Proposing water balance method for water availability estimation in Indonesian regional spatial planning

A T Juniati1*, D Sutjiningsih1, H Soeryantono1, E Kusratmoko2

1Civil Engineering Department, Faculty of Engineering, Universitas Indonesia, Depok, Indonesia
2Geography Department, Faculty of Mathematics & Natural Sciences, Universitas Indonesia, Depok, Indonesia

*Corresponding Author: atietrij@gmail.com

Abstract. The water availability (WA) of a region is one of important consideration in both the formulation of spatial plans and the evaluation of the effectiveness of actual land use in providing sustainable water resources. Information on land-water needs vis-a-vis their availability in a region determines the state of the surplus or deficit to inform effective land use utilization. How to calculate water availability have been described in the Guideline in Determining the Carrying Capacity of the Environment in Regional Spatial Planning. However, the method of determining the supply and demand of water on these guidelines is debatable since the determination of WA in this guideline used a rational method. The rational method is developed the basis for storm drain design practice and it is essentially a peak discharge method peak discharge calculation method. This paper review the literature in methods of water availability estimation which is described descriptively, and present arguments to claim that water balance method is a more fundamental and appropriate tool in water availability estimation. A better water availability estimation method would serve to improve the practice in preparing formulations of Regional Spatial Plan (RSP) as well as evaluating land use capacity in providing sustainable water resources.

Keywords: hydrological model, regional spatial plan, spatial and temporal variability, water availability, water balance

1. Introduction

Nature research field has been lately in focusing on the full integration of water resources aspects into spatial planning. Establishing strong connection between regional spatial plans and water resource management has been found to be able to prevent undesirable consequences of poor water resource management [1], [2], [3], [4], [5]. Spatial planning has a major impact in directing river basin management and is crucial in solving to water related problems [6].

Water related environmental problems; e.g. flood, landslides, and droughts; are often the effects of changes in land use as a consequence of regional spatial planning that lacks consideration to environmental carrying capacity [7]. Integrating water resource management pattern and regional spatial planning is expected to reduce such problems that accommodate competing land use interests. The relationship between water management patterns and spatial plan is dynamic and one should be able to adjust according to the other. The pattern used to manage water resources should be a key consideration in developing or revising spatial plans, likewise, water policies should be founded on existing spatial plans [4].
To address this problem, as well as to fulfill the legal mandate of the Explanandum of Article 25 of Law No 26/2007 on Spatial Planning, there is a need to set a Guideline to Determine Environmental Carrying Capacity in Regional Spatial Planning. The main purpose of this Guideline is an attempt in estimating regional carrying capacity. However, it will also be useful in the review and evaluation of actual spatial use, to be aligned with environmental carrying capacity.

The Guideline to Determine Environmental Carrying Capacity in Regional Spatial Planning (addendum to the Ministrial Regulation No 17/2009) states that environmental carrying capacity is considered to contain two components: environment’s capacity to supply resources (supportive capacity) and; its capacity to assimilate refuse and waste (assimilative capacity). Carrying capacity is essentially the region’s capacity to fulfill needs and therefore directly related to the availability and needs of land and water in an area/region. Since natural resource capacity depends on ability, availability, and needs upon land and water; the assessment of environmental support capacity in The Guideline is performed using three approaches, i.e. i). Regional land capacity to accommodate space utilization, ii). Ratio of land availability vis-à-vis land needs, iii). Ratio of water availability vis-à-vis water needs.

The integration of water management pattern with regional spatial plans is rely in the third approach. Water support in a regional system is considered in surplus when the water available in the system is sufficient to balance the water needs of the region, and considered in deficit otherwise [7].

Water availability is determined using a runoff coefficient method based on land use and annual rainfall information. Meanwhile, water need is calculated using a conversion result against decent living necessities. The calculation using runoff coefficient method as a modification from rational method uses this following equation:

\[ C = \frac{\sum (c_i \times A_i)}{\sum A_i}; \quad R = \frac{\sum R_i}{m}; \quad SA = 10 \times C \times R \times A \quad (1) \]

Where, SA = water availability (m$^3$/year), C = weight runoff coefficient, Ci = land use runoff coefficient I, Ai = area of land use i (ha), R = average of the regions annual rainfall (mm/year), Ri = yearly rainfall on observation station I, m = the number of rainfall observation station, A = area of the region (ha), 10 = converting factor from mm.ha to mm.m$^3$.

However, the method of determining the supply and demand of water on these guidelines, need to be improved, since the determination of water availability (SA) in this guideline uses a rational method.

The rational method has served as the basis for United States storm drain design practice since the turn of the twentieth century, where water condition is characterized by small drainage areas and a short time of concentration [8, 10]. It is essentially as a peak discharge method [11, 12].

Based on these problems, literature study will be conducted to study the alternative methods used by previous researchers to calculate water availability.

This paper argues the use of rational method as a means of determining water supply and demand is not suitable due to several reasons and that Guideline can be improved through the use of different methodologies.

2. Research Method

To write this paper, a review of literature of national and international journals will be performed, specifically on water availability research, is then described descriptively. As the first step of the research activities, the library study will be conducted from various scientific publications, focused on the aspects of water availability definition to the method of estimating WA.

3. Results and Discussion

Recent concept of water availability distinguishes two kinds of water sources: blue and green water. Blue water is defined as the water parts in the river, lakes, and ground water reserves available and directly consumable by people, either for agriculture, industry, or household consumptions. While green water is defined as water stored in the soil as ground moisture, available to be used by plants and vegetations before getting into the air through evapotranspiration processes [13], [14], [15], [16].
Water availability in river basin is affected by several factors, such as climate, soil topography and geology, and variety of vegetation lies above ground. Water availability in river basin is the minimum flow velocity during rain and dry seasons, measured in the river basins output/outlet [17].

Water measured in the outlet point is called surface runoff, whereas it consists of surface water and ground water that will be considered potential water source to be used as water supply for various human needs [18]. Further, water availability is defined by [19] as the total volume of river flow from water catchment area. Accordingly, water balance equation is often used for basic analysis of water availability in a region, e.g. to estimate the amount of water available for drinking or irrigation, Q or runoff is used [18].

To ensure availability of adequate water for human use, water resource managers need to be able to estimate the amounts of water that enter, pass through, and leave individual watersheds. This is a challenge because the relative magnitudes of the transfers of individual components in the hydrologic cycle can vary greatly [20]. In the hydrologic cycle, water availability can be estimated from the amount of water that can be utilized/storage, Figure 2 [21].

In the global hydrologic cycle a given molecule of water is always in one of the storage components of Figure 2. The term “storage” often connotes a static situation, water is always moving through any control volume. Water in the hydrologic cycle is always in motion and always in storage, and any hydrologic control volume represents storage. In many hydrologic reservoirs, such as lakes, segments of rivers, ground-water bodies, and watersheds, the outflow rate increases as the amount of storage increases. This research is focused on water needs for spatial planning purpose, the water availability to be studied is only surface water and groundwater storage.

3.1. Surface Water Availability Estimation

To date, there is a limited but growing number of model approaches dealing with water availability analysis. Most of these models are based on hydrologic water balance approach with time steps ranging between daily, monthly to annually. Among the most well known models is SWAT. The Oregon Water Resources Department (Department or OWRD) has created and maintains a database of the amount of surface water available for appropriation for most waters in the state. This database is used to evaluate applications for new uses of water [22]. Water availability (WA) is obtained from natural stream flow (QNSF) by subtracting existing storage (ST), out-of-stream
consumptive uses (CU) and in-stream demands (IS). The water availability methodology defines three types of expected demands: (1) Storage, (2) Consumptive uses, and (3) In-stream demands. Then water availability can be defined in this equation: $WA = QNSF - ST - CU - IS$. Where, $WA$= the water available, $QNSF$= the 80-percent exceedance natural stream flow at a specified point on the stream, $ST$= Storage in or from the stream and its tributaries upstream from the specified point, $CU$= Consumptive uses from the stream and its tributaries upstream from the specified point, $IS$ = In-stream flow demands for a stream reach that includes the specified point.

![Figure 2. The principal storages (boxes) and pathways (arrows) of water in the global hydrologic cycle.](image)

A case study in Tasmania carried out by [19] used for conducting large-scale assessments of current and future water availability and use. This study describes a robust methodology for determining current surface and groundwater availability and use, as well as future changes due to climate and land use changes. The methodology assesses current water availability through the application of rainfall–runoff and river models, and recharge and groundwater models. These were calibrated to stream flow records and groundwater levels, and parameterised using estimates of current surface and groundwater extractions and use.

3.2. Water Availability Estimation
Researchers in other countries such as [19, 23, 24] also in Indonesia [25, 31] defined water availability as river discharge, while [14] defined water availability as surface and ground water, [15] defines it as blue water. Most researchers calculate the water availability using the principle of water balance (WB) by hydrologic water balance. The WB principles are then used in the model, such as the distributed hydrological model "Soil and Water Assessment Tool" (SWAT). Some researchers were used SWAT to calculate water availability, such [14, 23, 24, 25, 28] while others used hydrological models such as
Mock, Nrec, Rainrun [26, 27, 29, 32]. In addition, some other researchers [30, 33, 34] were used long-term discharge data to predict water availability.

4. Conclusion

Water availability in a river basin, according to hydrology cycle, is storage. Thus, water availability for spatial planning is surface water and ground water. Surface water availability according to several researchers is river discharge and ground water. The most fundamental tool for calculating water availability is the water budget. A common method used by Indonesian researchers to estimate water availability is water balance method such as SWAT, Mock, EnReca, and Rainrun. Further research would be better aimed towards a search for a feasible and suitable water balance method to be used in Indonesia.

References

[1] G. Bouma, and A Slob. 2014. Risk-Informed Management of European River Basins, Handb. Environ. Chem. 29, DOI 10.1007/978-3-642-38598-8_12, ©Springer-Verlag Berlin Heidelb. 29:321–345.
[2] G Jeremy. 2007. Spatial planning, water and the Water Framework Directive: insights from theory and practice. Geogr. Journal; ProQuest. 173(4):330–342.
[3] S K, and D Shaw. 2007. Integrated Water Resource Management and Institutional Integration: Realising the Potential of Spatial Planning in England. Geogr. Journal. 173(4):312-329.
[4] P R Sianjir. Mitigasi Resiko Bencana Sumber Daya Air. Infl. 1–10. 2011.
[5] J Woltjer, and N Al. 2007. Integrating Water Management and Spatial Planning: Strategies Based on the Dutch Experience. Am. Plan. Assoc. J. Am. Plan. Assoc. 2:211.
[6] J Alahuhta, V Hokka, H Saarikoski, and S Hellsten. 2010. Practical integration of river basin and land use planning: lessons learned from two Finnish case studies. Geogr. J. 176(4):319–333.
[7] Anonim, Lampiran Peraturan Menteri Negara Lingkungan Hidup Nomor:17 Tahun 2009, tentang Pedoman Penentuan Daya Dukung Lingkungan Hidup Dalam Penataan Ruang Wilayah. Indonesia: Indonesia, Kemendikbud, Kementrian Lingkungan Hidup, p. 1–31, 2009.
[8] V Te Chow, D Maidment R, and L Mays W, Applied Hydrology, McGraw-Hill, Inc., p. 548. 1988.
[9] S A Thompson, Hydrology for Water Management. USA: A.A. Balkema Publishers, Old Post Road, Brookfield, VT 05036–9704, USA, p. 377. 1999.
[10] R H McCuen, Hydrologic Analysis and Design, Second Ed., Prentice Hall, Inc, Upper Saddle River, New Jersey 07458, p. 833, 1998.
[11] ASCE, Hydrology Handbook (Manual No. 28), Second. ASCE 345 East 47th Street. New York, NY 10017–2396, p. 825, 1996.
[12] H M Ragunath, Hyrology, Principle, Analisys, Design., Second ed., New Delhi: New Age International (P) Ltd., Publishers, p. 477, 2006.
[13] M Falkenmark. 2006. The New Blue and Green Water Paradigm: Breaking New Ground for Water Resources Planning and Management. J. Water Resour. Plan. Manage. ASCE. 6:129–132.
[14] J Schuol, K C Abbaspour, R Srinivasan, and H Yang. 2008. Estimation of freshwater availability in the West African sub-continent using the SWAT hydrologic model, J. Hydrol. 352(1–2):30–49.
[15] L Menezel, and A Matovelle. 2010. Current state and future development of blue water availability and blue water demand: A view at seven case studies. J. Hydrol. 384(3–4):245–263.
[16] C P Kumar, Water Balance Analysis, Natl. Inst. Hydrol. Roorkee – 247667, vol. 247667.
[17] F Irsyad, Analysis of Cidanau River Discharge using SWAT Application (Analisis Debit Sungai Cidanau dengan Aplikasi SWAT). Institut Pertanian Bogor. Bogor, Indonesia, 2011.
[18] C S Ojha, R Berndtsson, and P. Bhunya, Engineering Hydrology, Oxford University Press, p. 440. 2008.
[19] D A Post, F H S Chiew, J Teng, N R Viney, F L N Ling, G Harrington, R S Crosbie, B Graham, S Marvanek, and R McLoughlin. 2012. A robust methodology for conducting large-scale assessments of current and future water availability and use: A case study in Tasmania, Australia, *J. Hydrol.*, 412–413:233–245.

[20] S K Gupta, Modern hydrology and sustainable water development, First. UK and USA: John Wiley & Sons, p. 464. 2011.

[21] S L Dingman, Physical Hydrology, Third Ed. United States of America: Waveland Press, Inc., p. 657. 2015.

[22] R M Cooper, Determining Surface Water Availability in Oregon, State Oregon Water Resour. Dep. 2002.

[23] T B Le, River Basin Scale Hydrologic Modeling For Prediction of Water Availability, Dissertation. Presented to the Graduate Faculty of The University of Texas at San Antonio, in Partial Fulfillment of the Requirements for, the Degree of Doctor of Philosophy in Environmental Science and Engineering. 2014.