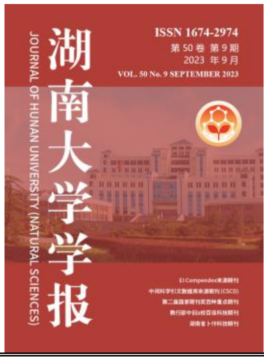


湖南大学学报（自然科学版）
Journal of Hunan University (Natural Sciences）

第 50 卷 第 9 期
2 0 2 3 年 9 月

Available online at http://jonuns.com/index.php/journal/index

Vol. 50 No. 9
September 2023

Open Access Article

https://doi.org/10.55463/issn.1674-2974.50.9.7

Potential Analysis of Surface Water Balance in the Water District of the Kali Lamong Watershed, Indonesia

Wisang Adhitya Yogo Purnomo[1]*, Lily Montarcih Limantara[2], M. Bisri[2]*, Moh. Sholichin[2]

[1] Doctoral Program at the Department of Water Resources, Faculty of Engineering, University of Brawijaya, Jl. MT Haryono No. 167 Malang, Indonesia

[2] Department of Water Resources, Faculty of Engineering, University of Brawijaya, Jl. MT Haryono No. 167 Malang, Indonesia

* Corresponding authors: wisang30@gmail.com, mbisri@ub.ac.id

Received: June 17, 2023 / Revised: July 14, 2023 / Accepted: August 11, 2023 / Published: September 29, 2023

Abstract: This research intends to evaluate the water availability condition and the development in the future in the water district of Kali Lamong Watershed, so the quantitative study that integrates the supply and demand at every water district is integrated from upstream until downstream, is necessary to be carried out. The methodology consists of comprehensive quantitative analysis to the water resources including the supply and demand in the water districts that have been carried out. Missed from the uncertainty that is big enough related with the development in the future, the water management nowadays and in the future can be seen from the analysis result of water balance potency that is carried out in each water district. Based on the analysis result of water balance that is carried out, there is obtained that the water balance in each water district gives the information about water surplus and deficit. Water deficit in the future is happened in the water district of Lamong Hulu, Sabeng, and Kalitemu, meanwhile the water surplus is happened in the water district of Lamong Tengah, Ngrembeng, and Lamong Hilir. The period of water deficit in the water district is very short by the small dimension. In 2100, the water deficit of Lamong Hulu water district will be about -1.024 m^3/s, in the Sabeng water district - about -2.99 m^3/s, and in the Kalitemu water district - about -2.128 m^3/s.

Keywords: watershed, water balance, water district, Kali Lamong.

印度尼西亚卡利拉蒙流域水区地表水平衡潜力分析

摘要：本研究旨在评估卡利拉蒙流域水区的水资源可利用状况及未来发展，因此有必要进行从上游到下游整合各水区供需情况的定量研究。出去。该方法包括对水资源进行全面的定量分析，包括已对水区的供需情况进行分析。忽略了与未来发展相关的足够大的不确定性，从各水区进行的水平衡效能分析结果可以看出现在和未来的水管理情况。根据水平衡分析结果，得出各水区的水平衡给出了水的盈余和亏缺信息。未来缺水发生在拉蒙葫芦、萨崩和卡利特姆水区，而水过剩发生在拉蒙登加、恩格伦本和拉蒙希里尔水区。由于水域面积小，缺水期很短。2100年，拉蒙乌鲁水区的缺水量约为-1.024立方米/秒，萨本水区约为-2.99立方米/秒，卡利特姆水区约为-

2.128立方米/秒。

关键词：分水岭，水平衡，水区，卡利拉蒙。

1. Introduction

To manage the water resources effectively are needed the assessment of detail, accurate and reliable water availability. There is a developed understanding that human intervention in a watershed and the increasing water demand determine the water availability now and in the future worldwide [1, 2]. Water resource is the base resource and essential for all of lifestyle that has given the good benefit for human as well as their socio-economic during the centuries [3]. In the last decade, the scarcity of water resources has become one of the factors with a serious negative effect on socioeconomic development [4]. Many areas in the world now face moderate to heavy water critics due to the population growth, industrialization, food production processes, increasing life standards, and bad water management strategies [9]. The world population in semi-arid areas is more than 25%, and the water deficit is a critical problem that needs immediate handling [5].

The condition of water resources in Indonesia is quantitatively sufficient, but spatially uneven. The water deficit occurs in several places, mainly in Java Island [6]. Water resources are needed for life. They are not only environmental resources for maintaining the ecological balance, but also strategic resources that determine the national design and development [7]. In recent years, there has been a bog contradiction between the demand and supply of water resources that causes the water deficit. In addition, due to the rapid economy and population growth, the water deficit becomes more serious, mainly in dry and semi-arid lands [8, 10]. In addition, the waste of water resources has worsened the crisis of water deficit. The fact shows that there is a decrease in river water production in some watersheds, mainly in Indonesia, which is very affected by the watershed characteristic changes. The biggest change occurred due to the land use change. The watershed characteristic change and increasing demand in some sectors (household, agriculture, industry, and environment) will increase the competition for water resource use. Decreased water availability and increased water demand will trigger the level of water criticality [11]. Nowadays, there are many reasons for threats to sustainable water resource management, such as water scarcity, drought risk due to conflicts, bad management of water resource systems [12], limited water resource distribution, lack of good water and infrastructure [13], complexity of water resource systems caused by meteorological elements, such as unpredictable variables such as water flow, rainfall [14], rapid increase in water demand for irrigation, and change in water supply as the reason for population growth [15].

The population growth in several cities/regencies such as Gresik, Lamongan, Mojokerto, and Surabaya caused increase in demand for water resources from Kali Lamong as the area support. Kali Lamong is one of the water sources for fulfilling the demand of the area ecosystem. Nowadays, the water of Kali Lamong is used for raw water, industry, and agriculture, so it has a critical value for society. To assess the condition of water availability, a quantitative study that integrates the water supply and demand in every water district that is integrated from upstream until downstream is necessary. A comprehensive quantitative analysis of water resources, including the supply and demand in the water district sensitive to the land cover change, has to be carried out. To exclude the big enough uncertainty that is related with the development in the future and data scarcity, the water management now and in the future, and the strong adaptive design needs the result of water modeling in the future by developing the scenario which means for medium and long term (after 2050). Realizing the importance of the Kali Lamong watershed in the context of area development, this study aims to develop a water balance model for assessing water supply and demand in the future until 2100 by combining the water balance model in each water district that is integrated from upstream to downstream.

2. Materials and Methods

2.1. Study Location

The study location is six water districts in the Kali Lamong watershed. The Kali Lamong watershed includes the administrative areas of Lamongan Regency, Mojokerto Regency, Gresik Regency, and Surabaya. The study location is presented in Fig. 1.

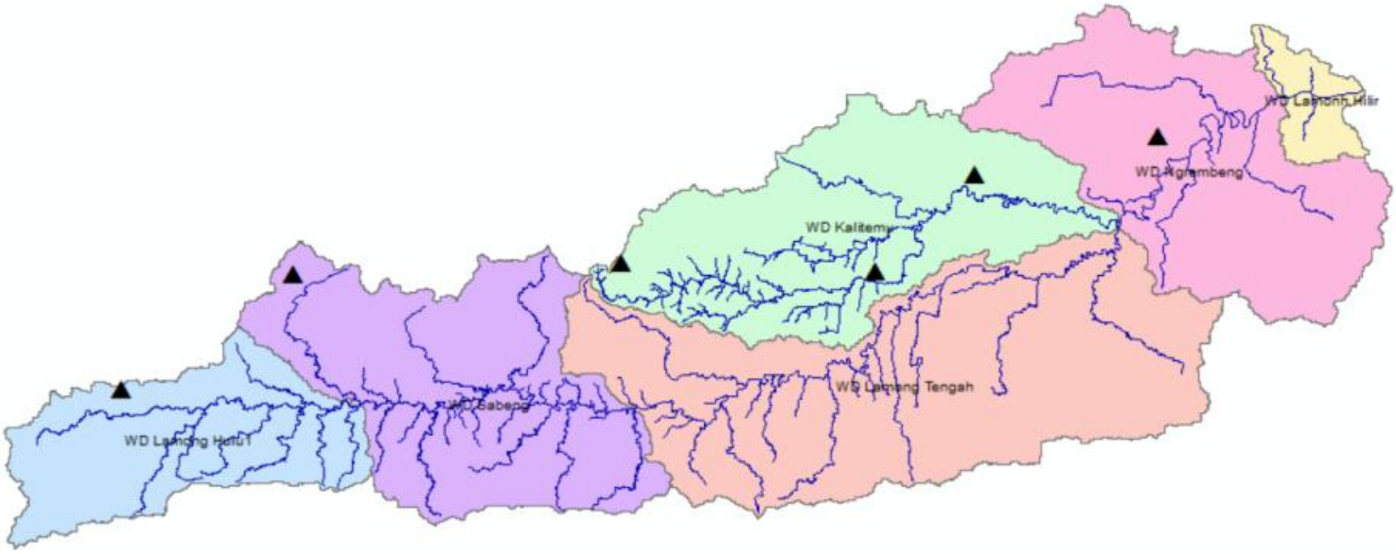


Fig. 1 Boundary of the service area in the Kali Lamong watershed

2.2. Data

In this study, the data used are as follows: population, technical irrigation area, and industry, which are sourced from the District Statistical Centre Institution (BPS) in Lamongan, Gresik, and Mojokerto Regencies and Surabaya. In the district BPS, the available information data begin from the village level, which is different if using the regency BPS that has district-level information. Water availability analysis uses the same hydrological data as those presented in [16].

2.3. Method

The method that is used for analysis of water balance potency in each water district in the Kali Lamong watershed uses some approaches like water availability analysis, water demand analysis for some sectors (domestic, agriculture, and industry) that is carried out in each water district including the projection in the future. The analysis of water balance potency for each water district that is integrated and simultaneously carried out from the water district upstream to downstream can follow the stage scheme of analysis as presented in Fig. 2.

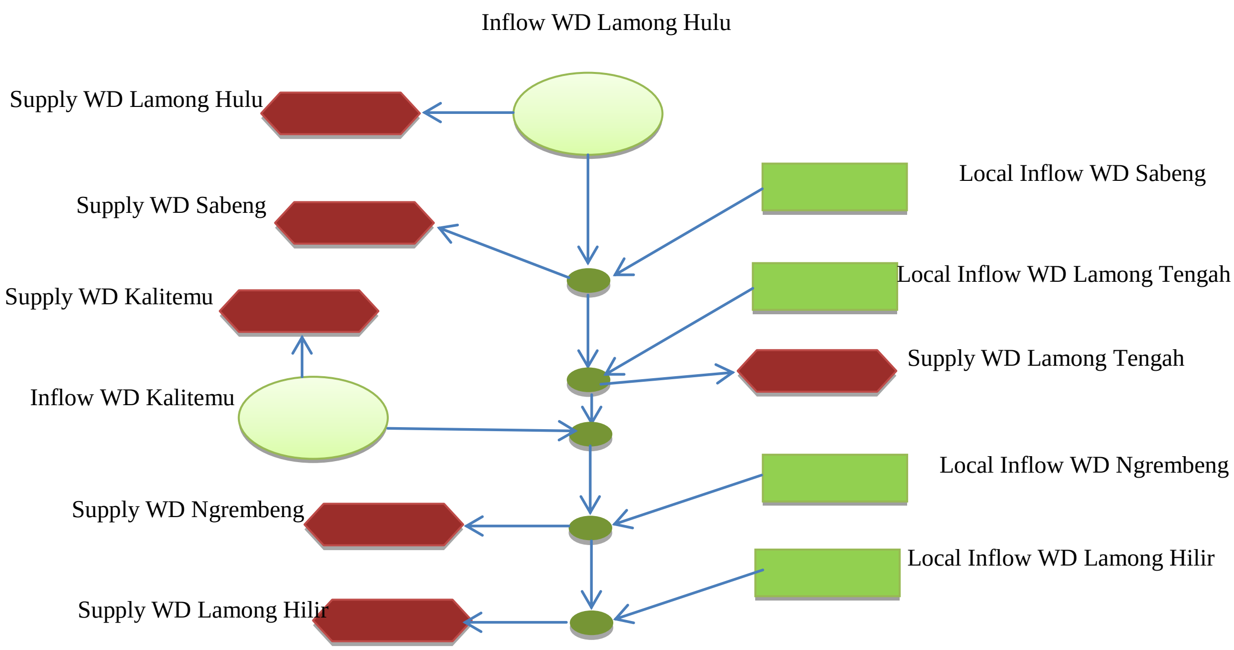


Fig. 2 Scheme of the water balance potential analysis

2.3.1. Analysis of Water Availability

In Indonesia, [17] and [18] define water availability as river discharge. However, [19] stated that water availability is surface water and ground water. [20] defined it as blue water. Most researchers analyze water availability using the principle of water balance with the hydrologic water balance. In addition, some other researchers use long-term discharge data to predict water availability. Because water availability is a natural phenomenon, it is often difficult to be accurately regulated and predicted. This is caused by spatial and temporal variability. Principally, the water availability analysis refers to the dependable discharge that is the minimum discharge of surface or river water with a certain dimension that may be reached so it can be utilized for some interests. For raw water requirement, the dependable discharge determined is 90%; however, for irrigation, it is 80% [21]. In this study, the dependable discharge or water availability is obtained from the previous analysis results presented in [16].

2.3.2. Water Demand

Water demand is number of waters that is needed or used by some sectors like domestic water need and industry need.

a) Domestic Water Need

Projection of population number in an area and in certain year can be carried out if there is known the level of population growth. Besides it, the population growth also depends on the Area and Spatial Plan (RTRW) in the regency or city. Analysis of domestic water demand is carried out based on the standard of water use for every person as presented in the Table 1.

Table 1 Standard of domestic water use (Ditjen Cipta Karya, DPU, 2006, "Unit Pelayanan", Materi Pelatihan Penyegaran SDM Sektor Air Minum (Peningkatan Kemampuan Staf Profesional Penyelenggara SPAM))

No.	City category	Population amount (persons)	Clean water demand (l/person/day)
1	Semi-urban (capital city of district/village)	3,000–20,000	60–90
2	Small city	20,000–100,000	90–110
3	Medium city	100,000–500,000	100-125
4	Big city	500,000–1,000,000	120–150
5	Metropolitan	> 1.000.000	150–200

b) Industry Water Need

Data of industry number in each water district is obtained from district BPS. The industry recorded in the document is differentiated into four types with the criteria of employer number as follows:

1) Household industry is an industry with 1-4 employers;
2) Small industry is an industry with 5-19 employers;
3) Medium industry is an industry with 20-99 employers;
4) Big industry is an industry with more than 100 employers.

For making the analysis easy, the water demand for industry is determined based on the employers' number as follows:

$$KAI = KAO \times TK$$

where:

KAI - industry water need (l/ day);

KAO - industry water needs per employer (l/ person/ day);

TK - number of employers (persons).

2.3.3. Rice Irrigated Water Requirement

Irrigation water requirement per unit irrigated area has been calculated for each water district in [16]. In this study, the cropping pattern is assumed the same as determined in [16] and not as a variable that will be changed. The irrigation water requirement is analyzed in every water district, and the parameter of irrigation water requirement is analyzed alone for each water district.

3. Results and Discussion

3.1. Water District

To optimize the management of water resources, so the Kali Lamong watershed is divided into several water districts. In the report of Water Resources Management Plan at Sungai Bengawan Solo Area Second Stage, the Kali Lamong watershed is divided into six water districts: Lamong Hulu, Sabeng, Lamong Tengah, Kalitemu, Ngerembeng, and Lamong Hilir (Fig. 1).

3.2. Analysis of Water Availability

The analysis of surface water availability for each water district is carried out based on two approaches [16]:

1. Based on the record of discharge data;
2. Based on the rainfall-run-off model.

The final value of water availability used for further analysis is the average result of the two approaches. The final result of dependable discharge in each water district can be seen in Table 2 and Fig. 3.

Table 2 The final value of dependable discharge in each service area [16, own study]

WD Lamong Hulu

Year	Half monthly average discharge (m^3/s)																						
	Jan-1	Jan-2	Feb-1	Feb-2	Mar-1	Mar-2	Apr-1	Apr-2	May-1	May-2	Jun-1	Jun-2	Jul-1	Jul-2	Aug-1	Aug-2	Sep-1	Sep-2	Oct-1	Oct-2	Nov-1	Nov-2	Dec-1	Dec-2
Q mean	4.302	5.025	5.652	4.840	5.871	5.088	4.367	2.888	2.151	1.823	1.472	1.213	0.935	0.675	0.535	0.517	0.520	0.412	0.422	0.826	0.710	1.752	2.685	3.335
Q 50%	3.634	4.650	4.832	4.027	4.995	4.779	3.924	2.285	1.707	1.430	1.107	0.924	0.757	0.586	0.479	0.377	0.336	0.302	0.272	0.323	0.310	0.925	2.006	2.581
Q 80%	1.172	2.181	3.258	2.540	2.797	2.537	2.246	1.359	1.118	0.898	0.666	0.578	0.516	0.414	0.338	0.291	0.251	0.211	0.200	0.189	0.181	0.240	0.636	0.949
Q 90%	0.834	1.702	1.735	1.845	2.232	1.926	1.744	1.128	0.767	0.705	0.609	0.495	0.448	0.365	0.298	0.258	0.216	0.186	0.157	0.171	0.154	0.159	0.390	0.612

WD Sabeng

Year	Half monthly average discharge (m^3/s)																						
	Jan-1	Jan-2	Feb-1	Feb-2	Mar-1	Mar-2	Apr-1	Apr-2	May-1	May-2	Jun-1	Jun-2	Jul-1	Jul-2	Aug-1	Aug-2	Sep-1	Sep-2	Oct-1	Oct-2	Nov-1	Nov-2	Dec-1	Dec-2
Q mean	10.213	12.143	13.860	11.974	14.415	11.794	10.560	6.914	4.939	4.216	3.374	2.620	2.084	1.531	1.214	1.148	1.150	0.892	0.794	1.392	1.760	3.717	5.793	7.876
Q 50%	8.608	11.458	12.330	10.420	12.836	10.574	9.272	5.342	3.925	3.560	2.682	2.285	1.872	1.479	1.210	0.950	0.836	0.730	0.617	0.652	0.799	1.752	3.656	5.518
Q 80%	2.916	5.642	7.170	6.489	6.241	5.920	4.573	2.904	2.409	1.821	1.356	1.188	1.051	0.846	0.691	0.597	0.517	0.452	0.414	0.372	0.419	0.511	1.217	2.026
Q 90%	1.900	3.824	3.903	4.736	5.414	4.119	3.321	2.261	1.631	1.286	1.125	0.933	0.907	0.712	0.580	0.510	0.428	0.388	0.343	0.340	0.311	0.331	0.679	1.158

WD Lamong Tengah

Year	Half monthly average discharge (m^3/s)																						
	Jan-1	Jan-2	Feb-1	Feb-2	Mar-1	Mar-2	Apr-1	Apr-2	May-1	May-2	Jun-1	Jun-2	Jul-1	Jul-2	Aug-1	Aug-2	Sep-1	Sep-2	Oct-1	Oct-2	Nov-1	Nov-2	Dec-1	Dec-2
Q mean	18.688	23.923	25.826	22.299	27.367	21.617	19.754	12.887	8.947	7.591	6.149	4.930	3.812	2.836	2.228	2.073	2.014	1.674	1.491	2.321	3.410	7.314	10.961	14.350
Q 50%	15.952	22.517	23.153	17.957	22.669	20.165	16.061	10.474	7.539	6.227	4.445	4.300	3.234	2.542	2.080	1.622	1.517	1.361	1.125	1.188	1.412	3.275	7.086	9.719
Q 80%	4.950	9.660	14.116	12.170	12.435	10.795	8.351	5.573	4.457	3.235	2.353	2.164	1.900	1.627	1.263	1.096	0.951	0.859	0.754	0.704	0.732	1.002	2.181	3.302
Q 90%	3.498	6.424	6.356	8.562	9.883	7.111	6.387	4.282	2.967	2.448	2.051	1.669	1.579	1.335	1.084	0.956	0.804	0.707	0.594	0.630	0.579	0.617	1.305	2.262

WD Kalitemu

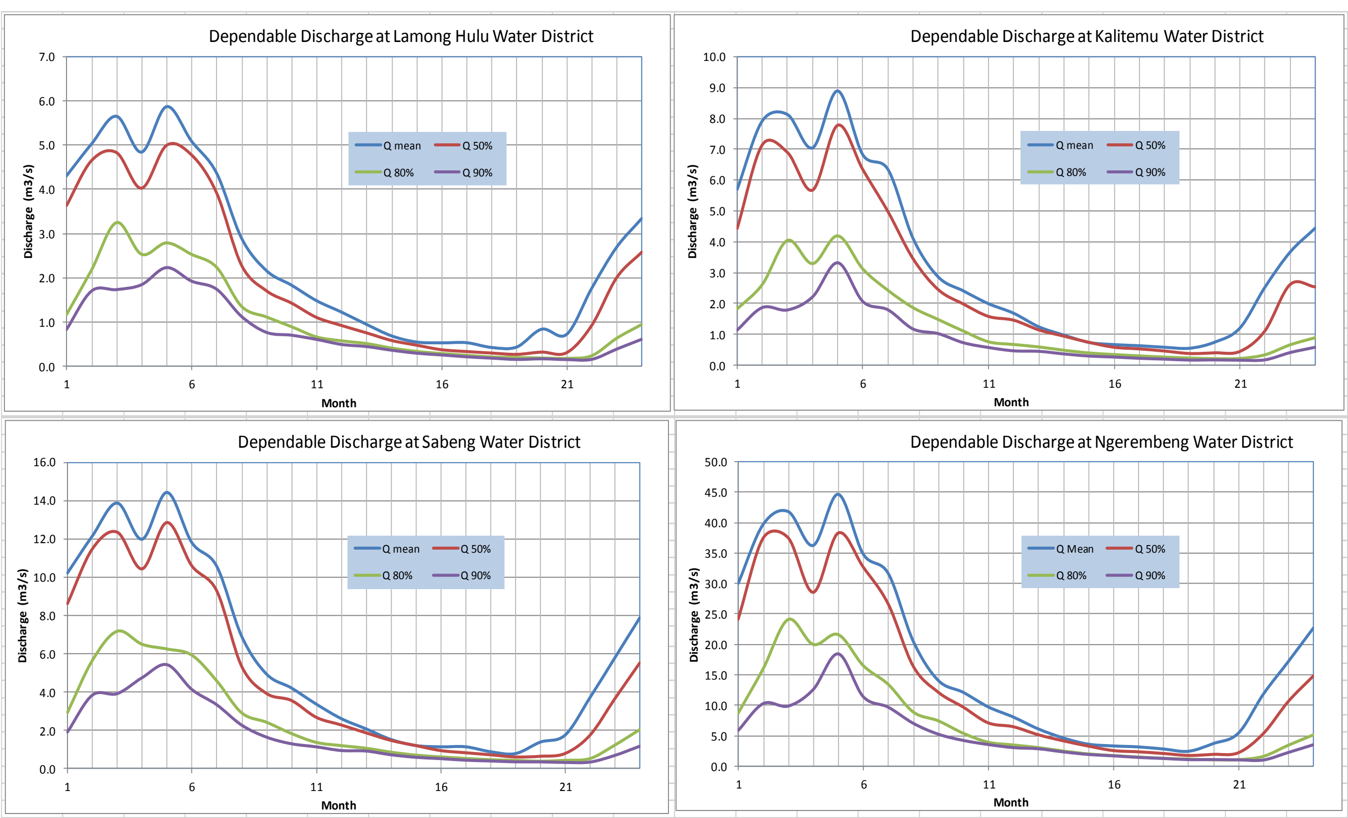
Year	Half monthly average discharge (m^3/s)																						
	Jan-1	Jan-2	Feb-1	Feb-2	Mar-1	Mar-2	Apr-1	Apr-2	May-1	May-2	Jun-1	Jun-2	Jul-1	Jul-2	Aug-1	Aug-2	Sep-1	Sep-2	Oct-1	Oct-2	Nov-1	Nov-2	Dec-1	Dec-2
Q mean	5.703	7.923	8.128	7.046	8.894	6.816	6.342	4.098	2.852	2.399	1.983	1.673	1.234	0.964	0.726	0.655	0.619	0.569	0.537	0.735	1.192	2.523	3.661	4.440
Q 50%	4.439	7.152	6.900	5.681	7.786	6.341	4.978	3.447	2.447	1.981	1.579	1.456	1.141	0.938	0.737	0.577	0.525	0.456	0.376	0.398	0.443	1.115	2.615	2.537
Q 80%	1.824	2.624	4.056	3.301	4.204	3.124	2.429	1.863	1.479	1.102	0.753	0.665	0.586	0.477	0.389	0.338	0.294	0.255	0.225	0.204	0.210	0.331	0.655	0.888
Q 90%	1.137	1.860	1.783	2.206	3.304	2.054	1.786	1.168	1.019	0.726	0.573	0.466	0.450	0.366	0.298	0.266	0.224	0.199	0.167	0.173	0.163	0.175	0.410	0.582

WD Ngrembeng

Year	Half monthly average discharge (m^3/s)																						
	Jan-1	Jan-2	Feb-1	Feb-2	Mar-1	Mar-2	Apr-1	Apr-2	May-1	May-2	Jun-1	Jun-2	Jul-1	Jul-2	Aug-1	Aug-2	Sep-1	Sep-2	Oct-1	Oct-2	Nov-1	Nov-2	Dec-1	Dec-2
Q mean	29.986	39.690	41.791	36.230	44.636	34.801	31.625	20.478	14.040	12.077	9.682	8.022	6.068	4.586	3.559	3.271	3.110	2.770	2.393	3.664	5.364	11.782	17.154	22.656
Q 50%	24.189	37.491	37.527	28.591	38.320	32.728	26.657	16.441	12.177	9.731	7.143	6.514	5.193	4.196	3.337	2.599	2.395	2.121	1.800	1.978	2.243	5.395	10.674	14.853
Q 80%	8.718	15.992	24.031	19.957	21.564	16.506	13.429	8.911	7.472	5.437	3.967	3.521	3.094	2.527	2.062	1.789	1.553	1.345	1.207	1.102	1.122	1.660	3.481	5.169
Q 90%	5.816	10.250	9.843	12.575	18.459	11.396	9.660	7.003	5.208	4.177	3.497	2.990	2.798	2.280	1.857	1.633	1.372	1.201	1.007	1.018	0.966	0.946	2.190	3.460

WD Lamong Hilir

Year	Half monthly average discharge (m^3/s)																						
	Jan-1	Jan-2	Feb-1	Feb-2	Mar-1	Mar-2	Apr-1	Apr-2	May-1	May-2	Jun-1	Jun-2	Jul-1	Jul-2	Aug-1	Aug-2	Sep-1	Sep-2	Oct-1	Oct-2	Nov-1	Nov-2	Dec-1	Dec-2
Q mean	30.610	40.561	42.653	36.994	45.560	35.505	32.241	20.871	14.302	12.313	9.856	8.186	6.186	4.676	3.628	3.333	3.165	2.829	2.435	3.740	5.448	11.998	17.425	23.093
Q 50%	24.506	38.172	38.227	29.396	39.258	33.481	27.311	16.754	12.341	9.904	7.309	6.601	5.267	4.251	3.383	2.634	2.439	2.166	1.833	2.021	2.282	5.519	10.894	15.267
Q 80%	8.916	16.300	24.623	20.258	21.855	16.859	13.729	9.161	7.648	5.566	4.062	3.631	3.188	2.597	2.119	1.838	1.595	1.381	1.231	1.122	1.156	1.694	3.559	5.324
Q 90%	5.941	10.505	10.047	12.556	18.637	11.605	9.590	7.145	5.311	4.266	3.571	3.051	2.855	2.327	1.895	1.667	1.400	1.226	1.028	1.044	0.985	0.965	2.235	3.505



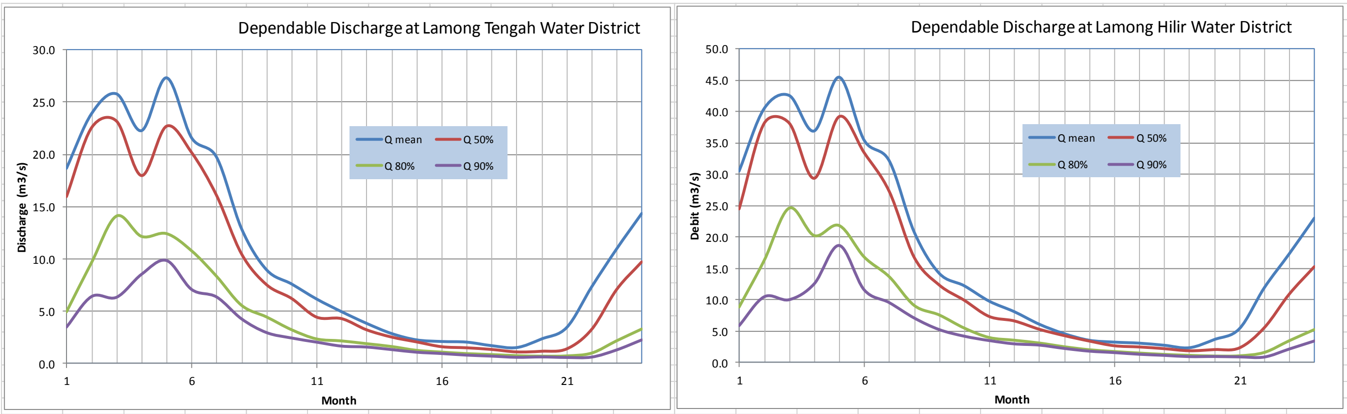


Fig. 3 Dependable discharge in each water district (Own study)

3.3. Water Demand

1) Domestic Water Demand

The analysis of population number in the water district is carried out based on the data of district BPS with the data information until village level. This is different from the analysis of domestic water demand presented in [16], in which the population number in the water district is analyzed based on the district BPS. For the village administration area is not all of them including in the certain water district, so the determination of population number is analyzed based on the density of population. For the analysis of water demand in each water district, the value of water demand per person is differentiated based on the development of each city. In this study, Gresik Regency and Surabaya is included in the category of medium city (115 l/person/day), Lamongan Regency is categorized as a semi-urban city (75 l/person/day), while Mojokerto Regency is categorized as a small city (100 l/person/day). The classification of this category is carried out based on the distance to Surabaya city which the closer the location to the Surabaya city, so it is categorized as a big city. In this study, the analysis of domestic water demand is conducted in each water district; however, the data and projection of the population are conducted based on the analysis result from the district BPS data. Data and projection of population number in the future until 2100 can be seen in Table 3.

Table 3 Projection of the population number for each water district (persons) (Own study)

No.	Water District	Year				
		2021	2025	2050	2075	2100
1	WD Lamong Hulu	66,934	72,824	112,878	174,961	271,189
2	WD Sabeng	72,259	78,065	117,445	177,863	270,781
3	WD Lamong Tengah	261,425	266,664	300,652	342,912	396,865
4	WD Kalitemu	159,291	165,084	203,856	260,051	342,959
5	WD Ngerembeng	462,732	471,544	527,747	591,134	662,668
6	WD Lamong Hilir	66,934	72,824	112,878	174,961	271,189

Based on the population number that has been obtained above, so the domestic water demand for each water district and the projection in the future can ba analyzed and the result is presented as in the Table 4.

Table 4 Domestic water demand for each water district (l/s) (Own study)

No.	Water District	Year				
		2021	2025	2050	2075	2100
1	WD Lamong Hulu	58.1	63.2	98.0	151.9	235.4
2	WD Sabeng	62.7	67.8	101.9	154.4	235.1
3	WD Lamong Tengah	302.6	308.6	348.0	396.9	459.3
4	WD Kalitemu	184.4	191.1	235.9	301.0	396.9
5	WD Ngerembeng	615.9	627.6	702.4	786.8	882.0
6	WD Lamong Hilir	96.8	105.4	163.3	253.1	392.3

2) Industry Water Demand

In this study, the water demand for industry is analyzed based on the employer number in the industry. The water demand for industry employer is determined about 10 l/employer/day. To analyze the industry water demand for each water district, there is determined based on the industry number that is in each water district. The industry number in each water district is analyzed based on the district BPS data with the information of industry number in the village level.

However, the industry number and the estimation of the employer number and water demand for industry sectors in each water district in 2021 can be seen in Table 5; industry water demand in the future is estimated based on the addition of industry number in each water district (Tables 6-9).

Table 5 Industry water demand in 2021

No.	Water District	2021								
		Number of industries			Estimation of the employer number			Industry Water Demand (l/s)		
		Light	Moderate	Big	Light	Moderate	Big	Light	Moderate	Big
1	WD Lamong Hulu	1,066	-	-	10,660	-	-	1.234	0	0
2	WD Sabeng	98	-	-	980	-	-	0.113	0	0
3	WD Lamong Tengah	166	-	-	1,660	-	-	0.192	0	0
4	WD Kalitemu	-	-	-	-		-	0.000	0	0
5	WD Ngerembeng	228	-	-	2,280	-	-	0.264	0	0
6	WD Lamong Hilir	18	-	-	180	-	-	0.021	0	0

Table 6 Industry water demand in 2025

Water District	2025									
	Number of industries			Estimation of the employer number			Industry Water Demand (l/s)			Total
	Light	Moderate	Big	Light	Moderate	Big	Light	Moderate	Big	
WD Lamong Hulu	1,279			12,792			1.481	0	0	1.481
WD Sabeng	118			1,176			0.136	0	0	0.136
WD Lamong Tengah	199			1,992			0.231	0	0	0.231
WD Kalitemu	5			50			0.006	0	0	0.006
WD Ngerembeng	274	1		2,736	60		0.317	0.007	0	0.324
WD Lamong Hilir	22	1		216	60		0.025	0.007	0	0.032

Table 7 Industry water demand in 2050

Water District	2025									Total
	Number of industries			Estimation of the employer number			Industry water demand (l/s)			
	Light	Moderate	Big	Light	Moderate	Big	Light	Moderate	Big	
WD Lamong Hulu	1,535			15,350			1.777	0	0	1.777
WD Sabeng	141			1,411			0.163	0	0	0.163
WD Lamong Tengah	239			2,390			0.277	0	0	0.277
WD Kalitemu	6			60			0.007	0	0	0.007
WD Ngerembeng	328	1		3,283	60		0.380	0.0069	0	0.387
WD Lamong Hilir	26	2	1	259	120	100	0.030	0.0139	0.012	0.055

Table 8 Industry water demand in 2075

Water District	2025									Total
	Number of industries			Estimation of employer number			Industry Water Demand (l/s)			
	Light	Moderate	Big	Light	Moderate	Big	Light	Moderate	Big	
WD Lamong Hulu	1,842			18,420			2.132	0	0	2.132
WD Sabeng	169			1,693			0.196	0	0	0.196
WD Lamong Tengah	287			2,868			0.332	0	0	0.332
WD Kalitemu	7			72			0.008	0	0	0.008
WD Ngerembeng	394	2	1	3,940	120	100	0.456	0.0139	0.0116	0.481
WD Lamong Hilir	31	2	1	311	120	100	0.036	0.0139	0.0116	0.061

Table 9 Industry water demand in 2100

Water District	2100									Total
	Number of industries			Estimation of the employer number			Industry Water Demand (l/s)			
	Light	Moderate	Big	Light	Moderate	Big	Light	Moderate	Big	
WD Lamong Hulu	2,210			22,105			2.558	0	0	2.558
WD Sabeng	203			2,032			0.235	0	0	0.235
WD Lamong Tengah	344			3,442			0.398	0	0	0.398
WD Kalitemu	9	1	1	86	60	100	0.010	0.007	0.012	0.029
WD Ngerembeng	473	3	2	4,728	180	200	0.547	0.021	0.023	0.591
WD Lamong Hilir	37	3	2	373	180	200	0.043	0.021	0.023	0.087

3.4. Rice Field Water Demand

3.4.1. Need Field Requirement (NFR)

The NFR in the rice field area for each water district is obtained from [16] (Table 10).

Table 10 Water demand per unit of the irrigation area (l/s/ha) for each water district [16]

No	Service Area	Des I	Des II	Jan I	Jan II	Feb I	Feb II	Mar I	Mar II	Apr I	Apr II	May I	May II	Jun I	Jun II	Jul I	Jul II	Aug I	Aug II	Sep I	Sep II	Oct I	Oct II	Nov I	Nov II
1	WD LAMONG HULU	0.90	0.94	0.96	1.25	0.49	0.47	0.23	0.07	0.91	1.15	1.15	1.24	0.95	0.73	0.64	0.46	1.28	1.28	1.33	1.33	1.15	0.91	0.69	0.31
2	WD SABENG	1.03	0.99	0.78	1.30	0.71	0.48	0.27	0.20	1.01	1.22	1.20	1.24	0.95	0.73	0.64	0.46	1.28	1.28	1.33	1.33	1.15	0.91	0.70	0.36
3	WD LAMONG TENGAH	1.05	1.02	1.00	1.35	0.75	0.49	0.34	0.23	1.08	1.22	1.17	1.24	0.95	0.73	0.64	0.46	1.28	1.28	1.33	1.33	1.15	0.92	0.72	0.43
4	WD KALITEMU	1.06	0.98	0.98	1.35	0.71	0.46	0.29	0.20	1.06	1.20	1.17	1.24	0.95	0.73	0.64	0.46	1.28	1.28	1.33	1.33	0.96	0.92	0.71	0.41
5	WD NGEREMBENG	1.01	1.07	0.88	1.24	0.72	0.49	0.43	0.28	1.08	1.17	1.22	1.24	0.95	0.73	0.64	0.46	1.28	1.28	1.33	1.33	1.15	0.92	0.72	0.36
6	WD LAMONG HILIR	1.03	1.05	0.93	1.26	0.76	0.52	0.42	0.34	1.09	1.19	1.24	1.24	0.95	0.73	0.64	0.46	1.28	1.28	1.33	1.33	1.15	0.92	0.74	0.40

3.4.2. Irrigation Area

The irrigation area that is further analyzed is the area for technical and semi-technical irrigation for each water district. However, the rice field area that has been elaborated for each village in each water district can be seen in Table 11.

Table 11 Irrigated rice area in the Lamong watershed

No.	Water district	Irrigated rice area (ha)
1	WD Lamong Hulu	147.6
2	WD Sabeng	443.6
3	WD Lamong Tengah	0.8
4	WD Kalitemu	294
5	WD Ngerembeng	-
6	WD Lamong Hilir	-

Based on the data above, the most rice field area that is irrigated is in the Sabeng water district and the least is in the Lamong Hilir and Ngerembeng water districts. The irrigation area in each water district is used to analyze the water demand for irrigation in each water district.

3.4.3. Irrigation Water Requirement

The increasing of irrigation area is carried out in the rained irrigation area that becomes as technical irrigation. Based on the analysis result in the previous research, the rice field area is still much wider than the irrigated area. The increasing of irrigated rice-field area is projected about 50% from the previous area, so the irrigation water requirement can be determined below.

Table 12 Irrigation water requirement in 2021

No	Service Area	Jan I	Jan II	Feb I	Feb II	Mar I	Mar II	Apr I	Apr II	May I	May II	Jun I	Jun II	Jul I	Jul II	Aug I	Aug II	Sept I	Sept II	Oct I	Oct II	Nov I	Nov II	Dec I	Dec II
1	WD LAMONG HULU	3.32	4.50	5.42	3.64	4.34	3.79	3.20	1.08	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.54	1.81	3.84	3.49
2	WD SABENG	4.88	4.11	3.50	3.49	4.03	2.67	2.36	0.47	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.44	1.39	2.71	3.06
3	WD LAMONG TENGAH	2.93	3.63	3.19	3.43	3.41	2.46	1.73	0.53	0.63	0.01	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.33	0.77	2.55	2.75
4	WD KALITEMU	3.14	3.64	3.54	3.70	3.86	2.70	1.84	0.64	0.60	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.42	0.94	2.47	3.11
5	WD NGEREMBENG	4.01	4.56	3.41	3.46	2.67	2.03	1.75	0.93	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	1.40	2.86	2.34
6	WD LAMONG HILIR	3.61	4.39	3.13	3.22	2.71	1.49	1.63	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	1.02	2.71	2.52

Table 13 Irrigation water requirement in 2025

No	Service Area	Irrigated rice area (ha)	Dec I	Dec II	Jan I	Jan II	Feb I	Feb II	Mar I	Mar II	Apr I	Apr II	May I	May II	Jun I	Jun II	Jul I	Jul II	Aug I	Aug II	Sept I	Sept II	Oct I	Oct II	Nov I	Nov II
1	WD LAMONG HULU	6,445	0.90	0.94	0.96	1.25	0.49	0.47	0.23	0.07	0.91	1.15	1.15	1.24	0.95	0.73	0.64	0.46	1.28	1.28	1.33	1.33	1.15	0.91	0.69	0.31
2	WD SABENG	5,760	1.03	0.99	0.78	1.30	0.71	0.48	0.27	0.20	1.01	1.22	1.20	1.24	0.95	0.73	0.64	0.46	1.28	1.28	1.33	1.33	1.15	0.91	0.70	0.36
3	WD LAMONG TENGAH	9,297	1.05	1.02	1.00	1.35	0.75	0.49	0.34	0.23	1.08	1.22	1.17	1.24	0.94	0.73	0.64	0.46	1.28	1.28	1.33	1.33	1.15	0.92	0.72	0.43
4	WD KALITEMU	11,236	1.06	0.98	0.98	1.35	0.71	0.46	0.29	0.20	1.06	1.20	1.17	1.24	0.74	0.73	0.64	0.46	1.28	1.28	1.33	1.33	0.96	0.92	0.71	0.41
5	WD NGEREMBENG	4,417	1.01	1.07	0.88	1.24	0.72	0.49	0.43	0.28	1.08	1.17	1.22	1.24	0.95	0.73	0.64	0.46	1.28	1.28	1.33	1.33	1.15	0.92	0.72	0.36
6	WD LAMONG HILIR	112	1.03	1.05	0.93	1.26	0.76	0.52	0.42	0.34	1.09	1.19	1.24	1.24	0.95	0.73	0.64	0.46	1.28	1.28	1.33	1.33	1.15	0.92	0.74	0.40

Table 14 Irrigation water requirement in 2050

No	Service Area	Irrigated rice area (ha)	Des I	Des II	Jan I	Jan II	Feb I	Feb II	Mar I	Mar II	Apr I	Apr II	Mei I	Mei II	Jun I	Jun II	Jul I	Jul II	Aug I	Aug II	Sept I	Sept II	Okt I	Okt II	Nov I	Nov II
1	WD LAMONG HULU	332.2	0.298	0.311	0.319	0.416	0.163	0.155	0.077	0.025	0.301	0.383	0.381	0.412	0.317	0.243	0.212	0.152	0.424	0.424	0.443	0.443	0.383	0.302	0.229	0.104
2	WD SABENG	998.0	1.026	0.986	0.778	1.294	0.710	0.483	0.269	0.204	1.003	1.222	1.201	1.238	0.951	0.730	0.636	0.458	1.272	1.272	1.332	1.332	1.151	0.910	0.702	0.362
3	WD LAMONG TENGAH	15.0	0.016	0.015	0.015	0.020	0.011	0.007	0.005	0.003	0.016	0.018	0.018	0.019	0.014	0.011	0.010	0.007	0.019	0.019	0.020	0.020	0.017	0.014	0.011	0.007
4	WD KALITEMU	661.5	0.698	0.649	0.649	0.894	0.468	0.304	0.191	0.133	0.704	0.796	0.775	0.821	0.492	0.484	0.422	0.303	0.843	0.843	0.883	0.883	0.633	0.608	0.467	0.275
5	WD NGEREMBENG	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	WD LAMONG HILIR	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 15 Irrigation water requirement in 2075

No	Service Area	Irrigated rice area (ha)	Des I	Des II	Jan I	Jan II	Feb I	Feb II	Mar I	Mar II	Apr I	Apr II	Mei I	Mei II	Jun I	Jun II	Jul I	Jul II	Aug I	Aug II	Sept I	Sept II	Okt I	Okt II	Nov I	Nov II
1	WD LAMONG HULU	498.3	0.447	0.467	0.478	0.624	0.244	0.232	0.116	0.037	0.452	0.575	0.571	0.618	0.475	0.365	0.318	0.228	0.635	0.635	0.665	0.665	0.575	0.454	0.344	0.157
2	WD SABENG	1497.0	1.539	1.478	1.167	1.941	1.066	0.725	0.403	0.305	1.505	1.832	1.802	1.858	1.426	1.095	0.955	0.686	1.909	1.909	1.998	1.998	1.726	1.365	1.053	0.543
3	WD LAMONG TENGAH	22.5	0.024	0.023	0.023	0.030	0.017	0.011	0.008	0.005	0.024	0.027	0.026	0.028	0.021	0.016	0.014	0.010	0.029	0.029	0.030	0.030	0.026	0.021	0.016	0.010
4	WD KALITEMU	992.3	1.048	0.974	0.973	1.341	0.702	0.456	0.286	0.200	1.056	1.194	1.163	1.231	0.738	0.726	0.633	0.455	1.265	1.265	1.324	1.324	0.949	0.913	0.700	0.412
5	WD NGEREMBENG	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	WD LAMONG HILIR	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 16 Irrigation water requirement in 2100

No	Service Area	Irrigated rice area (ha)	Des I	Des II	Jan I	Jan II	Feb I	Feb II	Mar I	Mar II	Apr I	Apr II	Mei I	Mei II	Jun I	Jun II	Jul I	Jul II	Aug I	Aug II	Sept I	Sept II	Okt I	Okt II	Nov I	Nov II
1	WD LAMONG HULU	747.5	0.671	0.701	0.717	0.936	0.366	0.349	0.174	0.056	0.678	0.862	0.857	0.928	0.712	0.547	0.477	0.343	0.953	0.953	0.998	0.998	0.862	0.680	0.516	0.235
2	WD SABENG	2245.5	2.308	2.217	1.750	2.912	1.598	1.088	0.605	0.458	2.257	2.748	2.703	2.787	2.140	1.643	1.432	1.030	2.863	2.863	2.997	2.997	2.589	2.048	1.579	0.814
3	WD LAMONG TENGAH	33.8	0.035	0.035	0.034	0.046	0.025	0.017	0.012	0.008	0.036	0.041	0.039	0.042	0.032	0.025	0.022	0.015	0.043	0.043	0.045	0.045	0.039	0.031	0.024	0.015
4	WD KALITEMU	1488.4	1.571	1.461	1.460	2.011	1.053	0.685	0.429	0.299	1.585	1.791	1.744	1.847	1.106	1.089	0.949	0.682	1.898	1.898	1.986	1.986	1.423	1.369	1.050	0.618
5	WD NGEREMBENG	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	WD LAMONG HILIR	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

3.5. Analysis of Water Balance Potential in the Water District

Based on the water balance result, the potential of water resources has not been optimally used, and there is information about the period of water resource deficit. Water balance in each water district is determined for now (2021 and 2025) and the projection for the medium (2050) and long (2075 and 2100) terms. The water balance analysis uses water availability as 80% dependable discharge with the total water demand (domestic, irrigation, and industry).

3.5.1. Potential of Water Balance in the Lamong Hulu Water District

The water balance analysis result will be the surplus and deficit values for a year period. The water balance result for Lamong Hulu water district for now and the medium and long terms can be seen in Fig. 4. The water balance analysis result shows that now (2021), the deficit of water balance occurs for two months, in September and October. In 2025, the deficit of water balance will become longer, four months, from August to early November. The water balance in the medium term will experience a deficit, which increases because the water total will increase in 2050, but the deficit value will be higher than in 2025. For the long term, the water deficit will become long and big, which can be seen in 2075, when the water deficit is from August until the end of November. However, in 2100, the water deficit will be longer, from the end of May until early December.

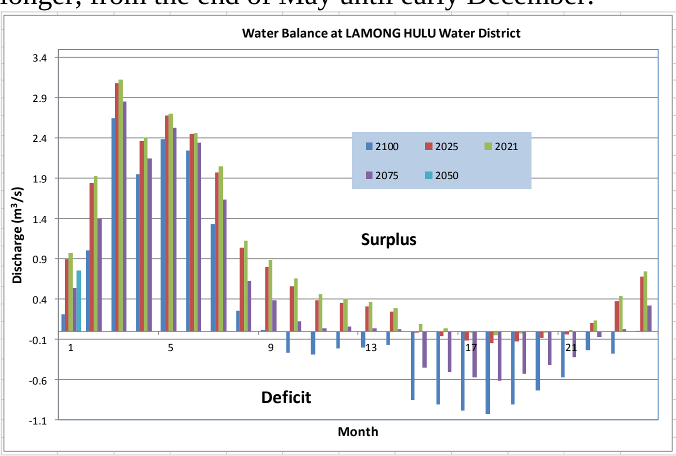


Fig. 4 Water balance in the Lamong Hulu water district (Own study)

3.5.2. Potential of Water Balance in the Sabeng Water District

The water balance analysis result will be the surplus and deficit values over a one-year period. However, the water balance result in Sabeng water district for now, medium term, and long term can be seen in Fig. 5. The water balance analysis result shows that now (in 2021), the deficit of water balance occurs for 3.5 months, from August until early November. In 2025, the deficit of water balance will increase, with the deficit period still the same as in 2021. In the medium term, the water balance will experience a big and long deficit because the water demand total will become big in the future. In 2050, the deficit of water balance will occur for seven months, from the end of May until early December. For the long term, the water deficit will be long and big, which is seen in 2075, when the water deficit occurs from May until the end of December; however, in 2100, the water deficit will become long, from the end of April until early January.

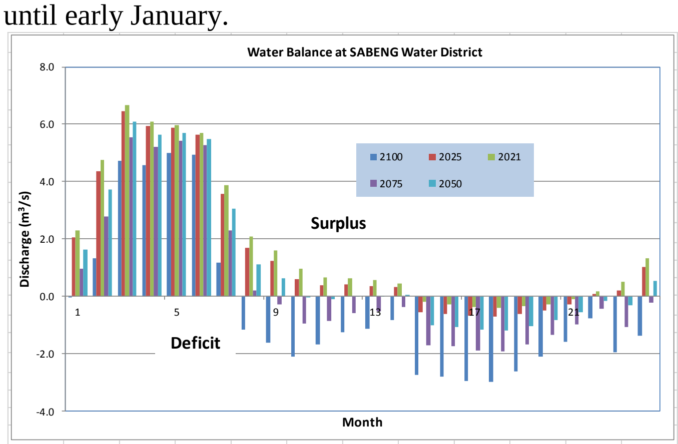


Fig. 5 Water balance in the Sabeng water district (Own study)

3.5.3. Potential of Water Balance in the Lamong Tengah Water District

The water balance analysis result will be the surplus and deficit values for a one-year period. The water balance analysis in Lamong Tengah water district for now and the medium and long terms can be seen in Fig. 6. The water balance analysis result shows that in 2021, there was surplus of water balance. In 2025, there will be a short deficit of water balance for 0.5 month, in early November. In the medium term, the water balance will experience a bigger and longer deficit because the total water demand will increase. In 2050, the water balance deficit will occur for 1.5 months, from the end of October until early November. In the long term, the water deficit will be longer, which is seen in 2075, when the water deficit occurs from the end of September until early November. However, in 2100, the water deficit will be longer, from the end of August until early November.

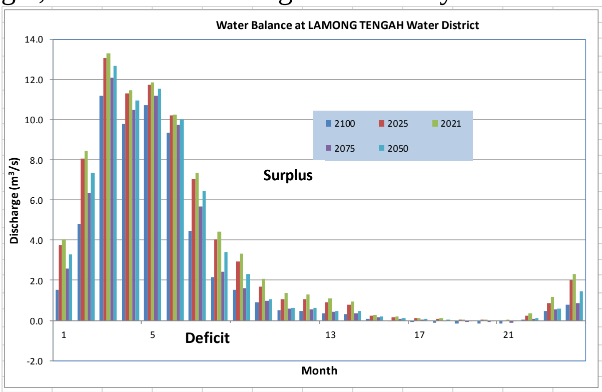


Fig. 6 Water balance in the Lamong Tengah water district (Own study)

3.5.4. Potential of Water Balance in the Kalitemu Water District

The analysis result for water balance in Kalitemu water district for now and the medium and long terms can be seen in Fig. 7. Based on the water balance analysis result, in 2021, the water balance deficit occurred for 3.5 months, from the end of August until early November. The biggest deficit occurred at about -0.321 m^3/s. In 2025, the water balance deficit will occur for 4.5 months, from the end of August until early December. The water balance for medium-term period will experience the getting bog and long deficit because the water demand total will increase. In 2050, the water balance deficit will occur for six months, from the end of June until early December. The highest deficit is approximately -0.86 m^3/s. In the long term, the water deficit will become long and big, which is seen in 2075, when the water deficit occurs for 7.5 months, from the end of May until the end of December, with the biggest deficit of about -1.37 m^3/s; however, in 2100, the water deficit will occur for nine months, from the end of April until early January, with the deficit of about -2,128 m^3/s.

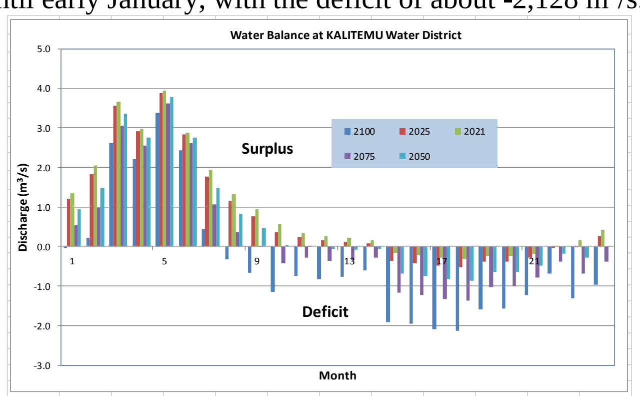


Fig. 7 Water balance in the Kalitemu water district (Own study)

3.5.5. Potential of Water Balance in the Ngrembeng Water District

The water balance analysis result will be the surplus and deficit values for a one-year period. The water balance results for the Ngrembeng water district for now and the medium and long terms can be seen in Fig. 8. The analysis result in Fig. 8 shows that in 2021, there was a longer water balance surplus period than the water deficit period that is only 1 month. In 2025, there will be almost the same condition as in 2021, when the water surplus was still longer than the water deficit, which occurred for 1.5 months, with the biggest deficit being about -0.208 m^3/s. In the medium term, the water deficit will become long and big because the water demand total will increase. In 2050, the water balance deficit will increase to two months, from the end of October until November. In the long term, the water deficit will become long, as seen in 2075, when the water deficit increases to 2.5 months, from the end of September until the end of November. However, in 2100, the water deficit will increase to three months, from September until November.

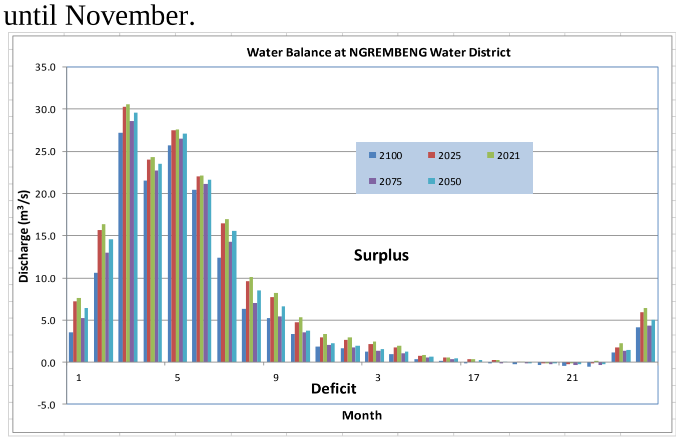


Fig. 8 Water balance in the Ngrembeng water district (Own study)

3.5.6. Potential of Water Balance in the Lamong Hilir Water District

The water balance analysis result for this water district will provide information about surplus and deficit values for a one-year period. The water balance results for the Lamong Hilir water district for now and the medium and long terms can be seen in Fig. 9. Based on the analysis result in Fig. 9, the water balance experiences water surplus; it shows water deficit in the short term with the small value. In 2021, there was longer water balance surplus than the water deficit, which occurred for only 1.5 months. 2025 still shows almost the same as 2021, when the water surplus was still longer than the water deficit, which occurred for two months, with the biggest deficit of about -0.085 m^3/s. The water balance in the medium term is similar to that in 2050; the water balance deficit increases to 2.5 months, from the end of September until November, with the deficit being about -0.143 m^3/s. In the long term, the water deficit will become long, which is seen in 2075, when the water deficit will increase to three months, from early September until the end of November. However, in 2100, the water deficit will increase to 3.5 months, from the end of August until November, with the biggest deficit being about -0.372 m^3/s.

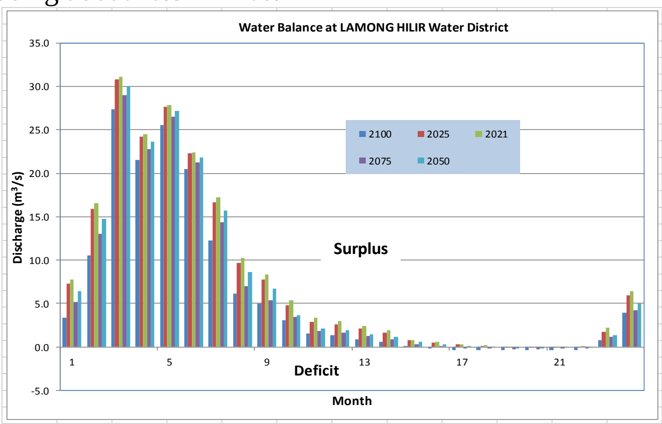


Fig. 9 Water balance in the Lamong Hilir water district (Own study)

4. Conclusion

Based on the analysis result of water balance in each district in Kali Lamong watershed for now until the projection in the future, it can be concluded as follow:

1. The water balance in each water district has been determined and provides information on the water surplus and deficit. Water deficit in the future is happened in Lamong Hulu, Sabeng, and Kalitemu water districts, while in the other water districts, the water surplus still has the longer period and the deficit is still very small.
2. The Lamong Hulu water district is in the watershed upstream and has very significant pressure to the water resources demand in the future. The water deficit will be longer and bigger, with the biggest deficit being about -1.024 m^3/s. The water surplus also happens in the Lamong Hulu water district, and the biggest surplus can be 2.385 m^3/s.
3. The Sabeng water district has very significant pressure to the water resources demand in the future. The water deficit will be longer and bigger in 2100, with the biggest deficit of about -2.99 m^3/s. The water balance that is presented in 2021 experiences the water balance deficit during 3.5 months that are from August until early December, however, in 2100 the water deficit starts from the end of April until early January.
4. The Lamong Tengah water district has the water balance in the future with the water surplus period is longer than water deficit. The biggest water deficit is only about -0.159 m^3/s. The analysis result for water balance in 2021 shows the water surplus. In 2025, the water balance deficit will only happen for 0.5 month, in early November. In 2050, the water balance deficit will happen for 1.5 months, from the end of October until early November. In 2075, the water deficit will happen from the end of September until early November; however, in 2100, the water deficit will be from the end of August until early November.
5. The Kalitemu water district is in the watershed center, has an independent water availability source for the area itself, and experiences very big pressure due to the water resource demand. The water deficit will be longer and bigger in 2100, with the biggest deficit of about -2.128 m^3/s. The analysis result for the water balance in 2021 shows the water deficit for 3.5 months, from the end of August until early November. The biggest deficit is about -0.321 m^3/s. In 2025, the water balance deficit will be longer, for 4.5 months, from the end of August until early December. In 2050, the water balance deficit will be for six months, from the end of June until early December. The biggest deficit is about -0.86 m^3/s. In 2075, the water deficit will be for 7.5 months, from the end of May until the end of December, with the biggest deficit of about -1.37 m^3/s. However, in 2100, the water deficit will be longer, for nine months, from the end of April until early January, with the biggest deficit being about -2,128 m^3/s.
6. The Ngrembeng water district is affected from the upstream due to the water availability. For the water balance in 2021 and 2025, the surplus period is longer than the water deficit period (only 1 and 1.5 months). In 2050, the water balance deficit will increase to two months, from the end of October until November. In 2075, the water deficit period will increase to 2.5 months, from the end of September until the end of November. However, in 2100, the water deficit will increase to three months, from September until November, with the biggest deficit being about -0.5 m^3/s.
7. The Lamong Hilir water district is generally expected to experience the water surplus in the future. In 2021 and 2025, the water balance surplus is longer than the water deficit, which is only for 1.5 and 2 months. In 2050, the water deficit will increase to 2.5 months, from the end of September until November, with the biggest water deficit of about -0.143 m^3/s. In 2075, the water deficit will increase to three months, from early September until the end of November. However, in 2100, the water deficit will increase to 3.5 months, from the end of August until November, with the biggest deficit being about -0.372 m^3/s.

References

[1] IMMERZEEL W. W. Importance and vulnerability of the world's water towers. *Nature*, 2020, 577: 364–369. https://doi.org/10.1038/s41586-019-1822-y

[2] VELDKAMP T. I. E. Towards a global water scarcity risk

assessment framework: incorporation of probability distributions and hydro-climatic variability. *Environmental Research Letters*, 2016, 11(2): 024006. http://dx.doi.org/10.1088/1748-9326/11/2/024006

[3] FISHER J. B., MELTON F., MIDDLETON E., HAIN C., ANDERSON M., ALLEN R., MCCABE M. F., HOOK S., BALDOCCHI D., TOWNSEND P. A., KILIC A., TU K., MIRALLES D. D., PERRET J., LAGOUARDE J.-P., WALISER D., PURDY A. J., FRENCH A., SCHIMEL D., FAMIGLIETTI J. S., STEPHENS G., and WOOD E. F. The future of evapotranspiration: Global requirements for ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources. *Water Resources Research*, 2017, 53(4): 2618–2626. https://doi.org/10.1002/2016WR020175

[4] CHANG F. J., HUANG C. W., CHENG S. T., and CHANG L. C. Conservation of groundwater from over-exploitation—Scientific analyses for groundwater resources management. *Science of the Total Environment*, 2017, 598(1): 828–838. https://doi.org/10.1016/j.scitotenv.2017.04.142

[5] KONDILI E., KALDELLIS J. K., and PAPAPOSTOLOU C. A novel systemic approach to water resources optimisation in areas with limited water resources. *Desalination*, 2017, 250(1): 297–301. https://doi.org/10.1016/j.desal.2009.09.046

[6] FARIDA F., DASRIZAL D., and FEBRIANI T. Review: Produktivitas air dalam pengelolaan sumber daya air pertanian di Indonesia. *Jurnal Spasial*, 2019, 5(3): 65–72. https://doi.org/10.22202/js.v5i3.3161

[7] REN C., & ZHANG H. An inexact optimization model for crop area under multiple uncertainties. *International Journal of Environmental Research and Public Health*, 2019, 16(14): 2610. https://doi.org/10.3390/ijerph16142610

[8] LI M., FU Q., GUO P., SINGH V. P., ZHANG C., and YANG G. Stochastic multi-objective decision making for sustainable irrigation in a changing environment. *Journal of Cleaner Production*, 2019, 223: 928–945. https://doi.org/10.1016/j.jclepro.2019.03.183

[9] UNITED NATIONS ENVIRONMENT PROGRAMME. *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication.* United Nations Environment Programme, Nairobi, 2011. https://web.unep.org/greeneconomy/sites/unep.org.greeneconomy/files/field/image/green_economyreport_final_dec2011.pdf

[10] LI M., FU Q., SINGH V. P., LIU D., and GONG X. Risk-based agricultural water allocation under multiple uncertainties. *Agricultural Water Management*, 2020, 233: 106105. https://doi.org/10.1016/j.agwat.2020.106105

[11] REJEKININGRUM P. Identifikasi kekritisan air untuk perencanaan penggunaan air agar tercapai ketahanan air di DAS Bengawan Solo. *Seminar Nasional FMIPA-UT*, 2014, 3(1): 170–184. http://repository.ut.ac.id/5026/1/fmipa2014_12.pdf

[12] JIANG Y. China's Water Scarcity: A Review. *Journal of Environmental Management*, 2009, 90: 3185-3196. https://doi.org/10.1016/j.jenvman.2009.04.016

[13] GOHAR A. A., AMER S. A., and WARD F. A. Irrigation infrastructure and water appropriation rules for food security. *Journal of Hydrology*, 2015, 520: 85–100. https://doi.org/10.1016/j.jhydrol.2014.11.036

[14] NAM W. H., & CHOI J. Y. Development of an irrigation vulnerability assessment model in agricultural reservoirs utilizing probability theory and reliability analysis. *Agricultural Water Management*, 2014, 142: 115–126. https://doi.org/10.1016/j.agwat.2014.05.009

[15] BLANKE A., ROZELLE S., LOHMAR B., WANG J., and HUANG J. Water saving technology and saving water in China. *Agricultural Water Management*, 2007, 87(2): 139–150. https://doi.org/10.1016/j.agwat.2006.06.025

[16] PURNOMO W. A. Y., LIMANTARA L. M., BISRI M., and SHOLICHIN M. Surface Water Balance Based on the Water District Analysis in Lamong Watershed, East Java Province, Indonesia. *Journal of Hunan University (Natural Sciences)*, 2023, 50(7): 89-101. https://doi.org/10.55463/issn.1674-2974.50.7.9

[17] POST D. A., CHIEW F. H. S., TENG J., VINEY N. R., LING F. L. N., HARRINGTON G., CROSBIE, R. S., GRAHAM B., MARVANEK S., and MCLOUGHLIN R. A robust methodology for conducting large-scale assessments of current and future water availability and use: A case study in Tasmania, Australia. *Journal of Hydrology*, 2012, 412–413: 233–245. https://doi.org/10.1016/j.jhydrol.2011.02.011

[18] LE T. B. *River Basin Scale Hydrologic Modeling for Prediction of Water Availability*. Ph.D. thesis, The University of Texas at San Antonio, 2014.

[19] SCHUOL J., ABBASPOUR K. C., SRINIVASAN R., and YANG H. Estimation of freshwater availability in the West African sub-continent using the SWAT hydrologic model. *Journal of Hydrology*, 2008, 352(1–2): 30–49. https://doi.org/10.1016/j.jhydrol.2007.12.025

[20] MENZEL L., & MATOVELLE A. Current state and future development of blue water availability and blue water demand: A view at seven case studies. *Journal of Hydrology*, 2010, 384(3–4): 245–263. https://doi.org/10.1016/j.jhydrol.2010.02.018

[21] TRIATMOJO B. *Hidrologi Terapan*. Beta Offset, Yogyakarta, 2008.

参考文:

[1] IMMERZEEL W.W. 世界水塔的重要性和脆弱性。自然，2020，577：364–369。https://doi.org/10.1038/s41586-019-1822-y

[2] VELDKAMP T.I.E. 迈向全球水资源短缺风险评估框架：纳入概率分布和水文气候变化。环境研究快报，2016年，11(2)：024006。http://dx.doi.org/10.1088/1748-9326/11/2/024006

[3] FISHER J. B.、MELTON F.、MIDDLETON E.、HAIN C.、ANDERSON M.、ALLEN R.、MCCABE M.F.、HOOK S.、BALDOCCHI D.、TOWNSEND P.A.、KILIC A.、TU K.、MIRALLES D.D. 、PERRET J.、LAGOUARDE J.-P.、WALISER D.、PURDY A. J.、FRENCH A.、SCHIMEL D.、FAMIGLIETTI J. S.、STEPHENS G. 和 WOOD E. F. 蒸散量的未来：生态系统功能、碳和碳排放的全球要求气候反馈、农业管理和水资源。水资源研究，2017，53(4)：2618–2626。https://doi.org/10.1002/2016WR020175

[4]常福杰，黄成伟，程世通，张立成。地下水过度开采保护——
地下水资源管理的科学分析。全环境科学，2017，598(1)：828–838。https://doi.org/10.1016/j.scitotenv.2017.04.142
[5] KONDILI E.、KALDELLIS J.K. 和 PAPAPOSTOLOU C.
水资源有限地区水资源优化的一种新颖的系统方法。海水淡化，2017，250（1）：297–301。https://doi.org/10.1016/j.desal.2009.09.046
[6] FARIDA F.、DASRIZAL D. 和 FEBRIANI T. 评论：印度尼西亚空气达拉姆彭格洛兰夏季达亚空气生产。空间杂志，2019，5(3)：65–72。https://doi.org/10.22202/js.v5i3.3161
[7] 任成，张红.
多种不确定性下作物面积的不精确优化模型。国际环境研究与公共卫生杂志，2019，16(14)：2610。https://doi.org/10.3390/ijerph16142610
[8] LI M., FU Q., GUO P., SINGH V. P., ZHANG C., 和 YANG G.
变化环境下可持续灌溉的随机多目标决策。清洁生产杂志，2019，223：928–945。https://doi.org/10.1016/j.jclepro.2019.03.183
[9]联合国环境规划署。迈向绿色经济：可持续发展和消除贫困之路。联合国环境规划署，内罗毕，2011年。https://web.unep.org/greeneconomy/sites/unep.org.greeneconomy/files/field/image/green_economyreport_final_dec2011.pdf
[10] 李明，付清，SINGH V. P.，刘德，龚旭.
多重不确定性下基于风险的农业用水分配。农业用水管理，2020年，233：106105。https://doi.org/10.1016/j.agwat.2020.106105
[11] REJEKININGRUM P.
识别空气琼脂实现了班加万梭罗流域的水安全。国家FMIPA-UT研讨会，2014年，3(1)：170–184。http://repository.ut.ac.id/5026/1/fmipa2014_12.pdf
[12] 蒋勇.
中国水资源短缺：回顾。环境管理杂志，2009，90：3185-3196。https://doi.org/10.1016/j.jenvman.2009.04.016
[13] GOHAR A. A.、AMER S. A. 和 WARD F. A.
灌溉基础设施和粮食安全用水拨款规则。水文学杂志，2015，520：85-100。https://doi.org/10.1016/j.jHydrol.2014.11.036
[14] NAM W. H., & CHOI J. Y.
利用概率论和可靠性分析开发农业水库灌溉脆弱性评估模型。农业用水管理，2014年，142：115–126。https://doi.org/10.1016/j.agwat.2014.05.009
[15] BLANKE A., ROZELLE S., LOHMAR B., WANG J., HUANG J. 节水技术与中国节水.
农业用水管理，2007，87(2)：139–150。https://doi.org/10.1016/j.agwat.2006.06.025
[16] PURNOMO W. A. Y.、LIMANTARA L. M.、BISRI M. 和 SHOLICHIN M.
基于印度尼西亚东爪哇省拉蒙流域水区分析的地表水平衡。湖南大学学报（自然科学版）, 2023, 50(7): 89-101. https://doi.org/10.55463/issn.1674-2974.50.7.9
[17] POST D. A.、CHIEW F. H. S.、TENG J.、VINEY N. R.、LING F. L. N.、HARRINGTON G.、CROSBIE、R. S.、GRAHAM B.、MARVANEK S. 和 MCLOUGHLIN R.
对当前情况进行大规模评估的稳健方法以及未来的水资源供应和使用：澳大利亚塔斯马尼亚的案例研究。水文学杂志，2012年，412–413：233–245。https://doi.org/10.1016/j.jHydrol.2011.02.011
[18] LE T. B.
用于预测可用水量的流域规模水文模型。博士论文，德克萨斯大学圣安东尼奥分校，2014年。
[19] SCHUOL J.，ABBASPOUR K.C.，SRINIVASAN R.，和 YANG H.
使用扑打水文模型估计西非次大陆的淡水可用性。水文学杂志，2008，352（1-2）：30-49。https://doi.org/10.1016/j.jHydrol.2007.12.025
[20] MENZEL L., & MATOVELLE A.
蓝水可用性和蓝水需求的现状和未来发展：七个案例研究的观点。水文学杂志，2010，384（3-4）：245-263。https://doi.org/10.1016/j.jHydrol.2010.02.018
[21] TRIATMOJO B.
水神特拉潘。贝塔偏移量，日惹，2008年。