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Impact of Land Use Change on Hydrological Response of Krueng Aceh Watershed in Aceh Province, Indonesia

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ABSTRACT

Population growth and improvement in the people's economy have caused the need for space to grow and have changed land use in the Krueng Aceh watershed. This study on the effect of changes in land use on the Krueng Aceh watershed hydrological response as a step to anticipate water shortage in the future using the geographical information analysis and the river regime coefficient (RRC) method approach. The results of this study revealed that the functional shifts from primary forests to production forests and from brushland to ricefield and settlements increased the RRC value from 14.59 to 56.74 in the last 20 years. The hydrological response showed that 18% of the water had the potential to not infiltrate and become runoff. The effect is a reduction in groundwater supply, flooding in the rainy season, drought in the dry season, and clean water scarcity in the future. The management of the future must be based on one river, one planning, and one management system principle.

INTRODUCTION

The land use changes in developing countries happen rapidly, from land covered by vegetation to developed land (Erkossa et al. 2015) and this has a global impact on the environment (Turner et al. 2007, Lambin et al. 2011). This phenomenon is caused by the rapid population growth and the increased development of the people's economy (Sherbinin et al. 2007). The need for space for agricultural land (Brandt & Philip 2006) and infrastructure development (Pereira et al. 2015) continues to increase. Uncontrolled land functional shifts which do not heed soil and water conservation principles have led to decreased water catchment areas, critical soil conditions (Tesfaye et al. 2014, Kieti et al. 2016), and a disrupted watershed hydrological cycle (Chen et al. 2012, Wang et al. 2014, Zhang et al. 2016), causing runoff to increase and affecting the fluctuations of the river discharge, reducing the groundwater supply (Niraula et al. 2015, Chithra et al. 2015) and causing water scarcity as in the Krueng Aceh watershed at present.

The Krueng Aceh watershed is located in Aceh Province, Indonesia. It covers an area of 197,903.62 ha (Muis et al. 2016). Krueng Aceh watershed has an important role in maintaining the water system as the supplier of water with a good quantity, quality, and continuity for the people living from upriver to downriver and could ensure the sustainability of the water resources (Muis et al. 2017). However, the condition of the Krueng Aceh watershed is currently believed to have undergone soil degradation due to deforestation, which has led to fluctuations in the river discharge ratio. Study results have revealed that the size of the primary forest has decreased. Nasrullah et al. (2010) stated that in 1994 there were 112,776 ha (57%) of primary forest, and according to Husnan et al. (2010) in 2002, it had become 94,178 ha (47.6%), and in 2005 only 79,141 ha (40%) of the primary forest remained. The results of the most recent study (LIF 2013) in 2010 identified a primary forest of 31,812 ha or 16.07% in the entire Krueng Aceh watershed. Land use changes in the Krueng Aceh watershed are believed to be probably continue to this day because observations of the Krueng Aceh river flow have shown that there is a large amount of runoff in the rainy season and drought in the dry season, indicating soil degradation. The purpose of this research was to study the effect of changes in land use on the Krueng Aceh watershed's hydrological response in order to anticipate water scarcity in the future.

MATERIALS AND METHODS

Time and Location

This study was conducted from July to December 2017 in the Krueng Aceh watershed, Aceh Province, Indonesia. The total area of this research site was 197,903.62 ha. It is geographically located at 5°10'38"-5°41'03"N and 95°46'49"-95°41'11"E (Fig. 1). The materials used for this study were a digital administrative map of Aceh Province at a scale of 1:100.000, a topographical map at a scale of 1:100.000, a Krueng Aceh watershed land use map at a scale of 1:100.000, a soil type map at a scale of 1:250.000, precipitation data from 7 precipitation observation stations (Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) Sultan Iskandar Muda Airport, BMKG Mata Ie, BMKG Indrapuri, Montasik Station, Jantho Station, Seulimum Station, Saree Station), and data of the Krueng Aceh river discharge for the period 1994-2014 from the Sumatra I Regional River Agency. The field survey equipment used was a global positioning system (GPS). For map data analysis the software ArcGIS 10.2 was used.

Spatial Analysis of Land Use

Land use changes in the Krueng Aceh watershed were analysed using a spatial analysis method by utilizing a geographical information system temporally so that it could give the most recent perspective of the land use and the changes that have occurred (Foresman 1997, Musavi 2015). The secondary data used were taken from the 1994-2014 digital land use map of the Krueng Aceh watershed from the Aceh Besar Regency, Aceh Province Regional Development Planning Agency. The land use data were analysed with the ArcGIS software. Using the overlay method through an intersect process (Tiede 2014) by overlaying the 1994 Krueng Aceh watershed land use map with the 2004 map, new spatial data were obtained. The 2004 land use map was again overlaid with the 2014 map, resulting in spatial data of the changes in land use in the Krueng Aceh watershed for the period 1994-2014.

Analysis of the River Regime Coefficient

If there is a biophysical changing activity in a watershed, it will cause a response in the river flow discharge. The river's discharge is measured using a tool called the AWLR (Automatic Water Level Recorder) at the river flow observation station in Kampung Darang, Sumatra I Regional River Agency Banda Aceh City. The discharge data are used to discover the maximum (*Qmax*) and minimum (*Qmin*) average daily discharge per year between 1994-2014, by using the month basic planning method (Limantara 2010), and the result was the river regime coefficient. The river regime coefficient (RRC) is the ratio between the maximum discharge (*Qmax*) and the minimum discharge (*Qmin*) in one period, namely the highest discharge during the rainy season and the lowest during the dry season in a certain watershed. A high discharge ratio suggests that the runoff is very high during the rainy season, and a low runoff shows drought in the dry season. The standard river regime coefficient in this study refers to the Minister of Forestry of the Republic of Indonesia's regulation Number P.61/Menhut-II/2014 pertaining to monitoring and evaluation of watersheds which is presented in Table 1.

To understand the changes in the watershed's carrying capacity in relation to the runoff quality, quantity, and continuity, it is necessary to discover the runoff coefficient. The runoff coefficient (C) is the ratio between the runoff depth (Q) and the precipitation depth (P) in one year. The C value was obtained from the discharge volume (m^3) from the measurement using an AWLR which was converted to millimetres (mm). The value of P was obtained from the results of the measurements of 7 precipitation observation stations (BMKG) using an ARR (Automatic Rainfall Recorder) and an observatory ombrometer, which was then analysed using the Thiessen polygon method (Arsyad 2010). The standard C value used referred to Minister of Forestry of the Republic of Indonesia's regulation Number P.61/Menhut-II/2014 which is presented in Table 2.

Table 1: Standard value of river regime coefficient

Indicator	Parameter	RRC Value	Classification
		< 20	Extremely low
		20 - 50	Low
Water Discharge	$RRC = \frac{Q_{max}\left(m^3/sec\right)}{Q_{min}\left(m^3/sec\right)}$	50 - 80	Moderate
		80 - 110	High
		> 110	Extremely high

Source: MFRID 2014.

Table 2: Standard value of runoff coefficient

Indicator	Parameter	C Value	Classification
		< 0.2	Extremely low
		0.2 - 0.3	Low
Direct runoff	$C = \frac{Volume\,of\;Discharge\left(mm\right)}{Rainfall\left(mm\right)}$	0.3 - 0.4	Moderate
		04 - 0.5	High
		> 0.5	Extremely high

Source: MFRID 2014.

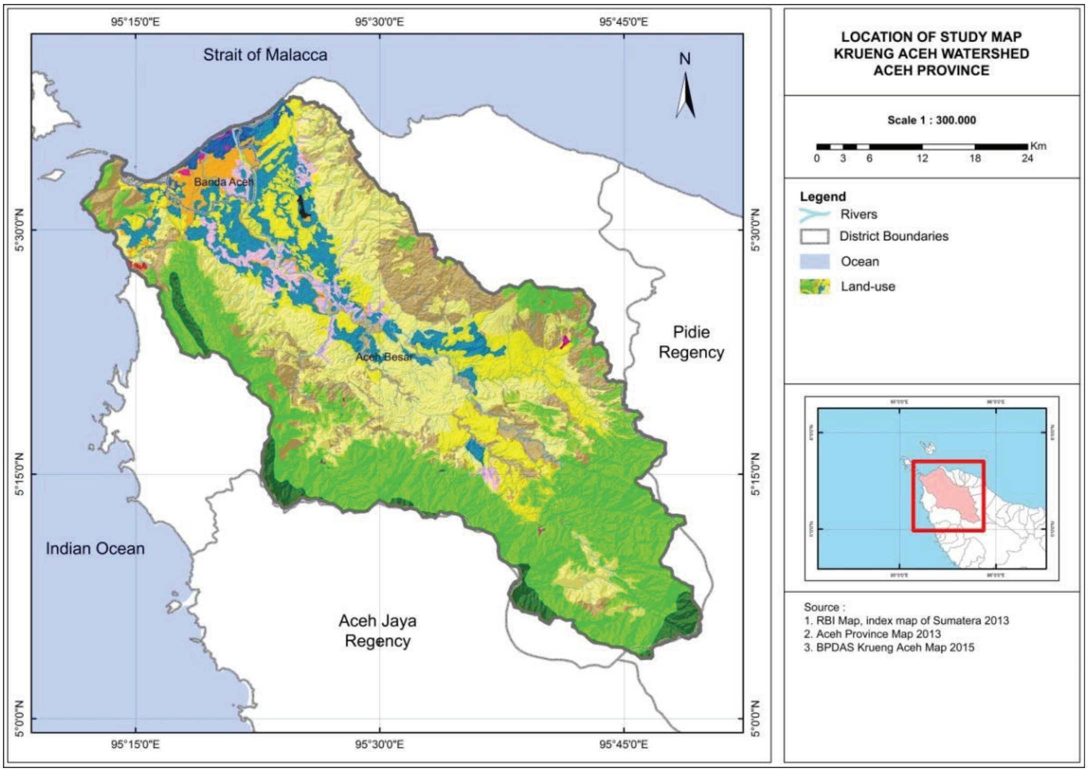


Fig. 1: Location of study in Krueng Aceh watershed, Aceh Province, Indonesia

RESULTS AND DISCUSSION

Land use Change in Krueng Aceh Watershed

There are 14 types of land use in the Krueng Aceh watershed: airport, primary forest, secondary forest, production forest, settlement, mining, dryland agriculture, mixed dryland agriculture, savannah/grassland, ricefield, brush, fish farming, bodies of water, and open land. Land use in the Krueng Aceh watershed in 1994 was dominated by secondary forests at 60,365.37 ha (30.50%), followed by savannah/grassland at 44,560.79 ha (22.52%), and rice fields at 30,421 ha (15.37%).

Land use in the Krueng Aceh watershed during the period 1994-2004 underwent a comprehensive and very dynamic change. The reduction in land size was dominated by brushland at 765.95 ha (5.18%), followed by secondary forest land at 114.21 ha (0.19%), and primary forest land 113.10 ha (1.07%). The decrease in land size was caused by functional shifts to ricefields which increased by 461.62 ha (1.49%), dryland agriculture which increased by 366.28 ha (1.54%), and production forests which increased by 73.62 ha (28.53%). The increase in the size of ricefields and dryland agriculture land was because the prices of a number of agricultural commodities rose (BPS 2005), encouraging the farmers to plant these superior commodities by utilizing the brushland and clearing secondary forest land.

Land use change in the Krueng Aceh watershed during the period 2004-2014 included growth in the size of land used for rice fields 593.38 ha (1.89%), production forests 235.75 ha (47.74%), settlements 44.94 ha (1.07%), and mixed dryland agriculture 33.04 ha (0.55%). As a result, in 2014 the remaining primary forests in the Krueng Aceh watershed only covered 9,999.50 ha (5.05%) of the total Krueng Aceh watershed area. The main cause of the reduction in the size of the primary forests was logging to fulfil the demand for timber used in the rehabilitation and reconstruction in the aftermath of the Aceh earthquake and tsunami on 26 December 2004 for the construction of temporary shelters and 75,000 units of permanent housing (BRR 2005). Land use change in the Krueng Aceh watershed in the past 20 years are presented in Table 3 and visually in Fig. 2.

The Effects of Land Use Change in the Krueng Aceh Watershed's Hydrological Response

The rainfall in the Krueng Aceh watershed area in the last

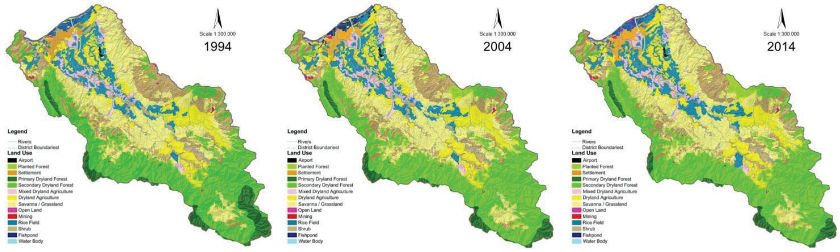


Fig. 2: Land use change in Krueng Aceh watershed during the period 1994-2014.

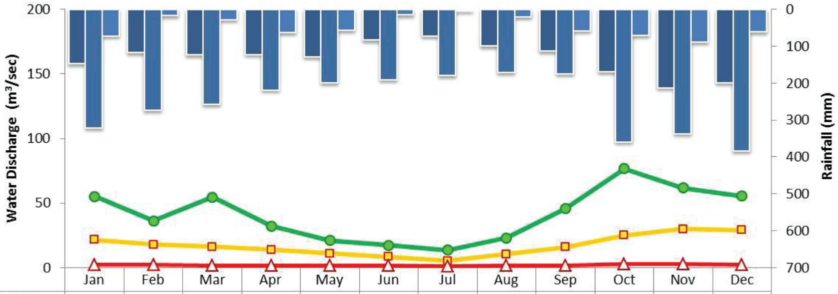
Table 3: Land use change of Krueng Aceh watershed during the period of 1994-2014.

No	Land use	Land use area			Land use changes			
		1994	2004	2014	1994-2004		2004-2014	
		(ha)	(ha)	(ha)	(ha)	(%)	(ha)	(%)
1	Airport	151.87	151.87	151.87	0.00	0.00	0.00	0.00
2	Primary dryland forest	10724.71	10611.61	9999.50	-113.10	-1.07	-612.11	-6.12
3	Secondary dryland forest	60365.37	60251.16	60193.55	-114.21	-0.19	-57.61	-0.10
4	Planted forest	184.46	258.08	493.83	73.62	28.53	235.75	47.74
5	Settlement	4107.79	4137.93	4182.87	30.14	0.73	44.94	1.07
6	Mining	90.66	107.60	90.91	16.94	15.74	-16.69	-18.36
7	Dryland agriculture	23386.75	23753.03	23524.19	366.28	1.54	-228.84	-0.97
8	Mixed dryland agriculture	5972.02	5982.50	6015.54	10.48	0.18	33.04	0.55
9	Savanna/Grassland	44560.79	44586.42	44600.09	25.63	0.06	13.67	0.03
10	Rice field	30421.00	30882.62	31476.00	461.62	1.49	593.38	1.89
11	Shrub	15563.22	14797.27	14761.00	-765.95	-5.18	-36.27	-0.25
12	Fishpond	1336.40	1342.56	1363.56	6.16	0.46	21.00	1.54
13	Water body	797.15	797.15	797.15	0.00	0.00	0.00	0.00
14	Open land	241.43	243.82	253.56	2.39	0.98	9.74	3.84
	Krueng Aceh watershed	197903.62	197903.62	197903.62	-	-	-	-

20 years was 2767.73 mm/year with an average of 131.80 mm/month. The highest rainfall was in December at 383.24 mm, and the lowest was 4.13 mm in July. Some of the rain that falls to the surface of the ground would infiltrate and the rest becomes runoff. The runoff produced by the Krueng Aceh watershed was monitored and measured using an AWLR, creating a graph for the correlation between the water surface height and time and produced discharge data. The river discharge data produced from the measurements were one of the very important hydrological data in observing the behavior of the effect of the changes in land use in the Krueng Aceh watershed.

The Krueng Aceh river discharge data for the period 1994-2014 (Fig. 3) revealed a maximum discharge (*Qmax*) of 76.60 m^3/second which occurred in October, and a minimum discharge (*Qmin*) of 1.35 m^3/second in July. The analysis results of the average annual *Qmax*for the past 20 years demonstrated a trend that increased exponentially from 32.25 m^3/second in 1994 to 45.60 m^3/second in 2004, and in 2014 the maximum discharge increased to 76.60 m^3/second. This differed from the *Qmin* distribution pattern which decreased linearly every year from 2.21 m^3/second in 1994 to 1.35 m^3/second in 2014.

The Krueng Aceh watershed is a paddy field development area and the leading sector for the people of Aceh Besar Regency's livelihood. The Aceh Besar Regency Government has planned to increase the area of rice fields by 2,500 ha in 2032. The increased ricefield area will have a direct contribution to the increase in runoff rate because there is a waterproof layer formed during mechanized soil



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall avg	147.03	116.70	123.07	121.62	127.83	83.04	71.45	99.26	112.67	168.77	212.00	198.12
Rainfall max	320.90	273.36	257.14	218.12	198.87	190.04	179.22	170.79	174.42	358.67	336.83	383.24
Rainfall min	71.79	16.96	27.27	62.66	55.96	14.63	4.13	19.67	57.64	70.19	88.22	60.51
Q avg	21.61	17.98	16.21	13.83	10.85	8.37	5.16	10.34	15.85	25.09	30.03	29.07
Q max	55.14	36.12	54.72	32.07	21.15	17.30	13.57	23.16	45.60	76.60	61.62	55.34
Q min	2.00	2.25	1.85	1.38	1.49	1.83	1.35	1.43	1.49	2.61	3.03	2.41

Fig. 3: The correlation between rainfall and water discharge of Krueng Aceh watershed in the period 1994-2014.

tilling which packs the soil. The application of a monoculture agricultural system which disregards planting according to the contour lines will also increase the runoff rate and decrease the watershed's supporting capacity, which will strongly affect the Krueng Aceh watershed's characteristics. The characteristics of a watershed can be seen from the fluctuations in its river discharge. The smaller the river regime coefficient, the better the hydrological condition of a watershed is, but if it rises from year to year, it means the condition of the watershed is compromised.

Fig. 4 shows that the Krueng Aceh river regime coefficient rose from 14.59 in 1994 to 32.79 in 2004 and rose again drastically to 56.74 in 2014. This proves that the Krueng Aceh watershed has undergone soil degradation due to a functional shift of the land from primary forest to production forests, brush to rice fields and settlements, thus causing the rain that falls to the ground to not fully infiltrate. The effect is a reduction in the availability of groundwater, water scarcity in the dry season, and unfulfilled domestic water demands.

The population growth that reached 2.12% per year and the increased growth in the people's economy have become factors that drive the increase in the need for land and have the potential to land use change in the Krueng Aceh watershed. The results of the runoff coefficient (C) analysis revealed that changes from vegetation-covered land to non-vegetation-covered land could affect the microclimate, from the evaporation process to the transpiration, condensation, and precipitation processes. Krueng Aceh watershed's hydrological response is shown by the value of C which

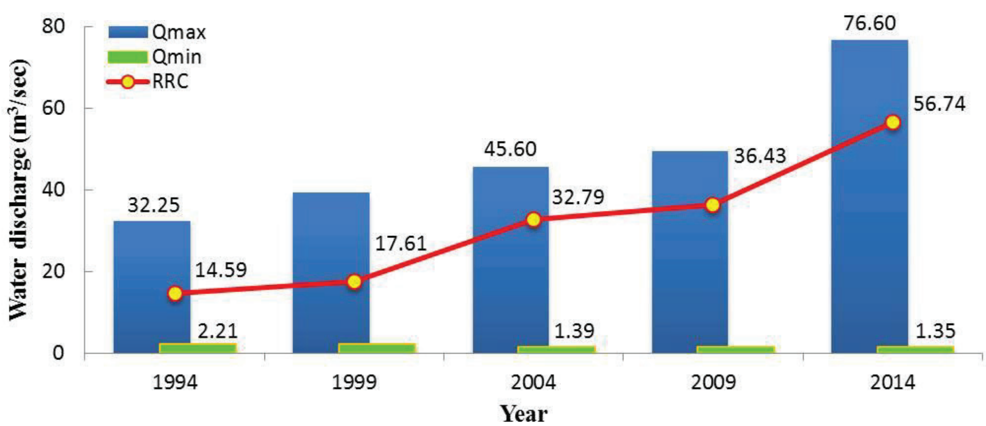


Fig. 4: Impact of land use change on hydrological response of Krueng Aceh watershed.

Table 4: Impact of land use change on runoff coefficient in Krueng Aceh watershed.

Year	Rainfall (mm/year)	Average discharge (m^3/sec)	Total discharge (m^3)	Volume of rainfall (m^3)	C
1994	1 391.45	11.51	362 962 587	2 753 737 159	0.13
2004	1 722.73	16.54	521 568 499	3 409 341 422	0.15
2014	1 957.95	22.14	698 332 423	3 874 844 319	0.18

increases linearly every year, from 0.13 in 1994 to 0.15 in 2004, and then 0.18 in 2014 (Table 4). This proves that the soil's ability to store rainwater has decreased, causing 18% of the potential water from the total precipitation in 2014 to be unable to infiltrate, becoming runoff and flowing to the river and being discarded to the sea. Field conditions revealed that there is a tendency for the Krueng Aceh watershed to become critical in the future. The effects of changes in land cover will reduce the groundwater supply, cause flooding in the rainy season, drought in the dry season, and scarcity of clean water for the people in the Krueng Aceh watershed.

CONCLUSION

Population growth and growth of the people's economy have caused changes in the land use in the Krueng Aceh watershed. Land use changes from vegetation-covered land to non-vegetation-covered land have disturbed the groundwater absorption system and affected the characteristics of the Krueng Aceh watershed. Krueng Aceh watershed's hydrological response showed that the higher the precipitation rate in the area, the higher the peak discharge is. Runoff increases in the rainy season and the groundwater supply decreases. The results of this study revealed that the Krueng Aceh watershed has undergone soil degradation and has the tendency to become critical and will lead to scarcity of clean water in the future.

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