

PAPER • OPEN ACCESS

Understanding and quantifying water balance for sustainable city and agriculture of Yogyakarta Province

To cite this article: Oki Setyandito *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **195** 012013

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Understanding and quantifying water balance for sustainable city and agriculture of Yogyakarta Province

Ok Setyandito¹, Yureana Wijayanti², Martin Anda³, Purwadi², Kadarwati Budihardjo²

¹Department of Civil Engineering, Faculty of Engineering, Bina Nusantara University, Jakarta, Indonesia 11480

²Faculty of Agriculture, Institut Pertanian Stiper (INSTIPER), Yogyakarta, Indonesia

³School of Engineering and Informatics, Murdoch University, Western Australia

Corresponding Author: osetyandito@binus.edu

ywijayanti@instiperjogja.ac.id

Abstract. Water availability is an important aspect for sustainable regional development. Yogyakarta has problems in water availability. The demand for water in Yogyakarta Province is gradually increasing with higher consumption for human consumption, industry, and agriculture and livestock production. Also, more inhabitants and farmers are utilizing groundwater for domestic purpose and irrigation due to long drought, respectively. This problem will be increasing as higher population leads to higher water consumption and food production. Therefore, this study aim to understand the current situation and long-term projections of water sources, and demands in 2017-2030 by using water balance concept. After that, the assessment of alternative scenarios to overcome water availability problem was performed using managed aquifer recharge concept and efficient irrigation.

The result shows that within the period 2017-2030, water storage is negative in 3 (three) regencies. This means that water deficit had occurred in these regencies where water demand rate is higher than recharge rate of groundwater. Also, it might shows that most of storm water goes to surface runoff and/or most of groundwater abstraction for water demand becomes waste water production. According to the Scenario-1, recharging the aquifer with storm water, converting 45% of surface runoff to groundwater can reduce water deficit in only 2 regencies. Scenario-2 shows that converting 65%, can overcome all 3 regencies from water deficit. Combining aquifer recharge by storm water and effective irrigation can solve water deficit problem in all regencies by only converting 40% of surface runoff to groundwater. The study shows that both approaches of managed aquifer recharge and effective irrigation are applicable in Yogyakarta. In small scale, these applications can be low cost, but at larger scale, can require higher investment cost. Therefore a site-specific knowledge on the project field is very important. Large scale application will need more stakeholders and regulators involvement, and also social awareness and acceptance.

Keywords. Water availability, water demand, water storage, water balance

1. Introduction

Groundwater has been used as a primary solution to fulfil water demand in areas after surface



water. Its amount is highly depends on the recharge rate and storage capacity. The source of groundwater is stormwater [1] and river-groundwater interaction [2].

In order to meet the Sustainable Development Goal (SDG) [3] which secure the water for food security and living, it is important to evaluate water availability in 2030 and to develop water security scenario to be implemented. However, increase of population and climate change impact are becoming a challenge for ensuring water availability in future. The decrease of rainfall intensity due to climate change has resulted in lower recharge of groundwater [4]. Higher population is affected more landuse change for residential area [5] and more livestock and agriculture production for food production. As a consequence, higher water quantity is needed for these demand. One of water resource that widely used is groundwater. However, its quantity could not meet the increasing of water consumption due to higher demand. Managed Aquifer Recharge (MAR) which defines the process of improving level of groundwater, is an effective technique to increase groundwater quantity [6,7,8]. The use of recharge well is one types of MAR that has been applied to increase groundwater recharge from stormwater [9]. Yogyakarta Province in one of the fastest growing economy of Indonesia, in 2017. The GDP growth rate at 5,05% and Yogyakarta is in the 14th position of 34 provinces in Indonesia, above South Sumatra, Riau Islands and West Papua [10]. Since 2003, Yogyakarta has been experiencing the problem regarding water availability. There is a water deficit in 2 regencies in Yogyakarta, which is appear in a water balance year 2003 where Java island calculated 38 million litre deficit during dry season. However it was reported the surplus of water during wet season of 27 million litre [11]. It shows there is an imbalance water budget in Java island and also seasonal water budget difference during dry and wet season.

Therefore, in this study, present condition of water balance was assessed and future condition was predicted. After that, scenarios were implemented to propose an alternative solution regarding water availability.

2. Methodology

2.1. Study Area and Data Collection

Yogyakarta Province is located in southern part of Java Island. It stretches from coordinate 110°22' E - 7°47' S, with an area of 3133.15 km². It covers all area of 5 (five) regencies (kabupaten): Sleman, Yogyakarta City, Bantul, Gunungkidul and Kulonprogo. The total population in this province is 3,594,290 people and 1100 people/km² density. The highest and lowest population density in year 2017 are Yogyakarta City and Gunungkidul, with the number of 12,854 and 486 inhabitants per km², respectively. Data for this study were collected from secondary sources for water resources, water demands, waste water generations and surface runoff. The secondary sources consisted of data in national, provinsional reports and documents, international and local journals, and international organisation databases and reports.

2.2. Conceptual Water Balance and Water Demand Projection in year 2018 - 2030

Water balance approach has been widely applied in the assessment of water availability and/or the determination of best scenarios to overcome water scarcity problems [12]. Therefore in this study, each regency will be calculated using the water balance method. The formula for calculation of water balance is modified from water balance approach using this formula [13]:

$$\text{Water source} - \text{water demand} = \text{output water} + \text{water storage} \quad (1)$$

This formula then modified with Urban Harvesting Approach (UHA) [14], which provides an option to quantify the storage from output water that infiltrate to groundwater as follows:

$$\text{Water storage} = \text{water source} - \text{water demand} - \text{surface runoff} - \text{evapotranspiration} - \text{industry wastewater} - \text{domestic wastewater} - \text{livestock wastewater} \quad (2)$$

The water sources are water from rainfall and groundwater. Water demands are water that being used for agriculture, industry, domestic and livestock. Output water consist of surface runoff, evapotranspiration, industry wastewater, domestic wastewater, livestock wastewater and water storage. Water storage is the remaining discharge in output.

According to Kepres No. 26 year 2011 of Aquifer basin in Indonesia, there are 2 aquifers in Yogyakarta province, Yogyakarta-Sleman Aquifer and Wates Aquifer [15]. However, the Bantul dan Gunungkidul Aquifer are not yet Groundwater source quantity is the aquifer yield of each regency. Aquifer yield of Kulonproge regency was determined from Wates aquifer characteristics [16]. The quantity of Kulonprogo aquifer is 1044 G lt/year. Aquifer yield in Gunungkidul is 708 G lt/year [17]. While Sleman, Yogyakarta City and Bantul aquifer capacity are 4272 G lt/year, 563 G lt/year, and 1535 G lt/year, respectively [18]. Highest groundwater quantity is in Sleman regency, It is in alignment with the fact that upper northern area of Sleman is a conservation area of Merapi volcano mountain and also a groundwater recharge area. Lowest groundwater quantity is gunungkidul regency.

Tabel 1. Water Demand in Yogyakarta Province, year 2017

Component of Water Demand	Unit	Sleman	Yogyakarta City	Bantul	Kulonprogo	Gunungkidul	Reference
Number of population	Person	1,194,409	422,673	995,133	421,600	731,004	[10]
Domestic water demand	lt/person/day	170	150	170	150	170	[21]
Total Domestic water demand	ML/year	203	63	169	63	124	Calculation
Rain Fed farming area	Ha	574	-	2147	1006	5685	[10]
Irrigation area	Ha	21,267	60	113	9360	2190	[10]
Irrigation water demand	h			2177			[19]
Total Agriculture water demand	ML/year	1,138	3	118	540	410	Calculation
Industry water demand	m ³ /day			0.35-0.70			[19]
Number of industry	Industry	17595	5469	21159	24023	22660	[10]
Total Industry water demand	ML/year	57	18	68	78	73	Calculation
Number of cows (dairy)	animal	31	247	0	3781	10	[10]
Number of cows (butcher)	animal	51047	54200	56040	53190	250	[10]
Number of buffalo	animal	87	486	3	544	4	[10]
Number of horses	animal	11	1775	6	365	25	[10]
Number of goat	animal	91611	95752	178498	36793	322	[10]
Number of sheep	animal	21392	70754	12020	72734	347	[10]
Cows/buffalo/horses water demand	ltr /day/animal			40			[20]
Goats/sheep water demand	ltr /day/animal			5			[20]
Total livestock water demand	ML/year	1051	5	1139	959	1173	Calculation

Note: Ha = Hectare

The water demand is calculated and presented in Table 1. Calculation of domestic water demand based on Ministry of Public Work [21], for population of 500 thousand – 1 million is 170 lt/person/day and for the population of 100 – 500 thousand is 150 lt/person/day.

Water demand of agriculture area in Sleman Regency is the highest compare to other regencies. The agricultural practices in Gunungkidul Regency depends on rainwater and groundwater. Water demand for industry in Kulonprogo, bantul and gunungkidul are high and at present the groundwater is water supply for this industries.

Domestic water demand in Sleman is the highest where many new residential areas are built as a peri-urban area of Yogyakarta City.

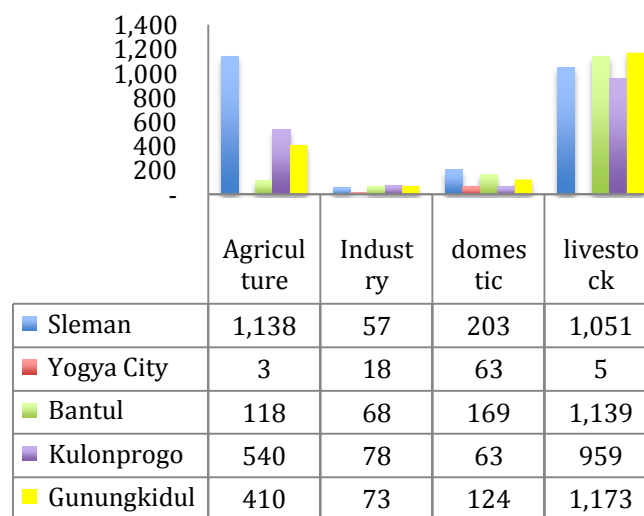


Figure 1. Water demand in 2017 (in ML/year) [10]

Wastewater production of domestic, industry and livestock are 80 % [20], 50% [22], and 90% [23] of clean water, respectively. Evapotranspiration is 5,8 mm/month [24,20]. Surface runoff is calculated using a formula [25]:

$$Q = 0.278 C.I.A \quad (3)$$

Where:

Q: Discharge (m^3/s)

C: runoff coefficient

I: Rainfall intensity (mm/hour)

A: Drainage area (m^2)

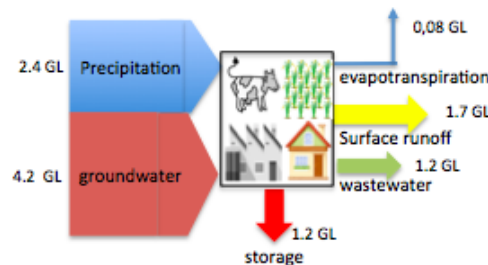
The calculation of water demand projection in 2030 based on the report [10] which stating that the increase of population is 1.18 % and the decrease of agriculture area is predicted to be 0.3 %. Also, there is an increasing number of industry and livestock of 5.4 % and 0.62 % per year, respectively.

3. Results and Discussion

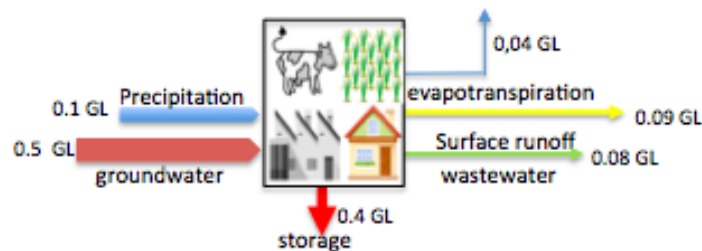
3.1. Water Balance at present and projection 2017-2030

The calculation result of water balance in Sleman, Yogyakarta City, Bantul, Gunungkidul and Kulonprogo in year 2017 shows that there are 3 (three) areas experience water deficit: Bantul, Gunungkidul and Kulonprogo regencies. It is in alignment with the condition at

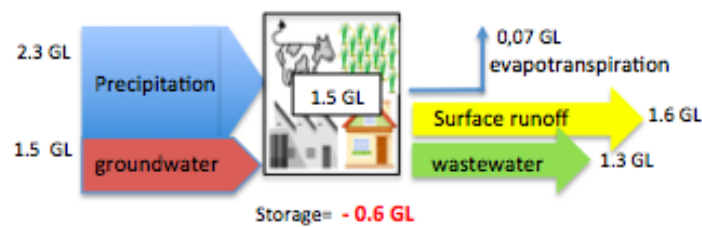
present, where few villages in these areas have been cancelling their agriculture activities due to lack of rainfall, had their well dry, or received water supply aid from local government.



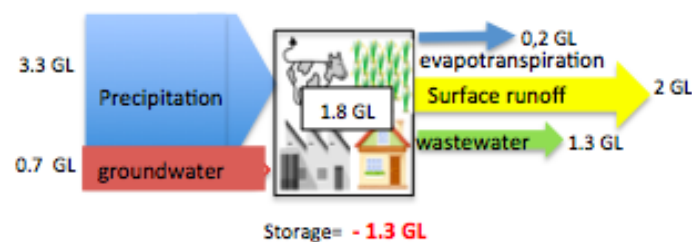
a. Sleman Regency



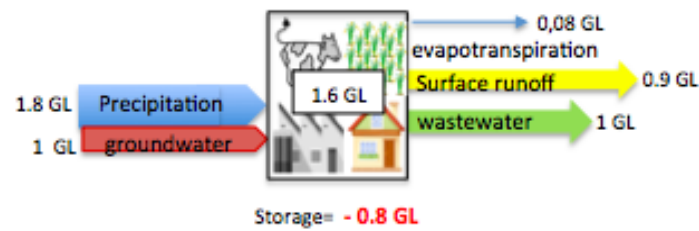
b. Yogyakarta Regency



c. Bantul Regency



d. Gunungkidul Regency



e. Kulonprogo Regency

Figure 2. Water balance model of each regency at year 2018

The projection of infiltration 2018-2030 shows the increase of negative value in Kulonprogo, Bantul and Gunungkidul (Figure 3)

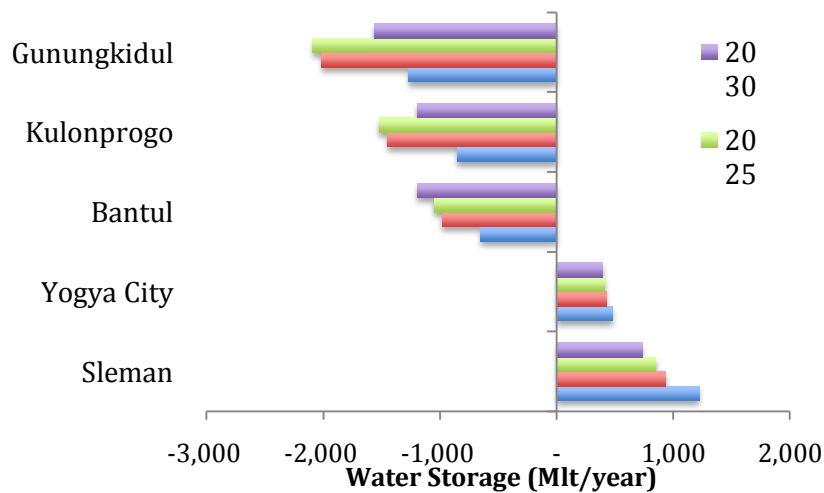


Figure 3. Projection of water storate in year 2018-2030

3.2.Scenarios of Solutions

To compare the effect of different solutions on the water balance, three scenarios were developed. There are 2 approach will be applied using surface runoff to recharge the groundwater, type of managed aquifer recharge, and applying effective irrigation, such as drip irrigation, to reduce agriculture water demand. Drip Irigation system is allowing water to drip slowly to the roots. This irrigation system can save irrigation water demand of 56,4% [26], so in this scenario, the agriculture water demand will be reduced by 56% due to effective irrigation practices scenario (Figure 4)

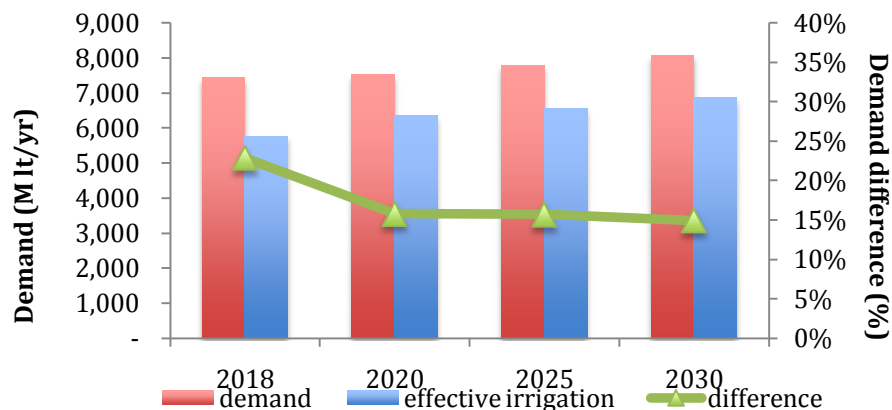


Figure 4. The reduction of water demand due to effective irrigation

The scenarios developed by determined which percentage could overcome the negative storage. The calculation result shows three alternatives as follows: Scenario 1 is 45% of surface runoff convert to water resource; Scenario 2 is 65% of surface runoff convert to water source; Scenario 3 is 40% of surface runoff convert to water source combine with water demand in agriculture. The result of scenario 1, 2 and 3 can be seen on Table 2.

Table 2. Water storage at present, projection in 2030, and 3 (three) scenarios in 2030

Water Storage (M lt/year)	sleman	yogya city	bantul	kulon progo	gunung kidul
Present (year 2018)	1,221	476	-653	-854	-1269
Projection (year 2030)	732	392	-1193	-1196	-1564
Scenario 1-45 % surface runoff (SR) to GW	2,500	484	490	-509	48
Scenario 2-65% surface runoff (SR) to GW	3,164	498	1130	4	901
Scenario 3-40% SR to GW & effective irrigation	2,609	476	710	21	477

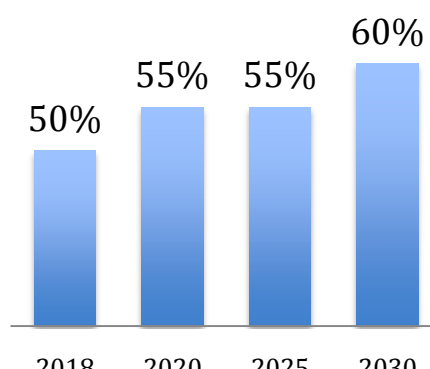


Figure 5. Percentage of surface run off convert to groundwater

There is 25% less storm water recharge to the aquifer by combining effective irrigation in agriculture area and storm water recharge at the same time. And 20% less storm water should be convert to groundwater, without application of effective irrigation. There is 5% less storm water being converted to groundwater by implementing effective irrigation. How much

percentage of storm water being converted to groundwater to get a positive storage within 2018-2030 can be seen in Figure 5.

4. Conclusions

Water demand of agriculture and livestock production is the highest among other purposes. Kulonprogo, Bantul and Gunungkidul regency have negative water storage in 2018-2030 projection. This means that water deficit had occurred in these regencies where water demand rate is higher than recharge rate of groundwater. Also, it might show that most of storm water goes to surface runoff and/or most of groundwater abstraction for water demand becomes waste water production. According to Scenario-1, recharging the aquifer with storm water, converting 45% of surface runoff to groundwater can reduce water deficit in only 2 regencies. Scenario-2 shows that converting 65%, can overcome all 3 regencies from water deficit. Combining aquifer recharge by storm water and effective irrigation can solve water deficit problem in all regencies by only converting 40% of surface runoff to groundwater. Lake, ponds and small dam development; surface runoff from agricultural area is flown using the drainage system and reserved in lake, ponds, or small dam. Water reserved in the systems is used for fulfilling domestic, cattle, fishpond, and irrigation demand. These lakes can be simply made, natural or technical. Rooftop RWH; water-resistant wells and other material are made to catch and retain rainwater from house roofs to underground. Big scale groundwater recharge scheme from storm water must be tested: technical, environmental, cost and social acceptance. Therefore, further study will be conducted in the economical analysis of rainwater harvesting methods application for groundwater recharge.

References

- [1] Wijayanti. Y., Nakamura. T., Nishida. K., Haramoto. E., Sakamoto. Y. 2013. Seasonal Differences and Source Estimation of Groundwater Nitrate Contamination. *Journal of Water & Environment Technology*. 11 (3). 163-174
- [2] Long. T. T., Koontanakulvong S. 2017. Groundwater Balance and River Interaction Analysis in Pleistocene Aquifer of the Saigon River Basin, South of Vietnam by Stable Isotope Analysis and Groundwater Modeling. *International Conference on Water Management and Climate Change Towards Asia's Water-Energy-Food Nexus*, 25-27 January, Bangkok, Thailand.
- [3] UNDP .2011. *Mainstreaming Climate Change in National Development Processes and UN Country Programming: A guide to assist UN Country Teams in integrating climate change risks and opportunities*. United Nations Development Programme: New York, NY, USA.
- [4] Wijayanti. Y., Setyandito. O. 2018. Groundwater Recharge Pattern in Agricultural Area. *Agroista Jurnal Agroteknologi*. 01(2). 197-205
- [5] Setyandito. O., Wijayanti. Y., Alwan. M., Chayati. C., Meilani. 2017. The Assessment of Urban Storm Inundation. *International Conference on Eco Engineering Development*. IOP Conf. Series: Earth and Environmental Science 109. 012010
- [6] Johnston. K., Nelson. D. 2018. Hatfield Park Water Proofing Project: Stormwater Harvesting using Aquifer Storage and Recovery, Perth, Western Australia. *The 10th International Conference on Water Sensitive Urban Design*. 12-15 February, Perth. Western Australia.

- [7] Hopkirk. C., Chandler. K., Epworth. R. 2018. Holistic Stormwater Design-Achieving Environmental, Social and Heritage Goals: A Case Study in Bellevue, Western Australia. . The 10th International Conference on Water Sensitive Urban Design. 12-15 February, Perth. Western Australia.
- [8] Coombes. P.J. 2018. Two Decades of Household Water and Energy Monitoring-Rainwater Harvesting to Solar Battery Storage. . The 10th International Conference on Water Sensitive Urban Design. 12-15 February, Perth. Western Australia.
- [9] Setyandito. O, Syafalni. St., Wijayanti. Y., Dara. I. C., Satrio. S. 2015. Groundwater Quality Assessment and Recharge Well Design of Cengkareng Area, West Jakarta. International Journal of Applied Engineering Research. Vol. 10. No.7. 18337-18348
- [10] BPS-Statistics of D.I. Yogyakarta Province. 2017. Daerah Istimewa Yogyakarta Province in Figures. ISSN: 0215-2185
- [11] Sumekto. C., Winata. E. S. 2010. Potensi Sumber Daya air di Indonesia. Seminar Nasional: Aplikasi Teknologi Penyediaan Air Bersih untuk Kabupaten/Kota di Indonesia. BPPT, 16 Juni, Jakarta
- [12] Juniati. A. T., Surjiningsih. D., Soeryantono. H., Kusratmoko. E. 2018. Proposing Water Balance Method for Water Availability Estimation in Indonesian Regional Spatial Planning. The 4th International Seminar on Sustainable Urban Development. IOP Conf. Series: Earth and Environmental Science 106. 012073
- [13] Hunt.J., Anda. M., Ho. G. 2011. Water Balance Modelling of Alternate Water Sources at the Household Scale. Water Science & Technolgy. 63 (9). 1873-1879
- [14] Leusbrock. I., Nanninga. A., Lieberg. K., Agudelo-Vera. C. M., Keesman. K.J., Zeeman. G., Rijnaarts. H. M. 2015. The Urban Harvest Approach as Framework and Planning tool for Improved Water and Resource Cycles. Water Science & Technology. 72. 6. 998-1006
- [15] Keputusan Presiden Republik Indonesia No. 26. 2011. Penetapan Cekungan Air Tanah
- [16] Ramadhika. R., Hendrayana. H. 2016. Management Priority of Groundwater Conservation Zone in Kulon Progo, Daerah Istimewa Yogyakarta. Skripsi S1 Teknik Geologi, Fakultas Teknik, Universitas Gadjah Mada.
http://studylibid.com/viewer_next/web/viewer_study.html?file=%2F%2Fs1.studylibid.com%2Fstore%2Fdata%2F000949475.pdf%3Fkey%3Df25b92d9c091ccea029ea40b35e754c%26r%3D1%26fn%3D949475.pdf%26t%3D1536710615748%26p%3D600
- [17] Cahyadi. A. 2016. Pemetaan Potensi Air Tanah di DAS Juwet Kabupaten Gunungkidul. Prosiding Seminar Nasional Geografi Lingkungan. Fakultas Geografi UGM Yogyakarta. 27 November. 184-190
- [18] Hendrayana. H., Vicente. V.A.D.S. 2013. Cadangan Air Tanah berdasarkan Geometri dan Konfigurasi Sistem Akuifer Cekungan Air Tanah Yogyakarta-Sleman. Prosiding Seminar Nasional Kebumihan Ke-Teknik Geologi Universitas Gadjah Mada, 11-12 Desember. L03
- [19] Brontowiyono. W. 2008. Sustainable Water Resources Management with Special Referenc to Rainwater Harvesting-Case Study of KartaManTul, Java Indonesia. Dissertation
- [20] Asian Development Bank. 2016. Indonesia-Country Water Assessment. ISBN 978-92-9257-360-7 (Print), 978-92-9257-361-4 (e-ISBN)
- [21] Kementerian Pekerjaan Umum dan Perumahan Rakyat. 2016. Buku 3: Sistem Pengelolaan Air Limbah Domestik-Terpusat Skala Permukiman

- [22] Tuan. P. T., Dung. M. T., Duc. P. T., Trang. H.M., Khai. N. M., Thuy. P.T. 2016. Industrial Water Mass Balance as a Tool for Water Management in Industrial Parks. *Water Resources and Industry*. 13. 14-21
- [23] Kusumadewi. R. Y., Bagastyo. A. Y. 2016. Perencanaan Instalasi Pengolahan Air Limbah Kegiatan Peternakan Sapi Perah dan Industri Tahu. *Jurnal Teknik ITS Vol.5, No. 2*. D98-D102
- [24] Febrianti. N. 2010. Analisis Evapotranspirasi Klimatologi Kabupaten Jawa Barat. *Prosiding Seminar Nasional Sains Atmosfer*. 16 Juni. Bandung. 375-382
- [25] Fitri. A., Ulfa. A. 2015. Perencanaan Penerapan konsep Zero run-off dan Agroforestri Berdasarkan Kajian Debit Sungai di Sub DAS Belik, Sleman, Daerah Istimewa Yogyakarta. *Jurnal Perencanaan Wilayah dan Kota*. Mol26. No 3. 192-207
- [26] Tagar. A., Chandio. F. a., Mari. I. A., Wagan. B. 2012. Comparative Study of Drip and Furrow Irrigation Methods at Farmers's Field in Umartot. *Internation Journal of Biological, Biomolecular,*