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Water footprint analysis in Krueng Aceh Watershed Aceh Province, Indonesia

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Abstract – Water is one the most important natural resources to maintain human life and all other living things in the earth. Around 65% water was consumed for drinking purpose, while others were used for daily needs. The increasing amount of work on water use and scarcity in relation to consumption and trade has led to the emergence of the field of Water Footprint (WF). Climate change, rural development, world population growth and industrialization have placed considerable stress on the local availability of water resources. Thus, it is necessary to perform the study in order to analyze water demands and supply for sustainable water availability. Recently, water footprint analysis has been widely drawing attention to the scientists and engineers. The water footprint analysis is closely related to virtual water from which it is defined as total water volume used for consumption and trade. The main aim of this present study is to analyze and assess the total water requirement based on community water footprint in Krueng Aceh watershed area. The virtual water used in this study are dominant consumption food commodities. The result shows that water footprint per capita in Krueng Aceh watershed area was 674.52 m3/year. Water footprint for the rural and urban population was 608.27 m3/year and 740.77 m3/year respectively. The WF of food consumption in the urban area of Krueng Aceh watershed is 690.74 m3/capita/year and 584.22 m3/capita/year or average 625.69 m3/capita/year, while for non-food, the WF per capita is 24.05 m3/year in rural or 32.46% of the total water footprint. Non-food consumption per capita in Krueng Aceh and in urban areas is 50.03 m3/year or 67.53%. The total water demand based on the water footprint is 378,906,655.05 m3 in 2015 which is consumed by most of the residents in the Krueng Aceh watershed area. Furthermore, total WF in the rural and urban area is 193,489,128.95 m3 and 185,417,526.10 m3 respectively.

Keywords: water footprint, virtual water, water use, Krueng Aceh watershed.

Introduction

Water is one of the most important natural resources to maintain human race. Water must be managed very well to maintain its availability, otherwise, it will scarce. Most people generally never realize and calculate the amount of water needed to meet their daily consumption needs. Current water needs should be prioritized for the continuity of water quantity and availability within the watershed area.

The Krueng Aceh watershed in Aceh Besar and Banda Aceh flows through the tributaries to the main river of Krueng Aceh in the district of Aceh Besar and downstream in Banda Aceh City. The need of water for the people of Banda Aceh, the central city of Aceh Province, is highly dependent on the availability of water in the Krueng Aceh watershed. Water availability in the Krueng Aceh watershed is very close to the geographic and climatic factors of the region.

Broadly speaking, water needs can be distinguished into primary, secondary, and tertiary needs, by giving priority scale to various water uses according to its urgency (Pawitan, 2015). The amount of water used to produce commodities, goods or services consumed by individuals, sectors or countries called water footprint concepts (Chapagain and Hoekstra 2004a). Water footprint calculation is very closely related to virtual water. It is defined as a total water volume used to produce commodities, goods or services. This virtual water was first introduced by Tony Allan in the early 1990s. The virtual water used in this research is the dominant food commodity type consumed by the population of Krueng Aceh watershed area, as for non-food goods and services from the average of water withdrawal per unit of added value or virtual water contained in non-food products.

From the water footprint analysis, it will achieve and obtain water needs for the respective population of the watershed area, either per capita per year or cubic meters per year with the number of rural (Aceh Besar) in the Krueng Aceh watershed area of 318,098 and the city (Banda Aceh) 250,303 people (BPS, 2016). The low water footprint in the Krueng Aceh watershed will be influenced by the daily consumption patterns of the population. From water users point of view, the water resources ultimately related to consumption patterns is a major factor in water management (Bulsink *et al.*, 2010).

Water footprint consumption of a watershed which states the amount of water needed to produce the various products that are consumed by the entire population within the watershed within a year is determined by the population and consumption pattern (Pawitan, 2015). As mentioned above, a research is obviously needed to find out the state of total water needs based on community water footprint in the Krueng Aceh watershed area. Therefore, the main objective of this study is to calculate and analyze water footprint in Krueng Aceh watershed area and define a minimum water needed to produce consumer products, goods, and services.

Materials and Methods

Main study area

This research was conducted from January to December 2016 in Krueng Aceh watershed area, Aceh Province. Geographically, research site is located between 5°03 '41 "- 5°38' 10" North Latitude (LU) and 95°11 '41 "- 95°49'46" East Longitude (BT) with a total area of 174,785.79 ha. The location of this study is presented in Figure 1.

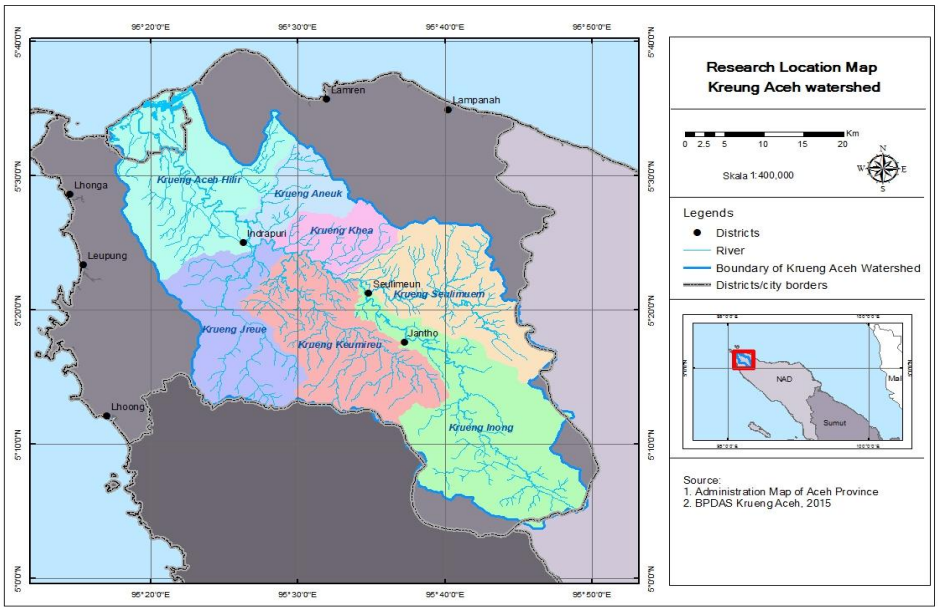


Figure 1. Research location map of Krueng Aceh Watershed

Materials and equipment support

The material used in this study was the administrative map of Aceh Province scale 1: 100 000, Krueng Aceh Watershed Map scale 1: 250,000, A 3 arc second of Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM), downloaded from CGIAR-CSI GeoPortal (http://srtm.csi.cgiar.org). National economic survey data from statistics bureau, population census data and population growth rate Kota Banda Aceh and Kabupaten Aceh Besar (BPS, 2016). Also, virtual data of plant, animal, animal products and industrial (non-food) products derived from plants, animals and industrial production (Mekonnen and Hoekstra, 2010a and 2010b) and (Hoekstra and Chapagain, 2007). While the content of the industrial water content of non-food products was taken from the average of global water-a-unit withdrawal in Indonesia from 1997 to 2001 (Chapagain and Hoekstra, 2004a and 2004b). Furthermore, equipment and other supports used in this present study are a set of personal computer, stationery, Microsoft Office 2010 and Microsoft Excel 2010 software.

Virtual water data of plant, animal, animal products and industrial (non-food) products derived from plants, animals and industrial production (Mekonnen and Hoekstra 2010a, 2010b) and (Hoekstra and Chapagain, 2007). While the content of virtual water content of industrial or non-food products is taken from the average withdrawal of water per unit of added value globally in Indonesia from 1997 to 2001 (Chapagain and Hoekstra, 2004a and 2004b). Population data and socioeconomic condition data of community of Krueng Aceh watershed.

Data analysis

Water requirement analysis based on Water Footprint is a concept used to track the amount of water used by a person, a community and a particular business or it can be defined also as the total volume of water used to produce commodities, goods or services consumed by an individual, business sector or Country (Chapagain and Hoekstra, 2004a). Water footprint in Krueng Aceh watershed can be estimated by multiplication of all services and goods multiplied by virtual water which is the total water volume used to produce the commodities or services of each consumed.

The water footprint is generally expressed in m^3; when the agricultural product is calculated, the water footprint can also be presented as the volume of water per piece. In the case of industrial products, the water footprint can be expressed in m^3/US $ or water volume per piece (Hoekstra *et al.*, 2011).

Water footprint analysis for food consumption

The virtual water calculation for many products and foodstuffs have been analyzed throughout the country including Indonesia. Mekonnen and Hoekstra (2010a, 2010b) have also calculated the average of 10 years of virtual water (1996-2005) for the province of Aceh, in this study the average value of virtual water on the type of food is fixed for the quantity data of food consumption. The measurement of virtual water based on the water source used by the product and the foodstuff (Menkonen and Hoektra, 2010a, 2010b).

The water footprint of food consumption is obtained from the type of food that is dominantly consumed by the people in Krueng Aceh watershed area. The virtual water used for water footprint calculations in this study refers to Mekonnen and Hoekstra 2010a and 2010b studies using the method used from "Water footprint of nations" (Chapagain and Hoekstra, 2004a) and the methodology used by FAO (Allen *et al.*, 1998). Data analysis starts from the calculation of evapotranspiration, precipitation, infiltration, irrigation to wastewater, whereas for food derived from animals begins to calculate the needs of drinking water for animals, cages, edible feeds and so on, to produce a food product would require liters of water. The equations of water consumption footprint analysis of food consumption used are as follows:

$$WF_{(P)cap\ (village)} = \sum_{i}^{n} KP\ (i) x\ VWP\ (i) \quad \text{.....} \quad (1)$$

$$WF_{(P)cap\ (urban)} = \sum_{i}^{n} KP\ (i) x\ VWP\ (i) \quad \text{.....} \quad (2)$$

Where, $WF_{(P)cap(rural)}$ is the water footprint for food product consumptions per capita in watershed area (m^3), $WF_{(P)cap(urban)}$ is the water footprint for food product consumptions per capita in urban area (m^3), $\sum_{i}^{n} KP$ (i) is the product consumptions (kg/year), and VWP is virtual water product (m^3/ton).

The calculation of water footprint of community per capita food consumption in the Krueng Aceh watershed is performed in the rural area and in the urban areas by projecting virtual water value contained in each foodstuff group from the estimation result based on Mekonnen and Hoekstra (2010a, 2010b). If the water footprint per capita is known then it can be accumulated based on the number of inhabitants in the watershed area, either in the city or in the rural which can be calculated by the following equation:

$$WF_{(p),village} = \sum_{i} WF_{(P)cap\ (village)} \text{ x village people in} \quad \text{.....} \quad (3)$$

$$WF_{(p),urban} = \sum_{i} WF_{(P)cap\ (urban)} \text{ x urban people in} \quad \text{.....} \quad (4)$$

$$WF_{(p)\ KA} = WF_{(p),urban} + WF_{(p),\ village} \quad \text{.....} \quad (5)$$

Where, $WF_{(p),\ village}$ and $WF_{(p),\ urban}$ are the water footprint for food product consumptions rural population and urban population in, and $WF_{(p)\ KA}$ is water footprint for food product consumption watershed Krueng Aceh population.

Water footprint analysis for non-food consumption

Water footprint analysis of non-food consumption produces by an individual, household or community in the Krueng Aceh watershed such as clothing, board, transportation, education, services and others that can be measured in Indonesian currency rupiah (IDR).

The content of virtual water of industrial or non-food products resulting from a dominant production in consumption by individuals, households or communities within the Krueng Aceh watershed is derived from the average withdrawal of water per unit of added value in Indonesia from 1997 to 2001 of 0.007 m^3/US $ or 7 liter/US $ (Chapagain and Hoekstra, 2004a and 2004b). This study was conducted with the assumption of one US dollar exchange rate equal to IDR 13 000.

Types of data on non-food consumption materials can be obtained from the survey conducted by the Bureau of Statistics (BPS 2016) which is the national socioeconomic survey data (Susenas) for the consumption expenditure of the people of Aceh Besar and Kota Banda Aceh. The equation used is as follows:

$$WF_{(NP)cap,\ village} = \sum_{i}^{n} Knp\ (i) x\ VWPnp\ (i) \quad \text{.....} \quad (6)$$

$$WF_{(Np)cap,\ urban} = \sum_{i}^{n} Knp\ (i) x\ VWPnp\ (i) \quad \text{.....} \quad (7)$$

$$WF_{(NP),\ urban} = \sum_{i} WF_{(NP)cap\ (urban)} \text{ x urban people in} \quad \text{.....} \quad (8)$$

$$WF_{(Np),\ village} = \sum_{i} WF_{(NP)cap\ (village)} \text{ x village people in} \quad \text{..... (9)}$$

$$WF_{(Np)\ KA} = WF_{(Np),\ urban} + WF_{(Np),\ village} \quad \text{..... (10)}$$

Where, $WF_{(NP)cap,\ village}$ is the water footprint for non-product consumption per capita in rural area (m^3), $WF_{(Np)cap,\ urban}$ is the water footprint for non-product consumption per capita in urban area (m^3), $\sum_{i}^{n} Knp\ (i)$ is the non-food product consumptions per capita (IDR/year), $VWPnp\ (i)$ is the average water expenses per added value or virtual water for non-food product, $WF_{(Np),\ village}$ and $WF_{(Np),\ urban}$ are the water footprint for non-food product consumptions rural population and urban population in, and $WF_{(Np)\ KA}$ is water footprint for non-food product consumption watershed Krueng Aceh population.

Total water requirement analysis based on water footprint

The water requirement expressed in water footprint is obtained from the total water requirement for food and non-food based on the water footprint obtained from the type of food and non-food dominantly consumed by the community in Krueng Aceh watershed area. The equation is as follow:

$$WF_{\ KA} = WF_{(P)\ KA} + WF_{(NP)\ KA} \quad \text{..... (11)}$$

Where, $WF_{\ KA}$ is the total water requirements based on water footprint (m^3) watershed Krueng Aceh, $WF_{(P)\ KA}$ is the water footprint for food product consumption (m^3), and $WF_{(NP)\ KA}$ is the water footprint for non-food product consumption (m^3).

Results and Discussion

Consumption types and patterns

Typical consumption patterns for food and non-food consumption is one socioeconomic indicator that is strongly influenced by local culture and environment. People living in the coastal areas and near the sea will have different consumption patterns, more mountainous areas consume vegetables, whereas people living on the coast generally consume fish or seafood. The expenditure of food and non-food consumption in the community of Krueng Aceh watershed with daily consumption patterns will illustrate the level of people's prosperity, that the higher the proportion of food and non-food expenditure, the lower the welfare. This requires a balance of both food and non-food consumption patterns.

Average vegetable commodities other than rice in rural communities become dominant when compared to urban communities, approximately 74.34 kg/capita/year. This because most of the rural population work as farmers who make it easier to get vegetable food. The condition of the Krueng Aceh watershed as a rice-producing region directly causes the people of Krueng Aceh watershed to make rice as staple food, so that rice consumption becomes higher when compared with other vegetable foods. On urban area, food consumption reached 66.1 kg/capita/year (Figure 2).

Consumption of the population of the Krueng Aceh watershed of animal-based foods has the highest proportion of chicken or chicken commodities approximately 9.48 kg/capita/year in the city. The low consumption of beef/buffalo about 0.67 kg/capita/year in the city and in the rural about 0.36 kg/capita/year. The decrease of beef/buffalo consumption by the population in Krueng Aceh watershed resulted in the high price of meat, so people prefer chicken eggs/eggs

because they have another source of animal protein that cheaper, people can buy eggs also obtained from the maintenance The chicken can be shown in Figure 3a. Where the Chickens/Chickens range from 3.67 kg/capita/year in the rural and 6.45 kg/capita/year in the city, the value of this commodity is below the number of egg commodities

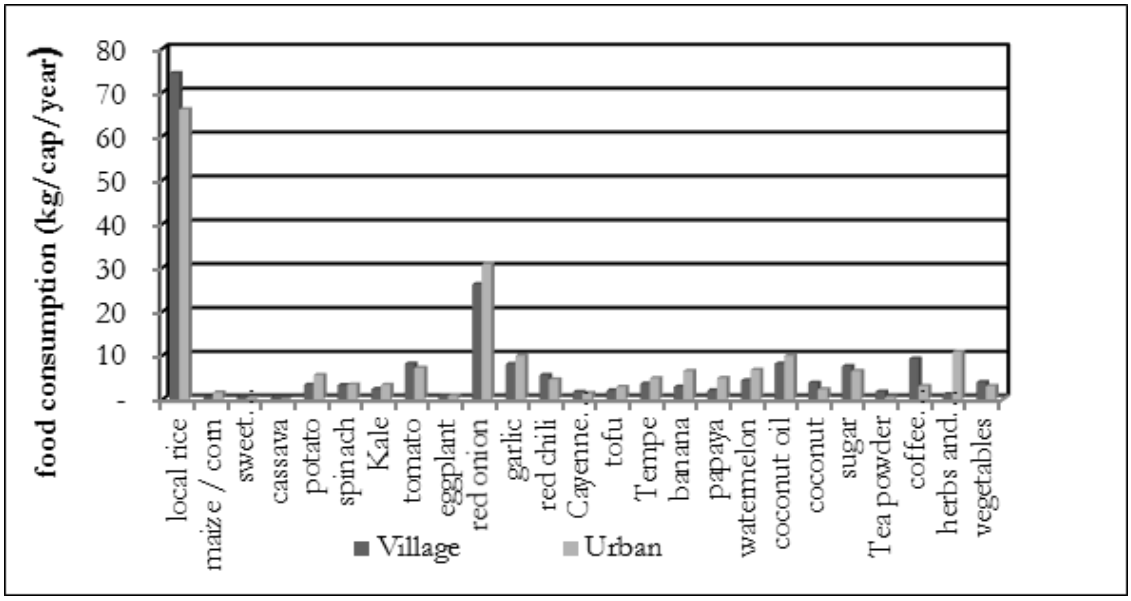


Figure 2. Animal-based food consumption pattern of Krueng Aceh Watershed populations on some dominant food types (kg/capita/year).

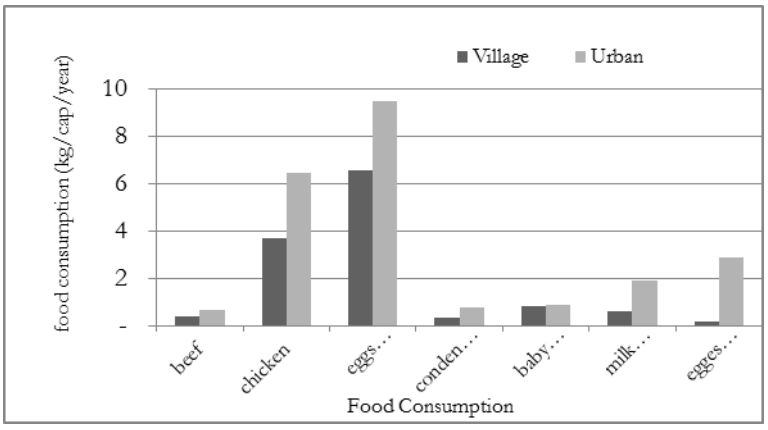


Figure 3. Animal-based Food Consumption Pattern of Krueng Aceh Watershed populations on some dominant food types (kg/capita/year)

Food water requirement based on water footprint

Water Footprint (WF) for food consumption calculated based on food consumption of Krueng Aceh Watershed community, in the month per capita which has been converted for one year that is in 2015. Water Footprint calculation of food consumption per capita done by accumulating food commodity as 32 commodities that is 25 kinds of vegetable food and seven types of animal foods, each type of food according to city and rural is calculated based on water content consisting of green, blue, and gray water footprint.

A blue water footprint is a freshwater volume derived from rainwater and soil moisture available for plants. Bluewater footprint is a volume of fresh water that comes from irrigation water from surface water and groundwater. Gray water footprint is the volume of polluted water as waste related to water quality (Flanchman *et al.*, 2012).

The people of Krueng Aceh watershed consumed more vegetable commodities than animal commodities. Consumption of these two commodities in urban communities is higher than rural communities. The water footprint of urban and rural vegetable consumption per capita was 560.07 m^3 / year and 513.12 m^3 / year respectively, while the water footprint of urban and rural animal consumption per capita was 130.67 m^3 / year and 71.09 m^3 / year respectively. People of Krueng Aceh watershed urban and rural areas need water for food consumption based on water footprint amount 690.74 m^3 / year/capita and 584.22 m^3 / year/capita (Figure 4a)

The water footprint of vegetable consumption derived from vegetables in rural and urban communities in the Krueng Aceh watershed scheme found greater in urban food consumption in comparison with rural one. It is approximately 163,223,533.79 m^3 and 140,186,928.73 m^3 with a total of 358,732,956 m^3 as shown in Table 1 and figure 4b. The largest contributor to water requirement based on Water footprint for food consumption is found in the animal group of 52.40% and 40.32% of rice commodities in rural areas.

Table 1. Water footprint of food consumption in the Krueng Aceh watershed

Krueng Aceh watershed	Rural	Urban/city
Number of inhabitants (persons)	318,098.00	250,303.00
WF for vegetable-based food (m^3)	163,223,533.79	140,186,928.73
WF for animal-based food (m^3)	22,614,972.09	32,707,521.44
Total WF food consumption (m^3)	185,838,505.88	172,894,450.18
Average in m^3/per capita/days	1.601	1.892

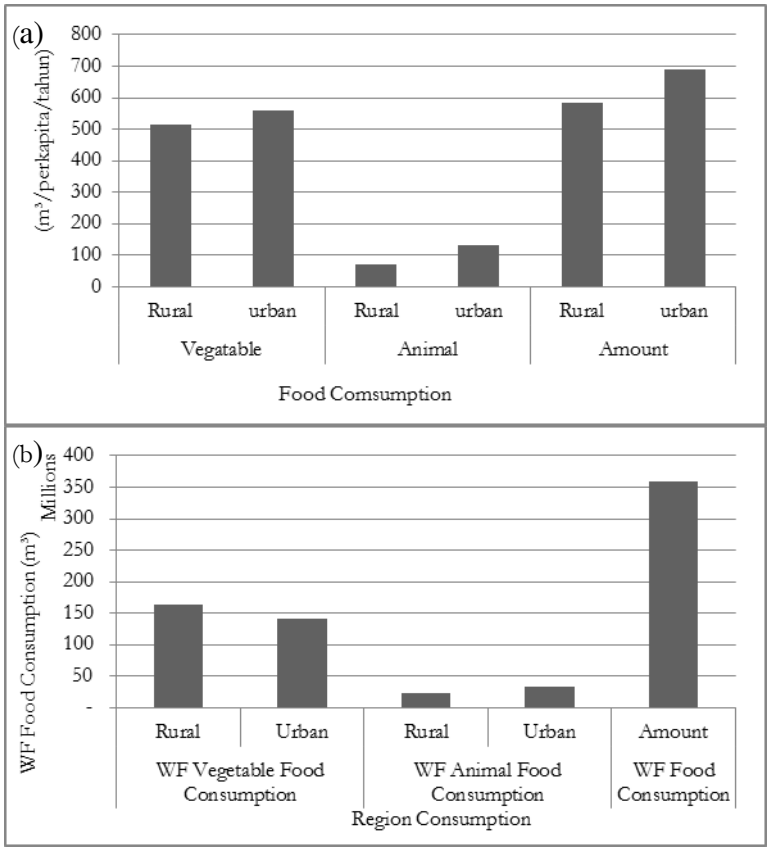


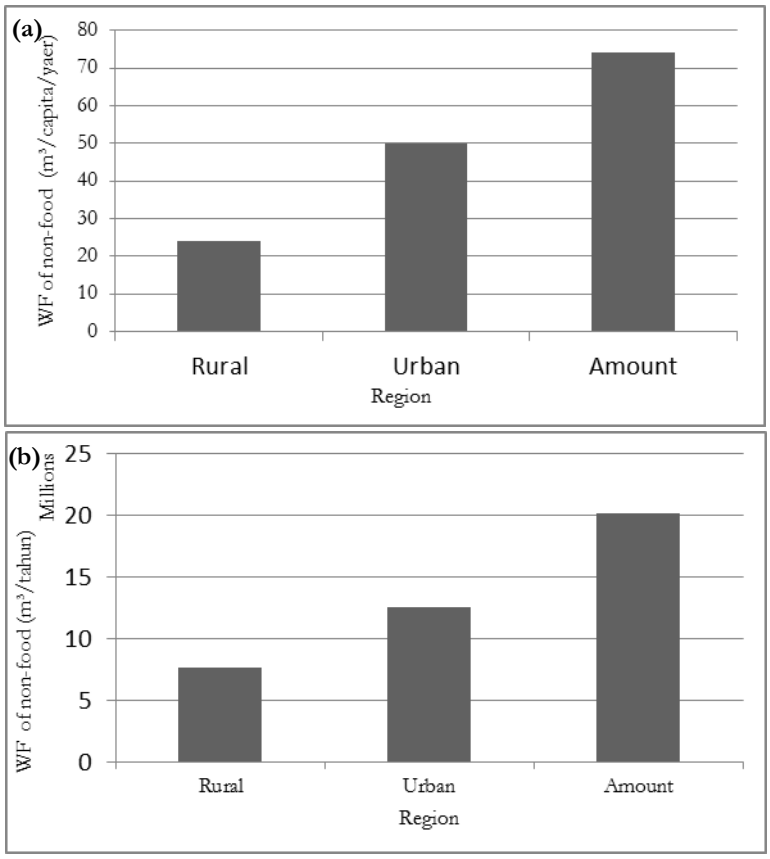
Figure 4. (a) Water footprint for food consumption in rural and urban area in 2015, (b) Water footprint for food consumption in Krueng Aceh Watershed area

The high demand for food consumption water in a year based on water footprint in Krueng Aceh watershed in rural compared with urban that is equal to 185,838,505.88 m^3/year and 172,894,450.18 m^3. This is indicated by the variation in the consumption of basic food based on local potency (Suyastiri, 2008). Foods that breed for life to be used will require water because all living things on this earth that survive as species we need to consume water. Water is the necessary biological and non-substituted resources that make life on this earth (Jackson *et al.*, 2016).

Non-food water requirement based on water footprint

Non-food consumption needs in urban areas are 62.08% higher than in rural areas. Non-food consumption expenditure in urban per capita is IDR 11,574,250/year with an average per capita per day of IDR 31,710 and IDR 3,990,863/capita/year. The non-food consumption expenditure per capita of urban areas in the Krueng Aceh watershed is very striking with rural spending. This is because in general urban communities spend most of their expenditure on non-food expenditures, but rural spend more on food consumption as a primary necessity, thus reducing the welfare of the rural population. The high income of the population will affect the pattern of life so that the water needs in the watershed fluctuates.

Water Footprint for non-food consumption per capita in Krueng Aceh watershed is 2.15 m^3/year in rural or 14.71% of total Water Footprint Non-food consumption per capita in Krueng Aceh watershed and urban 12.46 m^3/year or 85.29% as shown in Figure 5a and 5b. It can be seen that urban non-food per capita demand is higher in urban areas than in rural areas, indicating that urban communities in fulfilling day-to-day needs are more consumptive. Banda Aceh's household consumption is dominated by non-food consumption, a sign of a region that has become a real city (Bappeda, 2014).



Gambar 5 (a) Non-food consumption per capita in Krueng Aceh watershed, (b) Non-food water footprint in Krueng Aceh watershed.

Total water requirement based on water footprint

The total water needs in Krueng Aceh watershed is based on the water footprint used for daily activities, both in the form of food and non-food consumption. Water footprint in rural per capita of 608.27 m^3/year or 1.63 m^3/day and 740.77 m^3/year or 2.03 m^3/day in urban areas as shown in Figure 6. This is caused by people in urban areas tend to spend more for the consumption of animal materials, so that the amount of consumption also increases. The rapid growth of the concept of sustainable water consumption in urbanization can reduce water footprint (Arfanuzzaman and Rahman, 2017).

It shows that the food consumption water footprint of 358,733,507.78 m^3/year or 94.68% and non-food consumption water footprint of 20,173,147.27 m^3 or 5.32% of the total water needs of the community Krueng Aceh watershed of 378 906 655.5 m^3 based on water footprint (Figure 7). According Muis *et al.* (2016), total water demand analysis based on SNI 19-6728-6728. The Krueng Aceh watershed in 2014 requires a total water of 47 902 399 m^3 / year (Muis *et al.*, 2016).

The high demand for food water consumed by the population of the Krueng Aceh watershed compared with non-food water needs is very significant, this is due to the high consumption of food that requires a lot of water. The pattern of population consumption will affect water demand in the watershed. A water footprint can be reduced in daily life, by reducing the consumption of many water-based materials to a slightly aquatic material. Based on the results of this study, the water footprint is determined by the volume of consumed ingredients, consumption patterns, climatic conditions and agricultural practices used (Hoekstra and Chapagain, 2007), whereas to achieve sustainable, efficient and equitable water use, product openness, cooperation, Highest water footprint per watershed and water footprint benchmarks for intensive water commodities (Hoekstra, 2017). However, to achieve sustainable water resources management of the research results, it will greatly assist the water authorities in planning an effective water demand management strategy and developing a model for forecasting water requirements with appropriate climate factors (Haque *et al.*, 2015).

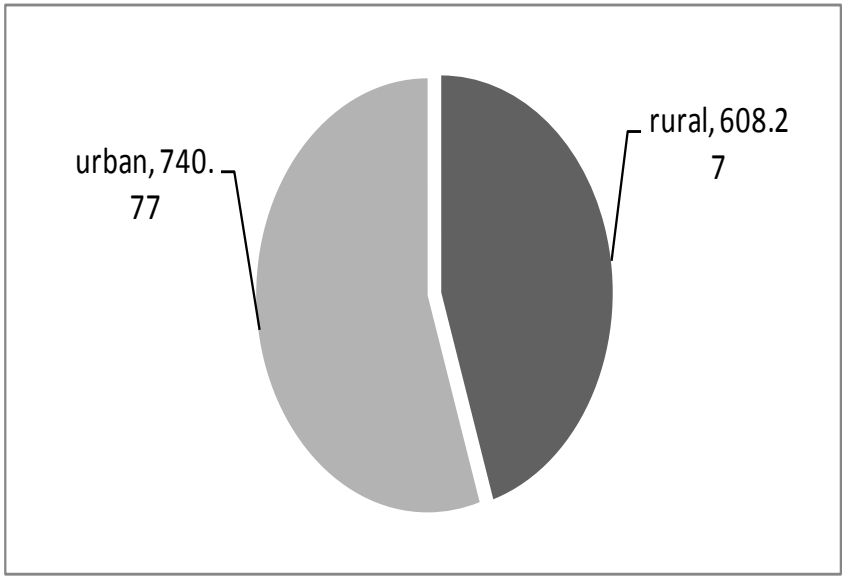


Figure 6. Water Footprint consumption per capita in Krueng Aceh watershed area (m^3) in 2015

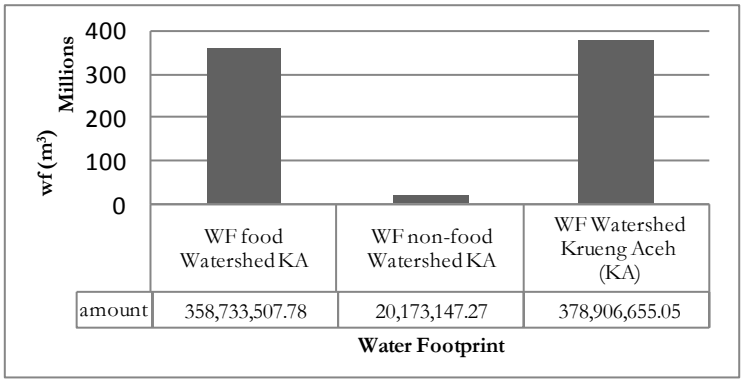


Figure 7. Water footprint in Krueng Aceh watershed

Water demand projection from water footprint consumption in krueng aceh watershed area

The Krueng Aceh watershed in 2005 has a population of 433,234 people, 255,353 inhabitants and 177,881 inhabitants of the city. In 2015 this amounted to 56,840 inhabitants are 318,098 the number of rural and 250 303 inhabitants of the city. The main factor determining the population's water needs is to know the number and growth of the population. For that reason, an analysis is needed to estimate the population in the next few years (Zulkipli *et al*., 2012). The calculation of population growth using geometry method (Tipka, 2011). The rate of population growth from 2003 to 2015 is 2.15% per year in rural and 3.18% per year in urban areas.

The amount of water consumed in the community settlements is as diverse as demand, none of the population has water satisfaction (Aper and aqbehi, 2011). The projected water needs of Krueng Aceh watershed from the water footprint each year increases with population growth as shown in Figure 11. In 2030 the water footprint becomes 562,388,205.65 m^3/year. The projection of population changes to provide a plausible scenario illustrates future water requirements (Pickard *et al.,* 2017).

Conclusions

Based on the analysis and discussion of water footprint in Krueng Aceh watershed area, it can be concluded that water footprint per capita of the population of the Krueng Aceh watershed is an average of 608.27 m^3/year. WF for the urban population is 740.77 m^3/capita/year, while WF for food and non-food consumption in the urban area is 690.74 m^3/capita/year and 584.22 m^3/capita/year respectively. Thus, every people in rural and urban watershed Krueng Aceh watershed required water for daily food and non-food consumption are 1.63 m^3 and 2.03 m^3 respectively.

Total water demand based on the water footprint concept of 378,906,655.05 m^3 which is consumed by residents in Krueng Aceh watershed area. Moreover, total water footprint in the rural area is 193,489,128.95 m^3 while for the urban area, total WF is 185,417,526.10 m^3. The projected water needs of Krueng Aceh watershed from the water footprint in each year is increases with population growth. In 2030 the water footprint is projected to become 562,388,205.65 m^3.

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