THE IMPACT OF LAND USE CHANGE ON THE WATER BALANCE OF ACEH BESAR, INDONESIA

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DECLARATION

I, **Zaitun Humaira**, certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university and, to the best of my knowledge and belief, does not contain any material previously published or written by another person except where due reference is made in the text.

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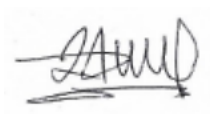

Zaitun Humaira

ABSTRACT

Land use changes have been occurring almost everywhere across the globe. In developing countries, the alteration of land use has occurred rapidly, from vegetation-covered land to developed land. Aceh Besar as part of Aceh Province, which is located in the westernmost point of the Indonesian island of Sumatra, is also experiencing land use transformation. Aceh Besar is one of the largest cities in Aceh constituting an area of 2822 km^2. Many studies have been conducted to investigate the impact of land use change on the hydrological cycle in Aceh Province. However, none has focused on land use change impacts on the water balance for Aceh Besar as an administrative area.

The aim of this study was to estimate the impacts of land use change on the water balance in Aceh Besar during ten years (2009-2018). The water balance components in this study were estimated using the WetSpass-M model, which was built as a physically-based methodology for assessing the long-term average and spatially varying components of the water balance. In addition, this study also aimed to generate a water balance map of the study area in the format of the ArcGIS software. As the WetSpass-M model requires input data at a raster level, climatological global data sets were used in this study due to data limitations of the study area. Accordingly, this study also aimed to test the use of climatological global data sets to overcome the limitation of local and regional data.

A major decrease during ten years was observed in the mixed forest cover, comprised of primary forest, primary dry land forest and secondary dry land forest. It reduced in extent by a total of 11.3 km^2 or 1.2%. The reduction in forest is closely related to a major increase of built up area and agricultural land (dry land agriculture and paddy field) by 8.3 km^2 and 4 km^2, respectively. The alteration of land use changes have been mainly driven by increased population, which is demanding more land for infrastructural development and agricultural intensification. Moreover, the changes of land use in the study area within the ten-year period have negatively influenced the hydrological systems of the area, with decrease in evapotranspiration and groundwater recharge by 23 million m^3 or 0.8% and 59 million m^3 or 11.8% during ten years, respectively. The reduction of evapotranspiration results in an increase of surface runoff for a total of 36 million m^3 or 1.6% over ten year period. The conversion of

land use from vegetation-covered land to non-vegetation covered land has hampered the groundwater absorption system by reducing the soil's ability to take up the water and support groundwater storage. Thus, the precipitation water, which is unable to be absorbed by the soil, becomes surface runoff, flowing to the river and being discharged to the sea.

The study found that the changes of land use in Aceh Besar during the ten years have influenced the hydrological system of the area in the form of reductions in evapotranspiration and groundwater recharge together with an increasing amount of surface runoff. The result show that these are likely to lead increasing soil degradation through erosion, declining availability of water for the human population, and problems of flood and drought in Aceh Besar during the rainy season and dry season, respectively.

DEDICATION

This research is dedicated to all my family members, and my teachers and friends in Australia, and to fellow researchers in my country who envisage a more environmentally sustainable future for our planet.

ACKNOWLEDGMENT

I wholeheartedly thank all individuals and institutions who contributed and participated in my thesis project. I grant my highest respect to Professor Okke Batelaan at Flinders University who openly shared his vast knowledge, experience and continuous advice with me, supporting me in term of both writing and technical issues in finishing my final project. You are valued, and I thank you wholeheartedly, for your kind help.

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LIST OF ABBREVIATIONS

ALC	Anthropogenic Land Cover
BAPPEDA	Badang Perencanaan Pembangunan Daerah (Development Planning Agency at sub-National Level)
BPS	Badan Pusat Statistik (Indonesian Central Bureau of Statistic)
CO_2	Carbon Dioxide
DEM	Digital Elevation Model
DEMNAS	Digital Elevation Model National
DREAM	Distributed model for Runoff, Evapotranspiration and Antecedents soil Moisture simulation
ESRI	Environmental System Research Institute
ET	Evapotranspiration
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GWP	Global Water Partnership
H2U	Hydrogramme Unitaire Universe
LAI	Leaf Areal Index
LIF	Leuser International Foundation
LULC	Land Use Land Cover
NRCS	Natural Resources Services
SWAT	Soil and Water Assessment Tool
SRTM	The Shuttle Radar Topography Mission
UNESCO	The United Nations Educational, Scientific and Cultural Organization
USDA-ARS	United States Department of Agriculture – Agricultural Research Service
USDA-NRCS	United States Department of Agriculture – Natural Resources Conservation Service
WetSpa	Water and Energy Transfer between Soil, Plants and Atmosphere
WetSpass	Water and Energy Transfer between Soil, Plant and Atmosphere under quasi-steady State

I. INTRODUCTION

1.1 Background

Land cover is one of the most crucial parameters in determining the water balance of an area. Land use changes are a result of human activities such as urbanisation, industrialisation, and agriculture. A recent study by Faulazzakiy (2014) found that the significant increase of human activities has resulted in growing demand for water and land. The conversion of open area (i.e., forest and agriculture) into commercial and residential purposes is spurring the transformation of open land area into closed area where the ability of the land to absorb the water is decreased. As a result, precipitation ends as surface runoff and flows to rivers which results in reductions of groundwater recharge. This condition leads to an imbalance in environmental conditions and triggers negative impacts such as floods during the rainy season and droughts during the dry season.

Land use and water balance components are strictly related as any alteration in the land use such as urbanisation may cause the occurence of negative impacts on the water resources sustainability. Groundwater recharge as one of the water balance components is described as the process of water percolating underground through the soil and reaching the water table to replenish groundwater storage (Arefaine, Nedaw, & Gebreyohannes 2012). For most developing countries, groundwater recharge is a major resource for urban and rural drinking water supply, irrigated agriculture, industry and even for the sustainability of river flows and aquatic ecosystems (Foster & Cherlet 2014). The study by Döll et al. (2012) revealed that groundwater provides for the needs of global water demands. It is used for 36% potable water, 43% for agriculture, and 24% for direct industrial water supply. Foster and Cherlet (2014) stated that groundwater resources often bring greater profit economically compared to surface water. Hence, it essential to maintain the sustainability of groundwater recharge to preserve environmental, economical, and social balance.

Furthermore, land use change also results in the escalation of runoff due to uncontrolled land functional shifts, which do not heed soil and water conservation principles (Muis 2019). This condition leads to lower water conservation in catchment areas, critical soil moisture conditions (Tesfaye et al. 2014), and an interfered hydrological cycle (Zhang et al. 2018). Consequently, the reduction of groundwater storage and water scarcity is inevitable as result of land use transformations.

Land use changes have been occurring almost everywhere across the globe. In developing countries, such as Indonesia, the alteration of land use has occurred rapidly, from vegetation-covered land to developed land (Erkossa et al. 2015). Aceh Besar is part of the Aceh Province located at the westernmost point of the island of Sumatra, is also experiencing land use transformation. It is stated in the study by Nasrullah and Kartiwa (2010) that the primary forest in Aceh Besar and Banda Aceh covered 1,128 km^2 (57%) in 1994, however had reduced to 791 km^2 (40%) by 2005 (Husnan et al. 2010). Furthermore, the reduction of primary forest cover since then has worsened, shrinking to only 318 km^2 (16%) in 2010 as reported by LIF (Leuser International Foundation) in the study by Muis (2019).

1.2 Study Area

The study area is located in Aceh Besar Regency, as shown in the Figure 1 Landsat satellite image. It covers an area of 2822 km^2. Aceh Besar is one of the largest cities in Aceh. This city lies at the northern end of Sumatra between latitude 5.05° to 5.75° north and longitude 94.99° to 95.93° east. It is bordered by the Strait of Malacca and Banda Aceh City in the north; Aceh Jaya City in the south; Pidie City in the east; and the Indian Ocean in the west.

Aceh Besar consists of 23 sub-districts, 68 *mukim* (administrative units), and 604 villages. Jantho, as the capital district of Aceh Besar, also claims to be the largest district with a total area of 593 km^2 or around 20% of the total area. Meanwhile, Baitussalam is the smallest district with an area of 20.84 km^2. According the Indonesian Central Bureau of Statistic (Badan Pusat Statistik [BPS] 2018), the majority of villages in Aceh Besar are located in the plain zone, and around 10% are located in the coastal zone. There are also some villages on small islands, such as Breueh Island, Teunom Island, and Bunta Island.

Aceh Besar also has a protected wild life area and a cultivation area. The protected wild life zone covers an area of about 1,714 km^2, with a vast part of it taken up by forest areas totalling 704 km^2 or 41% of the area (BPS 2018). The next largest land cover is the production forests with a total area of 686 km^2.

According to Akhmad (1993), the land cover of Aceh Besar can be grouped into six main classes: villages, rice fields, estate crops, mixed garden crops, forests, and open area such as bush, swamps, and wastelands. The proportion of those six groups changes over time as the alleviation of public demand may increase the percentage of villages and estate crops.

Figure 1. Location of Aceh Besar (Source: Google Earth 2020)

1.2.1 Climate

Aceh Besar is a city with a tropical climate, closely located to the equator. The physical geographical characteristics of this area are influenced by its tropical hydrology and climate. The mean temperature of this city ranges between 25° to 28° C, while the humidity is high (70% to 80%) (BPS 2018). Meanwhile, annual mean temperature might differ with elevation, decreasing from about 26° C at sea level by roughly 0.52° C per 100-metre rise in elevation (Binnie and

Partners 1988, cited in Akhmad 1993). Binnie and Partners (1988) claimed that the rainfall distribution in Aceh Province is influenced by the local topography. This is due to the interaction of the predominant monsoon and the Barisan mountain range. For the region of Aceh Besar, the mean annual rainfall for the period of 2009 to 2018 is 1,796 mm (BPS 2018).

Furthermore, there are other climate parameters in this region affecting its weather and environment. For example, wind speed ranges between 3 to 18 km/hour at 2 m from the ground. However, wind velocities are commonly light through the year with little seasonal difference. In addition, the duration of sunshine is highly variable spatially and seasonally. Traditionally, the amount of hours of sunshine is measured from 8 am to 4 pm. In this region, mean annual sunshine duration is approximately 44% of maximum possible, while mean monthly sunshine varies by up to 15% from the mean annual value.

1.2.2 Topography

Aceh Province is mainly mountainous, with the Barisan Mountain range having the highest peaks of about 3,000 to 3,400 m. Meanwhile, in Aceh Besar, the highest point is about 2,064 m and the lowest point is 0 m. According to the Topographic Map of Indonesia cited in the study by Joni (2019), the topographic condition of *Aceh Besar* is varied from lowland area to undulating hills where it can be categorised as lowland, plain, undulating hill, highland, and mountain. Terrain with 0-12% slope dominates the area in the central lengthen to the downstream area, meanwhile hills and mountain flanks dominate the upstream area as shown in Figure 2.

According to Binnie and Partners (1988), “this region consists of upper Palaeozoic and Mesozoic sedimentary rocks with granitic intrusions. The rivers are characterized by steep boulder-strewn upper catchments with dense primary forest cover, which flatten into braided channels, then meander in their lower reaches as they emerge from the foothills onto the coastal plains”.

1.2.3 Population

The BPS (2018) reported that the total population of Aceh Besar in 2018 was 417,302 inhabitants (214,005 male, and 203,298 female). For the year of 2016 and 2017, the population of Aceh Besar was 400,913 and 409,109 inhabitant respectively. This means that from the last two years, the population in this region has increased with a growth rate of 4%.

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Figure 2. Elevation map (Source: DEMNAS)

Among all districts, Darul Imarah has the highest population of about 55,350 residents and the district with the least population is Leupung with a total of 3,038 people. However, despite having the largest population, Darul Imarah is not the most densely populated. It is Krueng Barona Jaya that is considered to be most densely populated with 2,410 inhabitants/km^2. Jantho as the capital district of Aceh Besar has the lowest density with only 17 inhabitants/km^2 (BPS 2018).

1.3 The Aim of the Study

Many studies have investigated the impact of land use change on the hydrological cycle and water balance in Aceh Province. For example, the study by Husnan (2010) aimed to reveal water yield analysis and to study the impacts of rehabilitation and land use change for water yield of five catchments in Aceh Province with three subsequent models: H2U (Hydrogramme Unitaire Universe) model, Integration models between NRCS (Natural Resources Services) and base flow as well as Mock Model. Ferijal et al. (2016) have conducted simulation of land use and climate change effects on water resources of Krueng Jreu sub catchment in Aceh Province using the SWAT model (Soil and Water Assessment Tool). Furthermore, the latest study was done by Muis (2019) on the effects of land use conversion on the hydrological response of the *Krueng Aceh* watershed.

However, while many studies have been conducted for the catchment area located in Aceh Besar, none has focused on land use change impacts on the water balance for Aceh Besar as an administrative area. So far, there is no study which resulted in a water balance map for this area. Therefore, based on this gap of regional hydrological understanding, this research was aimed at studying the impacts of land use change on the water balance in Aceh Besar during ten years (2009-2018). The water balance components in this study were estimated using the WetSpass-M model, which was built as a physically-based methodology for assessing the long-term average and spatially varying components of the water balance. In addition, this study also aimed to generate a water balance map of the study area in the format of the ArcGIS software. The WetSpass-M model requires input data at a raster level. The study area experiences data limitations mostly for climatological data. Accordingly, this study also aimed to test the use of climatological global data sets to overcome the limitation of local and regional data. The main research questions of this thesis were formulated as:

- How does the effect of land cover change impact the water balance in Aceh Besar?
- Can climatological global data sets be used to overcome the limitation of regional data?

1.4 Thesis Structure

This thesis is composed of six chapters. Chapter one illustrates several aspects which link to the research objectives. The background of this study illustrates land use as one of the most crucial parameters for the hydrological cycle, how it cause the deteriorate water resource globally, and provides information about the changes of land use change in Aceh, which mostly consists of the conversion of forests into cropland area. This chapter also provides information about the study area such as the climate, topography, and population. In addition, the purpose of this research is presented in this chapter. Chapter two consists of the literature review associated with the research. It begins with the overview of global land use change along with its driving force and hydrological impacts. Then, it also provides some literature review about land use change in Aceh, water balance and the application of WetSpass-M. The next chapter elaborates the methodology used in this study. In this chapter, the importance of material of the study is described and the source of the material is presented. Moreover, this chapter explains all of the data that first is processed using software of ArcGIS 10.6 to create a uniform resolution, projection, and format. The process of water balance estimation using the WetSpass-M model is also explained in this chapter including the equations. The resulting findings are provided in chapter four, where all the results in this study are presented including description, table, maps and graphs. Chapter five discusses the results. Last but not least, chapter six presents the conclusion of the study including findings and results, limitation of the study, and recommendation for future study.

II. LITERATURE REVIEW

The chapter of literature review begins with the elaboration of global land use change, local and regional land use change, and the water balance and its components. It then yields to the evaluation of the pertinent literature regarding water balance with the use of WetSpass model as the tool to generate them.

2.1 Global Land Use Change

Land use change is described as the vulnerability of places and its human being in responding to the climatic, economic, or socio-political interference (Kasperson et al., cited in Lambin, Geist & Rinfuss 2006). DeFries and Eshleman (2004) asserted that the central aspect of earth system functioning is significantly affected due to global land use change. Lambin, Geist and Rindfuss (2006) stated that during the agenda of global environmental change several decades ago, the attention on land use change had arisen as the awareness increased of how land-surface affects the climate. Several impacts have emerged around the world as since the mid-1970s, the surface albedo and the surface atmospheric energy exchanges have been modified by land use change, which in turn influences the regional climate (Otterman 1974). Less than a decade later, in the early 1980s, Woodwell et al. (1983) reported that terrestrial ecosystems were noticed to be a source and sink of carbon, i.e. land use change impacts the global climate via the carbon cycle. Nowadays, more complex impacts arising from the alteration of the earth's surface have been identified as being driven mainly by a significant growth in the world population. The alteration of land use and land cover have significantly impacted soil degradation (Trimble & Crosson 2000), the escalation of CO_2 in the atmosphere, water scarcity, changing the cycle of biogeochemistry on earth, and leading to major losses of biodiversity around the globe (Dolman & Verhagen 2003). Furthermore, land use conversion also influences the water cycle through evapotranspiration (ET) as land cover change converts the energy availability, water availability, photosynthesis rates, nutrient levels and surface roughness at the land surface (Sterling & Ducharne 2008).

According to Davis et al. (2019), land use change results in positive and negatives outcomes for community and environment. Reviewing from society's standpoint, land use is responsible for food, feed, and fibre production for human use. It is also crucial to provide habitable space for people. Meanwhile, from the environmental side, land use is important to determine the product of the environment such as carbon emission and habitat loss in term of land clearing, soil degradation and erosion due to overgrazing, salinization, and other unsustainable practices. Thus, the correlation between the benefits of changes in land use for humans and changes in land use for the environment must be maintained in order to continue to support human life and environmental sustainability. Although to reconcile the multiple dimensions of land use change is not straightforward, we as society must have a strategy to support it through the actors who have implemented strategies to manage responsible land use change and to prevent the uncontrolled agricultural expansion.

2.1.1 The driving force of land use change

Population growth has experienced substantial escalation globally resulting in alteration of earth's land surface through conversion of natural landscapes to crop land, built-up land, grazing land, inundated land, reservoirs, and plantation (Sterling & Ducharne 2008). The increased exploitation of land has substantially triggered the changes in land use and land cover. Human activities are believed to be the predominant reason of the alteration in land use. The study of Sterling and Ducharne (2008) revealed that the conversion of land by humans has altered approximately 41% of the earth's surface. Moreover, another study by Vitousek et al. (1997) reported that human beings have been responsible for the alteration of earth's surface by about 39-50%. This alteration was the replacement of natural vegetation such as forest and wetlands, with anthropogenic land cover (ALC), for example croplands and built-up land.

The growing demand for food production is claimed to be the main driver of land conversion. According to the Food and Agriculture Organization of the United Nations (FAO 2004a), food production has increased significantly since the middle of the 20th century. This increase is mainly associated to agricultural intensification, as stated in Dolman and Verhagen (2003) that the development agricultural land is one of the main driving forces for land use change including deforestation of tropical rain forests, and cultivation of marginal land. FAO (1999) reported that, during the period of 1990-1995, the total area of forests reduced by 56.3 million hectares. In addition to agricultural driven changes in land use, infrastructural developments are also responsible for forest conversions occurring in developing countries, while in the developed world, forests are more likely allowed to grow on agricultural land that was taken out of production (Dolman & Verhagen 2003).

In some countries, where the availability of arable land is lacking, the high demand of food production can be maintained via technological changes in land use accomplishing higher returns per unit area of land (Dolman & Verhagen 2003). On the other hand, where the availability of land is abundant, the main strategy to achieve the target is land conversion. Consequently, the effect of escalation of demand on the scarce land resources has caused additional environmental stress. Nevertheless, despite the impacts that arise together with the widening issues of land use change, it is inevitable that land use change also has offered benefit for human beings, such as the target of high food demand of food production, resource-use efficiency, and wealth and well-being that can be achieved (Lambin, Geist & Rindfuss 2006).

2.1.2 Hydrological impacts

Land use change links to many impacts on the environment, particularly in terms of the hydrological cycle. It has a substantial influence on terrestrial hydrology by altering the evaporation and surface runoff (Bosmans et al. 2016). These impacts have been evaluated by many studies which generally have shown reduction of evapotranspiration and the enhancment of discharge rate. Gordon et al. (2005) suggest that the deforestation has a bigger contribution to reduced evapotranspiration rate compared to irrigation. This is due to the nature of tall vegetation (e.g. forest), which tends to use more water compared to short vegetation, as forests intercept rainfall, which later re-evaporates into the atmosphere without reaching soil surface (Dolman & Verhagen 2003). Generally, forests also use more water than short vegetation, as the roots of trees reach deeper and may capture more soil moisture. Accordingly, the change of land use from forests to crops are closely associated with the changes of water requirements and there are certain impacts on the groundwater replenishment and surface runoff for plantation other than forests (Dolman & Verhagen 2003).

2.2 Land Use Change in Aceh

It is inevitable that the changes in land use have been occurring worldwide. In developing countries, the alteration of land use has occurred more rapidly, from vegetation-covered land to developed land (Erkossa et al. 2015). Aceh Province, as one of the developing regions in Indonesia, is also experiencing land use conversion. Aceh Province has a total area of 56,770 km^2 and 40% of its land surface is mostly covered by forests with a total area of 22,908 km^2 (Aceh Province 2016). Agricultural land covers about 8,005 km^2, and the smallest area is covered by industry with about 39 km^2. As the time goes by, most of the forest area undergoes a change of its land cover. There were rapid transformations of land cover due to conversion of forests to palm plantations as well as due to illegal logging. The problem of illegal logging in Aceh is considered serious. According to Greenomics Indonesia, illegal logging in Aceh Province reached 200,000 ha between the periods of 2002-2004 (Serambi Indonesia 2006, cited in Ferijal et al. 2016). These transformations have triggered a sequence of flood events in Aceh due to severe soil degradation in up-stream areas of the catchments (Husnan 2010).

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Figure 3. *Krueng Aceh* watersheds (Source: Muis 2019)

Most of the watersheds in Aceh are dominated by agriculture and plantation activities (Ferijal et al. 2016). Among the 15 catchments in Aceh Province, the catchment *Krueng Aceh* is considered to be one of the catchments with the largest forest loss (Nasrullah & Kartiwa 2010). *Krueng Aceh* watershed lies between two cities which is Aceh Besar and Banda Aceh (capital of the province) as shown in Figure 3. This catchment has a total area of 1,979 km^2 (Muis 2019). The catchment is believed to have undergone soil degradation because of the rampant rate of deforestation. It is stated in the early study by Nasrullah and Kartiwa (2010) that the primary forest in *Krueng Aceh* covered 1,128 km^2 (57%) in 1994 and the number then dropped to 791 km^2 (40%) in 2005 (Husnan 2010). The reduction of primary forest appeared to have worsened to 318 km^2 (16%) in 2010, as reported by the Leuser International Foundation (LIF) (Muis 2019). According to recent studies, the conversion of land use in this catchment continues to the present, as it is stated in the study of Muis (2019) that *Krueng Aceh* river flows have experienced a large amount of runoff during the rainy season and drought during the dry season.

Muis (2019) has conducted research related to the changes of land use in *Krueng Aceh* watershed for the period of 1994-2004 and 2004-2013. The results revealed that between the periods of 1994-2004, this catchment has undergone comprehensive and very dynamic change. Brush land has dominated the reduction in land cover with 8 km^2 (5%), followed by secondary forest and primary forest at 1.1 km^2 (0.2%) and 1 km^2 (1%) respectively. The main reasons for this reduction was functional shifts to rice fields, dry land agriculture, and production forest with the percentage increase at 1.4%, 1.5%, and 29%. In addition, for the periods of 2004-2014, the major increase in land cover was rice fields at 6 km^2 (2%), followed by production forests at 2 km^2 (48%), residential area at 0.5 km^2 (1%) and mixed dry land agriculture at 0.3 km^2 (0.6%). These results showed that in 2014, the remaining primary forests in this catchment only covered 100 km^2 or 5% of the total area. During this period (2004-2014), primary forests logging was considered to be the main cause of land alteration. This activity was done to fulfil the high demand of timber used for rehabilitation and reconstruction in Aceh prior to earthquake and tsunami in December 2004. The results of land use change for the past two decades are presented in Table 1.

Table 1. Land use change of *Krueng Aceh* watershed for the period of 1994-2013

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(Source: Muis 2019)

2.3 Water Balance

In hydrological systems, a water balance is described as a balance tracking method between inflow and outflow of water in a system (Abdollahi, Bazargan & McKay 2018). Water balances can be estimated for any scale of system, including the largest water system namely the "global water balance". The cycle of water balance on earth is notable as the largest closed water system which has no starting point and depicts earth's water spatial distribution on the surface and subsurface (Abdollahi, Bazargan, & McKay 2018). The hydrological cycle is represented in Figure 4, where it shows how rain water is transported through surface runoff and flowing into the rivers or streams which then ends up in the ocean and lakes, evaporates into the atmosphere, and then reproduces rain again (Dolman & Verhagen 2003). Due to the complexity of the hydrological cycle, it is broken down into independent components, such as precipitation, which is considered as the input to this system, while evapotranspiration is considered an output.

Within the global water system, UNESCO estimates that 96.5% of the water is stored in the oceans, as shown in Table 2 (Korzoun & Sokolov 1987). Only a small part of all water is categorised as fresh water. In addition, over 70% of total fresh water is used to fulfil agricultural water demand (Hoogeveen et al. 2015). Therefore, it is believed that the skyrocketing urbanisation has impacted the hydrological processes in a negative way both on the surface and subsurface of the earth (Kajewska-Szkudlare, Kajewski & Otop 2018) as it demanding high food production and triggering more land use conversion to agricultural land.

2.3.1 Water balance components

The components of the water balance are a result of precipitation distributing into evapotranspiration, interception, surface runoff, and infiltration. Groundwater recharge is defined as the processes by which precipitation infiltrates to the soil and then percolates into the saturated zone of an aquifer (Wu, Zhang & Yang 1996).

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Figure 4 Hydrological cycle
(Source: Geography Revision 2020)

Evapotranspiration is defined as the process of evaporation from the land surface and transpiration from vegetation. Chow, Maidment and Mays (1988, p. 80) stated that "evaporation from land surface comprises direct evaporation from soil and vegetation surface, while transpiration through plant leaves where water is extracted by the plant's roots, transported upward through its stem, and diffused into the atmosphere through tiny openings in the leaves, called stomata”. In addition, potential evapotranspiration is defined as evapotranspiration which would occur from a well vegetated surface when moisture supply is not limiting, and this is calculated in a way similar to that for open water evaporation.

Furthermore, runoff is identified as overland flow of water, which occurs after rainfall. Overland flow begins when the amount of precipitation is greater than the capability of soil to infiltrate the water and increases along the flow path over the slope (Balasubramanian 2017).

2.3.2 Interrelationship of water balance and land use map

Land use change is associated with many impacts on the environment, particularly in terms of the hydrological cycle. It has substantial influence on terrestrial hydrology by altering the evaporation and surface runoff (Bosmans et al. 2016). Sterling and Ducharne (2007) have examined the influence of one or two types of human-dominated land covers, which result in the changes in evapotranspiration rate. Furthermore, Sterling. Ducharne and Polchere (2013) have conducted a study about the impact of global land cover change on the terrestrial cycle, which depicted that the area with rapid increase of evapotranspiration rate mostly overlies the area of high water demand. This means that the changes of land cover may play an essential role in deteriorating or relieving water scarcity in the area. Other than that, the land surface model presented in their study also showed that land cover change has escalated the amount of surface runoff by 6.8% along with the reduction of the groundwater recharge.

Nie et al. (2011) presented a case study of hydrological modelling of LULC (Land Use Land Cover) in the upper San Pedro watershed using SWAT (Soil and Water Assessment Tool). The results revealed that urbanisation was considered to be the strongest contributor to the intensification of surface runoff. Meanwhile, the replacement of scrub and grassland by mesquite strongly contributed to the reduction of infiltration along with the increased evapotraspiration. To conclude, the increment of runoff and evapotranspiration as well as the reduction of infiltration have shared negative impacts on water resources in San Pedro River Basin. Accordingly, the invasion of urbanisation and mesquite has led to major environmental stress, which has impacted local water resources.

Table 2. Global water balance as estimated by UNESCO

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Source: Korzoun & Sokolov 1987

2.4 The Application of WetSpass-M Model

According to Batelaan and De Smedt (2007), quantifying recharge is a complex and challenging processes due to its dependency on several variables, including land use, topography, soil texture, climatic conditions, groundwater depth, and other hydrologic characteristics. Hence, several models have been developed to simulate groundwater recharge spatially such as SWAT (Soil and Water Assessment Tool) by USDA-ARS (United States Department of Agriculture- Agricultural Research Service) to predict the effects of practices of land management on hydrology, sediment and agricultural chemical yields in large and ungauged basins (Arnold et al. 2000), DREAM (Distributed model for Runoff, Evapotranspiration, and Antecedents soil Moisture simulation) by Manfreda et al. (2005), and WetSpa (Water and Energy Transfer between Soil, Plants and Atmosphere) by Wang, Batelaan and DeSmedt (1996).

Furthermore, another model called WetSpass (Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-steady state) by Batelaan and De Smedt (2001) to estimate the distribution of water balance components. WetSpass is a distributed model that performs the computation of the water balance at a raster level (Abdollahi, Bazargan, & McKay 2018). It was built as a physically based methodology to assess the long-term average, spatially varying, water balance components. This model has been demonstrated to be suitable for studying long-term impacts of water balance associated with land use/land cover change under variable soil textures (Batelaan, De Smedt & Triest 2003; Wang et al. 2012). WetSpass was built upon the foundation of the time dependent spatial distributed model of water balance 'WetSpa' (Batelaan, Wang & De Smedt 1996). To run the data, this model requires many influencing parameters such as a land use map, soil map, digital elevation model, temperature, precipitation, wind speed and groundwater depth. WetSpass can be used to quantify the long-term impacts of urbanisation on the water regime in a catchment.

WetSpass has been used widely to assess water balance components and land use change impacts on water balance. As such, Aish (2014) estimated the water balance components in the Gaza Strip. In this study, the model generated digital maps of long-term average surface runoff, evapotranspiration, and groundwater recharge annually. The results showed that precipitation was converted to evapotranspiration for about 77%, while 11% of it becomes surface runoff and the remaining 12% infiltrated and replenished the groundwater system. This study claimed that the WetSpass model is effective to assess the hydrological water balance of the study area. Furthermore, Arefaine et al. (2012) also used the WetSpass model to estimate groundwater recharge, evapotranspiration, and surface runoff distribution in the Illala catchment, Northern Ethiopia. The result depicted that this catchment has 12% of its precipitation turned into groundwater recharge, whereas 81% evaporates back to the atmosphere and 7% of precipitation was flowing overland as surface runoff.

The application of WetSpass has been used in other countries, as shown in the study by Yun et al. (2011), which was conducted in the Guishui River Basin in Northwest Beijing, China. This study aimed to investigate the impact of land use change on groundwater recharge. The outcome of this study indicated that only 21.2% of precipitation was stored as groundwater recharge while the major, about 72.4%, was lost to evapotranspiration. The changes of land use in this basin decreased the amount of groundwater recharge with about 4×10^6 m^3, equivalent to a spatial average rate of 100 mm/yr in 1980 and 98 mm/yr in 2005. This variation was a result of the major increase in the urban area and rural settlements, as well as a reduction of cropland area.

III. MATERIALS AND METHODS

3.1 Study Area and Data Source

The developed methodology in this study was applied to simulate water balance components in Aceh Besar Regency. Aceh Besar is one of the largest cities in Aceh Province and comprises of 2,882.3 km^2. This city lies at the northern end of Sumatra between latitude 5.05° to 5.75° north and longitude 94.99° to 95.93° east. It is bordered by the Straits of Malacca and Banda Aceh City on the north; Aceh Jaya City on the south; Pidie City on the east; and the Indian Ocean on the west.

3.1.1 Climatological data

The physical geographical characteristics of Aceh Besar are influenced by its tropical hydrology and climate. As it is close to the equator, Aceh Besar is considered to have a relatively high humidity throughout the year. The humidity in this area is ranging between 70 – 80%, while temperature is ranging between 25° to 28°C (BPS 2018). In addition to those climate parameters, there are other climate parameters in this region, such as wind speed, which is ranging between 3 to 18 km/hour at 2 m from the ground. However, wind velocities are commonly light through the year with little seasonal difference. Moreover, the duration of sunshine is highly variable spatially and seasonally. Traditionally, the amount of hours of sunshine is measured from 8 am to 4 pm. In this region, mean annual sunshine duration is approximately 44% of maximum possible, while mean monthly sunshine varies by up to 15% from the mean annual value (BPS 2018).

In terms of rainfall characteristic, the Barisan Mountain Range controls the predominant monsoons, which results in sharp regional variations in rainfall (Bödecer 2008). The dry season occurs when the wind comes from the south, while the wet season generally happens when wind flows from the north (Melianda, 2009). The peak of wet season generally occurs from September to December, while the peak of the dry season mostly happens from June to September (Joni, 2019). However, Sea Defence Consultant (SDC 2009b, cited in Joni 2019) stated that rainfall patterns in Aceh Besar have been modified by climate change. Confirming this claim, SDC found that the mean annual precipitation has experienced a reduction both in wet and dry seasons. Furthermore, according to the observations on 30-year rainfall data, the wet season has been to be delayed and shortened.

Due to limitation in obtaining spatially distributed climatological data for the study area, global data sets were used in this study. Precipitation data was collected from https://neo.sci.gsfc.nasa.gov/ with the resolution of 0.25 x 0.25 degree, temperature data from https://power.larc.nasa.gov/ with the resolution of 0.5 x 0.5 degree, wind speed data from https://apps.ecmwf.int/ with the resolution of 0.125 x 0.125 degree, and potential evapotranspiration data was found from ClimWat 2.0. These climatological data sets are presented in Figure 5.

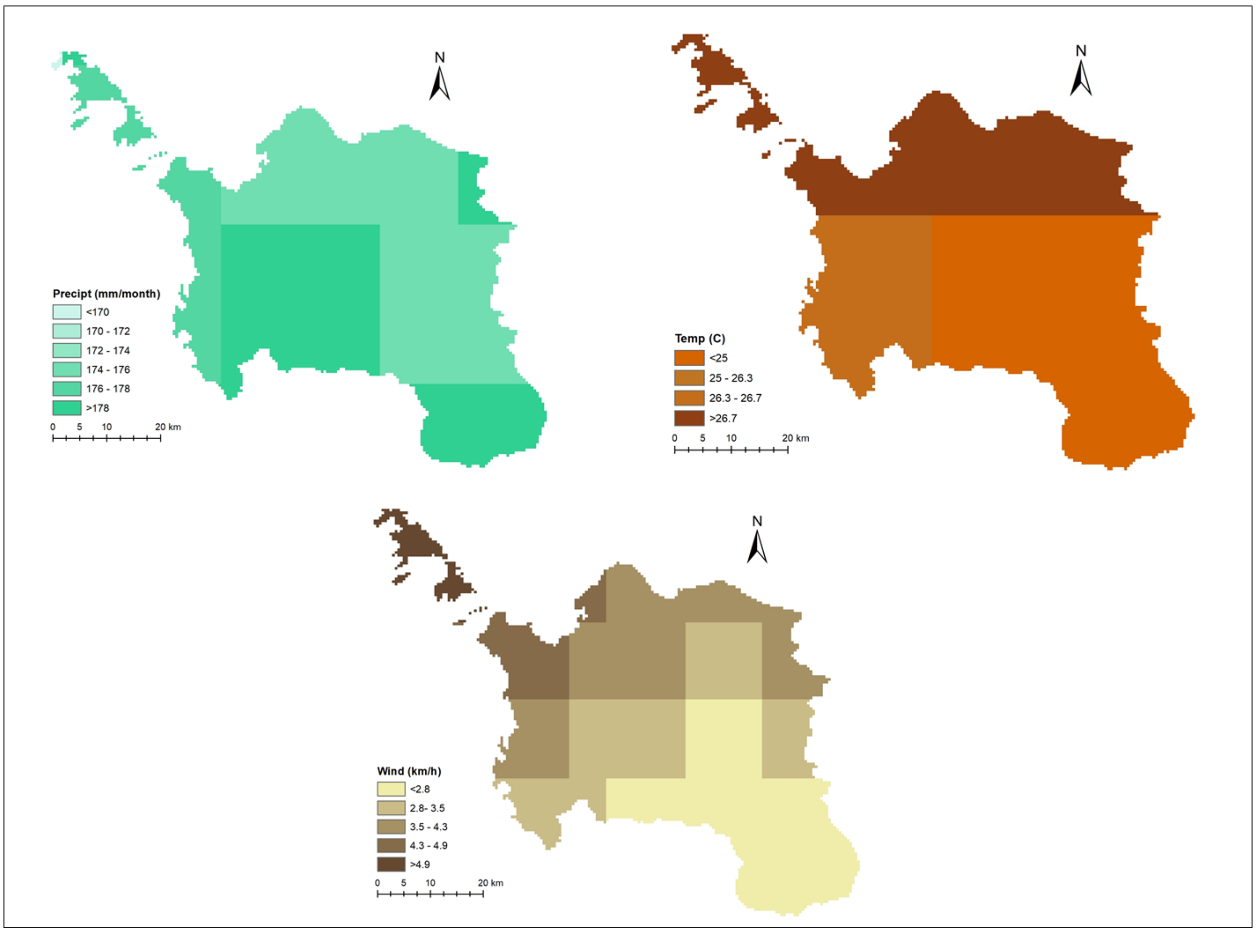

Figure 5. Annual spatial distribution of precipitation, temperature, and wind speed data of 2009

3.1.2 Physiographic data

Aceh Besar has varied topographic conditions from lowland area to undulating hills where it can be categorised as lowland, plain, undulating hill, highland, and mountain (Joni 2019). The average slope is <15% with an elevation varying between 0 m to 2,064 m. Terrain with 0-15% slope dominates the area in the central lengthen to the downstream area, meanwhile hills and mountain flanks dominate the upstream area. Binnie and Partners (1988) reported that "this region consists of upper Palaeozoic and Mesozoic sedimentary rocks with granitic intrusions. The river is characterised by steep boulder-strewn upper catchments with dense primary forest cover, which flatten into braided channels, then meander in their lower reaches as they emerge from the foothills onto the coastal plains".

According to Joni (2019), the drainage systems in this area mainly flow in a northwest-southeast direction and are managed by geological structure and lithology. The drainage patterns known in this area are:

- Radial patterns are present in the vast geological structures and volcano area, such as on the slopes of the *Seulawah Agam* volcano in the north direction,
- Trellis patterns are controlled by fold and faults, such as in the south direction,
- Dendritic patterns, occur in the area dominated by horizontal layers, such as in the west direction,
- Meandering patterns occur in the area with horizontal layer structure and particularly in soft sedimentary rock in the lowland areas, such as from the centre to the estuary area.

The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) used in this study was obtained from DEMNAS (http://tides.big.go.id/DEMNAS/) with resolution of 30m x 30m. Meanwhile, slope data was generated from the DEM. The elevation map can be seen in Figure 2 and slope map is presented in Figure 6.

3.1.3 Soil data

According to the Centre of Soil Assessment Bogor (PPT Bogor), soil types in Aceh Besar are grouped into six classifications, which are *Alluvial, Andosol, Litosol, Mediteran, Podsolic* and *Regosol*. In relation with water resources and erosion and infiltration rates, they could be explained as follows (Joni, 2019):

- *Alluvial*, generally located near the main river and low land area. This soil type contains organic components and sand material about 60% and the composition may be varied depending on its location.
- *Andosol*, sourced from denudation of volcanic activities.
- *Latosol*, sourced from denudation of basaltic material and relatively homogeneous. This soil type contains clay materials of more than 60%.
- *Mediteran*, sourced from deposition of argillic clay material and basaltic material, mostly sourced from denudation of meta-sedimentary rocks.
- *Podsolik*, similar to Mediteran, but this type of soil is containing less basaltic material.
- *Regosol*, has a similar description to *Alluvial*, however with coarse texture compared to *Alluvial*.

However, this data is scarce in Aceh Besar, and due to some limitations, an input of soil map in this study was obtained from SoilGrids (https://www.isric.org/explore/soilgrids) with the resolution of 1km x 1km. According to this map, Aceh Besar has four types of soil textures: sand, silty loam, silt and sandy clay loam, as shown in Figure 7.

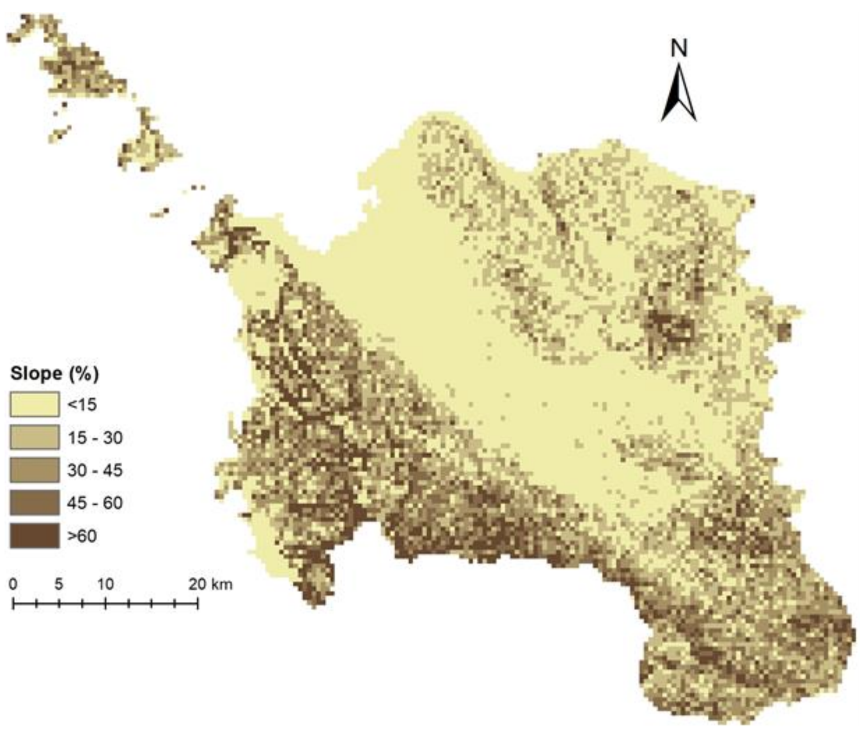

Figure 6. Slope map of Aceh Besar

3.1.4 Land use map

According to Akhmad (1993), land cover of Aceh Besar can be grouped into six main classes: villages, rice fields, estate crops, mixed garden crops, forests, and open area. However, the proportion of those groups changes over time as the alleviation of public demand may increase the percentage of villages and estate crops. Mostly, the forest area undergoes a change of its land cover. There were rapid transformations of land cover due to conversion of forests to palm plantations as well as due to illegal logging. These transformations have triggered a sequence of flood events in Aceh due to severe soil degradation in up-stream areas of the catchments (Husnan, 2010). Furthermore, The Leuser International Foundation (LIF-*Yayasan Leuser International*) have analysed the forest cover between 2006 and 2010 within the area of Aceh Besar and Banda Aceh in correspondence of land use land cover (LULC) allocation status based on the Minister of Forestry of Indonesia Decree No.170/Kpts-II/2000. As a result, they found that land with forest cover has reduced from 1.2 km^2 in 2007 to 1.1 km^2 in 2010. The reduction amounted to 3.3% annually.

In this study, the land use map was collected from BAPPEDA Aceh (Development Planning Agency at Sub-National Level). To analyse the impact of land use change on the water balance of the study area, two land use maps were used with a range of ten years (2009 and 2018). Therefore, the WetSpass-M was applied to obtain two estimates of the water balance, for 2009 and 2018. However, while land use maps were used from 2009 and 2018, the remaining input data were kept the same, i.e. based on the data of 2009. This was done because land use change was the main point of the study, whereas the impact of the changes of land use during ten years will be pointed out as one of the results.

3.1.5 Groundwater depth

Groundwater depth is an input layer for the WetSpass-M model. However, the data of groundwater depth in the study area cannot be found due to data limitations. According to the study by Sugiyanto et al. (2018), the water table of Banda Aceh and Aceh Besar ranges between 0.5 m to 4.0 m. Therefore, the data of groundwater depth for this study was assumed to be 3 m with homogeneous conditions for the whole study area. Groundwater table at 3 metre depth is deeper than the root depth based on WetSpass-M model, which has been determined at 2 m. Accordingly, the groundwater table is predicted not influence the evapotranspiration.

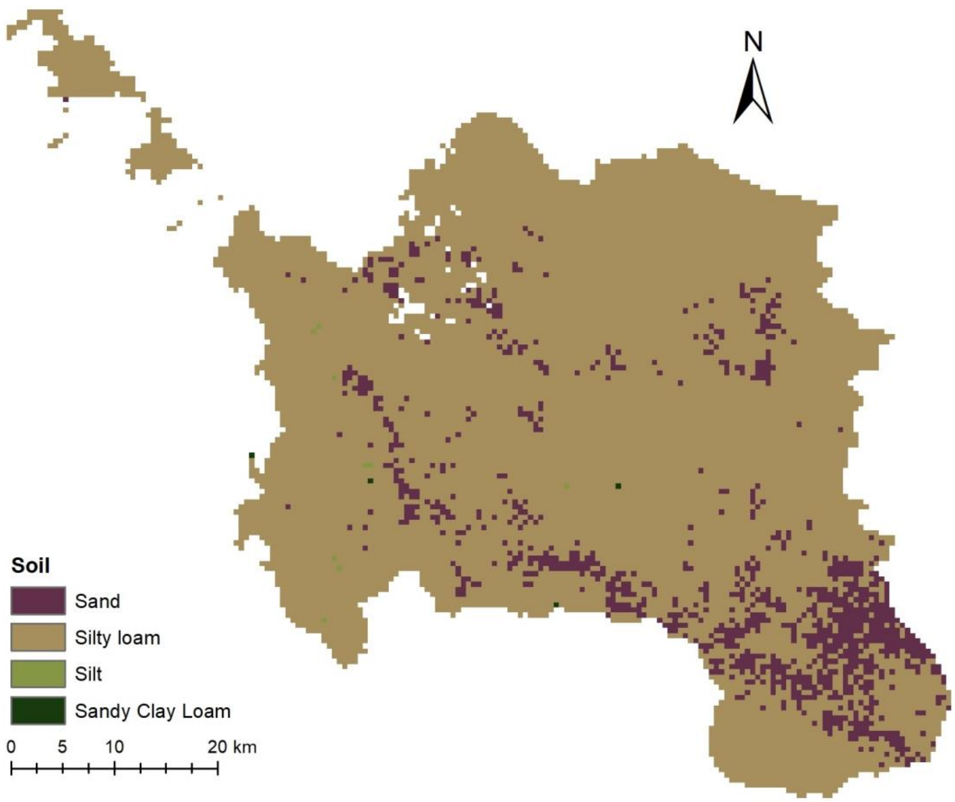

Figure 7. Soil map of Aceh Besar

3.1.6 Summary of data source

The main data used for this study consists of secondary data from a number of key sources: The Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with resolution of 30 m obtained from DEMNAS (http://tides.big.go.id/DEMNAS/), land use map of 2009 and 2018 sourced from BAPPEDA Aceh (Development Planning Agency at Sub-National Level), soil map obtained from SoilGrids (https://www.isric.org/explore/soilgrids) with the resolution of 1 km, groundwater data was assumed to be at 3 m depth, and potential evapotranspiration data was found from ClimWat 2.0. Furthermore, the other meteorological data, such as precipitation, was collected from https://neo.sci.gsfc.nasa.gov/ with the resolution of 0.25 x 0.25 degree, temperature data from https://power.larc.nasa.gov/ with the resolution of 0.5 x 0.5 degree, and wind speed data from https://apps.ecmwf.int/ with the resolution of 0.125 x 0.125 degree.

Tilahun and Merkel (2009) stated that GIS (Geographic Information System) is considered to be the only reliable tool for handling spatial and temporal variability. In this study, all of the ancillary data required were processed using GIS software to ensure the resolution, projection, and the format of all the input data was uniform and suited to the model of WetSpass-M.

3.2 Description of WetSpass-M Model

WetSpass-M is a distributed model that executes the computation of water balance at a raster level at a monthly time step (Abdollahi, Bazargan & McKay 2018). It was built as an extension of the physically based WetSpass methodology, which aimed to assess the long-term average spatial patterns of groundwater recharge, runoff, and evapotranspiration from long-term mean meteorological data in conjunction with land use, soil, as well as groundwater level grid maps by employing the relationship of physical and empirical (Batelaan & De Smedt 2001). This model has demonstrated to be suitable for studying long-term impacts of water balance associated with land use/land cover change under variable soil textures (Batelaan et al. 2003; Wang et al. 2012).

Spatially distributed land use, soil texture, groundwater depth, slope, and climatological data are compulsory as basic inputs of WetSpass-M model (Abdollohi et al. 2017). The total water balance for each raster cell is separated into independent water balances such as vegetated, bare soil, open water, and impervious surface to indicate the heterogeneity of land use within the cell as illustrated in Figure 8 (Batelaan & De Smedt, 2001). This separation enables to estimate the non-uniformity of the land use per cell, which is dependent on the raster cell resolution and the process of every part of a cell are managed in a cascading ways (Batelaan & De Smedt 2001).

According to Abdollahi et al. (2017), the original version of WetSpass model executes the hydrological processes based on seasonal timescale. However, the newly developed model (WetSpass-M) has been modified from the original version and it executes the input data according to the flowchart shown in Figure 9. Processing begins with reading the input data, which is considered as an independent internal process (process 0). The grid cell of the water balance per time step (monthly) involves interception as the first process, surface runoff (process

2), evapotranspiration (process 3) and groundwater recharge (process 4). Meanwhile, the fractions of land use/land cover in this model are used to determine the estimation of water balance at grid cell level.

Image removed due to copyright restriction.

Figure 8. The representation of water balance schematic for a non-homogenous land cover (Batelaan & De Smedt 2001)

3.2.1 Water balance components

The total water balance is calculated by the summing-up of the water balance of each raster grid cell. To illustrate the water balance for the vegetated area can be estimated using Equation 1:

$$\boldsymbol{P = I + S_v + T_v + R_v} \qquad \textbf{Eq. 1}$$

Where,

P = average precipitation [L/T],

I = interception by vegetation [L/T],

Sv = surface runoff [L/T],

Rv = groundwater recharge [L/T].

Image removed due to copyright restriction.

Figure 9. Flowchart for monthly spatially distributed of water balance model, WetSpass-M, and the modification from the original version of WetSpass model (Abdollahi et al. 2017)

Interception

Interception as a monthly value is considered as a precipitation fraction relied on land use/ land cover (Abdollahi et al. 2017). The alteration of land use can change the leaf area index (LAI), by which it will affect the evapotranspiration and interception. Total interception in WetSpass-M is calculated according Equation 2:

$$\boldsymbol{I_m = P_m I_R}$$ **Eq. 2**

where:

Im = interception (mm/month),

Pm = monthly precipitation (mm/month),

I_R = interception ratio, which calculated with the formula introduced by De Groen and Savenije (2006):

$$\boldsymbol{I_R = \frac{I_m}{P_m} = 1 - exp\left(\frac{}{}\right)}$$ **Eq. 3**

where *dp* the number of rainy days during a month (day/month) and I_D is a daily interception threshold, which depends on land use and can be estimated following the Equation 4 (Sutanto et al. 2012):

$$\boldsymbol{AI\left(1 \quad \frac{}{}\right)}$$ **Eq. 4**

where LAI is leaf area index and *a* is an interception parameter.

Surface runoff

Monthly surface runoff (SR_m) is estimated by WetSpass in mm/month using a rational method applied on a monthly time step with the use of two coefficients:

Eq. 5

where,

C_{sr} = actual runoff coefficient (-)

C_h = coefficient (-) to represent the conditions of soil moisture (Bahremand et al., 2007):

$$\left(\frac{s}{}\right)$$ **Eq. 6**

where O_s is the cell soil moisture in (m^3/m^3), θ_{sat} is soil porosity (m^3/m^3) and b is an exponent (-), which indicates rainfall intensity effects. When b = 1, a linear relation between C_h and soil moisture is assumed. The optimal value for b can be obtained through calibration using time series of discharge (Bahremand et al. 2007). However, considering that monthly time series of soil moisture data are scarce, the value of C_h (between 0 and 1) can be approximated through integrating the evaporative efficiency ratio into the adapted method of Turc (1955) at monthly scale (Pistocchi et al. 2008 cited in Abdollahi et al., 2017):

$$\boldsymbol{C_h} = \frac{\boldsymbol{P_m}}{\boldsymbol{LP(P_m^{\alpha} + ET_m^{\varkappa})^{\frac{1}{\varkappa}}}} \text{ if } ET_m > P_m, \text{ and } \boldsymbol{C_h = 1} \text{ if } ET_m \leq \boldsymbol{P_m} \qquad \textbf{Eq. 7}$$

where ET_m identified as potential evapotranspiration (mm/month), LP defined as calibration parameter (-), which decrease the value of potential evapotranspiration relying on the soil moisture (default determined as 0.65). Pistocchi et al., as cited in Abdollahi et al. 2017 proposed 1.5 as the value for the exponent $\boldsymbol{\varkappa}$ as mean value at monthly scale.

The coefficient of surface runoff incorporates a number of factor: surface roughness, infiltration and depression storage (Abdollahi et al. 2017). For improving the calculation of the potential runoff coefficient for each grid cell, it is estimated from the runoff coefficient for permeable areas (C_{per}) and for the impermeable area (C_{Imp}) based on their area. Runoff coefficient for permeable area (C_{per}) can be calculated by a weighted summation of land use (*w1*), soil (*w2*), and slope factors (*w3*) as represent in Equation 8:

$$\boldsymbol{C_{per} = w1 + \left(\frac{0.02}{n}\right) + w2\left(\frac{\theta w}{1-\theta w}\right) + w3\left(\frac{S}{10+S}\right)} \qquad \textbf{Eq. 8}$$

where *n is* identified as the Manning's roughness coefficient based on land use type (Dhakal et al. 2011), θw is the volumetric soil water content at wilting point (Saxton & Rawls 2006), and S is the slope in percentage. *w1, w2* and *w3* are considered to be the weights for the three parameters related to C_{per}:

$$\boldsymbol{w1 + w2 + w3 = 1} \qquad \textbf{Eq. 9}$$

The original model of WetSpass has listed the best combination of weights for the runoff coefficient in the lookup tables as *w1*=0.4, *w2*=0.3 and *w3*=0.3 (Abdollahi et al. 2017). Furthermore, the weighted potential runoff coefficient (C_{wp}) for a grid cell is estimated by splitting every grid cell into a permeable and an impermeable area as shown in Equation 10:

$$\boldsymbol{C_{wp} = \left(1 - \frac{A_{imp}}{100}\right) C_{per} + \frac{A_{imp}}{100} C_{imp}} \qquad \textbf{Eq. 10}$$

where:

C_{imp} = runoff coefficient for impervious area,

A_{imp} = percentage of impervious area in each grid cell.

Accordingly, to convert the potential runoff to coefficient of actual runoff, C_{wp} is adapted for mean daily precipitation days ($\bar{P}_{24}$) in mm/day per month as presented in Equation 11:

$$\frac{{}_{wp}\bar{P}_{24}}{{}_{wp}\bar{P}_{24}} \qquad \textbf{Eq. 11}$$

The formula in the Equation 12 provides a correction values for rainfall effect on runoff coefficient in the curve number methods (USDA-NRCS 1985, cited in Abdollahi et al. 2017). The correction factors depend on the ratio between the depths of runoff with daily values of precipitation, which ranging between 1 - 255 mm. The correction is closely to linear for lower potential runoff coefficients and rainfall, while the correction for higher values, the relationship tends to be non-linear.

As the surface storage is based on a monthly time scale, surface runoff from the previous month contributes to the next month ($m^{3/}$month) (Abdollahi et al. 2017):

Eq. 12

where *x* (-) is delay factor (between 0-1), $Q_{(t-1)}$ is the volumetric of surface runoff from the prior month (m^3/month) and *A* is the area (m^2). A delay factor of 0 indicates that there is no surface runoff during the month without precipitation event. The delay factor is similar to the weighting coefficient in the Muskingum method for open channels, but it is ranging between$0 \leq x \leq 1$.

Evapotranspiration

In calculating evapotranspiration, WetSpass-M follows a similar approach as the original WetSpass model. Potential evaporation at a monthly timescale and vegetation coefficients are used to calculate the actual evapotranspiration (Abdollahi et al. 2017). To estimate the reference transpiration from the potential evapotranspiration (ET_p), a vegetation coefficient is necessary and can be calculated as Equation 13:

$$\frac{-}{-\left(1 \; -\frac{c}{}\right)} \qquad \textbf{Eq. 13}$$

where:

= the psychometric constant (kPa/^{o}C),

r_c = (bulk) surface resistance (s/m),

r_a = aerodynamic resistance (s/m), which can be estimated following Equation 14:

$$\frac{\quad}{\quad}\left(\boldsymbol{ln}\left(\frac{\quad}{\quad}\right)\right) \quad \textbf{Eq. 14}$$

where K is defined as von Karman constant (0.41), U_a is wind speed in m/s at elevation Z_m (m), Z_d is zero displacement elevation (m) and Z_0 is the aerodynamic roughness of surface (m). Abdollahi et al. (2017) stated that vegetation coefficient is equal to 0 for groundwater discharge area with vegetation cover. Hence, the formula for reference transpiration (T_{rv}) is given by:

Eq. 15

Meanwhile, for vegetated area where groundwater table is lower than the root zone as the case in this study, the actual transpiration is modified as:

$$\left(\boldsymbol{1 - a_1{}^{w/T_{rv}}}\right)\boldsymbol{T_{rv}} \quad \textbf{Eq. 16}$$

where a_1 is a calibration parameter, which links to the sand content of the soil type and w is available water for transpiration as given by:

Eq. 17

where R_d is the root depth, $\theta_{fc} - \theta_{pwp}$ is the plant available water content per time step. The total actual monthly evapotranspiration (mm/month) per grid cell is given by (Batelaan & De Smedt 2001):

Eq. 18

where:

ET_m = total actual monthly evapotranspiration (mm/month),

ET_v = evapotranspiration for vegetated area,

ET_s = evapotranspiration for bare soil,

ET_O = evapotranspiration for open water,

ET_i = evapotranspiration for impervious area.

Groundwater recharge

The infiltration of groundwater recharge in WetSpass model is calculated from the balance difference as a function of vegetation, soil texture, slope, groundwater level and the precipitation

(Graf & Przybylek 2018). The WetSpass model allows obtaining legible spatial distribution of values of effective infiltration for soil types and land use types, which may be utilised as reference features for calculations in other balance models.

According to Abdollahi et al. (2017), monthly recharge (mm/month) in WetSpass-M is estimated as the residual term of water balance:

$$R_m = P_m - SR_m - ET_m \qquad \textbf{Eq. 19}$$

Considering recharge is a slow process, monthly base-flow per cell is estimated based on the storage of the prior month and the recharge in the considered month:

$$Q_{b(t)} = \beta Q_{b(t-1)} + 0.001 N_m (1-\beta) \emptyset R_m \qquad \textbf{Eq. 20}$$

where:

β = storage parameter (-) between 0 and 1,

$Q_{b(t-1)}$ = discharge from previous month (m^3/month),

N_m = monthly number of days,

$\emptyset$ = recharge contribution parameter to current base-flow (m^2/day) (Arnold & Allen 1999):

$$\emptyset = \frac{1.15A}{k} \qquad \textbf{Eq. 21}$$

where A is an area of grid cell (m^2) and *k* is recession index (day).

Hence, the total water balance per raster cell and hydrological season is given as:

$$ET_m = a_v ET_v + a_s ET_s + a_O ET_O + a_i ET_i \qquad \textbf{Eq. 22}$$

$$S_m = a_v S_v + a_s S_s + a_O S_O + a_i S_i \qquad \textbf{Eq. 23}$$

$$R_m = a_v R_v + a_s R_s + a_i R_i \qquad \textbf{Eq. 24}$$

The groundwater recharge now can be served as an input data for a groundwater model. Using the distribution recharge from WetSpass in a steady state groundwater model will rectify the prediction of simulated groundwater level, discharge and recharge areas (Batelaan & De Smedt 2001). Nevertheless, groundwater depth is involved as input data for the simulation of WetSpass-M model. Hence, the groundwater and WetSpass model is required to be executed one after the other, while exchanging recharge and groundwater depth, as shown in Figure 10.

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Figure 10. Schematic representation of the iteration process in the WetSpass-M model (Batelaan & De Smedt 2001; Graf & Przybylek 2014)

3.3 Implementation In ArcGIS

The WetSpass-M model is coupled with ArcGIS as a raster model and coded in Python (Abdollahi et al. 2017). The raster model structure of ArcGIS corresponds to the model and hence allows easy connection to numerical groundwater models as well as input data, which is derived from satellite imagery. The data structure of GIS is used efficiently since spatial information is stored in attribute tables. From the attributes, new raster layers can be derived for use in spatial calculations. The attribute table also enables easy specification of new land use or soil types, and also the changes in the parameter values, which allows future analysis of land and water management scenarios (Batelaan & De Smedt 2007).

In this study, the software of ArcGIS version 10.6 was used. All of the input data in this study was processed using ArcGIS. Starting point is adjusting the data into the same projection since the data was obtained from various sources with varied projection. The coordinate system applied in this study was WGS_1984_UTM_Zone_46N and datum D_WGS_1984. The resolution of the input data is also required to be changed due to the varied resolution from the original data sets. The dimension of the grid cell in this study was determined to be 500 m x 500

m. Next, it is crucial to make sure that all the input data have the same number of grid cells using 'extract by mask' tool. After that, all input maps need to be converted to ESRI ascii grid format, which can be converted by 'conversion' tool.

In addition to those requirements, the land use types had to be reclassified since WetSpass-M has its own classification and parameters (Appendix A) for land use type to estimate the water balance of the area. This reclassification can be done using 'reclassify' tool. As the result, while the original land use type has 14 classifications for the study area, in WetSpass-M model, the classification was reduced to only 8 classes as presented in Table 3.

Table 3. Reclassification of land use types to WetSpass-M land use types

No.	LU type	WetSpass LU Type
1	Primary forest	Mixed forest
2	Primary dryland forest	
3	Secondary dryland forest	
4	Planted forest	
5	Savannah	Meadow
6	Built up area	Built up
7	Paddy field	Agriculture
8	Dryland agriculture	
9	Shrub	Shrub
10	Mining	Bare soil
11	Bare soil	
12	Airport	Airport
13	Open water	Navigable river
14	Ponds	

3.4 Model Comparison

Since most of the data for this study were collected from global data sets, it is necessary to check whether the global data sets are applicable in the study area. Moreover, it is also important to compare the simulated discharge of WetSpass-M model with measured discharge. It can be seen that the better the match in the graphs the better the compatibility of the data and the model.

The discharge data used in this study was collected from Office of Irrigation of Aceh Besar for the year of 2018. The discharge data was obtained from the gauging station within *Krueng Aceh* catchment, which is located in Seulimum with the total area of 656 km^2. Actually, the discharge data was requested for the year 2009 since all the climatological data used in this study comprises of climate data of 2009. However, according to the office employees, there are some discharge data which are not traceable due to unknown reasons, thus, discharge data of 2018 was used in this study.

The simulated discharge data was obtained from the WetSpass-M model from the area of *Krueng Seulimum* sub-catchment. All the input data was clipped for this area with the help of 'clip' tool in ArcGIS software. Then, the WetSpass-M model can be run to estimate the discharge data of this sub-catchment. The simulated discharge per month is the summation of monthly surface runoff and recharge (becoming groundwater recharge) of the *Krueng Seulimum* catchment. This assumes that surface runoff and recharge contribute both to river and discharge at the outlet of the catchment.

IV. RESULTS

4.1 The Land Use Change

The changes in land use in the study area over the ten year period are shown in Figure 11. Forests are widely distributed in the western and southern parts, whereas agricultural areas are relatively scattered in the centre, northern, eastern parts. Savannah is one of the dominant land covers in Aceh Besar and it is distributed mainly in the centre and northern parts. The proportion of bare soil is very small and scattered and it may not be very visible on the map. The built-up areas are located mostly in the centre and become the most visible changes on the map since it was experiencing the major increase during ten years compared to the other land covers. The detail amount of increased and decreased area of the land use types between 2009 and 2018 is presented in Table 4.

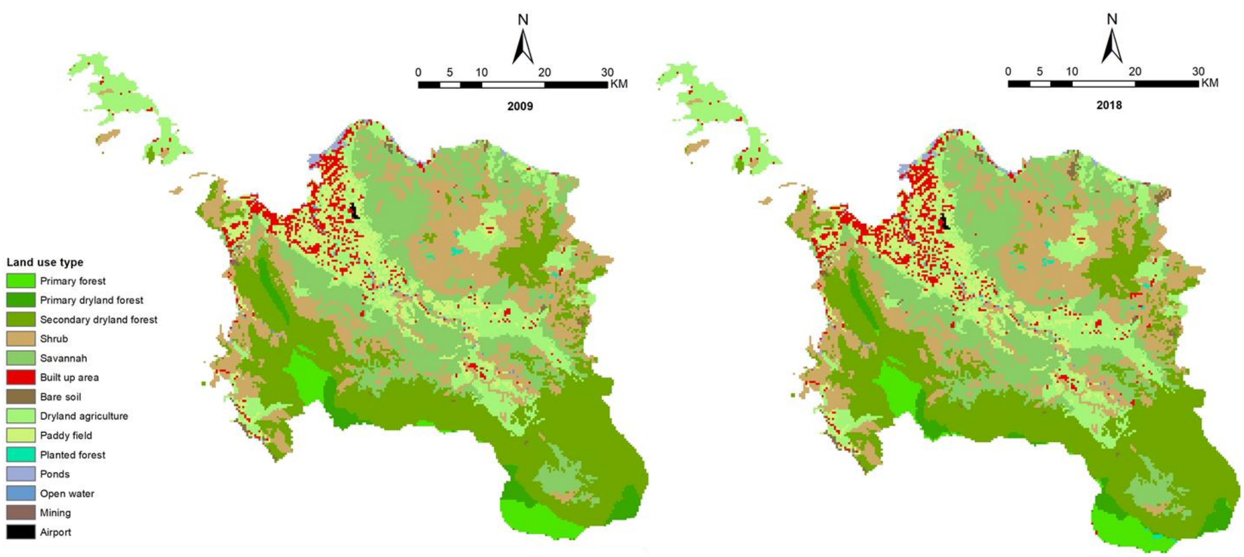


Figure 11. Land use map of 2009 and 2018

Table 4. The changes of land use between 2009 and 2018

No.	Land Use Type	Land use area		Land use change	
		2009	2018	2009-2018	
		km2		km2	%
1	Primary forest	148.0	141.2	-6.8	-4.8
2	Primary dryland forest	27.0	25.9	-1.1	-4.2
3	Secondary dryland forest	795.0	791.6	-3.4	-0.4
4	Shrub	609.8	608.0	-1.8	-0.3
5	Savannah	560.0	556.4	-3.6	-0.6
6	Built up area	89.0	97.3	8.3	8.5
7	Bares soil	9.5	11.4	1.9	16.7
8	Dryland agriculture	388.0	390.0	2.0	0.5
9	Paddie field	181.0	183.0	2.0	1.1
10	Planted forest	2.3	3.3	1.1	31.8
11	Ponds	3.5	4.4	0.9	20.5
12	Open water	6.0	6.0	0.0	0.0
13	Mining	1.0	1.5	0.5	33.3
14	Airport	2.3	2.3	0.0	0.0
	Aceh Besar	**2822.3**	**2822.3**		

4.2 Model Comparison

Model comparison is essential in this study since most of the data for this study were collected from global data sets. Moreover, it is also important to compare the simulated discharge of WetSpass-M model with measured discharge. A good match in the graphs should indicate a good compatibility of the data and the model for the study area. The measured data of 2018 can be seen in Table 5. However, there was discharge data missing in December, which means that the comparison could only be from January 2018 to November 2018.

Simulated discharge resulted from the WetSpass-M simulation of the area *of Krueng Seulimum* sub-catchment (Figure 12). The discharge is the summation of the surface runoff and recharge values of the area. All maps for the input data were clipped following the sub-catchment area using ‘clip’ tool in ArcGIS software.

Table 5. Measured and simulated discharge

Month	Qmeasured	Qsimulated	Difference
	mm/month		mm/month
January	109.71	108.83	0.89
February	138.65	78.27	60.38
March	183.20	108.79	74.41
April	117.80	106.91	10.88
May	145.29	100.30	44.99
June	58.60	88.50	-29.91
July	34.89	42.35	-7.46
August	29.42	93.07	-63.65
September	58.88	87.11	-28.23
October	117.29	99.04	18.25
November	145.48	125.30	20.18
Total	**1139.22**	**1038.48**	**100.74**
		Mean Difference =	**16.79**

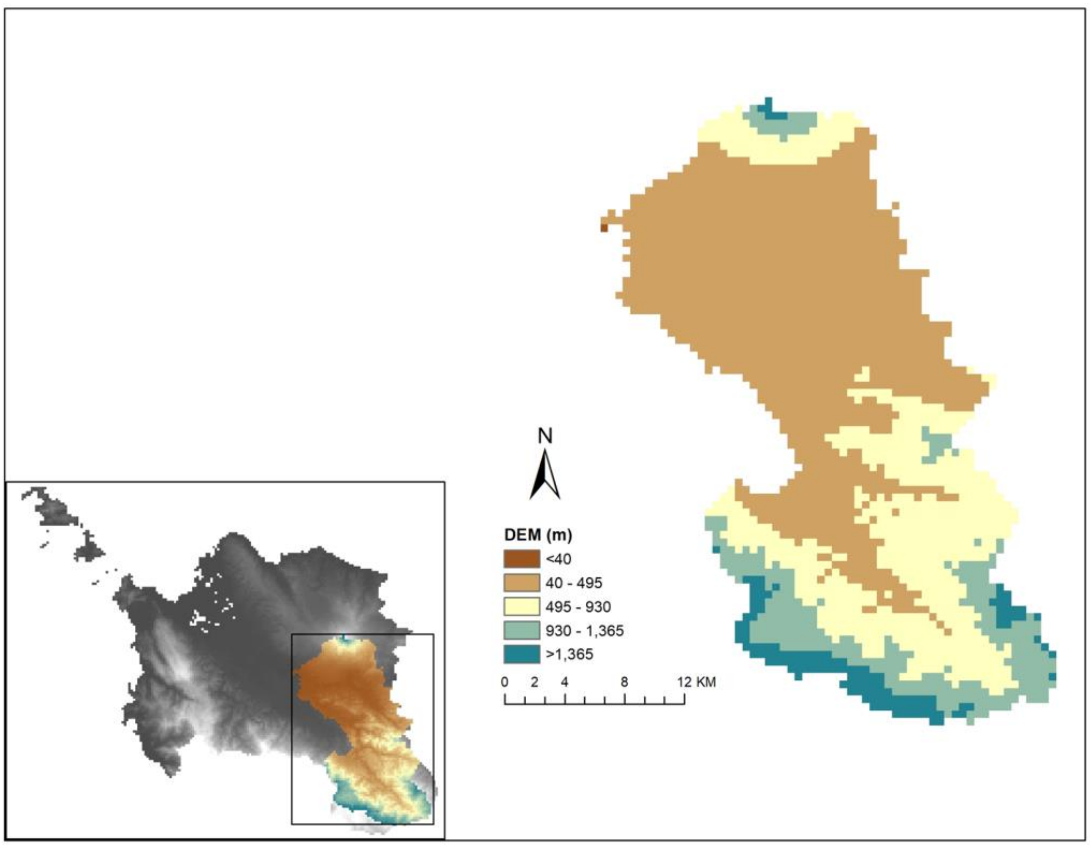


Figure 12. DEM of sub-catchment *Krueng Seulimum*

The comparison of measured discharge and simulated discharge of this area is presented in Figure 13. As illustrated in the graph, measured discharge and simulated discharge are not well-matched. There are several months showing a large gap between the two graph lines, such as in February, March, May and August. The remaining months show a better match to each other, even though there were no discharge values of measured and simulated, which show definite similarity except in January. This lack of matching in the two sets of data shown on the graph is due to the measured discharge data used was from 2018, whereas the simulated discharge data resulted from climatological data of 2009. Accordingly, it would be expected that the two sets of data shown in the graph would not perfectly match to each other.

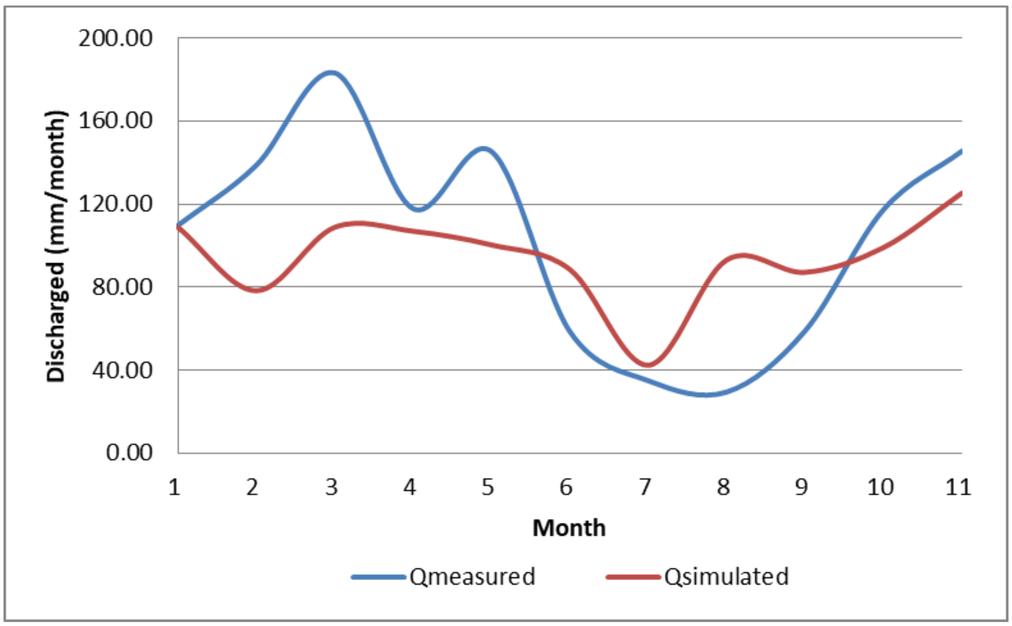


Figure 13. Measured discharge vs. simulated discharge of sub-catchment *Krueng Seulimum* in 2018

The total measured discharge and simulated discharge is 1139 mm/yr and 1038.48 mm/yr, respectively. Meanwhile the mean annual value is 104 mm and 94 mm, respectively. It shows that the measured discharge data of 2018 has a higher value annually compared to simulated discharge of 2009. The difference between mean values of the two discharges data is 17 mm, which revealed that the measured discharge has higher average value, about 17 mm, compared to simulated discharge.

4.3 Actual Evapotranspiration

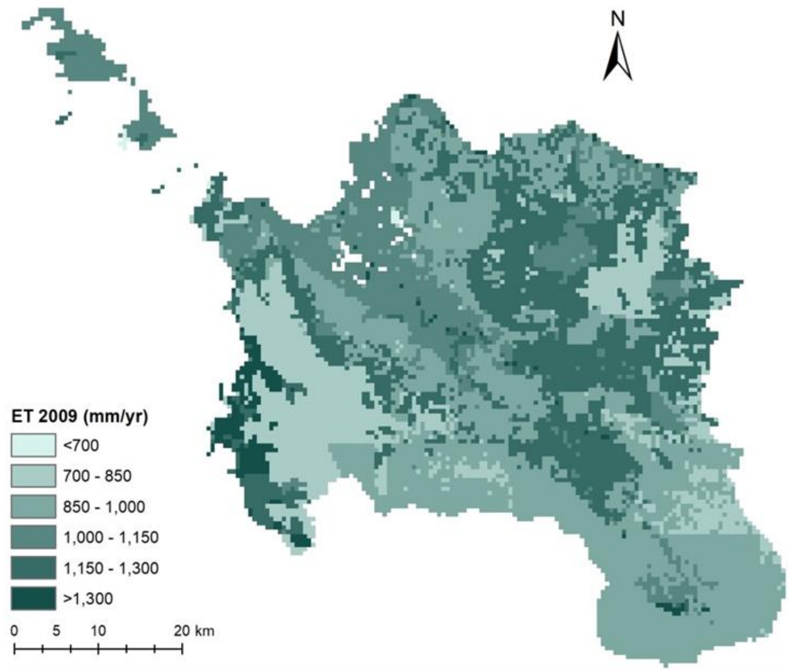
Mean annual actual evapotranspiration of Aceh Besar is 1,026 mm for 2009 constituting about 51% of the annual mean precipitation of the area. This value represents that evapotranspiration is responsible for the main process of water loss in Aceh Besar. The spatially distributed annual actual evapotranspiration maps of 2009 and 2018 are shown in Figure 13.

The evapotranspiration value as a result of WetSpass-M model has included the value of transpiration, interception, and soil evaporation. The evapotranspiration value is mostly influenced by root depth of the vegetation, leaf area index (LAI), aerodynamics resistance and stomata. In WetSpass-M model, all of those parameters have been specified as shown in Appendix A. The summary of parameter values which have been used in this study to estimate actual evapotranspiration is presented in Table 6.

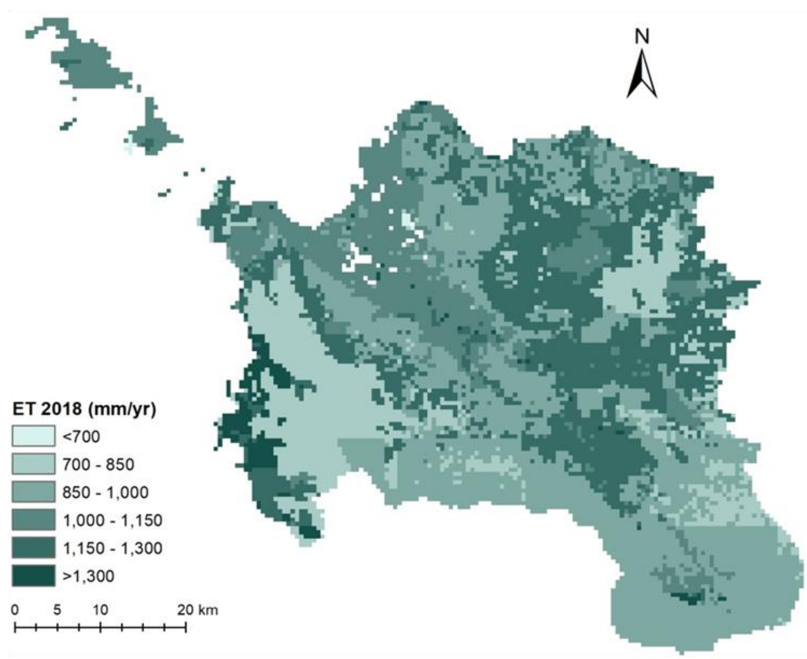
Table 6. Land use parameter based on WetSpass-M model

Land use type	**LU type based on WetSpass-M**	**Root depth (m)**	**LAI**	**Stomata**	**Aerodynamic resistance (s/m)**
Primary forest	Mixed forest	2	5	375	28.10
Primary dryland forest					
Secondary dryland forest					
Planted forest					
Savannah	Meadow	0.3	2	100	177.47
Built up area	Built up	-	0	100	212.01
Paddy field	Agriculture	0.4	4	180	115.01
Dryland agriculture					
Shrub	Shrub	0.6	6	110	66.33
Mining	Bare soil	-	0	110	426.67
Bare soil					
Airport	Airport	-	0	100	212.01
Open water	Navigable river	-	0	110	426.67
Ponds					

Based on the simulation, annual evapotranspiration for 2009 ranges from 520 mm to 2658 mm within the area. It can be seen in the maps of annual evapotranspiration (Figure 14a) that the ET value is spatially distributed following the land use types, which indicates that land use/land cover is the most determining factor of evapotranspiration values. In addition to land use, precipitation and soil types also determining factors of evapotranspiration.



(a)



(b)

Figure 14. Spatially distributed values of annual evapotranspiration of (a) 2009 and (b) 2018

Furthermore, another simulation of WetSpass-M has been run for the year of 2018 using the same input data as 2009 except for land use map. The result is shown in Figure 14b. Both of the maps look very similar and changes appear to be difficult to identify on the map of 2018. However, there are indeed differences between those years; the total annual evapotranspiration of 2018 experienced a reduction from that in 2009. The reduction of evapotranspiration clearly can be seen by converting them to volume (m^3), as presented in Table 7.

Table 7. Differences in ET between 2009 and 2018 in relation to each land use type

LU Type	**Evapotranspiration**		**Difference**
	2009	**2018**	
	m^3/yr		**m^3**
Built Up	96,230,500	99,865,300	3,634,800
Airport	1,407,250	1,395,250	-12,000
Bare soil	13,429,310	14,098,750	669,440
Agriculture	703,978,720	709,620,900	5,642,180
Meadow	527,224,000	519,263,000	-7,961,000
Mixed Forest	810,072,750	791,746,570	-18,326,180
Shrub	770,984,500	759,987,000	-10,997,500
Navigable River	25,175,000	29,150,000	3,975,000
Total	**2,948,502,030**	**2,925,126,770**	**-23,375,260**

According to Table 7, there are several land use types, which have undergone a reduction of evapotranspiration volume, while the others experience an increase. A major decrease was observed in mixed forests, where the evapotranspiration reduced by 18 million m^3 or 2.3%. Other land use types with a decrease are shrub and meadow, where the volume reduced around 11 million m^3 (1.4%) and 8 million m^3 (1.5%), respectively. Meanwhile, a major increase of evapotranspiration occurred in the agriculture area, i.e. 5.6 million m^3 or 1%. In addition, navigable river and built up area also show increases of around 3.9 million m^3 (4.1%) and 3.6 million m^3 (3.8%), respectively. Overall, the annual evapotranspiration decreased by about 23 million m^3. The percentage of the increase and decrease in volume of annual evapotranspiration during the ten years is shown in Figure 15.

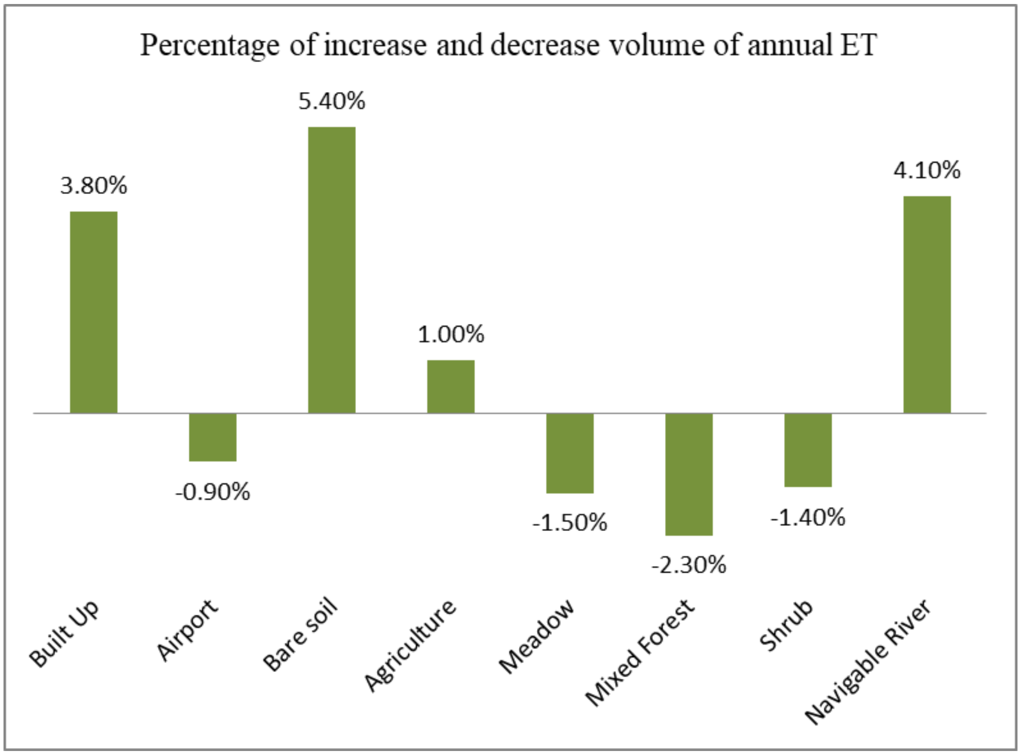
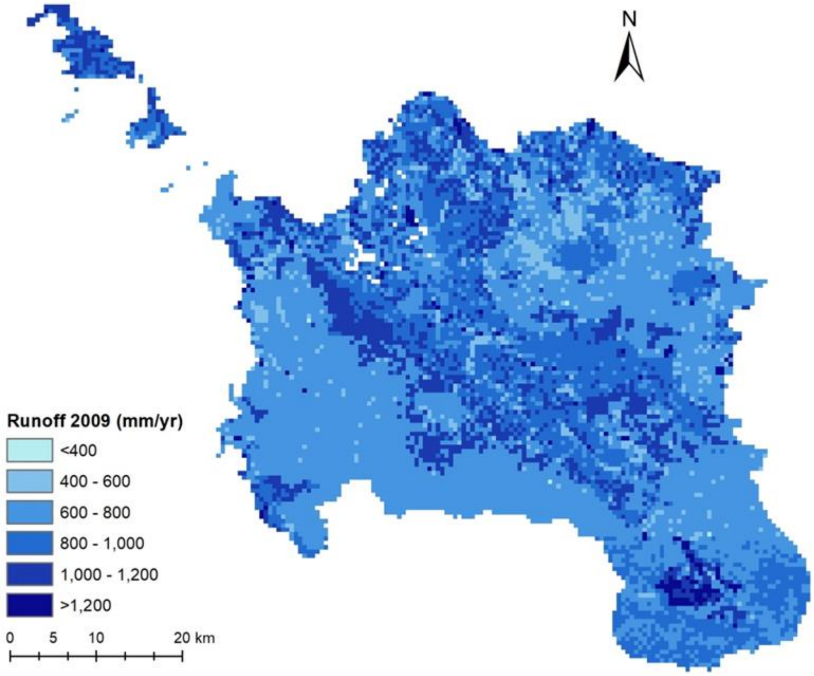


Figure 15. Percentage of increase and decrease amount of ET volume between 2009 and 2018

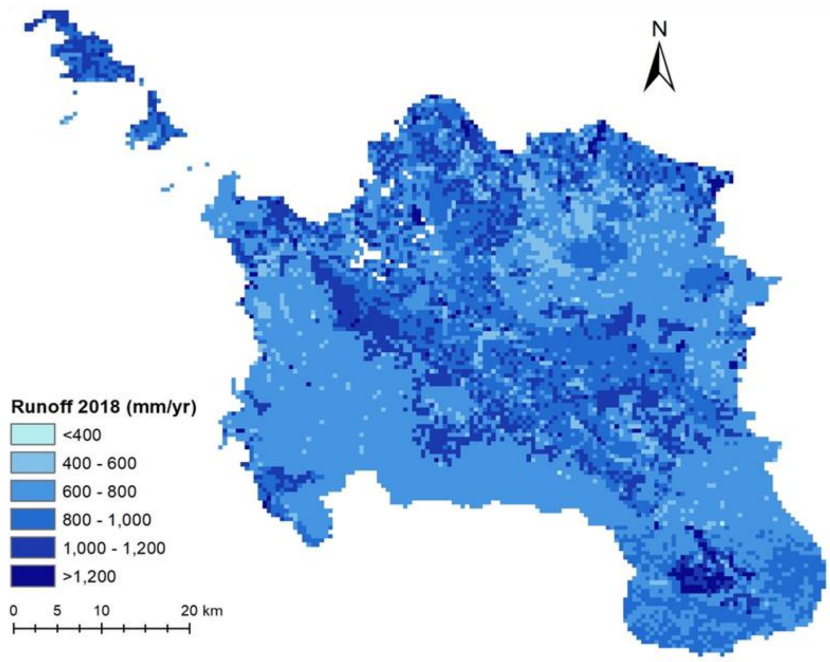
The escalation and reduction of annual evapotranspiration occurs due to the alteration of land use, which happened between 2009 and 2018. Land use change links to many impacts on the environment, particularly in terms of the hydrological cycle. As it is stated in the study of Bosman et al. (2016) that land use/land cover change has a substantial influence on terrestrial hydrology by altering the evaporation and surface runoff (Bosmans et al. 2016). Hence, land use/land cover is considered as the main controlling factor of evapotranspiration in the area.

4.4 Surface Runoff

The annual surface runoff of the study area varied spatially with vegetation type, soil texture and slope. The simulated annual surface runoff of Aceh Besar for the year of 2009 ranges from 295 mm to 1970 mm as the minimum and maximum values respectively (Figure 16a). The average annual surface runoff is 807 mm which accounts for 40% of the total rainfall. This represents that surface runoff is responsible for the second most important process of water loss after evapotranspiration.



(a)



(b)

Figure 16. Spatially distributed values of annual surface runoff of (a) 2009 and (b) 2018

Based on the simulated surface runoff, Aceh Besar is considered as an area with a high rate of surface runoff. The highest rate of surface runoff is spreading in the centre as it is dominated mostly by urban area. The surface runoff in the centre parts mostly has values of 800 mm or higher. The major soil type in the area is predominated by silty loam with a moderate permeability, however there is also minor presence of sandy clay loam in the centre part which has lower permeability that increases surface runoff. On the other hand, the western and southern parts of Aceh Besar have lower rates of surface runoff, which are mostly lower than 800 mm. This area is comprised of forests which hinder surface runoff. The types of soil in these parts are dominated by silty loam and sand, which has higher permeability. Thus, the results show that in this study, both soil types and land cover have significant impact on annual surface runoff of Aceh Besar. The soil parameter of WetSpass-M model is presented in Appendix A.

The annual surface runoff of 2018 in the study area also has been simulated as presented in Figure 16b. Similarly as the annual evapotranspiration map of 2009 and 2018, which did not show large changes on the map after ten years, both maps of annual surface runoff of 2009 and 2018 also do not show specific alteration. Nevertheless, the changes can clearly be seen by converting the annual surface runoff to volume in m^3, as presented in Table 8.

Table 8. Difference in surface runoff between 2009 and 2018 in relation to each land use type

LU Type	**Surface runoff**		**Difference**
	2009	**2018**	
	m^3/yr		**m^3**
Built Up	94,251,750	114,640,100	20,388,350
Airport	3,265,500	3,265,500	0
Bare soil	13,986,500	18,630,000	4,643,500
Agriculture	489,833,500	501,998,000	12,164,500
Meadow	558,578,500	541,705,750	-16,872,750
Mixed Forest	704,135,000	718,418,500	14,283,500
Shrub	386,094,000	385,678,000	-416,000
Navigable River	18,068,750	20,336,750	2,268,000
Total	**2,268,213,500**	**2,304,672,600**	**36,459,100**

According to Table 7, most of the land use types experience an escalation of surface runoff, except meadow and shrub. Built up area has undergone significant increase by 20 million m^3 or accounted for 22%. Mixed forest and agriculture also were observed to have increased amount of runoff about 14 million m^3 (2%) and 12 million m^3 (2.5%), respectively. While mixed forest experienced a reduction in its size, the volume of surface runoff in mixed forest increased by 2%. This may be due to the fact that part of the forest moved in 2018 to higher runoff producing locations (i.e. steeper areas). The other land use types, which have undergone an incremental change, were bare soil and navigable river. Meanwhile, the airport area did not show any changes in the annual surface runoff.

Significantly, the major decrease of annual surface runoff occurred for the land use class of meadow with the amount almost 17 million m^3 or 3%, while surface runoff in shrub land had undergone a minor decrease by 0.4 million m^3 or 0.1%. Overall, the annual surface runoff of the study area in 2018 was increasing by 36 million m^3. The percentage of the increase and decrease of annual surface runoff between 2009 and 2018 is shown in Figure 17.

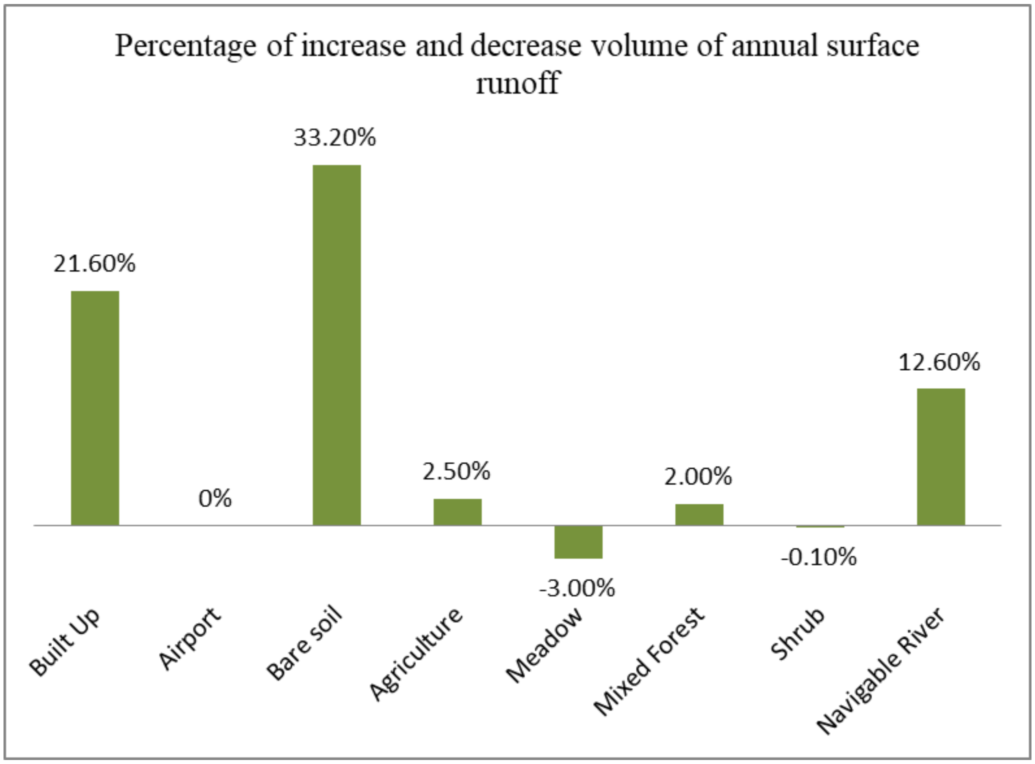
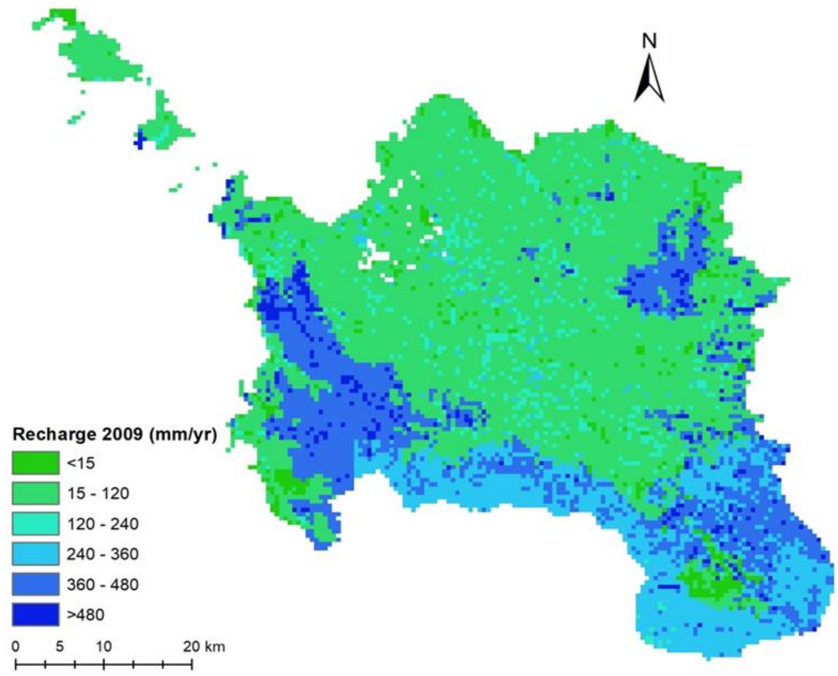


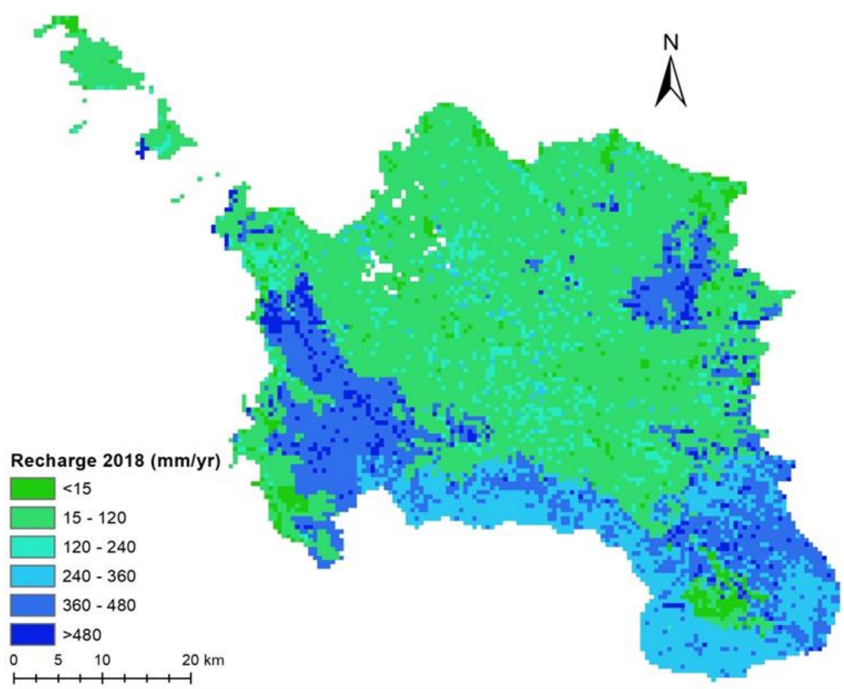
Figure 17. Percentage of increasing and decreasing amount of surface runoff volume between 2009 and 2018

4.5 Groundwater Recharge

The annual groundwater recharge of Aceh Besar Region in 2009 varied from 0 to 888 mm as shown in Figure 18a. Groundwater recharge constituted only 8.9% of the annual average precipitation of the area. The annual spatial groundwater recharge varies based on the factors that determine groundwater infiltration. The western and southern parts are recognised to have higher groundwater recharge (≥360 mm). On the other hand, groundwater recharge in the centre parts, which range from 15 to 240 mm, is lower compared to the western and southern parts.



(a)



(b)

Figure 18. Spatially distributed values of annual recharge of (a) 2009 and (b) 2018

The simulated groundwater recharge of 2018 was run using WetSpass-M model and results in a significant reduction for a total almost reaching 60 million m^3. The spatially distributed map of groundwater recharge for 2018 is shown in Figure 18b. Decreasing volumes of groundwater recharge were observed for all land use types except airport and navigable river as can be seen in Table 9. The major change was experienced in the mixed forest land use class with a total reduction almost 27 million m^3 or 7.1%. Furthermore, shrub and meadow were reduced by more than 12 million m^3 (23.7%) and 11 million m^3 (29.1%), respectively. The agricultural area between 2009 and 2018 increased, however the amount of groundwater recharge decreased by 8 million m^3. Overall, up to 59 million m^3 of groundwater recharge was reduced due to the conversion of land use from 2009 to 2018. The percentage of groundwater recharge reduction for each land use type is presented in Figure 19.

Table 9. Difference in groundwater recharge between 2009 and 2018 in relation to each land use type

LU Type	**Recharge**		**Difference**
	2009	**2018**	
	m3/yr		**m^3**
Built Up	1,645,000	1,635,100	-9,900
Airport	11,750	11,750	0
Bare soil	5,020	7,250	2,230
Agriculture	31,113,500	22,835,250	-8,278,250
Meadow	39,043,750	27,693,250	-11,350,500
Mixed Forest	377,431,250	350,504,750	-26,926,500
Shrub	53,336,000	40,675,250	-12,660,750
Navigable River	0	0	0
Total	**502,586,270**	**443,362,600**	**-59,223,670**

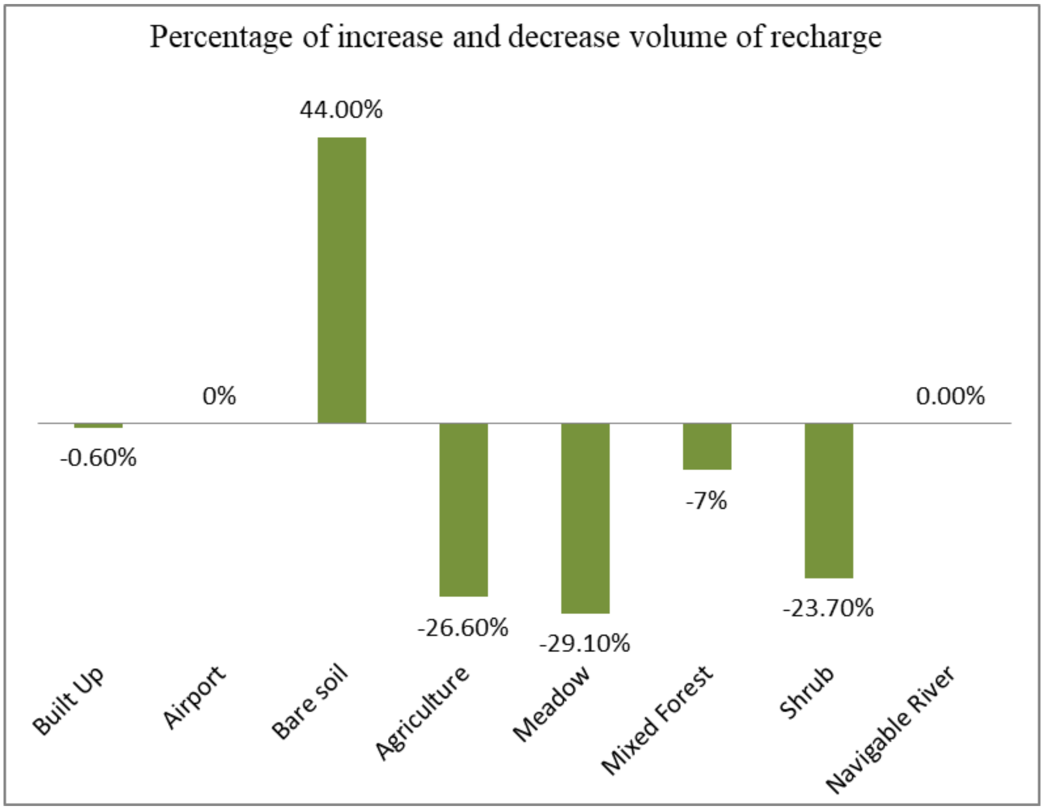


Figure 19. Percentage of increase and decrease in recharge volume between 2009 and 2018

4.6 Water Balance Components of 2009 and 2018

The spatially averaged water balance components of Aceh Besar for the year of 2009 are presented in Table 10. Overall, the water balance of 2009 presents that the precipitation is mainly lost through evapotranspiration and surface runoff for about 51% and 40%, respectively. Only a small amount of precipitation (9%) infiltrates and replenishes the groundwater recharge.

Table 10. Summary of annual water balance components in Aceh Besar (2009)

Water balance components	Annual values (mm/yr)			
	Min	Max	Mean	Std.dev.
Precipitation (P)	1907	2256	2008	65
Evapotranspiration (ET)	520	2658	1026	196
Surface runoff (Ro)	295	1970	807	177
Recharge (Re)	0	888	179	165
Water balance	P-ET-Ro-Re = -3			

Furthermore, the overall values of spatially averaged water balance components of 2018 are shown in Table 11. There was no significant difference between water balance components of 2009 and 2018. Only a slight increase occurred in average annual values of surface runoff and a minor decrease in recharge. The summation of evapotranspiration, surface runoff and groundwater recharge of both years are slightly exceeding the precipitation by 3 mm in 2009 and 4 mm in 2018. This indicates that the area undergone water deficit due to higher amount of evapotranspiration.

Table 11. Summary of annual water balance components in Aceh Besar (2018)

Water balance components	Annual values (mm/yr)			
	Min	Max	Mean	Std.dev.
Precipitation (P)	1907	2256	2008	65
Evapotranspiration (ET)	520	2658	1026	196
Surface runoff (Ro)	295	1971	809	180
Recharge (Re)	0	888	177	167
Water balance	P-ET-Ro-Re = -4			

V. DISCUSSION

5.1 Land Use Change in Aceh Besar

The change of land use during the ten year period is presented in Table 4. A major decrease was observed in primary forests. These forest areas reduce by a total of 6.8 km^2. By comparing land use map of 2009 and 2018, it is evident how most of the primary forests were converted into planted forests and agricultural land. Some parts of primary forest were also transformed to primary dry land forests. Furthermore, BRR (Badan Rehabilitasi dan Rekonstruksi [trans.] Agency for Rehabilitation and Reconstruction of Aceh and Nias) reported that the reduction in size of primary forest was also closely linked to logging activities to fulfil the demand for timber. The timber was used in the rehabilitation and reconstruction of towns and villages following the earthquake and tsunami on 26 December 2004 that caused widespread damage in Aceh (Muis 2019). In addition to primary forest, secondary dry land forest was reduced by 3.4 km^2. This reduction was caused mostly by a functional shift to rice paddy field, agricultural activities and increases in built-up area. This is in accordance with the study by Muis (2019), which stated that the increased size of paddy field and agriculture land was responsible for land clearing of secondary dry land forest. According to BPS (2015), the increase of rice fields and agricultural land is influenced by the rising prices of a number of agricultural products, which triggered growth in farming of these superior commodities.

In addition to forest areas, savannah has also experienced major decreased by 3.6 km^2. Savannah is located mainly in the central part of the region, which is also predominantly the residential area. Thus, most of the reduced savannah area was converted to built-up areas as a result of city expansion of Aceh Besar. The other land use types which have undergone reduction in size are primary dry land forests and shrub land with a minor decrease.

Significantly, during the ten years, a major increase was observed in the built-up area. It increased by more than 8 km^2. The built-up lands were mostly transformed savannah and secondary dry land forests. However, the reduction of other land use types, such as shrub lands and primary dry land forest, also links to the increase of built-up area. In addition to built-up area, dry land agriculture and paddy field also increased for the same area of 2 km^2. The intensification of agriculture and paddy field is in line with the priority programs of the Ministry of Agriculture, which targets the escalation of the self-sufficiency of rice, maize and soybean (Ministry of Agriculture's Annual Performance Plan for 2015, cited in Rifani 2015).

As demonstrated through the figures and data presented in this section, a comprehensive and dynamic change has occurred in the land use of Aceh Besar during the period of 2009-2018. A substantial decrease occurred in primary forest at 6.8 km^2 (4.8%), followed by savannah at 3.6 km^2 (0.6%), secondary dry land forest at 3.4 km^2 (0.4%), shrub land at 1.8 km^2 (0.3%) and primary dry land forest at 1.1 km^2 (4.2%). In contrast, the incremental increase in land cover was dominated by built-up area with 8.3 km^2 (8.5%), dry land agriculture and paddy field both with 2 km^2 (0.5% and 1.1%. respectively), bare soil with 1.9 km^2 (16.7%), planted forest with 1.1 km^2 (31.8%), as well as ponds and mining with a minor increase of 0.9 km^2 (20.5%) and 0.5 km^2 (33.3%), respectively. Meanwhile, open water and airport areas did not show any changes during the ten-year period.

5.2 Model Comparison

The model comparison in this study aimed to check the suitability of the data and the model for the study area. This is important since most of the data for this study were obtained from global data sets. A high suitability can be indicated by a good match in the graphs. The comparison of measured discharge and simulated discharge is shown in Figure 13. Based on the graph, measured discharge and simulated discharge are not well-matched, with significant differences for several months. However, it should also not be expected that the fit is perfect as the measured discharge and simulated discharges are not from the same year (measured discharge data from year 2018, meanwhile simulated discharge resulted from climatological data of 2009). Measured discharge data for 2009 was not available. Accordingly, the model comparison in this study cannot properly be done and is only very indicative.

Considering limitations existing in this study, the suitability of the model and the global data set for the study area cannot appropriately be judged. However, the credibility and reliability of WetSpass-M model in estimating the water balance components of tropical regions, such as Aceh has been demonstrated to be applicable. An example of this use of the WetSpass model was a study by Shresta et al. (2018), which was conducted in several tropical-Asian cities, including Bandung (Indonesia), Bangkok (Thailand), Ho Chi Minh City (Vietnam) and Lahore (Pakistan). This study aimed to assess climate change impact on groundwater recharge in these locations. One of the models Shresta et al. found to be suitable to estimate the groundwater recharge of the four cities was the WetSpass model. Hence, the WetSpass-M model simulation on water balance of Aceh Besar can be considered applicable for the area and the study application.

5.3 Actual Evapotranspiration

Actual evapotranspiration is a determinant in the water balance (Aish 2014). The approach of WetSpass-M model aims to describe the process of evapotranspiration in a physically based way. The actual evapotranspiration per grid cell is calculated as a summation of evaporation from water, intercepted by vegetation, the transpiration of the vegetative cover and evaporation from bare soil (Abu-Saleem 2010).

Both mean annual evapotranspiration in 2009 and 2018 was 1,026 mm. This means that evapotranspiration was the main process of water loss within the study area. It accounted for 51% of the precipitation. High evapotranspiration is caused by a high rate of radiation and strong dry wind. According to the simulation, annual evapotranspiration of Aceh Besar in 2009 and 2018 were spatially distributed following land cover types. According to Kahysay et al. (2018), generally, precipitation is also one of determining factors of evapotranspiration of a region, where the higher elevation parts of the region receive higher precipitation compared to the lower parts. Hence, the higher parts could potentially evaporate more water to the atmosphere. However, in this study, the highest evapotranspiration values were not occurring in the highest area. The highest rates of evapotranspiration mainly occurred in the eastern part, which represent major land surfaces covered by shrub, as can be seen in Figure 14a and b. The next highest rate of ET can be noticed in the central part as it covered mostly by paddy field, which is reclassified as agriculture in the land use types based on the WetSpass-M model in Table 3. On the other hand, the lowest rate of evapotranspiration occurred in the western part, which is mostly covered by mixed forests comprised of primary forest, primary dry land forest, and secondary dry land forest. These findings indicate that evapotranspiration in the study area is determined mainly by land cover rather than precipitation. Moreover, soil types also generally are a determining factor of evapotranspiration, where high water content or water availability in the soil will evaporate more water to the atmosphere. However, since the study area is mainly predominated by one type of soil (silty loam), the evapotranspiration in different soil types cannot be compared.

The amount of evapotranspiration in Aceh Besar during ten years decreased for a total 23 million m^3. A major decrease was observed in mixed forest by 18 million m^3 or 2.3%. This was due to the major loss of mixed forest by land conversion mostly to planted forest, and agricultural land, as well as logging activities. Gordon et al. (2005) suggested that decreased evapotranspiration as a result of deforestation is larger than the increase in evapotranspiration due to irrigation. Therefore, it could be argued that decreased evapotranspiration in mixed forest is triggering increases in the surface runoff of the study area. This is also mentioned in the study by Bosmans et al. (2016) that land cover change has impacted the global terrestrial hydrology, which generally means decreased evapotranspiration and increased discharge.

5.4 Surface Runoff

In Aceh Besar, surface runoff is considered as the second most important process of water loss. It accounted for 40% of the precipitation. According to the simulation, the study area has a high rate of surface runoff with an annual mean surface runoff of 807 mm in 2009 and 809 mm in 2018. The spatially distributed value of surface runoff is depending mostly on the land cover and soil types. The majority of the study area consists of silty loam soil type, which has a moderate permeability. However, there are also some parts in the south, which consist of sandy soil and have a higher permeability. Other than that, the minor presence of silt and sandy clay loam are also taken into account as they have lower permeability rate, which influences the surface runoff of the area. In addition to soil types, the influence of land use types on surface runoff is more obvious, as shown in Figure 16a and b. The highest surface runoff was spreading in the centre, which is dominated by the urban and agricultural area. Meanwhile, the lowest rate of surface runoff occurred in forest areas.

Comparing the surface runoff of the study area after ten years, the incremental increase was obvious. There was an escalation with a total of 36 million m^3. The largest escalation was observed in the built-up area by 20 million m^3 or 22%. This escalation was a result of the expansion of urban areas, which were driven mainly by population growth that reached a rate of 2.12% annually (Muis 2019). This driving force becomes the main factor of an increasing demand for land. Some parts of forests, savannah, and shrub land have been converted to built-up area. The conversion of land use from vegetation-covered land to non-vegetation covered land has hampered the absorption and storage of water by the land by reducing the soil's ability to absorb water and contribute to groundwater storage. Thus, the precipitation water, which is unable to be absorbed by the soil, becomes surface runoff, flowing to the river and being discharged to the sea.

5.5 Groundwater Recharge

Groundwater recharge is the entry into the saturated zone of water made available at the water table surface, together with the associated flow away from the water table within the saturated zone (Freeze & Cherry 1979). The amount of water that percolates through the soil into the groundwater depends on the vegetation cover, slope, soil types, water table depth, and the presence or absence of confining beds (Al Kuisi & El-Naqa 2013). In evaluating groundwater resources, recharge is one of the crucial factors; however it is difficult to quantify (Alley et al. 2002). Hence, the WetSpass-M model was developed to determine the long-term average spatially distributed recharge as a spatial variable dependent on the soil types, land use/land cover, slope, and meteorological conditions. This is primarily to take into account the influence of the spatial variability of the land surface on the groundwater system (Batelaan & Woldeamlak 2004).

The simulation of groundwater recharge in the study area had a mean annual recharge of 179 mm/yr and 177 mm/yr in 2009 and 2018, respectively. Groundwater recharge experienced a reduction after ten years with a total of 59 million m^3. Most of the land use types have undergone reduction in groundwater recharge, with the greatest reduction observed in the land surface covered by mixed forest at 26 million m^3 or 7%. This reduction was in line with the reduced area of mixed forests during the ten years and resulted in a large amount of groundwater recharge loss. Meadow and shrub land also experienced a decrease in recharge as the area of shrub and meadow decreased. On the contrary, agriculture was observed to have undergone a reduction in recharge of about 8 million m^3, while its land area increased. This was due to a much higher surface runoff in the agricultural area.

Looking at the maps of ground water recharge in Figure 18a and b, the western and southern parts of the study area are shown to have had higher groundwater recharge (≥360 mm) since the soil texture in the area is mainly silty loam and there is also a small part of the area of sand soil type. Silty loam has a moderate permeability, while sand has a higher permeability.

Moreover, land surfaces in the western and southern parts have higher elevation, which indicated a high precipitation occurrence and a predominant forest cover, which enhanced the groundwater recharge.

On the other hand, the central part is mostly dominated by built-up area and agriculture, which is known to have a lower capability to be infiltrated by the water. In addition to that, the silty loam is spreading in the area with little occurrence of sandy clay loam, which represents low permeability. Furthermore, the central areas have lower elevation and receive lower precipitation. Hence, groundwater recharge in these parts ranged from 15 to 240 mm, which was lower compared to the western and southern parts.

To conclude, groundwater recharge of the study area was mostly determined by land cover and precipitation events, as well as soil types. The changes in land use during ten years resulted in a reduction of the groundwater recharge. The decrease of mixed forest together with the significant increase of urban area from 2009 to 2018 was the major reasons for reduction in groundwater recharge.

5.6 Water Balance Components

The water balance components of the study area for both years (2009 and 2018) were estimated using the WetSpass-M model. The results of this model consist of digital map of the spatial distribution of monthly and annually average values of the water balance components (actual evapotranspiration, surface runoff, and groundwater recharge) of 2009 and 2018. These maps are in raster format in which every pixel indicates the magnitude of the water balance components, expressed as layer thickness (in mm).

The overall water balance analysis of Aceh Besar showed that groundwater recharge only accounted for a small fraction of the precipitation. Meanwhile, the rest of the precipitation water loss was mainly through evapotranspiration and surface runoff. According to Kahsay et al. (2018), a high standard deviation, revealed in water balance components, indicates a high spatial variation of the water balance components within the study area. This is particularly in response to the uneven distribution of the climatic parameters related to variation of land use, soil types, topography and slope.

VI. CONCLUSION

6.1 Research Findings and Outcomes

This study sought to answer two initial questions related to the impacts of land use change on the water balance in Aceh Besar and the use of global climatological data sets to overcome limitations of regional data availability. The impacts of land use change on the water balance have been identified, however the suitability of global data sets on the study area cannot properly be judged due to lack of discharge data.

The research findings have confirmed significant land use change from 2009 to 2018 in Aceh Besar with a major decrease in mixed forest and major increase in built-up area and agriculture. Mixed forests comprised of primary forest, primary dry land forest and secondary forest, have reduced for a total of 6.8 km^2, 1.1 km^2 and 3.4 km^2, respectively. The reduction in size of those land use types is closely related to a major increase of built-up area and agricultural land (dry land agriculture and paddy field) by 8.3 km^2 and 4 km^2, respectively. The alteration of land use changes have mainly been driven by increased population, which is requiring more land for infrastructural development and agricultural intensification due to high demand for food production. Hence, the change in land use has positively benefited the community as it has provided additional habitable space for people and supported the production of food, feed and fibre production.

On the other hand, the change of land use in the study area within the ten-year period have negatively influenced the hydrological systems of the area, where it decreased the evapotranspiration and groundwater recharge by 23 million m^3 and 59 million m^3, respectively. The reduction of evapotranspiration closely links to an increment of surface runoff for a total of 36 million m^3. This alteration is mainly caused by forest conversion to agriculture, logging activities and built-up area. The conversion of land use from vegetation-covered land to non-vegetation covered land has hampered the groundwater absorption system by reducing the soil ability to be infiltrated by the water as groundwater storage. Thus, the precipitation water, which is unable to be absorbed by the soil, becomes surface runoff, flowing to the river and being discharged to the sea.

The conclusion of the study is that land use change in Aceh Besar has resulted in positive and negative outcomes for the community and the environment. From the society's standpoint, land use provides spaces for residential area, infrastructure, and other public facilities. In addition to that, land use change also facilitates conditions for increasing food, feed and fibre production to meet human needs. However, from the hydrological systems point of view, land use changes have negatively influenced the water balance components by reducing groundwater recharge and increasing surface runoff. Escalation of surface runoff means an increasing amount of water flowing to the river and being discharged to the sea. Consequently, reduction in groundwater recharge means reduction in the groundwater supply for human use at a time when the requirements of a growing population may cause water to become an ever more scarce resource. These changes would also have an impact of soil degradation through erosion, as well as increasing the tendency of flood during the rainy season and drought during the dry season. Overall, the effects of land use change on the water balance in Aceh Besar are a reduction in evapotranspiration and groundwater recharge together with increasing amount of surface runoff, and these factors are likely to have serious impacts on the area in the future.

Finally, it is clear from the research that groundwater resources are crucial to the survival of human populations and the welfare of the earth's hydrological and ecological systems. Hence, it is essential to maintain the sustainability of groundwater recharge to preserve the balance of environmental, economical and social aspects of the community. Implications of this study for Aceh Besar point to the balanced relationship between changes in land use for humans and changes in land use for the environment, which must be maintained in order to continue to support human life and environmental sustainability. Reconciling the multiple dimensions of land use change is not a simple task. However, we as a society must have a strategy to manage responsible land use change and to preserve our vital water resources for future generations.

6.2 Study limitations

One of the aims was the use of global data sets to overcome local and regional data limitations. Hence, the major limitation of this study is the lack of local data, which are unavailable to be presented as input due to several reasons, including the scarcity of reliable recordings and problems of untraceable data. These data limitations were resolved by the use of global data sets. Accordingly, global data sets enabled the study about the impact of land use change on water balance of Aceh Besar to be accomplished.

In addition to that, the limitation of this study is the inability to compare the model properly because of the untraceable measured discharge data of 2009. Thus, the measured discharge used was from 2018, which is only available for eleven months (missing discharge data for December). The measured discharge data used was not in line with the simulated discharge that came from the climatological data of 2009. Accordingly, the suitability of the model and the input data of this study cannot be verified.

6.3 Recommendation for future study

To obtain a more precise and accurate result of the impact of land use change on the water balance of Aceh Besar, a more complete measured data set of the study area is required. In terms of understanding the land use change between 2009 and 2018, this study can provide a useful baseline and guideline for future studies related to the impact of land use change on Aceh Besar.

APPENDICES

Appendix 1. : Land use type and parameter values

Code	LUSE_TYPE	RUNOFF_VE	VEG_AREA	BARE_ARE	IMP_AREA	OPENW_AR	ROOT_DEPT	LAI	MIN_STOM	VEG_HEIGH	nManing	LandFactor	AerodynResistance
1	city center build up	grass	0.2	0	0.8	0	0.3	2	100	0.12	0.03	0.667	212.0135336
2	build up	grass	0.5	0	0.5	0	0.3	2	100	0.12	0.04	0.5	212.0135336
3	industry	grass	0.4	0	0.6	0	0.3	2	100	0.12	0.035	0.571	212.0135336
4	infrastructure	grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.04	0.5	212.0135336
5	sea harbour	grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.045	0.444	212.0135336
6	airport	grass	0.2	0	0.8	0	0.3	2	100	0.12	0.03	0.667	212.0135336
7	excavation	bare soil	0	1	0	0	0.05	0	110	0.001	0.09	0.222	426.6675763
10	open build up	grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.045	0.444	212.0135336
21	agriculture	crop	0.8	0.2	0	0	0.4	4	180	0.6	0.037	0.541	115.0131136
23	meadow	grass	1	0	0	0	0.3	2	100	0.2	0.07	0.286	177.4676321
27	maize and tuberous p	crop	0.8	0.2	0	0	0.3	4	180	1.5	0.05	0.4	76.02445568
28	wet meadow	grass	1	0	0	0	0.3	2	100	0.3	0.055	0.364	152.4954008
29	orchard	forest	0.8	0.2	0	0	0.8	6	150	3	0.05	0.4	54.69944736
31	deciduous forest	forest	1	0	0	0	2	5	250	18	0.1	0.2	27.19617047
32	coniferous forest	forest	1	0	0	0	2	6	500	15	0.1	0.2	28.63060022
33	mixed forest	forest	1	0	0	0	2	5	375	16	0.1	0.2	28.09756947
35	heather	grass	1	0	0	0	0.2	6	110	0.75	0.05	0.4	104.3903884
36	shrub	grass	1	0	0	0	0.6	6	110	2	0.05	0.4	66.32866791
37	beach/dune	bare soil	0.3	0.7	0	0	0.5	2	110	1	0.04	0.5	91.76072902
44	mud flat/salt marsh	open water	0.4	0.2	0	0.4	0.3	2	110	0.5	0.035	0.571	124.2208894
51	navigable river	open water	0	0	0	1	0.05	0	110	0.001	0.02	1	426.6675763
52	lake	open water	0	0	0	1	0.05	0	110	0.001	0.02	1	426.6675763
53	estuary	open water	0	0	0	1	0.05	0	110	0.001	0.02	1	426.6675763
54	sea	open water	0	0	0	1	0.05	0	110	0.001	0.02	1	426.6675763
55	unnavigable river	open water	0	0	0	1	0.05	0	110	0.001	0.02	1	426.6675763
201	highway	grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.025	0.8	212.0135336
202	district road	grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.04	0.5	212.0135336
301	spruce	forest	1	0	0	0	2	12	320	13	0.4	0.05	29.91872197
302	pine	forest	1	0	0	0	2	6	550	15	0.4	0.05	28.63060022
303	beech	forest	1	0	0	0	2	6	320	20	0.4	0.05	26.4629516
304	birch	forest	1	0	0	0	2	5	320	16	0.4	0.05	28.09756947
305	oak	forest	1	0	0	0	2	4	150	17	0.4	0.05	27.62241558
306	poplar	forest	1	0	0	0	2	5	250	18	0.4	0.05	27.19617047
307	reference grass	grass	1	0	0	0	0.3	2	140	0.12	0.035	0.571	212.0135336

Appendix 2. Soil types and parameter values

Code	SOIL	IELDCAPAC	VILTINGPNT	PAW	ESIDUALW	A1	EVAPODEPTH	TENSIONHHT	P_FRAC_SUM	P_FRAC_WIN	Teta
1	Sand	0.12	0.05	0.07	0.02	0.51	0.05	0.07	0.09	0.01	0.136
2	loamy sar	0.15	0.07	0.08	0.035	0.47	0.05	0.09	0.09	0.01	0.176
3	sandy loa	0.21	0.09	0.12	0.041	0.44	0.05	0.15	0.09	0.01	0.266
4	silty loam	0.29	0.1	0.19	0.015	0.4	0.05	0.21	0.26	0.07	0.408
5	loam	0.25	0.12	0.13	0.027	0.37	0.05	0.11	0.15	0.02	0.333
6	silt	0.3	0.1	0.2	0.04	0.35	0.05	0.61	0.09	0.01	0.429
7	sandy cla	0.26	0.16	0.1	0.068	0.32	0.05	0.28	0.54	0.3	0.351
8	silty clayl	0.36	0.19	0.17	0.04	0.29	0.05	0.33	0.62	0.41	0.563
9	clayloam	0.33	0.19	0.14	0.075	0.27	0.05	0.26	0.62	0.41	0.493
10	sandy cla	0.32	0.23	0.09	0.109	0.25	0.05	0.29	0.8	0.68	0.471
11	silty clay	0.43	0.27	0.16	0.056	0.23	0.05	0.34	0.84	0.75	0.754
12	clay	0.46	0.33	0.13	0.09	0.21	0.05	0.37	0.95	0.85	0.852

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