River Nile Natural Inflow Changes

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Abstract

The River Nile is considered the backbone of Egypt's water resources. It supplies Egypt with about 95% of its water demands for different purposes (drinking water, irrigation, industry, navigation and power generation). The River Nile is one of the longest rivers in the world. Its length is estimated over 6600 kilometers. The main water supply sources are the Equatorial Lakes, Bahr El-Gazal Watershed and the Ethiopian Plateau. The Nile basin consists of about three million square kilometers in different countries. The Nile Basin characteristics are very unique since it extends in different countries with different climate and the watershed has varied topography, soil nature and flow conditions. The major Nile water supply sources are coming from Ethiopian Plateau through the Blue Nile and Atbara during the period from August to December. Following this period, most of the water supply comes from the White Nile and its tributaries (the Sobat at first, then the Great Lakes Plateau). The flow data for the Blue Nile, Atbara River and White Nile were analyzed during the study period (1900-2009) and statistical tests were applied to monitor changes occurred during the study period. The major observed changes during the study period for the selected stations were highlighted. Moreover, the Lake Nasser arriving water changes were also traced and the correlations of the incoming flow and the major water inflow sources were studied.

***Key words*:** River Nile Water Resources, Nile Discharges Analysis, Nile flow changes

1. INTRODUCTION

Water is the vital and most important element for development of any country especially in Egypt. River Nile is the main source of water supply. It supplies Egypt with about 95% of its water demands. River Nile is one of the oldest rivers in the history. Its history goes back more than six million years ago (Saied, 1993) and also it is one of the longest rivers all over the world. The river length is about 6695 kilometers measured starting from its remote sources to the Mediterranean Sea (Aziz and Ismail, 2006). The Nile basin is formed by the Equatorial Lakes, Bahr El-Gazal Watershed and the Ethiopian Plateau. Rive Nile is a very special river for many reasons. It has a unique and exceptional ability because of its geological and hydrological unique characteristics. It conveys its water from equatorial and Ethiopian sources to the Mediterranean Sea along the Great Desert for about 2700 kilometers between Atbara River and the sea without getting any additional amount of water through this journey except for some minors and few rainfalls. It has two major water sources, the first is a continuous source and has a limited variability from one season to another named the Equatorial Lakes and the second is a seasonal and a wide varied source and named the Ethiopian Plateau. The flow in the Nile Basin depends on the basin hydrology which is related to the basin features (NRI, 1992). The special climatic and hydrological parameters along the Nile Basin play very important role in controlling river discharges. Throughout this research, water discharges for some selected three major stations were monitored. These three major stations, as will be explained in the paper, are representing the major River Nile water sources. The changes of the actual measured water discharges are recorded over a relatively long period of time.

2. ANALYZED RIVER NILE WATER DISCHARGES

The selection of the analyzed water discharge station was performed to represent the major River Nile water resources. The major River Nile contributors are the White Nile (from the Equatorial Lakes), Blue Nile and Atbara River (from the Ethiopian Plateau). The major and the most down stream station for each source was selected for this analysis. The analyzed selected stations for these Nile sources are listed in table 1 (NWS, 2005). This table shows the selected stations for the White Nile, Blue Nile, and Atbara. Malakal Station is selected for the White Nile, Atbara Station is selected for Atbara River, and Khartoum Station is selected for the Blue Nile. Both Atbara and Khartoum Stations are the end stations for both sources Atbara River and Blue Nile respectively.

However, Malakal Station is located about 800 kilometers from the joint of the Blue and White Niles but it is the only available down stream station which has enough and continuous flow records representing the White Nile and it is not affected by reservoir losses. The White Nile evaporation and seepage losses from Malakal Station to Khartoum are estimated by an average of 3.5 billion cubic meters per year (Saied, 1993).

Table 1: Selected water discharge stations

Basin	River	Discharge Station	Kilometer from OAD
Equatorial Lakes	White Nile	Malakal	2652
Ethiopian Plateau	Atbara	Atbara	1522
Ethiopian Plateau	Blue Nile	Khartoum	1845

3. WATER DISCHARGES

The recorded discharges for the selected stations (NRI, 2010) were analyzed for the study period 1900-2009. Figure 1 shows the annual discharges for the three stations during the study period.

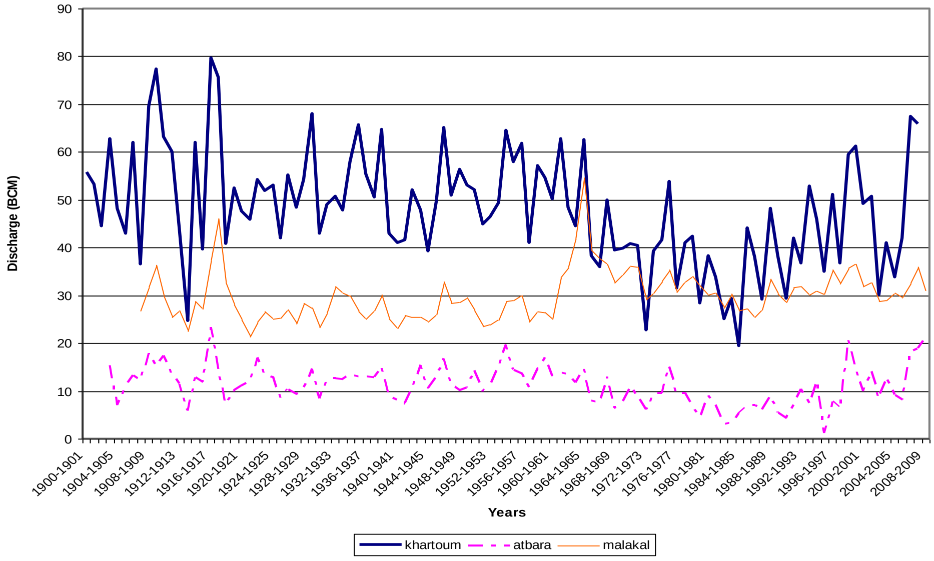

Figure 1: Annual Inflow for the three stations

3.1 Khartoum Station

Figure 2 shows Khartoum Station annual discharge histogram during the study period and figure 3 shows the normality plot for this station. The mean annual discharge is 48.138 billion cubic meters per year, standard deviation is 11.959 billion cubic meters per year. The recorded values have a minimum of 19.449 billion cubic meters per year, a maximum of 79.761 billion cubic meters per year and a median of 48.216 billion cubic meters per year. The normality plot shows the R-squared value of 0.993. Using Anderson-Darling (Anderson and Darling, 1952) test, the A-squared term is computed after the values X_i are standardized to create new values Y_i as:

$$Y_i = \frac{X_i - \bar{X}}{s}$$

Where $\bar{X}$ is the data mean and "s" is the standard deviation, with the standard normal cumulative distribution function (CDF) Φ for n values, A^2 is calculated using the following equation:

$$A^2 = -n - \frac{1}{n}\sum_{i=1}^{n}(2i-1)(\ln\Phi(Y_i) + \ln(1-\Phi(Y_{n+1-i}))).$$

The A-squared is compared with the critical values, to accept the null hypothesis; the A-squared should be less than the critical values. The P value is compared with the level of significance, to accept the null hypothesis; the P value should be greater than the level of significance. The test results for this case are:

A-squared	=0.297
P	=0.586
95% critical value	=0.787
99% critical value	=1.092

In this case, the data fit the normal probability line with R-squared value of 0.993, the P-value is 0.586 which is greater than alpha (level of significance) of 0.01, and the A-squared value (0.297) is less than both critical values 0.787, and 1.092. The null hypothesis is the data are normal can not be rejected.

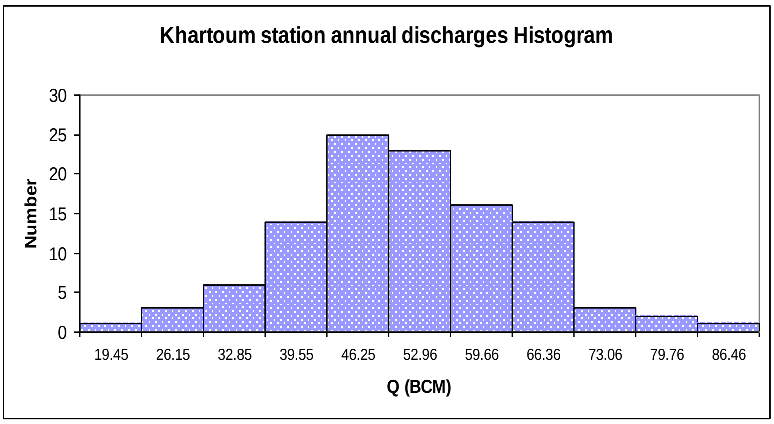

Figure 2: Discharge histogram for Khartoum Station

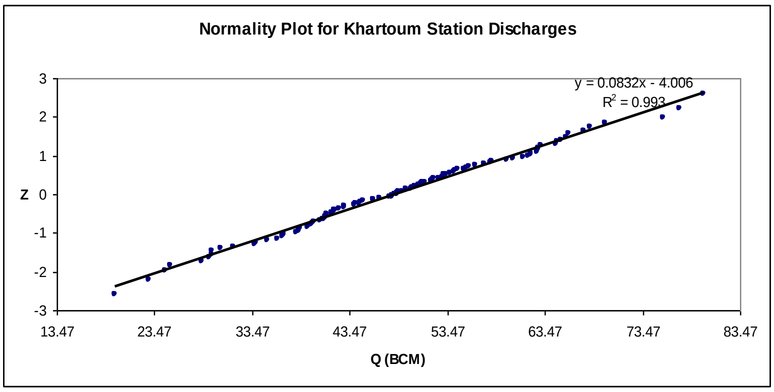

Figure 3: Normality plot for Khartoum Station Discharges

3.2 Malakal Station

Figure 4 shows Malakal Station annual discharge histogram during the study period and figure 5 shows the normality plot for this station. The mean annual discharge is 29.996 billion cubic meters per year, standard deviation is 5.089 billion cubic meters per year. The recorded values have a minimum of 21.370 billion cubic meters per year, a maximum of 54.560 billion cubic meters per year and a median of 29.520 billion cubic meters per year. The normality plot shows the R-squared value of 0.8985. Using Anderson-Darling test to test the normality distribution gives the following results:

A-squared	=1.516
P	=0.001
95% critical value	=0.787
99% critical value	=1.092

In this case, the data fit the normal probability line with R-squared value of 0.8985. However, according to Anderson-Darling test, the P-value is 0.001 which is less than alpha (level of significance) of 0.01, and the A-squared value (1.516) is higher than both critical values 0.787, and 1.092. The null hypothesis is the data are normal can not be accepted according to this test. The interesting part, if we exclude just two values for the years 1964/1965 and 1965/1966 which are 41.97 and 54.56 billion cubic meters per year and keep all the rest records for about 100 years, the normality testing results changes amazingly to the following:

R-squared	=0.961
A-squared	=0.761
P	=0.046
95% critical value	=0.787
99% critical value	=1.092

In this case, the data fit the normal probability line with R-squared value of 0.961, the P-value is 0.046 which is greater than alpha (level of significance) of 0.01, and the A-squared value (0.761) is less than both critical values 0.787, and 1.092. The null hypothesis is the data are normal can not be rejected.

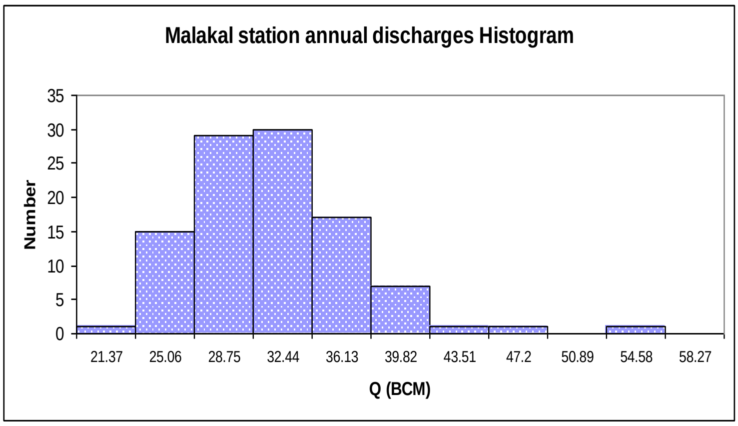

Figure 4: Discharge histogram for Malakal Station

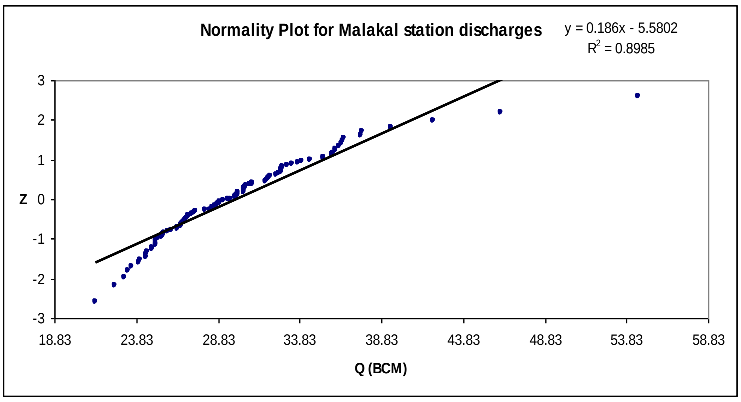

Figure 5: Normality plot for Malakal Station Discharges

3.3 Atbara Station

Figure 6 shows Atbara Station annual discharge histogram during the study period and figure 7 shows the normality plot for this station. The mean annual discharge is 11.204 billion cubic meters per year, standard deviation is 4.094 billion cubic meters per year. The recorded values have a minimum of 1.220 billion cubic meters per year, a maximum of 23.346 billion cubic meters per year and a median of 10.979 billion cubic meters per year. The normality plot shows the R-squared value of 0.9915. Using Anderson-Darling test to test the normality distribution gives the following results:

A-squared	=0.253
P	=0.729
95% critical value	=0.787
99% critical value	=1.092

In this case, the data fit the normal probability line with R-squared value of 0.9915, the P-value is 0.787 which is greater than alpha (level of significance) of 0.01, and the A-squared value (0.253) is less than both critical values 0.787, and 1.092. The null hypothesis is the data are normal can not be rejected.

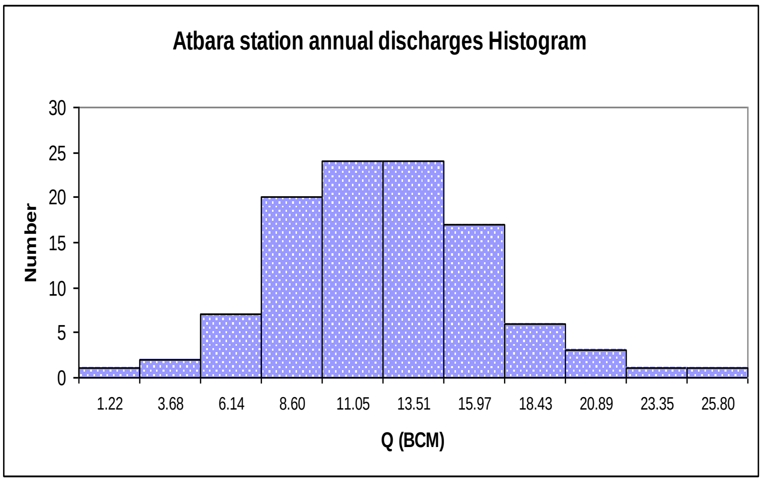

Figure 6: Discharge histogram Atbara Station

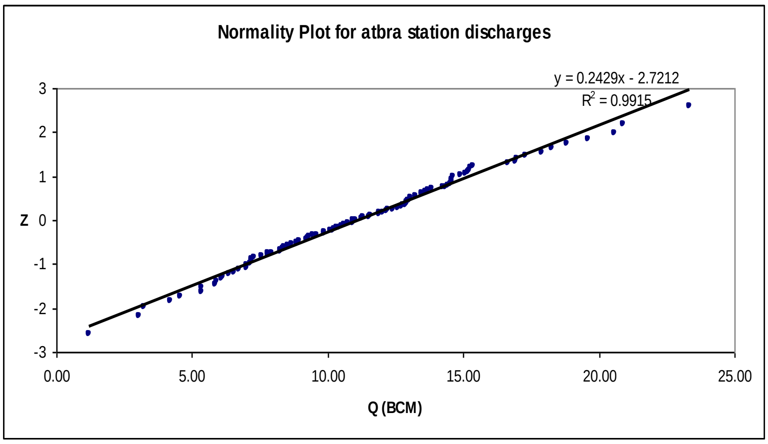

Figure 7: Normality plot for Atbara Station

3.4 Lake Nasser Arriving Water

Figure 8 shows arriving water annual discharge histogram during the study period and figure 9 shows the normality plot for this station. The mean annual discharge is 63.085 billion cubic meters per year, standard deviation is 15.813 billion cubic meters per year. The recorded values have a minimum of 34.816 billion cubic meters per year, a maximum of 119.080 billion cubic meters per year and a median of 62.181 billion cubic meters per year. The normality plot shows the R-squared value of 0.9406. Using Anderson-Darling test to test the normality distribution gives the following results:

A-squared	=0.469
P	=0.237
95% critical value	=0.787
99% critical value	=1.092

In this case, the data fit the normal probability line with R-squared value of 0.9406, the P-value is 0.237 which is greater than alpha (level of significance) of 0.01, and the A-squared value (0.469) is less than both critical values 0.787, and 1.092. The null hypothesis is the data are normal can not be rejected.

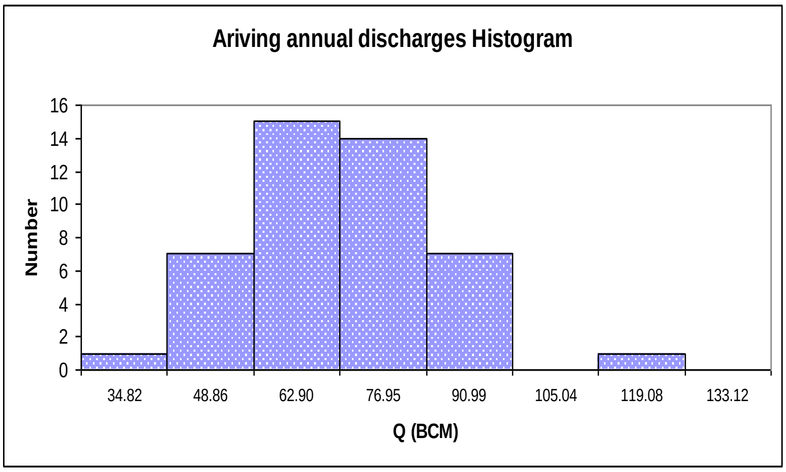

Figure 8: Discharge histogram Arriving water

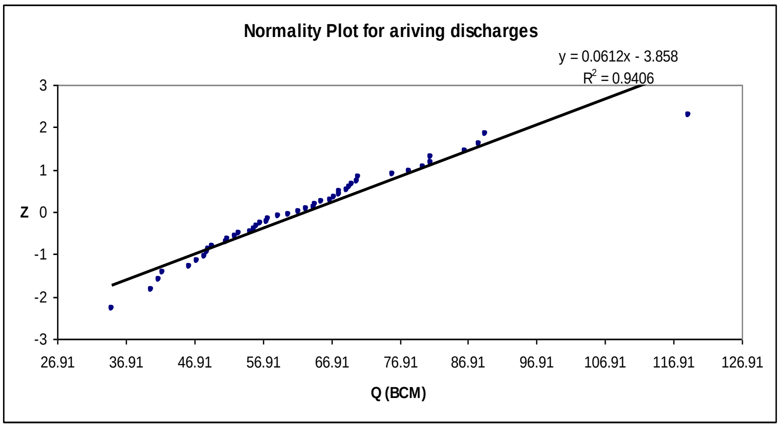

Figure 9: Normality plot for Arriving water

4. FLOW CHANGES

The flow records for the three major stations, Khartoum, Malakal, and Atbara show some variation during the study period as previously shown in figure 1. More detailed analyses are needed to focus on these changes and the major stations relationship with arriving water to Lake Nasser. The period from the construction of the High Aswan Dam till 2009 is divided into five periods. These periods are; the sixties, the seventies, the eighties, the nineties, and the two thousands periods. The next section is devoted to the analysis of these different periods.

4.1 ANOVA Test

The analysis of variance (ANOVA) is a statistical approach, in which, the observed variance is partitioned into components due to different sources of variation to examine these sources of variations (Moore and McCabe, 1989). This test can be used to study if the means of several groups are all equal or not and therefore it generalizes the student's two samples T-test to more than two groups (Haan, 1986). The sum of squares (SS) is computed for the between groups, within groups and total cases. The degrees of freedom (df) are determined for each case according to number of values and groups. The mean square (MS) is computed from both sum of squares and degree of freedom. Finally, F value is computed from mean square for both cases; between groups and within groups. The F value is compared with critical F value according the level of significance (P) to determine if we accept or reject the null hypothesis.

Table 2 shows the application of the ANOVA Test to Khartoum Station with different P values 0.01, 0.05, and 0.10 related to confidence levels of 0.99, 0.95, and 0.90 respectively. This table shows that for P=0.01 and P=0.05, the null hypothesis that all the mean of all groups of data; 1960's, 1970's, 1980's, 1990's, and 2000's are equal is accepted. On the other hand, if P=0.10, the null hypothesis that the means of all groups of data; 1960's, 1970's, 1980's, 1990's, and 2000's are equal is not accepted. If P is selected as 0.05 related to a confidence limit of 0.95 for the sake of general comparison, the null hypothesis is accepted. This means that there was no major variation in the flow means during these decades.

Table 2: Khartoum Station ANOVA Results.

Station	Khartoum			
P	0.01			
Source of Variation	SS	df	MS	F
Between Groups	1080.900485	4	270.2251	2.47531
Within Groups	4257.558981	39	109.1682	
Total	5338.459466	43		
P-Value	0.060045	F crit	3.842502	
Accept Null Hypothesis because P > 0.01				
P	0.05			
Source of Variation	SS	df	MS	F
Between Groups	1080.900485	4	270.2251	2.47531
Within Groups	4257.558981	39	109.1682	
Total	5338.459466	43		
P-Value	0.060045	F crit	2.612306	
Accept Null Hypothesis because P > 0.05				
P	0.10			
Source of Variation	SS	df	MS	F
Between Groups	1080.900485	4	270.2251	2.47531
Within Groups	4257.558981	39	109.1682	
Total	5338.459466	43		
P-Value	0.060045	F crit	2.094848	
Reject Null Hypothesis because P < 0.10				

Table 3 shows the application of the ANOVA Test to Malakal Station with different P values 0.01, 0.05, and 0.10 related to confidence levels of 0.99, 0.95, and 0.90 respectively. This table shows that for P=0.01, P=0.05 and P=0.10, the null hypothesis that all the mean of all groups of data; 1960's, 1970's, 1980's, 1990's, and 2000's are equal is not accepted. If p is selected as 0.05 related to a confidence limit of 0.95 for the sake of general comparison, the null hypothesis is not accepted for all groups. If the ANOVA test is applied for data of 1970's, 1990's, and 2000's, the null hypothesis that the means of these groups of data; are equal is accepted. This means that there were no major variation in the flow means during the decades of 1970's, 1990's, and 2000's. However, there were some mean changes during the decades 1960's and 1980's.

Table 4 shows the application of the ANOVA Test to Atbara Station with different P values 0.01, 0.05, and 0.10 related to confidence levels of 0.99, 0.95, and 0.90 respectively. This table shows that for P=0.01, P=0.05 and P=0.10, the null hypothesis that all the mean of all groups of data; 1960's, 1970's, 1980's, 1990's, and 2000's are equal is not accepted. If P is selected as 0.05 related to a confidence limit of 0.95 for the sake of general comparison, the null hypothesis is not accepted for all groups. If the ANOVA test is applied for data of 1960's, 1970's, 1990's, and 2000's, the null hypothesis that the means of these groups of data; are equal is accepted. This means that there was no major variation in the flow means during the decades of 1960's, 1970's, 1990's, and 2000's. However, there were some mean changes during the decade 1980's.

Table 3: Malakal Station ANOVA Results

Station	Malakal			
p	0.01			
Source of Variation	SS	Df	MS	F
Between Groups	415.2782	4	103.8195	7.95426
Within Groups	522.0827	40	13.05207	
Total	937.3609	44		
P-Value	8.14E-05	F crit	3.828294	
Reject Null Hypothesis because p < 0.01				
P	0.05			
Source of Variation	SS	Df	MS	F
Between Groups	415.2782	4	103.8195	7.95426

Within Groups	522.0827	40	13.05207	
Total	937.3609	44		
P-Value	8.14E-05	F crit	2.605975	
Reject Null Hypothesis because p < 0.05				
P	0. 10			
Source of Variation	SS	Df	MS	F
Between Groups	415.2782	4	103.8195	7.95426
Within Groups	522.0827	40	13.05207	
Total	937.3609	44		
P-Value	8.14E-05	F crit	2.09095	
Reject Null Hypothesis because p < 0.10				
Only data for 70's,90's,2000's				
P	0.05			
Source of Variation	SS	Df	MS	F
Between Groups	12.8299	2	6.414952	1.04625
Within Groups	159.4158	26	6.131376	
Total	172.2457	28		
P-Value	0.365577	F crit	3.369016	
Accept Null Hypothesis because p > 0.05				

Table 4: Atbra Station ANOVA Results

Station	Atbara			
P	0.01			
Source of Variation	SS	df	MS	F
Between Groups	255.1875	4	63.79688	4.009506
Within Groups	636.4562	40	15.9114	
Total	891.6437	44		
P-Value	0.007928	F crit	3.828294	
Reject Null Hypothesis because P < 0.01				
P	0.05			
Source of Variation	SS	df	MS	F
Between Groups	255.1875	4	63.79688	4.009506
Within Groups	636.4562	40	15.9114	
Total	891.6437	44		
P-Value	0.007928	F crit	2.605975	
Reject Null Hypothesis because P < 0.05				
P	0. 10			
Source of Variation	SS	df	MS	F
Between Groups	255.1875	4	63.79688	4.009506
Within Groups	636.4562	40	15.9114	
Total	891.6437	44		
P-Value	0.007928	F crit	2.09095	
Reject Null Hypothesis because P < 0.10				
Only data for 1960's, 1970's, 1990's, 2000's				
P	0.05			
Source of Variation	SS	df	MS	F
Between Groups	123.077	3	41.02567	2.119794
Within Groups	599.9618	31	19.35361	
Total	723.0388	34		
P-Value	0.118	F crit	2.911334	
Accept Null Hypothesis because P > 0.05				

Table 5 shows the application of the ANOVA Test to the arriving water with different P values 0.01, 0.05, and 0.10 related to confidence levels of 0.99, 0.95, and 0.90 respectively. This table shows that for P=0.01, the null hypothesis that all the mean of all groups of data; 1960's, 1970's, 1980's, 1990's, and 2000's are equal is accepted. It shows that for P=0.05 and P=0.10, the null hypothesis that all the mean of all groups of data; 1960's, 1970's, 1980's, 1990's, and 2000's are equal is not accepted. If P is selected as 0.05 related to a confidence limit of 0.95 for the sake of general comparison, the null hypothesis is not accepted for all groups. If the ANOVA test is applied for data of 1970's, 1980's, 1990's, and 2000's, the null hypothesis that all the mean of these groups of data; are equal is accepted. This means that there was no major variation in the flow means during the decades of 1970's, 1980's, 1990's, and 2000's. However, there were some mean changes during the decade 1960's.

Table 5: Arriving water ANOVA Results

Station	Arriving			
P	0.01			
Source of Variation	SS	df	MS	F
Between Groups	2841.454	4	710.3634	3.481999
Within Groups	8160.409	40	204.0102	
Total	11001.86	44		
P-Value	0.015663	F crit	3.828294	
Accept Null Hypothesis because P > 0.01				
P	0.05			
Source of Variation	SS	df	MS	F
Between Groups	2841.454	4	710.3634	3.481999
Within Groups	8160.409	40	204.0102	
Total	11001.86	44		
P-Value	0.015663	F crit	2.605975	
Reject Null Hypothesis because P < 0.05				
P	0. 10			
Source of Variation	SS	df	MS	F
Between Groups	2841.454	4	710.3634	3.481999
Within Groups	8160.409	40	204.0102	
Total	11001.86	44		
P-Value	0.016	F crit	2.09095	
Reject Null Hypothesis because p < 0.10				
Only data for 1970's, 1980's, 1990's, 2000's				
P	0.05			
Source of Variation	SS	df	MS	F
Between Groups	937.6563	3	312.5521	1.896789
Within Groups	5767.284	35	164.7795	
Total	6704.94	38		
P-Value	0.148145	F crit	2.874187	
Accept Null Hypothesis because P > 0.05				

5. ARRIVING WATER CHANGES

Figure 10 shows arriving water compared with the summation of the three major discharge sources; Khartoum, Malakal, and Atbara. Figure 11 shows the difference between the summation of the three major discharge sources and the arriving water. This figure illustrates how the difference between the major water resources and the arriving water deviates with time. It can be concluded from this figure that the difference is increasing during the 2000's years specially starting from year 2005/2006 which may be attributed to higher withdrawal of water during this period.

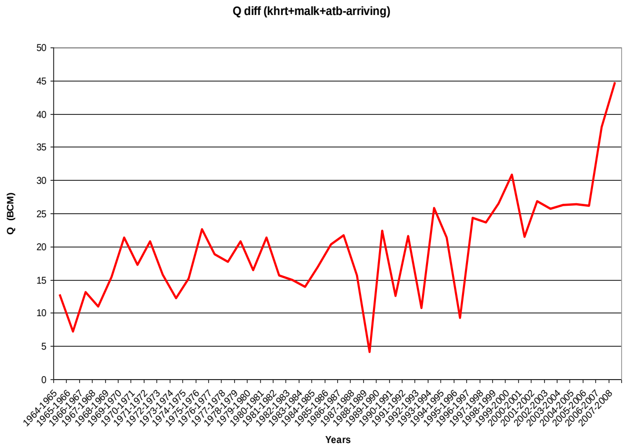

Figure 11: Major sources summation & arriving discharges

5.1 Flow Trend

The flow trend changes were traced during different periods. Figure 12 shows the trend lines of the arriving water compared with the summation of the three major discharge sources; Khartoum, Malakal, and Atbara. The figure shows the trend during different periods; 1960's, 1970's, 1980's, 1990's, and 2000's. It can be concluded from this figure that trend in the 2000's gives less arriving water than the trends for all other decades given the same summation of the three major discharge sources; Khartoum, Malakal, and Atbara. This may be attributed to higher withdrawal of water during recent periods.

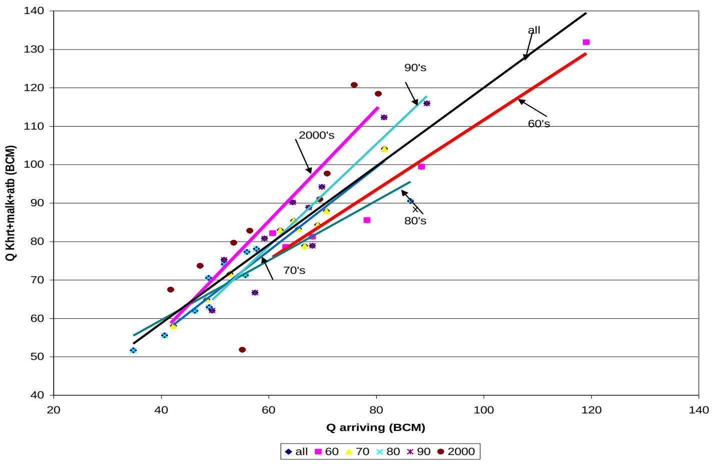

Figure 12: Discharge correlation for different periods

5.2 Multiple Regression

Table 6 shows the performed multiple regression results. The arriving water is taken as dependent variable and the three major discharge sources; Khartoum, Malakal, and Atbara are taken as independent variables for different periods. These results are used in the following equation:

Arriving Discharge = Constant + Khartoum discharge * C_{Khr} + Malakal Discharge* C_{Mlk} + Atbara Discharge * C_{Atb}

The multiple regression is used to trace the changes during different periods. The mean of the Khartoum Station discharge during the period 1960's to 2000's is 41.426 billion cubic meters per year. The mean of the Malakal Station discharge during the period 1960's to 2000's is 32.466 billion cubic meters per year. While the mean of the Atbara Station discharge during the period 1960's to 2000's is 9.081 billion cubic meters per year. These means are used in the developed multiple regression equations to trace the changes. The resulted arriving discharge due to using the means with the multiple regression coefficients given in table 6 are: 68.07, 65.61, 70.73, 64.43, and 56.93 billion cubic meters per year for the periods 1960's, 1970's, 1980's, 1990's, and 2000's respectively. It can be concluded that the resulted arriving water is generally decreased. This may be attributed to higher withdrawal of water during recent periods.

Table 6: Multiple regression results

Decades	Constant	C_{Mlk}	C_{Khr}	C_{Atb}	R-sq
1960's	-12.5712	1.432707	0.188685	2.89729	0.9242
1970's	7.675718	0.24894	1.003925	0.909489	0.9343
1980's	-55.392	2.483628	0.882347	0.983671	0.8516
1990's	12.18376	0.760967	0.408101	1.171572	0.8604
2000's	11.76129	0.108116	1.107509	-0.46454	0.8723

6. CONCLUSIONS

The flow data for the Blue Nile, Atbara River and White Nile were analyzed during the study period (1900-2009) and statistical tests were applied to monitor changes occurred during the study period.
The normality tests for different stations shows that the records follow the normal distribution. The analysis of variance (ANOVA) is applied, with different significance levels, to the three major stations and the arriving water to test the mean changes during different decades; 1960's, 1970's, 1980's, 1990's, and 2000's.

The ANOVA test indicates some mean changes, for Malakal Station during the 1960's and the 1980's.
The ANOVA test indicates some mean changes, for Atbara Station during the 1980's.
The ANOVA test indicates some mean changes, for arriving water during the 1960's.
The ANOVA test indicates no mean changes, for Khartoum Station.

The performed analysis on the deviation of the arriving water from the major sources sum, the flow trend analysis, and multiple regressions were together performed. The analyses indicate that the difference of the arriving water from the major sources sum is increasing during the 2000's years specially starting from year 2005/2006 .which may be attributed to higher withdrawal of water during this period.

It can be concluded from this study that some changes can be traced of the Nile Water sources. These changes can be attributed to different reasons; some of these reasons are due to climate changes such as the climate changes in the White Nile during the sixties. On the other hand, some changes of the arriving water can be attributed to the higher withdrawal of water such as the arriving water changes during the past few years.

7. REFERENCES

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