Re-assessing Rainwater Harvesting Volume by CHIRPS Satellite in Semarang Settlement Area

Yosef Prihanto1*, Raldi H Koestoer2, Dwita Sutjiningsih3

1 School of Environmental Science, Universitas Indonesia, Jl. Salemba Raya 4 Jakarta Pusat 10430, putranusa212@yahoo.com
2 School of Environmental Science, Universitas Indonesia, Jl. Salemba Raya 4 Jakarta Pusat 10430, ralkoest@yahoo.co.uk
3 Department of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, dwita@eng.ui.ac.id

Abstract. Semarang City is one of the most influential coastal cities in Java Island. The city is facing increasingly high-water demand due to its development and water problems due to climate change. The spatial physiography and landscape of Semarang City are also exposed the city to water security problem. Hence, rainwater harvesting treatment is an urgent effort to meet the city’s water needs. However, planning, implementation and management of rainwater harvesting are highly depend ed on multitemporal rainfall data. It has not yet been fully compiled due to limited rain stations. This study aims to examine the extent to which CHIRPS satellite data can be utilized in estimating volume of rainwater harvesting 16 sub-districts in Semarang and determine the water security status. This study uses descriptive statistical method based on spatial analyses. Such method was developed through spatial modeling for rainfall using isohyet al model. The parameters used are rainfall, residential rooftop area, administrative area, population, physiographic and altitude units. Validation is carried out by using monthly 10 rain stations data. The results show level of validity by utilizing CHIRPS Satellite data and mapping rainfall distribution. This study also produces a potential map of distribution rainfall volume that can be harvested in 16 sub-districts of Semarang.

Keywords: CHIRPS, Rainwater Harvesting, Isohyetal, Urban, Spatial

1. Introduction
City of Semarang is one of the most influential coastal cities in Java Island. The city is facing increasingly high-water demand due to its vast development and also water problems due to climate change. The spatial physiography and landscape of Semarang City shown in this paper shows that the city have water security problem. Therefore, rainwater harvesting treatment is suggested as an urgent effort to meet the city's water needs.

UN-Water has formulated an understanding in water security. Water security is defined as capacity of the population to safeguard sustainable access to adequate quantities of acceptable quality of water that can be used to sustain livelihoods, human well-being, and socio-economic development, as well as for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability [1]. Basically, water security problem is very
complex. It not only deals with physical and technological aspects in meeting the water needs, but it also concerns the impact on the environment and social, political, and economic conditions on a group of people, often associated with other community groups. Conflict of interest between groups of people also affects social and political stability that determine the water security itself. Semarang now faces water security problem. One of the answers for this problem is to apply rainwater harvesting.

Many researches and studies on rainwater harvesting have been done in various places in the world [2] [3] [4] [5] [6] [7] [8] [9]. Each of them concluded in benefits and advantages of this method. The studies undertaken include developing methods to choose suitable sites for application of rainwater harvesting [10], calculating potential volumes [2] [3] [4] [6], planning water catchment sizes [11], assessing feasibility and economic efficiency [9] [12], management aspects [7] [9] [13] even aspects of the sustainability of this method [14]. Utilization of remote sensing and geographic information system (GIS) technologies is also widely used in the development of method for identification location and the potential measurement of rainwater harvesting applications [8] [10] [15].

The use of remote sensing in various rainwater-harvesting studies is commonly used for the identification of land use, roof area, flow density and other physical aspects [8] [10] [15]. The use of GIS plays a larger role in modeling and calculating the potential volume of rainwater harvesting. Generally modeling and volume calculations are performed on relatively limited study areas and use only average rainfall values in micro coverage [8] [10] [15]. Whereas planning, implementation and management of rainwater harvesting highly depend on multitemporal rainfall data. In the case of Semarang City, this data has not been fully compiled due to limited rain stations. Based on that condition, this study utilizes CHIRPS satellite data to estimate the volume of rainwater harvesting in Semarang City’s 16 sub-districts and then determine water security status for the city.

2. Method
2.1. Location of the study
The study was conducted in the City of Semarang. It covers 16 sub-districts and 177 urban villages (kelurahan). Semarang is a city on the north coast of Java Island that has unique spatial physiography and landscape. The description of the location and administrative boundaries of Semarang city is presented in Figure 1. The city can be use to represent the condition in many big cities in Indonesia whereas there are continues growth and followed by challenges in water provision.

![Java Island](image)

**Figure 1.** Location of study.

2.2. Secondary data
This research uses land-use data obtained from BIG (Geospatial Information Agency). The data is the result of visual interpretation of high-resolution satellite image of recording in 2012. Data of interpretation result have been validated through field test survey in 2013 and 2016. Land-use unit as
observation priority is settlement and non-settlement. Population data uses data published by BPS (Central Bureau of Statistics) Semarang City in 2012 and 2015. Population data used are the population and the number of head of household. Average monthly rainfall data from 10 weather stations in Semarang uses data from 2012. CHIRPS dataset of Semarang City and surroundings using recording data for 10 years (2007-2016).

Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) is the name of a rain satellite developed for global interests. CHIRPS developed by U.S. Geological Survey (USGS) and Climate Hazards Group at University of California, Santa Barbara. Quasi-global gridded products are available from 1981 to near present at 0.05° spatial resolution (~5.3 km). New products are released approximately mid-month of the month following the observation [16].

2.3. Method of determining the virtual weather station point
The isohyetal method in this study was established by determining virtual weather station points. These points are considered to be the location of weather stations whose rainfall data values will be taken into account in model calculations. The nets of those points are set uniformly distributed and covering up to areas outside administrative boundaries of City of Semarang. This study calculates that 35 spatial spots that have a distance of 3 minutes north south and 3 minutes east west can represent study area. The upper left point starts at the coordinates 110°13’30”E and 6°55’30”S while the bottom right point at the coordinates 110°31’30”E and 7°7’30”S. Establishing nets with wider coverage than study area has aim to obtain a better spatial distribution modeling result.

2.4. Calculation of the average monthly rainfall value
Monthly rainfall calculation is obtained monthly based on monthly CHIRPS recording data of 10 years, 2007-2016. The monthly rainfall rate in one year at each virtual weather station is tabulated for 10 years. Monthly rainfall figures in the 10-year range tabulated based on the virtual weather station points are then sequenced on the basis of the value, from the lowest to the highest value. The value of the 8th order or the value that is considered to have an 80% probability, is the value chosen as average value of rainfall for corresponding virtual weather station point. By the result of this processing then can be found the average monthly rainfall value for each virtual weather station point.

2.5. Preparation of monthly rainfall maps by isohyetal method using GIS software
The result of calculation of the average monthly rainfall value then becomes input data to make isohyetal map using GIS software. Monthly average rainfall data processing from 35 virtual weather station points using the ArcGIS 10.3 application. The module facility used is Spatial Analysis Tools that is Interpolation with Spline method option. The Spline tool uses an interpolation method that estimates the value of a mathematical function that minimizes overall survival curvature, resulting in a smooth surface that passes exactly through the input points. The classification of interpolation results by using 7 rainfall classes each then has a difference of 100 mm wide range. This isohyetal modeling is simulated for every month of the year.

2.6. Model validation
Model validation of the utilization of CHIRPS recording data uses monthly average rainfall data from 10 stations in Semarang city in 2012 record. This validation is only monthly recaptured from one period January to December on the basis of 10 years record. This validation is trying to see and to know how far value deviations occur when this modeling method is used to utilize CHIRPS data.

2.7. Estimation the addition area rooftop of the settlement
Estimated addition of roof area of settlement is done by approach of population, average number of family member, number of head household and average of roof area every head count for family. This estimate is conducted due to unavailability of spatial data of the latest 2017 residential roof area. The calculation of the 2017 roof area is based on data of the roof data in 2012, the population in 2012 data,
and the number of head household in 2012 and 2015. The calculation of estimated population of Semarang City in 2017 is based on population data of each urban village. Growth rates are calculated based on the average population growth of each urban village in the last 10 years of observation (2006-2015). Calculation of 2017 population in 2017 can be estimated by using equation (1):

\[ P_n = P_0 (1+r)^n \]  

Remarks:
- \( P_n \) = number of population in year \( n \)
- \( P_0 \) = number of population in year 0 or base year
- \( n \) = number of years between 0 and \( n \)
- \( r \) = population growth rate per year (in %)

2.8. Estimation of rainwater that can be harvested

Estimation of rainwater volume that can be harvested is done by multiplying monthly average rainfall of the modeling results (\( P \), in mm/month), the width of the roof or the catchment area (\( A \), in \( m^2 \)), and the runoff coefficient (RC, nondimensional) [17] as shown in equation (2). Roof area is the result of the estimation of the roof area in each urban village area in 2017. Rainfall value is the value of the average rainfall of the proportion of isohyetal calculations and the distribution based on the width of the urban village. The runoff coefficient is set to 0.7 with the consideration that there is no detailed information about the type of roof and its slope. Another consideration in determining the value of runoff coefficient is the average type of residential roof in the study area is still dominated by roof tile [17]. The calculation of the population’s water needs, using the reference set by the Ministry of Public Works Indonesian, 120 liters/day/person.

\[ \text{RWH potential} = P \cdot A \cdot RC \]  

3. Result and Discussion

This section presents results of studies and discussions on results obtained. It consists of 6 sections, and each step of study activity will be described.
3.1. Determining virtual weather station point
The result of the determination of 35 virtual weather station points (P1-P35) visually distributed is shown in Figure 2. The virtual weather station points form a 7x5 matrix and spread evenly across the entire study area. The coordinates of each virtual weather station point of reference are to record the monthly precipitation value of CHIRPS data within the 10-year recording range. The rainfall number is used as input to the next processing.

3.2. Calculation monthly rainfall and monthly rainfall maps by isohyetal method
The result of rainfall data processing obtained from CHIRPS dataset is further processed using Spatial Analysis Tools facility module that is Interpolation with Spline method option. This processing produces an isohyetal map as illustrated in Figure 3. It only presents visually the results of isohyetal modeling for 6 months only. In this study isohyetal modeling is still done for 12 months in one year. Distribution and differences in rainfall over time can be seen in Figure 3. In July-September it can be observed that the study area's rainfall tends to be at a low value. In December-January actually shows the opposite condition, namely the value of rainfall area tend to be high.

The rainfall distribution sample illustrated in Figure 3 shows the potential volume of rainwater that can be harvested. The quantity is varied in volume each month. Differences of volume each month must be taken into consideration in rain harvest management in Semarang City.
3.3. Validation model

The result of modeling that has been done on CHIRPS data is then validated. Validation is done by comparing precipitation values obtained from the modeling at the existing weather station points. The spatial distribution of the weather station location referred to in Figure 4. In terms of distribution and quantity, these weather stations can be rated very limited.

Figure 3. Monthly rainfall maps by isohyetal method.
Figure 4. Distribution of 10 weather stations in City of Semarang.

Monthly average rainfall data from each weather station is shown in Table 1. Based on this table, it can be seen that wet months occur in January, February, March, October, November, and December. While dry months occur in April, May, June, July, August, and September. Very dry months occur in July, August, and September. Very wet months occur in January and December. Based on the table observation can also be seen some stations have record values of very high rainfall in wet season are station of Gunung Pati and Boja Mijen.

Table 1. Average monthly rainfall value weather stations in Semarang area.

| No. | Station      | January | February | March | April | May | June | July | August | September | October | November | December | Average |
|-----|--------------|---------|----------|-------|-------|-----|------|------|--------|-----------|---------|----------|----------|---------|
| 1   | Ahmad Yani  | 490     | 340      | 190   | 176   | 68  | 78   | 1    | 0      | 4         | 214     | 255      | 318      | 178     |
| 2   | Tanjung Mas | 440     | 308      | 266   | 173   | 63  | 1    | 2    | 0      | 29        | 187     | 256      | 283      | 176     |
| 3   | Tlogosari   | 406     | 401      | 318   | 221   | 85  | 116  | 2    | 3      | 13        | 258     | 444      | 191      | 205     |
| 4   | Semarang Barat | 498     | 370      | 220   | 170   | 90  | 110  | 2    | 3      | 271       | 256     | 327      | 327      | 185     |
| 5   | Beringin    | 595     | 331      | 231   | 245   | 133 | 98   | 0    | 0      | 268       | 161     | 334      | 197      | 197     |
| 6   | Ngaliyan    | 583     | 383      | 247   | 256   | 104 | 116  | 95   | 0      | 0         | 226     | 198      | 458      | 202     |
| 7   | Candi       | 460     | 292      | 231   | 193   | 112 | 79   | 2    | 0      | 0         | 202     | 295      | 342      | 183     |
| 8   | Klipang     | 313     | 232      | 293   | 187   | 129 | 112  | 20   | 0      | 1         | 75      | 266      | 370      | 167     |
| 9   | Gunung Pati | 682     | 479      | 334   | 285   | 221 | 161  | 0    | 0      | 0         | 218     | 447      | 589      | 285     |
| 10  | Boja Mijen  | 1,698   | 1,110    | 691   | 616   | 154 | 343  | 0    | 0      | 31        | 89      | 321      | 555      | 467     |

Source: weather station data.

The mean rainfall value of CHIRPS data modeling in reference to station reference coordinate point is presented in Table 2. In general, distribution of the pattern is similar to the average monthly
The lower average monthly rainfall value. While in the group of average values of monthly rainfall in the dry month that tends to have a higher value than the average monthly reference rainfall value. While in the group of average values of monthly rainfall in wet months, generally the model results show lower value than the average monthly reference rainfall value.

Table 2. Average monthly rainfall value from isohyetal model of weather stations in Semarang area.

| No. | Station            | January | February | March | April | May | June | July | August | September | October | November | December | Average (unit in mm) |
|-----|--------------------|---------|----------|-------|-------|-----|------|------|--------|-----------|---------|-----------|-----------|----------------------|
| 1   | Ahmad Yani         | 442     | 283      | 278   | 160   | 85  | 74   | 14   | 23     | 32        | 132     | 272       | 352       | 179                  |
| 2   | Tanjung Mas        | 462     | 288      | 286   | 158   | 93  | 72   | 13   | 21     | 30        | 138     | 276       | 347       | 182                  |
| 3   | Tlogosari          | 462     | 288      | 286   | 158   | 93  | 72   | 13   | 21     | 30        | 138     | 276       | 347       | 182                  |
| 4   | Semarang Barat     | 442     | 283      | 278   | 160   | 85  | 74   | 14   | 23     | 32        | 132     | 272       | 352       | 179                  |
| 5   | Beringin           | 452     | 284      | 287   | 170   | 91  | 75   | 15   | 24     | 30        | 143     | 278       | 353       | 184                  |
| 6   | Ngaliyan           | 407     | 291      | 258   | 161   | 95  | 77   | 12   | 22     | 31        | 129     | 230       | 314       | 169                  |
| 7   | Candi              | 443     | 292      | 280   | 167   | 94  | 80   | 13   | 21     | 31        | 143     | 242       | 338       | 179                  |
| 8   | Klipang            | 443     | 292      | 280   | 167   | 94  | 80   | 13   | 21     | 31        | 143     | 242       | 338       | 179                  |
| 9   | Gunung Pati        | 438     | 328      | 294   | 198   | 107 | 84   | 12   | 24     | 30        | 141     | 276       | 372       | 192                  |
| 10  | Boja Mijen         | 546     | 414      | 412   | 269   | 158 | 104  | 21   | 28     | 31        | 178     | 385       | 509       | 255                  |

Source: CHIRPS data processing.

Table 3. Value of difference between reference rainfalls compared to model.

| No. | Station     | January | February | March | April | May | June | July | August | September | October | November | December | Average (unit in mm) |
|-----|-------------|---------|----------|-------|-------|-----|------|------|--------|-----------|---------|-----------|-----------|----------------------|
| 1   | Ahmad Yani  | -48     | -57      | -88   | -16   | 17  | -4   | 13   | 23     | 28        | -82     | 17        | 34        | 1                    |
| 2   | Tanjung Mas | 22      | -20      | 20    | 49    | 80  | 9    | 12   | 21     | -49       | 20      | 134       | 64        | 6                    |
| 3   | Tlogosari   | -56     | -113     | -32   | -63   | 8   | 44   | 11   | 21     | 17        | -120    | -168      | 156       | -23                  |
| 4   | Semarang Barat | -56   | 13       | 58    | -10   | -5  | -36  | 12   | 23     | 29        | -139    | 16        | 25        | -6                   |
| 5   | Beringin    | -143    | -37      | 42    | -44   | 42  | 23   | 15   | 24     | 30        | -125    | 117       | 19        | -13                  |
| 6   | Ngaliyan    | -176    | -92      | 2     | 57    | -21 | -18  | 12   | 22     | 31        | -97     | 32        | -144      | -33                  |
| 7   | Candi       | -17     | 0        | 59    | -26   | 18  | 1    | 11   | 21     | 31        | -59     | -53       | -4        | -4                   |
| 8   | Klipang     | -130    | 60       | -13   | -20   | -35 | -32  | -7   | 21     | 30        | 68      | -24       | -32       | 12                   |
| 9   | Gunung Pati | -244    | -151     | -40   | 87    | 114 | -77  | 12   | 24     | 30        | -77     | -171      | -217      | -93                  |
| 10  | Boja Mijen  | -1152   | -696     | -279  | -347  | 4   | -239 | 21   | 28     | 0         | 89      | 64        | -46       | -212                 |

Source: calculation processing of weather station data and CHIRPS data.

The results in Tables 1 and 2 subsequently become the basis to calculate the value of difference between the average monthly rainfall values of the model-making product with the average monthly reference rainfall value. Based on the calculation data presented in Table 3, there is a difference in yield for wet and dry months. For wet months, the precipitation value of the modeling results has a lower value trend than the reference data. For dry months the value of the rainfall model tends to be higher than the reference value. In Table 3, a positive number indicates the higher excess value while the lower one is denoted by a negative value.
The result from calculating the difference in value of precipitation further becomes a reference to calculate value of error or deviation. The calculation result of deviation can be seen in Figure 5 and Table 4. The calculation result shows that the validation value of the model for each weather station varies in value. In general, the number of deviations on 8 stations is below 30%, but 2 stations have deviations of more than 30%, namely the station of Mount Pati and Boja Mijen. These two stations are located at an altitude above 200 m above sea level. Based on the direction of deviation, generally the modeling data is below the reference value; this is indicated by a negative error value.

Table 4. Percentage monthly rainfall error in weather station.

| No | Weather station | Error (%) |
|----|-----------------|-----------|
| 1  | Ahmad Yani      | 0.56      |
| 2  | Tanjung Mas     | 3.41      |
| 3  | Tlogosari       | -11.22    |
| 4  | Semarang Barat  | -3.24     |
| 5  | Beringin        | -6.60     |
| 6  | Ngaliyan        | -16.34    |
| 7  | Candi           | -2.19     |
| 8  | Klipang         | 7.19      |
| 9  | Gunung Pati     | -32.63    |
| 10 | Boja Mijen      | -45.40    |

Figure 5. Percentage distribution of monthly rainfall error in weather station.

3.4. Land-use of Semarang City and distribution roof top area of the settlement
The land-use classification used in this study is reclassified and simplified into 9 classes of land-use. The land-use unit used is; regular settlements, irregular settlements, public and social facilities, industrial estates, trade and service areas, agricultural cultivation areas, green areas, water bodies, others/identified. The results of land use GIS processing are shown in Figure 7. Figure 7 shows the general distribution of settlements that follow pattern of landscape transportation and physiography of City of Semarang. Figure 6 presents height surface and physiographic of Semarang City.

Figure 6. Landscape physiography of Semarang City.

Figure 7. Land-use of Semarang City.
3.5. Addition area rooftop of the settlement
The results of population data processing are presented in Table 5 and Table 6. Those tables show estimated population in 2017. Based on that estimation, it can be calculated the number of heads of households by 2017. The number of heads of households is used to estimate the roof area in 2017. The estimation of existing residential roof area in City of Semarang up to 2007 is estimated to reach 3,543.37 ha.

**Table 5.** Distribution of population, number of head household and the projected.

| Sub-dist (Kecamatan) | Population (person) | Projected Population (t=2) | Number of Head household (Hh) | Average Family members | Projected number of Head household (Hh) |
|----------------------|----------------------|-----------------------------|-----------------------------|------------------------|---------------------------------------|
| 2012                 | 2015                 | 2017                        | 2012                        | 2015                   | 2017                                  |
| Mijen                | 56,570               | 61,405                      | 65,715                      | 16,669                 | 18,916                                | 3                                     | 3                        | 20,244                  |
| Gumung Pati          | 75,027               | 78,641                      | 82,461                      | 21,501                 | 22,760                                | 3                                     | 3                        | 23,866                  |
| Banyumanik           | 128,225              | 132,508                     | 137,132                     | 35,529                 | 44,632                                | 4                                     | 3                        | 46,190                  |
| Gajahmungrur         | 63,430               | 63,707                      | 64,384                      | 14,885                 | 14,941                                | 4                                     | 4                        | 15,100                  |
| Semarang Selatan     | 82,931               | 79,620                      | 78,462                      | 24,746                 | 22,542                                | 3                                     | 4                        | 22,214                  |
| Candisari            | 79,902               | 79,258                      | 78,957                      | 19,909                 | 21,316                                | 4                                     | 4                        | 21,235                  |
| Tembalang            | 142,941              | 156,868                     | 166,680                     | 43,197                 | 45,898                                | 3                                     | 3                        | 48,769                  |
| Pedurungan           | 175,770              | 180,282                     | 185,951                     | 45,512                 | 46,101                                | 4                                     | 4                        | 47,551                  |
| Genuk                | 91,527               | 97,540                      | 103,606                     | 24,719                 | 29,952                                | 4                                     | 3                        | 31,813                  |
| Gayamsari            | 73,584               | 74,178                      | 75,789                      | 27,173                 | 19,790                                | 3                                     | 4                        | 20,220                  |
| Semarang Timur       | 78,889               | 77,331                      | 76,129                      | 21,842                 | 21,709                                | 4                                     | 4                        | 21,372                  |
| Semarang Utara       | 127,921              | 127,752                     | 128,366                     | 32,108                 | 32,865                                | 4                                     | 4                        | 33,023                  |
| Semarang Tengah      | 71,674               | 70,259                      | 68,944                      | 20,844                 | 20,796                                | 3                                     | 3                        | 20,407                  |
| Semarang Barat       | 158,981              | 158,131                     | 158,701                     | 44,302                 | 57,649                                | 4                                     | 3                        | 57,857                  |
| Tugu                 | 30,904               | 31,954                      | 33,428                      | 8,603                  | 9,038                                 | 4                                     | 4                        | 9,455                   |
| Ngaliyan             | 120,922              | 125,828                     | 131,889                     | 33,645                 | 42,422                                | 4                                     | 3                        | 44,465                  |
| Semarang City        | 1,559,198            | 1,595,267                   | 1,636,594                   | 435,184                | 471,327                               | 4                                     | 3                        | 483,779                 |

**Table 6.** Average roof every head household and wide roof of the settlement.

| No | Sub-dist (Kecamatan) | Average roof every head household (m²) | Wide roof of the settlement (person) | 2012 (m²) | 2012 (ha) | 2017 (ha) |
|----|----------------------|-----------------------------------------|-------------------------------------|-----------|-----------|-----------|
| 1  | Mijen                | 83.48                                   | 139.15                              | 168.99    |           |           |
| 2  | Gumung Pati          | 86.16                                   | 185.25                              | 205.62    |           |           |
| 3  | Banyumanik           | 79.74                                   | 283.32                              | 368.33    |           |           |
| 4  | Gajahmungrur         | 85.76                                   | 127.65                              | 129.49    |           |           |
| 5  | Semarang Selatan     | 43.65                                   | 108.02                              | 96.97     |           |           |
| 6  | Candisari            | 73.43                                   | 146.19                              | 155.93    |           |           |
| 7  | Tembalang            | 76.51                                   | 330.50                              | 373.13    |           |           |
| 8  | Pedurungan           | 61.73                                   | 280.94                              | 293.52    |           |           |
| 9  | Genuk                | 59.19                                   | 146.31                              | 188.30    |           |           |
| 10 | Gayamsari            | 32.49                                   | 88.28                               | 65.69     |           |           |
| 11 | Semarang Timur       | 51.52                                   | 112.54                              | 110.11    |           |           |
| 12 | Semarang Utara       | 55.42                                   | 177.93                              | 183.00    |           |           |
| 13 | Semarang Tengah      | 39.72                                   | 82.80                               | 81.06     |           |           |
| 14 | Semarang Barat       | 75.34                                   | 333.78                              | 435.90    |           |           |
| 15 | Tugu                 | 58.07                                   | 49.96                               | 54.91     |           |           |
| 16 | Ngaliyan             | 142.22                                  | 478.52                              | 632.41    |           |           |

P in Semarang City

70.57   3,071.13   3,543.37
3.6. Potential volume of rainwater that can be harvested

Based on average monthly rainfall data, estimation data of roof area and runoff coefficient can be calculated the estimation of rainfall volume that can be harvested in residential area. The calculation of potential volume of rainwater that can be harvested every month in residential area of Semarang can be seen in Table 7. The visualization of volume distribution per month can be seen in Figure 8. Based on those tables and figures, it appears that there are fluctuations in potential volume of rainfall affected by season. That condition has been identified at the time of making the isohyetal model. Hence, that condition requires the management of potential rainwater that can be harvested during wet months to cover shortfall in dry months.

Table 7. Monthly availability of rainwater harvesting in one year.

|     | January | February | March | April | May | June | July | August | September | October | November | December |
|-----|---------|----------|-------|-------|-----|------|------|--------|-----------|---------|----------|----------|
| RWH | 12,693  | 12,126   | 9,294 | 7,103 | 6,289 | 3,792 | 2,191 | 1,114  | 1,076     | 3,556   | 6,854    | 9,795    |
| $x\times10^6$ liter |           |          |       |       |       |       |       |        |           |         |          |          |

The calculation of value of urban water needs in urban settlements refers to value of water demand set 120 liters/day/person. The results show volume of water demand in residential area of each sub-district within a year. A comparison of water demand scores with potential volume of rainwater harvesting volume in one year will result in water resilience status of the area.

Table 8. Water needs and availability of rainwater harvesting in one year.

| No  | Sub-district      | One year water needs $x\times10^6$ liter | One year rainwater harvest $x\times10^6$ liter | Difference $x\times10^6$ liter | Status |
|-----|-------------------|-----------------------------------------|---------------------------------------------|--------------------------------|--------|
| 1   | Mijen             | 2,878                                   | 3,837                                       | 958                            | Surplus|
| 2   | Gunung Pati       | 3,612                                   | 4,512                                       | 900                            | Surplus|
| 3   | Banyumanik        | 6,006                                   | 8,299                                       | 2,293                          | Surplus|
| 4   | Gajahmungkur      | 2,820                                   | 2,632                                       | -188                           | Deficit|
| 5   | Semarang Selatan  | 3,437                                   | 2,103                                       | -1,333                         | Deficit|
| 6   | Candisari         | 3,458                                   | 3,207                                       | -251                           | Deficit|
| 7   | Tembalang         | 7,301                                   | 7,982                                       | 682                            | Surplus|
| 8   | Pedurungan        | 8,145                                   | 6,087                                       | -2,058                         | Deficit|
| 9   | Genuk             | 4,538                                   | 4,009                                       | -529                           | Deficit|
| 10  | Gayamsari         | 3,320                                   | 1,659                                       | -1,661                         | Deficit|
| 11  | Semarang Timur    | 3,334                                   | 2,266                                       | -1,069                         | Deficit|
| 12  | Semarang Utara    | 5,622                                   | 3,757                                       | -1,866                         | Deficit|
| 13  | Semarang Tengah   | 3,020                                   | 1,681                                       | -1,338                         | Deficit|
| 14  | Semarang Barat    | 6,951                                   | 9,445                                       | 2,494                          | Surplus|
| 15  | Tugu              | 1,464                                   | 1,160                                       | -304                           | Deficit|
| 16  | Ngaliyan          | 5,777                                   | 13,247                                      | 7,471                          | Surplus|
|     | Total Semarang City | 71,683                                   | 75,883                                      | 4,201                          | Surplus|

The water security status of each sub-district within the administrative area of Semarang City is presented in Table 8. Comparison between amount of community water demand and potential volume of water that can be harvested in settlement areas of each urban village is presented in Figure 9. The results of analysis and calculation of water security status presented in Table 8 indicate that 9 sub-
districts are in deficit status if their water sources are only using rainwater harvesting. On the other hand, the other 7 districts are in surplus status only if they utilize rain water as the sole source of water disregarding other water sources. Mostly, districts with deficit status are located in the urban areas with higher population density. Areas with surpluses are generally on the edge with lower population densities and average per-head household roof area is also wider. Figure 9 also illustrates importance of inter-regional water management in addition to time-based rainwater management, as has been mentioned in relation to the potential for monthly rainwater availability in one year (Figure 8).

4. Conclusions
Generally, it can be concluded that CHIRPS data can be used to construct rainfall isohyetal model for rainwater harvesting planning. This consideration was obtained based on validation results indicating that average error value of rainfall generated by the model is below 30% (8 weather stations). Only 2 stations have a deviation value exceeding 30%. This needs to be studied further related to the physiographic condition of the area where the weather station is located, which is above 200m height and is an area with hilly physiography. Another consideration that supports the CHIRPS data can be used for rainwater harvesting planning is the estimated value of rainfall generally lower than the reference value. This condition is considered much better as it avoids overly optimistic volume planning.

Water security status of Semarang City assessed based on the potential volume of rainwater harvesting generally shows a surplus. If Semarang City only relies on rainwater as the only source of water, the city is actually able to meet its water needs. However, the surplus condition should consider water management factor in terms of time and distribution of the region. The average monthly rainfall that changes within season and the condition of residential area as well as the extent of roof available in each region makes the potential distribution of rainwater harvesting volume becomes uneven. Based on the results of this study, it can be stated that rainwater harvesting in City of Semarang based on its potential volume can be used as an alternative source of water to meet water needs of the city’s population.

Acknowledgments
Acknowledgments to the Geospatial Information Agency (BIG) for the support of data and software used in this study. Acknowledgments are also conveyed to the Universitas Indonesia (UI), especially the School of Environmental Sciences for support in publication activities and Universitas Diponegoro, especially Urban Planning Studies Program for all supports during fieldwork process. Authors thanks to Sylvia Prisca Delima for her helpful comment on the first draft of this paper.
References

[1] UN University 2013 Water Security & the A Global Water Agenda UN-Water Analytical Brief Canada.

[2] Zaizen M, Urakawa T, Matsumoto Y, Takai H 2000 The collection of rainwater from dome stadiums in Japan Urban Water Journal 1 (4) 355–359

[3] Villarreal E L and Dixon A 2005 Analysis of a rainwater collection system for domestic water supply in Ringdansen Norrköping Sweden Building and Environment Journal 40 (9) 1174–1184

[4] Ghisi E 2006 Potential for potable water savings by using rainwater in the residential sector of Brazil Building and Environment Journal 41 (11) 1544–1550

[5] Nolde E 2007 Possibilities of rainwater utilisation in densely populated areas including precipitation runoffs from traffic surfaces Desalination Journal 215 (1–3) 1–11

[6] Abdulla F A and Al-Shareef A W 2009 Roof rainwater harvesting systems for household water supply in Jordan Journal of Desalination 243 (1-3) 195-207

[7] Zhang D, Gersberg R M, Wilhelm C, Voigt M 2009 Decentralized water management rainwater harvesting and greywater reuse in an urban area of Beijing China Urban Water Journal 6 (5) 375–385

[8] Akter A and Shoukat A 2015 Potentiality of rainwater harvesting for an urban community in Bangladesh Journal of Hydrology 528 84-93

[9] Jeremy G, Sam T and Divesh Kumar M 2012 Mandatory urban rainwater harvesting: learning from experience Water Science & Technology 65 (7) 1200-1207

[10] Rida A, Abdullah D, Ghada S 2010 Combining GIS with multicriteria decision making for siting water harvesting ponds in Northern Jordan Journal of Arid Environments 74, 1471-1477

[11] Guebali A, Djebbar Y, Guedri A, Boukhari S 2011 Rainwater harvesting in North Africa: A novel method for reservoir sizing Journal of Materials and Environmental Science 2 (S1) 469-472

[12] Farrenya R, Gabarrella X, Rieradevall J 2011 Cost-efficiency of rainwater harvesting strategies in dense Mediterranean neighbourhoods Resources, Conservation and Recycling 55 686–694

[13] Zeng B, Tan H, Wu L 2007 A New Approach to Urban Rainwater Management Journal of China University of Mining & Technology 17 (1) 82-84.

[14] Jaemins S, Mooyoung H, Tschung-il K, Jee-eun S 2009 Rainwater harvesting as a sustainable water supply option in Banda Aceh Desalination 248 233–240

[15] Funk C, Peterson P, Landsfeld M, Pedreros D, Verdin J, Rowland J, Romero B, Husak G, Michaelsen J, Verdin A, Pedreros P 2014 A Quasi-Global Precipitation Time Series for Drought Monitoring U.S. Geological Survey Data Series 832 Available online: pubs.usgs.gov/ds/832/ (accessed on 8 August 2014).

[16] Ramon F, Tito M P, Albert G, Carlota T, Joan R, Xavier G 2011 Roof selection for rainwater harvesting: Quantity and quality assessments in Spain Water Research 45 3245-3254