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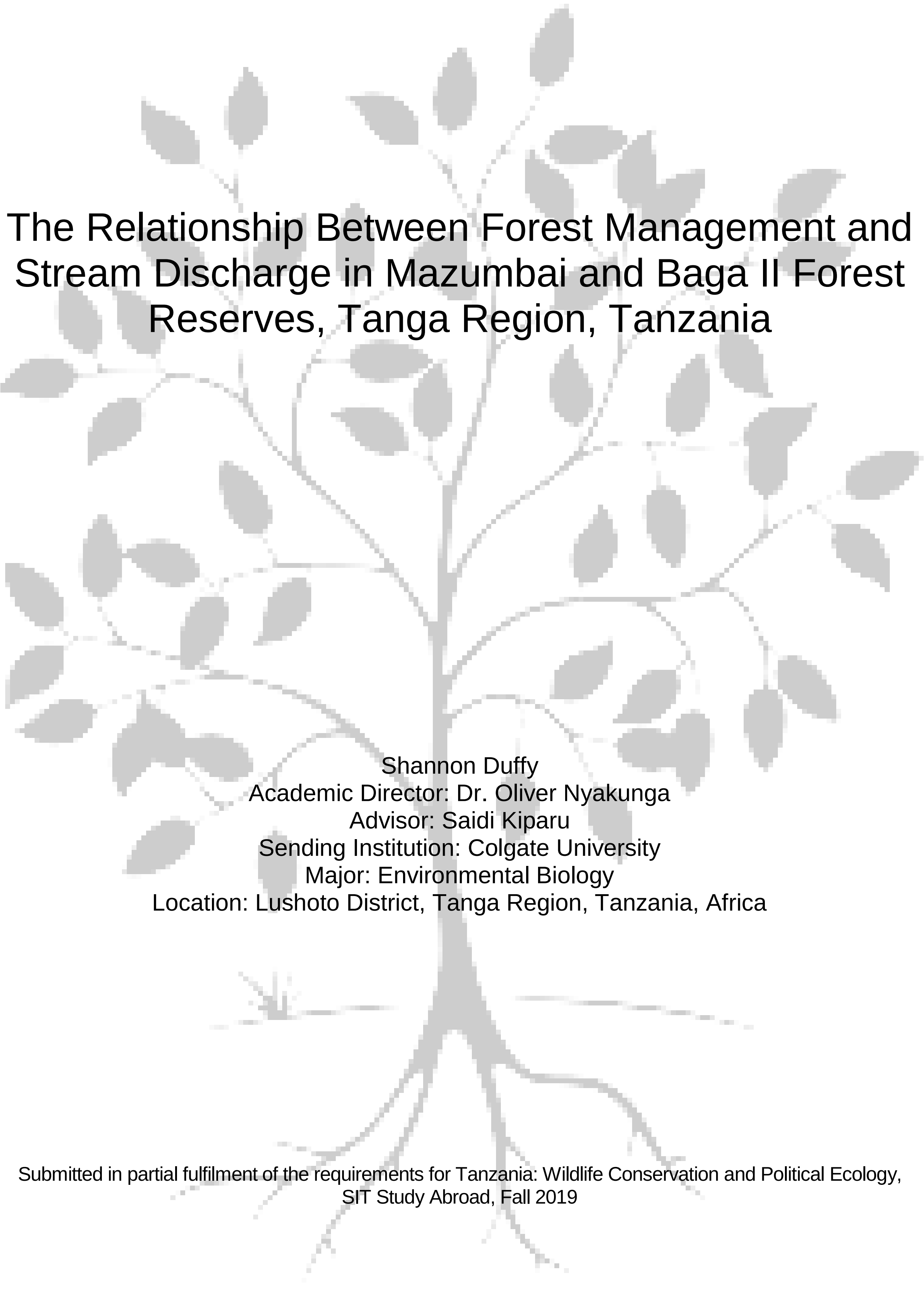

The Relationship Between Forest Management and Stream Discharge in Mazumbai and Baga II Forest Reserves, Tanga Region, Tanzania

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Abstract

Deforestation is known to alter hydrology by reducing interception, transpiration and infiltration capacity, and increasing runoff which all leads to higher stream discharge. For rural Tanzanian communities, surface water resources are crucial for meeting basic needs, so the integrity of headwater catchments need to be maintained to ensure their reliability. The objectives of this study were to a) map the streams in the two forests because none currently exist and b) determine the effect of deforestation on discharge variability. Over fifteen days of data collection, this study analyzed variability of discharge and the degree of correlation between discharge and rainfall on ten streams in Mazumbai and Baga II Forest Reserves in the West Usambara Mountains in Lushoto district, Tanzania which have different management practices and levels of forest integrity. This study found no significant difference in variability of discharge between the streams of the two forests and no significant correlation between rainfall and discharge for any stream. This is attributed to the low levels of wood extraction in the more disturbed Baga II Forest Reserve compared to the amount of deforestation typically required to significantly impact streamflow. Additionally, the methods for discharge measurement were not precise enough to accurately quantify discharge on the small streams, and the short timespan of the study did not allow for measurements to be made in both wet and dry seasons to capture the true extent of how variable in discharge the streams can be. Because of these findings, further studies are needed before recommendations can be made to the forest reserves on changes to make to ensure streamflow reliability.

Key words: streams, hydrology, deforestation, forest management, montane forests, mapping, GIS

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Introduction

Forests provide many ecosystem services and one crucial role they play is as water catchment areas. Forests recharge atmospheric moisture via transpiration which can produce localized rain effects (Motzer et al., 2010; Sheil & Murdiyarso, 2009). Trees also enhance infiltration into the soil which reduces runoff and allows water to be retained in the catchment longer (Gajić et al., 2008). Streams are thus recharged more slowly via flow from the subsurface rather than directly from runoff. Many people in rural communities in developing countries depend on ecosystem water sources such as streams, springs, and lakes. The World Health Organization (2019) estimates that 144 million people get their drinking water from surface water sources. In Tanzania, 31.7% of people use these types of water sources (Noel). Deforestation has the potential to alter hydrology of water catchments by reducing infiltration capacity, decreasing transpiration, and increasing runoff (Lundgren & Lundgren, 1979). All of these factors play a role in the water yield of streams which are crucial for the livelihoods of people who depend on these water sources.

Deforestation is prevalent worldwide which threatens water security, increases greenhouse gas emissions, endangers forest species, and reduces biodiversity. From 1990-2015, the percentage of the globe's land covered by forest decreased from 31.6% to 30.6% (FAO, 2018). Deforestation has reached particularly high levels in the tropics which lost 12 million hectares of tree cover- 3.6 million hectares of which were primary forest- in 2018 (Weisse & Goldman, 2019). More specifically, in sub-Saharan Africa forest cover decreased from 30.6% to 27.1% from 1990-2015 (FAO, 2018). In 2018, Tanzania ranked as the country with the 9th highest increase in loss of primary tropical rainforest from 2017 at a 3% increase (Weisse & Goldman, 2019). Tanzania lost 19.4% of its forest cover between 1990 and 2010 (Kideghesho, 2015). Statistics on deforestation in the Eastern Arc Mountains are conflicting, but one study found that 80% of the mountains' historic forested area has been lost, particularly in the lowland and sub-montane forests, and between 1955 and 2000, 25% of the forest was lost (Hall et al., 2009). A different study found that 50% of the Eastern Arc Mountains' montane and sub-montane forests were lost between 2000-2005, and if deforestation continues at this rate, the forests of the Eastern Arc Mountains could be lost in 20 years (Kideghesho, 2015). Another study found that between 2000 and 2010, the forested area of the Eastern Arc Mountains decreased by 12,673 hectares (1.4%) or 0.15%/year. (Tabor et al., 2010) The same study found that in the West Usambaras, 20 hectares (0.09%) were destroyed from 2000-2010 or 0.01%/year.

In the West Usambara Mountains in the Lushoto district, there are two adjacent forest reserves managed by two institutions. The Baga II Forest Reserve is managed by the federal government as a protected area and the Mazumbai Forest Reserve is a privately managed area owned by the Sokoine University of Agriculture which is used primarily for research. Officially, neither reserve allows human settlement, cultivation, or wood extraction, but in reality, illegal tree cutting and firewood collection occurs frequently in Baga II while Mazumbai remains a relatively pristine forest. A study by Persha and Blomley (2009) found that 40% of their study plots in Baga II were disturbed compared to 0% of plots in Mazumbai. They also found that Mazumbai exhibited more indicators of old growth forest than Baga II including greater average tree DBH (diameter at breast height), lower stem density, and a greater percentage of basal area covered with large trees. Multiple studies have attributed this disparity to the improper management of Baga II Forest Reserve. Persha and Blomely (2009) found that guards often took small bribes from village residents caught illegally harvesting wood in place of higher fines and did not enforce bans on logging leading to the perpetuation of these activities. A study comparing the management styles of Baga II and nearby community-managed Sagara Forest Reserve found logging present only in Baga II while tree cutting for building and firewood were present at similar frequencies in both forests (Ellis, 2012). Conversely, Mazumbai has experienced low levels of illegal wood harvesting because of its effective management. Two studies found a density of 50 cut trees/ha on the edge of Mazumbai over a 3.12 ha study plot (Briedis, 2002) and a density of 956 cut trees/ha on an adjacent 1.16 ha strip of forest within Baga II (Lenth, 1999). Briedis (2002) attributed this to the more effective protection of Mazumbai which has forest guards patrolling the area more regularly which deters villagers from entering the forest to cut trees in fear of being caught. Mazumbai employs 11 guards while Baga II employs only

4 guards who have to cover a forest 10 times larger than Mazumbai (Kiparu, pers. comm., December 2, 2019; Ellis, 2012). Additionally, the Baga II guards live far from the forest in Bumbuli town whereas Mazumbai guards live in villages right near the reserve (Kiparu, pers. comm. December 2, 2019). Overall, these studies show that Mazumbai's more effective management has led to more pristine forest conditions than in Baga II. This study seeks to understand how these differences in forest management and integrity impact streamflow within the forests.

Literature Review

The vast majority of studies on the impacts of deforestation on hydrology show an increase in water yield in streams following deforestation. A review of 94 case studies found that deforestation lead to increases in water yield- particularly strongly in conifer forests- however, measurable increases in discharge were only noticed in catchments that had lost more than 20% of their canopy cover (Bosch & Hewlett, 1982). This review was repeated in 1996 but focused just on studies in the United States and found similar results (Stednick, 1996). Conversely, following reforestation efforts, most studies show a decrease in water yield. A review of 167 papers with 308 case studies on reforestation and water yield found 79% of interventions led to reduced water yield (Filoso et al., 2017). However, most of these studies were short-term (less than 10 years after reforestation) and the authors found that in longer-term studies, water yields recovered. Very few studies focus on discharge variability but rather on peak flow and total yield increases. In assessing the impact of deforestation on low flows, forests are often thought of as metaphorical "pumps" for their transpiration function or "sponges" for their high infiltration capacity (Peña-Arancibia et al., 2019). The theory is that dry season low flows will increase post-deforestation if the contribution to streamflow from decreased transpiration exceeds the reduction in contribution from subsurface stores but if the opposite is true- as is the case in tropical ecosystems with highly seasonal rainfall- low flows will decrease. One study that indicated decreased low flows following deforestation was on the Mara River in Kenya and Tanzania which experiences distinct seasonal rainfall (Mango et al., 2011). Most other studies that included low flow observations, found that low flow increased post-deforestation but these increases were short lived (National Research Council of the National Academies, 2008). As forests regenerate, the fast growing pioneer species transpire a lot water which the authors found to decrease low flows below what they were pre-deforestation in some cases (Swank et al., 2001). While discharge variability is understudied, there are some studies that identify decreases in infiltration which is what slows the movement of water to streams. 83% of the 18 case studies reviewed by Filosio et al. (2007) that analyzed infiltration found infiltration increased after reforestation. However, isotopic tracing of water in a montane forest in Kenya found insignificant differences in modeled mean transit time of water in streams between catchments covered by forest, tea and tree plantations, and agricultural land (Jacobs et al., 2018). In the West Usambaras, reductions in low flows are not likely to be a problem as the area receives high rainfall year-round (although there have been some historical droughts) (Lundgren & Lundgren, 1979). The impact of deforestation most likely to threaten this area is flooding in the wet season. Forests are known to have flood risk reducing properties when soil has sufficient capacity to absorb heavy rainfalls and deforestation can intensify flood risk (Hamilton, 1992). This study seeks to add to the field by analyzing the effects of deforestation on streamflow with a focus on discharge variability rather than just yield and by contributing to the case studies in Africa which are not as numerous as in other regions.

Objectives

There is currently no data on stream discharge of any of the streams in Mazumbai or Baga II Forest Reserves. There are also no maps of these streams, so knowledge of water source locations for local communities is limited to personal observation and word-of-mouth information spread. Lack of maps also hinders stream research in the area. Many people rely on these streams as water sources, so it is important to understand how deforestation in Baga II is impacting stream flow. In face of these challenges, the objectives of this study are to a) map the streams to inform communities about places to access water and to facilitate future research on the streams and b) to compare the variability of streamflow and the correlation between rainfall and discharge of the two forests to determine how deforestation alters hydrology in order to inform conservation measures to ensure stream reliability. It is hypothesized that discharge of Baga II streams will be more variable and vary more with rainfall than streams in Mazumbai. This would indicate that increased deforestation causes faster discharge of water entering the ecosystem leading to increased flooding in times of high rainfall and increased droughts in times of low rainfall. These conclusions would call for better protection of Baga II Forest Reserve to ensure greater streamflow reliability. The mapping component of this study will be useful to inform future research on the streams in the forests and to inform residents of locations to access water.

Study Site Description

As stated, Mazumbai and Baga II Forest Reserves are located in the West Usambara Mountains which are part of the Eastern Arc Mountain Range. The reserves are in the Lushoto district of the Tanga region of northeastern Tanzania (Fig. 1). Mazumbai covers 320 ha and Baga II covers 3049 ha (Ellis, 2012). The forests are on an eastern (seaward) slope and elevation ranges from approximately 1300-1900 meters above sea level. The southern border of Mazumbai borders the northern border of Baga II and downslope (east) of the forests is agricultural land largely dominated by maize. There is a road running north-south through the middle of the forests at around 1500 m above sea level.

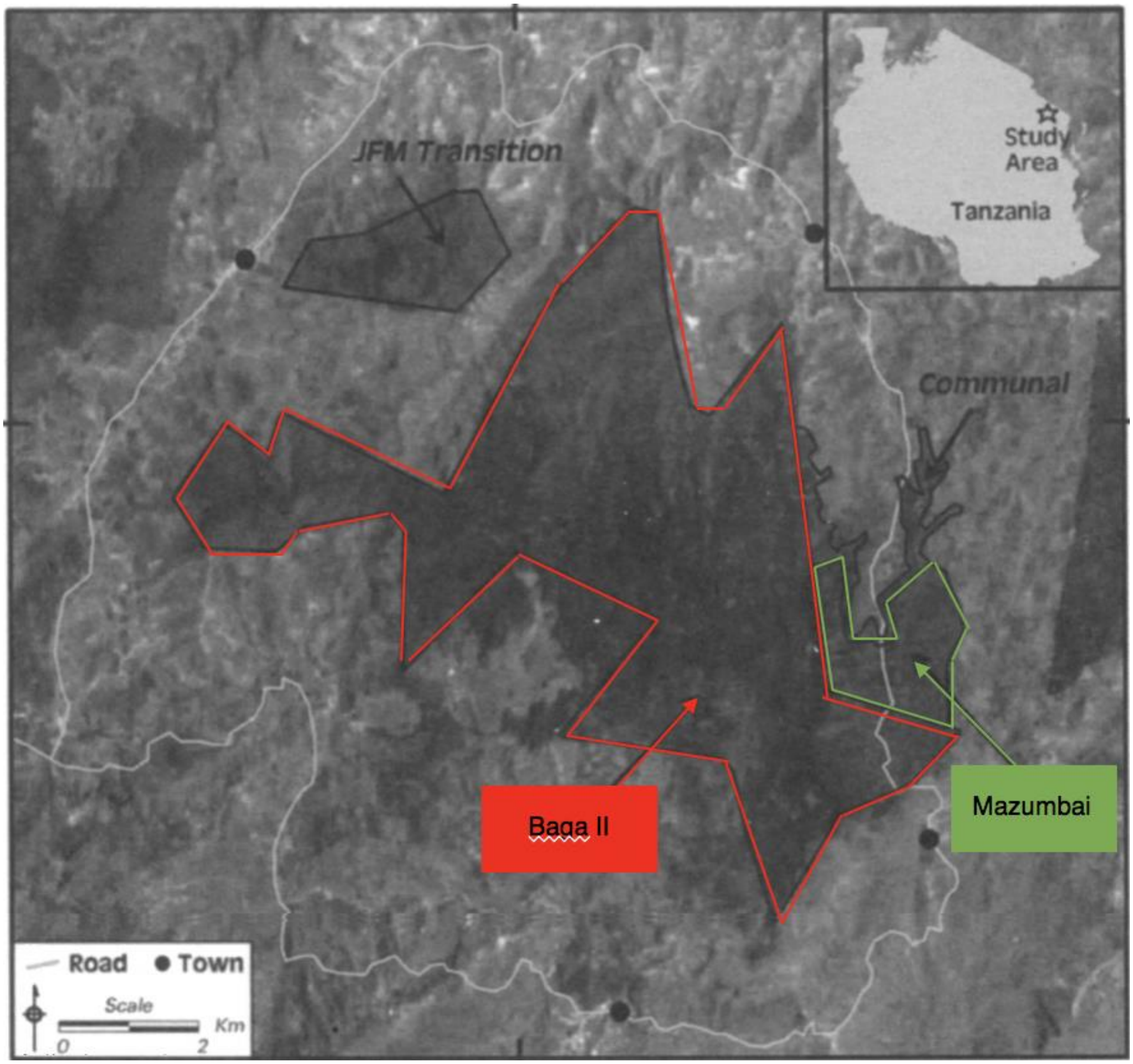

Figure 1: Satellite map of the locations of Mazumbai (green) and Baga II (red) Forest Reserves in Tanga Region, Lushoto District, northwestern Tanzania. (Photo source: Persha and Blomley, 2009.)

The area is characterized by high but variable levels of rainfall. Rainfall data collected at the Mazumbai Estate shows an average of 1174 mm of rain per year from 1945-2019 and 1196 mm of rain per year when years with missing data are removed (Fig. 2). However, rainfall ranged from 487-1958 mm/year with a standard deviation of 371.9 mm/year (not considering years with missing data). 2019 has had an above average amount of rainfall with 1444 mm from January to November while the average rainfall for these months is 1093 mm with a range from 487-1881 mm. Rain in the West Usambaras follows bimodal patterns due to the movement of the southeast trade winds from the Indian ocean. This causes a long-wet season in April-May and a short wet season arriving between November and December with dry seasons in-between (Fig. 3). The study period was from November 9th to 26th, 2019. The average monthly rainfall for November is 100 mm and ranges from 0-372 mm with a standard deviation of 76.8 (Fig. 4). November 2019 was slightly higher than average at 137.3 mm, but this falls within a typical range for the month. Over this study period, there were six days with no rainfall and the maximum daily rainfall was 20 mm. The average rainfall per rain day for the period was 8.4 mm while a study at Mazumbai from 1972-1975 found that rain days averaged 10.3 mm (Lundgren & Lundgren, 1979). So while the total rainfall was high for November, the rainstorms were low intensity.

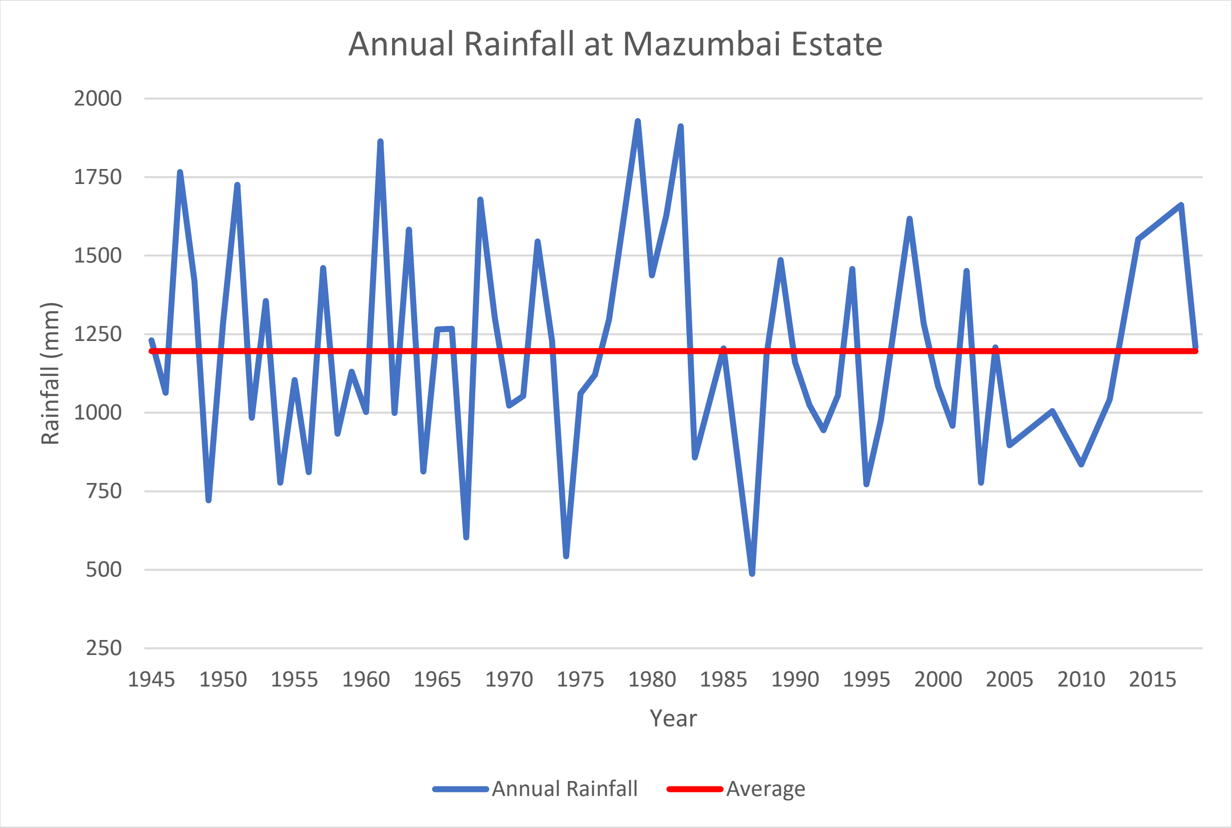

Figure 2: Annual rainfall collected at the Mazumbai Estate from 1945-2018. The red line represents the average over the period of 1196 mm (when years with missing data are excluded).

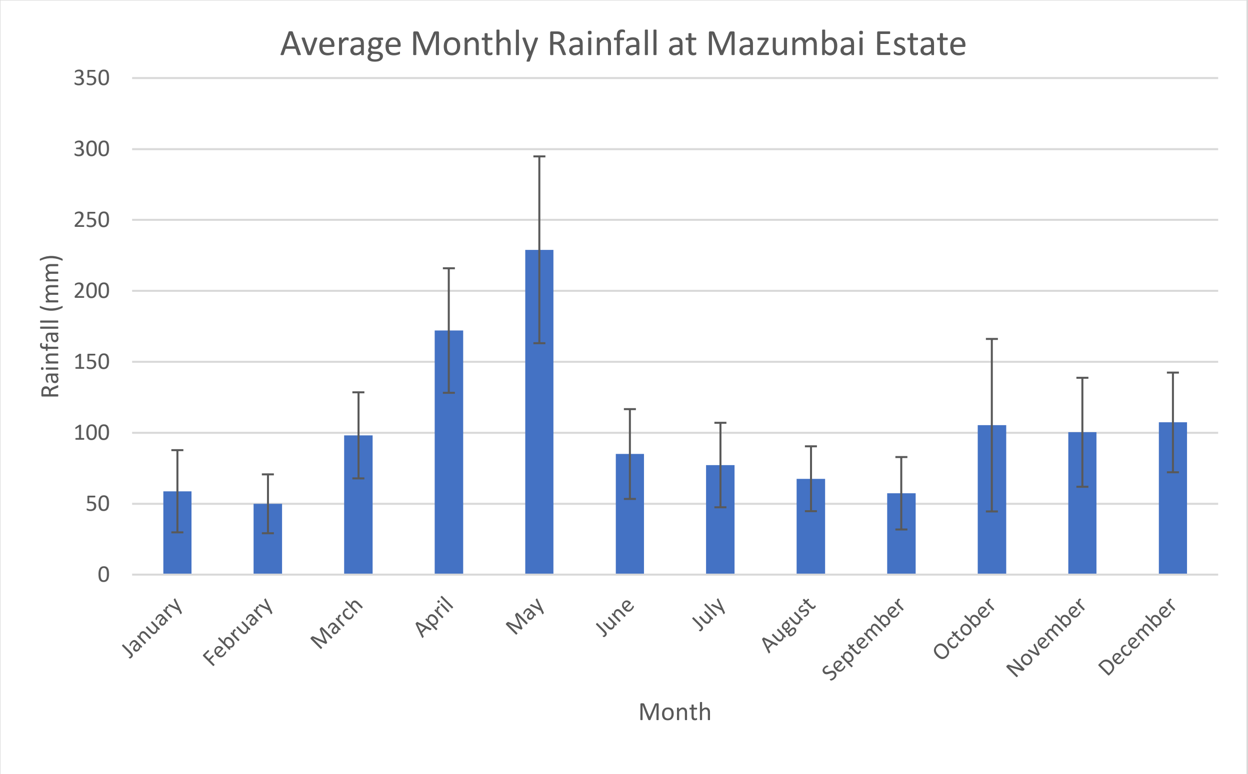

Figure 3: Average monthly rainfall at Mazumbai Estate from 1945-2019. Bars show standard deviation.

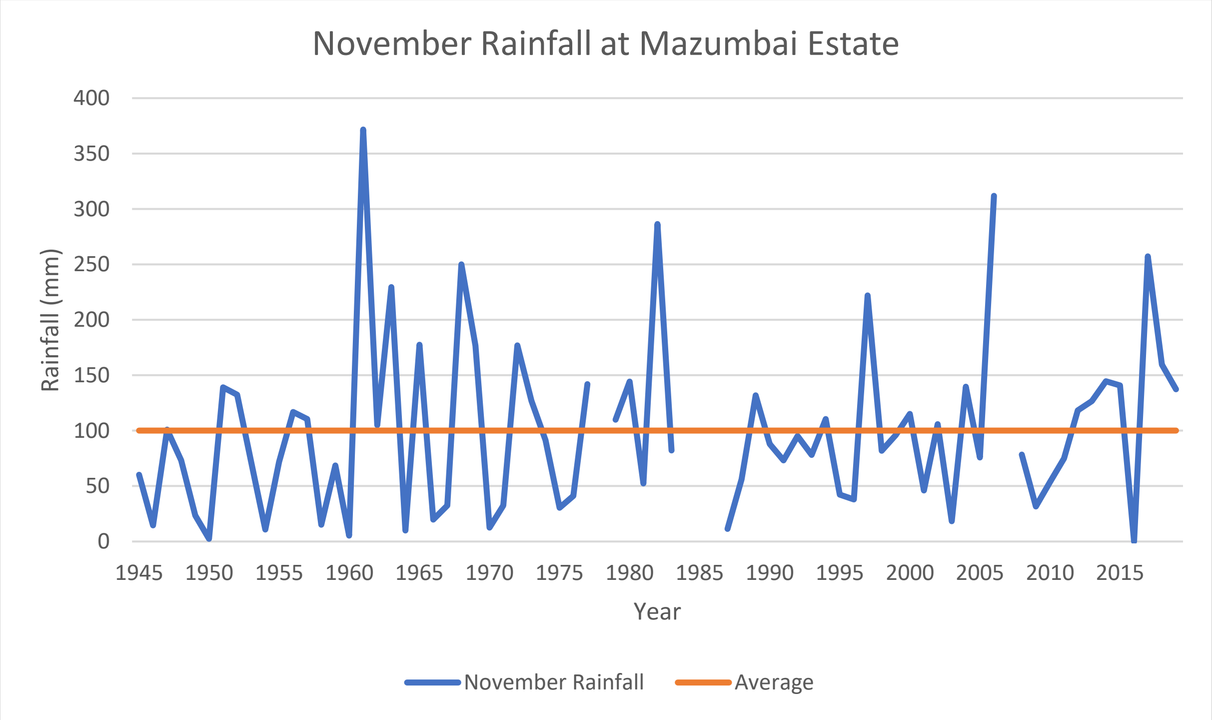

Figure 4: Rainfall for the month of November at Mazumbai Estate 1945-2019. The orange line shows the average over the period of 100 mm.

The soil has high clay and sand content but is low in silt and has low inherent fertility, but the top 10 cm of soil are fertile due to the deposition of organic matter from the forest (Lundgren & Lundgren, 1979). The vegetation type has been categorized as “intermediate evergreen forest” below 1400 m above sea level and “highland evergreen forest” above that altitude (Lundgren, 1980).

There are five streams in Mazumbai and five streams in Baga II which all run from west to east (Fig. 5, Table 1). In Mazumbai, from north to south, they are named Shamba Mayo, Kwepanga, Kwemahambalawe, Kwemapipa, and Damilwai. The Kwepanga and Kwemahambalawe flow into the Shamba Mayo and the Damilwai flows into the Kwemapipa. In Baga II, from north to south, the streams are named Hedeladja Mkonde, Kwengoto, Dalajani, Kwemubamba, and Kwavisi. All of the streams flow into the Kwengoto. The Shamba Mayo, Kwemapipa, and Kwengoto flow out of the forests, through farmland, and finally discharge into the Kaputi river. None of the streams cross the border between Baga II and Mazumbai.

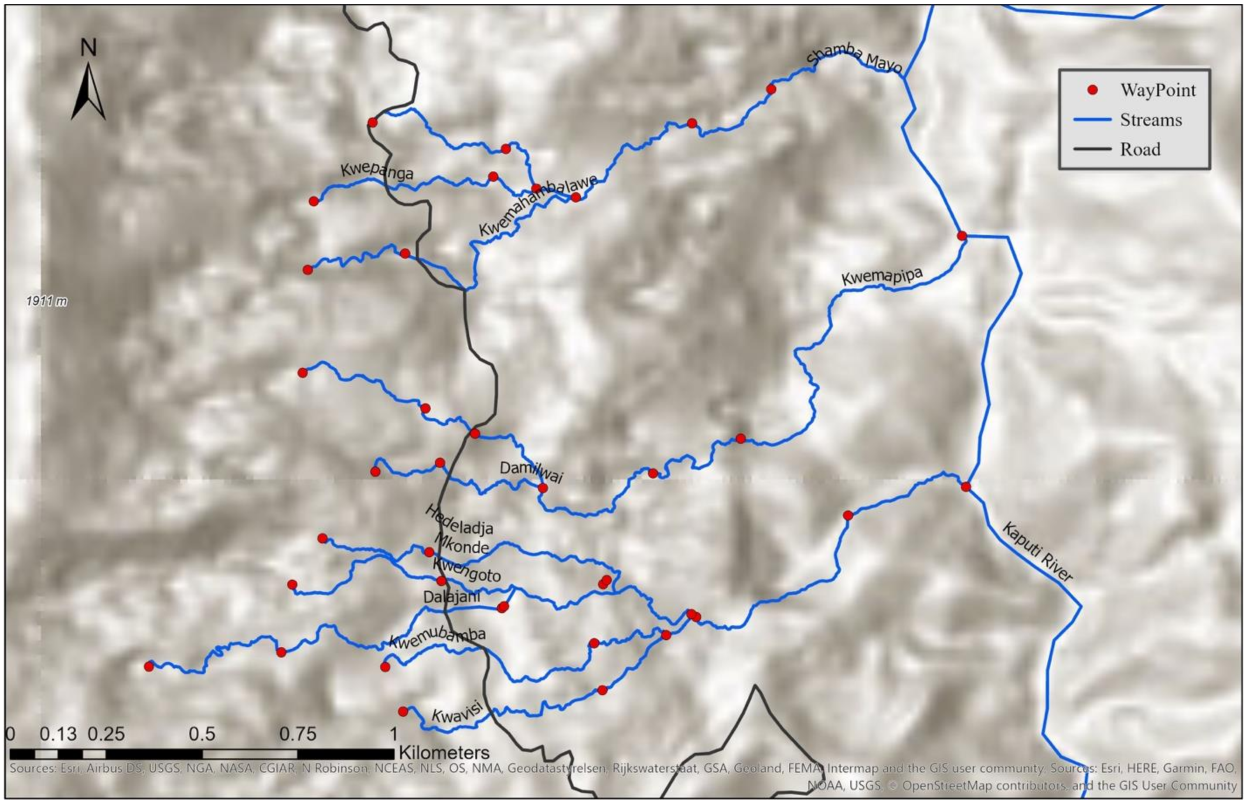

Figure 5: Topographic map of streams in Baga II and Mazumbai Forest Reserves. The locations where discharge was measured are marked by red waypoints.

Stream Name	Forest	Length (km)
Shamba Mayo	Mazumbai	3.52
Kwepanga	Mazumbai	1.99
Kwemahambalawe	Mazumbai	1.70
Kwemapipa	Mazumbai	4.05
Damilwai	Mazumbai	1.38
Hedeladja Mkonde	Baga II	1.23
Kwengoto	Baga II	2.86
Dalajani	Baga II	2.39
Kwemubamba	Baga II	1.65
Kwavisi	Baga II	2.88

Table 1: List of the streams in Baga II and Mazumbai with their corresponding lengths as mapped with the EasyTrails iPhone GPS application.

Methods

Mapping

Mapping occurred over seven days prior to the discharge measurement data collection period. To map the streams, the iPhone application “EasyTrails” was used ($3.99 in the App Store). The app uses the iPhone’s built in GPS to record the user’s position as they move and stores the paths as “tracks.” The author walked to the spot where the stream crossed the road, started recording, followed the stream on foot up to the source, and followed it back down past the road to the point where the stream discharged into another stream or river. This process relied on the knowledge of a forest guide who knew where the streams began and the stream’s name. At the point where the stream crossed the road, the source, and the discharge point, the author marked a “waypoint” on the app to record its coordinates and altitude. Waypoints were also recorded approximately every 500 m where the author would later measure discharge. In some cases, it was impossible to walk close to the river, so the recorded path strayed from the true location of the river in some spots. For this same reason, it was also impossible to get to the river every 500 m for some rivers.

The stream tracks and associated waypoints were imported into ArcGIS. The tracks were imported as a collection of points which were edited, with extraneous points deleted and the points moved to intersect the waypoints where discharge was measured. Then the points were transformed into a line shapefile using the “Point to Line” tool. The Kaputi River was digitized into a line shapefile following the low point indicated by the ArcGIS topographic basemap. The road running through the reserves was digitized into a line shapefile following the path indicated by the ArcGIS Open Road basemap.

Measuring Discharge

Every day between 9:00 and 10:00 AM, the discharge of all ten streams was measured at the point where the stream crossed the road. This was done using a tape measure to measure the width and depth of the stream to the nearest centimeter and then measuring the velocity by marking out one foot with the tape measure and then dropping a leaf into the stream and timing how long it took to travel that marked distance to the nearest hundredth of a second using an iPhone stopwatch. The width and depth values were converted to feet and the values were used to calculate discharge with the following equation:

$$Q = w \times d \times \frac{1}{t}$$

> where Q is the discharge of the stream in cubic feet per second, w is the width of the stream in feet, d is depth of the stream in feet, and 1/t is the velocity of the stream in feet per second (t is the time in seconds it takes a leaf to flow one foot downstream).

In addition to these daily measurements at the road, the discharge of each stream was measured three times at the source, the discharge point, and every 500 meters in-between. Each day starting after the road measurements and ending between 1:00 PM and 3:30 PM (depending on the stream length), one stream in Mazumbai and one stream in Baga II were measured in this more detailed manner. The rotation started with the southern-most stream in Baga II and the southern-most stream in Mazumbai and then moved one stream to the north each day. After five days, the rotation started over.

This amounted to fifteen days of data collection over eighteen days from November 9th, 2019 to November 26th, 2019 with no data collected on Sundays.

Statistics

To determine the variability of stream flow, the coefficient of variation was calculated for each individual stream and then averaged for all the streams in Mazumbai and averaged for all the streams in Baga II. The coefficient of variation is calculated using the following equation:

$$CV = \frac{S_x}{\mu_x}$$

where CV is the coefficient of variation, S_x is the standard deviation, and μ_x is the mean

To determine the relationship between rainfall and discharge, several Pearson's correlation tests were run using daily rainfall data and the measured discharge data for each stream using modifications consistent with modeling outlined by Kamruzzaman et al. (2014). Three variations were used: a) rainfall on the same day as the discharge measurement or rainfall on the day before the discharge measurement was taken, b) discharge represented as a raw value or as a change from the discharge of the previous day, and c) raw rainfall values or the number of days since a day with greater than 10 mm of rainfall (the average amount of rainfall per rain day in the study by Lundgren & Lundgren (1979)).

Results

Discharge of five streams in Mazumbai Forest Reserve and five streams in Baga II Forest Reserve were measured on fifteen days between November 9th to 26th 2019. Discharge for each stream where they cross the road is displayed in Figure 6 and statistics for each stream are summarized in Table 2.

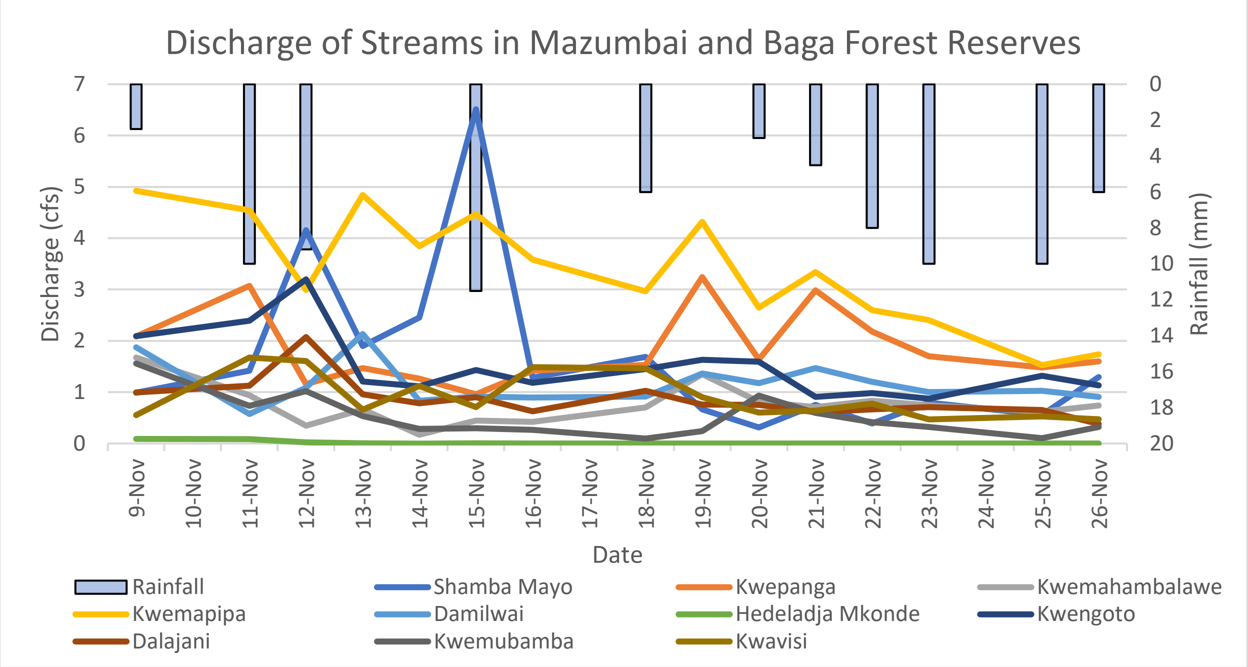

Figure 6: Discharge measured at the road for the ten streams in Mazumbai and Baga II Forest Reserves from 9 November 2019 to 26 November 2019. The streams on the top row of the legend are all in Mazumbai and the bottom row are all in Baga II. Daily rainfall measurements are presented as a bar graph descending from the top of the chart.

Stream	Mean	Minimum	Maximum	Standard Deviation	Coefficient of Variation
Shamba Mayo	1.68	0.31	6.51	1.66	0.99
Kwepanga	1.85	0.96	3.24	0.72	0.39
Kwemahambalawe	0.74	0.17	1.67	0.38	0.51
Kwemapipa	3.38	1.53	4.92	1.09	0.32
Damilwai	1.16	0.57	2.13	0.41	0.35
Mazumbai average	1.76	0.17	6.51	0.85	0.51
Corrected Mazumbai average*	1.78	0.17	4.92	0.65	0.39
Hedeladja Mkonde	0.01	0	0.09	0.03	2.27
Kwengoto	1.50	0.87	3.20	0.63	0.42
Dalajani	0.87	0.38	2.07	0.39	0.44
Kwemubamba	0.52	0.10	1.56	0.40	0.78
Kwavisi	0.91	0.47	1.67	0.44	0.48
Baga II average	0.76	0	3.20	0.38	0.88
Corrected Baga II average*	0.82	0	3.20	0.37	0.90

Table 2: Summary of statistics of discharge of each stream at the road over the 15-day study. Data for all of the streams in Mazumbai were averaged and likewise all of the streams in Baga II were averaged. *The corrected averages represent the statistics recalculated without data from the Shamba Mayo or the Kwemubamba which were unreliable due to pooling at the measurement site.

The streams in Baga II showed greater variability, averaging a coefficient of variation of 0.88 compared to that of Mazumbai streams of 0.51. Data from one stream in Mazumbai, the Shamba Mayo, and one stream in Baga II, the Kwemubamba, were considered unreliable because the stream pooled at the road, making it impossible to measure velocity in a consistent way each day. When data from these streams were removed, the coefficient of variation for Mazumbai streams was 0.39 and for Baga II streams was 0.90. The least variable stream in Mazumbai was the Kwemapipa with a coefficient of variation of 0.32 and the most variable was the Shamba Mayo with a coefficient of variation of 0.99 (and if the Shamba Mayo is excluded because of its unreliable data, the Kwemahambalawe is the most variable with a coefficient of variation of 0.51). In Baga II, the least variable stream was the Kwengoto with a coefficient of variation of 0.42 and the most variable was the Hedeladja Mkonde with a coefficient of variation of 2.27. However, while the Mazumbai streams were less variable than the Baga II streams, the coefficients of variance of the Mazumbai streams and Baga II streams were not significantly different as the p value produced by an ANOVA test was 0.36 and 0.25 when the unreliable data from the Shamba Mayo and Kwemubamba were disregarded which exceeds the p value of 0.05 necessary to reject the null hypothesis that there is no difference between the variances of the streams in the two forests.

Correlation with Rainfall

Several Pearson's correlation tests were run comparing rainfall data and discharge for each of the streams including using a one-day time lag, representing discharge as the increase or decrease from the previous day, and using a daily rainfall threshold of 10 mm and comparing discharge to the number of days since a storm of that intensity. However, none of these modifications produced significant correlations for any of the ten streams. Table 3 shows the Pearson's coefficients and the p-values for the test comparing the increase/decrease in discharge from the previous day to the previous day's total rainfall for each stream. To better explain this test, discharge on November 12th would be subtracted from discharge on November 13th and related to the rainfall on November 12th to test how much the rainfall on the 12th caused the discharge to increase from what it was on the 12th to what it was on the 13th. In theory, this test best captures the relationship between rainfall on one day and streamflow the next day.

Stream	Forest	Pearson's Coefficient	p-value
Shamba Mayo	Mazumbai	-0.4458123	0.1693
Kwepanga	Mazumbai	0.09773571	0.775
Kwemahambalawe	Mazumbai	0.1929861	0.5697
Kwemapipa	Mazumbai	0.1195261	0.7263
Damilwai	Mazumbai	0.4786721	0.1364
Hedeladja Mkonde	Baga II	-0.4287534	0.1882
Kwengoto	Baga II	-0.1707689	0.6156
Dalajani	Baga II	-0.09137391	0.7893
Kwemubamba	Baga II	-0.09677125	0.7771
Kwavisi	Baga II	0.04496068	0.8956

Table 3: Results of a Pearson's correlation test between the change in discharge from the previous day and the amount of rainfall in the previous day on five streams in Mazumbai Forest Reserve and five streams in Baga II Forest Reserve ($p < 0.05$).

None of the streams had a significant correlation between the change in discharge from the previous day to the amount of rainfall in the previous day. Positive correlations between these variables were found for five streams and negative correlations were found on the other five. Four of the five Mazumbai streams had positive correlations and four of the five Baga II streams had negative correlations.

Discussion

To understand how forest management impacts streamflow in the West Usambara Mountains in Tanzania, discharge was measured on ten streams for fifteen days in November 2019. Five of the streams were located in Mazumbai Forest Reserve, a privately-managed pristine montane evergreen forest, and five were located in Baga II Forest Reserve, a neighboring reserve protected by the federal government with high prevalence of illegal wood extraction. It was found that there was no significant difference in discharge variability between Mazumbai and Baga II streams (Table 2). The average coefficient of variation for Mazumbai streams was 0.51 and 0.39 when unreliable data was removed while the coefficient of variation for Baga II streams was

0.88 and 0.90 when unreliable data was removed. There was also no significant correlation between discharge and rainfall for any of the streams under any of the tested variations of data manipulation including adding a one-day time lag, representing discharge in terms of change from previous measurements, and using a threshold of 10 mm of rainfall/day (Table 3).

These findings indicating there was no significant difference between discharge variability or the degree of correlation between discharge and rainfall indicate that illegal wood extraction from Baga II has not reached levels high enough to significantly impact the forest's hydrology. Literature indicates that by decreasing infiltration capacity, deforestation reduces the soil's ability to stabilize stream flow by absorbing water in times of high rainfall and recharging streams via subsurface flow in times of low rainfall. Since streamflow variability was not significantly greater in Baga II Forest Reserve (which served as this study's example of a degraded forest) than in Mazumbai (the pristine forest example), the regulatory function of subsurface storage must not be significantly reduced in Baga II in its current state. In examining the metadata describing the forest at the 32 locations (16 in Mazumbai and 16 in Baga II) where sampling occurred on every 500 m of each stream, there was very little noticeable difference in the composition and integrity of the forest (Appendix A). In the two forests, the average humus depth, canopy cover, and number of layers in the tree canopy were nearly identical and the plant species noted had a lot of overlap. There are limitations to drawing conclusions about forest integrity from these observations because these characteristics were only measured along the river rather than throughout the whole watershed. Canopy cover over the river is likely to be less than the rest of the watershed, humus depth is likely to be greater by the riverbank than upslope of the river, and vegetation composition is likely to have more light-seeking, riverine or edge species than in the rest of the watershed. Walking through the forests, however, no large patches of cut trees were noticed. This could be because the catchments of the Baga II streams that were studied were located in the forest interior rather than near the edge where deforestation is most prevalent. A study by Persha and Blomley (2009) found that while forest disturbance was more prevalent in Baga II than Mazumbai, this disturbance was concentrated within 500 m of the forest edge and when just the forest inside of this boundary was considered, Baga II exhibited levels of disturbance nearly as low as in Mazumbai and exhibited similar characteristics of an old growth forest. In addition to its position of relative protection in the interior of the forest reserve, its proximity to Mazumbai Forest Reserve may also provide enhanced protection. Extracting wood close to Mazumbai increases the chance of being caught by one of the numerous Mazumbai guards on patrol which could act as a deterrent (Kiparu, pers. comm., December 7, 2019). While illegal wood extraction may be more common in Baga II than in Mazumbai, there is not mass clear-cutting and a study found that satellites could only detect a 0.87% decrease in forested area in Baga II from 2002-2012 (Lugazo, 2017). A review of 95 studies on deforestation and stream discharge found that measurable change could not be detected when less than 20% of the catchment had been harvested/cleared (Stednick, 1996). However, that review focused on studies just in the United States, so this threshold may differ in a tropical montane rainforest climate like the West Usambaras.

The lack of significant difference in discharge variability between Mazumbai and Baga II streams could also be attributable to the limitations and biases of this study. The methods for discharge measurement were not highly accurate which could have influenced the results strongly because the streams were very small. The fluctuations in discharge were so small that small inaccuracies in measuring stream width or depth or stopping the stopwatch fractions of seconds late could have caused these tiny fluctuations to not be properly demonstrated in the data. While the data shows no correlation with rainfall for any of the streams, three streams in Baga II had visibly different flow during dry and wet periods of the study. At the start of the study, the Kwengoto was overflowing its banks at the road, the Hedeladja Mkonde was flowing, and the Kwemubamba pooled in a large area. In the middle of the study when there had been several dry days in a row, the Hedeladja Mkonde dried up at the road, the Kwengoto retreated to its banks, and the spot where the Kwemubamba pooled at the road dried up in the middle creating an island of dry mud with two small pools to the side. At the end of the study after a few days of intense rain, the Kwengoto overflowed its banks again but the rainfall was insufficient to recharge the Hedeladja Mkonde to make it flow above ground again and the Kwemubamba still had the dry patch in the middle of the pooling area. This was not reflected in the data though because the discharge measurements were so inaccurate. It is interesting that all three of these streams were in Baga II and no noticeable changes in discharge were detected for any of the Mazumbai streams which would indicate that discharge of Baga II streams was more impacted by rainfall than Mazumbai streams.

Another limitation was that it was impossible to compare stream discharge directly from one stream to another because the catchment sizes differed, but the area of the catchments was impossible to measure using a geographic information system because the digital elevation model that was available was too low resolution (30 m) to detect the small hills that formed the catchment boundaries. Because of this, discharge could not be compared directly from stream to stream, so daily variability and correlation with rainfall were the only ways the streams could be compared. The range of rainfall that was captured during the study (0-20 mm/day) also only reflects variability for the month of November whereas on a yearly timescale, there is a larger range of rainfall which would likely cause greater variation in stream discharge. The range of rainfall over the study period is much smaller than historical data which shows Mazumbai has had days with over 100 mm of rainfall (Lundgren & Lundgren, 1979).

Conclusion

Over fifteen days of data collection, this study has found that differing forest management of Mazumbai Forest Reserve and Baga II Forest Reserve has not led to significant differences in stream discharge variability or differences in correlation with rainfall on the ten streams that were monitored. While previous studies have indicated that illegal wood extraction is much more common in Baga II than Mazumbai, the levels of deforestation in Baga II are not high enough to impact stream flow. Given these conclusions, it can be predicted that streamflow in both forests will be similarly consistent. However, recommendations can be made as to which streams provide consistently high volumes of water. The Kwemapipa and the Kwengoto had the highest discharge at the road and the lowest coefficients of variation out of the Mazumbai and Baga II streams respectively. The Kwemapipa had higher discharge and lower variation than the Kwengoto, so it is likely the most reliable water source. The Hedeladja Mkonde is not recommended as a water source because it dried up at the road after a few days without rainfall. The stream map created in this study can be used to disseminate information about the locations of the streams for easier access to water resources and to aid future studies. From the perspective of maintaining streamflow regularity, no recommendations can be made to the management bodies of either forest because current differences in management have not created significantly different streamflow variabilities. Further studies are needed to make any recommendations on this subject. However, both management bodies need to maintain their protective functions to sustain the current conditions of the forests and their streams.

To address some of the limitations of this study, future studies on stream discharge and forest management should use more precise instruments like a flume or weir to measure discharge. Additionally, future studies would better be conducted over the time span of a year or multiple years. With a study lasting at least a year, discharge and rainfall data could be analyzed on a monthly time scale to capture more drastic differences in discharge as rainfall fluctuates from wet to dry season. Creating a high-resolution digital elevation model would also aid research on streams by facilitating measurement of catchment areas which is necessary to compare discharge from one stream to another. DEMs of 10 and 15 m resolution exist for Tanzania, but they are not publicly available and even higher resolution DEMs could be created by mapping just Mazumbai and Baga II in high detail, potentially by using drones. Future studies can also focus on hydrological processes at the soil level by measuring infiltration, runoff, throughfall, and interception in each forest. A study of this kind could be used to confirm or refute the explanations in the present study that lack of difference in infiltration capacity and canopy cover between the two forests is why discharge variability and rainfall-discharge correlation is not significantly different between the forests. The stream map created in this project can be used to guide future researchers aiming to study these or other stream-related questions.

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Appendix A- Metadata

At the 16 sites in Mazumbai and 16 sites in Baga II where discharge was measured every 500 m along each river, metadata was also recorded. Humus depth was measured, canopy cover was estimated, canopy height was estimated and layers were categorized, slope was classified, and the names of some plants were recorded. Below are tables summarizing these observations.

Humus Depth, Canopy Cover, and Canopy Structure Summary

Metadata Parameter	Mazumbai	Baga II
Average Humus Depth	16.9 cm	17.7 cm
Average Canopy Cover	42.3%	42.0%
Average Number of Canopy Layers	1.9	1.8

Slope Categorization

The number of plots in each forest categorized under each slope classification are presented below.

Slope Classification	Mazumbai	Baga II
Gentle Slope	4	5
Mid-Gentle Slope	2	2
Mid Slope	2	3
Mid-Steep Slope	3	3
Steep Slope	5	3

Vegetation

The number of plots in each forest where each plant was present are presented below in order of frequency. The Latin names for plants are given when known and the Sambaa name is given if not (with the exception of banana and maize in English).

Plant name	Mazumbai	Baga II

aphloia theiformis	3	5
faurea saligna	5	3
albizia gummifera	3	4
zinge	3	4
fuzia	3	3
kiandama	2	4
kidadaishi	1	5
mhande	3	3
mkuyu	3	3
ong'e	3	3
mbawa	3	2
millettia dura	3	2
veronia myriantha	1	4
deinbollia kilimandscharica var. adusta	0	5
allanblackia stuhlmannii	3	2
shiu	3	2
banana	3	2
eza	1	3
myrianthus holstii	1	3
zanthoxylum gilletii	2	2
syzygium cordatum	3	1
maesalancelata	2	2
ndelema	2	2
maize	2	2
hombo	2	1
mg'wiza	2	1
casearia engleri	1	2
ocotea usambarensis	2	1
fagaropsis angolensis	2	1
mnavu	3	0
newtonia buchananii	1	2
msongoma	2	1
parinari excelsa	1	2
piper capense	2	1
papata	3	0
strombosia scheffleri	2	1
shungamzinga	2	1
toamaghasa	0	3
brugmansia suaveolens	1	2

boho	1	1
gimbi	2	0
gugufa	1	1
neoboutonia marcocalyx	1	1
toddalia asiatica	1	1
mfenesi	1	1
trichilia emetica	1	1
mhende	2	0
macaranga kilimandscharica	1	1
pupalia atropurpurea	1	1
ficus exasperata	2	0
mtaanda	1	1
muuka	0	2
ngaghe	1	1
ngoe	1	1
nkongo	2	0
nyangalanyangala	1	1
zia	1	1
ghoe	0	1
hozandogho	1	0
jeni	0	1
kanandae	1	0
cissus rotundifolia	1	0
king'ee	0	1
kingoe	0	1
koa	0	1
mbokoboko	1	0
mhoshwe	0	1
mhumba	0	1
mkeche	0	1
mmandai	0	1
mndeemzize	0	1
mndoo	1	0
mntaango	0	1
msaa	1	0
myrica salicifolia	1	0
mshichwi	1	0
syzigium guineense	0	1
trema orientalis	0	1

croton macrostachyus	0	1
mshunga	1	0
mtambakuzimu	1	0
mtambangoshwe	0	1
bersama abyssinica	0	1
muimo	1	0
muinu	0	1
muinukanguu	1	0
erythrina caffra	0	1
vangueria infausta	0	1
ficus thonningii	1	0
nkoko	0	1
nkondoti	1	0
puishi	1	0
shindakaya	1	0
shukizi	0	1
tikini	0	1
tindi	1	0
tua	1	0
tuanange	0	1
rytigynia schumannii	0	1
tughutu	0	1
ugoloto	0	1
ushwe	1	0
utaangoshwe	0	1
zaake	0	1