ANALYSIS OF WATER YIELD SERVICE OF CITARUM WATERSHED BASED ON ECOSYSTEM SERVICES

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ABSTRACT: Assessment of water security is very important for social development. However, most studies only focus on the status quo of air security in certain circumstances and spatial characteristics of air resources. The purpose of this study is to calculate the supply and demand of water resources and identify scarcity and pressure in the Citarum watershed in 2000 and 2020. In this study, water yield services were assessed using the InVEST model (the supply-demand balance model). While the Water Security Index (WSI) is assessed based on an analysis of the balance of water supply and demand to clarify and compare supply and demand. The results showed that: (1) From 2000 to 2020, the water supply in the Citarum watershed decreased by 31.89 X 10^8 m^3 $year^{-1}$ (30.76 %). (2) On the other hand, water demand shows a significant increasing trend, namely 27.91 x 10^8 m^3 $year^{-}$ (81.66%). (3) Based on the WSI index, the condition of water yields in almost all sub-districts is included in the poor class, in 2020 around there are 135 sub-districts (58.44 %) spread across Bandung: 5 sub-districts, West Bandung 5 sub-districts, Subang: 5 sub-districts Purwakarta: 5 sub-districts, Sumedang: 5 Indramayu sub-districts: 5 sub-districts nd Cianjur: 5 sub-districts) it was found that water consumption would exceed the water supply. Gradually, it is necessary to improve the management of water resources so that the sustainability of water resources can be maintained

1. INTRODUCTION

The guaranteed quantity, quality, and continuity of water in a watershed is essential to the concept of water security, which directly or indirectly supports national food and energy security [2 UN-Water]. Quantitative evaluation and visualization of WY is valuable for understanding trends in the function of water supply in an ecosystem. Understanding WY is very useful for water resource managers to determine the effect of human activities on water resources [3 Ouyang

Water scarcity has become a significant constraint on socio-economic development and a menace to livelihoods in several parts of the world (Liu et al. 2017). Concerns over water scarcity and its over-exploitation are increasing because of economic growth and the increase in demand for food and biofuels (Gheewala et al. 2018). T

Population increases affect (directly) rising water use and food production and consumption (indirectly). Regarding water management, we must consider that the world has developed rapidly in the last decade. The recent progress of economic growth, the acceleration of the urban expansion, the substantial increase in population, and the repercussions of climate change have bound to lead to a mass net loss of water balance system under specific locations. These are due to the increase in water consumption, while the volume of water for each capita consistently lowers [1; Li et al., 2021). Some countries, like Indonesia, face severe problems due to water shortage and groundwater depletion [3] (Figueroa et al., 2010).

In the last 20 years, environmental conditions and water quality along the Citarum River have declined significantly. Urban areas are hotspots that drive environmental change at multiple scales. Rapid urbanization, as a result of accelerated development, is linearly proportional to industrial activity, high rates of population growth, expansion of residential areas, and the conversion of land to built-up areas [4 Grimm]. Various negative impacts arise as cumulative compensation for the imbalance between rapid economic development activity and environmental preservation [5 Citarum)

The water supply and demand imbalance will affect regional ecosystems and sustainable socioeconomic development [10] (Xue et al. 2022). The ratio of water supply to demand provides a valuable index for geographic assessment of water value and the health of ecosystems, thereby revealing the essential locations to conserve water yield. Determining whether regions have water demands that are not being fully satisfied requires a spatial assessment of

supply and demand, as shown by a map [11]] (Boithias et al., 2014;). From the water management perspective, conservation programs aim to locate permanent water sources [12] (Guan et al., 2020).
In this study, water yield services were assessed using the InVEST model (the supply-demand balance model). While the Water Security Index (WSI) is assessed based on an analysis of the balance of water supply and demand to clarify and compare supply and demand.

2. MATERIALS AND METHODS

2.1 Study Area

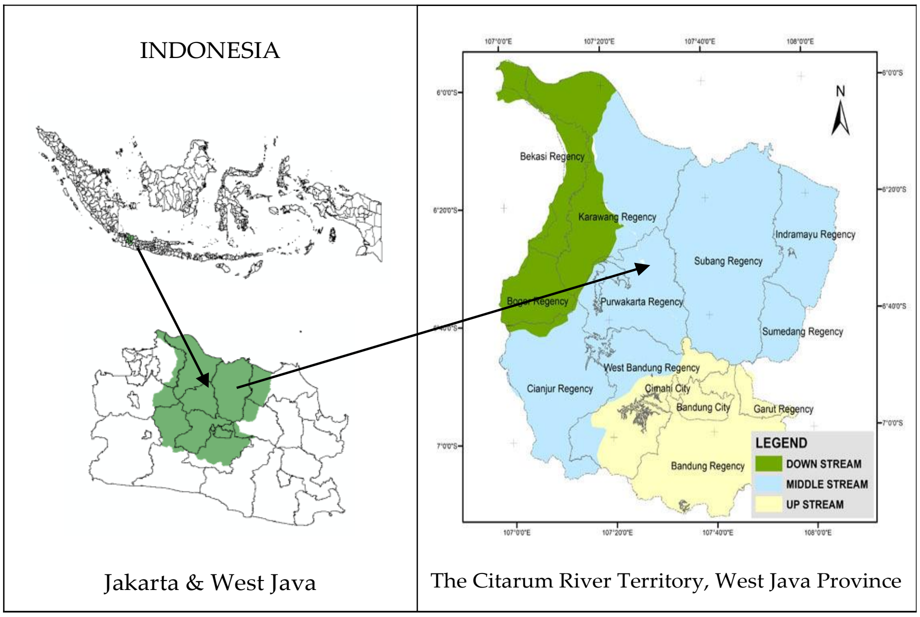

Figure 1. Study area in the Citarum River Territory, West Java Province, Indonesia.

The Citarum River's water is used to meet human needs as a source of domestic water, agricultural irrigation, industrial activity, and freshwater for society living in several regencies in West Java. Indeed, The Citarum River supplies 80% of Jakarta's freshwater needs (Sholeh et al. 2018).

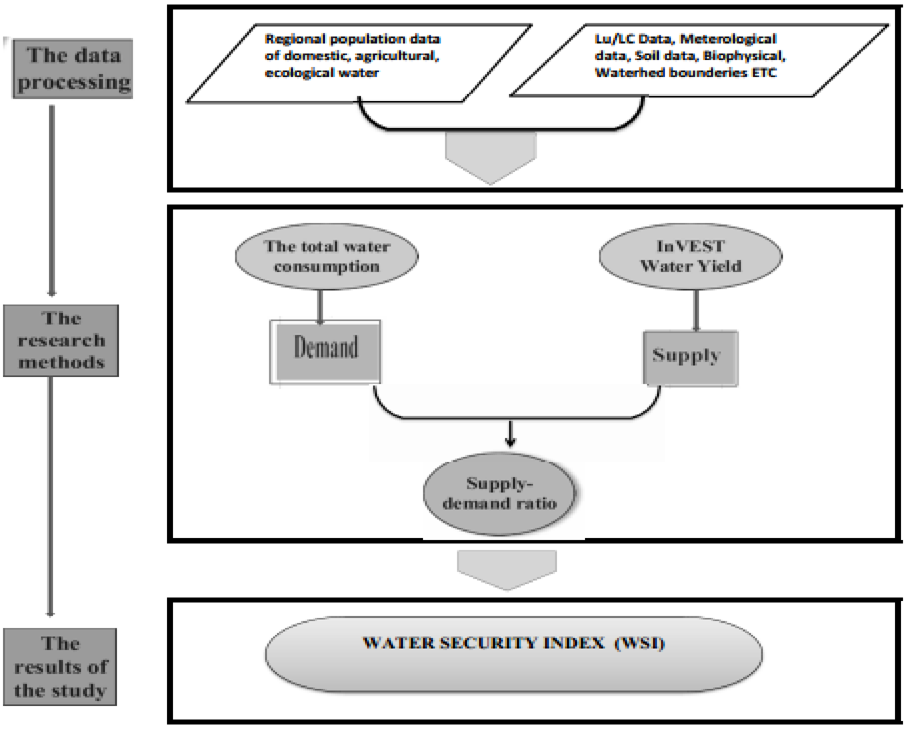

Figure 2. Research flowchart

2.2 Dataset

Remote sensing data and a series of secondary data are listed in Table 1. Data processing is carried out using the geographic information system (GIS) technique, InVEST Model and R Studio..

Table 1. Data set used this research

Parameters	Data Format	Scale	Data Sources
LU/LC maps 2000, 2010 Landsat 8 OLI 2018	Vektor Raster	1:100.000	Ministry of Environment and Forestry; USGS
Rainfall	Numerik		In this study, water yield services were assessed using the InVEST model (the supply-demand The National Bureau of Meteorology, Climatology, and Geophysics; Citarum Cilwung
Evapotranspiration map	Raster	kmx 1 km	WorldClim (https://worldclim.org/data/index.html)
Soil type data	Vektor	1 : 100.000	Citarum Cilwung River Basin Center
DEM (Watershed boundaries)	Raster		Citarum Cilwung River Basin Center
Biophysical	Csv		

The input data were converted into raster data format with 30 m spatial resolution and referred to WGS84 datum as input for InVEST

2.3 Methods

2.31. Calculating water yield in the InVEST model

The yearly water yield for a given LU/LC at each pixel, $Y_{(x)}$, was set in the following manner using equation 1: (sharp, et al. 2014)

$$Y_{(x)} = \left(1 - \frac{AET_{(x)}}{P_{(x)}}\right) \times P_{(x)} 1, \qquad (1)$$

where $AET_{(x)}$ i) is the yearly evapotranspiration measured at the pixel x and $P_{(x)}$ is the annual precipitation at pixel x.

For the vegetated type of LU/LC [40] (Zhang et al., 2004), $\frac{AET_{(x)}}{P_{(x)}}$ i is spatially explicit in its estimation of pixel x, which is calculated using Equation 2:

$$\frac{AET_{(x)}}{P_{(x)}} = 1 + \frac{PET_{(x)}}{P_{(x)}} - \left[1 + \left(\frac{PET_{(x)}}{P_{(x)}}\right)^{\omega}\right]^{\frac{1}{\omega}} \qquad (2)$$

where $PET_{(x)}$ is the potential evapotranspiration of pixel x, and ω is the non-physical variable that determines the interaction between climate and soil conditions; colloquially referred to as the coefficient of plant accessible water capacity.

The input data were converted into raster data format with 30 m spatial resolution and referred to WGS84 datum as input for InVEST. The working stages and formulas in detail refer to the INVESTMENT MODEL 2.2.3 Water Yield: Hydropower Reservoir Production (sharp, et al, 2014, Nahib et al, 2021

2.3.1 Balance of supply and demand for water yield service

It is possible to gain insight into the nature of the regional water service surplus or shortfall by calculating the water yield service supply ratio to the water demand. According to Bastola et al. (2019), the formula for the computation is as follows:

$$SDR = \frac{S_{\mathrm{i}}}{D_{\mathrm{i}}} \qquad (1)$$

The acronym SDR denotes the ratio of available water to the amount of water used. Sub-watershed I has a supply, denoted by S_i, and a demand, denoted by D_i. When it comes to water, a surplus occurs when supply is greater than demand, and a deficit occurs when demand is greater than supply.

By tallying up the amount of available water and how much is used, we can get the SDR for the entire Citarum Watershed. One standard dividing line between water supply and demand surplus and the deficit is the point where supply equals demand (demand exceeds supply). The relationship of water supply and demand, can also be calculated based on the Water Security Index (WSI). (Khan et al. 2020) :

$$WSI = \log(SDR) = log\left(\frac{S_i}{D_i}\right) \quad (13)$$

According to the WSI value, the water resources safety index was divided into three categories: Good water safety index (WSI > 0, the supply exceeds demand and there is a surplus of water resources), **Poor** water safety index (- 1 <, WSI < 0),. and Low water safety index (WSI , < 0, the demand exceeds the supply, it means the surplus of water resources is negative)

3. RESULTS

3.1 Spatio-temporal changes in water demand

Based on the results of the analysis of the InVEST model, in years 2000, the volume of WY at RBU Citarum is around 166.42 $\times 10^8$ m^3 $year^{-1}$, meanwhile in years 2020 is 101.44 $\times 10^8$ m^3 $year^{-1}$ (Table 2).

Table 2. Water yield and Water Consumtion in the Citarum watershed in 2000 and 2020.

No	**Sub-watershed**	**Year 2000**				**Year 2020**			
		Water Yiled		Consumtion		Water Yiled		Consumtion	
		10^8 m^8	%	10^8 m^8	%	10^8 m^8	%	10^8 m^8	%
1	Cikarokrok	3.06	1.84	2.19	4.44	1.62	1.60	3.70	4.19
2	Cibadak	1.10	0.66	0.92	1.87	0.52	0.51	1.52	1.72
3	Cimalaya	9.90	5.95	2.44	4.93	4.04	3.99	4.31	4.87
4	Ciasem	11.21	6.74	3.39	6.86	5.23	5.16	5.86	6.62
5	Cireungit	0.39	0.23	0.20	0.41	0.09	0.09	0.34	0.38
6	Cipunara	18.28	10.98	5.19	10.50	11.80	11.63	9.74	11.01
7	Cirandu	1.29	0.78	0.69	1.39	0.31	0.31	1.16	1.31
8	Sewo	1.51	0.91	0.56	1.13	0.37	0.36	0.94	1.06
9	Sukamaju	1.18	0.71	0.45	0.90	0.32	0.32	0.75	0.85
10	Cibodas	3.71	2.23	1.41	2.84	1.46	1.44	2.50	2.83
11	Bugel	1.13	0.68	0.41	0.84	0.34	0.34	0.69	0.79
12	Cidongkol	4.58	2.75	1.58	3.19	1.62	1.59	2.87	3.24
13	Batang Leutik	0.52	0.31	0.27	0.55	0.15	0.14	0.46	0.52
14	Cibadar Dua	2.35	1.41	1.23	2.49	0.81	0.80	2.05	2.32
15	Cisaga	1.11	0.67	0.40	0.80	0.32	0.31	0.67	0.75
16	Cisedari	4.16	2.50	0.93	1.88	0.78	0.77	1.56	1.76
17	Citarum	98.66	59.28	25.96	52.50	70.39	69.39	47.29	53.46
18	Cibanteng	0.71	0.42	0.48	0.97	0.47	0.46	0.81	0.92
19	Cigemari	1.58	0.95	0.75	1.52	0.81	0.79	1.26	1.43
	Total	**166.42**	**100**	**49.46**	**100.00**	101.44	100.00	88.46	100.00

This WY reflects natural river flow, not taking into account the use of water inhuman activity, such as by households, industry, and agriculture [Van Paddenburg,.]. The Citarum watershed has the highest annual rainfall (1.994 mm/year) with the lowest potential evapotranspiration (1.291 mm/year). With actual evapotranspiration of 649 mm/year, the Citarum Watershed produces the highest WY at 1.220 mm/year (Table 3). The producer of the second-largest WY is the Cipunara Watershed (1.126 mm/year), the third-largest is contributed by the Cimalaya Watershed (974 mm/year), and the fourth-largest is from theCiasem Watershed (969 mm/year).

In years 2020, in terms of the volume of water supply, the Citarum watershed which is the widest watershed, makes the largest contribution to WY, with 70.39 $\times 10^8$ m^3 $year^{-1}$ (63.39 %), followed by the Cipunara Watershed with 11.80 x 10^8 m^3 $year^{-1}$ (11.63 %), , the Ciasem Watershed at 5,23 x 10^8 m^3 $year^{-1}$ (5.16 %), and the Cimalaya Watershed with 4.03 $\times 10^8$ m^3 $year^{-1}$ (3.99 %),. In general, the distribution of water demand in the Citarum RBu area is relatively the same as the pattern of water supply. The Citarum watershed area which fulfills the largest water demand, with 47.29 $\times 10^8$ m^3 $year^{-1}$ (53.36 %), followed by Cipunara watershed with 18.28 x 10^8 m^3 $year^{-1}$ (10.98%),, The Ciasem watershed is 5.86 x 10^8 m^3 $year^{-1}$ (6.62 %), and the Cimalaya watershed is 4.31 x10^8 m^3 $year^{-1}$ (4.87%),.

In years 2000, in terms of the volume of water supply, the Citarum watershed which is the widest watershed, makes the largest contribution to WY, with 99.66 $\times 10^8$ m^3 $year^{-1}$ (59.28 %), followed by the Cipunara Watershed with 18.28 x 10^8 m^3 $year^{-1}$ (10.98 %), , the Ciasem Watershed at 11.21 x 10^8 m^3 $year^{-1}$ (6.74 %), and the Cimalaya Watershed with 9,90 $\times 10^8$ m^3 $year^{-1}$ (5.95 %),. In general, the distribution of water demand in the Citarum RBu area is relatively the same as the pattern of water supply.

In terms of distribution, the middle watershed produces the largest amount of water because it covers an area of 69.51 thousand ha (61.39%) with a total WY of 7.53 × 109 m3/year (61.89%). The remaining contribution of results is evenly distributed between upstream and downstream. While the highest average WY comes from the downstream area of 1201 mm/year, the middle area provides 1,084 mm/year, and the upstream area produces 951 mm/year.

The spatial distribution of water yields in the Citarum watershed in 2000 is shown in Figure 3a and Figure 3b in 2020. Meanwhile, the spatial distribution of water demand in 2000 is shown in Figure 4a and Figure 4b in 2020.

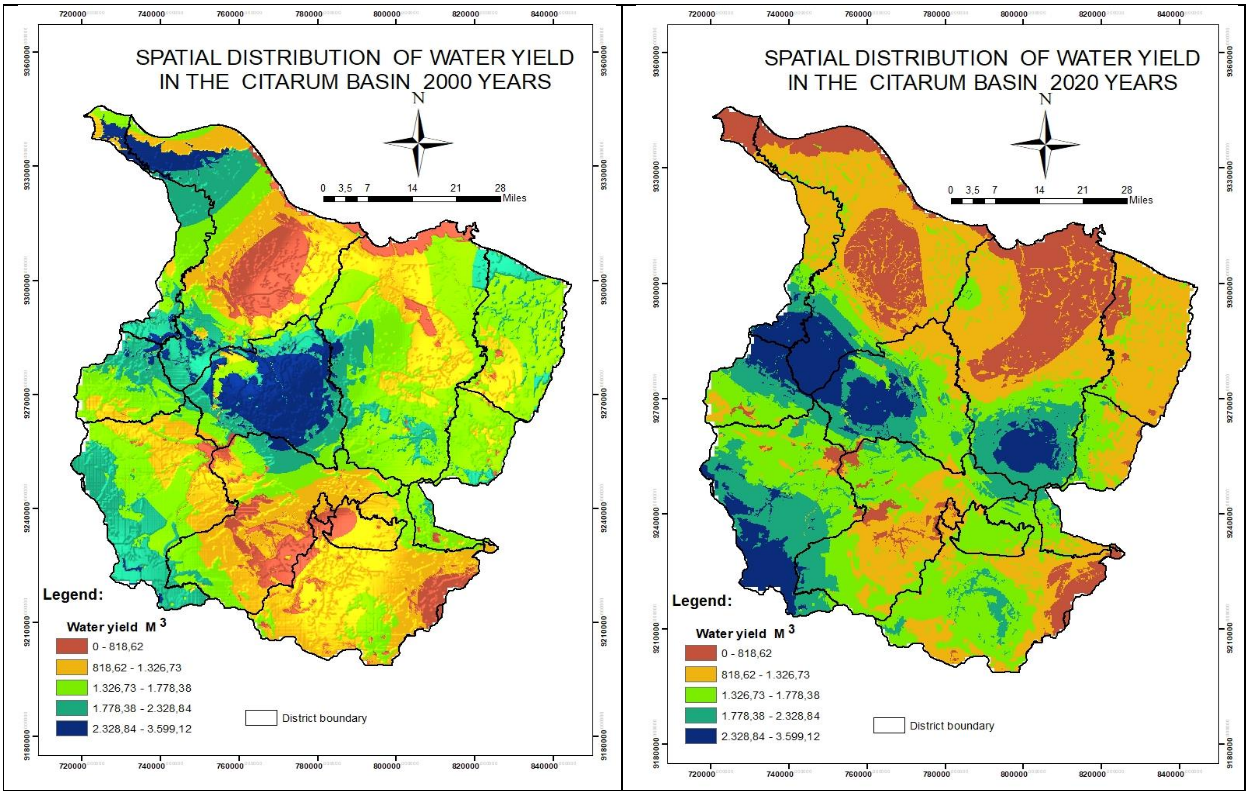

Figure 3. Spatial distribution of water yield: (a) in 2000 and (b) in 2020,

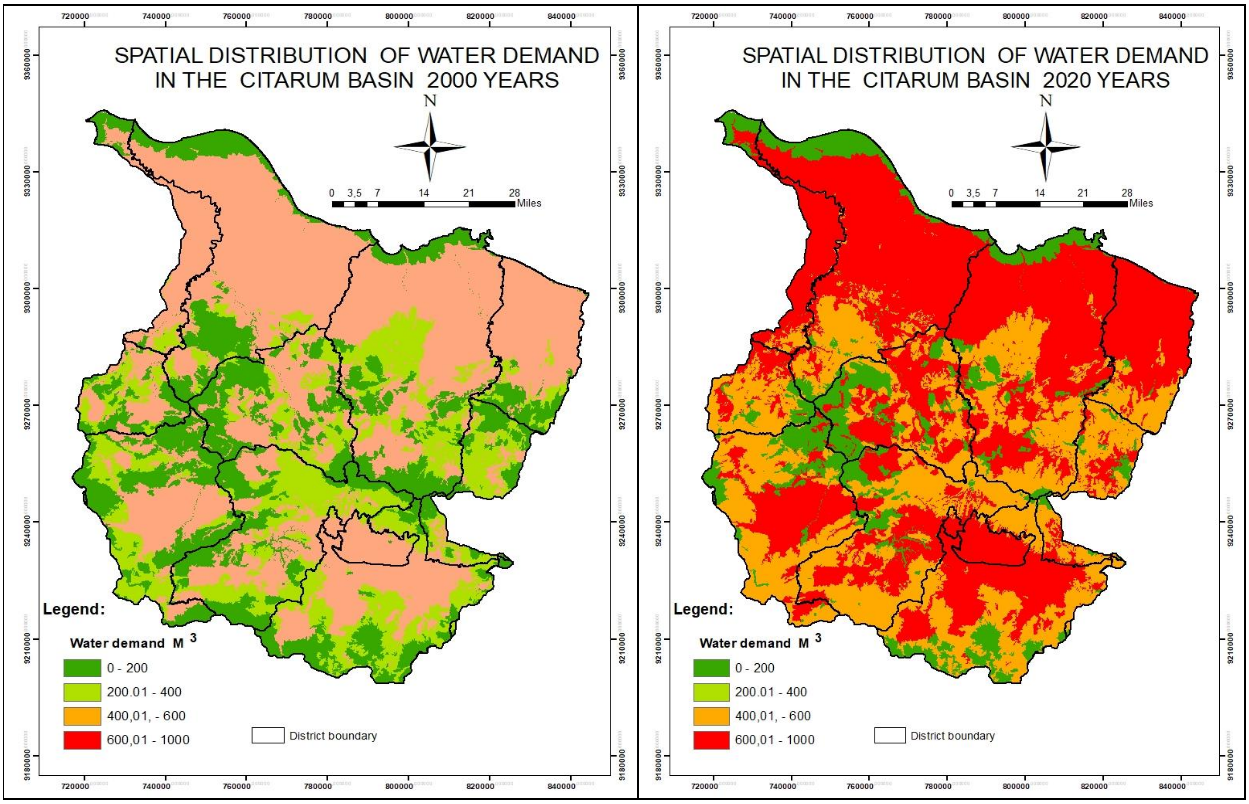

Figure 4. Spatial distribution of water dermand: (a) in 2000 and (b) in 2020,

In general, water demand is dominated by the 400-600 class. which are evenly distributed throughout the region. As for the 0-200 class and 200-400 class, it is found in the middle part (Citarum sub-watershed). The most significant changes in the concentration value of water consumption occurred in the Citarum sub-watershed which in 2000 was observed with high to medium MWY (red-brown), and in 2020 the MWY class was dominated by the medium-low MWY class (brown-green). The most significant water yield is in the Citarum Hilir Sub-watershed, which in 2000 was observed with a high to medium MWY (red-brown), and in 2020 the MWY class was dominated by a medium-low MWY class (brown-green).

The total availability of water in the Citarum watershed shows a downward trend, while the trend of water demand increases (Table 3).

Table 3 Changes in supply and demand of water yield service in the Citarum watershed

		Water Yiled			Consumtion		
No	**Sub-watershed**	10^8 m^8	%	Status	10^8 m^8	%	Status
1	Cikarokrok	- 1.44	- 47.14	ED	1.51	68.79	EI
2	Cibadak	- 0.59	- 53.17	ED	0.59	64.36	EI
3	Cimalaya	- 5.86	- 59.16	ED	1.87	76.57	EI
4	Ciasem	- 5.98	- 53.31	ED	2.46	72.57	EI
5	Cireungit	- 0.30	- 76.55	ED	0.13	66.48	EI
6	Cipunara	- 6.48	- 35.45	D	4.55	87.58	EI
7	Cirandu	- 0.98	- 75.99	ED	0.47	67.79	EI
8	Sewo	- 1.15	- 75.75	ED	0.38	68.00	EI
9	Sukamaju	- 0.86	- 72.98	ED	0.30	68.00	EI
10	Cibodas	- 2.24	- 60.48	ED	1.09	77.85	EI
11	Bugel	- 0.79	- 69.91	ED	0.28	68.00	EI

12	Cidongkol	- 2.96	- 64.66	ED	1.29	81.93	EI
13	Batang Leutik	- 0.37	- 71.91	ED	0.19	67.68	EI
14	Cibadar Dua	- 1.54	- 65.50	ED	0.82	67.04	EI
15	Cisaga	- 0.80	- 71.50	ED	0.27	67.65	EI
16	Cisedari	- 3.38	- 81.20	ED	0.63	67.70	EI
17	Citarum	- 28.27	- 28.65	D	21.32	82.13	EI
18	Cibanteng	- 0.24	- 33.77	D	0.33	68.93	EI
19	Cigemari	- 0.77	- 48.82	ED	0.51	68.00	EI
		- 64.98	- 39.05	D	39.01	78.87	EI

*ED = Extremely Decrease (<-40%); D = Decrease (-20% - -40%); NC = Non Change (-20% - 20%); I = Increase (20% - 40%); EI = Extremely Increase (>40%)

Table 3 Water yield change in the Citarum watershed from 2000 to 2020 The predicate of each watershed is based on the percentage change

In 2000, water availability was 166.42 x 10^8 m^3, decreased to x 10^8 m^3 , and 101.44 x 10^8 m^3 in 2020 Within 20 years, the water yield decreased by 64.98 x 10^8 m^3 or 39.05%. The most significant changes in the concentration value of water yields are in the downstream Citarum sub-watershed, which in 2000 was monitored by high to medium MWY (red-brown), and in 2020 the MWY class is dominated by

3.2 Balance of supply and demand for water yield service

Based on the calculation with formula (3) and formula 4 , SDR value. Water Scarcity IndeX (WSI) and Status of water presented in Table 4 and Figure 6.

No	**Sub-watershed**	Area 10^3 ha	SDR	Water Security Index		**SDR**	Water Security Index	
				WSI	Status		WSI	Status
1	Cikarokrok	36.329	1.40	0.14	Good	0.44	- 0.36	Poor
2	Cibadak	14.676	1.19	0.08	Good	0.34	- 0.47	Poor
3	Cimalaya	52.063	4.06	0.61	Good	0.94	- 0.03	Poor
4	Ciasem	73.192	3.30	0.52	Good	0.89	- 0.05	Poor
5	Cireungit	3.619	1.92	0.28	Good	0.27	- 0.57	Poor
6	Cipunara	128.059	3.52	0.55	Good	1.21	0.08	Good
7	Cirandu	12.827	1.87	0.27	Good	0.27	- 0.57	Poor
8	Sewo	8.774	2.72	0.43	Good	0.39	- 0.41	Poor
9	Sukamaju	6.837	2.65	0.42	Good	0.43	- 0.37	Poor
10	Cibodas	26.251	2.64	0.42	Good	0.59	- 0.23	Poor
11	Bugel	6.410	2.73	0.44	Good	0.49	- 0.31	Poor
12	Cidongkol	29.127	2.90	0.46	Good	0.56	- 0.25	Poor
13	Batang Leutik	4.901	1.89	0.28	Good	0.32	- 0.50	Poor
14	Cibadar Dua	19.449	1.91	0.28	Good	0.39	- 0.40	Poor
15	Cisaga	6.877	2.79	0.45	Good	0.48	- 0.32	Poor
16	Cisedari	23.130	4.49	0.65	Good	0.50	- 0.30	Poor
17	Citarum	659.501	3.80	0.58	Good	1.49	0.17	Good

18	Cibanteng	7.448	1.47	0.17	Good	0.58	- 0.24	Poor
19	Cigemari	12.732	2.09	0.32	Good	0.64	- 0.20	Poor
	Total	955.942	3.36	0.53	Good	1.15	0.06	Good

The SDR value in 2000 ranged from 1.47 to 4.49, with an overall SDR value of 3.36. This relatively high SDR value indicates that the availability of water can still meet water needs. In general, in 2000, the new water supply was produced by around 30%.

The SDR value in 2020 ranges from 0.27 to 1.49, with an average value for Citarum RBU of 1.15. SDR conditions in 2020 indicate that water has reached a critical level. Based on the SDR value in the 2000-2020 period, the SDR value decreased by 2.21 (65.77%). In general, the SDR value is positive, but less than 1 indicates a warning that the management of water products is to maintain sustainable water resources.

More specifically, changes in the SDR value are presented in **Figure 6**, wherein in 2020, about (49%) of the Citarum watershed had an SDR value < 1 , almost 35% had an SDR 1 - 2, and areas with an SDR value in between 2 - 3 were only 11 % and SDR >3 about 4 %.

In 2000, the water supply was very abundant compared to the demand While **Figure 6b** shows similar conditions to the SDR conditions in 2000, there was an addition of SDR < 1 (downstream Citarum) and SDR with a value of 1 < X < 2, which is almost double the condition in 2000

The finding of a decrease in SDR is in line with the results of **Hasbiah & Kurniasih's research** conducted in one of the areas in the Citarum watershed, namely the city of Bandung. The results of the study indicate that the increase in water consumption in the city is the impact of population growth.

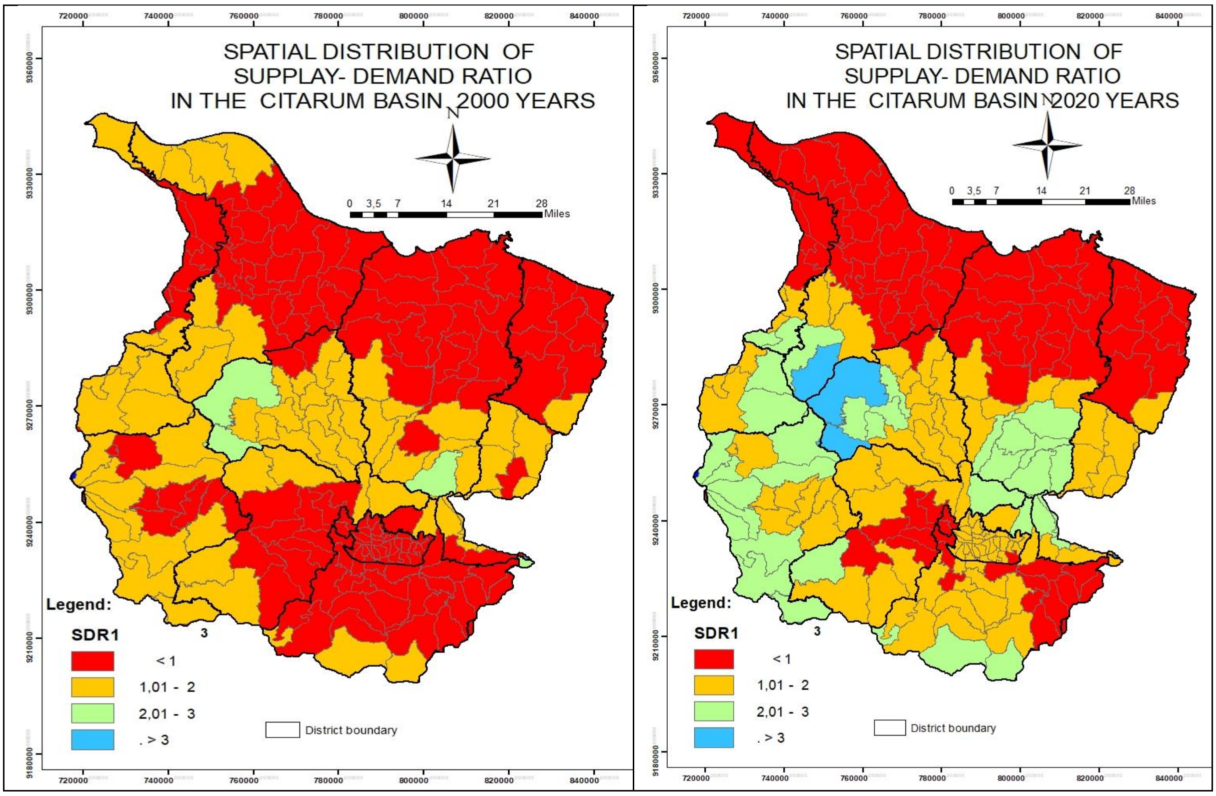

Figure 6. Supply-demand ratio map in the Citarum watershed in (a), 2000 and (b) 2020

In terms of time (Figure 6a and Figure 6b), the regional distribution of the supply-demand ratio in the Citarum watershed in 2000 and 2020 changed significantly. In 2000, the available water resources in the supply area were still able to meet the actual demand. In line with the development of time, the impact of development, the ratio of supply-demand water in all regions is predicted to decrease. This condition is shown in Figure 6b, in 2020, in several regions (Indramayu, Subang and Purwakarta) it was found that water consumption would exceed the water supply. Gradually, it is necessary to improve the management of water resources so that the sustainability of water resources can be maintained.

This condition is shown in Figure 6b, in 2020, in several regions There are 135 sub-districts (58.44 %) spread across Bandung: 5 sub-districts, West Bandung 5 sub-districts, Subang: 5 sub-districts Purwakarta: 5 sub-districts, Sumedang: 5 Indramayu sub-districts: 5 sub-districts nd Cianjur: 5 sub-districts) it was found that water consumption would exceed the water supply. Gradually, it is necessary to improve the management of water resources so that the sustainability of water resources can be maintained

According to the WSI value, the water resources safety index was divided into four categories: poor water safety index (WSI < -1), low water safety index (-1 < WSI < 0), good safety index 0 < WSI< 0.5 , very good water safety index (WSI > 0.5). Base on table, the spatial distribution of WSI by sub-district is presented in Figure 7…

Meanwhile, in 2020, the sub-watershed area (sub-district) with a WSI value of less than 0, there are around 121 sub-districts (52.38%) spread over the districts of Indramayu (21%), Sumedang (25 %), Purwakarta and Bekasi. This trend indicates that the shortage of water resources in the watershed is becoming increasingly serious and can have an impact on the production and livelihoods of the people in the area.

From the perspective of the spatial pattern of the balance between supply and demand, a WSI value of less than -1 LOW WSI) , was not found, indicating that there are no severe water resource shortage areas in this region. The situation of water scarcity is exacerbated by the addition of new industries that consume a lot of water, along with the increase in urban development and large-scale development.

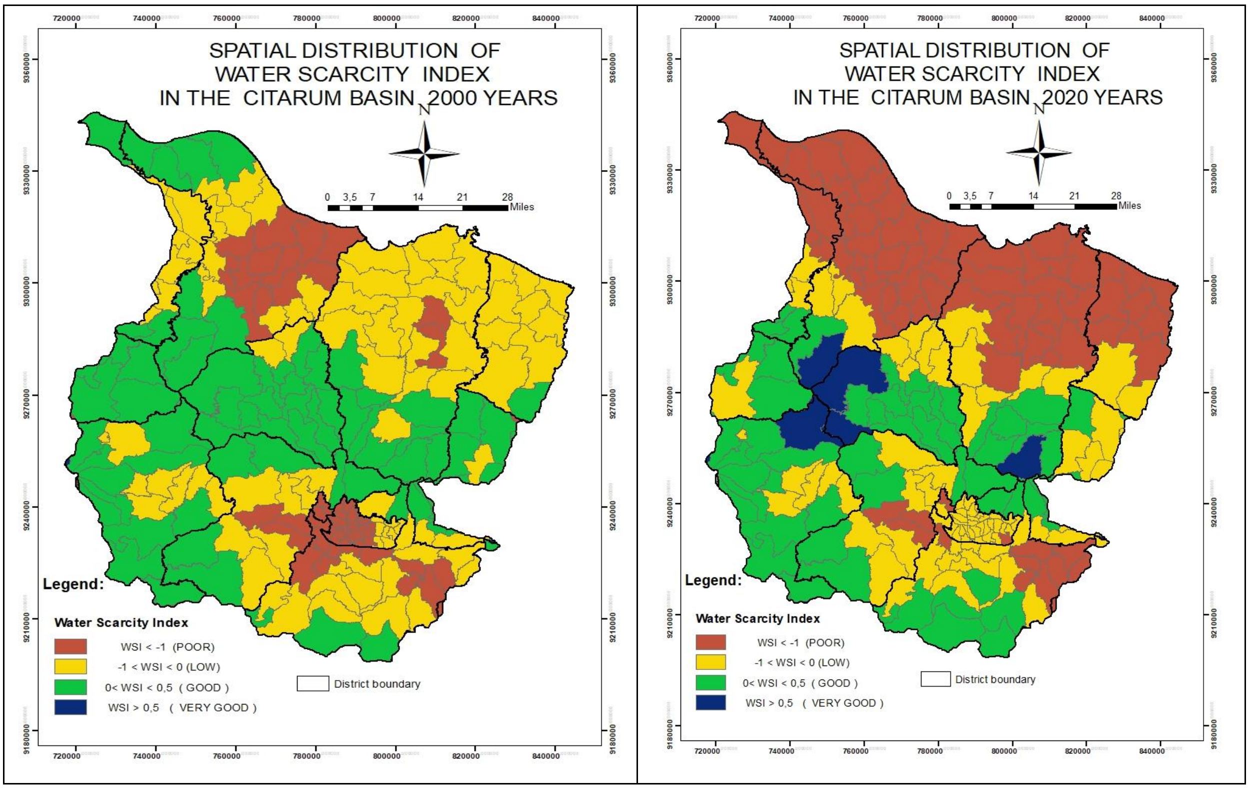

Figure 7. Water Scarcity Index map in the Citarum watershed in (a), 2000 and (b) 2020

The trajectory of the decline in the SDR value (WSI) in the Citarum watershed has been predicted by Boer et al. (2012). The Citarum River is an important resource for urban and industrial development, including economic development and community livelihoods by supporting agriculture, fisheries, hydroelectric power, and public water supply for West Java and the City of Jakarta. In addition, it supplies 80% of Jakarta's water needs. [Boer et al. 2012]. According to Tarigan, (2013) Changes in land use (increased residential area and reduced forest area) affect water availability, decrease reservoir storage capacity due to sedimentation and decrease watershed storage capacity (hydrological function) during this period.

4. CONCLUSSIONS

The results showed that: (1) From 2000 to 2020, the water supply in the Citarum watershed decreased by 3189 X 10^8 m^3/ year (30.76 %) (2) On the other hand, water demand shows a significant increasing trend, namely 2791 x 10^8 m^3 / year (81.66%) (3) Based on the WSI index, the condition of water yields in almost all sub-districts is included in the good class, while in 2020 around 58.44 % of the sub-districts experienced a water deficit (WSI < 0) spread out (Bekasi : 5 kecamatan) , Karawang : 5 kecamatan, Bandung : 5 kecamatan, Bandung Barat 5 kecamatan , Subang : 5

kecamatan Purwakarta : 5 kecamatan, Sumedang : 5 kecamatan Indramayu : 5 kecamatan nd Cianjur : 5 kecamatan) it was found that water consumption would exceed the water supply. Terdapat 135 kecamatan (58,44 %)

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