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Water balance analysis of Talau-Loes Watershed, a cross border watershed of Indonesia and East Timor

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Abstract. *Riwu-Kaho M, Mella WII, Mau YS, Riwu-Kaho NPLB, Nur MSM. 2020. Water balance analysis of Talau-Loes Watershed, a cross border watershed of Indonesia and East Timor. Trop Drylands 21: 17-24.* The Talau-Loes watershed is a cross-border watershed in Indonesia and Timor Leste (East Timor) which has traditionally been a natural resource for living, cultivation and conservation areas for communities in several districts of Belu Regency, Indonesia, and several areas in the Timor Leste territory. Water shortages in the land system are thought to play a significant role in the low productivity of agricultural crops. This study aimed to predict water balance in the Talau watershed, and to estimate river discharge in Malibaka Sub-watershed of Talau-Loes watershed. The study results showed that the amount of annual precipitation of 1679 mm was smaller than the total amount of water lost, amounting to 1914.79 mm per year, originating from evapotranspiration (ET) of 1650.91 mm and runoff water of 263.85 mm. Thus, theoretically, there would be an annual deficit of 235.79 mm in the Talau watershed. However, at the peak of the groundwater deficit, it turned out that the Malibaka River in the Malibaka sub-watershed and the Talau watershed had a discharge of 18 mm^3/sec. This gives a clue about the ability of the groundwater level to gradually release its water reservoir as a source of base flow. Soil and water conservation actions that combine integrated systems such as agroforestry systems with mechanical conservation actions are proposed as solutions that need to be studied and developed in the future.

Keywords: Agricultural productivity, river discharge, soil and water conservation, spatial water balance, Talau-Loes watershed

INTRODUCTION

From an Indonesian legal perspective, a watershed is defined as a land area that is an integral part of the river and its tributaries, which functions to accommodate, store and flow water that comes from rainfall into lakes or into the sea naturally, where the boundary in the inland is a topographic divider and the boundary in the sea is the waters that are still affected by land activities (Article 1 of Government Regulation No. 37 concerning Watershed Management). This definition implies that the watershed is a unitary area of the ecosystem, where catchment water flows from the ridge (upstream) to its outlets river (middle and downstream) to the sea. Watershed function in capturing and holding the water integrates various landscape features that function to capture water (Kendall and McDonnel 1998).

Watershed ecosystem services can vary, but in the aspect of agriculture, the carrying capacity of water in a watershed becomes a determinant factor. The balance between water intake and output will determine the amount of water available. This can be drawn through the estimation of watershed water balance which gives an illustration of the balance between the amount of stored water in the soil and the amount of water loss from the ground due to the evapotranspiration process and runoff. Water balance is simply the amount of rainwater that falls into the ground minus evaporation and surface runoff. In other words, the water balance depicts the relationship between the flows of water into the ground in the form of inputs with water output (output) within a certain time period. Output water can be in the form of actual evapotranspiration and surface runoff. Here, the most important variables for calculating water balance are the availability of rainfall data (precipitation) in addition to air temperature, land cover and soil type and condition (soil) in the study area. Therefore, discussing the water balance is inseparable from the components of rainfall, solar radiation, humidity, land cover, soil and rock conditions. Land water balance in watersheds is dynamic and differences can occur between time (dt/ds) depending on the determinants explained by Kendall and McDonnel (1998) such as rainfall, edaphic and biotic factors, especially land cover.

Talau-Loes River Basin is a watershed located on the border of the Republic of Indonesia and East Timor, covering an area of 260,457 ha in which around 28% is located in the Indonesian part (Talau). The upstream part of Talau-Loes watershed is a water conservation area and the downstream part is the mainland and coastal ecotone area, while the middle part is the only transportation and utilization area. The average rainfall of around 1600 mm/year is limited by the high evaporation which reaches 1800 mm/year. The type of Quartz geological formation that rapidly converts surface water to fast flow causes base flow and available water to become very scarce during the dry season, which lasts for 5-6 months in a year.

Traditionally, farming communities in the Talau watershed use water not only for domestic consumption but also for farming. Research by the Undana team (2018) shows that almost 95% of community that lives in Talau watershed are farmers who rely on water supplies from the watershed. Human nature and behavior also determine the success of the watershed farming community. Deforestation is triggered by destructive farming patterns such as slash and burn farming, illegal logging and off-farm, causing small amount of water to be retained on the water table matrix.

Based on the above-mentioned background, the condition of the water balance in the Talau-Loes watershed system, especially in the Talau (Indonesia) section (with Malibaka Sub-watershed) can be as assessed, which is useful to predict the spatial distribution of water, i.e., the area of additions or output from the catchment area. The size of the catchment area is a very important parameter for managing recharge areas as a water supply area for farmers' needs. Through the water balance approach, the area of the Talau watershed can be determined based on surface and subsurface conditions.

The objectives of this study were (i) to predict the Talau watershed water balance, and (ii) to estimate the Malibaka river discharge, Malibaka Sub-watershed of Talau-Loes watershed, as verification of the Talau-Loes watershed situation. The most important aspect of this research is that in Indonesia there are only 3 locations that have cross-border watersheds, namely Kalimantan, Papua and East Nusa Tenggara (ENT). Of these 3 locations, watershed on the border of ENT (Indonesia) and East Timor is the first watershed to be managed together by both countries with an emphasis on aspects of livelihood and food security.

As agriculture and food security are the main sectors in the Talau-Loes watershed, there is a crucial need for information about water carrying/holding capacity (DTA) and water balance in the watershed, which are presently unavailable. Thus, this research was intended to provide such information. Furthermore, this research is actually a synthesis of several scientific disciplines, namely animal nutrition, agriculture, forestry, socio-economic and cultural as well as engineering. Thus, the main contribution of this research to science and technology is an interdisciplinary integration as a precondition for watershed management that is cross-regional, system and discipline.

MATERIALS AND METHODS

Study area and period

This research was carried out in the Talau-Loes watershed with the location of the study focused on the Indonesian territory, in the Malibaka sub-watershed, Maumutin District, Belu Regency (Figure 1). The research was carried out from August to October 2019. The Talau-Loes area (Figure 1) is divided into 3 ecosystem zones, namely upstream, middle and downstream. (i) Upstream watershed is zone limited to the upstream part where > 70% of the land surface generally has a slope of > 8%. (ii) Middle watershed is zone where water flow and limited to the middle section, where approximately 50% of the land surface has a slope <8%. (iii) Downstream watershed is zone in the downstream part, where approximately 70% of the land surface has a slope <8%.

The analysis of the Talau-Loes watershed area shows that 102,029 ha (39.2%) of the Talau-Loes watershed is in the upstream area, 100,162 ha (38.5%) in the middle area and 58,266 ha (22.4%) are in the downstream area. By referring to the proportion of watershed zoning between the two countries, 88% of the upstream area and 93% of the downstream area of Talau-Loes watershed are in the East Timor territory, whereas 56% of the middle region is in the Indonesian territory.

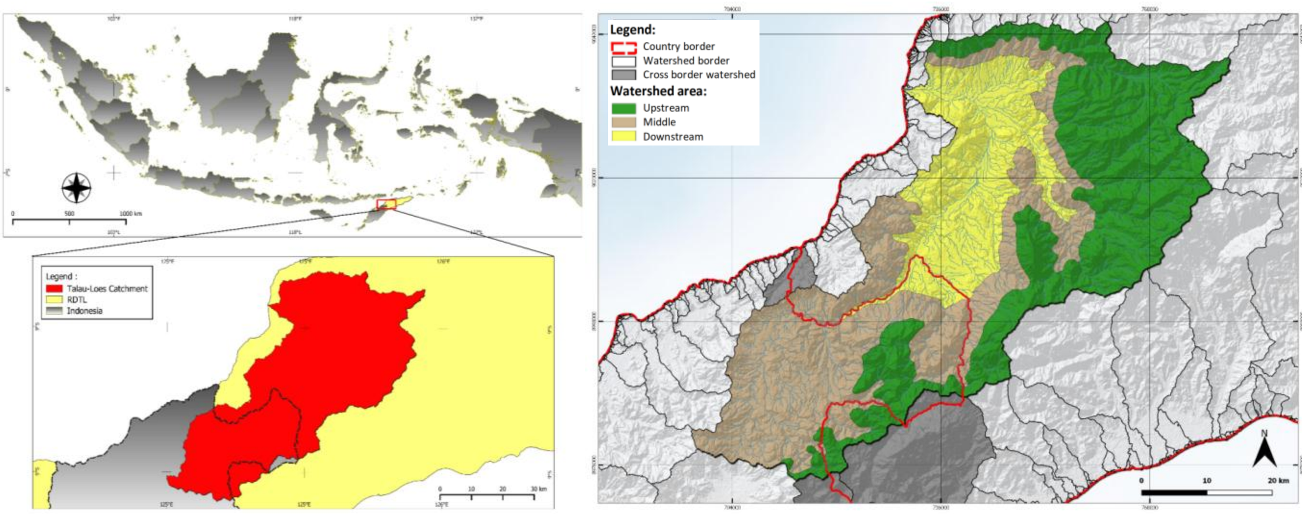

Figure 1. Research site in Talau-Loes Watershed, Timor Island (border between Indonesia and East Timor)

Geological properties in the Talau area consist of rocks such as silt, coral, filit, quartize, skiz, alluvium sand, and sandy beaches with foreign chunks (bobonaro). The previous survey in Atambua revealed that the groundwater level was around 11.2-11.25 m, with percolation of soil ranging from 1.15 x 10-6 to 2.8.10-7 $m^2.day^{-1}$, while water discharge through the aquifer surface was around 5 x 10-6-1 x 10-7 $m^2.day^{-1}$ (Arismunandar and Ruchijat 1995). The soils formed on these rocks are alkaline. This alkaline soil needs to be anticipated in the development of the agricultural sector, because the calcareous layer and clay are dominated by soil types of Entisol, Inceptisol, Vertisol with parent material of sandstone, clay and limestone. The Talau-Loes watershed is generally dominated by areas with elevation of 0-500 meters above sea level with an area of 12,476 ha (48.6%). The analysis shows that the slope class in the Talau-Loes watershed tends to be spread evenly. However, cumulatively, the slope class is rather steep to very steep of 143,850 ha (55%) of the entire Talau-Loes watershed.

Morphologically, the physiographic condition of the upper region of the Loes River are mountains and hills, and the terrain is choppy to bumpy. These physiographic conditions trigger erosion and landslides, causing the release of sediment materials from various places, which are then deposited downstream. There are about 6 types of soil in the Talau watershed with an average depth of up to 90 cm and a topsoil depth of around 20 cm. The soil is dominated by Inceptisol with shallow and moderate topsoils, solum and silt depth. Based on this data and that of Suprayogo (2003), relevant soil types in each sub-watershed with their depth can be estimated.

Referring to the river flow pattern, the Talau-Loes watershed is more inclined to form a dendritic pattern that forms a pattern like tree branches. The shape of the Talau-Loes watershed tends to be elongated, but the outlets in the middle and downstream tend to narrow so that the accumulation of flow tends to be high in the upstream and then slows down in the middle and downstream. At the peak discharge, buttresses are easy to occur, especially if the amount of sediment that causes siltation of the river downstream is taken into account. When the peak discharge occurs, flooding is easy to occur because the water overflows beyond the capacity of the river. Floods start from the meeting point of the river in the downstream area to the extent of flooding areas.

Based on data from Sukabitek climate station, monthly rainfall data from 1973 to 2013 (gap of data is found in 1982) (Figure 2) and East Tasifeto station data from 1989 to 2002, annual rainfall in the Talau watershed (part of Indonesia) varied between 625-1838 mm per year with an average rainfall of 1634 mm per year. Talau has a difference in the conditions of the rainy season and extreme dry season, where about 95% of the rain falls from November to April. Whereas, in the dry season the total monthly rainfall is very low with less than 50 mm per month. The average air temperature ranged between 23-27°C, with an evapotranspiration potential of 1430 mm per year.

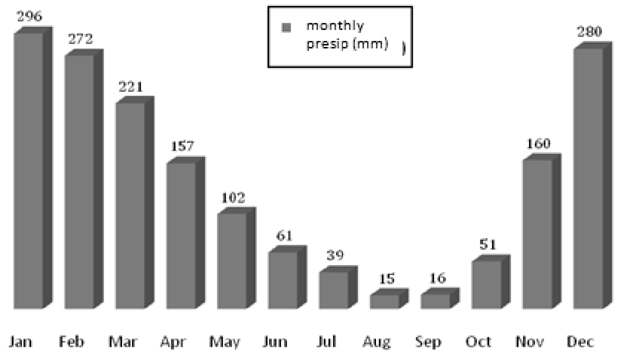

Figure 2. Average monthly rainfall of Talau-Loes watershed (Source: Climatology Station of Sukabitetek 1973-2013)

Methods

The estimated water balance in this study used the Thornthwaite-Mather model. This model was chosen to have several advantages including not requiring a lot of input data, relatively simple calculations and able to provide a complete picture of hydrological potential (Dianitasari and Purnama 2017).

Input data needed are: rainfall, potential evapotranspiration (ETP), soil moisture at the field capacity level (KL) of each soil type, and soil moisture content at the level of permanent withering point (TLP) of each type of soil. The sequence of how to calculate the land water balance in the Talau-Loes watershed is as follows: (i) Temperature is the data of average monthly air temperature in one year, which is calculated from the data of the last 10 years. (ii) Heat Index (I) is the sum of the monthly heat index value (i) calculated using the formula: i = (T / 5) 1.514. (iii) Potential evapotranspiration (ETP) before correction based on the temperature value monthly and heat index values (Mather Table). (iv) Corrected evapotranspiration, i.e., ETP x latitude position (Table Mather). (v) Rainfall, average monthly rainfall count over the past 10 years from stations around the Talau-Loes watershed (Indonesia part) (mm). (vi) Precipitation-ET corrected. (vii) Accumulated Potential Water Loss (APWL), to determine the potential for water loss in the dry month. Method of calculation: Starting from the P-EP value that has a negative value, then was sequentially summed with the next P-EP value up to the last negative P-EP value. (viii) Groundwater Content (ΔS), calculated from the ability of the soil to hold water. The ability of the soil to retain water is obtained based on the results of multiplication between percentages of land use, available water and root zone depth (using Thornwaite-Mather Table 1957). (ix) Δ KAT, calculated as the change in Soil Water Capacity (KAT) from month to month, i.e., reduce this month to the previous month. (x) Actual ET, ETA in the months where CH> ETP was corroded. (xi) Deficits (D), the conditions of the month in which ETP is corrected, ETA is different on deficit months. (xii) The surplus value (S) is obtained based on the formula S = (P-EP)-Δ KAT. (xiii) Surface flow Runoff (RO) is obtained from a surplus of water which is assumed to be 50% and the rest will come out to be runoff the following month.

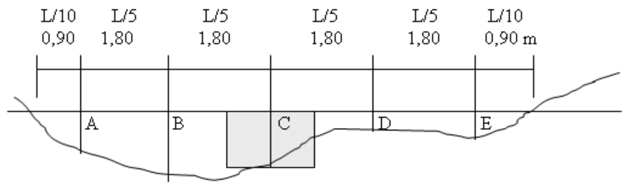

Figure 3. Method for calculating the momentary discharge

This analysis was done by calculating the momentary discharge at the outlet. The simplest method was used in this study. i.e., the calculated discharge was a spring and a river cross-section discharge (Figure 3).

RESULTS AND DISCUSSION

Total annual rainfall

Total annual rainfall in the Talau watershed was 1679 mm with 7 rainy months in a bimodal pattern. Monthly rainfall with intensity of more than 100 mm (Schmidt-Ferguson category) occurred between November and May. Meanwhile, there were five dry months (rainfall <60 mm month^{-1}), which is between May-October.

Total annual potential evaporation

Total annual potential evapotranspiration was 1650.91 mm/year. The largest potential evapotranspiration (ETP) occurred in May at 151.41 mm while the most recent actual evapotranspiration (ETA) occurred in December, at 280 mm when the average temperature reached 27.1^{o}C.

In January-May, the value of rainfall is higher than the potential evapotranspiration and at that time, there was a surplus of water (groundwater supply). The same condition also occurred in November-December. The total annual groundwater supply is 527 mm. Meanwhile, during May-October, there was a deficit of 150 mm of groundwater. Water loss from the cycle also occurs because the flow of water (Q), in this case, runoff, is 263.85 mm/year mm year^{-1}.

Focusing on the description of the water balance in the Talau-Loes watershed in the Indonesian part (Talau), it can be said that in general the hydrological conditions in the Talau watershed are marked by water balance imbalances. Total annual precipitation is 1679 mm while the water depletion component includes 1914.79 mm which includes 1650.91 mm of potential evapotranspiration and runaway water of 263.85 mm.

The water surplus that occurs in the rainy season which increases soil moisture levels will quickly decrease during the 5 consecutive dry months. There are indeed two rainy months at the end of the year but the magnitude of evapotranspiration, both potential and actual, will cause a constrained field capacity that makes it easy for plants to use water.

It should also be noted that the soil in the Talau watershed is dominated by quarts, inceptisol, bobonaro clay, which can easily convert water into gravitational water but on the other hand will hold the water too strong and make it difficult for the roots to absorb water. Affirmed by Lascano (1991, cited by Shebat 2014) that the factors affecting land water balance are mainly climate conditions and soil type conditions. The difference in the value of field capacity and the value of permanent withering points influence the availability of water in the soil (Shebat 2014).

Calculated water balance of Talau-Loes watershed is presented in Table 1 and Figure 4.

Table 1. Calculated water balance of Talau-Loes watershed, Timor Island

No.	Climate elements	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nop	Dec
1	Temp (T) °C	27.3	27.4	27.4	27.8	27.9	27.4	27.2	27.1	27.4	27.4	27.0	27.2
2	Heat Index (I)	13.07	13.14	13.14	13.43	13.5	13.14	12.99	12.29	13.14	13.14	12.85	12.99
3	ETP. non-adjust	4.7	4.8	4.7	4.9	4.9	4.7	4.7	4.7	4.7	4.7	4.6	4.7
4a	correction to ETP	31.5	28.2	31.2	30.3	30.9	30.0	31.2	31.2	30.3	31.2	30.6	31.5
4b	ETP adjust (ETPotential)	148.05	135.36	1466	148.47	151.41	141	146.64	146.64	142.41	146.64	140.76	148.05
5	Rainfall (P)	296	272	221	157	102	61	39	15	16	51	169	280
6	R – ETP adjust	147.95	136.64	7436	8.53	-49.41	-80	-107.64	-131.64	-126.41	-95.64	28.24	131.95
7	APWL (average potential water loss)					-49.41	-129.41	-237.95	-368.69	-495.1	-590.5		
8	Soil moisture storage (ST)	107.7	107.7	107.7	107.7	65	33	12	1	1	1	107.7	107.7
9	? ST	0	0	0	0	-42.7	-32	125.64	11	0	0	106.7	0
10	ETA	148.05	135.36	146.6'	148.47	144.7	93	86.64	120.64	126.41	52	169	280
11	Deficit (D)	0	0	0	0	22.71	48	60	26	16	0	0	0
12	Surplus (S)	1479.5	136.64	7436	8.53	0	0	0	0	0	0	28.24	131.95
13	Run-Off (Ro)	73.98	68.32	3718	4.27	0	0	0	0	0	0	14.12	65.98

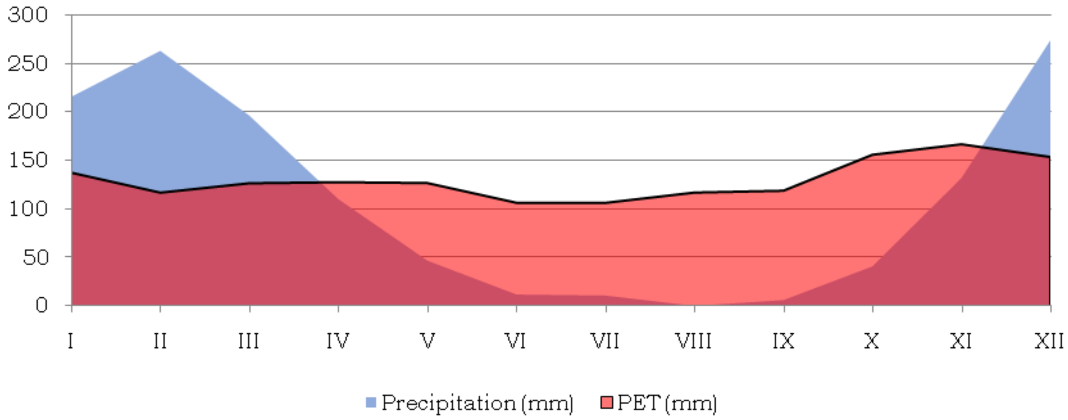

Figure 4. Average water balance of Talau-Loes watershed, Timor Island

River discharge

Measurements are made, firstly, by making a cross-section profile of the river open channel to get the length of the measurement trajectory. The total length of the cross-section of the river is 9 meters and, thus, according to the provisions, the estimated channel length is 27 meters rounded to 30 m. The observations showed that the Malibaka river discharge at the peak of the dry season (October 2019) was 18 mm^3/second (30 mm). Following the formulation of Thornwaite-Mather (1957) that run off when the deficit is 50%, it is estimated that in the rainy season, the discharge will reach 36 mm^3/second. This fact provides confirmation of the water balance data previously calculated in the May-October (dry) period that there was a water deficit of 150 mm/year. The fact that the Malibaka river still has a discharge of 18 mm^3/second gives a hint that even though groundwater depletion occurred during the dry season, the water in the "water table" zone in the Talau watershed is not completely depleted. This may be a theoretical description (Shebat 2014) that the river flow patterns in the Talau watershed can be broken down into three stages, namely (i) the initial phase is the phase of groundwater storage at the beginning of the rainy season, (ii) the second half of the rainy season where some large rainfall flowed into rivers, and (iii) the dry season in which rivers and springs obtain water through a gradual release of water reserves (gradual water release).

In general, groundwater level (water table zone) is water near the surface of the soil or in the vadose zone or soil zone (generally) where the roots uptake and get water (Shebat 2014). Soil area is mostly used for agriculture. Water will be lost due to transpiration, evaporation and percolation which causes water to be released gradually in the dry season. The contribution of water supply originating from the phreatic zone located below the water level zone needs to be observed in subsequent studies. Nevertheless, the facts resulting from the estimation of the water balance and discharge of the Talau watershed provide an indication that there is an opportunity to conserve water and soil in the Talau watershed to increase the carrying capacity of the water table for agricultural productivity. In other words, an agricultural system to be sought is not only water-saving but also at the same time increasing the carrying capacity of water resources.

Forest cover

At present, forest cover in the Talau-Loes watershed reaches 55.406 ha, equal to 21.3% of the total area of the watershed (260.457 ha). According to Indonesian Law No. 41/1999 on Forestry, the minimum requirement of forest cover is 30%, implying that the proportion of forest cover in Talau-Lowes watershed is still far below the minimum requirement. However, if observed carefully for each segment of the watershed area, the forest area in the upstream zone in the East Timor region is still adequate (62.7%). Unfortunately, the forest area in the middle zone of the watershed, mostly in the Republic of Indonesia territory, the forest area is only around 17.2%. When only accounting for Indonesian part, the forest area in the Talau watershed is only around 6-7%. This needs attention as it shows a high vulnerability of the environmental system. Allegedly, the slash-burn agriculture practices became an important part of the deforestation process that occurred.

Hydrological modeling for the Talau watershed has been carried out by the CIFOR team (2007) to support the development of an environmental service system. The study showed that although it can be useful for controlling surface runoff, reforestation in the Talau watershed is thought to have no significant effect on land discharge. Even though the results of this modeling are more likely to be true but there is still a chance that by controlling runoff, hypothetically, infiltration water can be increased. This is a way to increase the water level in the water surface zone which will be transformed for the groundwater level that is beneficial for the agricultural system. This situation is likely to come true considering the present study results on water balance and land discharge which shows a theoretical construction that supports the improvement of water reserves in the Talau watershed.

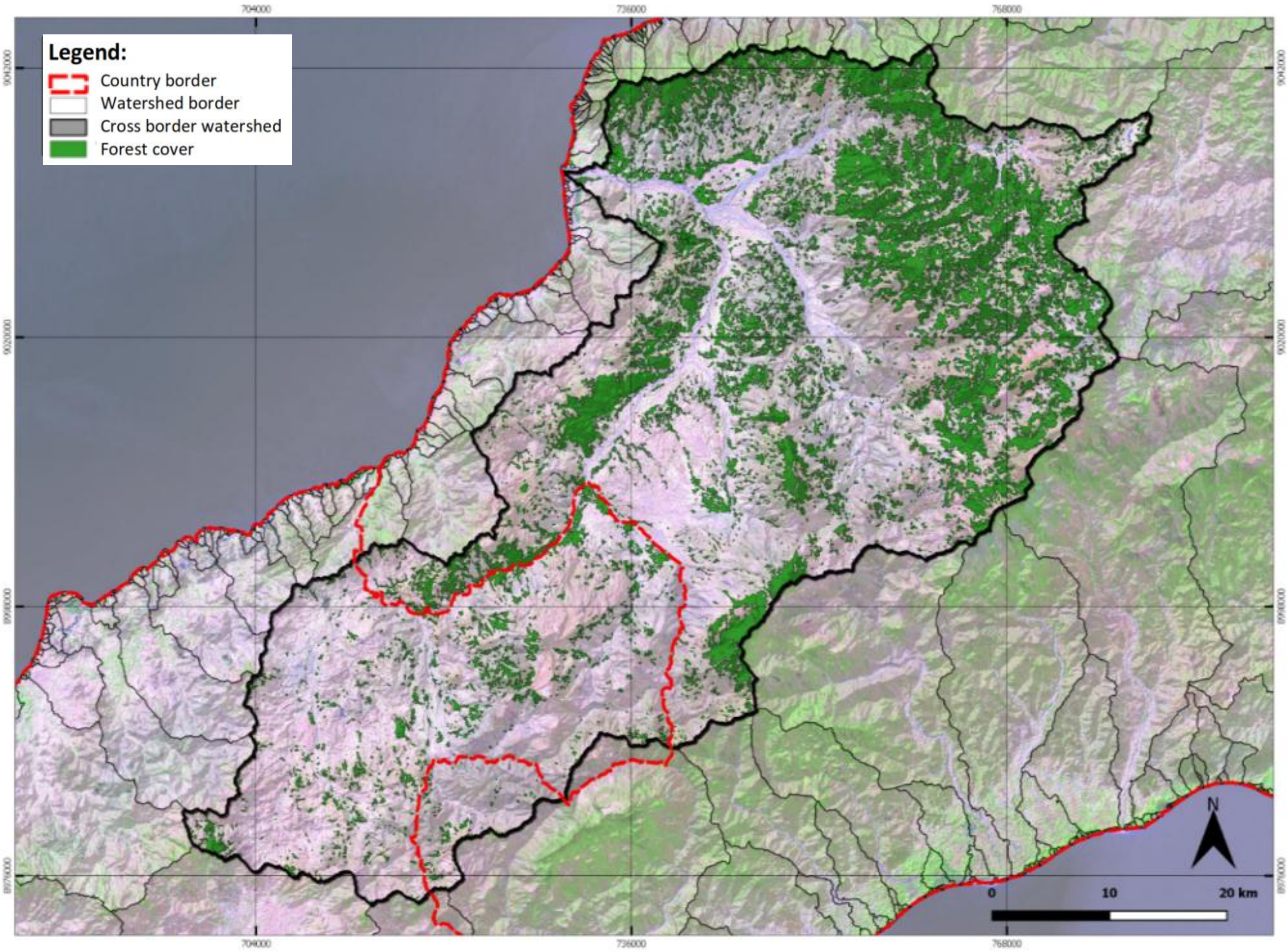

Figure 5. Forest cover of Talau-Loes Watershed, Timor Island (Source: Landsat Imagery 8-OLI, 2017)

There is a need to retain infiltrated water as long as possible in the Talau watershed with challenges to soil types, water zone profiles in the soil, and other ways to improve "water holding capacity". Combining reforestation and other soil and water conservation technologies will be the key answer to the problem of water imbalance in the Talau-Loes watershed. If reforestation is proposed, three things to consider: (i) conversion of unproductive land (grasslands and shrubs) into forests; (ii) conversion of unproductive land (grasslands and shrubs) into agroforestry; and (iii) conversion of unproductive land into agricultural systems with good land management under the rules of soil and water conservation.

The present study concludes the following: (i) The hydrological system in the Talau-Loes watershed is not balanced, where the water entering is smaller than the water coming out of the hydrological system. (ii) Annual rainfall as input is recorded at 1679 mmm but the total water lost is 1914.79 mm per year, originating from evapotranspiration (ET) 1650.91 mm and runoff water of 263.85 mm. Thus, theoretically, there would be an annual deficit of 235.79 mm in the Talau watershed. (iii). Malibaka river discharge, Malibaka sub-watershed, Talau-Loes watershed during the peak of the rainy season (October) was18 mm^3/second which is thought to originate from gradual release of water from the ground table (water table) in the Talau watershed. (iv) The proportion of land covered by tree or forests in the Talau-Loes watershed is only 21.3% which is below the standard value of tree cover area (30%) especially in the middle of the watershed, namely Talau watershed in Indonesia which is only 6-7%. Deforestation due to slash-burning agriculture practices is thought to be a determinant factor.

To be more comprehensively explain the groundwater balance in the Talau-Loes watershed and find solutions to the hydrological imbalance in the watershed, then the following recommendations need to be considered: (i) The groundwater in the Talau-Loes watershed needs to be balanced by combining reforestation to conserve soil and water in the water table. (ii) The relationship between the movement of water between water in the vadose zone and the phreatic zone needs to be further studied.

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