JCE
Journal of Civil Engineering
ISSN 2086-1206 E-ISSN 2579-9029

Urban Drainage System Simulation Using 1D Model, Case Study: North Kembangan Drainage System, Jakarta

Rayhan Airlangga Wijanarko Putra[a*], Satria Damarnegara[a], Yang R. Savitri[a]

Correspondence

[a]Department of Civil Engineering, Institut Teknologi Sepuluh Nopember, ITS Campus, Sukolilo, Surabaya 60252, Indonesia.

Corresponding author email adress:
rayhan.airlangga01@gmail.com

Submitted : 21 April 2024
Revised : 14 June 2024
Accepted : 16 June 2024

Abstract

Jakarta has a high level of urbanization, which causes land use changes and increasing inundation problems. One area that has experienced inundation is North Kembangan with a height of 20 - 30 cm in recent years and so of that the location is included in flood-prone sub-districts. Accordingly, a study is needed to estimate the North Kembangan drainage system actual conditions using the rainfall-runoff transformation model. This study simulates using the Storm Water Management Model (SWMM), and the calibration validation process is accomplished using the Nash-Sutcliffe model efficiency coefficient (NSE) and root mean square error (RMSE) method to evaluate the reliability of the model. The calibration for several model parameters is required to obtain the reliability model, including the channel Manning coefficient, land overflow Manning coefficient, and curve number. The calibration result shows that NSE values are 0,65, and the RMSE is 0,051 based on data in 2021. Then the validation result shows the NSE is 0,62 and RMSE is 0,040 based on data in 2022.

Keywords

Drainage system, inundation, North Kembangan, NSE, RMSE, SWMM

INTRODUCTION

Jakarta, as the center of the national economy, is still experiencing a high level of urbanization, so the need for land as a place to live will also increase. This causes the depletion of green open space, transforming it into impervious land that potentially results in inundation. One of the areas that often experiences inundation is North Kembangan, which is located in West Jakarta. This location has an area of 392,3 ha whose drainage system flows into several rivers, including Kali Angke, Kali Uangan, Cengkareng Drain, Kali Pesanggrahan, and Kali Pesing [1]. The location map of the study region is shown in Figure 1. The incidence of inundation has strengthened the issue of inundation in North Kembangan in recent years with a height of 20 - 30 cm as well as the inclusion of North Kembangan on the list of sub-districts prone to flooding [2].

Based on the problem described, a study is needed to determine the condition of the North Kembangan drainage system when it rains using the rain-discharge transformation model. This research uses the Storm Water Management Model (SWMM) to simulate hydrological and hydraulic models, especially in urban areas [3]. In this study, the calibration and validation process is accomplished using the Nash-Sutcliffe model efficiency coefficient (NSE) and root mean square error (RMSE) method to evaluate the model's reliability level in estimating actual conditions. This process is done by adjusting model parameters and comparing the water level at the outlet based on simulation results with observation data so that the model is expected to describe the existing condition of the North Kembangan drainage system.

This study tries to bring novelty by developing the North Kembangan detailed drainage system model based on the latest hydrological and hydraulic conditions. With a reliable model, more in-depth research on this location can be accomplished so that the current problems can be resolved thoroughly.

RESEARCH SIGNIFICANCE

This study aims to develop a model that can estimate the actual conditions of the North Kembangan drainage system. It will evaluate the level of model reliability through a calibration and validation process using the NSE and RMSE methods.

METHODOLOGY

A. LITERATURE STUDY

A literature review aims to obtain information about the issues discussed and support analysis through basic theory and alternative solutions relevant to the study topic. The literature used is previous research, books, journals, and scientific articles.

B. DATA COLLECTION

The data that supports the study is divided into three, including hydrological data, spatial data, and hydraulic data. Hydrological data is daily rainfall data for 2004 - 2023 recorded by the Kemayoran, Soekarno Hatta, and Banten rainfall stations according to Badan Meteorologi, Klimatologi, dan Geofisika (BMKG) [4]. Apart from that, there is water level data for 2021 and 2022 from the observation of the North Kembangan Teratai pump station [5] as validation data. Spatial data includes the North Kembangan detailed spatial plan map [6], the drainage network map, and the hydrologic soil groups (HSGs) map [7]. Meanwhile, hydraulic data is technical data for drainage channels at the study location referring to the Dinas Sumber Daya Air DKI Jakarta.

Figure 1 North Kembangan Location Map

C. RAINFALL ANALYSIS

Rainfall analysis is accomplished by determining the influential rain stations and analyzing the average rainfall using the Thiessen polygon method. This method is suitable for urban areas with plain topography [8]. This method aims to determine the weight of each rain station, which represents the area around it based on the polygon formed. Calculation of average rainfall using the Thiessen polygon method can be done according to the equation (1)[9][10].

$$\bar{R} = \frac{A_1R_1 + A_2R_2 + \cdots + A_nR_n}{A_1 + A_2 + \cdots + A_n} \quad (1)$$

With $\bar{R}$ is the average rainfall, R_n is the rainfall of each rain station, An is the influential area of each rain station, and n is the number of rain stations.

D. CATCHMENT ANALYSIS

Catchment analysis is accomplished by dividing the area according to the drainage network at the study location. The next step is an analysis of the characteristics of the catchment area, including land area, percentage of impervious area, slope, drainage width, and overland flow Manning coefficient. The results of this analysis will become one of the input data for the SWMM model.

E. SWMM MODEL DEVELOPMENT

The SWMM model is developed based on hydrological, spatial, and hydraulic data as well as the results of the previous stage analysis. Developing the model begins with drawing up the drainage network scheme, which includes sub-catchments, nodes, conduits, and outlets. After the scheme is formed, the parameters of each drainage component, such as sub-catchment parameters, are entered based on catchment area analysis. Node and outlet parameters include elevation, maximum depth, and boundary conditions. Meanwhile, conduit parameters include shape, dimensions, Manning coefficient, and channel elevation.

F. CALIBRATION DAN VALIDATION

Calibration and validation aim to ensure the model's reliability in estimating actual conditions. In measuring the reliability of the model, the Nash-Sutcliffe model efficiency coefficients (NSE) method is used according to equation (2)[11][12] and the root mean square error (RMSE) according to equation (3)[13][14]. Then, this process is re-iterated until the parameters fulfill the requirements.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{mean}\right)^2}\right] \quad (2)$$

$$RMSE = \sqrt{\left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{n}\right]} \quad (3)$$

Y_i^{obs} is the ith observation data, Y_i^{sim} is the ith simulation data, Y_i^{mean} is the ith average observation data, and n is the number of data.

RESULTS AND DISCUSSIONS

A. RAINFALL ANALYSIS

The study location has three influential rainfall stations, including the Kemayoran, Soekarno Hatta, and Banten rain stations. Based on these three rain stations, the average rainfall can be determined using the Thiessen polygon method according to the weight of each rain station, which represents the area, as can be seen in Table 1.

Table 1 Thiessen Weight of Rain Stations

Rain Station	Area (ha)	Thiessen Weight
Kemayoran	98,5	0,251
Soekarno Hatta	19,2	0,049
Banten	274,6	0,700
Total	392,3	1,000

B. CATCHMENT ANALYSIS

The study location is divided into several land uses, including residential, commercial business, industrial, public facilities, offices, warehouses, open land, agriculture, fisheries, and roads, as shown in Figure 2. Several main parameters of the catchment were analyzed, including area, percentage of impervious area, width, slope, overland flow Manning coefficient, and curve number.

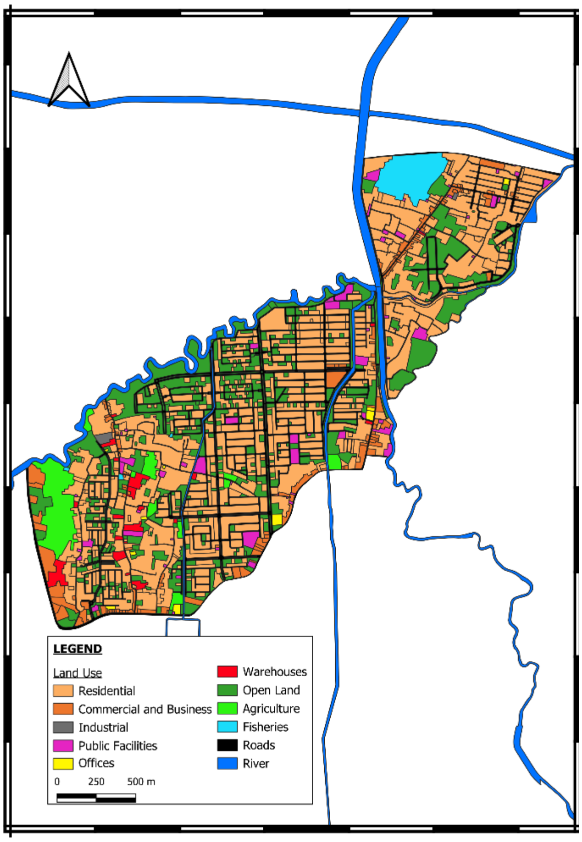

Figure 2 Land Use Map of North Kembangan

Catchment geometric parameters such as area, percentage of impervious area, and width are determined based on the North Kembangan detailed spatial plan map and measurements via Google Earth. These catchments have several land cover types, including roof, concrete, asphalt, grass, fallow soil, and agricultural land, with an overland flow Manning coefficient determined as shown in Table 2.

Table 2 Overland Flow Manning Coefficient

Land Cover	Manning Coefficient
Roof	0,015
Concrete	0,012
Asphalt	0,011
Grass	0,15
Fallow soil	0,05
Cultivated land	0,17

The curve number is determined based on land use and hydrological soil groups. The soil type at the study location is included in hydrological soil group D, which has a high runoff potential, so the curve number tends to have a high value. The curve number used for each land use can be seen in Table 3.

Table 3 Curve Number

Land Use	Curve Number
Residential	98
Commercial and business	95
Industry	93
Public facilites	95
Offices	95
Warehouses	95
Open land	
• Green open spaces	84
• Fallow land	84
• Cemeteries	84
• Parking lots	98
Agriculture	81
Fisheries	98
Road	98

C. SWMM MODEL

The SWMM model consists of 1511 subcatchments, 1035 channels, and 46 outlets. The sub-catchment parameter inputs are based on catchment analysis. The channel`s type is an open channel flow model based on the North Kembangan drainage network, which has various dimensions starting from 300x300 mm until 2000x1500 mm. These channels are u-ditch and box culverts made of concrete or plastered bricks, with estimated Manning coefficient values of 0,012 and 0,020. The SWMM schematic model of the North Kembangan drainage system is shown in Figure 3.

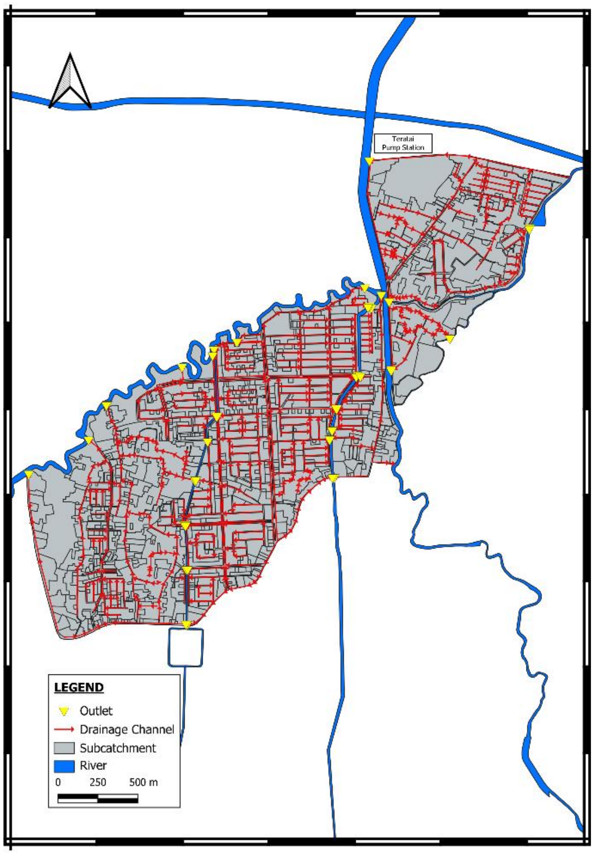

Figure 3 North Kembangan Drainage System Schematic Model

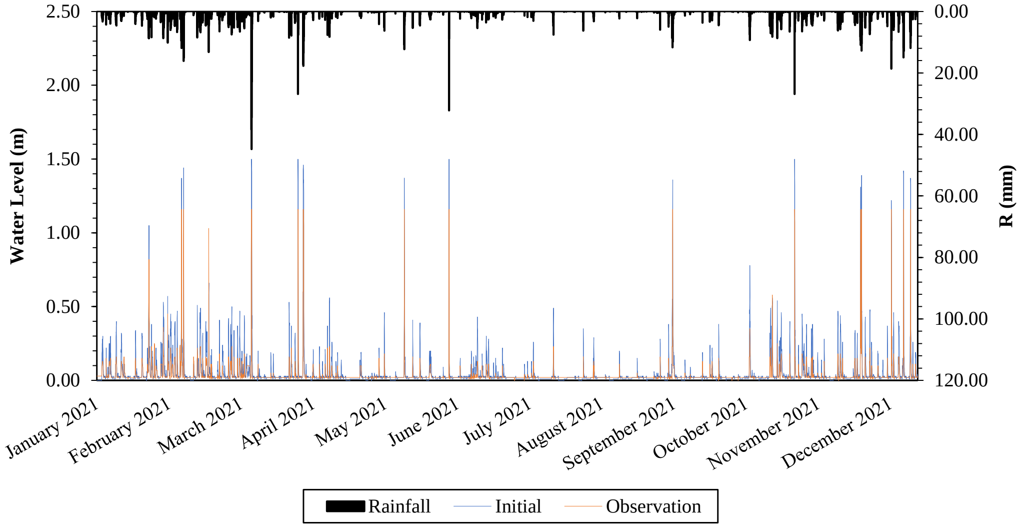

Figure 4 Comparison of Initial Simulation and Observation Data during 2021

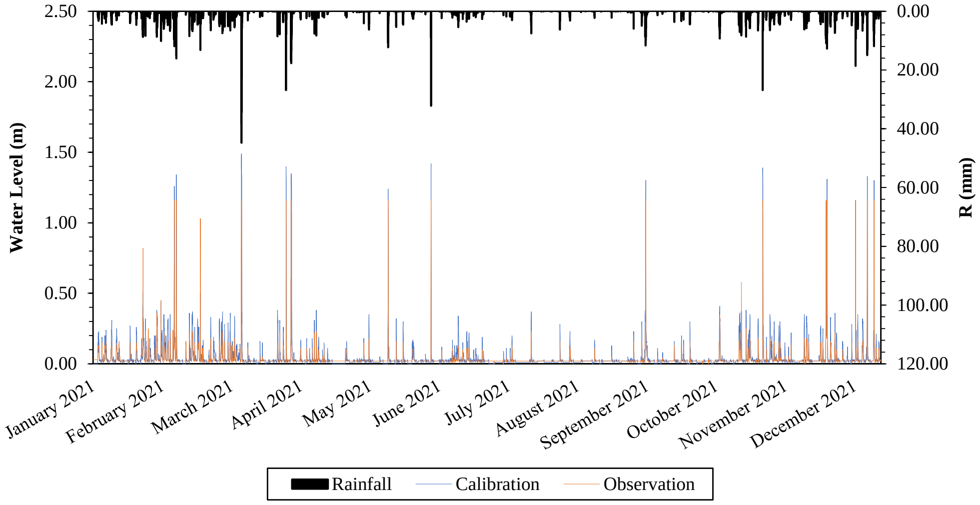

Figure 5 Comparison of Calibration Result and Observation Data during 2021

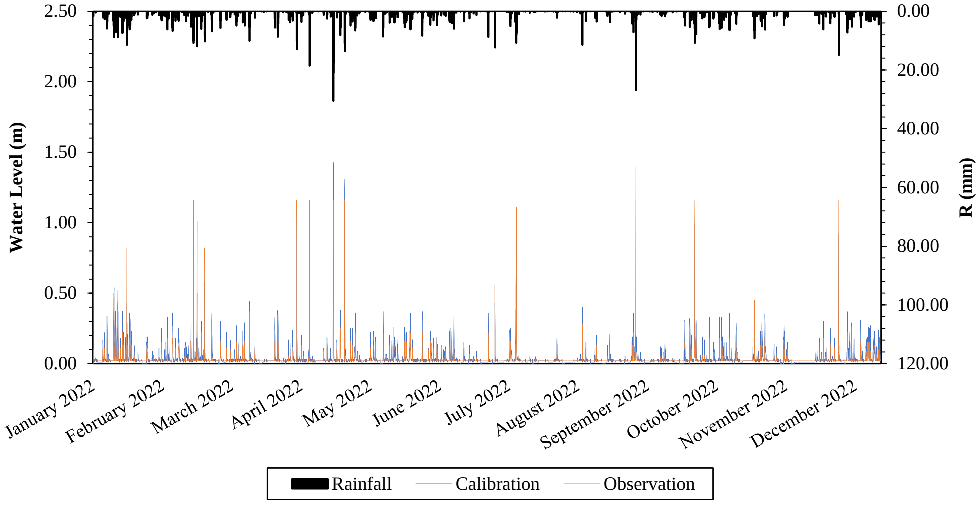

Figure 6 Comparison of Calibration Result and Observation Data during 2022

D. CALIBRATION AND VALIDATION

Calibration of the model parameters is accomplished by comparing the results of the initial model simulation with the water level observations at the North Kembangan Teratai pump station during 2021. As shown in Figure 4, the water level from the model is higher than the observation. The initial simulation has an NSE value of 0,38 and an RMSE of 0,068.The NSE value does not fulfill the requirement to be greater than 0,50 [15]. Therefore, several model parameters must be calibrated.

In this study, calibration is done by trial and error on several model parameters, including the channel Manning coefficient, land overflow Manning coefficient, and curve number, as values change can be seen in Table 4. Several trials to calibrate these parameter values show that the channel Manning coefficient has the most excellent significant effect on the simulation results. Meanwhile, other parameters still change the results but are not very significant. Based on the calibration result shown in Figure 5, the NSE value of 0,65 and RMSE of 0,051 are obtained. This NSE value meets the requirement of being greater than 0,50 so that the model has a fairly good level of reliability. Meanwhile, the RMSE value has decreased compared to the initial simulation, which indicates that the model error level has decreased.

Validation of the calibration results is also accomplished through comparison with the water level observation at the exact location during 2022. Based on the validation results, as shown in Figure 6, the NSE value of 0,62 and RMSE of 0,040 is obtained, which indicates that the model still meets the requirements at satisfactory reliability.

Table 4 Calibration of Model Parameters

Component	Parameters	Values	
		Initial	Calibrated
Channel	Manning coef. of concrete	0,012	0,014
	Manning coef. of brick	0,020	0,016
Subcatchment	Manning coef. of asphalt	0,011	0,013
	Manning coef. of grass	0,15	0,13
	Curve number of residential	98	95

CONCLUSIONS

The present paper presents the 1D model simulation of the urban drainage system in North Kembangan, Jakarta using the Storm Water Management Model (SWMM). Based on the obtained results, several conclusions can be drawn:

1. The study location is divided into several land uses, mostly impervious area, with curve number ranging from 81 to 98.
2. The drainage network consists of u-ditch and box culvert flowing towards 46 outlets with various channel dimensions.
3. The initial simulation of the model has the NSE value of 0,38 and the RMSE of 0,068. The NSE value does not fulfill the requirement so calibration is necessary.
4. To obtain the reliability model, several model parameters, including the channel Manning coefficient, land overflow Manning coefficient, and curve number, must be calibrated. The channel Manning coefficient is the most significant factor in the simulation results.
5. Calibration results show the model has the NSE values of 0,65 and the RMSE of 0,051 for the 2021 data and the NSE values of 0,62 and RMSE of 0,040 for the 2022 validation data which means that the model is reliable to estimate the actual conditions of the North Kembangan drainage system.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to Dinas Dinas Sumber Daya Air DKI Jakarta and Badan Meterologi, Klimatologi, dan Geofisika (BMKG) for getting access to use the data in the region under study.

REFERENCES

[1] Dinas Sumber Daya Air DKI Jakarta, “Peta Jaringan Drainase Kecamatan Kembangan Utara Kota Administrasi Jakarta Barat,” Jakarta, Dinas Sumber Daya Air DKI Jakarta, 2022.

[2] Gubernur DKI Jakarta, “Rencana Kontijensi Penanggulangan Banjir,” nomor 13 tahun 2021, Jakarta, Gubernur DKI Jakarta, 2021.

[3] L. A. Rossman and M. A. Simon, “Storm Water Management Model User’s Manual Version 5.2,” Washington DC, Environmental Protection Agency, 2022.

[4] Badan Meteorologi, Klimatologi, and Geofisika, “Tinggi Hujan Harian Stasiun Hujan Kemayoran, Soekarno Hatta, dan Banten, 2004-2023,” Table, Jan. 2024.

[5] Dinas Sumber Daya Air DKI Jakarta, “Tinggi Muka Air Pos Pompa Teratai Kembangan Utara, 2021-2022,” Table, Jan. 2023.

[6] Gubernur DKI Jakarta, “Rencana Detail Tata Ruang Wilayah Perencanaan DKI Jakarta,” nomor 31 tahun 2022, Jakarta, Gubernur DKI Jakarta, 2022.

[7] C. W. Ross et al., “Global Hydrologic Soil Groups (HYSOGs250m) for Curve Number-Based Runoff Modelling,” Oak Ridge, ORNL DAAC, 2018.

[8] Suripin, “Sistem Drainase Perkotaan yang Berkelanjutan,” 1st edition, Yogyakarta, ANDI, 2004.

[9] “Badan Standardisasi Nasional, Standar Nasional Indonesia Tata Cara Perhitungan Debit Banjir Rencana,” nomor 2415 tahun 2016, Jakarta, Badan Standardisasi Nasional, 2016.

[10] B. Triatmodjo, “Hidrologi Terapan 1st edition,” Yogyakarta: Beta Offset, 2008.

[11] D. N. Moriasi et al, “Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations,” American Society of Agriculture and Biological Engineers, vol. 50, no. 3, pp. 885-900, 2007.

[12] K. B. C. Eckart, "Multiobjective Optimization of Low Impact Development Stormwater Controls Under Climate Change Conditions," M. S. thesis, Department of Civil and Environmental Engineering, University of Windsor, Windsor, 2015.

[13] B. Abdelkebir et al., "Evaluating Low-Impact Development Practice Performance to Reduce Runoff Volume in an Urban Watershed in Algeria," Arabian Journal of Geosciences, vol. 14, no. 814, pp. 1-10, 2021.

[14] H. Sun et al., "The Multi-Objective Optimization of Low-Impact Development Facilities in Shallow Mountainous Areas Using Genetic Algorithms," Water, vol. 14, no. 2986, pp. 1-19, 2022.

[15] C. Liang et al., "The Effect of Sponge City Construction for Reducing Directly Connected Impervious Areas on Hydrological Responses at the Urban Catchment Scale," Water, vol. 12, no. 1163, pp. 1-16, 2020.