Statistical Analysis to Investigate the Possible Impact of Climate Change on Water Availability in Letaba River of South Africa

P. K. Sinha, Rajesh Kumar

Abstract: ***Global warming and changing climate is a major concern in the water availability. Letaba River in South Africa is facing reduction in water availability and this paper is an attempt to understand impact of climate change on reservoirs of Letaba River in South Africa. The Letaba River System falls within the Limpopo basin. This is subdivided into three sub-systems namely: Groot Letaba, Klein Letaba and lower Letaba. More than 20 dams are located in the Groot Letaba catchment. Most of the dams are having less water than there used to be earlier. The general perception for this change is related with the Climate change induced low precipitation and increased temperature in the river catchment. The historic climate and long term hydrology records are used for quantifying relationship between climate change and the amount of water in the Dam. The main long term hydrology parameters available in the department of water affairs on prominent rainfall stations of Letaba River catchment are temperature, stream flow and rainfall and their trend is the indicator of climate change in the Letaba River. A statistical analysis has been done to study the impact of climate change on the Letaba catchment.***

Keywords: Letaba River, Climate change, Water availability, Reservoirs

I. INTRODUCTION

Climate: "This is the long-term average weather conditions (usually taken over a period of more than 30 years as defined by the world meteorological organization, WMO) of a region including typical weather patterns such as the frequency and intensity of storms, cold spells and heat waves." Climate Variability: "Variations in the mean state and other statistics (e.g. standard deviations or the occurrence of extreme events) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural external processes outside the earth system, or to natural or anthropogenic internal forcing." Climate change from the IPCC point of view refers to "Any change in climate over time, whether due to natural variability or as a result of human activity." This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines climate change as: 'A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.' Climate change has brought about severe and possible permanent alterations to geological, biological and ecological systems all over the world. Douben (2009: 78) asserts that there is new and stronger evidence that most of the warning observed over the last 50 years is attributed to human activities. In South Africa water availability is never taken for granted. The South African National Strategy Document on weather patterns (2010: 16) indicates that the sub-continental warning will be accompanied by increasing incidence of both droughts and floods with prolonged dry spells followed by intense storms. Floods are reported everywhere in the world and in Africa. For example, Global Humanitarian Forum Reported (2009: 6) indicates prevalence of floods in countries like Kenya, Uganda, Ghana, Mozambique and South Africa. In South Africa floods are most prevalent in the Kwazulu Natal, Eastern Cape, Limpopo and the Mpumalanga Provinces.

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Status of Recent Research at National level and International level.

South Africa has launched its new National Climate Change Response Policy; the policy gives a roadmap for responding to the urgency of Climate change as it pushes towards a green economy. Accordingly, various studies on the effects of climate change have been carried out using different numeric models for the South African Catchments, namely WRYM (Water Resources Yield Model), MIKE Models etc. The hosting of the COP 17 climate change negotiations in Durban on the 28 November, 2011 announced that is a measurable reality. It further stated that if the impacts are not dealt at the early stage, then will have disastrous social and economical consequences. The effects of drought on hydrology may not be noticed for several months (IPCC 2001). Drought is felt when the area experience low rainfall, the area will experience drought causing serious hydrological inequity that negatively affect agricultural production putting countries economy in danger and water supply shortage leading to negative impact on the people's health (DWA,2004). Drought is divided into four groups: Meteorological drought, Agricultural drought, Socio-economic and Hydrological drought. The study done by DWA (2004) stated that Letaba Catchment is water stressed with results that during drought (hydrological), almost all flow is abstracted from the river and very little is left to meet the required amount in farming activities (Agricultural drought) and are hit hard with severe local economic consequence (Socio-economic drought).

Status of Recent Research at International level

Various studies on the effect of climate change on hydrology have been carried out internationally (by Katambra & Ndiritu 2010) and have used different models to examine the effects of climate change on hydrological regime. There are uncertainties at all level in the methodology of climate change effect assessment and there are two methods which attempt to account for these uncertainties; namely scenario analysis and risk analysis.Scenario analysis comprises a set of technique that anticipates and prepare for the impact of uncertain future events. The Risk analysis deals with uncertainties in terms of the risk of impact (Katambra & Ndiritu 2010)

Effects of climate change on hydrology:

Effects of climate change are already being felt across the world. Its impacts are negatively affecting the availability of water as well as the quantity and quality of water that is available. Rising of temperature will lead to an intensification of the hydrological cycle, resulting in dryer dry season (drought) and wetter rainy season (floods), and subsequently heightened risks of more extreme events. The hydrological cycle that operates across the climate system is being intensified due to apparent changes of global temperature.

Effects on Climate Change on drought:

Drought is defined as a phenomenon that exists when rainfall has been significantly below normal, serious hydrologic inequity that negatively affects land resources productive system (IPCC, 2001). For example, problem such as crop damage and water supply shortage. Droughts occur when there is insufficient rainfall in an area and water drops to a lower level leading to negative impacts on people and environment. The effects of drought on hydrology may not be noticed for several months (IPCC 2001). Drought is felt when the area experiences low rainfall, the area will experience drought causing serious hydrological inequity that negatively affect agriculture production putting countries economy in danger and water supply shortage leading to negative impact on the people's health (DWA,2004).

II. STUDY OBJECTIVE

It is required to assess in the Letaba River Catchment that the long prevailing drought is due to impact of climate change or due to periodic cycle. SAWS (South Africa Weather Services) has indicated that in South Africa, wet cycles of seven years followed by dry cycles of seven years are seen since last fifty years. The status of storage Dams (as shown in the table below) of the Letaba River Catchment has indicated that water level in the Dams are most of the years are decreasing.

WMA (Water Management Areas)	Dams in Groot Letaba Catchment	FSC (million m^3)	Studies (1st July) % of FSC (full supply capacity)							
			2000	2001	2002	2004	2005	2006	2007	2008
Luvuvhu and Letaba	Ebenezer	60	45	43	42	46	59	46	39	37
	Dap nande	1.9	60	61	62	64	60	58	43	40
	Thabina	2.8	70	59	60	58	60	57	51	52
	Tzaneen	156.5	75	72	70	74	65	76	66	65

2009	2010	2011	2012
40	39	46	45
43	40	43	47
51	50	51	50
64	59	55	53

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The government of South Africa has indicated a drought prone area of Letaba River catchment (DWA: River report 1994). The biggest Dams in the catchment (Tzaneen, Ebenezer and Middle Letaba) failed to meet the required water demand (for agriculture and Domestic).

III. THE MAIN OBJECTIVE OF THE STUDY

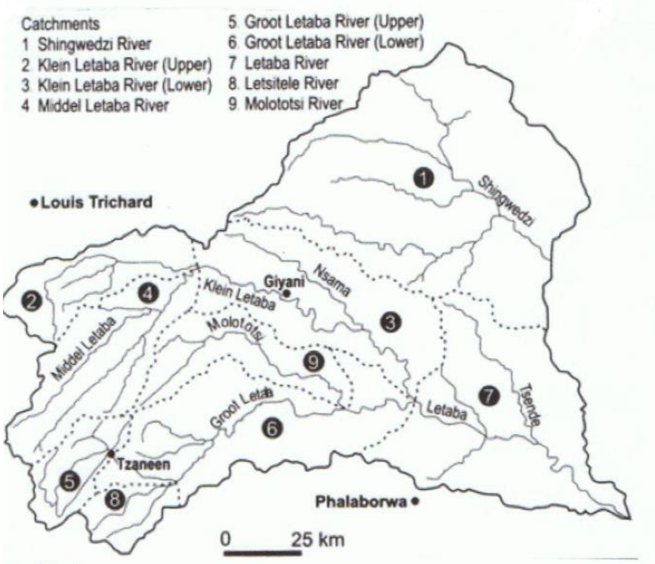
To determine the trend in rainfall, temperature and water availability in the Letaba River catchment and their correlations.

IV. STUDY AREA

The areal extent of this study is the Letaba River Catchment of Limpopo province.

Location and Topography:

The Letaba River Catchment is located in the north-eastern part of South Africa and covers an area of approximately 13670 km^2 (DWA, 2006). The catchment is located between latitude 22º56'00" S and 23º58'00" S longitude 30º2'00" E and 31º35'00" E (Fig below). The Letaba River Catchment forms part of the Luvuvhu/ Letaba Water Management Area of South Africa. The Topography of Letaba River Catchment varies from a zone of high mountains in the west of the mountain through low mountains and foothills to the low lying plains in the east part of the mountain. The below figure shows the main River of Letaba River catchment and the area of study will be from point 1 to 9. The listed catchments belong to Letaba River.



Climate:

The Letaba River catchment experiences a dry climate; the relative humidity is higher during wet month than during dry months. Humidity is high during the month of February ranging from about 70% in the west to above 72% in the east of the catchment (DWA, 2004). The summers are very hot and the winters are mild with frost as the exceptions in the bottomlands (State of the Rivers Report, 2001). The mean annual temperature ranges between 18ºC in the mountainous regions to more than 28ºC in the eastern parts of the catchment with an average of about 25.5ºC. High and low temperatures occur in the month of January and July respectively (DWA, 2004).

Hydrology:

The Letaba River Catchment is drained by Groot Letaba River and its major tributaries namely, Klein Letaba, Middle Letaba and Letsiletsi which originates in the Drakensberg Escarpment descending in long runs with an occasional riffle or pool mostly in the Limpopo Province (State of River Report, 2001). Several reservoirs exist with Tzaneen dam (capacity of 157.7x106m^3) being the largest and the most downstream reservoir across the Letaba River (DWAF, 2006). The gross surface water availability in the Groot Letaba sub-area is estimated at 168 million m^3/a, which is derived from the yield of the Tzaneen and Ebenezer dams as well as significant run-off-river abstractions. The gross surface water availability in the Klein Letaba sub-area is estimated at 27 million m^3/a, most of which is derived from yield of the Middle Letaba dam and smaller dams upstream. The Tzaneen dam, if operated in isolation, provides a yield of approximately 60 million m^3/a. However, when operated in a systems context to supply water to irrigators downstream only when the run-of-river flows are inadequate, the total yield is much greater. The mean annual runoff (MAR) is 574 million cubic meters (range from 100 to 2 700 million cubic meters) (State of River Report, 2001). The Groot Letaba River is the major river in the catchment and the Tzaneen Dam is the largest in the catchment. The Kruger National Park (KNP) is at the tail end of the Letaba River. The KNP requir5es that at least 0.6 m^3/s of water released from the Tzaneen Dam in the park. Due to decreasing trend of water availability in the Dam, KNP does not get the required amount of water. The study area, showing its location and where the locations of measuring weirs are attached in the Appendix.

V. DATA COLLECTION

For the statistical analysis to indicate whether the climate change has any impact on the catchment or not, the eighty years of monthly rainfall, temperature and stream flow data have been collected for the period 1930 to 1970, however till the preparation of this paper, rainfall data for the period 1930 to 1969 could not be obtained, so the data have been analysed for the period 1970 to 2009 only and the relevant correlation between the above parameters have been studied. The stream flow data is at the measuring weirs B8H050 (as shown in the Appendix) which is located at the upstream of the Tzaneen Dam, since it is approximate value of the natural flow. At this station, the stream flow is uncontrolled.

VI. DATA ANALYSIS

In this article, an analysis of data collected from the department of Water Affairs and the department of Weather services for the period 1970 – 2009 have been done. Discussion of these findings will be based on the data obtained on the average monthly maximum temperature, rainfall and stream flow data of the Letaba catchment.

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The research instrument

From the 40 years for the period examined, the researcher wishes to investigate whether the climate change has an impact on the catchment or not?

Method of Analysis

In the data analysis, the researcher has made use of:

1. The frequency analysis which provides descriptive statistics (mean and variance or standard deviation) and some graphical display such as pie charts and bar charts. The frequency analysis assisted to determine whether a particular distribution fitted the data or in a case it is needed to compare different distribution from one period to another.
2. The time series and autocorrelation function. Using thesetechniques the researcher will show for better understanding on the average monthly maximum data distribution through the analysis plot including the time series and autocorrelation functions (ACF).
3. The ARIMA model parameter has been used to display values to display all the parameter in the model. Using the Expert Modeller all significant parameters have been determined.

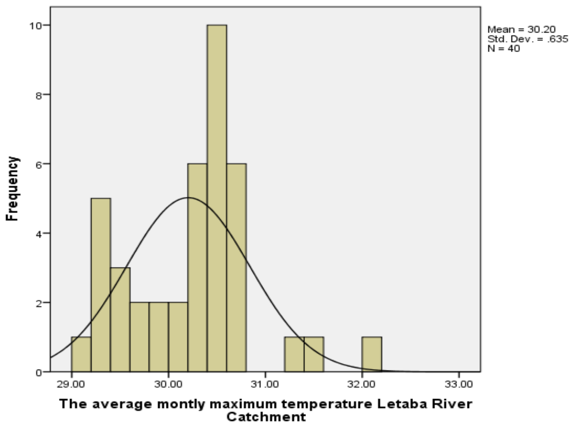
Section 1: Frequency

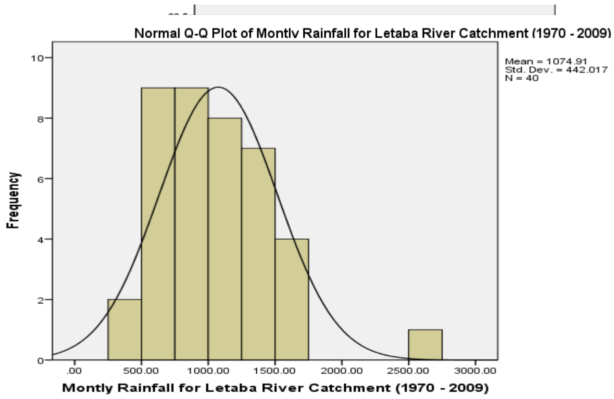
In statistics, frequencies approach provides statistics and graphical display such as bar chart, pie chart in easy-to-understand form, without using a statistical model or having formulated a hypothesis. Frequencies are useful for describing the variables such as temperature, rainfall and stream flow. This gives a good start when looking at the data. The descriptive statistics observed for the periods 1970 – 2009 on average monthly maximum temperature, rainfall and stream flow at Letaba River catchment are shown in table 2.

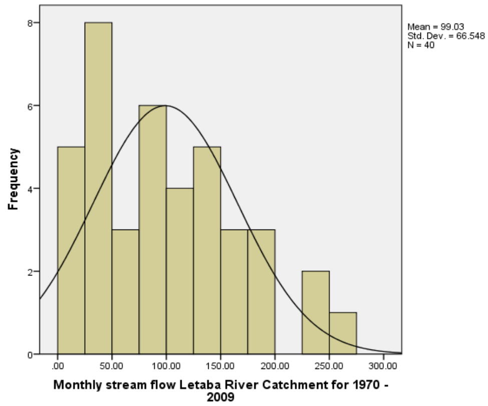
Parameters	1970 to 2009 Mean	1970 to 2009 Stand deviation	1970 to 2009 Min	1970 to 2009 Max
Temperature	30.20	0.635	29.10	32.10
Rainfall	1074.9	442.017	290.05	2662.44
Stream flow	99.03	66.548	15.66	256.25

Table 2: Statistics of average monthly for the period 1930-1969 and 1970-2009

Each period, the climate change on water availability in Letaba River catchment has been estimated by comparing average monthly mean and standard deviation for variables temperature, rainfall and stream flow. Results showed that the average monthly for period 1970-2009 is high. This could indicate climate change contribute to the availability of water in the reservoir. An appropriate model will be discussed by performing a validation of the study in which the model is assumed by comparing the results of the model with the data. The graphical display and density plots of variables temperature and stream flow reveal an insignificant positive skewed distribution but the distribution is probably normal. In case that data are not nearly normal and outliers free, the results obtained maybe misleading when statistical inference is used. To correct such situation, it is suggested that nonparametric methods maybe used. Histograms in temperature and stream flow for the period 1970-2009 suggest that the data are not normal even though the Q-Q plots are nearly normal. This is an indication that the data may contain outliers and do not represent strong autocorrelation. Histogram in rainfall and density plot reveals a significant normality and the Q-Q plot is fairly straight to indicate a normal distribution with outlier free. When the normality is violated we can conclude that the variables of Letaba River catchment do not hold all the assumptions of parametric data analysis.







SECTION 2: TIMES SERIES AND AUTOCORRELATION FUNCTIONS

In this section, the researcher wants to investigate whether autocorrelation or serial dependency among observed data points. It is assumed that the data may display serial correlation.

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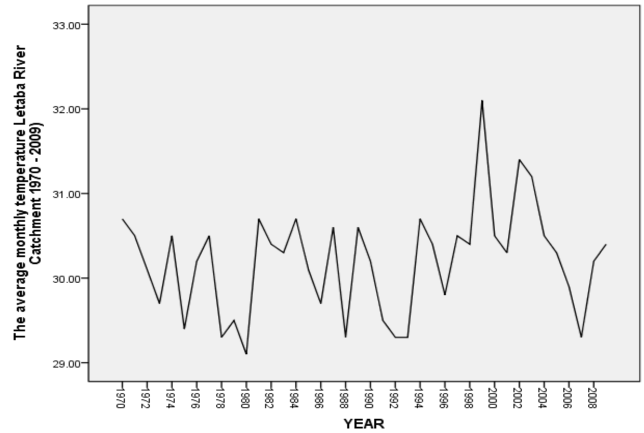
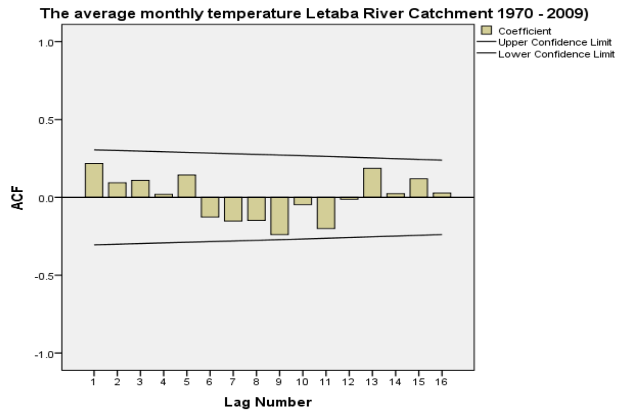
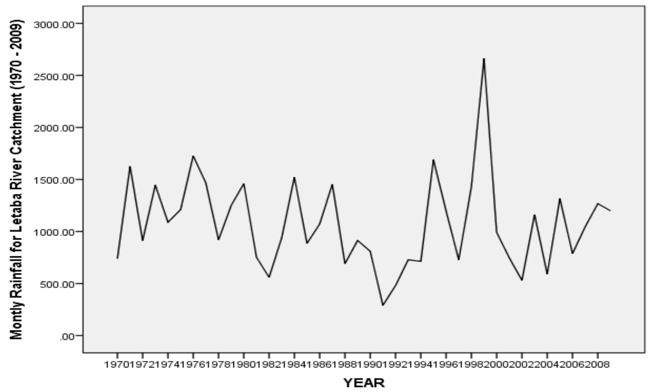
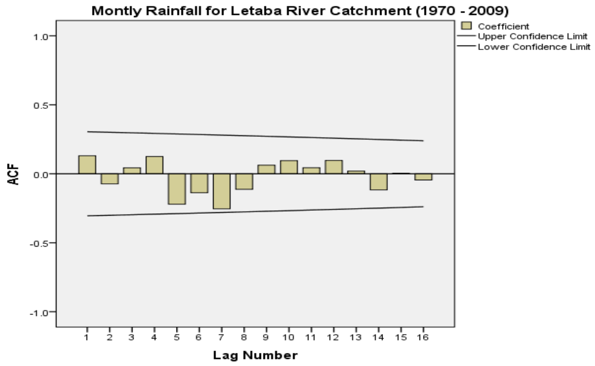
A good picture of checking autocorrelation can be obtained by looking at the timesseries and autocorrelation function plots. In time series plots variables temperature, rainfall and stream flow were plotted against time to check the presence of trends or cycles. In other hand autocorrelation plot displayed serial autocorrelation. 2.1 Time series and autocorrelation function for the period 1970 – 2009. The first analysis helps us to determine first, whether a particular distribution fits the data and secondly, when we need to compare different distribution such as for the period cited earlier. In this section, the researcher wanted to investigate whether autocorrelation or serial dependency exist among observed data points. Since the data were collected overtime, the data may display serial correlation. A good way of checking autocorrelation can be obtained by looking at the time series and autocorrelation function plots.

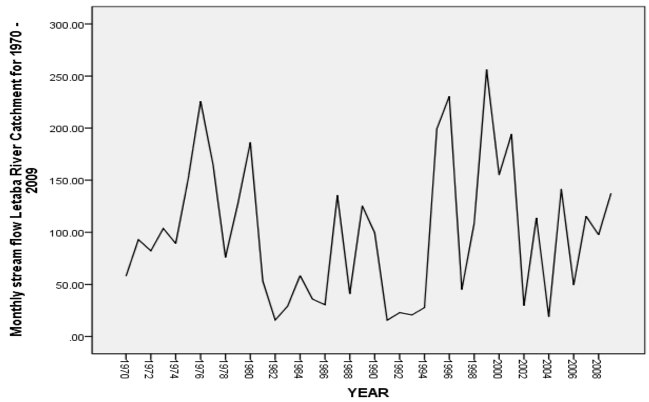
The findings of the time series and the ACF plots display by the average monthly maximum temperature, rainfall and stream flow reveal no serial correlation among data points at the 95% confidence level. This is because all the ACF values lie within the 95% confidence limits

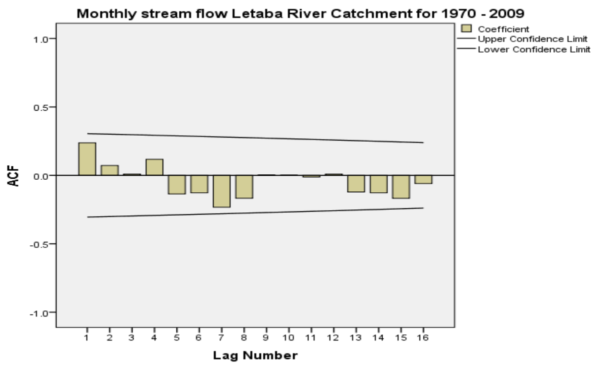












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Autocorrelations

Series: The average monthly temperature Letaba River Catchment 1970 - 2009)

Lag	Autocorrelation	Std. Error[a]	Box-Ljung Statistic Value	df	Sig.[b]
1	.218	.152	2.045	1	.153
2	.094	.150	2.436	2	.296
3	.109	.148	2.972	3	.396
4	.020	.146	2.989	4	.560
5	.144	.144	3.985	5	.552
6	-.127	.142	4.776	6	.573
7	-.152	.140	5.958	7	.545
8	-.148	.138	7.114	8	.524
9	-.239	.136	10.216	9	.333
10	-.046	.134	10.336	10	.412
11	-.200	.131	12.664	11	.316
12	-.012	.129	12.673	12	.393
13	.186	.127	14.835	13	.318
14	.024	.124	14.874	14	.387
15	.119	.122	15.828	15	.394
16	.028	.120	15.884	16	.461

a. The underlying process assumed is independence (white noise).
b. Based on the asymptotic chi-square approximation.

Autocorrelations

Series: Monthly Rainfall for Letaba River Catchment (1970 - 2009)

Lag	Auto correlation	Std. Error[a]	Box-Ljung Statistic Value	df	Sig.[b]
1	.131	.152	.739	1	.390
2	-.073	.150	.972	2	.615
3	.043	.148	1.056	3	.788
4	.125	.146	1.788	4	.775
5	-.220	.144	4.122	5	.532
6	-.137	.142	5.052	6	.537
7	-.254	.140	8.349	7	.303
8	-.113	.138	9.018	8	.341
9	.063	.136	9.231	9	.416
10	.095	.134	9.740	10	.464
11	.044	.131	9.851	11	.544
12	.097	.129	10.412	12	.580
13	.019	.127	10.435	13	.658
14	-.116	.124	11.312	14	.661
15	.004	.122	11.313	15	.730
16	-.045	.120	11.455	16	.781

a. The underlying process assumed is independence (white noise).
b. Based on the asymptotic chi-square approximation.

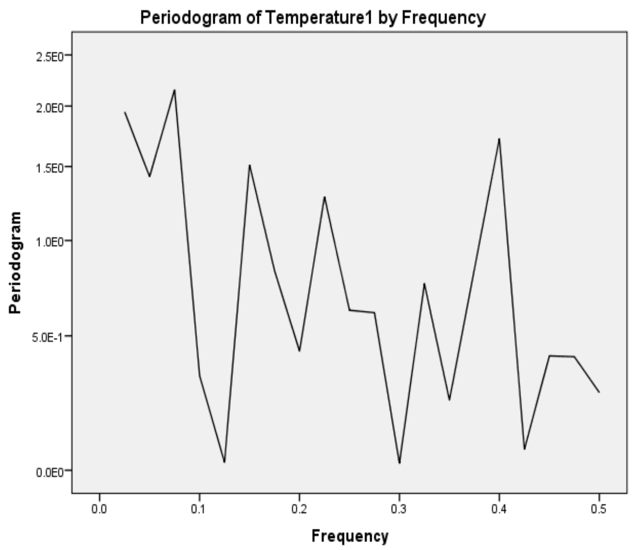
Autocorrelations

Series: Monthly stream flow Letaba River Catchment for 19

Lag	Auto correlation	Std. Error[a]	Box-Ljung Statistic Value	df	Sig.[b]
1	.237	.152	2.424	1	.119
2	.072	.150	2.654	2	.265
3	.009	.148	2.657	3	.448
4	.117	.146	3.297	4	.509
5	-.136	.144	4.180	5	.524
6	-.128	.142	4.988	6	.545
7	-.233	.140	7.756	7	.355
8	-.167	.138	9.228	8	.323
9	.003	.136	9.228	9	.416
10	.002	.134	9.228	10	.511
11	-.012	.131	9.237	11	.600
12	.009	.129	9.242	12	.682
13	-.121	.127	10.158	13	.681
14	-.128	.124	11.209	14	.670
15	-.168	.122	13.112	15	.594
16	-.060	.120	13.361	16	.646

a. The underlying process assumed is independence (white noise).
b. Based on the asymptotic chi-square approximation.

The two above autocorrelation tables were used to test the following hypotheses:
H_0: there is no autocorrelation among the observed data points
H_1: There is autocorrelation among the observed data points
Since the p-value is greater than the level of significance 0.05, H_0 is not rejected and we conclude that there is no autocorrelation among the data points. This confirms the results obtained earlier.



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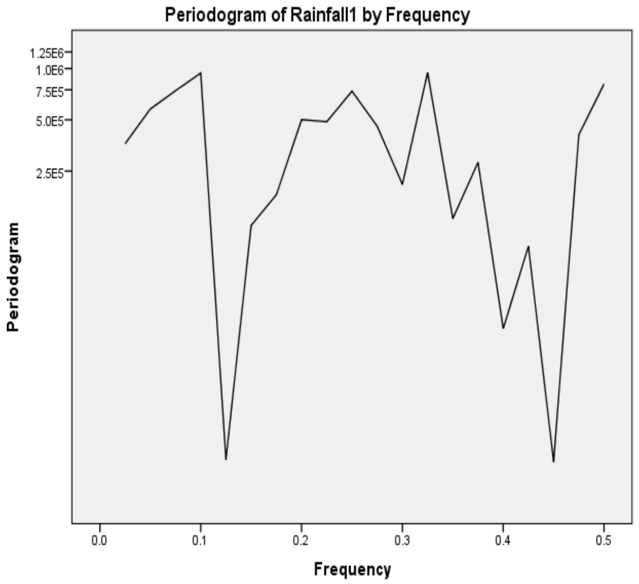
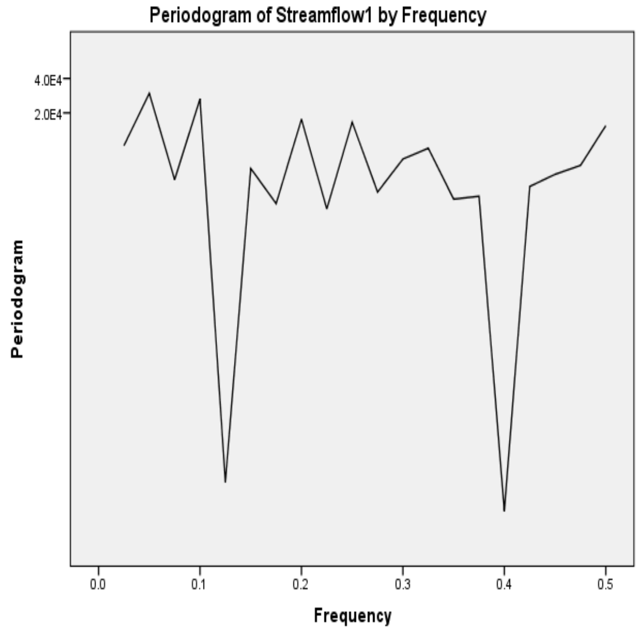
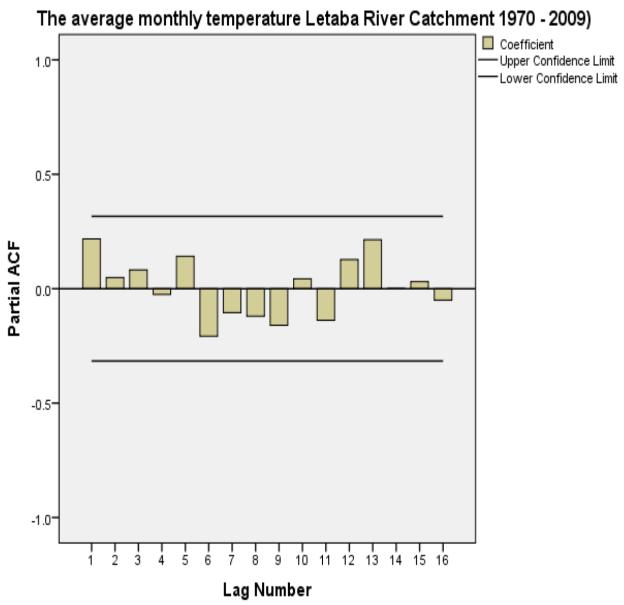
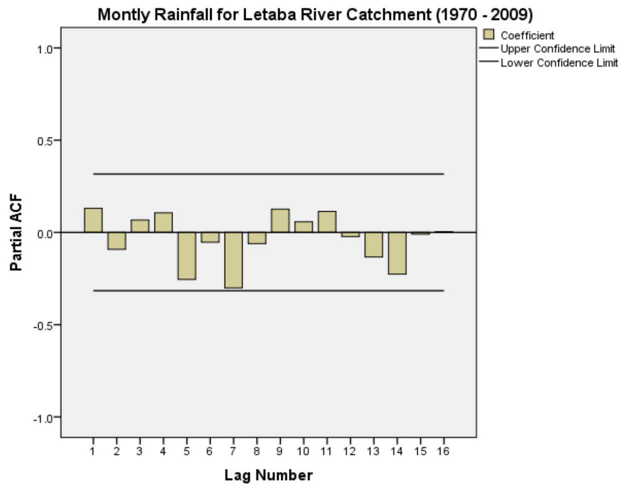
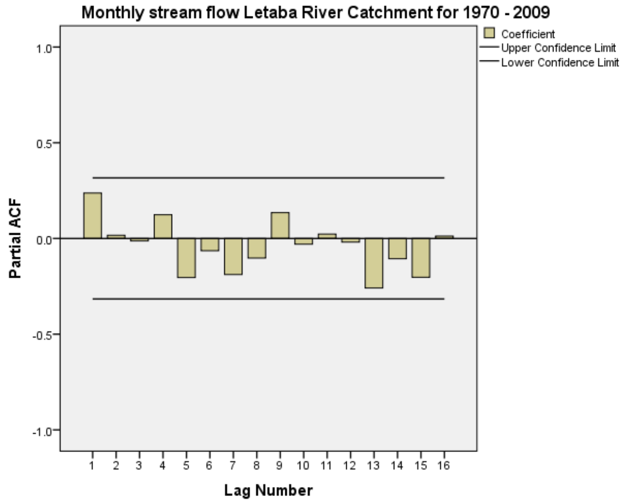


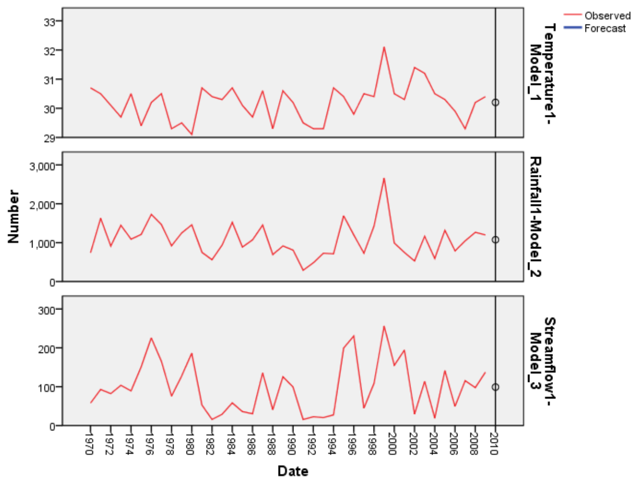








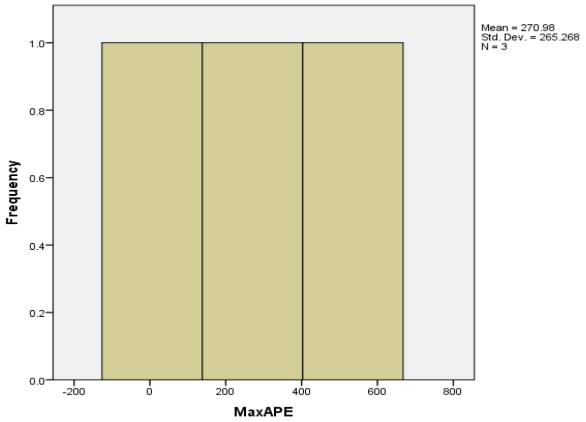
Sequence charts



The series exhibits a non-smooth series with hint of seasonal variation. Individual series with seasonality as it is prominent feature of the data in general. The predicted values show good agreement with the observed values, indicating that the model has satisfactory predictive ability. This is indicated on how well the model predicts the seasonal peaks.

Model summary charts

The maximum absolute percentage error (MaxAPE)



The histogram displays above the maximum absolute percentage error (MaxAPE) across all the models. It shows that the largest percentage error for each model falls in the range -100 to less than 800%. This is a situation in which the researcher sense comes into play because acceptable risk and climate change are present but these factors will change from year to year.

1. Model fit summary

The model fit presented in the following tables provides fit statistics calculated across all the three models (average monthly temperature model_1, monthly rainfall model_2 and monthly stream flow model_3). It provides a summary on how well the models are, for each statistic, the table provides the following: the mean, the standard error (SE), the minimum and the maximum value across all the three models. The table contains also the percentiles that provide information on the distribution of statistic across models.

Model Fit

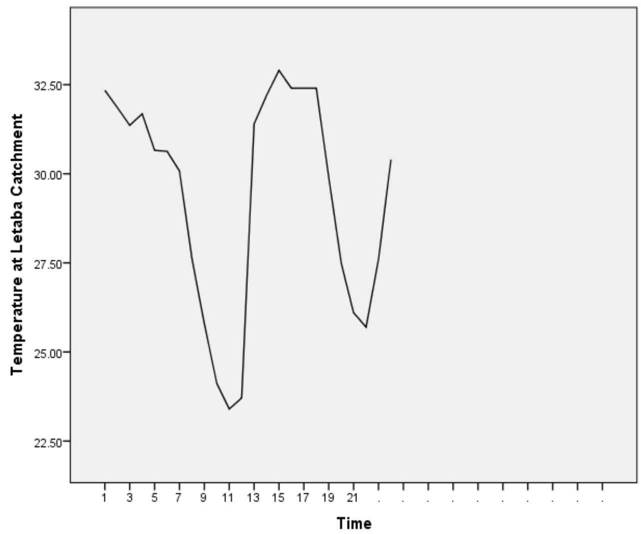
Fit Statistic	Mean	SE	Minimum	Maximum	Percentile						
					5	10	25	50	75	90	95
Stationary R-squared	-8.244E-17	1.434E-16	-2.481E-16	4.879E-19	-2.481E-16	-2.481E-16	-2.481E-16	2.711E-19	4.879E-19	4.879E-19	4.879E-19
R-squared	-8.244E-17	1.434E-16	-2.481E-16	4.879E-19	-2.481E-16	-2.481E-16	-2.481E-16	2.711E-19	4.879E-19	4.879E-19	4.879E-19
RMSE	169.733	238.096	.635	442.017	.635	.635	.635	66.548	442.017	442.017	442.017
MAPE	52.059	57.610	1.614	114.837	1.614	1.614	1.614	39.727	114.837	114.837	114.837
MaxAPE	270.984	265.268	5.911	536.446	5.911	5.911	5.911	270.594	536.446	536.446	536.446
MAE	132.075	183.115	.487	341.202	.487	.487	.487	54.535	341.202	341.202	341.202
MaxAE	582.217	874.087	1.898	1587.533	1.898	1.898	1.898	157.219	1587.533	1587.533	1587.533
Normalized BIC	6.649	6.736	-.815	12.275	-.815	-.815	-.815	8.488	12.275	12.275	12.275

The results show that for 95% of the models have a value of MaxAPE that is less than 536.446. From a number of fit statistic reported in the above table, we will focus on two: MAPE and MaxAPE. MAPE (mean absolute percentage error) is a measure of how much dependent series varies from its model-predicted level and it provides an indication of uncertainty in the predictions. In this situation MAPE varies from a minimum 1.614% to a maximum of 114.837% across all the three models. The MaxAPE varies from 5.911% to 536.446% across all the three models. This means the mean uncertainty in each model's prediction is about 2% and the MaxAPE is around 6% with a worst scenario of about 536%. It is noted that whether these values represent an acceptable amount of uncertainty about climate change but this depends on the degree of risk the researcher is willing to accept.

2. Data examination

It is always a good idea to have a feel for the nature of the data before building a model. This is to answer to the question: Does the data exhibit seasonal variation?

The graphs display bellow for the average monthly temperature, rainfall and stream flow exhibit a non-smooth series with seasonal variations. Individual series with seasonality as it is prominent feature of the data in general. The series exhibit down peak which appear to be spaced one to the other. This gives a sense of equally spaced down peaked suggesting the presence of a periodic component to the time series. Given the seasonal nature of the monthly average temperature, rainfall and stream flow with high typically in winter season, we are not surprised to find an annual seasonal component to the data.



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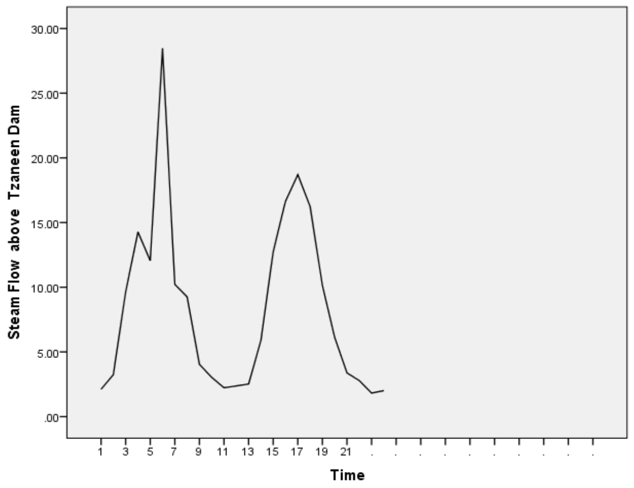

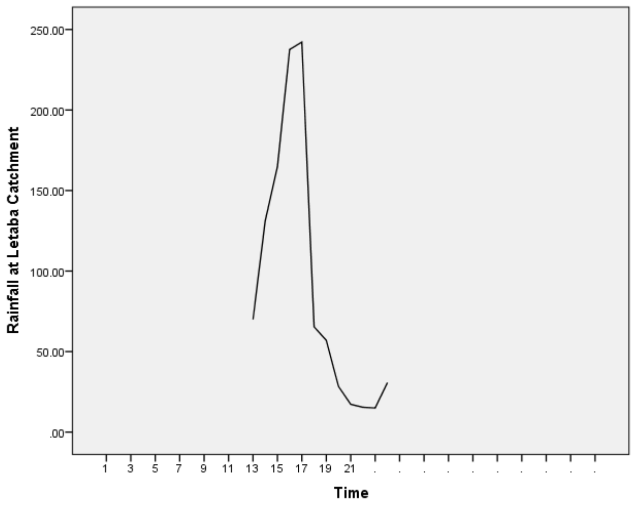

3. Model statistics

The time series allows building no seasonal or seasonal ARIMA (Autoregressive Integrated Moving Average) models. The procedure uses an Expert modeller technique that attempts to automatically identify and estimate the best-fitting ARIMA.

ARIMA Model Parameters[a]

				Estimate	SE	t	p-value
The average monthly temperature Letaba River Catchment 1970 - 2009)-Model_1	The average monthly temperature Letaba River Catchment 1970 - 2009)	No Transformation	Constant	30.202	.100	300.586	.000
Monthly Rainfall for Letaba River Catchment (1970 - 2009)-Model_2	Monthly Rainfall for Letaba River Catchment (1970 - 2009)	No Transformation	Constant	1074.907	69.889	15.380	.000
Monthly stream flow Letaba River Catchment for 1970 - 2009-Model_3	Monthly stream flow Letaba River Catchment for 1970 – 2009	No Transformation	Constant	99.031	10.522	9.412	.000

a. For some models, some predictor series are not considered by expert modeler due to missing values found in the estimation period.

The researcher is interested in developing a forecasting model, has collected the data on monthly average for the temperature, rainfall and stream flow along with time and other factors that might be used to explain climate change influence from Letaba River catchment. The expert modeller was used to find the best model which is statistically significant. The hypotheses are:

H_0: The model cannot be used for forecasting

H_1: The model can be used for forecasting

The results show that the three models are all significant (p-value = 0.000 < 0.05 level of significance) as all the predictors assumed such as time and climate change relate to the dependent variable. The model description table shown above contain the model identifier which assigns name to the model such as model_1 for the monthly average temperature, rainfall model_2 and stream flow model_3. The models provide the information of the estimate value for each model and each model is appropriate for forecasting. The seasonal nature of the model account for the seasonal down peak that was been confirmed while using the series of plot.

One of the most important reasons for doing time series is to try to forecast future values of the series. The models obtained of the series explained the past values to predict whether and how much the next values will increase or decrease. The ability to make such predictions successfully is an indication to be reliable for use.

V. CONCLUSION

To study potential impacts of climate change on water availability of reservoir Letaba River has been selected in the territory of South Africa. The study includes monthly average for maximum temperature, rainfall and stream flow data series were observed over time for the period 1970 to 2009 under the condition of climate change to be a major factor among others to influence the availability in the reservoir.

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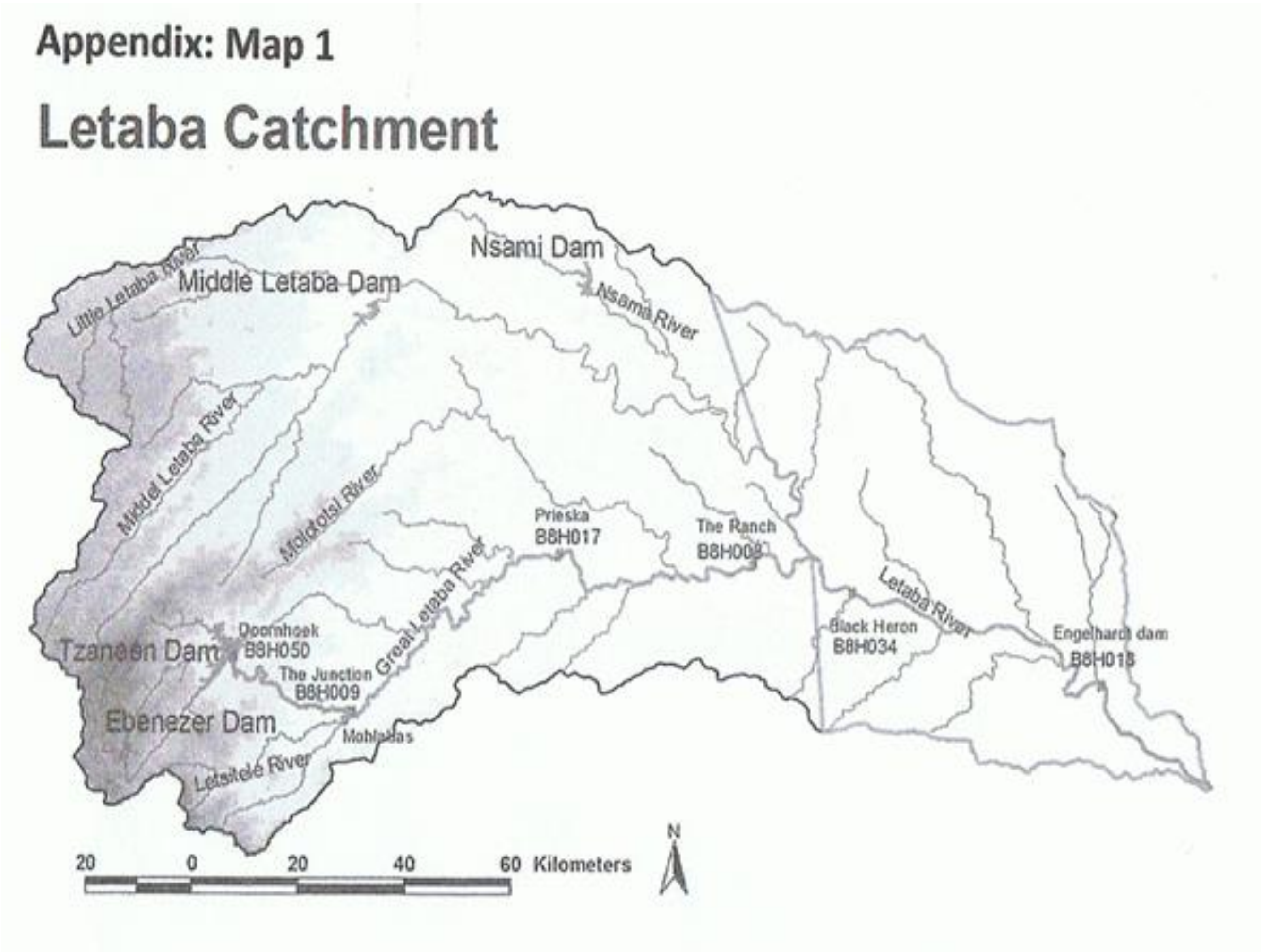
Time series and forecasting models have been used for comparison purposes of the observed and fit models. The data exhibits seasonal variations for the three models identified since seasonality is prominent feature of the data in general. The sense of equally spaced peaked suggested the presence of periodic component to time series. ARIMA was found to be the best model through the expert modeller which selected the model for forecasting. The predicted values showed good agreement with the observed values, indicating that the model had satisfactory predictive ability with good indication of well the model predicts the seasonal peaks. The sense comes into play because of acceptable the risk of climate change but the information might change from year to year.

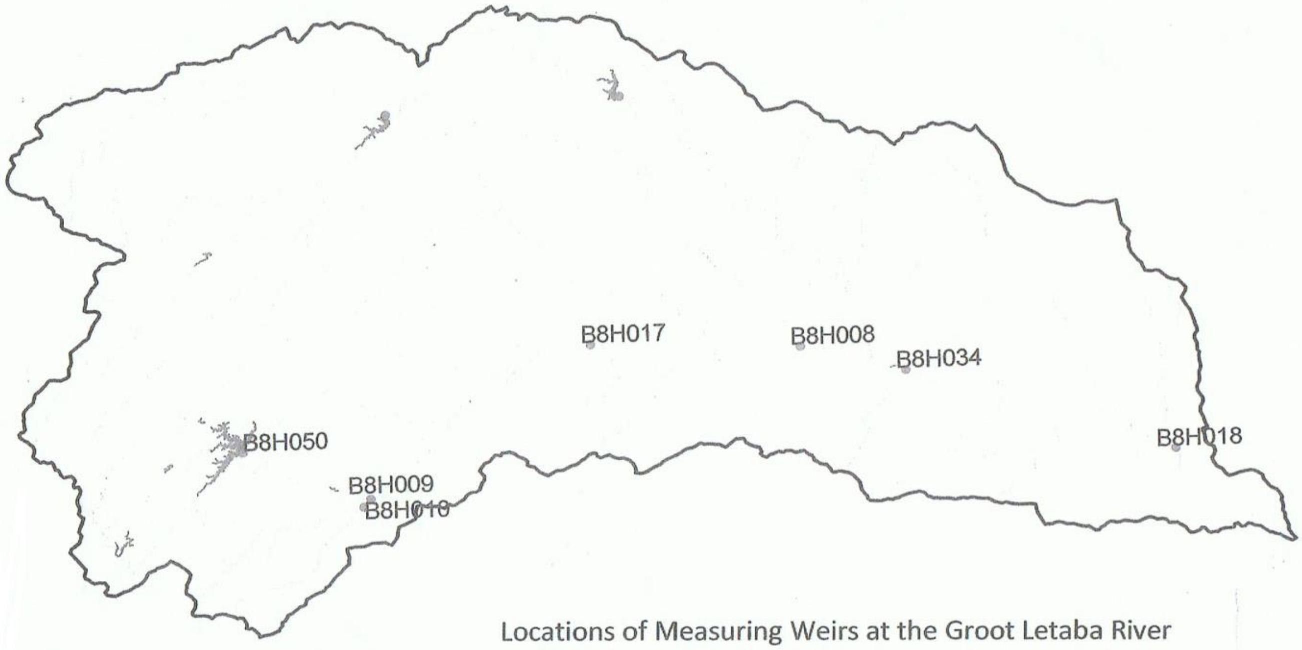
Further studies:

1. Transform data by using appropriate techniques
2. Eliminate the background noise from the period gram as this will allow the underlying structure to be more clearly isolated.

VI. APPENDIX



Appendix: Map2



Locations of Measuring Weirs at the Groot Letaba River Catchment
Measuring Weirs B8HO50 is above the Tzaneen Dam

VII. ACKNOWLEDGEMENT

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