Validation of the Weather Generator CLIGEN with Precipitation Data from Uganda

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ABSTRACT. Precipitation records from highland and central plains sites in Uganda were used to validate the CLImate GENerator (CLIGEN) weather sequence generator. Daily records from twenty years and recent records of recording gage data were used to evaluate the generator. Results show that the generator was successful in modeling the annual and monthly precipitation totals, the monthly probabilities of wet and dry days, and predicted average storm duration. There were some differences in some of the standard deviations between observed and generated values.

KEY WORDS. Africa Stochastic Climate

Since 1985, the U.S. Department of Agriculture (USDA) has been developing a process-based soil erosion model for extension agents and government planners to assess levels of nonpoint soil erosion and surface water sedimentation. This has resulted in the development of the Water Erosion Prediction Project (WEPP) computer model (Flanagan and Livingston, 1995). WEPP was developed as a physically-based model so that it could be applied to a wide range of topographies, vegetative scenarios, soil conditions, and climates. The WEPP model requires daily climate including rainfall amount and duration. A relatively simple technology was needed to accompany WEPP to provide such a daily climate. A separate climate generator, CLImate GENerator (CLIGEN), was therefore adopted to generate the climate files required by the WEPP program (Nicks et al., 1989). The statistical algorithms in CLIGEN were based on climates in the Midwest and southern U.S. Baffaut et al. (1996) determined that when WEPP was driven by CLIGEN-generated files, it gave similar geographic trends in rainfall erosivity to the Revised Universal Soil Loss Equation (RUSLE) erosivity maps (Renard et al. 1991). They did, however, find that there could be unexpectedly high variations in erosion rates predicted by WEPP due to differences in generated climates between nearby stations. There were no apparent differences in the climate statistics of those stations. Baffaut and others proposed that a smoothing

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algorithm be developed to reduce this variability. They also suggested that for erosion prediction, periods of climate greater than 30 years are necessary to reduce average annual variability. There study was limited to continental U.S. climates only. In order to use the CLIGEN technology outside of the U.S., particularly in the tropics, the ability of the generator to capture the variation of these climates should be tested.

There are significant differences in the weather patterns between the central U.S. and many other climate patterns not only in the U.S., but in the rest of the world (Trewartha and Horn 1980). If CLIGEN is found to be sufficiently robust to generate climates for these other areas, then natural resource modelers will be able to focus research activities elsewhere, using CLIGEN to provide typical weather sequences to drive their models. Arnold and Elliot (1996) found that CLIGEN generated climates with similar seasonal and day to day rainfall patterns, and similar lengths of wet spells and dry spells. They did not analyze the ability of CLIGEN to predict daily, monthly, and annual precipitation mounts. The objective of this paper is to evaluate the ability of CLIGEN to generate satisfactory precipitation statistics outside of the central U.S. by comparing the CLIGEN-generated and observed rainfall amounts, probabilities of occurrence, and durations for two sites in Uganda.

The CLIGEN Model

The input file to CLIGEN contains statistics from observed precipitation records described in table 1. The outputs of CLIGEN can be set to model a weather record of any length, up to 999 years. The CLIGEN output file contains the rainfall amount, storm duration, maximum intensity and time to peak intensity for each day of precipitation formatted for the WEPP model.

The algorithms in CLIGEN are based on the climate generators developed for the Erosion-Productivity Impact Calculator (EPIC) model (Williams et al., 1984) and the Simulator for Water Resources in Rural Basins (SWRRB) model (Arnold and Williams, 1989). A second order Markov chain generates the occurrence of precipitation on each day. Inputs to the Markov chain include the probability of a wet day following a wet day, P(W/W), and the probability of a wet day following a dry day, P(W/D). The precipitation amount on each wet day is stochastically generated as a skewed normal distribution from the relationship:

$$x = \frac{6}{g}\left(\left(\frac{g}{2}\left(\frac{X - u}{s}\right) + 1\right)^{1/3} - 1\right) + \frac{g}{6} \qquad (1)$$

where: x = normal standard variate; X = raw variate; u, s, g = mean, standard deviation and skew of the raw variate. The parameter values for this equation are all calculated from available records for input to the CLIGEN model.

The storm duration is estimated as a function of precipitation amount (Williams et al. (1984), and Arnold and Williams (1989)):

$$\text{Duration} = 9.21 / [-2 \ln(1 - rl)] \tag{2}$$

where: Duration = event duration in hours; and *rl* = dimensionless parameter, equal to the ratio of the precipitation in the maximum 30-min intensity period to the total storm amount, taken from a gamma distribution of half-hour monthly average precipitation amounts (Nicks et al. 1995). This equation was developed under the assumption that the maximum length of storm was equal to 24 h, and the time to peak is equal to 40 percent of the total storm duration (Arnold and Williams, 1989). Equation (2) was developed from records in the Midwestern U.S., and the validity for other areas has not been tested.

Experimental Procedures

Uganda straddles the equator and is situated on a high plateau area between two mountainous regions on its East and West, Mount Elgon and the Ruwenzori Mountains respectively (fig. 1). Data for this study were collected at two sites in Uganda (Arnold, 1993). The first site, Kabanyolo, is located near Lake Victoria, 60 km north of the equator at an elevation of 697 meters. The precipitation at this site exhibits a strong wet season/dry season pattern, with two rainy seasons per year, March 1 to June 15 and August 15 to December 15. The second site, Buginyanya, is located on the slopes of Mount Elgon at an elevation of 2030 meters, and has a long wet season from mid March until November, with a dry season the remainder of the year. The first site is representative of the central "lowland" rainfall found in much of Uganda, while the second site is representative of the rainfall patterns found in the mountainous borders of Uganda.

Twenty years of continuous daily precipitation data were available from each site. These observations were the basis for the first five lines of input statistics summarized in table 1. In addition, as much recording rain gage data as possible were collected from the two sites to determine the last two lines of statistics for table 1. The recording rain gage data were limited, and are not adequate for a rigorours validation of the duration and intensity predictions from the CLIGEN model. All of the available recording gage data were used, however, to produce the inputs required by CLIGEN, such as maximum 30-minute intensity and time to peak. Table 2 gives a monthly summary of some of the recording rain gage data for the two sites. Estimates were made for the missing values for Buginyanyi based on the November observation because the November precipitation patterns more closely match the missing months of December through March than would the rainy season data from April or May.

From analysis of these records, input files to the CLIGEN model were developed for each site (table 1). CLIGEN Ver 4.0 (Nicks et al. 1995) randomly generated 10 sets of 20-year records for each of the Ugandan sites. The mean and standard deviation of each of the 10 sets were calculated and tested for significant differences from the CLIGEN-generated populations. Comparisons were made between the observed values and each of the ten sets of generated values for the mean annual totals and the monthly totals, and P(W/W) and P(W/D) probabilities with a t statistic, using the observed standard deviations. A Chi-squared statistic tested for significant differences between the observed and CLIGEN-generated standard deviations for each set. We then determined how many of the ten sets of generated precipitation statistics were different from the observed set.

We carried out a similar analysis for the generated durations, but used the standard deviation from the generated values to calculate the t statistic as there were insufficient observed data to provide a credible standard deviation. There were no comparisons made between the observed and the generated standard deviations of the durations.

Results from the Daily Records

Table 3 shows that CLIGEN-generated means and standard deviations of the annual precipitation amount are not significantly different from the observed annual precipitation over a 20-year period for either of the Ugandan sites. Table 3 also shows that there are differences between the means of the annual observed number of precipitation events and the generated number of events for the Kabanyolo site, but no differences for the Buginyanya site. Both of the generated number of events are less than the observed number of events, even though the total amounts of precipitation are not different. If the total number of events are less, and the total amount is the same, then on the average, there must be greater precipitation for each event.

Table 4 presents the monthly precipitation amount comparisons for the two sites. The results show no significant differences between the CLIGEN generated monthly mean amounts and the means of the observed monthly precipitation. Significant differences, however, were noted in the comparisons of the standard deviations for some of the months. For the central plains site of Kabanyolo, the transitional months of February, November and December indicated a significant difference in the standard deviations. CLIGEN predicted a smaller standard deviation than observed during these periods. In July and August, the standard deviation for the generated climate was greater than the observed for this generally dry month. Apparently the natural monthly variation in the dry season is less than the predicted. This may be due to the greater variability in the prediction of wet days as shown in Tables 5 and 6.

For the highland site, Buginyanya, table 4 shows significant differences in standard deviations for all months. CLIGEN predicted standard deviations similar to Kabanyolo, but they were less than the observed standard deviations at Buginyanya in all months. It is possible that with the inherent variability of rainfall, that CLIGEN's assumptions, based on the U.S. temperate climate, are reasonable for the lowland climate, but are not valid for the variability for the highland precipitation pattern.

Tables 5 and 6 indicate no significant differences between the observed and CLIGEN-generated 20-year mean probabilities, P(W/W) and P(W/D), for either site. In all but four months, however, the predicted P(W/W) values were lower than the observed values, which may have led to the cumulative difference in the number of storms shown in Table 3. This effect may be offset by the fact that the generated P(W/D) is greater than the observed value for most months.

Significant differences were noted in the standard deviations of the probabilities over a 20-year period for both P(W/W) and P(W/D) for both sites. As with precipitation amounts, more differences were noted in predicting the variability of the data at the highland site. CLIGEN does not allow the user to input a variability associated with the probabilities of precipitation, and it appears that the random sampling of P(W/W) by CLIGEN (Nicks et al. 1995) tends to over-predict the variability observed for the drier months, and under-predicts the variability for the wetter months. The observed standard deviations for P(W/D) appear to be less than the predicted values for all months at both sites. The Ugandan wet season precipitation tends to be driven by frontal processes which are likely to be less volatile, and have less year to year variability in occurrence than the dry season, or the central U.S. climate which receives most precipitation from convective storms (Trewartha and Horn 1980).

If additional years of observed data were available, then there may have been greater standard deviations in the observed rainfall statistics. We found that combining the 20-year sequences of predicted data resulted in a standard deviation similar to the mean of the standard deviations of the ten individual sequences presented in tables 3 through 6. This is similar to the findings of Buffaut et al. (1996), who indicate that 20 years of record is not adequate to evaluate the ability of CLIGEN to model the variability associated with a given climate, or to predict the long-term average soil erosion rate when combined with the WEPP model. Not having a good estimate of the variability of precipitation could lead to an underprediction or overprediction of major precipitation events. These major events are generally the cause of the majority of soil erosion, and are the driving factor in determining average annual erosion values. Twenty years of record, however, may be adequate to estimate the monthly precipitation means of an observed climate.

Results from the Recording Rain Gage Data

Table 7 presents a comparison of the storm durations for the observed monthly mean and ten 10-year sets of CLIGEN-generated monthly means. The observed data represent only a limited record and cannot be used for a stringent comparison. For the t-test comparing the means, the standard deviation of the generated values was used because there were insufficient observations to estimate a true standard deviation. The results indicate that the generated storm durations are not significantly different from those observed. More years of recording-range data are necessary before any firm conclusions about duration can be made.

If CLIGEN is generating storms for erosion studies, small variations in duration prediction may not be a problem. The WEPP model is less sensitive to variations in precipitation duration than in amount (Nearing et al. 1989). CLIGEN appears to predict amount reasonably well.

Summary and Conclusions

No significant differences were noted between the 20-year observed means and the mean of ten 20-year sets of CLIGEN 4.0 generated values for the annual precipitation totals, monthly totals, number of events and P(W/W) and P(W/D) for two sites in Uganda. In comparing the standard deviations within the means, a few months were shown to be significantly different (P=0.95). The highland site exhibited more variability than the central plains site. In general, the CLIGEN model was successful in modeling the daily precipitation patterns for both the central plains and eastern highland regions of Uganda. From a limited data set, there were no significant differences noted between the CLIGEN-generated storm durations and observed recording gage records. In a previous analysis, Arnold and Elliot (1996) had found that there were no significant differences in the length of wet spells and dry spells.

From this study and Arnold and Elliot (1996), it appears that CLIGEN is capable of generating a stochastic climate in which the amounts and durations of precipitation are similar to observed amounts. There may be fewer storms, which indicates that individual storm amounts may be greater. The standard deviations of the generated amounts are often less. The standard deviations of the probabilities of a wet day following a wet day are less, but following a dry day are greater. The effect of these differences on predicting soil erosion requires further investigation.

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Table 1. CLIGEN input file precipitation data for two sites in Uganda. Units are those required by the current version of CLIGEN to allow direct comparison to other climates in the CLIGEN climate database.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kabanyolo												
Mean *	6.4	8.1	9.7	9.4	7.9	7.9	5.6	7.1	7.4	7.6	9.7	7.4
Std †	6.9	7.6	10.9	12.2	12.2	10.9	9.9	13.2	10.4	9.9	9.7	4.3
Skew ‡	1.58	1.12	1.48	1.69	1.72	1.99	1.98	1.89	1.54	1.57	1.68	1.37
P(W/W) §	0.41	0.46	0.54	0.66	0.54	0.44	0.46	0.47	0.58	0.60	0.64	0.49
P(W/D) Ψ	0.22	0.29	0.42	0.54	0.50	0.29	0.29	0.40	0.46	0.49	0.51	0.28
I_{30} #	3.3	3.3	3.3	6.1	13.2	10.2	7.6	12.7	7.1	6.6	3.3	3.3
t_p **	0.29	0.39	0.30	0.34	0.32	0.33	0.34	0.21	0.37	0.33	0.33	0.30
Buginyanya												
Mean	6.9	8.1	11.9	13.0	10.9	9.4	9.4	11.4	9.7	9.4	9.4	4.8
Std	4.3	5.3	7.6	11.2	10.9	14.5	16.3	15.5	14.5	8.9	9.1	6.1
Skew	3.11	2.27	2.23	3.08	2.16	3.33	3.08	2.56	3.69	2.11	3.02	2.17
P(W/W)	0.52	0.61	0.62	0.69	0.81	0.72	0.74	0.79	0.79	0.79	0.70	0.48
P(W/D)	0.14	0.17	0.22	0.37	0.42	0.50	0.60	0.64	0.48	0.42	0.30	0.14
I_{30}	1.0	1.5	2.3	7.4	10.7	17.0	10.9	16.3	5.3	4.3	2.0	1.5
t_p	0.40	0.40	0.40	0.53	0.38	0.46	0.41	0.36	0.41	0.43	0.48	0.40

* The mean daily precipitation in each month, for wet days only (mm)

† The standard deviation of the daily precipitation within each month (mm)

‡ The skew of the daily precipitation within each month (dimensionless)

§ The probability of a wet day following a wet day within each month

Ψ The probability of a wet day following a dry day within each month

The maximum 30-minute intensity of the storm (mm h^{-1})

** The mean time to peak intensity of the storms within each month (h)

Table 2. Summary of recording rain gage observations.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Kabanyolo						
Years	3.5	5	3	4	4	5	4	2.5	3	1.5	2.5	3
Events	29	46	38	70	87	64	75	48	59	22	26	25
I_{30}*	3.3	3.3	3.3	6.1	13.2	10.2	7.6	12.7	7.1	6.6	3.3	3.3
Dur†	1.64	2.35	2.74	3.99	4.8	2.83	4.03	5.2	4.44	3.97	1.92	3.31
						Buginyanya						
Years	- ‡	-	-	1	1	1	1	1	1	1	1	-
Events	-	-	-	17	27	32	38	35	30	38	27	-
I_{30}	-	-	-	7.4	10.7	17.0	10.9	16.3	5.3	4.3	2.0	-
Dur	-	-	-	2.16	4.32	2.65	3.23	1.84	2.15	2.62	2.01	-

* Maximum 30-min rainfall intensity (mm h^{-1})

† Duration (h)

‡ No data available

Table 3. Annual comparisons of the means and standard deviations (Std. Dev.) of the observed to the CLIGEN-generated weather record

	Total Precipitation (mm)		**Number of Events**	
	Kabanyolo	Buginyanya	Kabanyolo	Buginyanya
20-year Mean of Observations	1311	1903	162.8	191.6
Mean of ten 20-year CLIGEN sets	1341	1831	121.3	168.5
Standard Deviation of observations	192.4	298.7	8.42	13.85
Significance (P=0.95) between Means	N.S.*	N.S.	S.D.†	N.S.
Mean Std. Dev. ten 20-year CLIGEN sets	153.7	217.7	9.23	10.75
Significance (P=0.95), Chi Square test	N.S.	N.S.	N.S.	N.S.

* Not Significantly Different;

† Significantly Different (P = 0.95)

Table 4. Monthly comparisons of the 20 years of observed data to the CLIGEN results for ten sets of 20-y simulated weather for precipitation amounts in mm.

Mon	Kabanyolo						Buginyanya					
	Observed		CLIGEN		Times Diff*		Observed		CLIGEN		Times Diff	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Jan	53.3	26.4	52.6	25.4	0	1	47.8	44.2	42.9	28.2	0	7
Feb	81.0	54.6	77.5	31.8	0	8	69.9	65.3	66.0	35.8	0	10
Mar	143.0	51.8	147.1	48.3	0	2	134.4	84.3	130.3	54.1	0	8
Apr	174.8	63.0	184.9	68.6	0	1	210.8	105.9	202.9	55.9	0	10
May	128.8	47.8	138.7	52.6	0	1	234.4	77.5	221.7	42.2	0	10
Jun	80.5	41.9	84.1	43.2	0	1	178.8	58.4	171.2	34.3	0	8
Jul	59.4	25.4	65.0	37.8	0	7	200.9	94.7	192.0	32.3	0	10
Aug	94.0	48.8	108.7	57.2	0	3	263.9	70.6	258.6	33.3	0	10
Sep	113.8	49.0	117.1	45.0	0	1	199.6	79.8	187.5	35.3	0	10
Oct	131.1	50.8	133.9	47.8	0	1	194.6	75.4	182.6	36.1	0	10
Nov	168.7	70.9	157.2	50.0	0	7	135.6	72.1	131.3	41.1	0	9
Dec	82.3	38.4	77.5	24.9	0	7	31.0	28.4	29.5	18.3	0	8

* Number of sets in which the generated mean or standard deviation was different from the observed statistics

Table 5. Monthly comparisons for 20 years of observed data to the CLIGEN results for ten sets of 20-y predictions for precipitation probability of a wet day following a wet day (P(W/W)).

Mon	Kabanyolo						Buginyanya					
	Observed		CLIGEN		Times Diff *		Observed		CLIGEN		Times Diff	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Jan	0.41	0.03	0.40	0.14	0	10	0.52	0.12	0.49	0.16	0	4
Feb	0.46	0.10	0.43	0.15	0	9	0.61	0.14	0.57	0.16	0	2
Mar	0.54	0.10	0.53	0.12	0	4	0.62	0.15	0.59	0.15	0	2
Apr	0.66	0.12	0.66	0.11	0	2	0.69	0.16	0.67	0.12	0	4
May	0.54	0.13	0.53	0.12	0	1	0.81	0.21	0.79	0.09	0	10
Jun	0.44	0.10	0.44	0.15	0	7	0.72	0.12	0.71	0.10	0	2
Jul	0.46	0.07	0.45	0.14	0	10	0.74	0.19	0.74	0.09	0	10
Aug	0.47	0.10	0.46	0.12	0	3	0.79	0.21	0.79	0.08	0	10
Sep	0.58	0.11	0.56	0.14	0	4	0.79	0.19	0.77	0.09	0	10
Oct	0.60	0.19	0.59	0.11	0	9	0.79	0.20	0.78	0.08	0	10
Nov	0.64	0.17	0.62	0.12	0	5	0.70	0.16	0.66	0.15	0	1
Dec	0.49	0.10	0.46	0.14	0	6	0.48	0.07	0.47	0.15	0	10

* Number of sets in which the generated mean or standard deviation was different from the observed statistics

Table 6. Monthly comparisons for 20 years of observed data to the CLIGEN results for ten sets of 20-y predictions for precipitation probability of a wet day following a dry day (P(W/D)).

Mon	Kabanyolo						Buginyanya					
	Observed		CLIGEN		Times Diff*		Observed		CLIGEN		Times Diff	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Jan	0.22	0.06	0.24	0.09	0	7	0.14	0.04	0.16	0.08	0	10
Feb	0.29	0.06	0.31	0.11	0	9	0.17	0.06	0.20	0.10	0	9
Mar	0.42	0.05	0.43	0.13	0	10	0.22	0.05	0.23	0.10	0	10
Apr	0.54	0.05	0.56	0.17	0	10	0.37	0.06	0.41	0.16	1	10
May	0.50	0.06	0.50	0.14	0	10	0.42	0.06	0.46	0.18	0	10
Jun	0.29	0.06	0.30	0.10	0	9	0.50	0.06	0.54	0.17	0	9
Jul	0.29	0.05	0.29	0.10	0	10	0.60	0.06	0.65	0.20	1	10
Aug	0.40	0.04	0.43	0.12	0	10	0.64	0.07	0.68	0.21	0	10
Sep	0.46	0.05	0.46	0.14	0	10	0.48	0.05	0.50	0.18	0	10
Oct	0.49	0.06	0.50	0.15	0	10	0.42	0.06	0.43	0.17	0	10
Nov	0.51	0.05	0.51	0.14	0	10	0.30	0.04	0.31	0.13	0	10
Dec	0.28	0.06	0.29	0.10	0	10	0.14	0.05	0.15	0.08	0	9

* Number of sets in which the generated mean or standard deviation was different from the observed statistics

Table 7. Monthly comparisons of the durations measured by recording rain gages to the average durations generated in 200 years by the CLIGEN weather generator (h).

Month	Kabanyolo				Buginyanya			
	Observed	CLIGEN		Times Diff *	Observed	CLIGEN		Times Diff
	Mean	Mean	Std	Mean	Mean	Mean	Std	Mean
Jan	1.64	3.10	1.67	0	- †	3.18	1.68	-
Feb	2.35	2.98	1.58	0	-	3.21	1.61	-
Mar	2.74	3.39	1.73	0	-	3.08	1.64	-
Apr	3.99	3.08	1.63	0	2.16	3.04	1.59	0
May	4.80	3.07	1.64	0	4.32	3.04	1.59	0
Jun	2.83	3.07	1.61	0	2.65	3.11	1.70	0
Jul	4.03	3.06	1.66	0	3.23	3.09	1.71	0
Aug	5.20	3.06	1.64	2	1.84	3.07	1.63	1
Sep	4.44	3.08	1.64	0	2.15	3.10	1.66	0
Oct	3.97	3.11	1.71	0	2.62	3.11	1.63	0
Nov	1.92	3.14	1.72	0	2.01	3.11	1.76	0
Dec	3.31	2.96	1.57	0	-	3.28	1.77	-

* Number of sets in which the generated mean or standard deviation was different from the observed statistics

† No observations

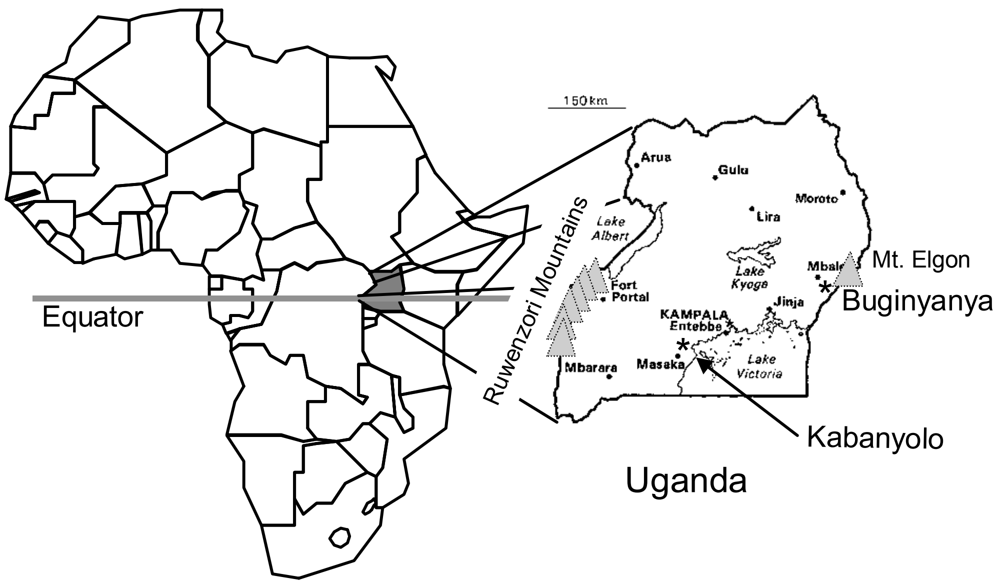

Figure 1. Location of weather stations within Uganda.

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