International Journal of GEOMATE, March., 2021, Vol.20, Issue 79, pp. 147-154
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2021.79.j2037
Geotechnique, Construction Materials and Environment

# MODELLING OF POTENTIAL RECHARGE ZONE USING GEOGRAPHICAL INFORMATION SYSTEM BASED ON INDONESIA REGULATION AND WATER BALANCE MODEL

*Dina P A Hidayat[1,5], Sri Legowo W Darsono[2] and Mohammad Farid[3,4]

[1] Doctoral Program of Civil Engineering Institut Teknologi Bandung; [2,3] Water Resources Engineering Research Group, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Indonesia; [4]Center for Coastal and Marine Development, Institute for Research and Community Services, Institut Teknologi Bandung, Indonesia; [5]Civil Engineering Department Universitas Trisakti

*Corresponding Author, Received: 25 Nov. 2020, Revised: 30 Dec. 2020, Accepted: 21 Jan. 2021

**ABSTRACT:** Recharge zone is an important aspect for sustainable water resources management. Recharge are difficult to measure directly and the field-based methods are time consuming, expensive, and require large number of skilled manpower. Application of remote sensing and geographical information system (GIS) has wide application and good result in delineating recharge zone and various other fields. The present study aim to delineating potential recharge zone using GIS based on Indonesia Regulation with comparison of water balance modelling (NRECA and FJ Mock) in Cisadane watershed Indonesia. Water balance model is used for generating rainfall data into monthly discharge (base flow and direct runoff) with validation of 3 discharge station (Genteng, Batubeulah and Serpong) as representative of upstream, middle and downstream of Cisadane watershed. Rainfall is a dynamic and sensitive factor for generating potential recharge zone, there is a significant changing of potential recharge zone between using 3 parameters and 4 parameters, potential recharge zone can increase or decrease based on annual rainfall. The accuracy of NRECA and FJ Mock model and result fairly good validation with acceptable NSE (0.52-0.61) and R values (0.76-0.87). Potential recharge zone map using 4 parameters (land use, slope, soil and rainfall) is suitable with the results of baseflow percentage of NRECA and FJ Mock model. Cisadane watershed is dominated by medium (33.62%) to high potential recharge (55.49%).

*Keywords: Baseflow; GIS; Recharge zone; Sensitivity; Water balance model*

## 1. INTRODUCTION

Groundwater is the main source of domestic use, irrigation, sustainable ecosystems, nutrients and stable temperature [1]. For the last 30 years, the use of groundwater has increasing due to the rising of population and urbanization, global impact due to climate and weather change, and drought condition [2]. Groundwater recharge is important for balancing water demand and water supply. Other than increasing water demand, decreasing groundwater recharge is caused by significant land use change [3]. In Indonesia, urbanized watershed especially in Java Island is threatened by significant land use change due to high urbanization, forest conversion and agricultural expansion [4]. Therefore, delineating potential recharge zone is important to make decision for sustainable groundwater resource management, and prevent land use change especially in high potential recharge area [5].

Groundwater recharge is one of difficult components to understood in hydrologic cycle, because it difficult to measure directly and varies in space and time [6][7]. The conventional field based method using investigations of soil hydrologic properties is more consuming in time, more expensive and need large number of skilled manpower [8]. Remote sensing and GIS has powerful for processing spatial and earth surface data within short time [2]. Combination of remote sensing and GIS has wide application in water resources analysis, such as: generating potential recharge zone [9]. Various techniques have been adopted by various researchers such as multi influencing factor (MIF) [10], fuzzy logic [11] and Analytical Hierarchy Process (AHP) [12]. Potential recharge zone maps can be validated with field survey [13] or comparison with other recharge model that has been validated [14][15] such as: water balance model (NRECA, FJ Mock, etc) [16], numerical model (MODFLOW, SWAT, etc) [17]. Water balance method (WBM) is a simple and commonly used for rainfall runoff modelling with good result [18]. The present study using validated water balance method (NRECA and FJ Mock) as comparison model of potential recharge zone maps.

Various hydrogeological factors has been analyzed for delineating recharge zone, such as: rainfall, land use, slope, soil, geology, geomorphology, lineament, and drainage density [19][20]. Based on Indonesia regulation (Ministry of Public Works and Housing Regulation Number 10/2015), 4 factor has been used consist of: rainfall, land use, slope and soil. The groundwater recharge processes is influenced by changing of land use and land cover, such as: converting the bare soil cover into impermeable land use reduces the groundwater recharge [21]. Slope is an important factor for the delineation of potential recharge zones. A steep of slope results in high runoff and increased erosion rate with less recharge potential [22]. The soil as land surface data, was used for groundwater potential recharge analysis. Soil texture influence the penetration rate of surface water into groundwater system [23]. The present study aims to delineating recharge zone using combination of GIS and spatial weight with comparison of water balance modelling in Cisadane watershed Indonesia and rainfall sensitivity analysis as the most dynamic factor. The results of present study can use for planners, policy makers and local authorities to reach sustainable groundwater management, and to prevent destructive land use change.

## 2. MATERIALS AND METHODS

### 2.1 Site Description

Cisadane watershed is one of priority watershed in Indonesia, has catchment area of 154547 ha, and mostly located in West Java and Banten Province which is close to the capital city of Indonesia, DKI Jakarta. As the supporting area of capital city and along economic growth, Cisadane watershed has increasing population about 1.17-2.41% for the last 5 years. The selection of research location based on varying watershed characteristics and hydrology condition from upstream to downstream. Cisadane watershed has varying topography, the upstream is dominated by mountain area with quite steep slope (10-30%), and the middle-downstream is dominated by field and housing area with flat slope (0-5%). Based on hydrology condition, upstream side has higher annual rainfall about 3200 mm than downstream side about 2700 mm.

### 2.2 Potential Recharge Zone Mapping

Delineation recharge zone using combination of GIS and remote sensing continue to be developed to obtain better result. In Indonesia, delineation recharge zone regulated in Ministry of Public Works and Housing regulation, using hydrology and watershed characteristics factor: annual rainfall, slope, land use and soil texture, with catchment area boundaries following the boundaries of water resource management in Indonesia (Fig.1). Therefore, there is possibility that area outside catchment still contribute to recharge system. The present study is developed based on the regulation in Indonesia with several modification, consist of: modelling accuracy with scalable grid, modelling scheme, and validation method. Recharge potential zones were obtained by the weighted analysis method using spatial analysis tools in ArcMap. During weighted analysis, a rank was given for each individual parameter of each thematic layer map (1-5), and same weights were assigned for each layer map. Sensitivity of rainfall factor was determined by removal of the factor from the analysis [24]. The present study analyzed sensitivity of rainfall factor by analyzing 3 parameters slope, land use, soil (Eq.1) and 4 parameters slope, land use, soil, rainfall (Eq.2). Potential recharge weight calculated based on following equation:

Potential recharge weight per grid = (weight of land use + slope + soil) /3 (1)

Potential recharge weight per grid = (weight of land use + slope + soil + rainfall per station)/4 (2)

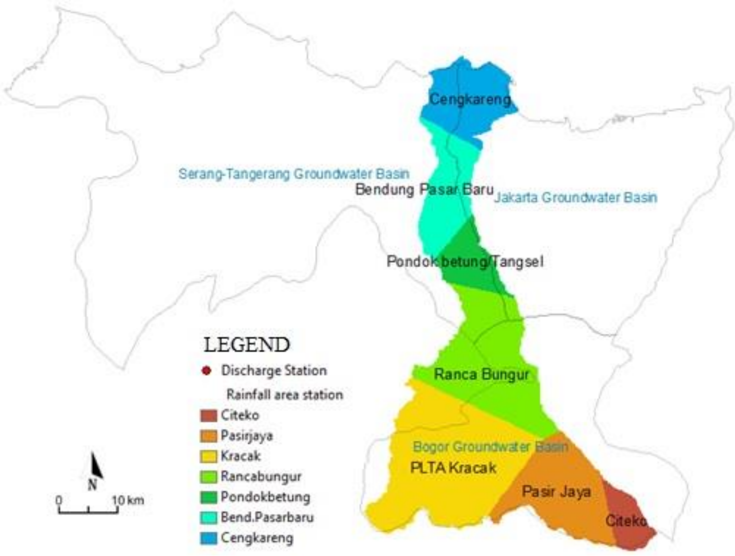



Fig.1 Discharge station and rainfall area station

## 2.3 Water Balance Model

National Rural Electric Cooperative Association (NRECA) model was first developed by Norman H Crawford [25] to generate rainfall data into monthly discharge data, with basic equation of water balance. NRECA model divides discharge into direct runoff (DF) and baseflow (GF), and storages into moisture storage and groundwater storage. Direct runoff is determined based on the excess rain water by considering potential evapotranspiration and infiltration rate (PSUB). Baseflow from groundwater storage flow to the river linearly according to the storage (GWSTOR) and groundwater parameter (GWF) (Eq.3-5).

$Q = (DF_i + GF_i)\ A$ (3)
$DF_i = E_i\ (P_i - AET_i)\ (1 - PSUB)$ (4)
$GF_i = GWF\ (PSUB \times E_i\ (P_i - AET_i) + GWSTOR_{i-1})$ (5)

FJ Mock model first developed by FJ Mock [26] with the principle of water balance. This model divided runoff as direct runoff (DF) and baseflow (BSF) with less input data [27]. Direct runoff depends on water surplus ($WS_i$) and infiltration ($I_i$), while baseflow depends on infiltration ($I_i$) and groundwater on saturated zone (GWSi) (Eq.6-8).

$Q = (DF_i + BSF_i)\ A$ (6)
$DF_i = WS_i - I_i$ (7)
$BSF_i = I_i - (GWS_i - GWS_{i-1})$ (8)

## 2.4 Model evaluation

To evaluate the efficiency of the different models for the calibration, it used Pearson Correlation Coefficient (R) and Efficiency Parameter of Nash and Sutcliffe (NSE) (Eq.9,10) [28]. This statistical parameters as the objective function to be minimized at optimizing both the Nash-Sutcliffe efficiency (NSE) and the fit between the observed and modelled discharge [29]. The present study use rainfall data based on 7 rain station entire watershed and validation point on 3 observed discharge upstream (Genteng), Middle (Batubeulah) and downstream (Serpong) (Fig.1).

$$NSE = 1 - \frac{\sum_{n=1}^{N}(Qmodel - Qobs)^2}{\sum_{n=1}^{N}(Qobs - \overline{Qobs})^2} \quad (9)$$

$$R = \frac{\sum_{n=1}^{N}(Qobs - \overline{Qobs})(Qmodel - \overline{Qmodel})}{\sqrt{\sum_{n=1}^{N}(Qobs - \overline{Qobs})^2 \sum_{n=1}^{N}(Qmodel - \overline{Qmodel})^2}} \quad (10)$$

## 3. RESULTS

## 3.1 Potential Recharge Zone Mapping

The present study determinates potential recharge zone using thematic layer of slope, land use, soil texture and rainfall. Each thematic layer is classified by the rank/weight of 1-5, 1 for the least supportive recharge and 5 for the most supportive recharge. The least supportive recharge (rank 1) for steep slope (>60%), impermeable land use, clay soil, and annual rainfall <500 mm, while the most supportive recharge (rank 5) for flat slope (<5%), forest (permeable land use), sand soil and annual rainfall > 3000 mm. Cisadane watershed dominated by flat slope (<5%) in the downstream covering 54% of the area, the upstream dominated by quite steep slope (5-20%) (Fig. 7). Land use dominated by 42% of paddy field and 25% of housing and commercial area especially on the downstream (Fig. 8). For the last 8 years, there is significant changing of land use from permeable to impermeable area especially housing in the upstream. Soil texture dominated with fine sand clay in the downstream and clay sand in the upstream (Fig. 9).

Rain data for analysis obtained from Indonesia Ministry of Public Works and Housing and Meteorology and geophysical agencies. The rainfall map was prepared using annual data from 7 rain station (Citeko, Pasirjaya, PLTA Kracak, Rancabungur, Pondok betung, Bendung pasarbaru, Cengkareng) with years of 2010-2019, then assigned by the rank of 1-5, 1 for annual rainfall (R) < 500 mm, 2 for R =500-1000 mm, 3 for R = 1000-2000 mm, 4 for R = 2000-3000 mm, and 5 for R>3000 mm. Figure 10 indicates that the highest annual rainfall is Citeko, Pasirjaya, Kracak in the upstream with annual rainfall > 3000 mm, and the lowest annual rainfall is Pasar baru, Rancabungur and Cengkareng with annual rainfall < 2000 mm dominantly located in the downstream area.

Sensitivity of rainfall factor is obtained by removal rainfall in potential recharge analysis and using rainfall factor (Fig. 11). It results significant different area between potential recharge with 3 parameters and 4 parameters. High rainfall can increase potential recharge especially in the upstream area (Citeko, Kracak, Pasir Jaya) from medium potential to high potential recharge.

## 3.2 Comparison of Recharge Zone

Validation is important part for modelling process. To compare water balance model result (NRECA and FJ Mock) with potential recharge zone, it must be validated first. Validation of water balance model using 3 outlet which represent the upstream area (Genteng), middle area (Batubeulah) and downstream area (Serpong) (Fig.1). NRECA model result higher NSE and R value than FJ Mock model which is still acceptable with R> 0.6 and NSE >0.5 (Table 1). Model comparison is done by comparing the suitability of recharge parameter between water balance model (baseflow percentage) and potential recharge per station area (Fig.2,3,4).

**Table 1.** Model evaluation of Water Balance Model

| Discharge Station | Model Evaluation | | | |
|---|---|---|---|---|
| | NRECA Model | | FJ Mock | |
| | NSE | R | NSE | R |
| Genteng | 0.61 | 0.87 | 0.61 | 0.82 |
| Batubeulah | 0.52 | 0.82 | 0.59 | 0.77 |
| Serpong | 0.56 | 0.80 | 0.56 | 0.76 |

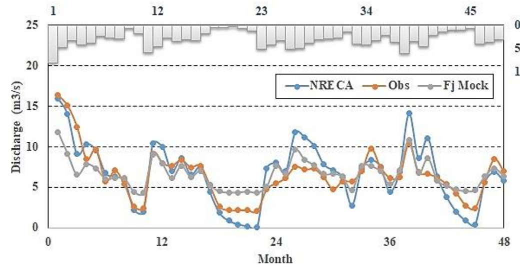



Fig.2 Discharge comparison at upstream outlet (Genteng)

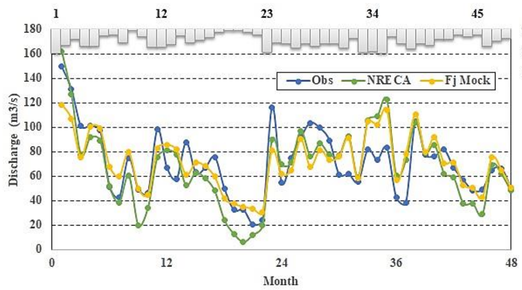



Fig.3 Discharge comparison at middle outlet (Batubeulah)

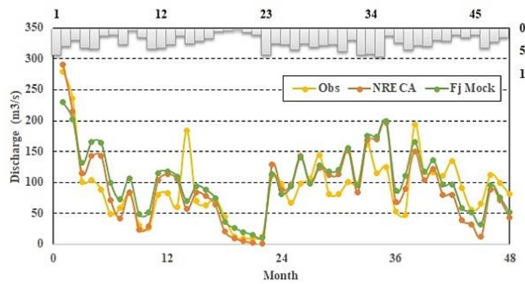



Fig.4 Discharge comparison at downstream outlet (Serpong)

## 4. DISCUSSION

Based on all the factors analyzed for potential recharge zone, rainfall is the most dynamic factor than land use, slope and soil texture. The present study is using non uniform annual rainfall value based on area of each rainfall station (7 value of annual rainfall entire watershed). Apart from the number of rain station, sensitivity of rainfall factor obtained by comparison of analysis using 3 parameters (land use, slope and soil) and analysis using 4 parameters (land use, slope, soil and rainfall). Figure 11 and figure 12 indicates that rainfall is a sensitive factor for generating potential recharge zone. There is a significant changing of potential recharge zone between using 3 parameters and 4 parameters, for upstream station which have higher rainfall (Citeko, Pasirjaya and Kracak) the potential recharge is increasing significantly from medium potential (yellow) to high potential recharge (green). For downstream station which have lower rainfall (Bendung Pasarbaru and Cengkareng) the potential recharge is less decreasing from high potential (green) to medium potential (yellow).

Water balance model is the commonly used model for hydrology modelling because of simplicity and good validation [18]. The present study uses NRECA and FJ Mock model to generate rainfall data into monthly discharge data with 3 outlet of Cisadane watershed, Genteng outlet in the upstream, Batubeulah outlet in the middle and Serpong outlet in the downstream. Pearson Correlation Coefficient (R) and Efficiency Parameter of Nash and Sutcliffe (NSE) are used to evaluate the accuracy of NRECA and FJ Mock model. It result fairly good validation for NRECA model with NSE values ranging from 0.52 to 0.61 and R values ranging from 0.80-0.87. FJ Mock model generate acceptable NSE and R values with NSE values ranging from 0.59 to 0.61 and R values ranging from 0.76-0.82 (Table 1).

The present study compared suitability of potential recharge zone mapping using 4 parameters (land use, slope, soil and rainfall) and baseflow percentage of NRECA and FJ Mock model. The upstream outlet (Genteng) with Citeko and Pasirjaya influenced area result highest baseflow percentage than the other outlet in the middle and downstream (Fig.5,6). It is suitable with potential recharge zone map for Citeko and Pasirjaya station with domination of high and very high potential recharge (Fig.12). The middle outlet (Batubeulah) with Citeko, Pasirjaya, Kracak and Rancabungur influenced area result lower baseflow percentage than the upstream outlet (Fig 5,6). It is suitable with potential recharge zone map for Citeko, Pasirjaya, Kracak station with domination of high potential recharge and for rancabungur station with medium potential recharge (Fig.12). The downstream outlet (Serpong) with Citeko, Pasirjaya, Kracak, Rancabungur and Pondok betung influenced area result lowest baseflow percentage than the other outlet (Fig.5,6). It is suitable with potential recharge zone map for Citeko, Pasirjaya, Kracak, Rancabungur and Pondok betung (Fig.12). Baseflow percentage also depends on rainfall. During the dry season, baseflow/runoff percentage is higher than rainy season. Heavy rainfall causes the possibility of flow being runoff is higher, if supported by steep slope, impermeable land use and dense soil. Figure 5 and Figure 6 indicates that Fj Mock and NRECA model result same trend of baseflow percentage, with a slight percentage difference, NRECA model relatively higher than FJ Mock model.

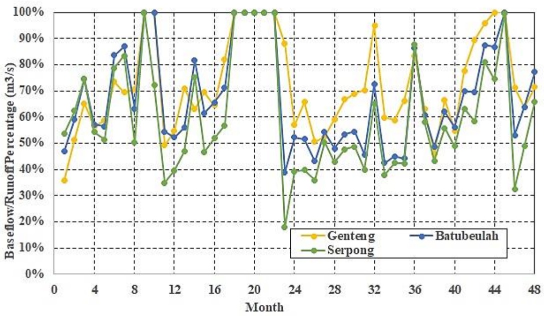



Fig.5 FJ Mock baseflow percentage for 3 outlet

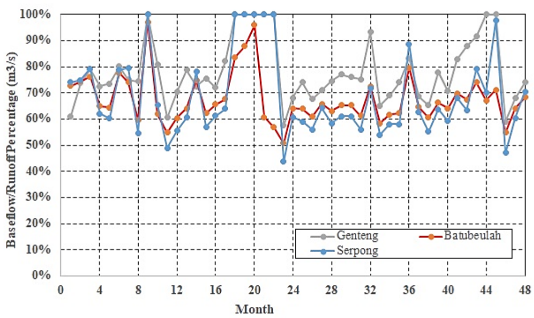



Fig.6 NRECA baseflow percentage for 3 outlet

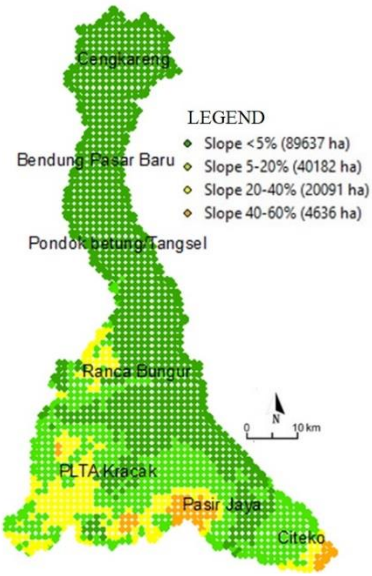



Fig.7 Slope classification with scalable grid (1000 x 1000 m)

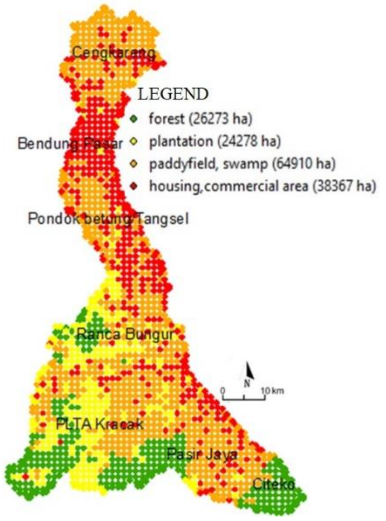



Fig.8 Land use classification with scalable grid (1000 x 1000 m)

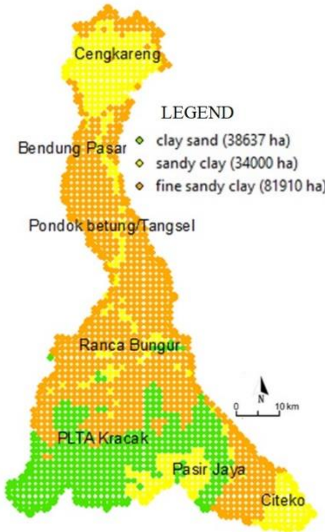



Fig.9 Soil classification with scalable grid (1000 x 1000 m)

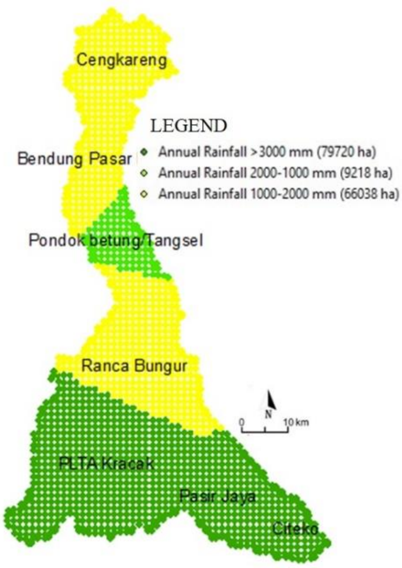



Fig.10 Rainfall classification with scalable grid (1000 x 1000 m)

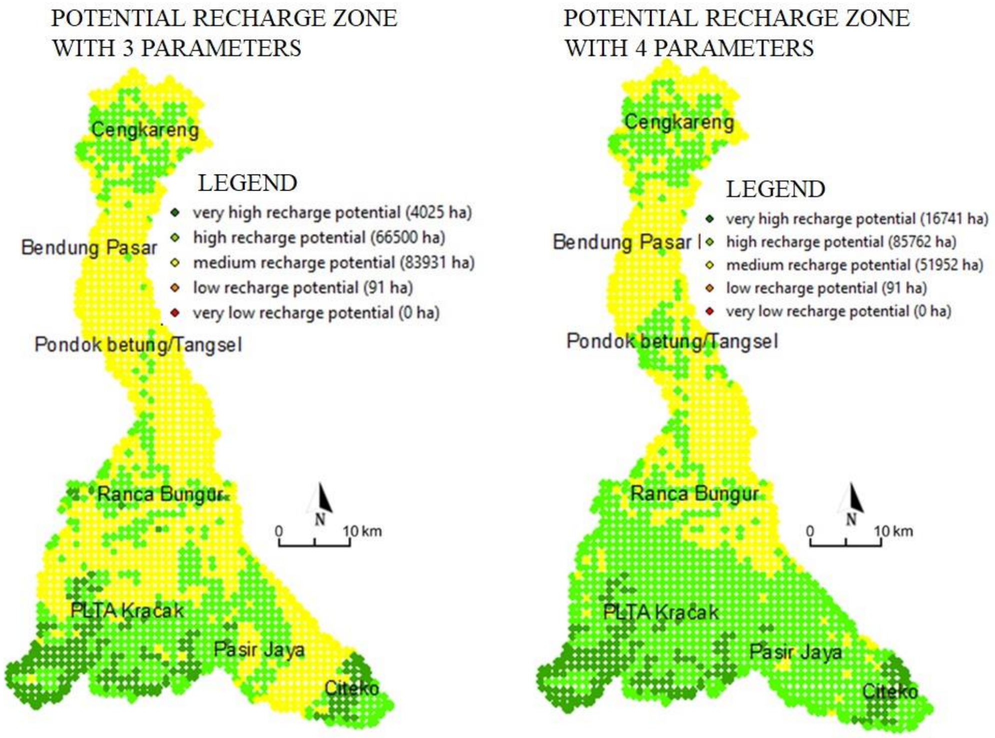
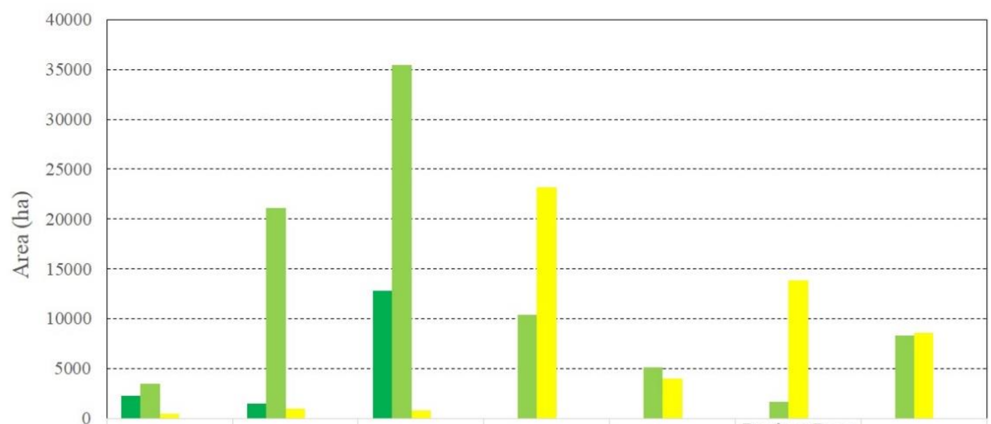



Fig.11 Potential recharge zone mapping using 3 and 4 parameters




| | Citeko | Pasir Jaya | PLTA Kracak | Ranca Bungur | Pondok betung | Bendung Pasar Baru | Cengkareng |
|---|---|---|---|---|---|---|---|
| very high potential | 2343 | 1555 | 12843 | 0 | 0 | 0 | 0 |
| high potential | 3555 | 21133 | 35435 | 10387 | 5180 | 1739 | 8334 |
| medium potential | 485 | 1006 | 844 | 23163 | 4039 | 13827 | 8589 |
| low potential | 0 | 91 | 0 | 0 | 0 | 0 | 0 |
| very low potential | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Fig.12 Area of potential recharge zone using 4 parameters

## 5. CONCLUSION

The number of rain station and rainfall data affects accuracy of potential recharge zone delineation. Rainfall is a sensitive factor for generating potential recharge zone, potential recharge zone can be increasing/ decreasing based on annual rainfall. Pearson Correlation Coefficient (R) and Efficiency Parameter of Nash and Sutcliffe (NSE) are used to evaluate the accuracy of NRECA and FJ Mock model and result fairly good validation with acceptable NSE and R values. Potential recharge zone mapping using 4 parameters (land use, slope, soil and rainfall) is suitable with the results of NRECA and FJ Mock baseflow percentage. For future research comparison of water balance model and potential recharge zone can be improved by monthly rainfall analysis as the input of potential recharge zone, delineation recharge zone can be added by groundwater factors and groundwater systems boundaries as comparison.

## 6. ACKNOWLEDGMENTS

We acknowledge support by Ministry of Research, Technology and Higher Education of Republic Indonesia for doctoral research grant, Ministry of Public Works and Housing of Republic Indonesia, and Meteorological, Climatological and Geophysical Agency for supporting data. Further, we want to express our gratitude for the support by the team of Institut Teknologi Bandung and Universitas Trisakti.

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