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# WATER BALANCE ANALYSIS AND ZERO ARTIFICIAL RUN-OFF (ZARo) CONCEPT IN METROPOLITAN BANDUNG AREA, WEST JAVA PROVINCE

*Imam Priyono[1,2], Deny Juanda Puradimaja[3], Budi Sulistijo[4], Muhammad Syahril Badri Kusuma[5]

[1]Doctoral Program, Bandung Institute of Technology, Indonesia
[2] Department of Geological Engineering, Pertamina University, Indonesia
[3] Department of Geological Engineering, Bandung Institute of Technology, Indonesia
[4] Department of Mining Engineering, Bandung Institute of Technology, Indonesia
[5] Department of Civil Engineering, Bandung Institute of Technology, Indonesia

*Corresponding Author, Received: 22 March 2022, Revised: 25 April 2022, Accepted: 28 May 2022

**ABSTRACT:** The development of Bandung City which will become Bandung Metropolitan City must receive attention from the hydrogeological and spatial planning aspects. Understanding hydrogeological conditions in the regional spatial planning concept are necessary. Hydrogeological conditions can be used as a reference in the development of surface areas. Based on historical flood data in the Bandung basin from 1986 to 2014, several areas that are frequently affected by floods each year do not show significant reductions in flood discharge. Metropolitan Bandung Area has contained seven Sub watersheds and the development area is Sub DAS Cikapundung which has an area of 464.806.445 $m^2$ and the highest Run Off 1.351.904.665 $m^3$. Water balance analysis was conducted from eight Meteorological stations from the year 2008 – to 2019 and resulted average get the Direct Run-Off (DRO) of 250 mm/month a and Base Flow (BF) of 100 mm/month. From the land use map, it can be described that 89% of the area of Metropolitan Bandung Raya already become urban area and only 11% area remains undeveloped area. The application of the Zero Artificial Run-off (Zaro) concept is expected to reduce flood discharge and be able to infiltrate into the aquifer as water reserves during the dry season. From the amount of infiltration well from seven Sub DAS in Metropolitan Bandung Raya, it needs 4000 infiltrations well to infiltrate 3.826.349.498 $m^3$ runoff volume. The concept of Zero Artificial Run-off is expected to control and reduce flooding in the Metropolitan Area of Bandung. The Zero Artificial Run-Off (ZARo) concept can reduce almost 40% runoff to reduce floods in Metropolitan Bandung Area.

*Keywords: Water balance, Zero artificial run-offs, Hydrogeology, Spatial planning, Flood reduction*

## 1. INTRODUCTION

### 1.1 The Objective and Background

In the last 20 years, the City of Bandung has been developed to become a metropolitan city where the area is expanded so that it will also cover a part of the natural floodplain of the Bandung Basin [1-5]. However, this city is also well known not only as flood vulnerable but also for water scarcity [1], [3], [6], [7]. During the rainy season, Bandung Basin suffered from the flood hazard generated by the 13 tributaries of the Upstream Citarum River, where Cikapundung is one of them [1], [3], [6], [7], [8], [9], [10]. Several measures of structural flood solution like river normalization, river cut-off, river dredging, and reservoir development are applied to control the peak of flood discharge of Citarum River [1-5]. These measures could decrease direct river runoff with significant result in reducing the flood risk but could not increase the resiliency of Bandung City from water scarcity [1-3].

In the last two decades, Cikapundung Rive became one of the most developed catchment areas among the 13 tributaries river of the Upstream Citarum River where increasing peak direct runoff and decreasing base flow are indicated [1], [2], [3], [6], [8]. This phenomenon is a common problem of the Indonesian river where devastated-use use change is observed [1], [3], [6], [11], and reservoir as one of the rain harvesting infrastructures is proposed as a favorite solution [9], [10]. Nowadays, reservoir development became more difficult due the to increased risk of dam bread breaking socio-environmental issues [1], [3], [12], [13], [14].

Therefore, future rain harvesting infrastructures should address not also surface water storage but also groundwater as well. The combination of surface and groundwater storage capacity is a potential choice from the aspect of green water management. This combination rain harvesting system use is more favorable to develop in Indonesia as it has many advantages compared to a large reservoir. Its development is less socio complex, has fewer sedimentation influences es, has lower risk, and more matched to climate change adaption compared to a large reservoir [9], [10], [14], [15]. However, it still requires a more in-depth and comprehensive study to find out the feasibility of its application in Indonesia [1], [2], [3], [10]. In this case, more analytical tools such as the rainfall-runoff model is required to predict the runoff and infiltration as there is not enough subsurface data in the study area [8], [16]. A good understanding of hydrogeological conditions in the area is compulsory to define the capacity of groundwater storage that can be used as rain harvesting infrastructure.

Most of previous study on rain harvesting in Indonesia focused on discussing the surface water storage capacity so this study will also study the groundwater storage capacity. This paper discusses the conceptual model applicability of the Zero Artificial Run-off method based on water balance analysis to develop a hybrid rain harvesting system.

The application of the Zero Artificial Run-Off (ZARO) concept is a measure to optimize the groundwater storage capacity in receiving the surface runoff infiltration for reducing peak discharge during the rainy season and increasing water supply during the dry season. Two types of ZARO systems, individual and communal system implementation, are then deployed based on the Recharging Capacity of the Groundwater Catchment Area (RCGCA). The characteristic of RCGCA is described based on the Water balance and geological surface condition of that area. Based on the ZARO implementation it is found that the flood peak of Cikapundung could be reduced by as much as 44 % and the water supply capacity could be increased by as much as 30 %. However more detailed data of not only groundwater level and its geological characteristic, but also masterplan development of the study area are needed for further research shortly.

The population of Bandung City is almost 2,5 Million people [17] (Fig. 1). With this high population, there will be a lot of problems in Bandung City, especially regarding water consumption and land use. Population growth will increase residential buildings, social facilities, and settlement [18]. These development cause land to become watertight which has an impact on the increased surface flow [19]. Urban population growth is hand in hand with urban runoff pollute damage to the environment. Urban runoff pollution is caused when the runoff crossed the urban environment and t, acquires contaminants that affect water quality [20]. The human being lives in a certain area to meet their needs. To meet their needs, human beings have utilized the land, causing disturbance to the stability and equilibrium of the environment [20]. Change in land cover has an impact on the hydrological unit on the hydrological cycle and water quality [21]. They can cause floods, droughts, and changes in the rivers and groundwater regime that affect water quality [22]. Hydrological units where water flows, downhill result increase in water runoff. The dynamics of runoff can be predicted by forecasting and simulating future land use [23]. The runoff also correlates with the water table condition [24].

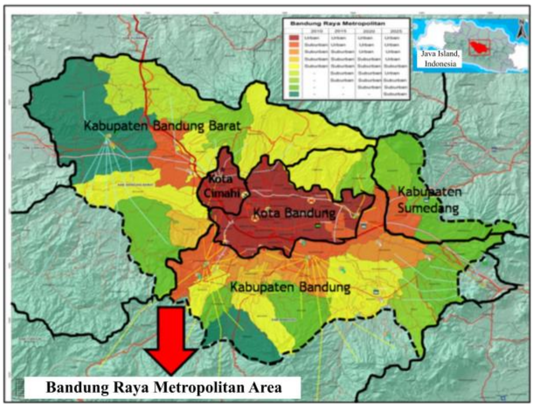


Fig. 1 Map of Metropolitan Bandung City

Practical and convenient methods applicate to reduce flood problems in Bandung City Area are using zero artificial run-off method and artificial recharge [25]. These methods are considered promising due to the various rainfall in the Metropolitan Bandung Raya area cannot penetrate the ground because of the large number of building areas and it gives an impact on decreasing water catchment areas. As a result, during the rainy season, the water has an impact for being flooding cause of failure for infiltrating and widely spread in the part of Bandung Metropolitan City, meanwhile in the drought season, the groundwater is decreasing due to the absence of water supply which occurring in the dry season [26]. Through the zero artificial run-off method, the problem is expected resolved properly.

### 1.2 Geology and Regional Hydrogeology

Bandung Basin is a basin surrounded by the quaternary volcano and irrigated by Citarum River. The tectonic of the Bandung basin is controlled by faults, Northwest – Southeast trending which is controlled by the direction pattern of Sumatra Fault, the pattern of Meratus Fault has Northeast – Southwest trending, and the trend of North-South which is controlled by the faults in the Bandung Basin area [27], there is four possibilities formation of basins, including fault direction pattern on bedrock [28]. The Bandung Basin is the result of an exogenous process because the basin is located between mountains or intra-mountain basin [29], The Bandung Basin is the result of tectonic deformation, namely graben, the Bandung Basin is a caldera formed due to pure volcanic eruptions, and the Bandung Basin is a tectonic-volcanic caldera formed by tectonic processes and volcanism.

In the Bandung Metropolitan City Area, according to Hutasoit [28] (Fig. 2), there is the Cibeureum Formation which is consists of volcanic breccias with scoria fragments of igneous rocks andesite basalt – pumice and low consolidated tuff and several of lava basalt insertion in Late Pleistocene – Holocene age. These rocks are the main aquifer that has fan-shaped distribution from Tangkubanparahu Mountain. In addition, the Kosambi Formation or Lake Deposit [28] is composed of claystone, siltstone, and uncompact sandstone in the Holocene age. These rocks act as Aquitard in the Bandung Metropolitan City area. This formation has a fingering relationship with the upper Cibeureum Formation (Fig. 2).

The other form is the Cikapundung Formation where are consists of conglomerates and compact breccias, tuffs, and end site lava of the Early Pliocene age and acts as a hydrogeological bedrock [28]. Apart from Cikapundung Formation, the bedrock are Quaternary volcanic rocks (except in the Cibereum Formation and the Cikapundung Formation), Tertiary volcanic rocks, and intrusion rocks [28] (Fig. 2).

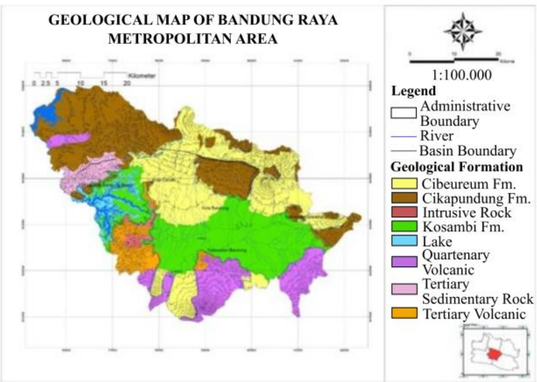


Fig.2 The Geological Maps of Study Area, (Compiled and modified by Hutasoit (2009) from Silitonga (1973), Koesoemadinata and Hartono (1981), Iwaco Waseco and PU (1990), Alzwar. (1992)

## 2. METHODS

This study has been used several methods approaches, namely:

1. Survey method is the acquisition of BMKG data namely climatological data from Bandung Geophysics Station
2. Overlay map method, for land use map, watershed map, the geological map used digitization process and it became a shapefile format. Thus, an overlay could be carried out, and the results was in a potential flood area. The outcome of the potential flood would be compared with the historical map of floods in the Bandung Raya Basin. The permeability data of recharge wells and water balance calculation have been used to consider the number of infiltration wells required to achieve the zero artificial run-off concept.

## 3. DATA ANALYSIS

The data used for this study entitled "The Analysis of Water Balance and Application of the Zero Artificial Run-Off Concept in Metropolitan Bandung City" including of:

### 3.1 The Watershed Map

The watershed map was obtained from the Citarum River Map. The river that flow surrounded the Bandung Basin can be grouped into several sub-watersheds (Sub DAS): Cihaur Sub DAS, Cikapundung Sub DAS, Citarik Sub DAS, Cirasea Sub DAS, Cisangkuy Sub-DAS, Ciwidey Sub-DAS, and Ciminyak Sub-DAS, and all the watersheds are empties into the main river, Citarum River (Fig.3).

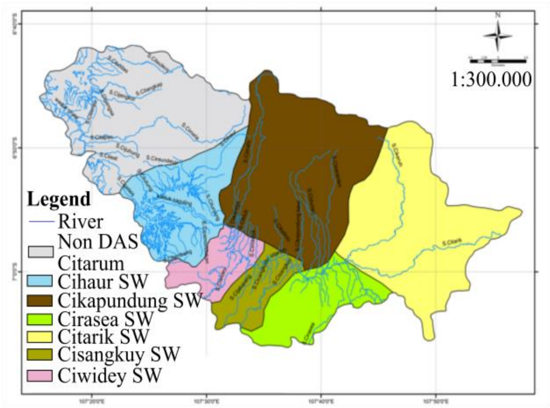


Fig.1 The Watershed (DAS) Map of Bandung Metropolitan Area

### 3.2 The Land Use Map

The land use map (Fig.4) was obtained from the Regional Development Planning Agency of West Java Province [30]. Based on data from the Ministry of Agrarian Affairs and Spatial Planning or the National Land Agency, the amount of land is 49.288,05 Ha (14,41% of the total land area) until 2004, it has been turned into developed land and the rest is still undeveloped land, which is 85,59%. Therefore, in 2004 most of the Bandung Metropolitan City Area was still an undeveloped area. Then in Bandung City and also Cimahi City which is a system of the Bandung Metropolitan City Area, most of the administrative areas are built-up areas, exactly in Bandung City which is reaching up to 71.17% and Cimahi City 61.55% of the total area.

Bandung Regency, which accounts for 89% of the total area in the Bandung Metropolitan City Area has only 10.56% become a developed area. On the other hand, the part of Sumedang Regency which is located in the suburbs of the Bandung Basin urban area has a 13.03% built-up area in 2004. Therefore, it can be concluded that most of the Bandung Basin Urban area undeveloped. However, most of the undeveloped area is in the administrative area of Bandung Regency and West Bandung Regency, so the land concentration of built-up is in the City of Bandung-Cimahi.

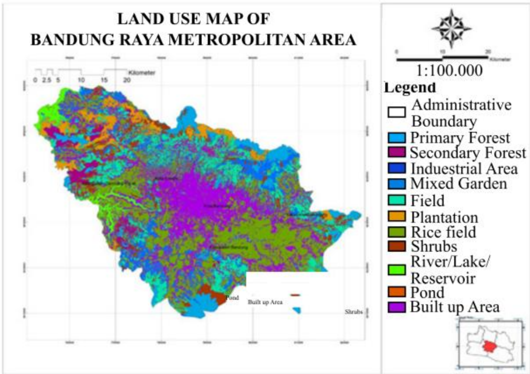


Fig.4 The Land use Map of Metropolitan Bandung City (ATRBN, 2019)

### 3.3 The Permeability Data of Infiltration Well

The data was obtained from the calculation of permeability of recharge wells in The Bandung Metropolitan Area. This recharge well has a depth of 120-150 m targeting the Cibereum Formation as an aquifer (Table 1).

Table 1. The Permeability Data of Recharge Wells in Bandung Metropolitan Area (Field Survey 2018-2019)

| WELL NAME | COORDINATE (UTM) | | PERMEABILITY (m/second) | PERMEABILITY (m/year) |
|---|---|---|---|---|
| SI-01 | 788446 | 9234303 | 0.0235 | 730944 |
| SI-02 | 815503 | 9224329. | 0.0332 | 1032652.8 |
| SI-03 | 792355 | 9235684 | 0.0823 | 2559859.2 |
| SI-04 | 790147 | 9246417 | 0.0227 | 706060.8 |
| SI-05 | 786708 | 9234757 | 0.0417 | 1297036.8 |
| SI-06 | 790136. | 9232711 | 0.0282 | 877132.8 |
| SI-07 | 791935 | 9236618 | 0.0319 | 992217.6 |
| SI-08 | 775725 | 9238428 | 0.0169 | 525657.6 |
| SI-09 | 778271 | 9240058 | 0.0141 | 438566.4 |
| SI-10 | 778365 | 9239986 | 0.0135 | 419904 |
| SI-11 | 782387 | 9236372 | 0.00926 | 288023.04 |
| SI-12 | 782290 | 9236409 | 0.00973 | 302641.92 |
| SI-13 | 782450 | 9236506 | 0.01167 | 362983.68 |
| SI-14 | 782131 | 9236580 | 0.00996 | 309795.84 |
| SI-15 | 781815 | 9234380 | 0.01020 | 317260.8 |
| SI-16 | 781501 | 9234670 | 0.01354 | 421148.16 |
| SI-17 | 803731 | 9218742 | 0.0391 | 1216166.4 |
| SI-18 | 776052 | 9241430 | 0.0587 | 1825804.8 |
| SI-19 | 775894 | 9241444 | 0.0478 | 1486771.2 |
| SI-20 | 789714 | 9234223 | 0.0419 | 1303257.6 |
| SI-21 | 789565 | 9236210 | 0.0225 | 699840 |
| SI-22 | 782772 | 9202940 | 0.07728 | 2403717.12 |
| SI-23 | 782598 | 9203272 | 0.07567 | 2353639.68 |
| SI-24 | 798048 | 9232325 | 0.0427 | 1328140.8 |

Well Location Information
Outside Watershed Citarum
Cikapundung SW
Cihaur SW
Citarik SW

### 3.4 Climatological Data from 2008-2019

The climatic data used rainfall, solar radiation, air temperature, relative humidity, and wind speed. These climate data were obtained from Bandung Geophysical Station. Based on the climate classification according to Oldeman, the climate type in the Bandung Metropolitan City Area includes the climate types E1, E2, and E3. The area's average annual rainfall is 1.500-4500 mm/year, and the average temperature is 24° – 28°C.

### 3.5 The Flood Historical Map in Bandung Raya Basin

The flood historical map of the Bandung Raya Basin (Fig. 5) was used as data to view changes in the area affected by flooding and as a consideration for determining the location of the infiltration well points.

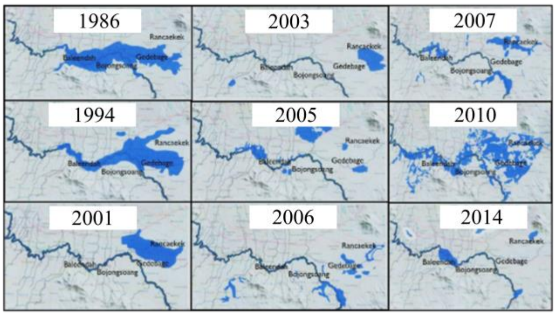


Fig. 5 Flooding Historical Map in Bandung Raya Basin (BBWS Citarum, 2017)

## 4. RESULTS AND DISCUSSION

This study used a water balance calculation and an overlay of a land-use map with a DAS map. The water balance calculation was carried out in each Sub-DAS. The purpose of water balance calculation is for looking at the volume of water available in each of these Sub-DAS. The method of overlaying map was carried out to determine the locations that had the potential for flooding though considering the historical flood of the Bandung Raya Basin.

### 4.1 Water Balance Calculation

The climatological data needed in this calculation were humidity, air temperature, sunshine duration, rainfall, wind speed, and rainy days. The results of the water balance calculation that will be used are 4 parameters, namely: Base Flow, Direct Run-off, Rainfall, and Water Surplus (Fig. 6-10).

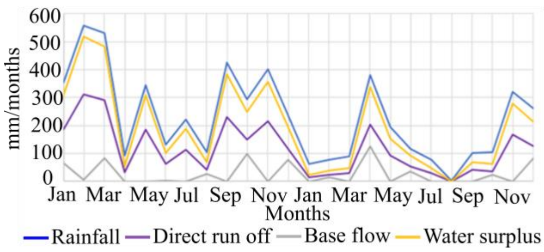


Fig.6 The Monthly Chart of Water Balance in 2010-2011

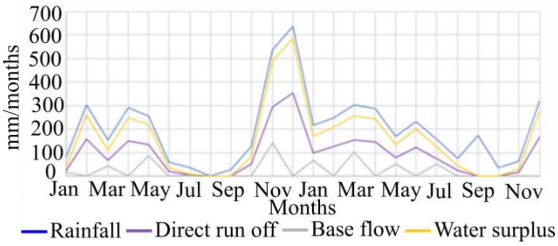


Fig.7 The Monthly Chart of Water Balance in 2012-2013

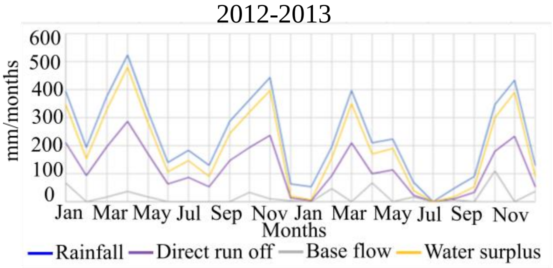


Fig.8 The Monthly Chart of Water Balance in 2014-2015

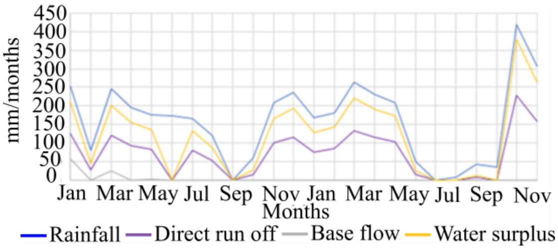


Fig.9 The Monthly Chart of Water Balance in 2016-2017

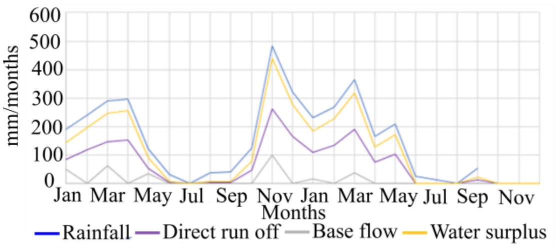


Fig.10 The Monthly Chart of Water Balance in 2018-2019

### 4.2 Application Concept of Zero Artificial Run-Off

Spatial planning is another matter that needs attention in this study. Land use was used to identify the potential areas for water catchment. The increase of the population is directly proportional to the reduction in the air catchment areas and gains an impact as flooding in several places. This case occurs due to the increase of population and the impact, it needs more development to fulfill the necessity of humans. Therefore, nature can no longer maximize the absorption of water into the soil. One of the solutions for fixing this problem is by making infiltration wells.

### 4.3 Land Use and River Area

Besides water calculation, spatial planning also needs attention in this study. The use of land use was carried out to identify areas that had the potential for water absorption. The increase of the population is directly proportional to the reduction in the air catchment areas and gain an impact as flooding in several places and it occurs because of increasing development for fulfilling the necessities of humans. Therefore, nature can no longer maximize the absorption of water into the soil when the rains come and flow into the river. The rainwater that can no longer be accommodated by rivers or ditches, will flow and cause flooding. One of the solution to infiltrate the water is by making absorption wells.

This study was conducted in the Citarum watershed area with various large rivers, Cisangkuy River, Cikapundung River, Citarik River, Ciwidey River, Cirasea River, and Ciwidey River. From the Citarum DAS map, an area of each river can be made (Fig. 3). Then the area was obtained to produce the volume of water in the area (direct run-off). The river area includes built or unbuilt areas. When the rains come, some of the water will flow into rivers and another will be absorbed into the ground. Thus, if the area has been developed, the process of soil absorption cannot be maximized so that the water will flow into the river.

Though, the construction infiltration wells would be expected to be absorbed into the ground before the water flow and assemblage in the river. Based on the overlay result of land use and watershed map data also the consideration of the flood history map, it is known that the areas which have potential floods are the Rancaekek, Gedebage, and Baleendah areas. This could be seen in the flood history in 2010 and 2014 (Fig. 9).

### 4.4 The Determination of Infiltration Wells

The location and the number of infiltration wells were determined based on the calculation of water balance and the permeability of infiltration wells. Water balance data was used to determine the amount of incoming water and multiplied by the area to gain the direct run-off volume (Fig. 11-15).

From each river area, the highest volume was selected from 2009-201to 9 as a determinant of the number of infiltration wells needed. The total volume of each river area is divided by the permeability of existing recharge wells. On the north side of the Bandung Metropolitan area, the Cikapundung River has an area of 464.806.445 $m^2$ and the highest direct run-off is 1.351.904.655 $m^3$ (Fig. 11). Based on reference, the areas have 15 wells with known permeability values (Table 1). The average permeabilities of these wells are

833.089,54 m/year (Table 2), so the required number of recharge wells is 1623 units.

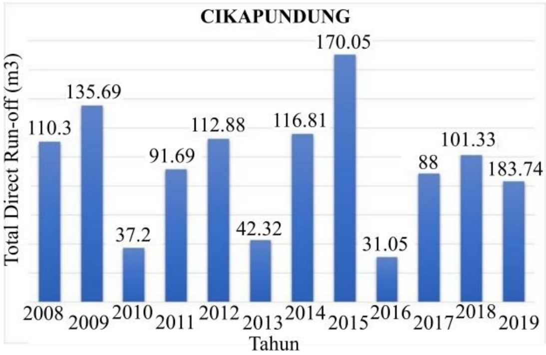


Fig. 11 Total Run Off Volume of Cikapundung River

Then in the west, there is the Cihaur River with an area of 217.449.887,7 $m^2$ and the most direct run-off is 797.604.042,2 $m^3$ (Fig. 12). This area has 5 wells with an average permeability of 939.340,8 m/year so 850 recharge wells are needed.

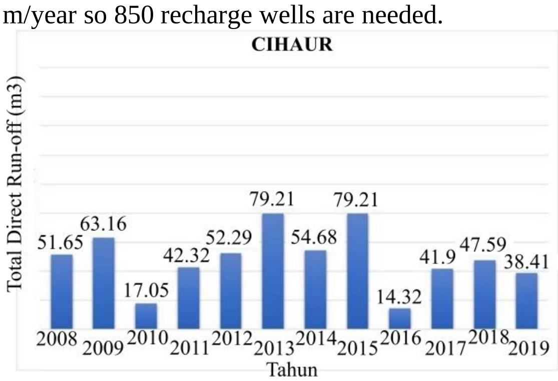


Fig. 12 Total Run Off Volume of Cihaur River

On the southeast side, there is Cirasea River with an area of 155.715.521.9 $m^2$ with the highest direct run-off of 571.162.997,6 $m^3$ (Fig. 13). Based on good data, the wells cannot find in this area, then the calculation is carried out by using a well located on the south side with a permeability value of 1.216.166,4 m/year. The Cirasea River area requires 470 units of recharge wells.

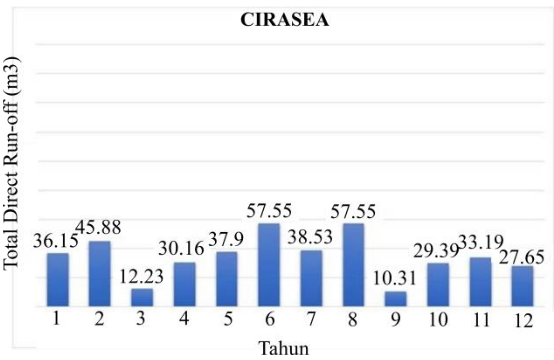


Fig. 13 Total Run Off Volume of Cirasea River

On the north side of the Cirasea River, there is the Citarik River which has an area of 429.680.847,6 $m^2$ with a direct run-off of 1.576.065.109 $m^3$ (Fig. 14). In this area, only 1 well can be found, and it has a permeability of 1.032.352,8 m/year so 1527 units of recharge wells are required.

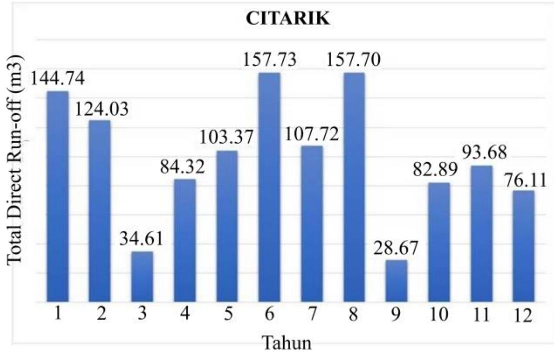


Fig. 14 Total Run Off Volume of Citarik River

On the south side of the Bandung, the Metropolitan area discovers the Cisangkuy River with an area of 89.208.726,71 $m^2$ and a direct run-off of 327.216.727,2 $m^3$ (Fig. 15). The wells cannot find in this area so the permeability data from the closest wells in Cikapundung SW has a permeability of 877.132,8 m/year.

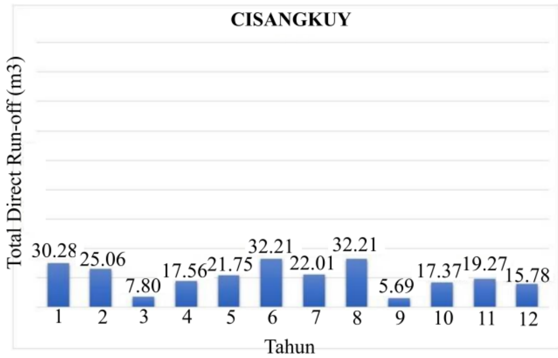


Fig. 15 Total Run Off Volume of Cisangkuy River

In the Cisangkuy River area, 374 units of recharge wells are required. And the last is the Ciwidey River area with an area of 89.827.562,32 $m^2$ and a direct run-off of 329.486.612,1 $m^3$ (Fig. 16).

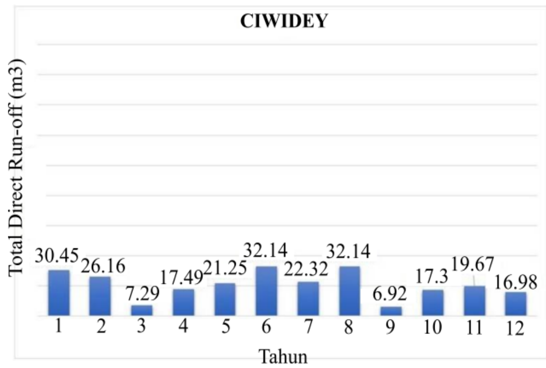


Fig. 16 Total Run Off Volume of Ciwidey River

Based on good data, the wells cannot find in this area, so the good data use the closest well with a permeability value of 421.148,16 m/year and 783 additional wells are required. The locations of infiltration wells are determined based on regional land use. The developments of infiltration wells are more needed than several tree areas. The construction infiltration wells are recommended for residential areas and upstream of the river, thereby it can help for reducing the potential flooding downstream. In addition, for making infiltration wells, a reservoir is also needed to drain water into the infiltration well. The water reservoir can control the water supply at that location until finally absorbed by the infiltration well.

Based on the overlay of land use and watershed map data also the consideration of the flood history map, it is known that the area has a potential for flooding are the Rancaekek, Gedebage, and Baleendah areas. This can be seen from the flood history in 2010 and 2014 (Fig. 9). This flood circumstance originated from the existing water supply which comes from the Cikapundung River, Citarik River, Cirasea River, and Cisangkuy River so the application of infiltration wells in the upstream area of these rivers is required due to the Bandung Basin has own potential for flooding in the Rancaekek, Gedebage, and Baleendah. It takes about 4000 wells to absorb runoff water with a volume of 3.826.349.498 $m^3$.

Table 2. The Numbers Infiltration Wells Calculation Table in Each Watershed (DAS)

| River Area | Area (m2) | *Direct Run-off* (m3) | Average Permeability (m/tahun) | Number of Recharge Wells |
|---|---|---|---|---|
| CIKAPUNDUNG SW | 464,806,445 | 1351904665 | 833089.536 | 1622.76 |
| CIHAUR SW | 217449887.7 | 797604042.2 | 939340.8 | 849.11 |
| CIRASEA SW | 155715521.9 | 571162997.6 | 1216166.4 | 469.64 |
| CITARIK SW | 429680847.6 | 1576065109 | 1032652.8 | 1526.23 |
| CISANGKUY SW | 89208726.17 | 327216727.2 | 877132.8 | 373.05 |
| CIWIDEY SW | 89827562.32 | 329486612.1 | 421148.16 | 782.35 |

## 5 CONCLUSION

Based on the analysis, of the results of this study, Bandung Basin has its potential for flooding in the Rancaekek, Gedebage, and Baleendah areas. It takes about 4000 wells to absorb runoff water with a volume of 3.826.349.498 $m^3$. The installation of infiltration wells was carried out in the upstream part of the watershed which supplied water to potential flood areas. It is expected when the excessive rainfall, water might assemblage and infiltrates deep aquifers to minimize water run-off to potential flood areas.

## 6 ACKNOWLEDGEMENTS

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## 7. REFERENCES

[1] BAPPENAS; Asian Development Bank, “ATLAS Pengelolaan Sumber Daya Air Terpadu Wilayah Sungai Citarum,” 2012.

[2] Cita-Citarum, “Cita-Citarum.” [Online]. Available: http://citarum.org. [Accessed: April 11, 2017].

[3] Kusuma M. S. B., Hutasoit L. M., Kombaitan B., Syafila M., Setiadi T., Aryantha I., Piliang Y. A., “Strategi pengelolaan terpadu penyelesaian permasalahan DAS Citarum,” 2018, Forum Guru Besar ITB.

[4] Adesbg., 2014, Peta DAS Citarum, ArcGis.https://www.arcgis.com/home/item.html?id=ddd2f4046aca42cfa41710ae7f0e78a6. [Accessed January 25, 2022.]

[5] ATRBN., 2019, Cekungan Bandung, http://sifataru.atrbpn.go.id/kawasan/Cekungan-Bandung. [Accessed January 20, 2022.]

[6] Kusuma M. S. B., Kuntoro A. A., and Silasari R., Preparedness Effort toward Climate Change Adaptation in Upper Citarum River Basin, West Java, Indonesia. Society for Social Management Systems Internet Journal, 2011. http://hdl.handle.net/10173/855, pp. 25-32.

[7] Sarminingsih A., Soekarno I., Hadihardaja I. K., Kusuma M. S. B., “Flood vulnerability assessment of upper citarum river basin, West Java, Indonesia,” Int. J. Appl. Eng. Res., vol. 9, no. 23, 2014, pp. 22921–22940.

[8] Kuntoro A. A., Putro A. W., Kusuma M. S. B., Natasaputra S., 2017. The effect of land-use change to maximum and minimum discharge in Cikapundung river basin the 3rd International Conference on Construction and Building Engineering (ICONBUILD) 1903, DOI: https://doi.org/10.1063/1.5011621, pp. 100011-1-100011-7

[9] Kusuma M. S. B., Rahayu R. A., and Cahyono, Development Study of Turbulent κ-ε Model for Recirculation Flow III: Two Dimension Recirculation Flow in a Reservoir. ITB Journal of Engineering Science, Vol. 41, Issue B(1), 2009, pp. 1-16.

[10] Juliana I. C., Kusuma M. S. B., Cahyono M., Kardhana H., and Martokusumo W., Performance of Rainwater Harvesting System based on Roof Catchment Area and Storage Tank Capacity, MATEC Web of Conferences 101, 2017, 05014, pp. 54-60.

[11] Abfertiawan M. S., Gautama R. S., Kusuma S. B., Notosiswoyo S.. Hydrology simulation of Ukud River in Lati Coal Mine. Journal of Novel Carbon Resource Sciences and Green Asia

Strategy 2016;3(1), pp. 21-31.
[12] Kusuma M. S. B., Setiawati T., and Farid M., Experimental Model of Dam Break Flow around several Blockages Configurations. International Journal of GEOMATE, Vol. 16, Issue 58, 2019, pp. 26-32.
[13] Gunawan T. A., Kusuma M. S. B., Cahyono M., and Nugroho J., The Application of Backpropagation Neural Network Method to Estimate the Sediment Loads. MATEC Web of Conferences 101, 2017, 05016, pp. 44-50.
[14] Sengara I. W., Latief H., Kusuma M. S. B., Probabilistic seismic and tsunami hazard analysis for design criteria and disaster mitigation in rehabilitation and reconstruction of a coastal area in the city of Banda Aceh, Geotechnical Engineering for Disaster Mitigation and Rehabilitation - Proceedings of the 2nd International Conference GEDMAR08, 2008, pp. 224–230.
[15] Jonathan R. V., Faizal R., Hadi K., Kusuma M. S. B., Yatsrib M., Sadewa satellite remote sensing data to Manggarai 1-hour water level machine learning model, 2021 8th International Conference on Advanced Informatics: Concepts, Theory, and Applications (ICAICTA), IEEE, pp. 1-6.
[16] Farahnaz N., Kuntoro A. A., Kusuma M. S. B., (2020), Statistical Downscaling for the Projection of the Keetch Byram Drought Index in the Barito Basin, Int J. on Advanced Science Engineering Information Technology, Vol 10 (2010), pp. 873-879.
[17] Badan Pusat Statistik Kota Bandung., 2020, Kota Bandung Dalam Angka, BPS-Statistics of Bandung Municipality.
[18] Sugandi D., 2014, A Model of Environmental conservation of Segara Anakan, International Journal of Conservation Science, pp. 95 – 106.
[19] Putro S., and Hayati R., 2007, Dampak Perkembangan Permukiman Terhadap Perluasan Banjir Genangan di Kota Semarang, Jurnal Geografi UNNES, pp. 35-43.
[20] Waters S., Farrell P. K., and Wagner K., 2011, When it Rains it Runs off: Runoff and Urbanized Areas in Arizona. Arizona Cooperative Extension, The University of Arizona, pp. 1-5.
[21] Iskandar D., and Sugandi D., 2015, Flood Mitigation Efforts in The Special Capital Region of Jakarta, International Journal of Conservation Science, pp. 685-696.
[22] Seizarwati W., Syahidah M., Rengganis H., 2017, Penurunan Kapasitas Imbuhan Airtanah Cekungan Air Tanah Jakarta Menggunakan Neraca Air untuk Daerah Urban, Riset Geologi dan Pertambangan, Vol. 27 Juni 2017, pp. 27-37
[23] Jyotiba B. G., and Regulwar D. G., 2013, Rainwater Harvesting – A Case Study, Sustainable Water Resources Development and Management, pp. 179-183
[24] Sanjay J., Jaivir T., and Vishal S., 2010, Simulation of Runoff and Sediment Yield for a Himalayan Watershed Using SWAT Model, Journal of Water Resources and Protection, pp. 276-280.
[25] Yong H. S., Qi F., Gao F. Z., Zhang Q., 2022, Evaluating the Different Methods for Estimating Groundwater Evapotranspiration using Diurnal Water table Fluctuation, Journal of Hydrology, pp. 31-38.
[26] Yang S., Tsai F., 2020, Understanding Impacts of Groundwater Dynamics on Flood and Levee in Greater New Orleans, Journal of Hydrology, pp. 16-23.
[27] Bronto S., and Hartono U., 2006, Potensi sumberdaya geologi di daerah Cekungan Bandung dan sekitarnya. Jurnal Geologi Indonesia, Vol. 1 No. 1 Maret 2006: pp. 9-18.
[28] Hutasoit L. M., 2009, Kondisi Permukaan Air Tanah dengan dan tanpa peresapan buatan di daerah Bandung: Hasil Simulasi Numerik. Jurnal Geologi Indonesia, Vol. 4 No. 3 September 2009, pp. 177-188.
[29] ATRBN., 2019, Cekungan Bandung, http://sifataru.atrbpn.go.id/kawasan/Cekungan-Bandung. [Accessed January 20, 2022]
[30] WJP-MDM., 2013. Konsep Awal Pengembangan Metropolitan Bandung Raya. West Java Province Metropolitan Development Management.