# ESTIMATION OF GROUNDWATER RECHARGE USING WETSPASS MODEL IN THE PHANOM THUAN–SONG PHI NONG–BANG LEN OPERATION AND MAINTENANCE PROJECTS, THAILAND

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## ABSTRACT

WetSpass model was applied in this study to simulate and visualize the distribution of groundwater recharge and amount of yearly and seasonal averages groundwater recharge during 2000–2017. The study area covers the Phanom Thuan–Song Phi Nong–Bang Len Operation and Maintenance Projects in western region of Thailand where groundwater has been used as an alternative source of water for irrigation and industrial sectors. The recharge rates performed by WetSpass model were consequently compared with those achieved by empirical relations namely; Chaturvedi Formula (CF), Sehgal Formula (SF), Krishna Rao Formula (KRF), and Bhattacharya Formula (BF). It was exhibited that average rate of yearly groundwater recharge for calibration periods during 2000–2010 was 178.05 mm/yr with RMSE, $r^2$, and d of 48.72 mm, 0.78 and 0.66, respectively. However, average rate of groundwater recharge for validation periods during 2011–2017 was slightly increased which was 186.35 mm/yr with RMSE, $r^2$, and d of 55.09 mm, 0.24 and 0.53, respectively. The simulation result obtained from WetSpass shows that the average annual recharges in the Phanom Thuan, Song Phi Nong, and Bang Len Operation and Maintenance Projects are 22.5%, 22.4%, and 14.8% of average annual rainfall, respectively according to the different soil types. The average groundwater recharges in clay, loam soil, and sandy loam soils are approximately 14.8%, 24.6%, and 25.7% of average annual rainfall, respectively. Moreover, groundwater recharges in dry and wet seasons are quantified as 12.0%, and 88.0% of average annual recharge due to seasonal variation of rainfall magnitudes.

*Keywords*: Groundwater Recharge, Groundwater Modelling, WetSpass model, Phanom Thuan–Song Phi Nong–Bang Len Operation and Maintenance Projects

## 1. INTRODUCTION

Groundwater recharge is the foundation of hydrologic processes of subsurface water system that replenishes water in aquifer system. Due to processes of groundwater recharge which are occurred beneath the ground surface, measuring groundwater recharge in the field has become a difficult task and it has also contained uncertainty. However, information on groundwater recharge is highly useful for the evaluation of groundwater resources and risk of groundwater depletion. In general, there are several techniques used to estimate quantity of groundwater recharge such as Water Table Fluctuation (WTF), water budget, Darcy's law, empirical relationships, groundwater model, and Tracer techniques (Hiwot, 2008). Selection of the proper technique depends on available data, local geographic and topographic conditions, spatial and temporal scale required and reliability of results (Islam et al., 2016). Groundwater recharge model has been considered as an effectively used tool in estimating groundwater recharge as it can estimate spatial and temporal distributions of groundwater recharge. In addition, the precision of the model estimation is subject to the successful calibration and validation of the model.

WetSpass model (Water and Energy Transfer between Soil, Plants and Atmosphere under quasi Steady State), is selected in this study. WetSpass is one-dimension steady state spatial distribution water balance model which has been widely used for groundwater recharge estimation. WetSpass integrates the Geographic Information System (GIS) with the water balance equation to determine potential groundwater recharge (Batelaan & Smedt, 2007). WetSpass model is suitable for studying the distribution of groundwater recharge with different parameters and visualizing the distribution of groundwater recharge in a specific area.

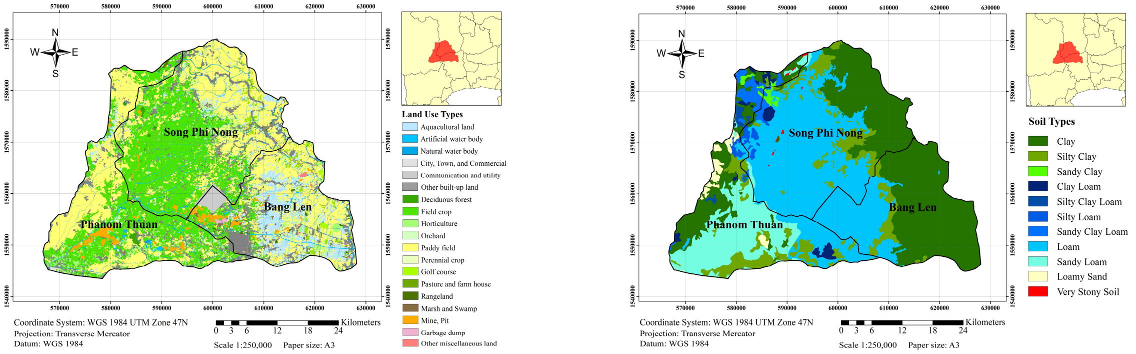
The Phanom Thuan–Song Phi Nong–Bang Len Operation and Maintenance Projects are part of the Greater Mae Klong Irrigation Project in the western region of Thailand. Groundwater in this region has been used specifically for agriculture to supplement the limited surface water from canal irrigation system (Teartisup & Kerbsueb, 2013). Groundwater has been withdrawn by pumping from both private and government wells for agricultural and industrial uses. Use of groundwater in this region is expected to increase due to the economic expansion and increasing number of people and industrial activities.

Therefore, understanding the groundwater systems in potential groundwater recharge and current groundwater uses in the Phanom Thuan–Song Phi Nong–Bang Len Operation and Maintenance Projects areas are considerably important to develop appropriate groundwater management or to avoid the excessive uses and unsustainable withdrawal of groundwater in the future.

## 2. MATERIAL AND METHOD

### 2.1 Study area

The study area is the Phanom Thuan–Song Phi Nong–Bang Len Operation and Maintenance Projects, which are located in both Mae Klong and Tha Chin River Basins. The irrigation water is mainly supplied and diverted from Mae Klong River Basin for agriculture. Most of the area is agricultural area including paddy field (yellow) and field crop area (green) as shown in Figure 1(A). There are 3 main soil types, which cover about 81.7% of the study area including clay (34.96%, dark green), loam (34.58%, blue), and sandy loam (11.93%, light green) soil as shown in Figure 1(B). Distribution of land use types varies in the different soil types, which paddy field and field crop area are located on clay and both loam and sandy loam soils, respectively.



(A) Land use types (B) Soil types

Figure 1. Land use type and soil type in the Phanom Thuan–Song Phi Nong–Bang Len Operation and Maintenance Projects.

In this study, estimation of groundwater recharge was achieved by using WetSpass model based upon the yearly and seasonal distributions of groundwater recharge during 2000–2017.

### 2.2 Data collection

There are 5 main data for the estimation of groundwater recharge using WetSpass model including (1) geological data, (2) meteorological data, (3) land use data, (4) soil data, and (5) groundwater data. These data are collected from literature review and government agencies including the United States Geological Survey (USGS), Thai Meteorological Department (TMD), Royal Irrigation Department (RID), Land Development Department (LDD), Department of Groundwater Resources (DGR), field measurement and laboratory test. Details of required data are summarized in Table 1.

Table 1. Data used in WetSpass model.

| DATA TYPE | INPUT | SOURCE | DURATION |
|---|---|---|---|
| **GEOLOGICAL DATA** | Digital Elevation Model (DEM) | USGS | 2011 |

| DATA TYPE | INPUT | SOURCE | DURATION |
|---|---|---|---|
| **METEOROLOGICAL DATA** | Slope | Calculated from DEM | - |
| | Rainfall | TMD & RID | 2000–2017 |
| | Temperature | TMD | 2000–2017 |
| | Potential Evapotranspiration | Calculated from temperature by using Thornthwaite method | - |
| **LAND USE DATA** | Wind speed | TMD | 2000–2017 |
| | Land use types | LDD | 2011 |
| | Land use parameters; runoff, land cover fraction, root depth, LAI, minimum stomata resistance, crop height, n-Maning, land factor, and aerodynamic resistance | Literature review; (Allen et al, 1998), (Foxx et al, 1984), (Khunsanit & Yingjajaval, 2011), (Lesschen et al., 2004), (ODOT, 2011), (Pan Uthai et al, 2009), (USDA, 1997), (USDA, 2016) | - |
| **SOIL DATA** | Soil types | LDD | 2011 |
| | Soil parameters; filed capacity, permanent wilting point, plant available water, residual water content, evaporation depth, tension saturated height, precipitation fraction, and water content | Field measurement and laboratory test | - |
| **GROUNDWATER DATA** | Groundwater level | DGR | 2000 – 2017 |

### 2.3 Data preparation

WetSpass model is GIS-based spatial distribution model in which all the inputs are provided in the format of spatial data (ASCII format, .asc). Due to different sources of data gathered and also different formats of data found, the data must be converted by spatial analysis method depending on specific data type. In this study, rainfall, wind speed, and groundwater level data were gathered from various stations over the entire area. The Thiessen Polygon, Inverse Distance Weighting (IDW), and Kriging methods were selected for the spatial analysis of rainfall, wind speed and groundwater level, respectively.

### 2.4 Model calibration and validation

Due to insufficient data of observed groundwater recharge in Thailand, empirical equations were selected to be a representative of observed groundwater recharge in the study area including Chaturvedi Formula (CF), Sehgal Formula (SF), Krishna Rao Formula (KRF), and Bhattacharya Formula (BF). These empirical relationships have been developed between groundwater recharge and rainfall data. Therefore, these empirical equations were then used for model calibration and validation comparing with the model results of WetSpass. It is found from the previous researches that empirical equations have been applied for estimation of groundwater recharge worldwide. Khalil et al. (2018) studied relationships between annual groundwater recharges performed by WEAP model and empirical equations in the Mae Klong River Basin, Thailand. The results showed that ranges of correlation were relatively high varying from 0.781 to 0.815 (Khalil et al., 2018). Details of each equation are described below;

1. Chaturvedi Formula (CF)

$$R = 2.0\,(P - 15)^{0.4} \tag{1}$$

where, R is groundwater recharge (in/yr) and P is annual rainfall (in)

2. Sehgal Formula (SF)

$$R = 12.6\,(P - 406.4)^{0.5} \tag{2}$$

where, R is groundwater recharge (mm/yr) and P is annual rainfall (mm)

3. Krishna Rao Formula (KRF)

$$R = K(P - X) \tag{3}$$

where, R is groundwater recharge (mm/yr), P is annual rainfall (mm), and values of K and X depend on values of P as shown below;

If P between 400–600 mm; $R = 0.20(P - 400)$ (4)
If P between 600–1,000 mm; $R = 0.25(P - 400)$ (5)

If P between 1,000–2,000 mm; $R = 0.30(P - 500)$ (6)

If P more than 2,000 mm; $R = 0.35(P - 600)$ (7)

4. Bhattacharya Formula (BF)

$$R = 3.47\ (P - 38)^{0.4} \tag{8}$$

where, R is groundwater recharge (cm/yr) and P is annual rainfall (cm)

The observed groundwater level can be calibrated parameter instead of observed groundwater recharge. According to incomplete observation, groundwater level was obtained insufficiently. In order to prepare input groundwater level for WetSpass model, most of groundwater level data were predicted. Therefore, observed groundwater level obtained from LDD were completely unreliable to be calibrated parameter for this study.

The statistical parameters can be applied for evaluation of model performance by comparing the observed and simulated values. The values of these statistical parameters are defined to show the picture on how the simulated values are close to observed value (Krause et al., 2005). In this study, empirical recharges are used as observed values while the WetSpass recharges are signified as simulated recharges. WetSpass model performance is evaluated by statistical parameters namely; Root Mean Square Error (RMSE), coefficient of determination ($r^2$), and index of agreement (d). Details of each parameter are described below;

1. Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \tag{10}$$

where, O is observed value and P is simulated value

Root mean square error (RMSE) are used in the comparison and evaluation of simulation models. RMSE measures the differences between observed and simulated values (Willmott et al., 1985). The range of RMSE is not determined by specific criteria directly. However, the accepted value of RMSE depends on scale of simulation, variance of observed value, and decision of modeler.

2. Coefficient of determination ($r^2$)

$$r^2 = \left(\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\ \sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}}\right)^2 \tag{11}$$

where, O is observed value and P is simulated value

The range of coefficient of determination ($r^2$) lies from 0 to 1, which explains the dispersion between observed and simulated values. The zero value of $r^2$ describes no correlation and the 1 value of $r^2$ describes dispersion of observed values and simulated values which are definitely equal (Krause et al., 2005).

3. Index of agreement (d)

$$d = 1 - \left(\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}|P_i - \bar{O}| + |O_i - \bar{O}|}\right) \tag{11}$$

where, O is observed value and P is simulated value

The range of index of agreement (d) is the same as range of $r^2$, which lies from 0 to 1. The value of d describes the ratio between mean square error and the potential error. The index of agreement can be used to expose additional differences of mean and variance in observed and simulated values. However, d is definitely sensitive to intense high or low values (Krause et al., 2005).

## 3. RESULTS AND DISCUSSION

### 3.1 Estimation of groundwater recharge

In this study, results of groundwater recharge are obtained from WetSpass model. Results of WetSpass recharge are compared with empirical recharge as representative of observed groundwater recharge. Empirical recharge is determined by empirical equations including Chaturvedi Formula (CF), Sehgal Formula (SF), Krishna Rao Formula (KRF), and Bhattacharya Formula (BF).

The estimation of groundwater recharge using WetSpass model shows that the results of average simulated recharge during 2000–2010 is about 178.05 mm/yr which is quantified as 20.64% of average annual rainfall (862.63 mm). The results of average empirical recharges performed by CF, SF, KRF, and BF equations during 2000–2010 are 162.90, 265.47, 115.34, and 161.69 mm/yr, which are about 18.88%, 30.77%, 13.37%, and 18.74% of average annual rainfall, respectively. According to recharge performed by empirical equations varying with annual rainfall data only, the pattern of annual empirical recharge during 2000–2010 is definitely the same as pattern of annual rainfall data as shown in Figure 2. It is also exhibited that the pattern of annual

WetSpass recharge during 2000–2010 is similar to pattern of annual empirical recharge, however, its variance is lower than annual empirical recharge.

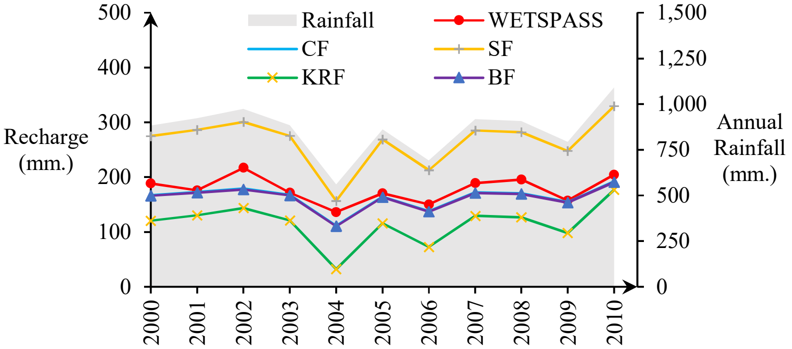


Figure 2. Groundwater recharge performed by WetSpass and empirical equations during 2000-2010.

Comparison of the empirical recharge rates performed by CF, SF, KRF, and BF equations with those obtained by WetSpass are explicitly shown in Figure 2. It is found that CF and BF equations are almost equal to each other with a bit lower than WetSpass recharge. Recharge obtained from SF and KRF equations are relatively different from CF and BF equations. SF recharge is definitely higher than CF, BF, and WetSpass recharges. On the other hand, KRF recharge is lower than CF, BF, and WetSpass recharges.

The estimation of groundwater recharge using WetSpass model exhibits that the results of average simulated groundwater recharge during 2011–2017 is about 186.35 mm/yr which is approximately 18.67% of average annual rainfall (998.36 mm). The results of average empirical recharges performed by CF, SF, KRF, and BF equations during 2000–2010 are 181.66, 305.84, 151.17, and 180.27 mm/yr, are about 18.20%, 30.63%, 15.14%, and 18.06% of average annual rainfall, respectively. During 2011–2017, the average annual rainfall relatively increases from average annual rainfall during 2000–2010. The pattern of annual WetSpass recharge is almost the same as the pattern of annual empirical recharge.

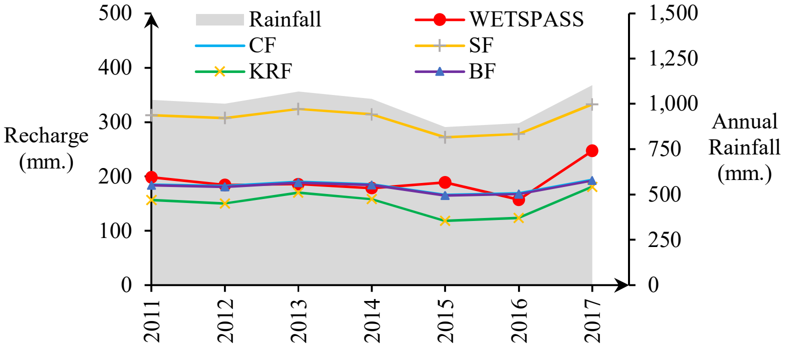


Figure 3. Groundwater recharge performed by WetSpass and empirical equations during 2010-2017.

## 3.2 Calibration and validation of groundwater recharge results

Model calibration and validation are conducted by using statistical parameters including Root Mean Square Error (RMSE), Coefficient of determination ($r^2$), and index of agreement (d) to evaluate performance of WetSpass model for estimation of groundwater recharge. Annual WetSpass recharge (simulated recharge) is compared with empirical recharges (as observed recharge) to calculate value of RMSE, $r^2$, and d.

### *3.2.1 Model calibration*

Model calibration was conducted during 2000–2010. The values of statistical parameters are shown in Table 2. RMSE of WetSpass recharge comparing with empirical recharge is about 48.7 mm, which is about 28.7% of average empirical recharge. The highest RMSE is 91.3 mm (51.7% of average empirical recharge) and 65.5 mm (37.1% of average empirical recharge), by comparing WetSpass recharges with SF and KRF recharges, respectively. As shown in Figure 2, high distinction is explicitly found between WetSpass recharge and SF and KRF recharges. On the other hand, RMSE of WetSpass recharges comparing with CF and BF recharges are definitely lower than those obtained with SF and KRF, which are about 18.6 mm (10.5% of average empirical recharge) and 19.6 mm (11.1% of average empirical recharge), respectively.

The values of $r^2$ between WetSpass recharge and the empirical recharges are almost the same ranging between 0.78–0.79 as shown in Table 2. Even the values of $r^2$ show good correlation between WetSpass recharge and empirical recharges, however, the difference of WetSpass recharge and SF and KRF recharges are relatively high. It is because $r^2$ predictor cannot indicate the variance of data significantly. This brings the index of agreement (d) to be considered to explicitly explain the strength of their relations.

According to Table 2, the values of d comparing WetSpass recharge with CF and BF recharges are definitely high, about 0.83 and 0.81, respectively. On the other hand, the values of d comparing WetSpass recharge with SF and KRF recharges are relatively low about 0.49 and 0.51, respectively. This signifies the intensively high differences between mean and variance of SF and KRF recharges to WetSpass recharge.

Table 2. Statistical parameters of WetSpass recharge comparing with empirical equation during 2000–2010.

| STATISTICS | CF | SF | KRF | BF | AVERAGE |
|---|---|---|---|---|---|
| **RMSE (mm)** | 18.6 | 91.3 | 65.5 | 19.6 | 48.7 |
| **%RMSE** | 10.5 | 51.7 | 37.1 | 11.1 | 27.6 |
| **$r^2$** | 0.78 | 0.78 | 0.79 | 0.78 | 0.78 |
| **d** | 0.83 | 0.49 | 0.51 | 0.81 | 0.66 |

### *3.2.2 Model validation*

Model validation was conducted using data during 2011–2017. The values of statistical parameters are shown in Table 3. RMSE of WetSpass recharge comparing with empirical recharge is about 50.0 mm, which is about 24.4% of average empirical recharge. The highest RMSE is 120.6 mm (58.9% of average empirical recharge) and 38.3 mm (18.7% of average empirical recharge), which is a comparison of WetSpass recharge with SF and KRF recharges, respectively. The values of RMSE during 2011–2017 are slightly higher than RMSE during 2000–2010, except KRF recharge. However, %RMSE of WetSpass recharges are slightly decreased during 2000–2010, except KRF recharge.

The values of $r^2$ during 2011–2017 are significantly lower than during 2000–2010 in the range of between 0.63–0.68 as shown in Table 3. The lower values of $r^2$ represent poor correlation between WetSpass recharge and empirical recharge.

According to table 3, the value of d in 2011–2017 are significantly lower than values of d in 2000–2010, which lie within the range of 0.60–0.68, except SF (0.26). This is representing to extremely high differences between mean and variance of empirical recharge to WetSpass recharge.

Table 3. Statistical parameters of WetSpass recharge comparing with empirical equation during 2011 – 2017.

| | CF | SF | KRF | BF | AVERAGE |
|---|---|---|---|---|---|
| **RMSE (mm)** | 20.3 | 120.6 | 38.3 | 20.7 | 50.0 |
| **%RMSE** | 9.9 | 58.9 | 18.7 | 10.1 | 24.4 |
| **$r^2$** | 0.63 | 0.64 | 0.68 | 0.63 | 0.65 |
| **d** | 0.66 | 0.26 | 0.60 | 0.65 | 0.54 |

It can summarize from the model results that the statistical performance for model calibration is much better than the model validation. The reason might be that WetSpass recharge is manipulated by spatial analysis in which effects of uncertainty is reduced to all recharge areas. Meanwhile, the amount of empirical recharges performed by empirical equations depends on rainfall data significantly. If rainfall variability is found to be high, empirical recharge is consequently high and leads to the poor correlation to WetSpass recharge.

## 3.3 Distribution of groundwater recharge

The average annual groundwater recharge by Wetspass during 2000–2017 is 183.59 mm, which is quantified as 20.5% of average annual rainfall. The spatial distribution of average annual groundwater recharge ranges between 0–460 mm as shown in Figure 4. It is observable that the distribution of groundwater recharge in the study area is related to the distribution of soil types as shown in Figure 1(B). The average annual recharges of clay, loam, and sandy loam soil during 2000–2017 are 132.21, 219.67, and 229.65 mm, which are about 14.8%, 24.6%, and 25.7% by average annual rainfall, respectively as shown in Table 4.

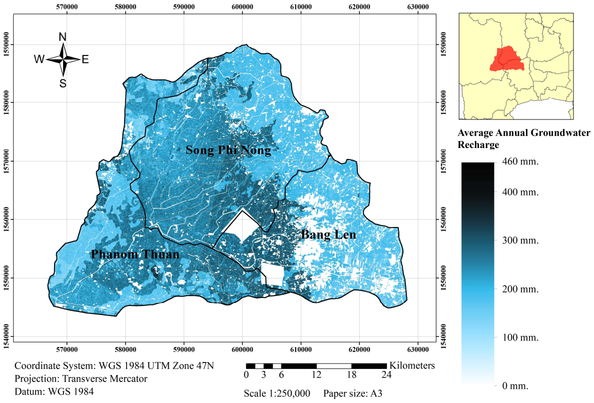


Figure 4. Average annual groundwater recharge performed by WetSpass (2010-2017).

The groundwater recharges in loam and sandy loam in the Phanom Thuan and Song Phi Nong Operation and Maintenance Projects are considerably the same due to the similarity in distribution of land use and soil properties. Meanwhile, rate of groundwater recharge in clay soil especially in Bang Len Operation and Maintenance Projects is the lowest.

The average annual recharges in the Phanom Thuan (PT), Song Phi Nong (SPN), and Bang Len (BL) Operation and Maintenance Projects during 2000–2017 are 201.67, 200.46, 132.29 mm, which are about 22.0%, 21.9%, and 14.5% by average annual rainfall, respectively as shown in Table 4.

Table 4. Details of average annual groundwater recharge distribution during 2000 – 2017.

| | RECHARGE (mm) | % BY RAINFALL |
|---|---|---|
| **PNT** | 201.67 | 22.0 |
| **SPN** | 200.46 | 21.9 |
| **BL** | 132.29 | 14.5 |
| **CLAY** | 132.21 | 14.4 |
| **LOAM** | 219.67 | 24.0 |
| **SANDY LOAM** | 229.65 | 25.1 |

However, no recharge area (white area) is found in Figure 4, which can occur by 2 main reasons. Firstly, the land cover of area is classified as impervious area including city, town, commercial, community and utility, and other built-up land. Secondly, amount of evapotranspiration is higher than inflow by the rainfall amounts. This is generally found in open water body area including aqua–cultural land, artificial water body, and natural water body. These areas are not covered by plants, hence the value of actual evapotranspiration is increased by effects of wind speed and soil evaporation.

## 3.4 Seasonal groundwater recharge

According to Figure 5, groundwater recharge in dry season is absolutely much lower than in wet season. The average groundwater recharge in dry season is 22.07 mm, which is approximately 12.0% of average annual recharge. On the other hand, the average groundwater recharge in wet season is 161.52 mm, which is about 88.0% of average annual recharge.

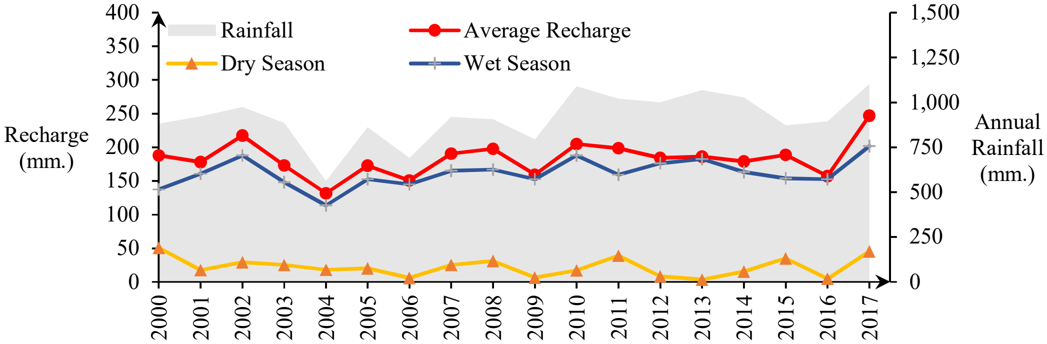


Figure 5. Seasonal groundwater recharge during 2010-2017.

## 4. CONCLUSIONS

The study on estimation of groundwater recharge using WetSpass model in the Phanom Thuan–Song Phi Nong–Bang Len Operation and Maintenance Projects is conducted. Results of average annual groundwater recharge during 2000–2017 is 183.59 mm, which is about 20.5% of average annual rainfall. The average annual recharge in the Phanom Thuan (PT), Song Phi Nong (SPN), and Bang Len (BL) Operation and Maintenance Projects are about 22.5%, 22.4%, and 14.8% by average annual rainfall, respectively. WetSpass model is spatial distribution model, which is suitable in studying the temporal and spatial distribution of groundwater recharge. Distribution of groundwater recharge in the study area relatively depends on soil types. The average groundwater recharges in clay, loam soil, and sandy loam soils are about 14.8%, 24.6%, and 25.7% of average annual rainfall, respectively. Therefore, soil type is a key parameter influencing the amount of groundwater recharge. In order to properly manage groundwater resources and reduce effects of groundwater overuse in a long run, the potential of seasonal and yearly groundwater recharges should be brought for sustainable groundwater development and management practices.

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