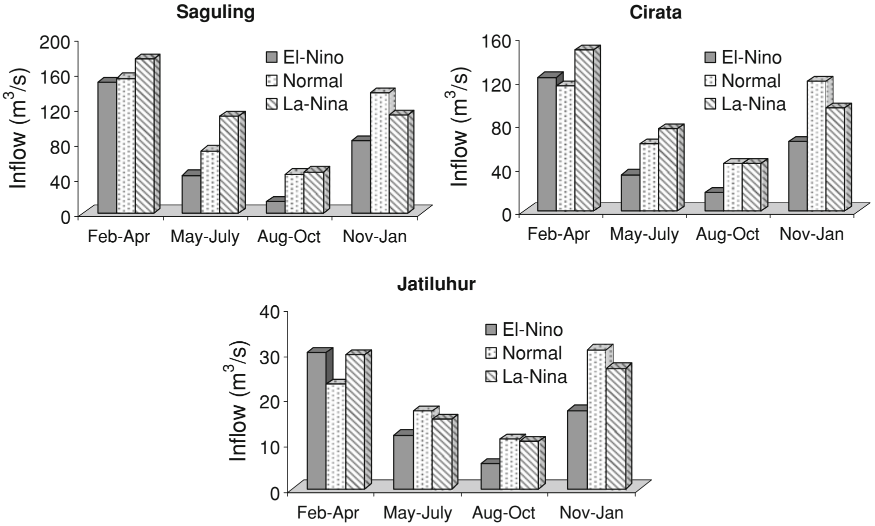


Fig. 2 Mean inflow to the three dams during El Niño, normal and La Niña conditions

Results of Analysis

Impact of ENSO on Streamflow

The impact of ENSO on inflows to the three dams was found to be significant in particular seasons. The impact on streamflow from February to April was statistically insignificant and the impacts of El Niño and La Niña were inconsistent. The impact of El Niño was clear for May–July, August–October and November–January streamflows, while the impact of La Niña was only clear for May–July inflow. The reduction of inflow to the three dams during El Niño years could be as much as 60% of normal inflow (Fig. 2).

Further analysis of the long-term historical streamflow data of Citarum watershed at Nanjung station also showed similar results. The impact of El Niño was significant only during May–July and August–September streamflows. The results of the regression analysis between the seasonal rainfall and SOI showed that May–July streamflow increased by 0.37 $m^3 s^{-1}$ for every 10 unit increase in SOI, while August–October streamflow increased by 0.24 $m^3 s^{-1}$ for every 10 unit increase in SOI (Fig. 3). The November–January and February–April streamflows were not significantly correlated with SOI.

The seasonal streamflow distribution developed from SOI phases one month before the season starts is shown in Fig. 4. The distribution suggests that the August-October streamflow distribution changes when the July SOI falls rapidly or is consistently negative, or when the July SOI increases rapidly or is consistently positive. The same relationship applies to November–January streamflow.

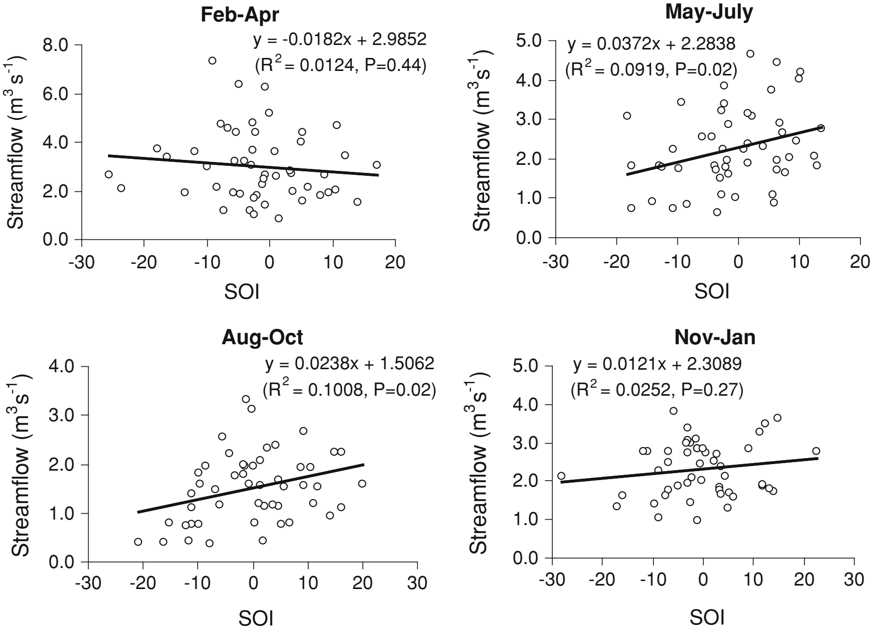


Fig. 3 Relationship between SOI and streamflow of Citarum at Nanjung Station

This analysis suggests that when the SOI phase in July falls rapidly or is consistently negative, the chance of high streamflow from August to October is low. On the other hand, if the SOI phase in July increases rapidly or is consistently positive, the chance of having high streamflow in August–October will increase. Similarly, the chance of having high streamflow from November to January will be low if the October SOI falls rapidly or is consistently negative. For example, the probability of having a November–January streamflow of least 2 m^3 s^{-1} when the October SOI falls rapidly or is consistently negative (Phase 1 + 3) is only 0.35, but when the October SOI increases rapidly or is consistently positive (Phase 2 + 4), the probability will increase to more than 0.60 (Fig. 4). This finding is consistent with a study conducted by D'Arrigo et al. (2009). They found a significant correlation between Citarum streamflow and Southern Oscillation Index (SOI) for June–September.

Water Supply

In the Citarum watershed, the relationship between annual rainfall and total annual streamflow is presented as simple linear regression equations (Fig. 5). Every 1,000 mm of rainfall yields 547 mm of streamflow for the upstream area, 736 mm for the middle area, and only 92 mm for the lower area.

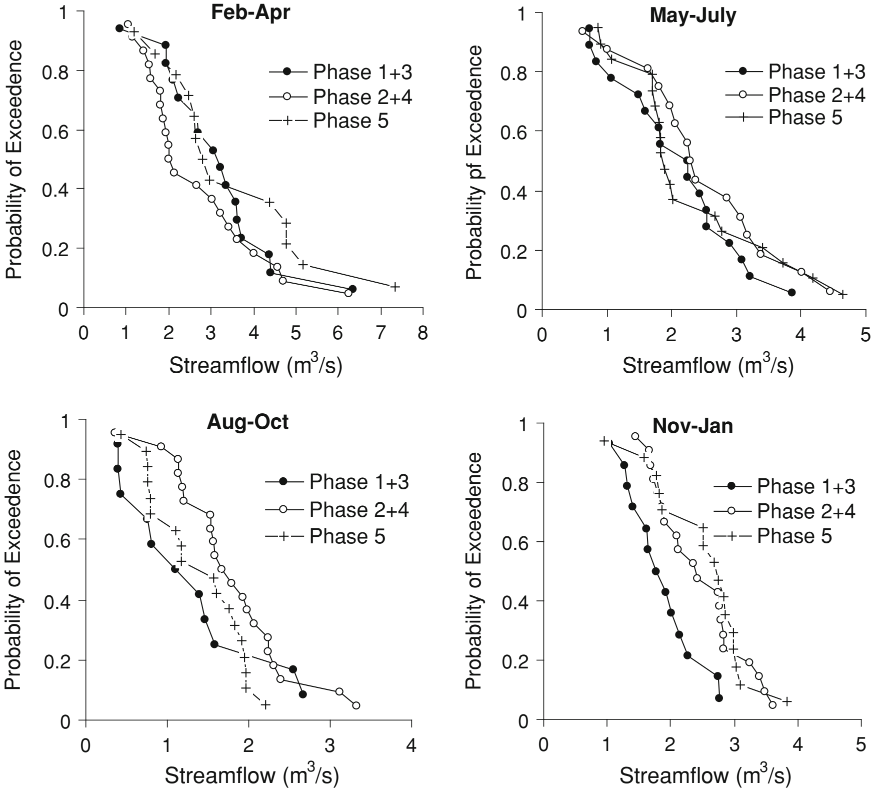
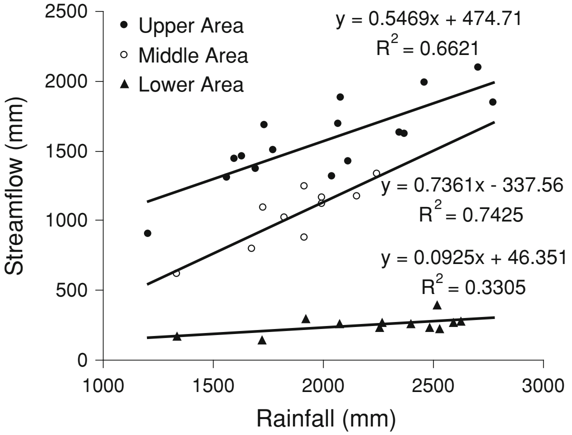


Fig. 4 Seasonal streamflow probability distribution for Citarum watershed at Nanjung station, associated with SOI phase of the previous month

Fig. 5 Relationship between annual streamflow and annual rainfall in the upper (*upstream*), middle and lower (*downstream*) areas of Citarum watershed



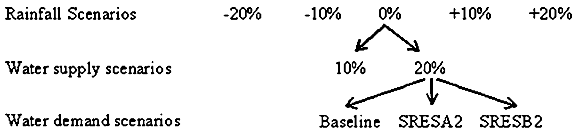


Fig. 6 Water balance scenarios

The middle and lower areas receive water primarily from the local rivers, as well as dams (see Fig. 1). The middle area receives outflow from Saguling Dam (Inflow Saguling-Is), and the lower area from Cirata Dam (Inflow Cirata-Ic). The outflow from Saguling Dam is approximately 710 mm per year (equivalent to 56 m^3 s^{-1}) during normal years and 434 mm (34 m^3 s^{-1}) during dry years. The outflow from Cirata Dam is approximately 1,532 mm (122 m^3 s^{-1}) during normal years and 888 mm (71 m^3 s^{-1}) during dry years; outflow from Jatiluhur Dam is about 2,505 mm (200 m^3 s^{-1}) during normal years and 1447 mm (116 m^3 s^{-1}) during dry years.

Water Balance

The water balance analysis consists of 30 scenarios: five rainfall scenarios, two water supply scenarios and three water demand scenarios ($5*2*3 = 30$). A diagram tree of the scenarios is shown in Fig. 6.

No Change in Rainfall Scenario

Under present climate (no change in rainfall) scenario, if increases in the volume of water extracted from the streamflow were limited to 10%, all sub-districts in the region would continue to have a water deficit problem, particularly in the lower areas of sub-districts in Kerawang, Bekasi and Purwakarta (Fig. 7). The water deficit in these sub-districts would total more than 60 m^3 per year.

Under projections of demand changes, more areas in the sub-districts of Kerawang, Bekasi and Purwakarta would experience severe water deficits by 2020. In 2080, the water supply for most of the sub-districts in this lower area would be insufficient. Increasing the volume of water extraction by 20% would not change the water status of these sub-districts (Fig. 8). Therefore, these sub-districts are considered vulnerable areas. However, Fig. 8 also shows that by increasing the level of water extraction from 10 to 20%, the status of water balance in a number of sub-districts in Sukabumi and Purwakarta the middle areas would be in surplus most years except 2080. By 2080, all districts in the region would face serious problems with water scarcity.

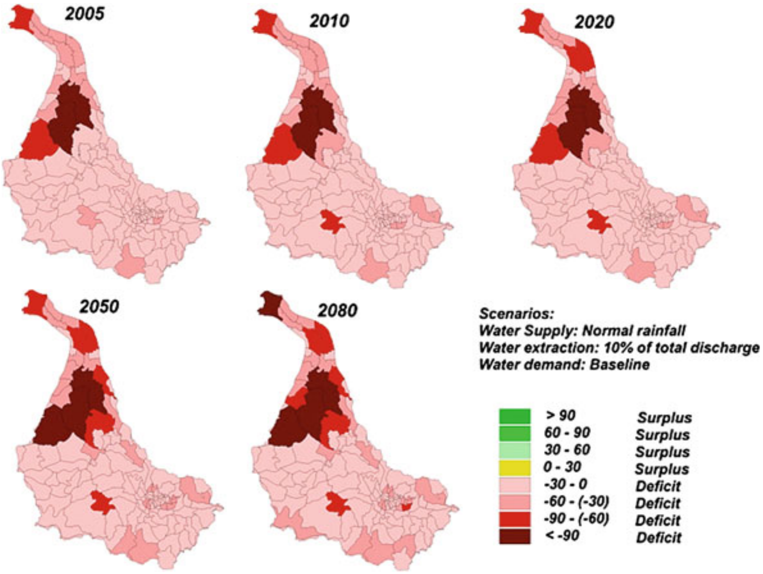


Fig. 7 Projection of water status with no change in rainfall and water extraction of 10% using baseline demand scenario by sub-district in the Citarum watershed

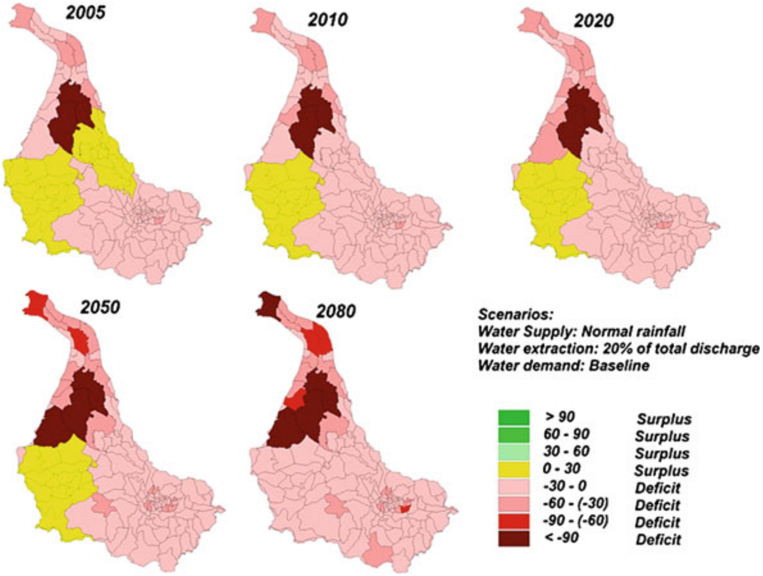


Fig. 8 Projected water status with no change in rainfall and water extraction of 20% using baseline demand scenario by sub-district in the Citarum watershed

Table 6 Percent change in rainfall under SRESA2 and SRESB2 using ECHAM model in West Java, Indonesia

Scenarios	Year	DJF	JJA
SRESA2	2020	0 to 5	−10 to −20
	2050	−5 to −10	−25 to −35
	2080	−5 to −20	−40 to −50
SRESB2	2020	+5 to −5	−10 to −20
	2050	0 to −5	−10 to −15
	2080	−5 to −10	−20 to −30

Change in Rainfall Scenario

As indicated by some of the GCM models, rainfall in West Java may change in magnitude by +5 to -50%. The ECHAM model projects mainly decreases in regional rainfall. The magnitude of the decrease will increase over time from 2020 to 2080 due to global warming (Table 6). Furthermore, rainfall decreases during the dry season are projected to be more pronounced than those during the rainy season. This projection is consistent with historical trends (Pawitan 2002).

By decreasing rainfall by 10 or 20%, and increasing the level of water extraction by 20%, the sub-district in Sukabumi would remain in surplus irrespective of water demand scenarios until the year 2010. If the increase in water extraction is minimized to 10%, all sub-districts would experience deficits similar to those shown in Fig. 7. However, if water demand scenarios followed SRESA2 and SRESB2, the number of sub-districts with a deficit of more than 60 million cubic metres (MCM) would be less. Further analysis showed that if water extraction increased by 10%, an increase in rainfall by 10 or 20% would not change the status of water deficits in the Citarum watershed significantly, irrespective of water demand scenarios. The condition would be similar to those with no change in rainfall (Fig. 7). However, if the level of water extraction were increased to 20%, the water status of most of the sub-districts within Citarum watershed would improve to a surplus (Fig. 9). Sub-districts in Sukabumi might experience a surplus until the year 2080. The CSIRO model suggests that rainfall in West Java will potentially increase up to 20% of the current rainfall under global warming.

Discussion

The results of the analysis suggest that the Citarum watershed is extremely vulnerable to current climatic conditions and, moreover, to future climate change. This finding is consistent with previous analysis conducted by The Directorate of Plant Protection (2000). The aforementioned study reported that West Java is the most vulnerable province to drought and flood events. During El Niño years,

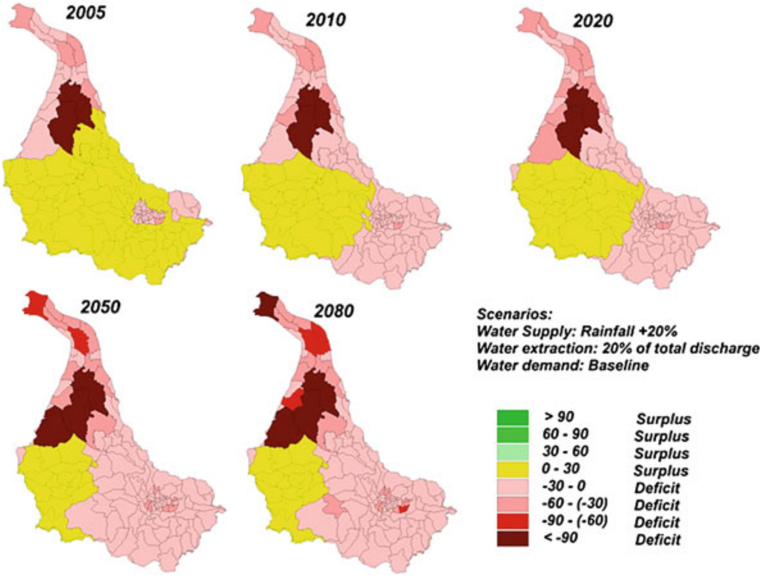


Fig. 9 Projected water status with 20% rainfall increase and water extraction of 20% using baseline demand scenario by sub-district in the Citarum watershed. Note: Water status for SRESA2 and SRESB2 was the same as the baseline

the area suffering from drought increased dramatically, while during La Niña years, areas susceptible to flood also increased significantly. D'Arrigo et al. (2009) found that there was a tendency for greater drought in Java during ENSO warm events (negative SOI).

Our study found that the occurrence of water deficit in the region under current climatic conditions ranges from one to three times over a 10-year period. The frequency of occurrence will potentially increase in the future, as suggested by a number of GCM models such as ECHAM and CGCM (CRU 1999) and based on historical trend data (Pawitan 2002; Kaimuddin 2000). Analysis of annual rainfall data for Citarum watershed over the period 1896–1994 indicated that the annual rainfall in this watershed has decreased at a rate of 10 mm/year. The mean annual rainfall was approximately 2,800 mm per year in the early 1900s, and decreased to about 2,350 mm by the 1990s (Pawitan 2002).

Furthermore, analysis of the long-term land use strategy of Bandung district indicated that the total area of rice paddy field is planned to increase from about 40,000 ha to 100,000 ha (Bapeda, 2002). When this plan is implemented, agricultural demand for water would increase significantly, while the available water supply from Citarum would not change. Under this condition, conflicts between water users might increase. In addition, if programmes for reforesting critical land are not achieved as planned, the area under forest cover might decrease. Consequently, the flood and drought risk in the districts within the Citarum watershed are likely to increase in the future.

Conclusion

Citarum watershed is an important watershed in West Java, Indonesia. Water supply from this watershed is used for many purposes, including electricity generation, domestic consumption, irrigation water and flushing the canal.

The results of the analysis suggest that the Citarum watershed is very vulnerable to current climatic conditions and, moreover, to future climate change. Under the current climate, the chances of experiencing a severe deficit problem are between one and three times over a 10-year period. This frequency is expected to increase in the future.

Under the scenario of no changing climate and if the level of water extraction from the stream flow were limited to 10% of the mean annual flow, it was found that all sub-districts within the Citarum watershed region, particularly in the lower areas in a number of sub-districts in Kerawang, Bekasi and Purwakarta, already have water deficit problems and do not meet their demands. By 2080, the water deficit problem would become even more serious. Increasing water extraction to 20% of the mean annual streamflow would not change the water status of these sub-districts.

Potential water deficit problems may trigger conflicts among water users in these regions in the future. Therefore, the long-term land use strategy for the Citarum watershed and its catchment areas, such as reforesting critical land, should be devised carefully in order to overcome or at least minimize the potential problems of water deficit in the region.

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References

ADPC (2000) ENSO impact and potential forecast applications. in Indonesia. Extreme Climate Events Program, Asian Disaster Preparedness Center, Bangkok, Thailand, 90

Bapenas (1991) Perkiraan kebutuhan air industri sampai tahun 2020. In: Pengkajian Kebijaksanaan Strategi Pengembangan Sumberdaya Air Jangka Panjang di Indonesia. Badan Perencanaan Nasional, Jakarta

Bina Program Cipta Karya (1991) Perkiraan perkembangan penggunaan air di Indonesia menjelang tahun 2020. In: Pengkajian Kebijaksanaan Strategi Pengembangan Sumberdaya Air Jangka Panjang di Indonesia. Badan Perencanaan Nasional, Jakarta

CRU (1999) Climate change scenarios for Indonesia. Climatic Centre Research Unit, UEA, Norwich, UK. Available at www.cru.uea.ac.uk

D’Arrigo R, Wilson R (2008) El Nino and Indian Ocean influences on Indonesian drought: implications for forecasting rainfall and crop productivity. Int J Clim 28:611–616

D’Arrigo R, Abram N, Ummenhofer C, Palmer J, Mudelsee M (2009) Reconstructed streamflow for Citarum River, Java, Indonesia: linkages to tropical climate dynamics. Clim Dyn. doi:10.1007/s00382-009-0717-2

Dinas Pertanian Jawa Barat (2002) Jawa Barat dalam Angka. Biro Pusat Statistik Propinsi Jawa Barat, Bandung

Directorate of Plant Protection (2000) Impact of extreme climate events on crop management in Indonesia, Directorate General of Food Crops and Horticulture, Ministry of Agriculture Indonesia in collaboration with NOAA/OFDA. USA and Asian Disaster Preparedness Center, Bangkok

Hernowo (2001) Pengelolaan waduk Ir. H. Juanda di Jatiluhur. In: Prosiding Lokakarya Selamatkan Air Citarum 75:80

IPCC (2000) Emission scenarios, A Special Rerport of Working Group III of the IPCC, Intergovernmental Panel on Climate Change, Cambridge University Press

Kaimuddin (2000) Dampak perubahan iklim dan tataguna lahan terhadap keseimbangan air wilayah Sulawesi Selatan: Studi kasus DAS Walanae Hulu dan DAS Saddang, Disertasi Program Pasca Sarjana, IPB, Bogor

Kirono D, Partridge IJ (2002) The climate and the SOI. In: Partridge IJ, Ma'shum M (eds) Will It Rain?: The effect of the Southern Oscillation and El Niño in Indonesia. Queensland Government, Department of Primary Industry, Australia, pp 17–24

Pawitan H (1996) Keseimbangan Hidrology menurut Kabupaten di Indonesia. Laporan Penelitian ARMP, Bogor (unpublished report)

Pawitan H (2002) Long-term hydrological balance of Citarum Basin and Java island. Indones J Agric Meteorol 16:49–60

Perum Jasa Tirta II (2003) Data utama bendungan Jatiluhur, Perusahaan Umum Jasa Tirta II, Jatiluhur

Stone R, Hammer GL, Marcussen T (1996) Prediction of global rainfall probabilities using phases of the Southern Oscillation Index. Nature 384:252–255

Yoshino M, Urushibara-Yoshino K, Suratman W (2000) Agriculture production and climate change in Indonesia. Global Environ Res 3:187–197