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CLIMATE CHANGE IMPACT ON IRRIGATION WATER SECURITY IN WEST JAVA

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ABSTRACT

Climate change will change water availability characteristics in the future, and impact on irrigation water security. West Java contributes about 15% of national rice production from almost one million hectares of rice field. Irrigation water security in this region plays an important part in the national food security. This paper analyzes the climate change impact on irrigation water security in West Java. Climate change impact on rainfall in the future is projected using the worst scenario Representative Concentration Pathways (RCP) 8.5 that assumes high energy demand and greenhouse gas emissions in the absence of climate change policies, as mentioned in the latest IPCC report AR 5. The monthly rainfall is projected until the year of 2045 using ensemble of seven models CNRM CM5, CNRM RCA, CNRM v2 Reg CM, CSIRO MK3,6, EC EARTH, GFDL ESM, and IPSL. These models are bias-corrected with the CHIRPS rainfall data set that represents ground stations for the baseline period of 1981 to 2005. For the projection period from the year of 2006 to 2045, a statistical bias correction using quantile mapping methods is applied. Projected river discharge is calculated using a water balance equation, where discharge change is assumed to be influenced by changes in the rainfall and the evaporation. Irrigation water security index from Asian Water Development Outlook is reformulated to enable assessment of nature change, as well as human effort to control the water by means of reservoirs and weirs. The new irrigation water security index consists of: a) Natural hydrological condition represented by coefficient of variation of the monthly discharge within year and annual discharge; b) Competitive environment by water stress condition; and c) Infrastructures of reservoirs and irrigation weirs. It is concluded that the West Java irrigation water security in the future would be significantly reduced if no substantial effort is made to compensate the variability of water availability. All of the six river basins in West Java except Cilaki-Ciwulan are vulnerable to the climate change impact on irrigation water security.

Keywords: irrigation, water security, food security, climate change, discharge variability, water stress

1. INTRODUCTION

Climate change affect rainfall and river flow, and change water availability characteristics in the future. It is predicted that the dry season with decreasing low flow will be of longer duration (IPCC, 2014). This would threat the irrigation water security and food security. West Java is an important rice producing province in Indonesia. Being the third largest rice producer, West Java contributes about 15% of national rice production from almost one million hectares of rice field. Irrigation water security in this region plays an important part in the national food security. This paper analyzes the climate change impact on irrigation water security in West Java.

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2. METHODS

2.1 Case Study: River Basins in West Java

The study area is the river basins in West Java, Indonesia. The location of the six river basins in West Java is presented in Figure 1. Northern part of West Java is heavily populated. Capital City of Jakarta is situated inside Cliwung-Cisadane River Basin, and the three cascades of reservoirs in Citarum River Basin supplying 240 thousand technical irrigation area as well as public water supply to Jakarta.

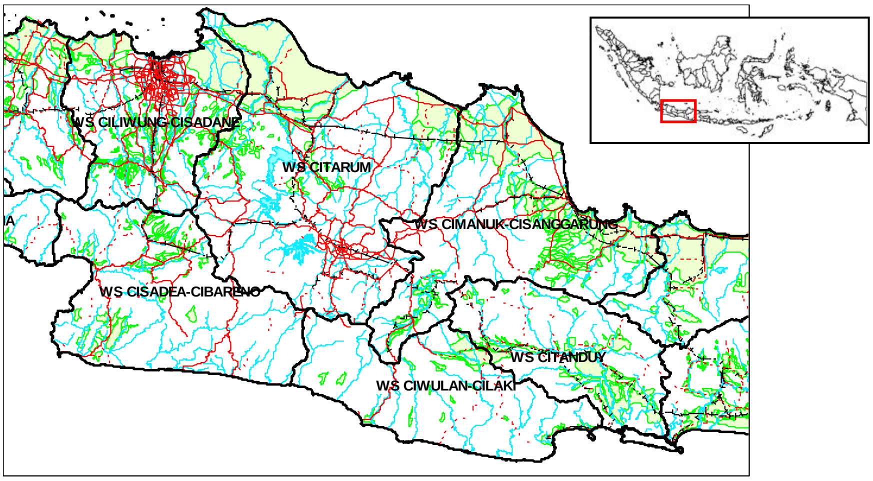


Figure 1. Thesix river basins in West Java Province

The Southern part of West Java, especially Ciwulan-Cilaki basin is less populated and less developed. The following table shows the list of the irrigation area in the river basins.

Table 1. River basins in West Java

River Basins	**Area (km^2)**	**Irrigation area (ha)**	**Population**
Ciliwung-Cisadane	5,267.84	81,479	27,606,881
Citarum	11,321.79	295,502	15,599,964
Cimanuk	7,703.75	213,321	7,963,252
Cisadea-Cibareno	6,806.24	79,353	4,579,045
Ciwulan-Cilaki	5,372.33	73,882	4,005,096
Citanduy	4,506.99	75,403	3,580,368

2.2 Climate Change Projections and Datasets

Climate change impact on rainfall in the future is projected using the worst scenario Representative Concentration Pathways (RCP) 8.5 that assumes high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and greenhouse gas emissions in the absence of climate change policies, as mentioned in the latest IPCC report AR 5. The monthly rainfall is projected until the year of 2045 using ensemble of seven model commonly used by Indonesian Agency for Meteorology, Climatology and Geophysics, that are CNRM CM5, CNRM RCA, CNRM v2 RegCM, CSIRO MK3,6, EC EARTH, GFDL ESM, and IPSL. These seven models are bias-corrected with the CHIRPS rainfall data set that represent ground stations for the baseline period of 1981 to 2005. For the rainfall projection period from the year of

2006 to 2045, a statistical bias correction using quantile mapping methods is applied. Quantile mapping is proved to give best results in annual maximum hydrological simulations compared to other bias correction methods(Teutschbein& Seibert, 2013) and the most efficient in removing rainfall bias compared with several downscaling approaches(Themeßl, Gobiet, & Heinrich, 2012).

Projected river discharge is calculated using a water balance equation, where discharge change is assumed to be influenced by changes in the rainfall and the evaporation. This empirical relationship between the effect of climate factor changes on discharge changes use monthly potential evaporation from Potential Evaporation Climatic Research Unit Time Series (CRU TS) version 4.01 (University of East Anglia, n.d.), observation rainfall data, and observation gauged discharge data in 1981-2005. Empirical methods steps to make the discharge projection is following Risbey & Entekhabi (1996) and Fu, Chiew, Charles, & Mpelasoka (2011)).Rainfall-runoff relationship to project the discharge in the year of 2006 to 2045 using rainfall data projection was carried out by dividing the time series into four groups based on rainfall seasonal characteristic in West Java (December-January-February, March-April-May, June-July-August, September-October-November).

2.3 Water Security Indicators

Irrigation water security index from Asian Water Development Outlook (ADB, 2016)is reformulated to enable assessment of nature change, as well as human effort to control the water by means of reservoirs and irrigation weirs. The new irrigation water security index consists of: a) Natural hydrological condition of water variability represented by the coefficient of variation of monthly river discharges, for seasonal within year and annual inter years; b) Competitive environment by water stress condition; and c) Infrastructures of reservoirs and irrigation weirs.

Water variability, is expressed by the statistical coefficient of variation

$$C_v = \frac{s}{Q_{mean}}$$

where:

C_v = cofficient of variation
S = standard deviation
Q_{mean} = average discharge

There are two kinds of river discharge variability: 1) intra year or seasonal variability; and 2) inter year or annual variability. Higher variability, makes more difficulties in managing the water, and have lower water security score.

Table 2. Score for discharge variability

Inter-annual discharge		**Intra-annual discharge**	
CV	**Score**	**CV**	**Score**
0 – 0.025	5	0 – 0.20	5
0.025 – 0.050	4	0.20 – 0.40	4
0.050 – 0.100	3	0.40 – 0.60	3
0.100 – 0.150	2	0.60 – 0.75	2
0.150<	1	0.75<	1

Competitive of irrigation water demand with other water demand is indicated using the water stress indicator, Critically Index (CI) which is a ratio between water demand and water available in the river basin(ADB, 2016; Alcamo, Henrichs, &Rösch, 2000).The higher CI means less water available to fulfill the water demand, and lower irrigation water security.

Table 3. Score for water stress

Critically Index	Score	Status
< 10%	5	Excellent
10% - 20%	4	Good
20% - 40%	3	Moderate
40% - 80%	2	Poor
80%<	1	Bad

Infrastructures of reservoirs and irrigation weirs improve the supply of irrigation water significantly. These human efforts to enhance irrigation water security is recognized by the ratio of Reservoir Storage to Mean Annual Renewable Resources (MARR) of water available in the river basin; and the same ratio for irrigation weirs capacity.

Table 4. Score for infrastructures

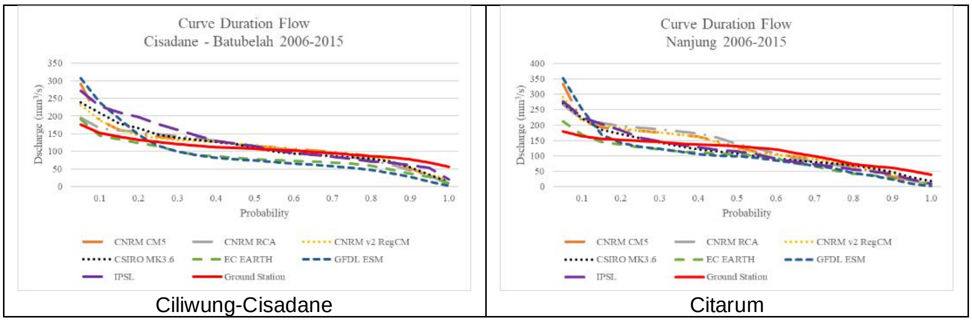
Reservoir Storage and Irrigation Weir Capacity	
Proportion of capacity to water available	**Score**
50% <	5
20% – 50%	4
5% – 20%	3
3% – 5%	2
0% – 3%	1

The final overall irrigation water security index is a combination from the dimensions of natural condition, competitive environment, and infrastructures. It is assumed that each dimension has the same contribution in influencing irrigation water security. Climate change has direct influence to the discharge coefficient of variation; and competitive environment through the change of dependable flow. It is assumed that 1) climate change has no influence on infrastructure capacity, and 2) the water demand remains the same in the future, an unrealistic assumption to be more focus on climate change impact.

3. RESULTS AND DISCUSSION

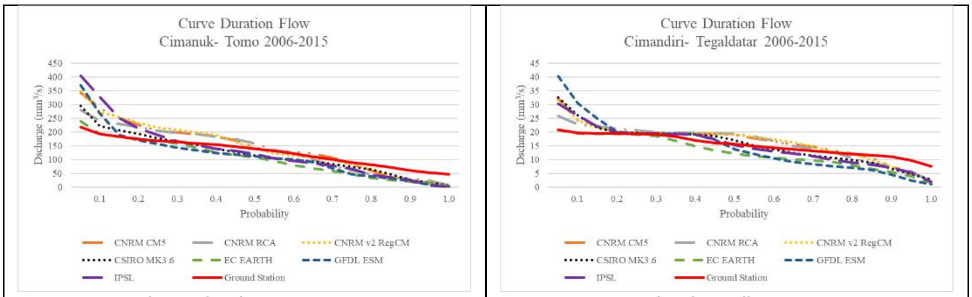
3.1 Climate Change Projections

Validation for the river discharges from the seven projections model in the control period of 2006-2015 show that their flow duration curves are having the same pattern as the river gauging station data (Figure 2).



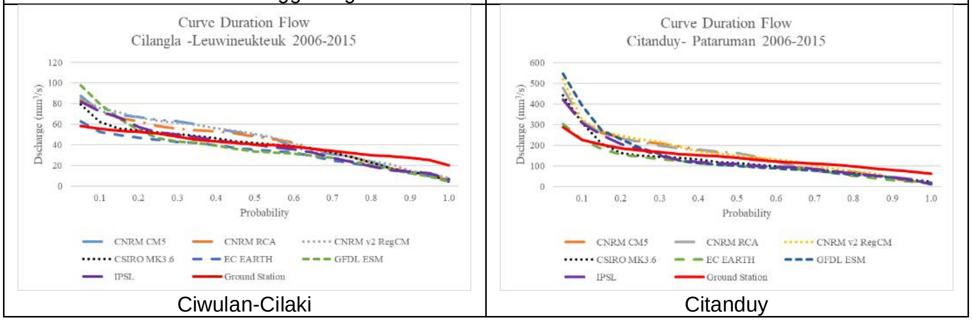
Ciliwung-Cisadane

Citarum



Cimanuk-Cisanggarung

Cisadea-Cibareno



Ciwulan-Cilaki

Citanduy

Figure 2. Flow duration curve of the projected river discharge

In Ciliwung-Cisadane River Basin, for the probability of 0 to 40% the seven models tend to overestimate the actual discharge, while for the probability value of 50% to 100% the model tends to be an underestimate. Whereas in the Citarum River Basin, Cimanuk-Cisanggarung River Basin, Ciwulan-Cilaki River Basin the change from overestimated pattern begin to be underestimated in the probability value 30%, except CNRM CM5, CNRM RCA, and CNRM v2 RegCM models that tend to overestimate. In Cisadea-Cibareno River Basin model overestimate at probability of exceedance of 20%, and the Citanduy River Basin at a probability value of 25%. All of the projection models at low to the average discharge tend to be close to the observation value.

At the mean flow Q50 and dependable flow Q80 discharge values, the projection discharge value can be adequately described as the actual condition. In Ciliwung-Cisadane River Basin five models showed a 2% to 7% error for Q50, four models had a 0.11% to 13% error for Q80. In other river basins, Citarum has four models (Q50, 3% to 13%, Q80 5% to 18%), Cimanuk-Cisanggarung River Basin four models (Q50 0.4% to 14%, Q80 19% to 25%), Cisadea- Cibareno River Basin four models (Q50 2% to 21%, Q80 0.4% to 18%), Ciwulan-Cilaki River Basin four models (Q50 1% to 13%, Q80 20% to 25%), and Citanduy River Basin four models (Q50 6% to 18%, Q80 22% to 36%).

Although the CNRM CM5 model, CNRM RCA, and CNRM v2 RegCM tend to overestimate the ground observation value with a small probability, but at low discharge can describe the discharge quite well. The EC EARTH and GFDL ESM models actually give values that are too underestimated and reach an error value of 27% to 46% in Q50 and Q80 values against actual discharge values in the six river basins. As for each river basin, the model that provides the best projected value varies for each river basin.

Ciliwung-Cisadane River Basin with CNRM CM5 model (Q50 error 7% and Q80 0.11%), Citarum River Basin CNRM v2 RegCM (Q50 6% and Q80 5%), Cimanuk-Cisanggarung River Basin CNRM v2 RegCM (Q50 0.4% and Q80 19%), CSIRO

MK3.6 Cisadea-Cibareno River Basin (Q50 9% and Q80 18%), Ciwulan-Cilaki River Basin CSIRO MK3.6 (Q50 3% and Q80 25%), Citanduy River Basin CNRM v2 RegCM (Q50 8% and Q80 22%). This validate that the projection values can adequately describe the actual conditions of mean flow and low flow in the year of 2006 to 2015.

3.2 Results of Discharge Projection for The Future

To predict the climate change impact on irrigation water security in the future, the analysis is carried out for the river discharges in the two decades of 2013-2035 and 2036-2045. The hydrological characteristic that influence irrigation water security are: 1) coefficient of variation CV; and 2) annual and dependable flow.

Projections of the coefficient of variation for seasonal and annual discharges are presented in the following two tables. Not any significant trend can be identified for the average of the coefficient of variation from the seven projection models. However, in the worst case of the seven models there is a clear tendency of increasing variability in the future.

Table 5. Projections of seasonal CV

River Basin	**Seasonal Coefficient of Variation CV**				
	Average			**Worst Case**	
	Present	**2035**	**2045**	**2035**	**2045**
Ciliwung-Cisadane	0.38	0.35	0.38	0.43	0.46
Citarum	0.45	0.43	0.45	0.47	0.52
Cimanuk	0.58	0.55	0.56	0.67	0.67
Cisadea-Cibareno	0.38	0.38	0.39	0.48	0.46
Ciwulan-Cilaki	0.43	0.44	0.42	0.55	0.50
Citanduy	0.48	0.45	0.46	0.54	0.54

Table 6. Projections of annual CV

River Basin	**Annual Coefficient of Variation CV**				
	Average			**Worst Case**	
	Present	**2035**	**2045**	**2035**	**2045**
Ciliwung-Cisadane	0.16	0.16	0.18	0.34	0.41
Citarum	0.18	0.17	0.16	0.34	0.36
Cimanuk	0.18	0.17	0.20	0.32	0.33
Cisadea-Cibareno	0.17	0.18	0.18	0.35	0.40
Ciwulan-Cilaki	0.22	0.23	0.22	0.38	0.44
Citanduy	0.20	0.19	0.20	0.35	0.40

Projections of the annual mean flow of the seven models, on the average of the six models show a consistent decreasing trend, and this trend are more pronouncing for the worst case (Table 7). This would lead to less water available for irrigation, and decrease the irrigation water security level.

Table 7. Projections of annual mean flow

River Basin	Average (mcm)			Worst (mcm)	
	Present	2035	2045	2035	2045
Ciliwung-Cisadane	6,356	6,240	6,139	4,493	5,378
Citarum	14,328	14,012	13,743	11,221	11,467
Cimanuk	17,111	16,958	16,544	15,305	11,381
Cisadea-Cibareno	12,679	12,185	11,944	8,965	9,371
Ciwulan-Cilaki	8,074	7,987	7,710	6,611	7,152
Citanduy	7,904	7,863	7,588	5,974	7,046

3.3 Climate Change Impact on Irrigation Water Security

3.3.1 Natural Condition

Natural hydrological condition is represented by the variability of monthly discharge within year and variability of annual discharges; and theaverage amount of annual discharge. The seasonal discharge coefficient of variation within year in Table 8 shows that the irrigation water security related with average seasonal variability does not change in future. However, the worst-case projection predict decrease of one level in irrigation water security for Ciliwung-Cisadane, Cimanuk and Cisadea-Cibareno river basins.

Table 8. Seasonal discharge variability impact on irrigation water security

River Basin	Seasonal Coefficient of Variation Cv					Seasonal Variability Score				
	Average			Worst Case		Average			Worst Case	
	Present	2035	2045	2035	2045	Present	2035	2045	2035	2045
Ciliwung-Cisadane	0.38	0.35	0.38	0.43	0.46	4	4	4	3	3
Citarum	0.45	0.43	0.45	0.47	0.52	3	3	3	3	3
Cimanuk	0.58	0.55	0.56	0.67	0.67	3	3	3	2	2
Cisadea-Cibareno	0.38	0.38	0.39	0.48	0.46	4	4	4	3	3
Ciwulan-Cilaki	0.43	0.44	0.42	0.55	0.50	3	3	3	3	3
Citanduy	0.48	0.45	0.46	0.54	0.54	3	3	3	3	3

Table 9. Annual discharge variability impact on irrigation water security

River Basin	Annual Coefficient of Variation Cv					Annual Variability Score				
	Average			Worst Case		Average			Worst Case	
	Present	2035	2045	2035	2045	Present	2035	2045	2035	2045
Ciliwung-Cisadane	0.16	0.16	0.18	0.34	0.41	1	1	1	1	1
Citarum	0.18	0.17	0.16	0.34	0.36	1	1	1	1	1
Cimanuk	0.18	0.17	0.20	0.32	0.33	1	1	1	1	1
Cisadea-Cibareno	0.17	0.18	0.18	0.35	0.40	1	1	1	1	1
Ciwulan-Cilaki	0.22	0.23	0.22	0.38	0.44	1	1	1	1	1
Citanduy	0.20	0.19	0.20	0.35	0.40	1	1	1	1	1

Annual discharge variability in Table 9 shows that the annual variability is having the trend of increasing. However, this typical phenomenon in tropical area is already at the lowest level of irrigation water security, then the indexes remain the same.

3.3.2 Water Stress

Water stressis caused by competitive environment. Table 10 present that no climate change impact on water stress on average projections, but Citarum, Cimanuk and Citanduy river basin will degrade one level of irrigation waters security on worst-case scenario.

Table 10. Water stress impact on irrigation water security

River Basins	Water Stress Ratio					Water Stress Score				
	Average		Worst Case			Average			Worst Case	
	Present	2035	2045	2035	2045	Present	2035	2045	2035	2045
Ciliwung-Cisadane	99%	101%	104%	140%	165%	1	1	1	1	1
Citarum	67%	68%	71%	85%	106%	2	2	2	1	1
Cimanuk	37%	37%	38%	41%	62%	3	3	3	2	2
Cisadea-Cibareno	20%	21%	22%	28%	38%	3	3	3	3	3
Ciwulan-Cilaki	28%	28%	30%	34%	39%	3	3	3	3	3
Citanduy	29%	29%	31%	39%	43%	3	3	3	3	2

3.3.3 Infrastructures of Reservoirs and Irrigation Weirs

Reservoirs and irrigation weirs play important part in irrigation water security. Citarum and Cimanuk river basin gain high score of irrigation security due to their reservoir storage while most of the river basins have substantial irrigation weirs except Ciwulan-Cilaki river basin.

Table 11. Irrigation water security based on existing storage and irrigation weirs

River Basins	Water Available (mcm)	Reservoir Storage			Irrigation Weirs			Overall Score
		Capacity(mcm)	Ratio	Score	Capacity (mcm)	Ratio	Score	
Ciliwung-Cisadane	6,356	0	0%	1	719	11%	3	2.0
Citarum	14,328	4,464	31%	4	4,395	31%	4	4.0
Cimanuk	17,111	1,073	6%	3	4,063	24%	4	3.5
Cisadea-Cibareno	12,679	0	0%	1	1,243	10%	3	2.0
Ciwulan-Cilaki	8,074	0	0%	1	169	2%	1	1.0
Citanduy	7,904	0	0	1	1,515	19%	3	2.0

3.3.4 Overall Irrigation Water Security in The Future

The overall water security index is composed of natural condition, competitive environment, and infrastructures. Using the same weight factors forthese three components, the irrigation water security index for present, average and worst-case futures in each river basin in West Java are presented in the following table.

Table 12. Overall irrigation water security

River Basin	Average			Worst Case	
	Present	2035	2045	2035	2045
Ciliwung-Cisadane	1.83	1.83	1.83	1.67	1.67
Citarum	2.67	2.67	2.67	2.33	2.33
Cimanuk	2.83	2.83	2.83	2.33	2.33
Cisadea-Cibareno	2.50	2.50	2.50	2.33	2.33
Ciwulan-Cilaki	2.00	2.00	2.00	2.00	2.00
Citanduy	2.33	2.33	2.33	2.33	2.00
West Java	2.36	2.36	2.36	2.17	2.11

At present condition, the best irrigation water security is achieved by Cimanuk river basin with big storage of newly built Jatigede dam and considerable irrigation weirs capacity. The second best is Citarum river basin due to the existing of the cascade of reservoirs and substantial irrigation weirs capacity, but lower score in term of water stress caused by optimal water usage of serving vast irrigation area and raw water supply to the capital city of Jakarta. Citanduy river basin with no reservoir storage but sizeable irrigation weir and less water stress is becoming the third best. Ciliwung-Cisadane river basin which include capital city of Jakarta has the lowest irrigation water security because of water stress and no reservoir storage capacity. This results is in line with the similar study on present irrigation water security for the river basins in Indonesia (Hatmoko, Radhika, Firmansyah, &Fathoni, 2017).

In the average situation projected by the seven models, this present situation of irrigation water security is remaining the same until the year of 2045. However, in the worst-case situation almost all of the river basins except Ciwulan-Cilakiwill be suffering degraded irrigation water security level due to impact of climate change.

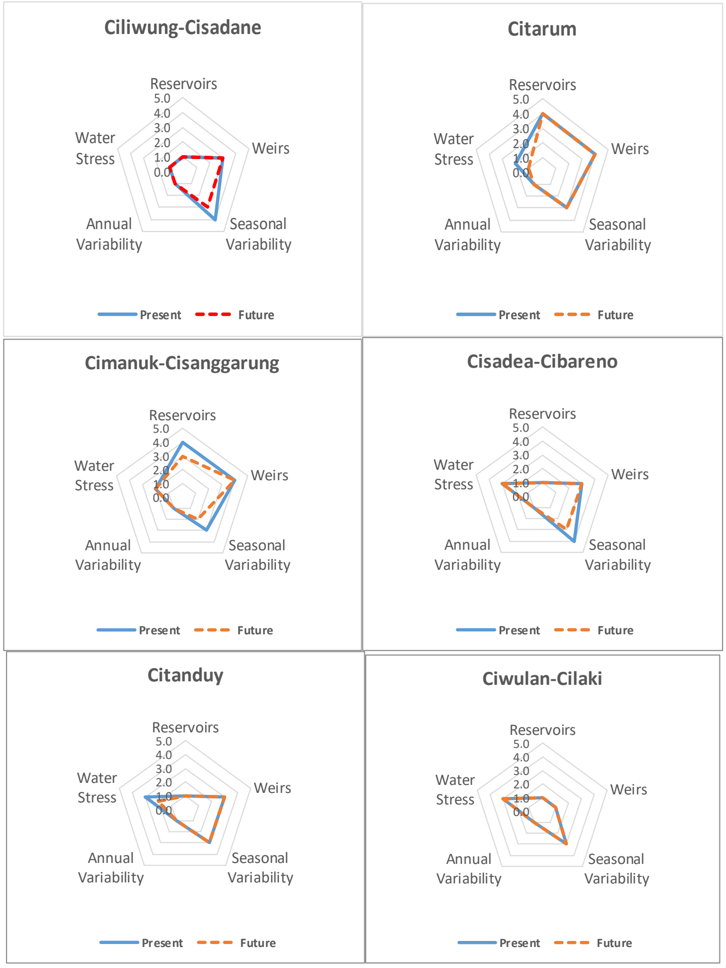


Figure 3. Radar diagram of irrigation water security in West Java

Figure 3 presents the radar diagrams of the irrigation water security components for the six river basins in West Java at present and projected future. The strength and weakness of the irrigation water security are recognized from the shape of the diagram. River basins which tend to upper right corner are having good infrastructures of irrigation weirs and reservoir, such as Citarum and Cimanuk river basins. The red dashed lines of future condition are the worst-case climate change projectionsshowingthe impact of climate change on the components of irrigation water security, that are seasonal and annual variability as well as water stress,

Using the framework in this paper, strategies to cope with the degrading of the irrigation water security level in West Java are: 1) more reservoir storage should be constructed to stabilize the flows variability; 2) Irrigation weirs still can be built in Cisadea-Cibareno and Cilaki-Ciwulan river basin that have potential irrigation field and available water; and 3) water saving in irrigation water demand and demand management for other competing water users are necessary to overcome the ever-increasing water stress.

4. CONCLUSIONS

It is concluded that the West Java irrigation water security level in the future might be significantly reduced if no substantial effort is made to compensate the variability of water availability and decreasing amount of river discharge. All of the six river basins in West Java except Cilaki-Ciwulan are vulnerable to the climate change impact on irrigation water security. Strategy to improve and maintain irrigation water security in West Java among others are constructing more reservoirs, increase irrigation efficiency, demand management for other competitive water users, and build more irrigation weirs in potential area.

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