

Development of *Soil & Water Assessment Tool* Application In Krueng Aceh Watershed Review

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Abstract

The problem of the water availability has become a global issue so that it needs a tool for water management such as the Soil and Water Assessment Tool (SWAT). This study aims to measure how far the uses and developments of the SWAT model in the Krueng Aceh watershed. This paper reviewed applications of SWAT Model in Krueng Aceh Watershed. The developments data were obtained from five publications. This study has limitations in assessing the performance of the SWAT developed in the Krueng Aceh watershed/sub-watershed because not all publications report on the calibration or validation process. From the search results, there is one modeling application that performs the calibration process with statistical parameters on a daily scale and the other three papers on monthly data. The availability of observation data has not had a long time series makes researchers face limitations in improving the model performances.

Keywords: *SWAT, Hydrological Model, Water, Soil*

Abstrak

Masalah ketersediaan air telah menjadi isu global sehingga diperlukan suatu alat untuk pengelolaan air seperti *Soil and Water Assessment Tool (SWAT)*. Penelitian ini bertujuan untuk mengukur sejauh mana pemanfaatan dan perkembangan model SWAT di DAS Krueng Aceh. Artikel ini mengulas penerapan Model SWAT di DAS Krueng Aceh. Data perkembangan diperoleh dari lima publikasi mengenai Model SWAT. Kajian ini memiliki keterbatasan dalam menilai kinerja SWAT yang dikembangkan di DAS/sub-DAS Krueng Aceh karena tidak semua publikasi melaporkan proses kalibrasi atau validasi. Dari hasil pencarian, terdapat satu aplikasi pemodelan yang melakukan proses kalibrasi dengan parameter statistik pada skala harian dan tiga aplikasi lainnya pada data bulanan. Ketersediaan data lapangan yang belum memiliki data time series yang panjang membuat peneliti menghadapi keterbatasan dalam meningkatkan performa model.

Kata Kunci: *SWAT, Model Hidrologi, Air, Tanah*

1. Introduction

The problem of the need and availability of clean water has become a global issue because it is related to the livelihoods of people in various parts of the world. Various approaches and scientific disciplines try to solve problems related to the need and availability of water resources. The application and development of hydrological modeling is very rapid to assist in solving water problems in a watershed. Proper watershed management will maintain a balance of water demand and availability at the watershed scale. The main reason of utilization of hydrological modeling is accessible and easily used to solve water related problems from large social problems as well as it can be interfaced with the help of GIS (Sui and Maggio, 1999). Hydrological models embedded in modeling systems can represent various environmental processes at various time and space scales (Wagener et al., 2001). The SWAT model is a model that can simulate environmental processes that exist in a watershed. This model is based on complex physics and is designed to test and predict the circulation of water and sediment in a basin (Devia et al., 2015). Each basin is divided into several sub-basins based on land use type and soil type into Hydrologic response units (HRUs) (Zheng et al., 2010). HRUs are defined in SWAT as a cluster result from the uniqueness of soil type, soil cover, and slope class (White et al., 2011).

The development of a hydrological model (SWAT Model) in Krueng Aceh watershed is the right step to manage water resources and avoid potential damage in the watershed. The Krueng Aceh watershed is administratively located in Aceh, exactly Banda Aceh City and Aceh Besar District. The city of Banda Aceh is the central areas and the administration center of the Aceh Province. Banda Aceh in particular is the area with the highest population density in Aceh Province, with a population density of 43 people/ha in 2020 (BPS, 2021). In addition, the net migration rate for Banda Aceh City is increasing recently. The Krueng Aceh River is the main water source for the cities of Banda Aceh and Aceh Besar. Population growth in the central area of the provincial government will certainly affect the conditions in the watershed. Therefore, this study aims to measure the extent to which the SWAT model is used in the Krueng Aceh watershed. SWAT Model is a hydrological model that is classified as semi-distribution and is currently widely used in various parts of the world.

2. Research Methodology

This paper is a review study on the uses and developments of the hydrological modeling in Krueng Aceh watershed. In this case, the model being reviewed is the semi-distribution model; the Soil and Water Assessment Tool (SWAT). This study reviewed five published reports using the SWAT Model in the Krueng Aceh Watershed area. Review publications are publications that have passed peer-review and are published online. The data search was carried out from January 1 to January 7, 2022.

2.1 Location of Study Area

The Krueng Aceh watershed is located in the province of Aceh, Indonesia and is located in four districts including the districts of Banda Aceh, Aceh Besar, Pidie,

and Aceh Jaya (as shown in Figure 1). The watershed area for each district/city consists of 190601.05 ha (96.31%) located within the district of Aceh Besar, an area of 6279.10 ha (3.17%) within the city of Banda Aceh, an area of 788.60 ha (0.40%) located within the district of Pidie and an area of 234.88 ha (0.12%) within Aceh Jaya District. Geographically, the Krueng Aceh watershed is located at 5°03' 41"–5°38' 10" North Latitude and 95°11' 41"–95°49'46" East Longitude (Satriyo et al., 2018). The Krueng Aceh watershed has 7 (seven) sub-watersheds spread across the city of Banda Aceh and Aceh Besar district, the Krueng Aceh Hilir sub-watershed, the Krueng Jreue sub-watershed, the Keumireu sub-watershed, the Krueng Inong sub-watershed, the Seulimum sub-watershed, the Krueng Khea sub-watershed and the Krueng Aneuk sub-watershed. The water flows into the main river, namely the Krueng Aceh river, this river is a large river that divides the two Banda Aceh cities.

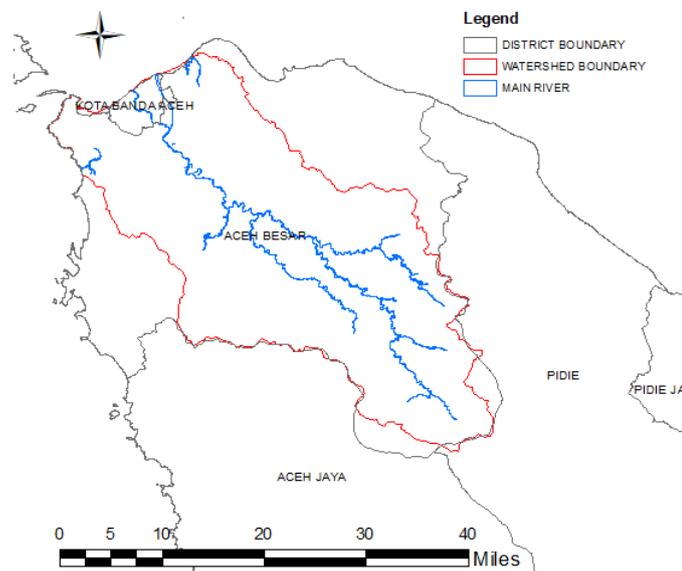


Figure 1 Study Area (Krueng Aceh Watershed)

2.2 SWAT Model Concept

The Soil and Water Assessment Tool (SWAT) is an effective and sophisticated tool for simulating various cycles of water and land problems both quality and quantity (Gassman et al., 2014; Jayakrishnan et al., 2005) however the concept of water balance is the driving force behind everything that happens in the watershed. The hydrological cycle as simulated by SWAT is based on the water balance equation (Neitsch et al., 2011) :

$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad (1)$$

where SW_t is the final soil water content (mm H₂O), SW_0 is the initial soil water content on day i (mm H₂O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H₂O), Q_{surf} is the amount of surface runoff on day i (mm H₂O), E_a is the amount of evapotranspiration on day i (mm H₂O), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H₂O), and Q_{gw} is the amount of return flow on day i (mm H₂O).

Before using the SWAT Model for the main purposes of its development, it is necessary to carry out a statistical analysis of its reliability. The statistics most often used to assess a SWAT model are the coefficient of determination (R^2) in Equation 2 and Nash-Sutcliffe Efficiency (NSE) in Equation 3. In general, that model performance can be judged “satisfactory” for watershed-scale models daily, monthly, or annual $R^2 > 0.60$, $NSE > 0.50$, and $PBIAS \leq \pm 15\%$ (Moriassi et al., 2007).

$$R^2 = \left[\frac{\sum_{i=1}^n (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^n (P_i - \bar{P})^2}} \right]^2 \quad 0 \leq R^2 \leq 1 \quad (2)$$

$$NSE = \frac{\sum_{i=1}^n (O_i - \bar{O})^2 - \sum_{i=1}^n (P_i - O_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} \quad (3)$$

Where:

- P_i : Measured data (m^3/sec);
- O_i : Simulated data (m^3/sec);
- \bar{P} : Measured mean data (m^3/sec); and
- \bar{O} : Simulated mean data (m^3/sec)

3. Discussion

3.1 SWAT Model Application

The SWAT Model is a powerful tools to simulate and analyze components of water resources such as leaf area index (LAI), river discharge, surface runoff, lateral runoff, groundwater, total runoff, evapotranspiration, and ground water based on water balance (Zhang et al., 2020). The SWAT model can simulate runoff and soil erosion to a good degree of accuracy (Tibebe and Bewket, 2011). In addition, the SWAT model can estimate groundwater recharge at high spatial and temporal resolution (Awan and Ismaeel, 2014).

The ability of SWAT to simulate almost all storage of water resources in a watershed scale makes this model a popular choice in Indonesia in analyzing various needs such as climate change analysis (Barkey et al., 2019), landuse change analysis (Astuti et al., 2015; Definnas et al., 2020; Hermawan et al., 2019; Junaidi and Indrajaya, 2018; Marhaento et al., 2019; Mubarok et al., 2015; Nur and Noor, 2021; Nurdin et al., 2019; Nursaputra et al., 2021; Wiyono Wit Saputra et al., 2020; Yamamoto et al., 2020; Yuliana et al., 2019), erosion analysis (Bakhtiar, 2018; Dhoke et al., 2020; Ramadhan and Supriatna, 2019; Syahdiba and Kusumandari, 2021; Widyasa et al., 2020), as well as other needs.

In general, the method of utilizing the SWAT Model is divided into 3 stages; the data preparation stage, the model running stage, and the calibration and validation stage. The data preparation stage is the first step that must be taken by a modeller, such as inputting data such as DEM (Digital Elevation Model), weather, soil type, and land use and others. The next stage is the running model stage with the data that has been input based on the data taken from the study area. After the hydrological model is built, then it is followed by a calibration and validation process with data from observations in the field. The calibration process can be

carried out using two methods, namely the manual method by trial and error and the automatic method using the help of other applications such as SWAT-CUP. Both calibration methods can be carried out in one SWAT application to get satisfactory results.

3.2 Input Data of SWAT Model

The SWAT model is now widely used for various purposes of water resource management and development planning at the watershed scale. To run the SWAT Model, several main data are needed, such as DEM (Digital Elevation Model), weather, soil type, land use, and the others. The availability of good data will improve the performance of the SWAT Model. This makes it easier for SWAT Model users in the process of model calibration and validation.

DEM data in running SWAT Model aims to delineate watershed boundaries and is used to determine slope. The quality of the resolution of the DEM will affect the creation of the watershed, river network, and also the determination of the classification of the sub-basin (Chaubey et al., 2005). Weather data is obtained from the results of measurements in the field, including rainfall, temperature, solar radiation, and so on. In addition, land use conditions and soil types in the watershed greatly affect the results and processes of running the SWAT Model (Romanowicz et al., 2005).

3.2.1 Climatic Conditions

The climatic conditions of the Krueng Aceh watershed are included in the SWAT Model data input to show the humidity and energy conditions that will control the water balance. Climatological data or parameters were entered into the model, such rainfall, temperature, solar radiation, wind speed and relative humidity. Figure 2 shows the distribution of rainfall stations located in the Krueng Aceh watershed. There are five rainfall stations and three stations for climatological data observation, consisting of the Aceh Besar Climatology Station, the Aceh Besar Geophysical Station, and the Sultan Iskandar Muda Meteorological Station.

Krueng Aceh Watershed, which is in Aceh Province, has a tropical climate with its characteristics having a fairly high rainfall. Annual rainfall recorded at the Sultan Iskandar Muda Meteorological Station is 2833.8 mm and at the Aceh Besar Climatology Station approximately 1835.9 mm (BPS, 2021). The difference in the measured rainfall is also influenced by the location of the observation station. Higher topography tends to have higher rainfall.

The average monthly rainfall in the Krueng Aceh watershed is included in the moderate rainfall category (153-236 mm) with the highest rainfall in November and the lowest in January. *BMKG* Indonesia divides monthly rainfall into four categories, low (0-100 mm/month), medium (100-300 mm/month), high (300-500 mm/month) and very high (> 500 mm/month). The average temperature of the region ranges from 25.3-27.9 °C with the lowest temperature being 22.0 °C and the highest being 35.6 °C. Other climate data measured include an average wind speed of 3.6 knots, air pressure of 1012.4 knots, an average humidity of 74.9-88.1 with the highest humidity being 98.3% and the lowest being 54.2% (BPS, 2021).

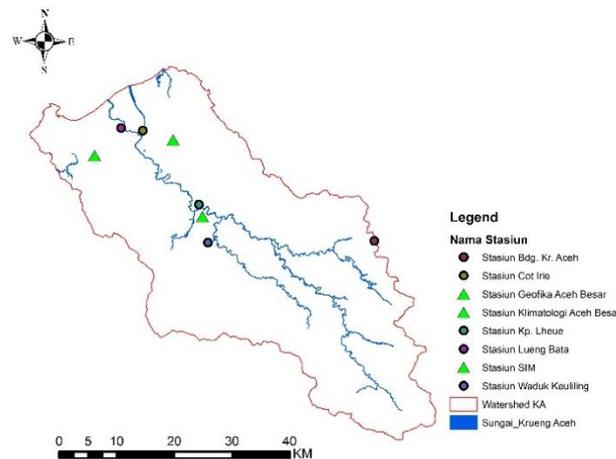


Figure 2 Rainfall station distribution in Krueng Aceh Watershed

3.2.2 Landuse Condition

The Figure 3 shows that the land use in Krueng Aceh watershed is very diverse. Protection forest, production forest and conversion production forest occupy the most extensive land use, reaching 93,230 hectares, followed by wet and dry land agriculture. The settlement occupies a fairly large land use, reaching 12,840 hectares.

In Krueng Aceh watershed there are many nature reserves that are opened as tourist attractions for the surrounding community, sorted from the most extensive, namely the Jantho Pine Nature Reserve, Tahura Pocut Meurah Intan, Kuta Malacca Nature Park. Furthermore, there is land use for mangroves, shrubs, ponds, water bodies and swamps. This area also includes an airport and port covering an area of 127 hectares and a built area for defense and security of 54.22 hectares. The cemetery and other open land area of 203.8 hectares. In this area there is also a cultural heritage with an area of 15.47 hectares.

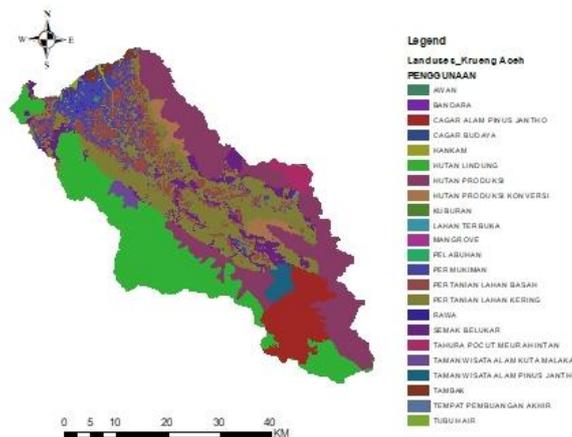


Figure 3 Land use mapping in Krueng Aceh Watershed

Land use condition is important for the SWAT model for many purposes. Land use change affected the streamflow at the watershed outlet. Even tough protection forest and conversion production forest are the largest land use in

watershed Krueng Aceh, but the conversion of native vegetation could change the streamflow outlet of watershed (Bressiani et al., 2015).

3.2.3 Soil Texture

Figure 4 shows the distribution soil textures of Krueng Aceh watershed. Based on USDA textural classes, soil texture in Krueng Aceh watershed dominated by clay-loam, 94,898.80 Ha. Other texture, from the largest is loam, clay, sandy-clay-loam. Clay-Loam and sandy-clay-loam has percentage of sand, silt and clay content divided proportionally. It has a moderately fine texture. Loam is dominated with silt which has a medium texture. Clay has a finer texture. The soil textures represent the water infiltration, so does the permeability properties and plasticity. The finer the soil particle the lowest of properties mentioned before. Soil texture affects the infiltration, the retention and nutrient movement in soil layer, besides the soil characteristics have the greatest effect on runoff during precipitation events (Whitford and Duval, 2020).

Krueng Aceh Watershed has typical tropical soil which is potential for agricultural activities. Land use for agriculture in Watershed Krueng Aceh is second largest, about 57,000 Hectare.

3.2.4 Discharge Observation

River discharge data is very important in the development of hydrological models in the watershed. River water discharge data will be used for the calibration and validation model. Distribution of discharge observation points are shown in Figure 5. There are 3 sampling points along the Krueng Aceh river. Discharge generated from the Krueng Aceh watershed was measured using the AWLR tool. The debit of river data from field observations is also one of the most important hydrological data in the planning and design of water resources.

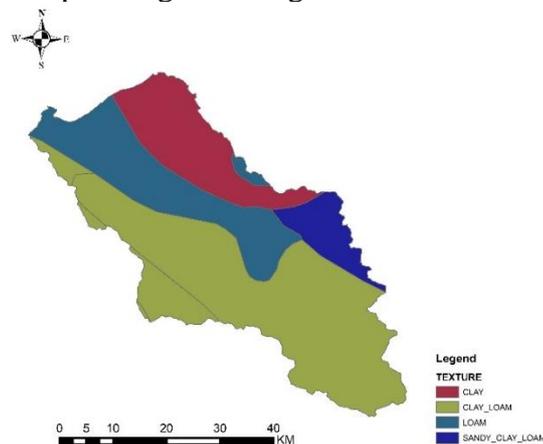


Figure 4 Soil texture distribution of Krueng Aceh Watershed

The maximum discharge value of Krueng Aceh River during the period 1994-2014 were 76.60 m³/sec in October, and minimum discharge were 1.35 m³/sec in July. The amount of water availability of surface water in Krueng Aceh watershed in 2014 were 700,193,659 m³ (Muis et al., 2017). Krueng Aceh watershed has been affected by climate change and proven by the decreasing of water discharge in this

area (Ferijal et al., 2016). A watershed condition could be described by water supply-demand scenario. Even though, Krueng Aceh watershed could be fitted the demand at rainy season, but it was lack of supply in dry season (Muis et al., 2017; Satriyo et al., 2018).

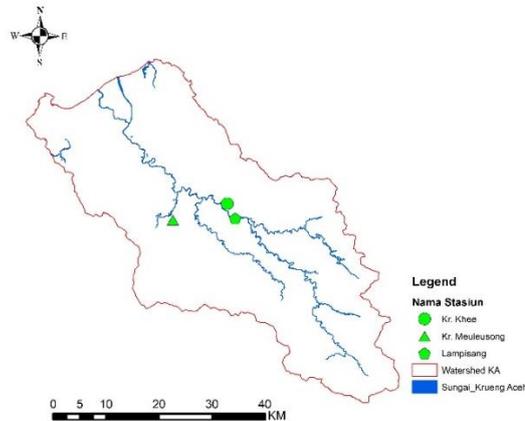


Figure 5 Distribution of discharge observation points

3.3 Overview of SWAT applications in Krueng Aceh

The use of the SWAT Model in the Krueng Aceh watershed has been applied several times by several researchers for various purposes (as tabulated in Table 1). Data on the uses of the SWAT Model in the area was obtained from the results of a search for publications including peer-reviewed journal articles and conference proceeding papers written in Indonesian and English. There are five publications that have used the SWAT Model in the Krueng Aceh watershed from 2010 to 2016.

Table 1 SWAT Applications in Krueng Aceh Watershed

Title	Watershed Name	Area (Ha)	Size	Uses	DEM Source	DEM Resolution
Landuse Change Analysis in Relation to Hydrological Characteristic of Krueng Aceh Watershed (Nasrullah and Kartiwa, 2010)	Krueng Aceh Watershed	149440	Medium	Land use change	Not reported	12.5
Predicting Runoff and Erosion Rate from Krueng Jreu Sub watershed Using SWAT Model (Ferijal, 2012)	Krueng Jreu Sub watershed	22726.03	Small	Erosion and runoff	SRTM	Not reported
SWAT Model Application To Simulate Discharge From Krueng Meulesong Sub Watershed Using The Actual And Predicted Climatological Data (T. Ferijal, 2013)	Krueng Meulesong Sub Watershed	401.83	Very Small	Simulating Streamflow	CGIAR-CSI	90
Keliling Reservoir Catchment Area Modeling Using SWAT Model (Ferijal et al., 2015)	Waduk Keliling Cathment Area	3820	Very Small	SWAT Application	CGIAR-CSI	90

Modeling hydrologic response to land use and climate change in the Krueng Jreu sub watershed of Aceh Besar (Ferijal et al., 2016)	Krueng Jreu sub watershed	1736.51	Very Small	Climate and Landuse Change	SRTM	90
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The application of SWAT is applied throughout the Krueng Aceh watershed and in several parts of Krueng Aceh sub-watersheds. The Krueng Jreu sub-basin has been applied to the SWAT Model twice with different purposes. In 2012, the SWAT application in the Krueng Jreu Sub-district was developed to predict runoff and erosion that occurs in the sub-watershed, while in 2016 SWAT Model was used to assess the hydrological response to land use and climate change. Meanwhile, the other three applications were used to model Waduk Keliling Cathment Area (2015), Simulation of water discharge in the Meulesong sub-watershed (2013), and analyze the relations of land change and hydrological characteristics in the entire Krueng Aceh watershed.

The sizes of each sub-watershed that has been applied SWAT model are 3820 Ha (Keliling Reservoir Catchment), 1736.51 - 22726.03 Ha (Krueng Jreu), and 401.83 Ha (Krueng Meulesong). Meanwhile, the total area of the Krueng Aceh watershed is 149440 hectares. The size of a watershed greatly affects the process of running the SWAT Model. The size of the watershed allows for greater uncertainty in the SWAT simulation as the size of the watershed increases (Thampi et al., 2010). The bigger a watershed the longer the time it takes to run. The size of a watershed application area also affects computer specification requirements.

Another parameter that significantly affects the performance of the SWAT model is Digital Elevation Model (DEM). High resolution availability of DEM is still rare for the Krueng Aceh watershed area. Of five publications that have been carried out, there are 4 studies using DEM with a resolution of 90 meters and a study using a resolution of 12.5 meters.

The use of the SWAT model in the Krueng Aceh watershed is only for watersheds/sub watersheds on the medium, small and very small watershed size. According to the Regulation of the Director General of Watershed Management and Social Forestry Directorate General (General BPDAS and Social Forestry Directorate, 2013), watersheds are classified into 5 groups based on watershed area; Very Large (1500000 Ha and above), Large (500000 - 1500000 Ha), Medium (100000 - 500000), Small (10000 - 100000) and Very Small (Less than 10000). Based on the following table, the most use of SWAT in a very small watershed cluster is three times.

3.4 Performance of SWAT Applications in Aceh Krueng Watershed

However, this study has limitations in assessing the performance of the SWAT developed in the Krueng Aceh watershed/sub-watershed due to not all publications report on the calibration or validation process. Table 2 shows the performance of the SWAT model in the Krueng Aceh watershed/sub-watershed. From the search results, there is one modeling application that performs the calibration process with statistical parameters NSE and R^2 on a daily scale. The other three papers carry out the calibration process using monthly data.

Tabel 2 SWAT Model performances in Krueng Aceh Watershed

Year	Watershed / Sub-watershed	Monthly				Daily			
		Calibration		Validation		Calibration		Validation	
		NSE	R ²	NSE	R ²	NSE	R ²	NSE	R ²
2010	Krueng Aceh watershed								
2012	Krueng Jreu Sub watershed	0.71	0.77	NP	NP	NP	NP	NP	NP
2013	Krueng Meulesong Sub watershed	NP	NP	NP	NP	0.37	0.67	NP	NP
2015	Waduk Keliling Catchment	0.95	NP	NP	NP	0.55	NP	NP	NP
2016	Krueng Jreu sub watershed	0.65- 0.72	0.58 - 0.72	NP	NP	NP	NP	NP	NP

*NP: Not Reported

The availability of climate observation data and river discharge in the Kreung Aceh watershed area which has not had time series with a long period makes researchers or modelers have limitations in improving the performance of the SWAT model during the calibration and validation processes. The reliability of a hydrological model depends on how well the model is calibrated. Therefore, the calibration procedure must be carried out carefully to maximize the reliability of the model (Sorooshian and Yapo, 1999).

3.5 Future Direction of SWAT Application in Krueng Aceh Watershed

Research on hydrological modeling in the Krueng Aceh sub- or watershed is still relatively rare. The first research on the SWAT Model was conducted in 2010 throughout the Krueng Aceh watershed. Krueng Aceh watershed is a watershed in the capital of Aceh province (Banda Aceh) and Aceh Besar district. Proper watershed management will ensure the sustainability and balance of the water cycle in it, thereby reducing the potential for floods and droughts event. The development and increase of research on hydrological modeling throughout the Krueng Aceh watershed/sub-watershed will make a major contribution to the proper management of water resources within the watershed. Hydrological modeling with good simulation performance will provide convenience in finding solutions to watershed problems that are being experienced.

Hydrological modeling applications require good quality and large number of input data to provide satisfactory simulation results. The current condition of data availability is still far from satisfactory, making it difficult for modelers to develop hydrological models. Therefore, in the future, the government needs to improve monitoring infrastructure or measuring data in the field, such as discharge measuring devices, rainfall gauges and other climate data measuring tools. The availability of time series data will widen opportunities for other researchers to apply hydrological modeling in the Kreung Aceh Watershed area. In addition, the provision of high-resolution DEM data will also attract other research enthusiasts to improve modeling performance.

When viewed from the modeling objectives that have been used, the application of SWAT modeling only revolves around the analysis of land use changes, climate change, simulation of river water discharge. In the future, the direction of using other objective such as analysis of erosion, sediment, irrigation

water needs, domestic, industrial and for other needs will follow availability of field data. To analyze the segment for other uses, researchers also need to open opportunities in finding auxiliary models to be coupled with the SWAT Model.

4. Summary and Recommendations

4.1 Summary

Based on the purpose of this review study to see how far the development and uses of the SWAT Model in the Krueng Aceh watershed, there have been five publications of utilizing SWAT applications based on reports that have been published in the journal. The uses of the SWAT Model have been used for various purposes such as effect analysis of land use, climate change, combination of land and climate change, simulation of river discharge, as well as analysis of erosion and runoff. The condition of the availability of observation data on climate and river discharge in the Krueng Aceh watershed area which has not had a time series with a long period makes researchers or modelers have limitations in improving the performance of the model. In the future, the application of SWAT in the Krueng Aceh watershed/sub-watershed will provide prospects for the development of more advanced hydrological models. SWAT Model is a semi-distribution hydrological modelling tool that is still free so that it will be easy for researchers to glance at.

4.2 Recommendations

As we know in the current era, hydrological models have emerged with various types in solving water resource problems. In increasing the number of hydrological model applications in the Krueng Aceh watershed, the government or stakeholders must build infrastructure for observing data for the development of hydrological models.

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