REVIEW OF THE WATER CARRYING CAPACITY AND WATER FLOW AT RDTR OF THE SPATIAL PLANNING OF TEGALLUAR RESIDENTIAL INTEGRATED AREA IN BANDUNG REGENCY

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Abstract

The development of Tegalluar area as a strategically planned integrated residential center, potentially serving as the new provincial government center for West Java, stands as a top priority for the Bandung Regency Government. To support this vision, the Regional Detailed Spatial Plan (RDTR) for Tegalluar Integrated Settlement Area and the Planning Area (BWP) of Bojongsoang have been formulated. Concurrently, the region has grappled with persistent water resource management challenges, marked by annual flooding during the rainy season and water shortages in the dry season. This research aims to comprehensively analyze the water flow cycle within the area and explore potential scenarios for water management in alignment with the RDTR. The research findings reveal that, in the development scenario, the water flow pattern remains largely unchanged, with limited efforts to harness rainfall or manage wastewater. Precipitation and surface water predominantly contribute to the water inflow in the research area. Furthermore, the provision of clean water heavily relies on external sources. Based on this water flow analysis, there exists an opportunity to implement water-sensitive urban design principles in the research area. This involves capturing rainwater through effective harvesting techniques and adopting wastewater reuse strategies, focusing on non-potable applications. Such measures can enhance water sustainability and mitigate the region's water-related challenges.

Keywords: *water flow, water carrying capacity, water cycle, water sensitive urban design*

Introduction

The objective of spatial planning is to establish a harmonious relationship between the natural and artificial environments. It seeks to foster the integration of natural and artificial resource utilization while considering human resources. Moreover, it aims to safeguard the functionality of spaces and mitigate adverse environmental effects resulting from their utilization, as stipulated in Law Number 11 of 2020 regarding Job Creation.

In the conventional approach to spatial planning for water resource infrastructure, a typical method involves a supply-demand approach. For instance, when calculating the requirements for drinking water infrastructure, the initial step is to determine the water requirement, followed by a subsequent analysis to assess how these needs can be met. If there is an ample local water source within the planning area, infrastructure is established accordingly. However, if such a source is lacking, efforts are made to identify and tap into water sources from external regions

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(Jørgensen et al., 2013). In the context of wastewater management, a similar approach is employed to conserve water resources. The process begins with an estimation of wastewater generation, followed by the development of a management plan. This plan may encompass options such as local systems (on-site sanitation) or centralized systems (off-site sanitation). Similarly, when addressing rainwater, the focus is on mitigating its destructive potential. Strategies include the creation of drainage channels, infiltration ponds, oxbows, and other structures. It is essential to note that these efforts often seem disconnected, lacking an apparent integration between the conservation, utilization, and control of water resources and their associated challenges.

The approach outlined above often leads to the creation of urban areas that embody significant challenges in water resource spatial planning. These challenges manifest in the form of issues like flooding and stagnant water during the rainy season, drought conditions in the dry season, and pollution of both surface water and groundwater (Renouf et al., 2017). Such problems are evident in documents like the Detailed Spatial Plan for Tegalluar Settlement Integrated Area Planning Area for 2020 – 2039, which has been officially ratified through Bandung Regent Regulation Number 24 of 2021. Within this plan, water resource management is segmented into distinct systems, including a water resource network system, a drinking water network system, and a wastewater management network system. Regrettably, it appears that the conventional "business as usual" approach fails to establish meaningful connections between these three systems, further exacerbating the existing water-related challenges.

Water Sensitive Urban Design (WSUD) represents a concerted endeavor to seamlessly blend urban planning with the adept management, safeguarding, and preservation of the urban water cycle. This approach is instrumental in ensuring that urban water management remains attuned to the nuances of natural hydrological and ecological processes (Wong, 2006). In simpler terms, WSUD is a proactive strategy aimed at the holistic integration of water resource management encompassing conservation, utilization, and the mitigation of water's destructive potential into every facet of spatial planning.

A city can earn the distinction of being considered water-sensitive or water-friendly when it fulfills several key criteria. Firstly, it functions as a potential water catchment, capable of efficiently harnessing and managing water resources on various scales and for diverse purposes. Secondly, such a city plays a vital role in providing ecosystem services that benefit both the built environment and the natural world. Lastly, it boasts communities that possess knowledge and a genuine desire to make informed and prudent choices regarding water. These communities actively participate in the decision-making process and exhibit positive behaviors in their interactions with water resources (Santoso & Therik, 2016; Kaloeti & Dewi, 2020).

The implementation of Water Sensitive Urban Design (WSUD) marks a significant shift in the integration of water resource infrastructure planning into every facet of spatial allocation planning. Consider an industrial area as an example: under this approach, not only will there be a plan for the industrial zone itself, but also a comprehensive strategy for rainwater harvesting and the efficient reuse of wastewater, seamlessly integrated with the plan for fulfilling industrial water requirements within that area. This holistic concept translates into reduced reliance on groundwater (conservation), minimal pollution of rivers (conservation), decreased rainwater runoff into rivers (mitigation of damaging potential), and ultimately resulting in a more sustainable supply of drinking water and water for various other needs within the region (utilization).

A pivotal element within the framework of Water Sensitive Urban Design (WSUD) involves gaining a comprehensive understanding of water flow, often referred to as the urban water cycle within a given area. The urban water cycle concept delves into the intricate examination of water balance and inventory within urban settings (Marsalek et al., 2006). Graphically, this urban water flow can be illustrated as depicted in Figure 1 below.

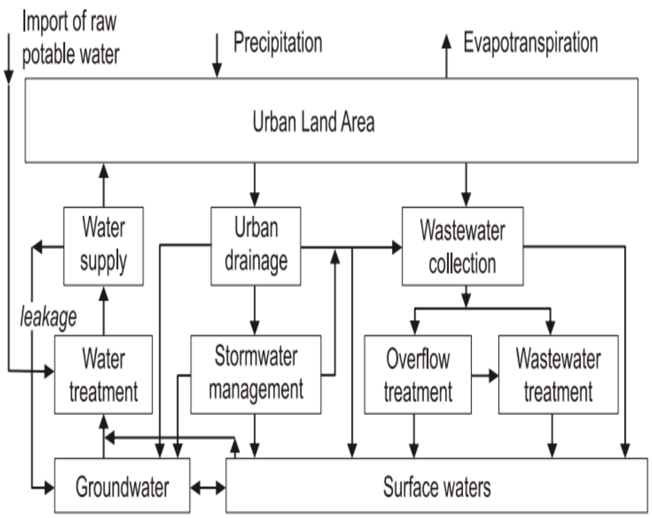

Figure 1. Urban Water Flow (Marsalek et al., 2006)

A profound comprehension of urban water flow within a spatial plan serves as the foundation for proposing the Water Sensitive Urban Design (WSUD) concept. WSUD embodies water management practices that are finely attuned to all water flows within the designated area (Kenway et al., 2011).

In light of these critical considerations, research endeavors were undertaken, culminating in the research titled "Research of the Carrying Capacity of Water Resources and Water Flow in the RDTR Section of the Integrated Regional Planning Area for Tegalluar Settlement, Bandung Regency." The research scope encompasses four sub-districts within Bandung Regency, specifically Bojongsoang, Cileunyi, Rancaekek, and Solokan Jeruk. The primary objective of this investigation is to assess the capacity of water resources and the patterns of water flow within the spatial utilization plans as delineated in the Regional Detailed Spatial Plan (RDTR).

The overarching aim of this research is to comprehensively map the dynamics of water input and output within the designated research area, guided by the spatial utilization plans outlined in the Regional Detailed Spatial Plan (RDTR). To further clarify the specific objectives that will drive the achievement of this aim, the following targets have been delineated:

1. The assessment of the water resource capacity concerning the spatial utilization plan outlined in its RDTR.
2. The identification of inputs and outputs of water resources, including water usage by all activities based on the plan.

The formulation of an evaluation of the water flow analysis in the Regional Detailed Spatial Plan (RDTR) document for the Planning Area of Tegalluar Integrated Settlement in Bandung Regency, serving as the foundation for the development of Water Sensitive Urban Design (WSUD) concepts at the research site.

Research Methodology

Water Carrying Capacity Measurement

The assessment of water carrying capacity hinges on a straightforward comparison between water availability (SA) and water demand (DA). When **SA surpasses DA**, the water carrying capacity is deemed to be in a surplus state. Conversely, when **SA falls short of DA**, the water carrying capacity is declared to be in a deficit or exceeded state as predetermined by the criteria within Minister of Environment Regulation, (2009).

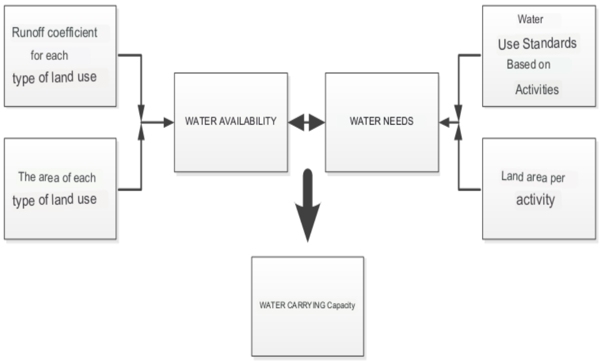

Figure 2. Water Carrying Capacity Determination

The water supply was measured using the following approach (Minister of Environment Regulation, 2009): (1)(2)(3).

$$SA = 10 \times C \times R \text{ v } A \quad (1)$$
$$C = \sum (ci \times Ai) / \sum Ai \quad (2)$$
$$R = \sum Ri / m \quad (3)$$

SA = Water availability (m^3/year)
C = Weighted runoff coefficient
Ci = Land use runoff coefficient for land use category i
Ai = Land use area for category i (hectares) from spatial utilization data on the RDTR map
R = Average annual rainfall for the region (mm/year) from the Central Statistics Agency (BPS), Meteorological Agency (BMG), or relevant local department data
Ri = Annual rainfall at station i
m = Number of rainfall observation stations
A = Area of the region (hectares)
10 = Conversion factor from mm. hectare to m^3

Table 1 Ci Coefficient (Minister of Environment Regulation, 2009)

Description	Ci
City, Asphalt Roads, Tiled Roofs	0.7 – 0.9
Industrial Area	0.5 – 0.9
Multi-Unit Residential, Commercial	0.6 – 0.7
Housing Complex	0.4 – 0.6
Villa	0.3 – 0.5
Park, Cemetery	0.1 – 0.3
a. Heavy Soil Yard a. > 7% b. 2 – 7% c. < 2%	 0.25 - 0.35 0.18 – 0.22 0.13 – 0.17
a. Light Soil Yard a. > 7% b. 2 – 7% c. < 2%	 0.15 - 0.2 0.10 – 0.15 0.05 – 0.10
Heavy Soil	0.40
Grassland	0.35
Agricultural Land	0.30
Production Forest	0.18

Method for calculating water requirement based on the Integrated Residential Area (KTP) Tegalluar Spatial Planning (RDTR) and Bojongsoang Planning Area (BWP)

Water requirements are typically categorized into two primary groups: domestic and non-domestic water requirement. Domestic needs encompass the use of water for various household purposes, including drinking, cooking, bathing, washing, and other everyday requirements. In contrast, non-domestic needs pertain to water usage for urban support activities and are influenced by the varying physical activities and habits of individuals.

The calculation of water requirement employs a target-oriented planning approach, relying on land area data outlined in the Regional Spatial Plan (RTRW). For the computation of domestic drinking water requirements, this is derived from the land use areas designated for high-density housing, medium-density housing, and low-density housing. In accordance with the Indonesian National Standards from 2004, which delineate procedures for planning housing environments in urban areas, the number of residents for each type of settlement is as follows:

– The population in high-density settlements: 201 - 400 people per hectare.
– The population in medium-density settlements: 151 - 200 people per hectare.
– The population in low-density settlements: < 150 people per hectare.

The water usage per person is 144 liters per person per day, which is the result of a survey conducted by the Directorate of Water Supply Development, Directorate General of Spatial Planning, Ministry of Public Works, in 2006.

To calculate non-domestic water requirements (Trade and Services, Industry and Warehousing, Health Facilities, Educational Facilities, Places of Worship, Sports Facilities, Government Offices, Artificial Tourism, Defense and Security), it is done by considering the land area allocation and using standards as presented in Table 2.

Table 2. Non-Domestic Water Requirement (*Petunjuk Teknis Perencanaan Rancangan Teknik Sistem Penyediaan Air Minum vol VI, 1998, Dept. PU*)

Sector	Value	Unit
Hospital	10	liters/student/day
Community		liters/bed/day
Health Center (Puskesmas)	200	
Mosque	2.000	liters/unit/day
Office	3.000	liters/unit/day
Market*)	100	liters/employee/day
Hotel	12.000	liters/hectare/day
Restaurant	150	liters/bed/day
Military Complex	100	liters/seat/day
Industrial Area	60	liters/person/day
Tourism Area	0.2 - 0.8	liters/second/hectare
Hospital	0.1 - 0.3	liters/second/hectare

Note: *) *Noerbambang, Sofyan M. 1986*

Water flow analysis in the area

The calculation of water inflow into the research area involves considering multiple factors. This includes a) quantifying the volume of precipitation within the research area (Development et al., n.d.), and b) assessing the combined inflow of surface water within the research area along with the supply of clean water sourced externally on an annual basis.

a. *Rain water volume per year = 10 × R × A* (Minister of Environment Regulation, 2009, modified)

- R = Average annual rainfall (mm/year) for the region from data provided by Statistics Indonesia and the Meteorological, Climatology, and Geophysics Agency, or relevant local authorities.
- $R = \sum Ri / m$
- Ri = Annual rainfall at station i, m = number of rainfall observation stations
- A : Area (Ha)
- 10 : Conversion factor from mm.ha to m^3

The volume of surface water inflow was measured based on secondary data of river water discharge entering/crossing the research area.

b. External water supply

Determining the external supply of drinking water to the research area is accomplished through a comprehensive review of the RDTR document, which provides insights into the infrastructure within the research area.

In the context of visualizing water flow, the author employs Sankey Diagrams. Sankey diagrams, traditionally employed for illustrating the flow of energy or materials in diverse networks and processes, serve to convey quantitative data regarding flows, relationships among energy or materials, and their conversions. A Sankey diagram constitutes a directional, weighted graph with a weight function that adheres to the principle of flow conservation: the total incoming weights for each node equal the outgoing weights. Typically, these diagrams are crafted manually or generated using specialized software (Riehmann et al., 2005).

Several researchers also used Sankey diagrams in analyzing the water flow in an area are (Curmi et al., 2013) , (Lehrman, 2018), (Ou et al., 2014), (Subramanyam et al., 2015) dan (Pronk et al., 2021).

Result and Discussion

Area Delineation

Tegalluar Integrated Residential Area holds a strategic designation according to Bandung Regency Regional Regulation Number 27 of 2016, which pertains to the Bandung Regency Regional Spatial Plan (RTRW) for the period spanning 2016 to 2036. The RDTR (Rencana Detail Tata Ruang) delineates Tegalluar Settlement Integrated Area, encompassing an approximate expanse of +/- 3,707.17 hectares. This area spans across four sub-districts and encompasses a total of 12 villages.

Development Plan/Spatial Plan

The detailed spatial layout plan for Tegalluar Settlement Integrated Area for the period of 2020 to 2039 delineates the land use plan, which serves as the tangible representation of the spatial arrangement within Tegalluar Settlement Integrated Area (KTPT). This land use plan includes the allocation of land for protected areas as well as cultivation areas, reflecting the intended land utilization pattern within the area as seen in Table 3.

Table 3. Spatial Plan for the Integrated Settlement Area of Tegalluar 2020 – 2039 (Bandung Regency Regulation, 2021 Regarding the Detailed Spatial Plan (RDTR) for Tegalluar Integrated Settlement Area)

No	Spatial Plan	Area (Ha)
1	Water Area	149.32
2	Road Area	273.36
3	Industrial Zoning	266.18
4	Cemetery	14.79
5	Trade and Services at BWP Scale	51.52
6	Trade and Services at City Scale	80.12
7	Trade and Services at Sub-BWP Scale	175.17
8	Warehousing	382.72
9	Office Space	45.75
10	Housing & Trade and Services	63.31
11	Housing & Office Space	2.40
12	Housing, Trade and Services, & Office Space	19.73
13	Non-Green Open Space	4.59
14	Low-Density Housing	667.16
15	Medium-Density Housing	766.05
16	High-Density Housing	114.31
17	Lake and Reservoir Buffer	56.46
18	River Buffer	44.12
19	Village-Scale Spatial Plan	4.73
20	City-Scale Spatial Plan	24.22
21	Village Park	10.40
22	City Park	367.55
23	Crop Cultivation	106.78
24	Transportation	0.26
25	Buffer Zone	33.60
	Total	3,724.61

The measurement of water carrying capacity

The status of water carrying capacity is determined as follows: it is declared as surplus when the availability of water (Sa) exceeds the demand for water (Da). Conversely, if the availability of water (Sa) falls short of the demand for water (Da), then the carrying capacity status is declared as a deficit.

a. Water supply measurement

Water availability was measured using equation 1, 2 and 3.

a.1 Measurement of Rainfall Volume

The rainfall volume was measured based on the average rainfall per year observed in the nearest observation station.

Table 4 The Rainfall Volume of Tegalluar Observed at Sapan Station

Month	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
January	0.0	283.0	180.0	111.0	273.0	47.0	51.0	55.0	370.0	125.0
February	0.0	404.0	95.0	169.0	365.0	74.0	132.0	190.0	438.0	111.0
March	0.0	170.0	460.0	233.0	334.0	135.0	123.0	111.0	209.0	233.0
April	0.0	269.0	259.0	228.0	184.0	0.0	53.5	107.0	202.0	97.0
May	48.0	190.0	123.0	97.0	182.0	0.0	60.0	120.0	102.0	98.0
June	68.0	90.0	127.0	6.0	166.0	0.0	0.0	0.0	39.0	166.0
July	0.0	110.0	0.0	1.0	175.0	2.0	1.0	0.0	2.0	8.0
August	46.0	6.0	0.0	0.0	36.0	74.0	37.0	0.0	9.0	3.0
September	83.0	10.0	5.0	3.0	150.0	0.0	0.0	0.0	2.0	66.0
October	162.0	160.0	51.0	62.0	173.0	97.0	68.0	39.0	217.0	208.0
November	215.0	147.0	264.0	319.0	159.0	342.5	230.0	143.0	74.0	288.0
December	458.0	440.0	550.0	339.0	88.0	90.0	151.5	213.0	62.0	215.0
Rainfall Volume	**1,080.0**	**2,279.0**	**2.,114.0**	**1.,568.0**	**2,285.0**	**861.5**	**907.0**	**978.0**	**1,726.0**	**1,618.0**

The average rainfall volume for 2012-2022 at the site is 1.541 mm.

Table 5 The Rainfall Volume of Tegalluar Observed at Rancaekek Station

Month	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
January	236	146	190	237	140	117	0	165	304	194
February	219	252	48	294	360	177	0	416	413	89
March	148	525	477	174	468	467	0	363	364	446
April	196	337	350	205	183	262	0	321	341	6
May	83	191	14	43	153	111	0	40	148	104
June	92	99	173	6	85	0	0	0	30	106
July	0	79	72	0	125	4	0	0	2	17
August	0	4	6	0	82	0	0	0	4	11
September	37	0	0	0	170	18	0	0	10	23
October	140	52	33	24	533	196	0	16	217	104
November	123	143	273	238	351	497	0	154	175	349
December	582	474	425	197	138	228	241	219	207	358
Rainfall Volume	**1,856**	**2,302**	**2,061**	**1,418**	**2,788**	**2,077**	**241**	**1,694**	**2,215**	**1,807**

The average rainfall recorded at the Rancaekek observation station within the research area from 2012 to 2021 was 1,846 mm. Consequently, the overall average rainfall for the entire research area is calculated as (1,541 + 1,846) / 2, resulting in an average of 1,693 mm.

a.2 Calculating the weighted runoff coefficient.

Table 6. Calculation of Weighted C

No	Spatial Planning	Area (Ai) (Ha)	C Coefficient	Ai x Ci
1	Water Area	149,32	0.001	0.15
2	Road Area	273,36	0.8	218,69
3	Industrial Zoning	266,18	0.7	186,33
4	Cemetery	14,79	0.2	2,96
5	Trade and Services at BWP Scale	51,52	0.6	30.91
6	Trade and Services at City Scale	80.12	0.7	56,08
7	Trade and Services at Sub-BWP Scale	175,17	0.6	105,10
8	Warehousing	382,72	0.7	267,90
9	Office Space	45,75	0.7	32,03
10	Housing & Trade and Services	63,31	0.6	37,99
11	Housing & Office Space	2,40	0.6	1,44
12	Housing, Trade and Services, & Office Space	19,73	0.6	11,84
13	Non-Green Open Space	4,59	0.2	0.92
14	Low-Density Housing	667,16	0.4	266,86
15	Medium-Density Housing	766,05	0.5	383,03
16	High-Density Housing	114,31	0.6	68,58
17	Lake and Reservoir Buffer	56,46	0.2	11,29
18	River Buffer	44,12	0.2	8,82
19	Village-Scale Spatial Plan	4,73	0.5	2,36
20	City-Scale Spatial Plan	24,22	0.5	12,11
21	Village Park	10.40	0.2	2,08
22	City Park	367,55	0.2	73,51
23	Crop Cultivation	106,78	0.3	32,03
24	Transportation	0.26	0.8	0.20
25	Buffer Zone	33,60	0.3	10.08
	TOTAL	**3.724,61**		**1.823,30**

The weighted C coefficient :

$$C = \sum (ci \times Ai) / \sum Ai$$
$$= 1.823,30/3.724,61 = 0.49$$

a.3 Water availability

$$SA = 10 \times C \times R \times A$$
$$= 10 \times 0.49 \times 1.693 \times 3.724,61$$
$$= 30.894.016 \text{ m}^3\text{/year}$$

b. *Calculation of water requirement in the research area based on the Plan*

1. *Domestic water requirement*

In the Spatial Plan for the Integrated Tegalluar Settlement Area (RDTR Kawasan Terpadu Permukiman Tegalluar), land has been designated for residential purposes, with a high-density residential area covering 77 hectares, a medium-density residential area covering 760 hectares, and a low-density residential area covering 655.51 hectares. The population in each type of residential area is as follows:

- Population in high-density settlements: 201 – 400 people per hectare
- Population in medium-density settlements: 151 – 200 people per hectare
- Population in low-density settlements: < 150 people per hectare (Standar Nasional Indonesia, 2004)

The water consumption per person is 144 liters per person per day, as determined by a 2006 survey conducted by the Directorate of Drinking Water Development, Directorate General of Cipta Karya, Department of Public Works. As a result, the estimated utilization of surface water in the area is calculated based on the population.

- High-density housing: Area of 77 hectares, population = 77 × 400 = 30,812 people
- Medium-density housing: Area of 760.19 hectares, population = 760.19 × 200 = 152,038 people
- Low-density housing: Area of 655.51 hectares, population = 655.51 x 100 = 65,500 people
- Total population = 248,350 people

Assuming that each type of housing needs the same water, namely 144 liters/person/day, the total water demand for housing in Tegalluar Integrated Residential Area is:

Assuming that every type of housing has the same water requirement, which is 144 liters per person per day, the total water requirement for housing in Tegalluar Integrated Residential Area is as follows:

248,350 people × 144 liters/person/day

= 35,762,400 liters/day = 13,053,276 m^3/year.

2. Water requirements in other areas:
Using the water requirement standard, the non-domestic water requirement can be calculated as follows:

a. Trade and Services Area: The standard water usage is 12,000 liters per hectare per day. With a planned area of 305.21 hectares, the total water usage is 306.81 × 12,000 liters, equaling 3,681,720 liters per day. Assuming there are 300 working days in a year, the annual requirement totals 1,104,516 m^3.
b. Industrial use areas: The standard water usage is 0.5 liters per second per hectare. With a planned area of 266.18 hectares, the water usage is 266.18 hectares × 0.5 liters per second per hectare, which amounts to 133 liters per second or 4,162,752 m^3 per year.
c. Office area: The standard water usage is 100 liters per person per day. The effective area, accounting for 80% of 45.75 hectares, is 36.6 hectares. The standard space requirement per worker is 10 square meters, and the number of employees is calculated as the effective area divided by the standard space requirement per worker, resulting in 36,600 workers. Therefore, the water requirement is 36,600 × 100, totaling 3,660,000 liters per day. Assuming there are 260 working days in a year, the annual water requirement is 951,600 m^3.
d. For mixed-use areas (comprising residential, trade and services, housing, and offices), standards are applied based on high-density settlements using a population approach. The total area of medium-density housing use is 63.31 hectares + 2.4 hectares + 19.73 hectares, totaling 85.44 hectares. With an estimated population of 85.44 × 200, which equals 17,088 people, and a water requirement of 144 liters per person per day, the daily water requirement is 2,460,672 liters, equivalent to 898,145 m^3 per year.
e. SPU (public infrastructure), such as schools, government offices, hospitals, places of worship, and others, follows the water requirement standard for office areas. The total SPU area is 4.73 hectares + 24.22 hectares, totaling 28.95 hectares. The water requirement for SPU is calculated as follows: the standard water use is 100 liters per person per day. The effective area, considering 80% of 28.95 hectares, is 23.16 hectares. With a standard space requirement of 10 square meters per person and a number of people calculated as the effective area divided by the standard space requirement per worker (231,600/10), the water requirement is 23,160 × 100, resulting in 2,316,000 liters per day. Assuming 260 working days in a year, the annual water requirement is 602,160 m^3.
f. Water requirement for rice field farming: According to SNI 19-6728.1-2002, the water requirement for paddy fields is 1 liter per second per hectare. With a planned rice field area of 106.78 hectares, the water requirement is 106.78 liters per second or 3,374,352 m^3 per year.

g. Water requirement for green open space (RTH): According to Widarto (1996) in Bahri (2018), the water requirement for plants with an area of 20 square meters is 40 liters per day. The planned green open space area is 378 hectares, equivalent to 3,780,000 square meters. Therefore, the daily water requirement is 7,560,000 liters or 2,759,400 m^3 per year. The total water demand for Tegalluar Integrated Residential Area is calculated as follows:

Total water requirement = 13,053,276 + 1,104,516 + 4,162,752 + 951,600 + 898,145 + 602,160 + 3,374,352 + 2,759,400 = 26,905,201 m^3 per year.

The status of water carrying capacity is determined by comparing water availability (SA) to water demand (DA). In this case, water availability (SA) is calculated as 32,267,041 m^3/year, and water demand (DA) is 26,905,201 m^3 per year. Since SA is greater than DA (SA > DA), the carrying capacity of water is declared as a surplus.

Inflow Water Analysis

A. Water Inflow/Water resources

In the research area, three types of water sources contribute to the water supply: rainfall (precipitation), surface water, and other clean water originating from outside the area (Li & Yu, 2010).

1. Rainfall

The quantity of rainwater that falls in the research area is determined by using average rainfall data obtained from the nearest rain observation stations, specifically the Rancaekek rain observation station and the Sapan rain observation station. This data is then multiplied by the total area of the research area. According to the calculations provided in Tables 4 and 5, the average annual amount of rainwater in the research area is 1,693 millimeters (mm).

The amount of rainfall in the research area in year t was calculated as follow:

= Average annual rainfall (mm) x area of the region

= 1.693 mm × 3.700 Ha. = 62.641.000 m^3

2. Surface Water

In the research area, there are two rivers that traverse it: the Cikeruh River and the Citarik River. Both of these rivers fall within the jurisdiction of the Citarum River Basin Center (BBWS). Water monitoring stations have been established along these two rivers to regularly measure their discharge rates. The annual data recorded at these river monitoring stations is as follows:

1. Sungai Cikeruh has a flow rate of 0.42 m^3 per second.
2. Sungai Citarik has a flow rate of 0.778 m^3 per second.

3. External Piped Drinking Water

According to the RDTR for Tegalluar Integrated Settlement Area, the clean water supply plan will encompass two systems: a piped network system and a non-piped network system. The piped network system will source water from the Ciparay IPA in Ciparay District, which is located outside Tegalluar integrated residential area. In contrast, the non-piped network system will not rely on pipelines but instead may involve the use of shallow wells or other methods for water supply.

The piped water system will provide water to industrial areas, trade and service areas, office spaces, mixed-use areas, and residential areas that are within the same block as those zones. On the other hand, the non-piped water system is designed for residential areas that are situated in blocks outside of the aforementioned zones.

The measurement of external piped drinking water was conducted as follows.

- *Drinking water for residential areas*

According to the spatial pattern plan, the types of housing located within the same block as industrial areas, trade and service areas, office areas, and other mixed-use areas consist of medium-density housing and high-density housing.

In the RDTR (Spatial Plan) for the Integrated Settlement Area of Tegalluar, a total of 77 hectares of land has been designated for high-density settlements, 760 hectares for medium-density settlements, and 655.51 hectares for low-density settlements, forming the basis for the area's residential planning and development.

The population in each type of settlement is as follows:

- The population in high-density settlements: 201 - 400 people per hectare.
- The population in medium-density settlements: 151 - 200 people per hectare
- The population in low-density settlements: < 150 people per hectare (Standar Nasional Indonesia, 2004)

The water usage per person is established at 144 liters per person per day, and this figure is the outcome of a survey conducted by the Directorate of Drinking Water Development, Directorate General of Human Settlements, Department of Public Works in the year 2006.

- The population in high-density settlements with an area of 77 hectares is 77 x 400 = 30,812 people.
- The population in medium-density settlements with an area of 760.19 hectares is 760.19 x 200 = 152,038 people.
- The population in low-density settlements with an area of 655.51 hectares is 655.51 x 100 = 65,500 people.
- Total population = 248,350 people.

Residents who have access to piped water supply include those residing in medium-density settlements and high-density settlements with a combined population of 182,850 (30.812 + 152,038). With a standard water usage rate of 144 liters per person per day, the daily water requirement for this population is 26,330.400 liters, which is equivalent to 9,610.596 m^3 per year.

- *Drinking water requirement of other area*

Other areas that receive the piped drinking water from external resources include:

a. Trade and service areas: The standard water usage is 12,000 liters per hectare per day. With a planned area of 305.21 hectares, the water usage amounts to 306.81 x 12,000 liters, totaling 3,681,720 liters per day. Assuming 300 working days in a year, the annual requirement is 1,104,516 m^3.

b. Industrial designation area: The standard water consumption is 0.5 liters per second per hectare. With a planned area of 266.18 hectares, the water usage is 266.18 hectares x 0.5 liters per second per hectare, equaling 133 liters per second or 4,162,752 m^3 per year.

c. Office area: The standard water use is 100 liters per person per day. The effective area, which accounts for 80% of 45.75 hectares, is 36.6 hectares. The standard space requirement per worker is 10 square meters, and the number of employees is calculated as the effective area divided by the standard space requirement per worker, resulting in 36,600 workers. Therefore, the water requirement is 36,600 x 100, amounting to 3,660,000 liters per day. Assuming there are 260 working days in a year, the annual water requirement is 951,600 m^3.

d. Mixed-use areas (residential and trade and services, housing and offices, housing, trade and services, and offices) are determined using standards for high-density settlements, primarily through a population-based approach. The total area of medium-density housing allocation, as mentioned earlier, includes 63.31 hectares + 2.4 hectares + 19.73 hectares, totaling 85.44 hectares. Thus, the estimated population is 85.44 x 200, resulting in 17,088 people. With a per-person need of 144 liters per day, the daily water requirement is 2,460.672 liters, equivalent to 898,145 m^3 per year.

e. Public facilities, such as schools, government offices, hospitals, places of worship, and others, follow the water requirement standard for office areas. The total SPU area is 4.73 hectares + 24.22 hectares, totaling 28.95 hectares. The water requirement for SPU is calculated as follows: the standard water use is 100 liters per person per day. The effective area, considering 80% of 28.95 hectares, is 23.16 hectares. With a standard space requirement of 10 square meters per person and the number of people calculated as the effective area divided by the standard space requirement per worker (231,600/10), the water requirement is 23,160 x 100, resulting in 2,316,000 liters per day. Assuming 260 working days in a year, the annual water requirement is 602,160 m^3.

Based on the performance audit data from Perumda Tirta Raharja in Bandung Regency, the distribution system water loss rate is reported as 27.2%. Therefore, the amount of water that needs to be supplied from the Ciparay IPA to the research area should be equal to the total demand of the piped network plus 27% of that total demand.

The total piped water requirements, considering the populations you've mentioned earlier, are calculated as follows:

Total piped water requirements = (9,610.596 + 1,104,516 + 4,162,752 + 951,600 + 898,145 + 602,160) = 17,329,769 m^3/year.

Now, taking into account the 27.2% distribution system water loss, the total piped water supplied to the research area is:

Total piped water supplied = 1.272 x 17,329,769 m^3/year = 22,043,466 m^3/year. As a result, the total water entering the research area, based on the RDTR, is the sum of various sources, and it amounts to:

Total water entering the research area = 62,641,000 + 37,780.128 + 22,043,466 = 122,464,594 m^3/year.

B. Water usage in the research area

By using the standard water requirement, the water demand in the research area can be calculated as follows.

The water requirement in the research area was determined based on the water requirement standards as follows.

a. Residential Areas in the research area have a standard water usage of 144 liters per person per day, with a planned population of 248,350. The total requirement is 13,053,276 m^3 per year.

b. Trade and Services Zone: The standard water usage is 12,000 liters per hectare per day. With a planned area of 305.21 hectares, the daily water usage is 306.81 x 12,000 liters, resulting in an annual requirement of 1,104,516 m^3.

c. Industrial designation area: The standard water consumption is 0.5 liters per second per hectare. With a planned area of 266.18 hectares, the annual water usage is 266.18 hectares x 0.5 liters/second/hectare, equaling 4,162,752 m^3.

d. Office area: The standard water use is 100 liters per person per day. The effective area, covering 80% of 45.75 hectares, is 36.6 hectares. With a standard space requirement of 10 square meters per worker, and considering there are 366,000/10 = 36,600 workers, the daily water requirement is 3,660,000 liters. If there are 260 working days in a year, the annual water requirement is 951,600 m^3.

e. Mixed-use areas (residential and trade and services, housing and offices, housing, trade and services, and offices) are designated according to standards for high-density settlements, employing a population-based approach. The total area of medium-density housing allocation, as previously mentioned (63.31 hectares + 2.4 hectares + 19.73 hectares), amounts to 85.44 hectares. The estimated population is 85.44 x 200, resulting in 17,088 people. With a per-person water requirement of 144 liters per day, the annual water requirement is 898,145 m^3.

f. Public facilities, such as schools, government offices, hospitals, places of worship, and others, follows the water requirement standard for office areas. The total SPU area is 28.95 hectares (4.73 hectares + 24.22 hectares). The water requirement for SPU is calculated as follows: the standard water use is 100 liters per person per day. The effective area, covering 80% of 28.95 hectares, is 23.16 hectares. With a standard space requirement of 10 square meters per person and a population of 23,160 people (Effective area / Standard space requirements per worker = 231,600/10), the daily water requirement is 2,316,000 liters. Assuming 260 working days in a year, the annual water requirement is 602,160 m^3.
g. Agricultural Land Water Requirements: The agricultural land in Tegalluar integrated area consists of rice fields. According to SNI 19-6728.1, 2002, the water requirement for rice fields is 1 liter per second per hectare. With a planned rice field area of 106.78 hectares, the annual water requirement is 3,374,352 m^3.
h. Water requirement for green open space (RTH): According to Widarto (1996) in Bahri (2018), the water requirement for plants with an area of 20 square meters is 40 liters per day. The planned open space area is 378 hectares, which is equal to 3,780,000 square meters. Therefore, the daily water requirement is 7,560,000 liters or 2,759,400 m^3 per year.

Total water requirement: 13.053.276 + 1.104.516 + 4.162.752 + 951.600 + 898.145 + 602.160 + 3.374.352 + 2.759.400 = 26.905.201 m^3 per year

C. Returning water

1. Wastewater

Up to 30% of water infiltrating the ground originates from various sources, including domestic wastewater, trade and service activities, offices, and mixed areas. Specifically, domestic wastewater accounts for 80% of the water used by these activities, calculated as 80% of the sum of their water consumption: (80% x (13,053,276 + 1,104,516 + 951,600 + 898,145 + 602,160)), which equals 16,609,697 m^3 per year. Consequently, the volume of black water entering the soil annually amounts to 30% of this total, equivalent to 4,982,909 m^3 per year.

The wastewater flowing into surface water bodies, such as rivers, comprises several sources, including domestic gray water waste, wastewater from trade and service activities, offices, education, health, and other community activities, which collectively amount to 70% of the total domestic wastewater: (70% x 16,609,697 m3/year) = 11,626,788 m3/year. Additionally, industrial wastewater contributes to this flow, accounting for 80% of 4,162,752 m3/year, which equals 3,330.201 m3/year. Therefore, the cumulative volume of wastewater entering surface water annually is 14,956,989 m3/year.

2. Evaporation

Within the research area of 3,700 hectares or 37,000.000 hectares, the amount of evaporation is 176,924,000 liters/year = 164,095 m^3/year. (1 mm = 1 liter)

3. Rainwater absorbed into the soil

Based on the calculations, the weighted runoff coefficient is 0.6, which is determined as follows: $10 \times 0.6 \times 1{,}693 \times 3{,}700 = 37{,}584{,}600$ m^3.

The amount of water seeping into the ground is calculated by subtracting the amount of rainfall, the amount of water flowing as runoff, and the amount lost to evaporation from the total precipitation. Thus, it is 62,641,000 - 37,584,600 - 164,095 = 24,892,305 m3/year.

For a visual representation of the water flow in Tegalluar integrated residential area based on the Regional Detailed Spatial Plan (RDTR), please refer to the accompanying image.

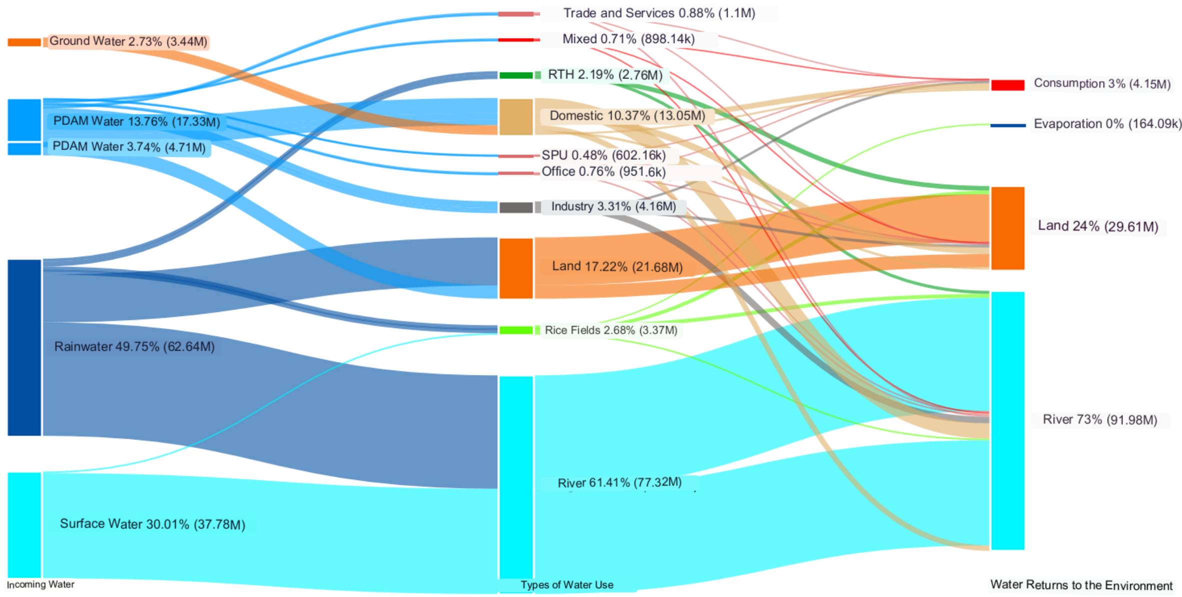

Figure 3. Sankey Diagram of Water Flow based on Regional Detail Spatial Plan

Based on the Sankey Diagram provided, the water sources entering Tegalluar Integrated Settlement Area, as per the RDTR guidance, encompass three main sources. Firstly, *PDAM/*Tap Water (13.76%) is allocated for fulfilling various urban needs, serving both domestic and non-domestic purposes. Secondly, Rainwater (49.75%) constitutes a significant portion of the incoming water. It is distributed as follows: a portion is utilized to maintain green open spaces (specific percentage not specified), and another portion is directed toward irrigating rice fields (specific percentage not specified). Lastly, Surface Water (30.01%) flows into rivers (Pusdiklat SDA, 2017), as indicated by the Pusdiklat SDA in 2017. Additionally, a smaller portion of Groundwater (2.73%) is allocated for specific domestic activities. Overall, of all the incoming water, 3% is consumed and wasted as wastewater, 0% evaporates, and 24% seeps into the ground, while the majority, 73%, is returned to the rivers.

The analysis results reveal that the water flow, as directed by the RDTR for Tegalluar Integrated Settlement Area, aligns better with its intended purpose. Urban water requirements are now met primarily through the use of PDAM water, eliminating the reliance on groundwater, as was the case previously. Furthermore, a larger proportion of water is returned to the environment, with 73% flowing back into rivers and 24% seeping into the land. However, it's evident that the RDTR still heavily depends on external water sources (Bartlett et al., 2017). This suggests that the RDTR lacks a closed-loop water management approach and does not fully utilize excess rainwater and wastewater as potential water sources.

Conclusions

Based on the calculations, it is evident that the water resources in the research area still have a surplus in terms of their carrying capacity. The primary water inputs into this area consist of rainwater and surface water, with a relatively small contribution from piped water sources. Currently, groundwater serves as the primary water source for various activities in the research area, except for agricultural practices, which rely on rainwater and surface water. Moreover, a significant portion of the wastewater generated by activities within the research area is discharged into surface water flows, while the remainder infiltrates the ground.

In Tegalluar KTP Detailed Spatial Plan, there has been a notable shift in the water flow pattern. Previously, water use was predominantly reliant on groundwater within the research area. However, the new plan has introduced a significant change by emphasizing the use of piped water sourced from outside the research area. Despite this shift, rainwater and surface water remain crucial sources for agricultural activities and maintaining green open spaces. Additionally, there has been a change in the wastewater flow, with a shift away from greater infiltration into the ground toward more discharge into surface water bodies.

It can be drawn to the conclusion that the current water flow is linear. However, there is potential to make the water flow circular by utilizing unused rainwater flow through water harvesting efforts and utilizing wastewater through water reuse efforts (Loucks, 2017*;* Makropoulos et al., 2012).

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References

Bahri, A. (2018). *Teknologi bercocok tanam di lahan sempit di Kecamatan Tempe Kabupaten Wajo*. 605–608.

Bartlett, T., Planning, D., & Unit, P. (2017). *Urban metabolism in practice*. *186*.

Curmi, E., Fenner, R., Richards, K., Allwood, J. M., Bajželj, B., & Kopec, G. M. (2013). Visualising a Stochastic Model of Californian Water Resources Using Sankey Diagrams. *Water Resources Management*, *27*(8), 3035–3050. https://doi.org/10.1007/s11269-013-0331-2

Development, L. I., Barrels, R., & Gardens, R. (n.d.). *Rainfall as a Resource*.

Jørgensen, C., Larsen, J., & Schrøder, O. (2013). *Rethinking urban water for new value in cities*.

Kaloeti, P. P., & Dewi, S. P. (2020). Analisis Faktor Konfirmatori Konsep Water Sensitive City pada Kawasan Permukiman Di Kecamatan Banyumanik. *Jurnal Permukiman*, *15*(2), 84. https://doi.org/10.31815/jp.2020.15.84-94

Kenway, S., Gregory, A., & Mcmahon, J. (2011). *Urban Water Mass Balance Analysis*. *15*(5). https://doi.org/10.1111/j.1530-9290.2011.00357.x

Lehrman, B. (2018). Visualizing water infrastructure with sankey maps: A case research of mapping the los angeles aqueduct, California. *Journal of Maps*, *14*(1), 52–64. https://doi.org/10.1080/17445647.2018.1473815

Li, S., & Yu, W. (2010). *Urban Water Balance Analysis by Holistic Approach*. 1284–1289.

Loucks, D. P. E. van B. (2017). *Water Resource Systems Planning and Management*, *An Introduction to Methods, Models, and Applications*.

MAKROPOULOS, C., ROZOS, E., BRUASET, S., FRIJNS, J., & MARIËLLE VAN DER ZOUWEN. (2012). *Best practices for Sustainable Urban Water Cycle Systems AN OVERVIEW OF AND ENABLING AND CONSTRAINING FACTORS FOR A TRANSITION TO SUSTAINABLE UWCSs*.

Marsalek, J., Jiménez-Cisneros, B., Karamouz, M., Malmquist, P. A., Goldenfum, J., & Chocat, B. (2006). Urban water cycle processes and interactions: Urban water series. *Urban Water Cycle Processes and Interactions: Urban Water Series - UNESCO-IHP*, *78*, 1–131.

Ou, X., Zhang, X., Xing, Y., Zhang, Q., & Zhang, X. (2014). China's energy-water nexus in 2009 by Sankey diagram. *Chemical Engineering Transactions*, *42*(2010), 31–36. https://doi.org/10.3303/CET1442006

Peraturan Bupati Bandung. (2021). *Peraturan Bupati Nomor 24 Tahun 2021 Tentang RDTR Kawasan Terpadu Permukiman Tegalluar* (Nomor 6, hal. 6). JDIH Kabupaten Bandung.

Minister of Environment Regulation. (2009). Peraturan Menteri LH No. 17 Tahun 2009 Tentang Pedoman penentuan daya dukung lingkungan hidup dalam penataan ruang wilayah. *Pedoman Tata Cara Pengukuran Kriteria Baku Kerusakan Tanah Untuk Produksi Biomassa*, 1–34.

Presiden Republik Indonesia. (2020). Undang Undang Republik Indonesia Nomor 11 Tahun 2020 Tentang Cipta Kerja. *Peraturan.Bpk.Go.Id*, *052692*, 1–1187. https://peraturan.bpk.go.id/Home/Details/149750/uu-no-11-tahun-2020

Pronk, G. J., Stofberg, S. F., Van Dooren, T. C. G. W., Dingemans, M. M. L., Frijns, J., Koeman-Stein, N. E., Smeets, P. W. M. H., & Bartholomeus, R. P. (2021). Increasing Water System Robustness in the Netherlands: Potential of Cross-Sectoral Water Reuse. *Water Resources Management*, *35*(11), 3721–3735. https://doi.org/10.1007/s11269-021-02912-5

Pusdiklat SDA. (2017). *Modul hidrologi dan hidrolika sungai pelatihan pengendalian banjir 2017*.

Renouf, M., Sochacka, B., Kenway, S., Lam, K. L., Serrao-, S., Morgan, E., & Choy, D. L. (2017). *Urban metabolism for planning water sensitive city-regions Proof of concept for an urban water metabolism*. 1–55.

Riehmann, P., Hanfler, M., & Froehlich, B. (2005). Interactive sankey diagrams. *Proceedings - IEEE Symposium on Information Visualization, INFO VIS*, *May*, 233–240. https://doi.org/10.1109/INFVIS.2005.1532152

Santoso, E. B., & Therik, L. V. (2016). Faktor Penentu Bertempat Tinggal Pada Kawasan Kumuh Di Kota Malang Berdasarkan Teori Doxiadis. *Tataloka*, *18*(4), 261. https://doi.org/10.14710/tataloka.18.4.261-273

SNI 19-6728.1. (2002). Standar Nasional Indonesia No. 19-6728.1-2002 Penyusunan Neraca Source Daya - Bagian 1: Source Daya Air Spasial. *Badan Standardisasi Nasional (BSN), ICS 13.060.* 10.

Standar Nasional Indonesia. (2004). SNI 03-1733-2004 Tata Cara Perencanaan Lingkungan Perumahan di Perkotaan. *Badan Standardisasi Nasional*, 1–58.

Subramanyam, V., Paramshivan, D., Kumar, A., & Mondal, M. A. H. (2015). Using Sankey diagrams to map energy flow from primary fuel to end use. *Energy Conversion and Management*, *91*, 342–352. https://doi.org/10.1016/j.enconman.2014.12.024

Wong, T. H. F. (2006). Water sensitive urban design - the journey thus far. *Australasian Journal of Water Resources*, *10*(3), 213–222. https://doi.org/10.1080/13241583.2006.11465296