International Journal of GEOMATE, Nov., 2023 Vol.25, Issue 111, pp.24-32
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.111.3853
Geotechnique, Construction Materials and Environment

# WATER BUDGET ASSESSMENT UNDER RAPID URBANIZATION IN YOGYAKARTA, INDONESIA USING A DISTRIBUTED WATER BALANCE MODEL

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*Corresponding Author, Received: 11 Mar. 2023, Revised: 22 Aug. 2023, Accepted: 05 Sep. 2023

**ABSTRACT:** Rapid urbanization has increased the challenge of freshwater provision for the urban population. Modelling water balance can help visualizing the occurrence in a hydrological system due to urbanization that is beneficial for future water-resource management. A hybrid distributed monthly water balance model adopted from Xinanjiang model and TOPMODEL by (Chen et al. 2007) has succeeded to simulate the distributed water storage in a catchment area and applied to the water resources change assessment by districts in peri-urban area of Yogyakarta City, Indonesia. The hybrid model was modified to include water uptake in urban area. The optimized model estimated monthly river discharge with R = 0.77. The model demonstrated the saturation distribution change by the intensified water uptake in expanded urban area especially in dry season. The model simulation could point out the sensitive districts of which water storage possibly decrease caused by the urbanization progress.

*Keywords: Urbanization, Water Balance, Monthly Distributed Model, Water Storage, Yogyakarta*

## 1. INTRODUCTION

Water is an essential element for life, industry and society. According to the US Geological Survey there is only less than 10% of Earth's surface and ground water is available for human being in the form of freshwater. Chow [1] has explained the total volume of freshwater is globally constant. However, water moves through a cycle process with the energy from the sun and the gravity force thus its distribution varies regionally. Moreover, the UN-Water [2] reported rapid urbanization growth has increased the challenge of freshwater provision for the urban population. In addition, the challenge is worsened by land conversion into urban use [3].

In Southeast Asia, urbanization process has a distinguished characteristic because the rapid urban expansion occurs not only in metropolitan cities but also in the small to medium sized cities due to the shifting employment sectors from agriculture to industry-oriented economy [4]. Woltjer [5] has identified this urban expansion sets off the emerge of peri-urban area as the center of rapid urban activities that has a fusion of urban-rural economic activities. The perimeter of peri-urban area is very dynamic thus the authority to provide access to urban infrastructure to the inhabitants, including water service connection, is still problematic that may lead to informal water uptake in an exploiting way which is not supporting the achievement of Sustainable Development Goals (SDGs).

Urbanization as an occurrence of urban expansion and population growth creates more pavements that disrupt the water cycle, especially when it occurs in the catchment area [6,7]. The rapid rate of urbanization often goes beyond the rate of water cycle adjustment. An example is a small city in the northeastern Thailand where urbanization increases the domestic water use per capita at 1.48 times higher than the national standard and the water use conflict between mix urban-agricultural land use pose the city to water crisis threat in the future [8]. Independent studies in small-medium city in Spain and in the US show that urban development pattern is significantly affecting the water consumption of the inhabitants. Urban sprawl with low density housing is more likely to experience water shortage with higher intensity and duration than that of the high-density pattern [9,10].

In order to support the decision-makers in creating sustainable water use policy to achieve the SDGs, plausible assessment to water resource availability is urgently needed. Understanding the extent of urbanization to the water cycle condition is prerequisite for appropriate water resource assessment [10]. Water balance is one scientific conception applicable for the shorthand assessment of impacts of urbanization to water cycle in a hydrological system. The concept of water balance is basically tracing the balance of changes in the amount of inflow and outflow in a hydrological system for a specific period of time [11,12]. In regard to water resource assessment in urban area, it is crucial to identify the complete water cycle in the urban system that is the amount of water inputs to the hydrological system and the amount that arrives at the urban inhabitants as the main user [13,14]. There are few water balance studies incorporating the water quantity that reaches the end users, such as in [13,15]. Therefore, in this study, the water use by population is taken into account as a variable of outflow in the urban water system. Despite the complexity of the real water cycle process in a hydrologic system due to many factors, such as climate, topography, geology, and land cover [1], a simple water balance approach can potentially provide a brief prediction of water cycle change by urbanization.

Modelling a water cycle can help visualizing the occurrence in a hydrological system due to terrain and atmospheric transformations that is beneficial for future water-resource management, such as for estimating the regional water availability [16], for assessing the impact of land use change on the river discharge [17], and for assessing the impact of land use change on the climate alteration [18]. Basically, there are three types of structure to model water cycle, such as empirical, conceptual, and physical, with their own distinctiveness [19]. Empirical and conceptual models are relatively simpler and faster in calculation as they consider the entire catchment as one hydrological unit at a specific time, disregarding any spatial resolution, which is good for simulating just the average hydrological conditions [19,20]. They cannot accommodate the need to assess the sources of water supply (e.g., the existing and the potentially installed wells) over a catchment area. In this case, the distributed-physical model that incorporates spatial variability in land use, slope, and topography at a small-scale unit of location (e.g., grid cell) such as WetSpass in Adigrat area, Nortern Ethiopia [21] and in Black Volta Basin, West Africa [22] is better to apply. However, distributed-physical models were rarely applied in Southeast Asia due to the data-extensive input. Indonesia is one country in Southeast Asia that is still facing such technical challenges to provide periodical and consistent water-related that hamper the integrated water resources management (IWRM) due to intricate water-related issues [23]. Moreover, most population access water directly from the shallow aquifer using self-installed dug-well, which are not registered in the municipality that makes it is hard to monitor the state of water availability periodically [24]. This challenge is even harder in peri-urban due to the vague perimeter of urbanization in the area. A study of [25] using the gridded Variable Infiltration Capacity (VIC) Land Surface Model (LSM) in Java Island, Indonesia showed unsatisfactory performance due to a combination of inconsistent data quality, outliers in hydrometeorological data for validation process, and over-fitting parameters for the model calibration. Both WetSpass and VIC includes soil heterogeneity as spatial variation [20] which may be hard to acquire in Southeast Asian countries. Therefore, the objective of this study is to assess the water balance using a feasible monthly distributed model to visualize the distribution of water storage and saturation in high resolution with data inputs from the catchment area in peri-urban of Yogyakarta City, Indonesia from 2010 to 2050. This will help decision-makers in developing policies and strategies for IWRM to meet the future water demand without jeopardizing the quantity of the available water resource.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

Yogyakarta City is located in 7° 47' S in latitude and 110° 22" E in longitude. Urban expansion to the north and south suburbs generates an agglomeration area namely Kartamantul (e.g., Yogyakarta City, Sleman Regency, and Bantul Regency) covering approximately 100,000 hectares (ha) of area (Fig. 1(a)). Since 2001, the urban development in Kartamantul has been managed by an inter-governmental institution namely Joint Secretariat of Kartamantul.

The area has a tropical climate with an annual average temperature of 26.5°C and an annual average humidity of 85%. Rain falls monthly throughout the year with an average annual precipitation of 2681 mm, but the highest precipitation occurs between December and May.

Coincidently, Kartamantul shares similar hydrological system of Opak catchment of Merapi Aquifers System (MAS) that extents from the slope of mount Merapi at 2930 meters above sea level (MASL) down south to Indian Ocean coast in the altitude range of 15m-700m with the slope of 0%-15%. Opak catchment area consists of unconfined aquifer in the top (shallow aquifer) which is inter-connected with confined aquifer in the bottom (deep aquifer) and its catchment area covers the most part of Sleman Regency [26]. The slope is symmetry around the peak of Merapi, and the geology is homogeneous with volcanic sediments. The upper slope above 500 MASL is the recharge zone of deep aquifers, and springs and streams connected with shallow aquifers occur below this elevation [27].

The study area is predominantly covered by agricultural land. According to Statistics Indonesia 2020, the total population of Kartamantul is 3.7 million with annual population growth of 1.61%.

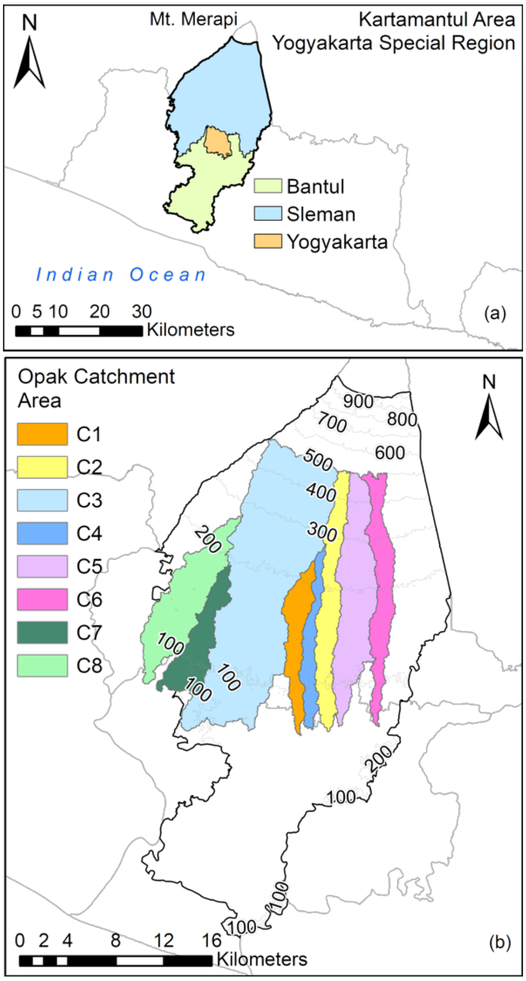


Fig.1 Study area for water resources change assessment in Yogyakarta urban agglomeration area; (a) Kartamantul area in Yogyakarta Special Region; (b) Sub-catchments in Opak catchment area for model calculation (see section 2.4).

Only 10.18% of the total population lives in Yogyakarta City. The highest percentage of the population stays in Sleman Regency (30.69%) followed by Bantul Regency (26.87%). The rest of population are living in rural area of the province. The Japan International Cooperation Agency [24] described the water resources for municipal water service in Kartamantul area were pumped from natural springs, shallow aquifer, and deep aquifer in 2004-2005. During that period, the total water consumption is dominated by domestic use in all three regions. However, the service ratio of municipal water was very low even for the Yogyakarta City (e.g., 37.9%), followed by Sleman Regency at 9.9% and Bantul Regency at 6.3% in 2005.

### 2.2 Monthly Distributed Water Balance Model

This study applied a distributed model adopting a hybrid of the physics-based Xinanjiang model [28] and the conceptual TOPMODEL [29] constructed by [30] using monthly precipitation inputs and optimization of certain parameters. Devi et al. [20] suggested that TOPMODEL is best used in a catchment area with shallow soil and moderate topography. The concept of TOPMODEL responds to the spatial variability with statistics of the topography that can be integrated to Xinanjiang model`s simulation to estimate the distribution of water storage capacity of a large catchment area. The model allows a long time-interval (monthly) and high spatial-resolution water balance simulation. To incorporate water consumption term by urban population in the calculation would be our modest modification to the original model of [30].

In order to assess the water resource change in the catchment area in peri-urban of Yogyakarta City, Indonesia under urbanization, monthly water balance is simulated, and then the distribution of saturation was assessed as a proxy indicator of ground water recharge. Model validation and calibration were done before simulation based on river discharge observation.

### 2.3 Data Collection and Preparation

In order to apply the monthly distributed water balance model for Opak River catchment area, a 30 m resolution digital elevation map processed from a satellite SAR images (AW3D30) was used for a topography map. Due to limited observation data, we used the hydrological data of only 24 months in 2012-2013 from Balai Besar Wilayah Sungai-Serayu Opak (BBWS-SO) of Yogyakarta Special Region Province including monthly rainfall at 3 rainfall monitoring stations, such as Station Santan (110.44E, 7.79S), Station Tanjungtirto (110.46E, 7.78S), and Station Beran (110.36E, 7.72S), and monthly river discharge at Station Wonokromo (110.39E, 7.87S). Potential evapotranspiration was calculated by Thornthwaite Mather method [17] from monthly air temperature at Station Plunyon (110.42E, 7.59S). Due to the data availability limitation, the hydrological data in 2012 and 2013 was commonly used for the water balance simulation in the control year and future.

The land use data of urban (U) and non-urban (NU) area in 2010 (control year) and 2050 (future) was predicted from the Land Change Modeler (LCM) using multitemporal LANDSAT-5TM image in 100 m resolution from our previous study [31]. Meanwhile, population data is derived from Statistics Indonesia in each respective year. Water consumption per capita was taken from [32].

### 2.4 Water Balance Simulation and Water Resources Assessment

Water balance simulation consisted of the following processes; segmenting the study area to sub-catchments and calculating topographic index; modeling and optimizing the distributed monthly water balance model and validating accuracy; calculating monthly water balance of the sub-catchments and predicting the saturated regions as a proxy of ground water resources map.

The study region was segmented into sub-catchments from the AWD3D30 high resolution (30 m) elevation map by the channel network and drainage basins module of SAGA 7.8.2 [33] processed on QGIS ver. 3.28.3 [34]. Eight sub-catchments in Opak catchment area which overlapped the study area were selected from the ten segmented ones, and the two sub-catchments in the east and west border that collect water from outside of the study area were excluded (see Fig. 1(b)). The upper slopes of the sub-catchments were eliminated by the contour line at 500 m because the precipitation above the line is mostly transferred to deep aquifers than to the shallow aquifers and streams [17]. The area of the sub-catchments was from 13.9 km$^2$ to 146.0 km$^2$ and 346.0 km$^2$ in total. A catchment that discharges at Station Wonokromo was also segmented for the purpose of model optimization and validation, of which area was 99.2 km$^2$.

Topographic index (TI) of the sub-catchments was calculated using the topographic water index module of SAGA 7.8.2 after calculating the slope angle and the flow accumulation area of cells. The TI value represents the soil moisture capacity variable of each cell in the study area. The higher TI means the higher capacity of soil to generate runoff. The TI is converted to index of relative difficulty of runoff generation (IRDG) variable using min-max normalization method to be incorporated to the monthly model [30]. The IRDG represented the N-th segment of soil moisture, $W_t$, corresponds to the fraction the scale of discretized IRDG by an interval of 0.1, therefore, the total N = 1000 for each sub-catchment.

The distributed monthly water balance model [30] was implemented and run on R Statistics 4.2.2 [35] and the geographic packages of raster 3.6.14 [36] and sf 1.0.9 [37]. The model was modified to input ground water uptake and monthly water balance was redefines as below.

$$W_t = W_{t-1} + P_t - E_t - R_t - U_t \tag{1}$$

where, $W_t$ is catchment storage of month $t$, $P_t$, $E_t$, $R_t$ , and $U_t$ are monthly precipitation, evapo-transpiration, runoff, and uptake, respectively. $W_t$ corresponds the cumulative normalized TI, thus, it also corresponds the distribution of saturated cells in a catchment. Note that the term of "saturation" was defined as the soil water state exceeding a field capacity and thus runoff and drainage are occurring in this study. $E_t$ and $R_t$ are the functions of $W_t$ (refer [30] for detail). $U_t$ was given by the water consumption per capita [32], population density, and urban area in the sub-catchments, therefore, its change by urbanization was predicted from 2010 and 2050.

The model has three adjustable parameters: the maximum soil moisture storage capacity in a catchment area (WMM); conversion coefficient from pan evaporation to potential evaporation ($\eta$); and runoff regulation parameter ($\alpha$) [30]. These parameters were optimized by optim() function in R Statistics to minimize the error between observed and simulated river discharge at Station Wonokromo of 24 months in 2012 and 2013. These parameters were assumed to be constant among the sub-catchments in the study region. This assumption is reasonable because the geological and topographic features that affect WMM, and climatic condition that affects $\eta$ were considered to be homogeneous in the region, and $\alpha$ has no contribution for the water balance calculation but river discharge.

Finally, the monthly distribution of saturated cells was mapped from calculated $W_t$ by the sub-catchments and aggregated to the whole catchment. The model simulates soil water storage which directly interacts with stream flow and does not consider ground water. However, ground water recharge and discharge must closely correlate the soil water balance in relatively flat and homogeneous hydraulic system. Therefore, we utilized the change of saturated cell distribution as a proxy indicating the relative change of ground water resources recharge. We assessed the seasonal change of saturated cells as well as the change by urbanization between 2010 and 2050.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Optimizing Water Balance Model

Observed and modeled river discharge at Station Wonokromo of 24 months in 2012 and 2013 are shown in Fig. 2. The optimized model parameters of the distributed monthly water balance model for Opak catchment area were WMM = 524.8 mm, $\eta$ = 0.896, and $\alpha$ = 0.418. Correlation between observed and simulated river discharge in 24 months showed strong similarity with R = 0.77 and mean absolute percentage of error was 39%. Therefore, the monthly model was acceptable to use for water balance assessment in the study area.

### 3.2 Predicted Water Balance Change in Catchments

Monthly water balance of the 8 sub-catchments was simulated for 24 months by using predicted water uptake in 2010 and 2050. Table 1 below is an example of monthly water balance simulation of sub-catchment C3 in 2010.

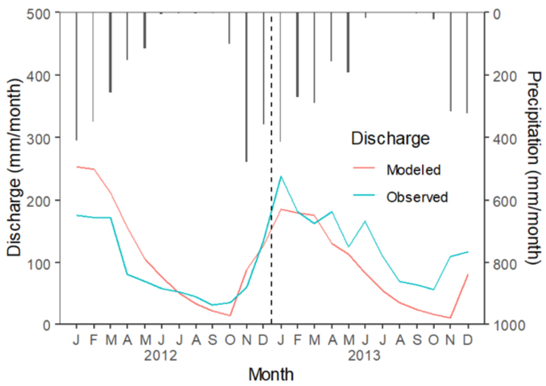


Fig. 2 Hydrograph of observed and modeled monthly river discharge at Station Wonokromo with monthly precipitation of 24 months in 2012 and 2013 for the validation of distributed monthly water balance model.

Table 1 An example of monthly water balance simulation of sub-catchment C3 in 2010 using 24 months data of 2012 and 2013 sequentially. The units are in mm/month excluding that of mm for $W_t$.

| Month | $P_t$ | $E_t$ | $U_t$ | $R_t$ | $W_t$ | $Q_t$ |
|---|---|---|---|---|---|---|
| 2012 | | | | | | |
| 1 | 412.1 | 98.6 | 14.2 | 268.6 | 255.7 | 268.6 |
| 2 | 350.3 | 86.8 | 12.8 | 250.7 | 255.7 | 262.5 |
| 3 | 257.0 | 98.4 | 14.2 | 144.4 | 255.7 | 222.1 |
| 4 | 153.0 | 83.9 | 13.8 | 55.4 | 255.7 | 165.1 |
| 5 | 115.0 | 85.9 | 14.2 | 67.6 | 203.0 | 131.8 |
| 6 | 4.9 | 61.4 | 13.8 | 0.0 | 132.8 | 86.8 |
| 7 | 0.7 | 56.8 | 14.2 | 0.0 | 62.5 | 57.1 |
| 8 | 2.7 | 29.6 | 14.2 | 0.0 | 21.4 | 37.6 |
| 9 | 1.1 | 11.9 | 13.8 | 0.0 | 0.0 | 24.8 |
| 10 | 100.0 | 0.0 | 14.2 | 0.0 | 85.8 | 16.3 |
| 11 | 481.7 | 49.8 | 13.8 | 248.2 | 255.7 | 95.6 |
| 12 | 357.3 | 134.0 | 14.2 | 209.1 | 255.7 | 134.4 |
| 2013 | | | | | | |
| 1 | 414.4 | 97.9 | 14.2 | 302.3 | 255.7 | 191.8 |
| 2 | 270.2 | 80.4 | 12.8 | 177.0 | 255.7 | 186.7 |
| 3 | 290.2 | 98.1 | 14.2 | 177.9 | 255.7 | 183.7 |
| 4 | 157.4 | 95.7 | 13.8 | 47.9 | 255.7 | 137.3 |
| 5 | 190.2 | 89.8 | 14.2 | 86.2 | 255.7 | 119.8 |
| 6 | 16.4 | 80.2 | 13.8 | 6.6 | 171.6 | 81.1 |
| 7 | 0.2 | 66.7 | 14.2 | 0.0 | 90.9 | 53.4 |
| 8 | 0.0 | 35.3 | 14.2 | 0.0 | 41.4 | 35.2 |
| 9 | 1.1 | 18.2 | 13.8 | 0.0 | 10.5 | 23.1 |
| 10 | 22.1 | 6.1 | 14.2 | 0.0 | 12.3 | 15.2 |
| 11 | 317.4 | 7.0 | 13.8 | 0.0 | 255.7 | 10.0 |
| 12 | 325.7 | 88.9 | 14.2 | 222.6 | 255.7 | 82.7 |

*Note: $P_t$ = precipitation; $E_t$ = evapo-transpiration; $U_t$ = uptake; $R_t$ = runoff; $W_t$ = water storage; $Q_t$ = river discharge.*

The water balance components of all sub-catchments were aggregated in the whole catchment by area weighted average. The monthly values were then averaged in wet (from December to May) and dry (from June to November) seasons (see Table 2). There was a clear contrast of the water balance between wet and dry seasons; the higher evapotranspiration ($E_t$), runoff ($R_t$), and saturation in wet season.

As the predicted water uptake ($U_t$) was increased from 15 mm/month in 2010 to 23 mm/month in 2050 due to urbanization, water storage ($W_t$) significantly decreased from 250.2 mm to 155.6 mm and from 96.9 mm to 89.6 mm in wet and dry seasons, respectively.

Table 2 Average monthly water balance of Opak catchment area in wet and dry seasons by the model simulation using water uptake in 2010 and 2050.

| | Monthly flux (mm/month) | | | | $W_t$ (mm) | Avg_sat |
|---|---|---|---|---|---|---|
| | $P_t$ | $E_t$ | $U_t$ | $R_t$ | | |
| WS_10 | 274.4 | 94.7 | 14.8 | 164.7 | 250.2 | 0.983 |
| DS_10 | 79.0 | 36.4 | 14.9 | 19.3 | 96.9 | 0.381 |
| WS_50 | 274.4 | 94.3 | 23.1 | 155.6 | 155.6 | 0.971 |
| DS_50 | 79.0 | 33.4 | 23.2 | 11.0 | 89.6 | 0.352 |

*Note: $P_t$ = precipitation; $E_t$ = evapo-transpiration; $U_t$ = uptake; $R_t$ = runoff; $W_t$ = water storage; Avg_sat = average saturation; WS = wet season (from December to May); DS = dry season (from June to November); _10 and _50 denote 2010 and 2050, respectively.*

As Table 2 shows that the whole catchment was almost fully saturated in wet season, there is no discrepancy in 2010 and 2050 to assess distribution of saturated cells. Thus, the distribution of saturated cells over the catchment area by water uptake in 2010 and 2050 was compared only in dry season (Fig. 3). High saturation area is mainly distributed along streams and the upper slope of the catchment area tended to have relatively high saturation. The maximum cell's saturation within the catchment area were showing decreasing trend, from 0.744 in 2010 to 0.655 in 2050.

### 3.3 Urbanization and Water Resource Change Assessment

The effect of urbanization to hydrology system from 2010 to 2050 was shown in the decreased of soil moisture or "saturation" level which is similar to infiltration. The average cell's saturation showed decreasing trend of potential water resources in almost all districts due to predicted urbanization from 2010 to 2050. The potential water resources change due to urbanization process were assessed by the change in average cell's saturation from 2010 to 2050 in persistent urbanized area and the newly urbanized area in 17 districts according to our previous study [31]. The change in persistent

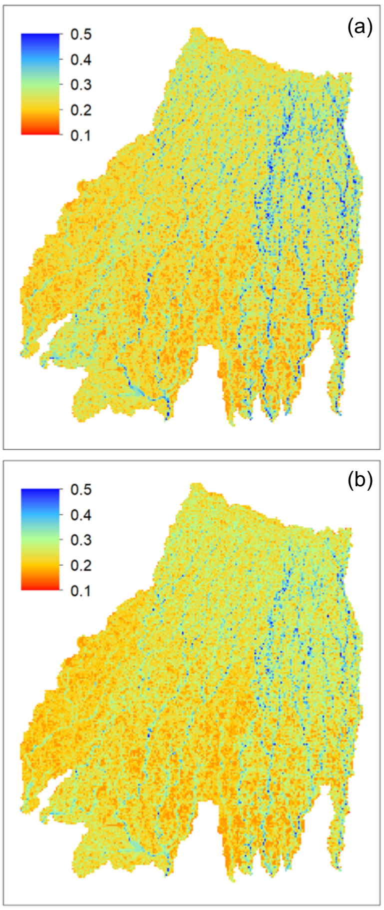


Fig. 3 Distribution of average saturation of Opak catchment area in dry season (from June to November) by the model simulation using water uptake in (a) 2010 and (b) 2050.

urbanized area was estimated by the difference between the average cell's saturation of U class in 2010 and that of the persistent U class in 2050, whereas the difference in newly urbanized area were estimated from the average cell's saturation of NU in 2010 and that of the NU in 2010 which were changed into U in 2050.

The predicted urbanization in most districts showed considerable increasing trend from 2010 to 2050 as presented in Fig. 4 except for district nos. 15, 16, 19, 21, 22, 24, and 26, which were administratively located within Yogyakarta City. The loss of water resources due to urbanization in each district was indicated by the negative value of average cell's saturation level change as demonstrated in Fig. 5 and Table 3.

According to Figs. 4 and 5, most districts in Sleman Regency were facing threat of decreasing potential water resource in various magnitude of change in dry season in 2050. In particular, Table 3 showed the most alarming loss of potential water resource was predicted to be experienced by district no.20 (Umbulharjo) whose average cell's saturation level changes were -0.0056 and -0.0122 in persistent U area and in newly urbanized area,

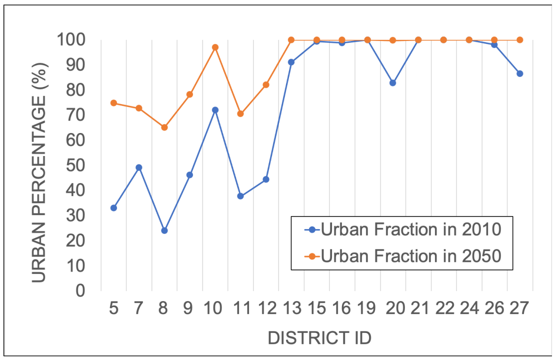


Fig. 4 Urban fraction in 2010 and 2050 in 17 districts according to our previous study [31].

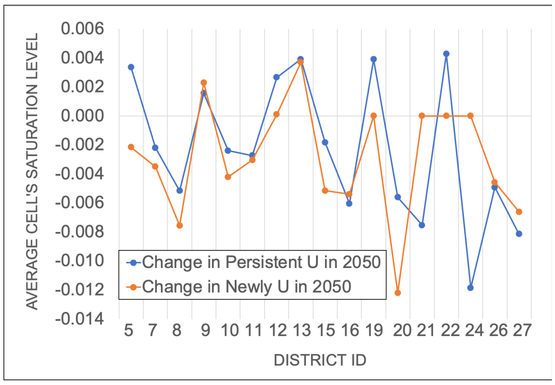


Fig. 5 Change in average cell's saturation level in persistent U (urban) area of 2010 in 2050 and in newly developed U area in 2050.

Table 3 The change in average cell's saturation level in the persistent U (urban) cells and newly U cells in 2050 and the percentage of urban fraction in each district.

| District ID | Average Cell's Saturation Level Change | | Urban Fraction (%) | |
|---|---|---|---|---|
| | Persistent U cells | Newly U cells | 2010 | 2050 |
| 5 | 0.0033 | -0.0022 | 33.1 | 74.8 |
| 7 | -0.0022 | -0.0035 | 49.2 | 72.7 |
| 8 | -0.0052 | -0.0076 | 24.0 | 65.1 |
| 9 | 0.0016 | 0.0023 | 46.2 | 78.2 |
| 10 | -0.0024 | -0.0042 | 72.1 | 97.0 |
| 11 | -0.0027 | -0.0030 | 37.8 | 70.6 |
| 12 | 0.0027 | 0.0001 | 44.4 | 82.1 |
| 13 | 0.0039 | 0.0037 | 91.1 | 100.0 |
| 15 | -0.0018 | -0.0052 | 99.4 | 100.0 |
| 16 | -0.0060 | -0.0054 | 98.8 | 100.0 |
| 19 | 0.0039 | 0.0000 | 100.0 | 100.0 |
| 20 | -0.0056 | -0.0122 | 82.8 | 99.7 |
| 21 | -0.0075 | 0.0000 | 100.0 | 100.0 |
| 22 | 0.0043 | 0.0000 | 100.0 | 100.0 |
| 24 | -0.0119 | 0.0000 | 100.0 | 100.0 |
| 26 | -0.0049 | -0.0046 | 98.1 | 100.0 |
| 27 | -0.0081 | -0.0066 | 86.6 | 100.0 |

respectively. Coincidently, district no.20 was one of districts in the city that was projected having highest urban growth where urban fraction was 82.8% and 99.7% in 2010 and in 2050, respectively. The next alarming loss was predicted to occur in district no.8 (Seyegan) whose average cell's saturation level changes were -0.0052 and -0.0075 in persistent U area and in newly urbanized area, respectively. District no.8 was having the highest urban growth among all other districts in the suburb where urban area was 24% and 65.1% in 2010 and in 2050, respectively. This phenomenon was also predicted to occur in the suburb, especially in district no.5 (Sleman), no.7 (Ngaglik), no.10 (Depok), and no.12 (Gamping) where the urbanization was still predicted to be dramatically increasing from 2010 to 2050 and the average cell's saturation level change were showing decreasing trend mostly in the newly urbanized area. If the urbanization process within the respective districts were not controlled, the loss of potential water resources was unavoidable.

This result was in accordance with most of water balance calculation that recognized the increase of impervious area and reduction of vegetative area in urbanization has significantly influenced hydrology system in increasing surface runoff, decreasing infiltration, and decreasing evapotranspiration such as in southern China [38] and across the Conterminous United States [39]. In addition, the water resource assessment in this study offered significant improvement to the previous calculation that were only done partially (e.g., one sub-catchment or smaller) without any consideration to topographical factor by [16] and [40] in comparatively similar location. The finding in this study provided holistic investigation of water movement in urban system (e.g., to the pixel unit) that includes topographical factor in a larger extent of catchment area.

## 4. CONCLUSION

Rapid urbanization has increased the challenge of freshwater provision for the urban population. The challenge is worsened by land conversion into urban use. Modelling water balance can help visualizing the occurrence in a hydrological system due to urbanization that is beneficial for future water-resource management. A hybrid distributed monthly water balance model adopted from Xinanjiang model and TOPMODEL by (Chen et al. 2007) has succeeded to simulate the distributed water storage in the catchment area using monthly water balance and incorporating the water uptake in urban area. The optimized model was acceptable to assess the water resources change assessment by districts in peri-urban area of Yogyakarta City, Indonesia since correlation between observed and simulated river discharge showed strong similarity with R = 0.77. The result of model simulation demonstrated the saturation distribution change by the intensified water uptake in expanded urban area especially in dry season. Moreover, the result could point out the sensitive districts of which water storage possibly decrease caused by the urbanization progress. This finding would provide suggestions on the sustainable water management measures at the district level such as to ban informal dug-well installation, to enhance municipal water service, and to facilitate IWRM in the city planning.

## 5. ACKNOWLEDGMENTS

The corresponding author express a great deal of gratitude to Lembaga Pengelola Dana Pendidikan (LPDP) Indonesia for the scholarship to conduct this study.

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