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Kihansi spray wetlands under mitigation measures and its implication to the biodiversity of the resultant ecosystems

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Abstract

Originally, the Kihansi River Falls produced sprays that created microhabitat with high humidity and low temperatures. These microhabitats were the only habitats for Kihansi Spray Toad (KST) *Nectophyrinoides asperginis*, while adjacent forest supported other endemic species. However, in 1999 the Kihansi Hydropower Project diverted over 90% of the water from Kihansi River to the reservoir resulting into population crash of some wetland dependent species due to dryness. In 2001, artificial sprinklers were installed in three spray wetlands within the Kihansi Gorge (KG) to mitigate effects especially for KST, which unfortunately were declared extinct in the wild in 2009. Wetlands and forest microclimate under these mitigation measures were examined from 2010 to 2012 using data loggers set and left in the study sites to record temperature and humidity. Data were then downloaded and analysed. Temperature and relative humidity (RH) showed variation according to location and time but remained within tolerable limits for KST survival (16-21°C;60-100%) with varying mean differences at -0.860°C (2010), -0.585°C (2011), and 0.274°C (2012) and RH (±9.576%) between 2010 and 2012. Temperatures were significantly higher in adjacent forest than in wetlands and vice versa for RH suggesting that species outside the artificially maintained wetlands currently experience considerable dryness. This indicates that, the collapse or terminating artificial sprinklers may cause immediate negative effects to the ecosystem, and especially the endemic species. Thus, a long-term monitoring program and expansion of the artificial sprinklers are recommended for the healthier KG ecosystem.

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Introduction

Kihansi Gorge (KG) is located in the Eastern Arc Mountains within the Eastern Afromontane and Coastal Forest Hotspot (Lee *et al.*, 2006). It has an interesting wetland ecosystem created by the Kihansi River that traverses along a rapid raised mass of the Udzungwa Escarpment. A combination of the high altitude, water falls, and forest patches gives this Gorge the characteristic microclimate. This created a special ecosystem comprising of spray wetlands and the adjacent forest. The mentioned wetlands are the original habitat for the Kihansi Spray Toad (KST) *Nectophyrinoides asperginis* (Poynton *et al.*, 1999), *Arthroleptides yakusini* (Channing *et al.*, 2002), the unique high diversity of the spray wetland vegetations, the high diversity of wet environment adapted insect that comprise of the KST food. The adjacent forest accommodates the water and humidity sensitive plants like the Wild Coffee *Coffea kihansiensis* (A. P. Davis and Mvungi) and the Cheek species (triuridaceae) *Kupea jonii* (Cheek) and *Kihansia lovetii* Cheek which are endemic to the KG and highly threatened to extinction (Davis and Mvungi, 2004). A diversity of about nine species of anurans exists in the adjacent forests and is supported by the high humidity and low temperatures

In 1990s, the Government of Tanzania was attracted by the Kihansi River structure to invest on hydroelectric production (Hirji and Davis, 2009). Construction of the hydropower plant including the 1.6 Million m^3 reservoir started in 1994 and was completed in 1999 (Channing *et al.*, 2006; LKEMP, 2011, NEMC, 2011). While construction of the Hydropower plant had began, in 1996 in the four (4) ha area below the reservoir there was discovered the KST (Channing *et al.*, 2006; Hirji and Davis 2009; LKEMP, 2011). The whole ecosystem below was also discovered to be sensitive to water flow (LKEMP, 2011). There were about six places where the spray meadows were created and these contained special wetland vegetation that remained short due to heavy winds and continuous spray. In 1999 the Hydropower plant was commissioned (Channing *et al.*, 2006; LKEMP, 2011). Over 90% of the water was directed into the dam and then to the Hydropower plant through the underground tunnel (LKEMP, 2011). The entire KG underwent considerable desiccation (Channing *et al.*, 2006; LKEMP, 2011). In 2001 mitigation measures were put in place to rescue the newly discovered Spray toad and the KG ecosystem as a whole (Channing *et al.*, 2006; LKEMP, 2011). About 500 KSTs were taken into the USA zoos as the assurance population colony (Hirji and Davis 2009; LKEMP, 2011). The remaining population of the KST in the KG declined in number (Hirji and Davis, 2009; LKEMP, 2011). In 2001 the bypass flow from the reservoir was opened and in three wetlands the artificial sprinklers were installed to mimic the original spray. The main aim was to maintain the sprays in the wetlands for the KSTs including improving the microclimate of the spray wetlands and the adjacent forests. The KSTs improved in number and health status. Suddenly in 2003 through 2004 KST population crashed (LKEMP, 2011). In 2009 KST was described by IUCN as a Wild Extinct Species (Channing *et al.,* 2009; LKEMP, 2011).

Artificial sprinkling was maintained and different parameters including wetland vegetation, wetland vegetation insects that comprise of the KST feeder insects, microclimate and water flow have been monitored to observe the improvement. In 2012 an attempt was done to reintroduce the KST back to the KG and these efforts are ongoing. Reintroduced individuals are drawn from the breeding facility at Kihansi station, University of Dar es Salaam and two zoos in the USA.

Little effort has been done to document the information about microclimate before and after water diversion of this area. Many of the studies in this area report on microclimate of the gorge but are not specific to locations and season of the year (Channing *et al.*, 2006; Rija *et al.*, 2011).

This study was carried out in order to observe the trend of the microclimate parameters mainly temperature and relative humidity in the rehabilitated spray wetlands and adjacent forests after about 10 years of water diversion and considerable desiccation of the wetland and the construction of the artificial sprinklers, such information are crucial to support restoration programs. We report the variation of the microclimate between different locations in the wetlands and the adjacent forest, the trend and variation of the microclimate (temperature and humidity) between the different months of the year and variation between the years. Rainfall was recorded throughout the study period at four permanent stations in the KG. We also provide a list of the Amphibian recorded in the spray wetland and adjacent forest between 2010 and 2012.

Materials and methods

Study area description

Kihansi Gorge is located in the Southern part of the Udzungwa Mountains Scarp in the Eastern Arc Mountains (Quinn *et al.*, 2003). It is located at S 8°35', E 35°51' about 600 km East-south from Dar Es Salaam (Quinn *et al.*, 2003; Channing *et al.*, 2006). The KG is approximately 4 km long. The spray wetlands where the KSTs were discovered were about 4 ha but are now estimated to be not more than 2 ha. These are currently receiving the artificial spray from the artificial sprinklers. The area receives annual rainfall between 1,000 mm to 3,200 mm (LKEMP, 2011). The study site spans between altitudes of 650 m a.s. l. to 975 m a.s l.

Study sites and data collection

The study was carried out in the KG Spray Wetlands and the adjacent running forest. Electronic data loggers "DataHog 2" by Skye Instruments Limited 2008 were deployed in the field and recorded the data remotely for a range of two to three months in different periods of the year from 2010 to 2012. The calendar year was divided in four periods of three months each. The data was collected for two to three months on the base of the data logger battery life. The data loggers were calibrated in a uniform temperature room before they were taken to the field. The study was conducted at some permanent positions (Fig. 1) in the spray wetlands and adjacent forest that were set for the purpose of ecological monitoring since 2002. The three wetlands namely Upper Spray Wetland (USW), Lower Spray Wetland (LSW) and Mid Gorge Spray Wetland (MGSW) are currently artificially sprinkled to mimic the original situation whereas the Mhalala Spray Wetland (MSW) is naturally sprayed depending on the Mhalala Stream that joins the Kihansi Main stream at LSW (Fig. 1). Stations LK 1 and LK 2 are located at USW, LK 4 at the Upper Spray Forest (USF) (the forest adjacent to the USW), LK 7 at Lower Spray Forest (LSF) (the forest adjacent to the LSW), LK 5 and LK 12 at LSW, LK 6 at the entrance of the LSW, LK 8 at MSW and LK 19 and LK 20 are located at MGSW.

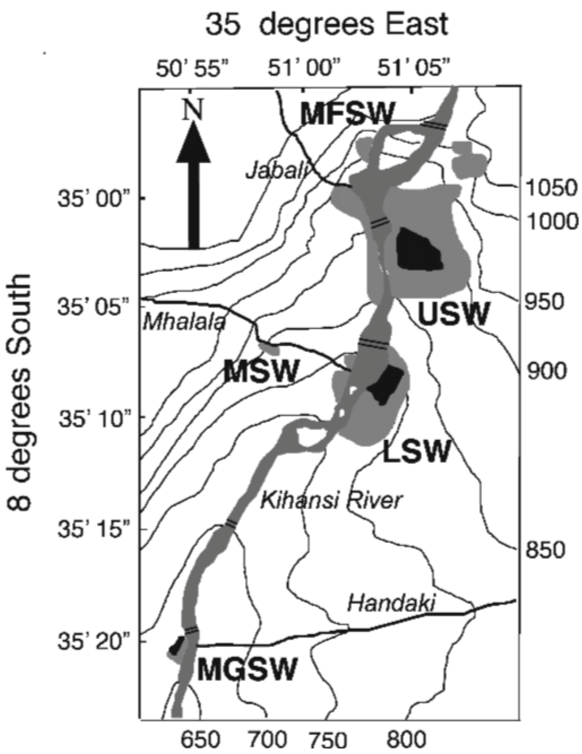

Fig. 1. Study area showing the Spray Wetlands.

Rainfall data were recorded for the 2010-2012 period for the whole KG at four permanent stations. These include the Upper Spray Forest (USF), the Rungwe Camp (Rungwe), the Suspension Bridge (SB) and the Lower Kihansi Forest (KLF).

Amphibian survey was also conducted throughout the study in the spray wetlands and the adjacent forest. The surveys were visual and were conducted in day and during the night based on the present/absent that aimed at obtaining the number of anurans species likely to benefit from mitigation measures.

Data analysis

Data were analysed with the Generalized Linear Model (GLM) with SPSS version 12 to check the general relationship between temperature; relative humidity against location, month, and year of the study. Interactive graphing of the year 2010 was also produced in support of the main results. The general relationship was: Intercept + location * MONTH * YEAR + location + MONTH + YEAR. All the tests were verified by Least Significant Difference (LSD) in a GLM Post-Hoc Comparison.

T-test analysis was performed to examine the difference in means of both temperature and RH for a group of data loggers that were located in the spray wetland against the group of data loggers that were located in the adjacent forest. We used univariate analysis to examine differences in rainfall between and among the study stations, the month of the year and the years through out 2010 to 2012.

Results

Microclimate in the Gorge Spray wetland stations

Through multiple comparison of the GLM, Multivariate tests for both temperature and RH were statistically significant (Wilks'Lambda) with intercept ($F_{2, 1514}$=278868.3), an interaction between location of the data logger, month and year of data collection (p<0.001, $F_{108, 3028}$=21.035), location of the data logger (p<0.0005, $F_{18, 3028}$=139.651), month of data collection (p<0.001, $F_{20, 3028}$=134.674) and year of data collection (p<0.001, $F_{4, 3028}$=42.935); R Squared = 0.826.

Spatial variation: Temperature, Relative Humidity with location

The multiple comparisons for individual location temperature and RH with variations between other locations are summarized in Table 1 and 2. The positions in the wetlands have lower temperatures and high relative humidity compared to the positions in the adjacent forest (Table 1 and 2). The positions at the lower altitude have relatively higher temperature and lower relative humidity as compared to those at higher altitude e.g. LK 19 versus LK 1 (Table 1 and 2). The results for individual year's temperature and RH were consistent with the general results above for example for the year 2011 shown in Fig.s 2 and 3.

Table 1. Spatial variation of temperature with location at Kihansi Gorge between 2010 and 2012.

Loca-tion	Estimated marginal means	Highest significant temperature difference	Location with the highest significant temperature difference	Lowest significant temperature difference	Location with the Lowest significant temperature difference	Number of Locations with insignificant difference	Location ID with insignificant temperature Difference
LK 1	19.383	0.778	LK 12	-1.436	LK 20	1	LK 6
LK 2	19.105	0.443	LK 12	-1.771	LK 20	1	LK 6
LK 4	20.700	1.948	LK 12	-0.266	LK 20	2	LK8, LK 20
LK 5	18.924	1.367	LK 12	-0.847	LK 20	1	LK7
LK 6	19.950	0.524	LK 12	-1.690	LK 20	1	LK2
LK 7	18.501	0.524	LK 12	0.758	LK 20	1	LK 5
LK 8	20.309	1.861	LK 12	-0.353	LK 20	3	LK 4, LK19, LK20
LK 12	20.109	-0.443	LK 2	-2.214	LK 20	0	-
LK 19	20.624	1.764	LK 12	-0.450	LK 20	1	LK8
LK 20	21.017	2.214	LK 12	0.266	LK 4	2	LK 4,LK 8,

Table 2. Spatial variation of Relative Humidity with location n the Kihansi Gorge between 2010 and 2012.

Location	Estimated marginal means	Highest significant RH difference	Location with the highest significant RH difference	Lowest significant RH difference	Location with the Lowest significant RH difference	Number of Locations with insignificant difference	Location ID with insignificant RH Difference
LK 1	82.111	7.498	LK 8	-18.815	LK 20	1	LK6
LK 2	87.399	13.779	LK 8	-12.534	LK 20	1	LK 7
LK 4	84.671	12.565	LK 8	13.748	LK 20	2	LK2, LK7
LK 5	82.844	26.164	LK 8	-0.149	LK 20	2	LK 12, LK 20
LK 6	87.547	8.933	LK 8	-17.380	LK 20	1	LK1
LK 7	98.406	14.049	LK 8	-12.264	LK 20	2	LK 2, LK4
LK 8	95.258	-7.498	LK 1	-26.313	LK 20	0	-
LK 12	99.839	24.646	LK 8	-1.666	LK 20	2	LK5, LK20
LK 19	74.319	22.675	LK 8	-3.638	LK 20	0	-
LK 20	100.000	26.313	LK 8	0.149	LK 5	2	LK 5, LK12

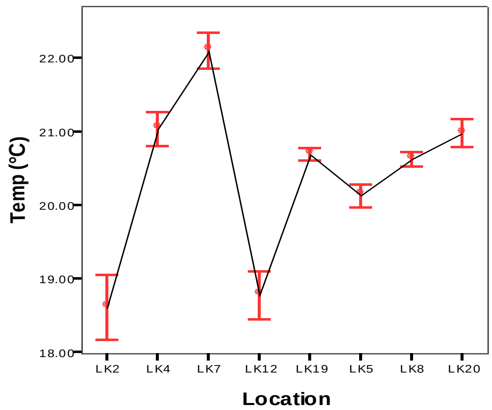

Fig. 2. Temperature in the Kihansi Gorge 2011 showing locations in the spray wetlands and adjacent forest.

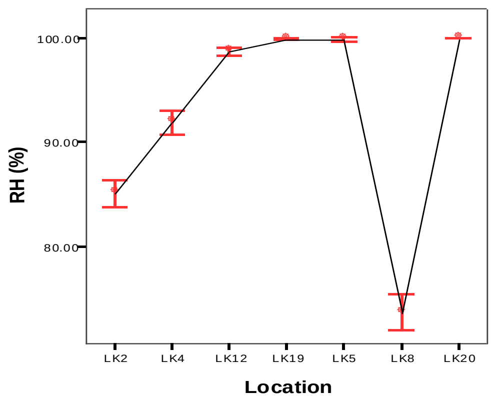

Fig. 3. Relative Humidity (RH) in the Kihansi Gorge 2011 showing locations in the spray wetlands and adjacent forest.

Temporal variation: temperature, Relative Humidity with months, year

Both temperature and RH varied significantly for the annual cycle (Appendix I). Multiple comparison between the study years indicated significant diffrences from 2010 to 2012. LSD of the GLM indicated that temperature in 2010 varried significantly with temperature in 2011 (Mean Difference -0.860 °C, $p<0.001$) and temperature in 2012 (Mean Difference -0.585 °C, $p<0.001$). Likewise 2011 temperature differed significantly with 2012 (Mean Difference 0.274 °C, $p<0.001$). Throughout the year temperature decreases from January to July when it is the lowest and then increases till December when it is maximum again (Appendix I). For example the lowest recorded temperature in 2010 was in June (12.71°C at LK 2). Unlike temperature relative humidity peaks up from January to April and is lowest during September (Appendix I).

Microclimate: spray wetland versus adjacent forest

A comparison of wetland stations with the adjacent forest stations indicated a significance difference in both temperature and RH. Group statistics show that temperature in the spray wetlands was as low as 19.56 °C while in the adjacent forest temperature was as high as 20.57°C. Likewise RH was as high as 91.64% compared to 86.15% in the adjacent forest. Temperature and RH varied significantly ($p<0.001$,

$t_{853.246}$=-11.441 and RH; p<0.001, $t_{888.711}$=10.393). The temperature mean difference was -1.01°C while the RH was 5.48%.

Appendix I. Annual Microclimate Mean Differences in the Kihansi Gorge 2010-2012.

Dependent variable	Estimated marginal Means	Reference month	Mean Difference (I-J)				No. Of months with significance
			Highest Mean Difference (°C)/%	Month	Lowest Mean Difference (°C)/%	Month	
Temperature	21.918°C	January	5.111°C	July	0.778°C	December	9
	21.472°C	February	5.012°C	July	0.679°C	December	9
	20.577°C	March	4.130°C	July	-0.981°C	January	9
	19.699°C	April	3.239°C	July	-1.872°C	January	9
	19.383°C	May	3.159°C	July	-1.952°C	January	9
	17.940°C	June	1.385°C	July	-3.726°C	January	10
	16.536°C	July	-1.385°C	June	-5.111°C	January	10
	19.128°C	September	1.837°C	July	-3.274	January	10
	20.220°C	October	3.413°C	July	-1.670	January	10
	20.751°C	November	4.234°C	July	-0.877	January	8
	21.018°C	December	4.333°C	July	-0.778	January	9
RH	90.571%	January	12.713%	October	-2.750	April	9
	93.201%	February	12.045%	October	-3.418	April	9
	95.868%	March	14.732%	October	-0.732	April	9
	96.620%	April	15.463%	October	0.732	April	9
	92.607%	May	8.077%	October	-7.386	April	8
	86.528%	June	7.406%	October	-8.057	April	9
	89.717%	July	9.280%	October	-6.183	April	9
	77.937%	September	1.653%	October	-13.810	April	9
	82.846%	October	-1.653%	September	-15.463	April	9
	88.503%	November	6.316%	October	-9.148	April	9
	88.940%	December	8.436%	October	-7.027	April	9

The stations in the spray wetlands have lower temperature and higher relative humidity as opposed to the locations in the adjacent forest. However MHSW (LK 8) that receives only the natural sprays experienced a dry condition during the dry season (Fig. 2 and 3).

Rainfall

Rainfall results for the year 2010-2012 are shown in Fig. 4. In the year 2010 the KG received about an average rainfall of 1,747.03 mm, 1, 686.00 mm in 2011 and 1,137.00 mm in 2012.

The highest rainfall was recorded at USF with about 1,946.80 mm in the year 2010 while the lowest recorded rainfall was about 1,555.00 mm at KLF in the year 2012 (P<0.001; $F_{3;66}$=48.112) (P<0.001; $F_{3;66}$=48.112). Consequently the highest rainfall was recorded in 2010 and the lowest in 2012 (P<0.001; $F_{2;66}$=228.405; R Squared = 0.997).

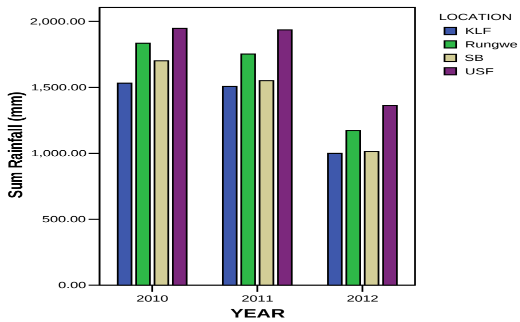

Fig. 4. Rainfall pattern in the Kihansi Gorge 2010-2012.

Drier months were July, August, September and October recording between 0.00 mm and 1.00 mm mostly in 2010 and 2012. Highest rains were recorded to be 665.00 mm in April 2011(P<0.001; $F_{11;66}$=1411.181; R Squared = 0.997).

Amphibians

During the study period we recorded twelve species of anurans in the KG (Table 3). Some species like

Arthloreptides yakusini and *Arthloreptis stenodactylus* were observed in the wetlands at daylight and during the night. Other species such as *Leptopelis uluguluensis* though not wetland dependant species, moved into the spray wetland for obtaining moisture. *Nectophrynoides tornieri* usually inhibit the edge of the spray wetlands and rarely enters the spray zone.

Table 3. Amphibian species in the Order Anura recorded in the Kihansi Gorge between 2010 and 2012.

Class	Order	Family	Genus	Specific Epithet	Scientific Name	Scientific Name Authorship
Amphibia	Anura	Bufonidae	*Nectophrynoides*	*tornieri*	*Nectophrynoides tornieri*	Roux, 1906
Amphibia	Anura	Bufonidae	*Nectophrynoides*	*asperginis*	*Nectophrynoides asperginis*	Poynton, Howell, Clarke and Lovett, 1999
Amphibia	Anura	Bufonidae	*Mertensophryne*	*micranotis*	*Mertensophryne micranotis*	Loveridge, 1925
Amphibia	Anura	Arthroleptidae	*Arthroleptis*	*stenodactylus*	*Arthroleptis stenodactylus*	Pfeffer, 1893
Amphibia	Anura	Arthroleptidae	*Scheutedenella*	*xenodactyla*	*Schoutedenella xenodactyla*	Boulenger, 1909
Amphibia	Anura	Hyperoliidae	*Afrixalus*	*fornasini*	*Afrixalus fornasini*	Bianconi, 1849
Amphibia	Anura	Hyperoliidae	*Hyperolius*	*puncticulatus*	*Hyperolius puncticulatus*	Pfeffer, 1893
Amphibia	Anura	Hyperoliidae	*Leptopelis*	*uluguruensis*	*Leptopelis uluguruensis*	Barbour & Loveridge, 1928
Amphibia	Anura	Ranidae	*Ptychadena*	*anchietae*	*Ptychadena anchietae*	Bocage, 1867
Amphibia	Anura	Ranidae	*Ptychadena*	*mascareniensis*	*Pytachiedinae mascareniensis*	Duméril & Bibron, 1841
Amphibia	Anura	Ranidae	*Arthroleptides*	*yakusini*	*Arthroleptides yakusini*	Channing, Moyer, and Howell, 2002
Amphibia	Anura	Rhacophoridae	*Chiromantis*	*xerampelina*	*Chiromantis xerampelina*	Peters, 1854

Discussion

Temperatures and relative humidity are important parameters for the survival and population performance of anurans in any location (shoo *et al.*, 2011). We studied the microclimate of the KG from 2010 to 2012. The results describe the general tendency of the microclimate in the KG especially in the Spray Wetlands and the adjacent forest. Microclimate of the KG is the function interaction of combined factors including location i.e. the position where the data logger was located, the month and year in which the data were taken. This shows dynamism in the temperature and relative humidity in the KG depending on the location, month and year of the study.

Spatial variation: Temperature, Relative Humidity with location

Looking at the results, spatial distribution of the data loggers provided us with valuable information. This shows that though some areas are sprinkled by the same system there is still variation in microclimate parameters. Lower positions for example at MSW had higher temperatures than higher locations at USW and vice versa for RH. This does not mean redundancy of the sprinklers contribution into the microclimate at USW but the altitude adds some degree in the microclimate of the area.

Temporal variation: temperature, Relative Humidity with months, year

The annual cycle pattern in the results is important for providing ecological information about some organisms that follow an annual cycle for reproduction. Annual cycle pattern observed seems favourable for reproduction of most of the anurans in the KG that starts with the shorter rain season from early November to May (Channing *et al.*, 2006).

There has been an annual variation since 2010 to 2012. The marginal means of temperature was approximately 19.3°C in 2010 and was as high as 20.20°C in 2011 and then down to approximately 19.80°C in 2012. RH has been increasing from 2010 to 2012 ranging from 85% to 95%. This is a good trend for the amphibians' life as well as the whole ecosystem functions. Despite of lower rainfall in 2012 temperatures were still low in the whole gorge for 2012.

Microclimate: spray wetland versus adjacent forest

A comparison of spray wetlands and the adjacent forest indicated variations in both temperature and relative humidity. The difference is contributed by the little flow mist remaining and largely by the artificial sprinklers. This is a special condition where ecological engineering contributes to microhabitat creation in the KG by creating low temperatures and high humidity. This is a good environment for the KST and other organisms in the area.

There was a notable difference in both temperature and relative humidity due to the influence of the artificial sprinklers. This would compromise the well being of the KST to be reintroduced if they are not attended accordingly. However both temperature and relative humidity are still within the ranges (16-21°C; 60-100%) at which KST survives within the captive environment (Channing *et al.*, 2006). According to LKEMP (2003) the temperature without the sprinklers was as high as 30°C in September 2002 and RH of about 50% at the centre of the USW in the KG. This is a lethal temperature for the KST (Msuya pers. Com). Shoo *et al.* (2011) commend the importance of sprinkler system that is ecologically driven engineering that protects the microclimate and hence the microhabitat for the amphibians and the ecosystem as whole.

Currently Microclimate of the KG in terms of temperature and relative humidity is characteristic of the headwater falls sprays in the riparian area, buffer zone between the riverbank and the spray wetland zone, the spray wetland zone and the adjacent forest during heavy rains. During the dry season microclimate depends mainly on artificial sprinkling of low temperature water from the highlands.

The spray zone where the spray wetlands lie has relatively cooler microclimate- low temperature as low as 12.71°C and 99.88% RH (LK 2 -2010 May and June, respectively). The spray forest zone is slightly warmer as 20°C to 25°C and 90-65% RH. KST survive well in the spray zone (Channing *et al.*, 2006). Eight anuran species in the KG have been reported at different time to be found in the spray wetlands and the ecotone between the forest and the spray wetlands. This signifies the importance of the combination of microclimate due to waterfalls (artificial sprays) and the forest edge microclimate.

Hawkes *et al.*, (2006) also show that the spray wetlands vegetations are critical to the KST feeder insects mainly the water tolerant dipterans that also support other anurans in these areas. These wetland vegetations are also important to the survival of the KST and other anurans by providing hiding, perching and hunting opportunities. A vegetation monitoring study in 2012 by the University of Dar es Salaam commended the wetlands vegetations as going back to the pre-diversion state (H. Ndangalasi pers. Com.). The performance of these vegetations is a function of high RH, low temperature, heavy winds and sprays from the river falls (Zilihona *et al.*, 2004). However these are suitable conditions for the chytrid fungus (Skerratt *et al.*, 2007) that threatens the world amphibian populations and is suggested as one of the causes of extinction of the KST in the KG.

Rainfall

The variations in rainfall recorded are attributed to the altitude of the station where the rain gauges were located. USF is about which recorded highest rains in each year is approximately 916 m. a.s. l. while KLF which recorded the lowest rainfall is approximately 571 m. a.s.l.

High rainfall also contributes to the high river flows. In the March-May period the reservoir usually overflows and the KG goes back to the pre-diversion period state. Artificial sprinklers during this period contribute less to the microclimate of the spray wetlands.

Amphibians

The spray forest is important for the survival of other anurans like the leaf litter toads (*Arthroleptis Spp*.). Furthermore it contributes to the microclimate as a result of the forest edge effect (Newmark, 2001). This area is crucial as it supports important woody and non woody plant community with different important conservation status like Critically Endangered *Coffea kihansiensis* (Davis and Mvungi, 2004; Rija *et al*., 2011) and triuridaceae family.

Conclusions

This study has observed the difference in both temperature and relative humidity within the recording stations in the spray wetlands, a difference of both parameters for stations in the adjacent forest, a difference in both parameters between the years throughout the study time. Temperatures were higher in adjacent forest than in wetlands and vice versa for RH. It is important to maintain the artificial sprinklers for the well being of the Gorge ecosystem. This is very critical now that since 2012, the re-introduction program of the KST has been taking place necessitating a close monitoring of the reintroduced individuals who are bred at University of Dar es Saalam, Kihansi Station, and Toledo and Bronx zoos in the USA facilities. Species in the forests currently experience considerable dryness signifying insufficient mitigation measures to the whole gorge ecosystem and hence further actions, which could include expansion of the sprinklers to cover the original spray wetland habitats, are required.

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