Effect of Change of Discharges at Dongola Station due to Sedimentation on the Water Losses from Nasser Lake

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Abstract

The aim of this paper is to investigate the decrease of the water losses from Nasser Lake in recent years than before. The water losses from Nasser Lake were estimated by the water balance method from 1964 to 2010. It is imperative to measure the Nile discharges at Dongola station accurately as these discharges are used to estimate the water losses from Nasser Lake as an input to the water balance equation. Investigations showed that sedimentation occurred at Dongola station and the cross sectional area was reduced by 2.5-6%. Also, daily Flow measurements showed that the flow at Dongola was reduced by 16-19%. This flow reduction is due to the formation of some islands in the location of the station that divert part of the discharge at Dongola from the Main Nile to a newly formed channel that discharges downstream the flow measuring station. The discharge of this new channel is not gauged consequently it affects the computation of the water losses from Nasser Lake. It is very crucial to find another location at the Main Nile to measure the discharges that flow to Nasser Lake instead of Dongola to alleviate this problem.

***Key Words**: Dongola Station, Nasser Lake, Discharge, Water Losses, Sedimentation, Islands.*

1. INTRODUCTION

The water losses from Nasser Lake in the south of Egypt are one of the national apprehensions, because the lake represents the water bank of Egypt. The lake is located in a hyper–arid region in the south of Egypt. Evaporation is by far the most important factor in explaining the water losses from the lake. For many years, the Egyptian Ministry of Water Resources and Irrigation adopted the figure of 7.54 mm/day as the annual mean evaporation rate with a maximum value in June of 10.8 mm/day (Whittington & Guariso, 1983). The water losses from the lake was estimated to be from 10 to 16 billion cubic meter (BCM) every year, which represent 20 to 30% of the Egyptian income from Nile water (Moslem Shaltout & El Housry, 1997).

The lake is located in the lower Nile River Basin at the border between Egypt and Sudan at 182 m above mean sea level. The lake was created from the late 1960s to the 1970s together with the construction of the Aswan High Dam (AHD) upstream of the old Aswan dam, about 5 km south of the city of Aswan. The AHD created a multi-purpose storage reservoir to provide adequate water supply in summer, hydropower, flood protection, and improved river navigation. The lake has an area of about 6,540 km^2 and a length of about 500 km, 350 km of which lies in Egypt and 150 km in Sudan. The lake has an average width of about 10 km, a maximum width of about 60 km, an average depth of 25 m, and a maximum depth of about 90 m. the total capacity of the reservoir is 162.3×10^9 m^3 at its highest water level (Sadek et al. 1997; Omar & El-Bakry 1981). The level of water oscillates between 147 to 182 meter above the mean sea level during a year, and from year to year.

In order to investigate the available water resources quantity in the lakes as well as impacts and influences of natural and man-induced factors a water balance should be established for the lake. The knowledge of water balance of lakes and reservoirs is an essential component of water management. Water management decision as far as possible should be based on a thorough quantitative understanding of the hydrologic cycle of the lakes/reservoirs in the basin. To obtain better management scenarios for Nasser Lake, an accurate estimation of the lake water losses thus is essential.

This paper is an update of previous water losses of the lake, making use of the hydrological data collected from gauged stations upstream Aswan High Dam (AHD) as input to the water balance equation. The overall flow of the Nile and its tributaries is measured at Dongola station on the Main Nile.

The gauged station at Dongola is located on the right bank of the Main Nile at Dongola town, about 782 km from Aswan Dam. Figure (1) shows the location of the Dongola Station on the Main Nile. The discharge measured at Dongola is used as the main input to the water balance equation when estimating the water losses from Nasser Lake. Any error in estimating the discharge at Dongola will affect the calculation of the water losses from Nasser Lake. A record from the year 1964 to 2010 was used to calculate the water losses of Nasser Lake using the water balance equation and the discharge at Dongola as the input to the equation. This paper will investigate the change of the water losses during the record period and highlight the reasons for these changes and make recommendations.

1.1 Description of the Dongola Station

The gauge at Dongola was erected in May 1962 on the right bank of the Main Nile at Dongola town, about 782 km from Aswan Dam and 430 km from Halfa town.Figure (1) shows the location of the Dongola and Atbara stations on the Main Nile. It consists of 8 one meter concrete steps of standard type with marble scales fixed to them and readings are from 9.50 to 17.50 meters. Daily readings of the gauge commenced on May 26th, 1962. The level of the zero of the gauge is 212.03 meters referred to mean sea level at Alexandria, Egypt.

Dongola station is considered one of the most important discharges measuring station on the Nile River as these discharges are used to quantify the water arriving Nasser Lake and consequently quantify the water arriving Aswan. Also the discharges at Dongola are used to estimate the water losses of Nasser Lake using the water balance method. It is very crucial to estimate the discharges at Dongola using the rating curve that relates the water level and the discharge.

2. BASIC EQUATIONS OF WATER BALANCE

The input and output components of the water balance of Nasser Lake depends not only on the physical dimensions of the water body, but also on the climatic, hydrological and geological factors affecting the water body and its surrounding areas (Ferguson & Znamensky, 1981, 1984). The water balance equation can be written, from continuity equation at any time which is governed by the conditions that the water volume remains constant. The continuity equation intern governed by conservation of matter, which described by equilibrium between added water volume or depth, lost water volume or depth and change in volume or depth as:

$$V_{in} - V_{out} + P - E - \Delta S = 0 \tag{1}$$

where:

V_{in}: water inflow
V_{out}: water outflow
P: precipitation volume
E: Evaporation volume

ΔS: change in storage

3. DATA OF WATER BALANCE COMPONENETS FOR NASSER LAKE

All water balance equations are based on the premise that the difference between water inflow and water outflow over a given time period for the hydrologic system of a lake must equal the change in water storage. A lake water budget is computed by measuring or estimating all of the lake's water gains and losses and measuring the corresponding change in the lake volume over the same time period (Benduhn & Renard, 2004, Vallet-Coulomb et al. 2001). Nasser Lake Basin is located in arid and subtropical zone. According to the meteorological data, the rainfall is nearly rare. Therefore, the above equation can be re-written as:

$$V_{in} - V_{out} - E - \Delta S = 0 \quad (2)$$

The followings are the main components of the water budget of Nasser Lake:

- Inflow = Discharge at Dongola – losses between Dongola and the Lake – Pump Discharges
- Outflow = Discharge downstream Aswan High Dam
- Losses from the Lake = Evaporation losses
- Change in storage of Lake Aswan

It is clear that, the discharge at Dongola station is essential in calculating the losses of Nasser Lake and any error in measuring or estimating the discharges at Dongola will affect the calculation of the water losses of Nasser Lake as calculated by the water balance method. Also, the Nile River and its tributaries in Sudan are subject to the sedimentation problem as these rivers are alluvial rivers.

3.1 Description of the Sedimentation at Dongola Station on the Main Nile

The Nile River and its tributaries within the Nile Basin in Sudan are typically alluvial rivers. Flow in an alluvial river is basically similar to flow over an inclined plain. Its available energy is balanced by dissipation of energy due to bed, side and internal friction as well as the energy required transporting the sediment load. On the other hand, the natural processes of erosion, transport and deposition of sediments have occurred throughout geologic times and have shaped the landscape of the world in which we live. Erosion always causes serious damage to agricultural land by reducing fertility and productivity of soils. Eroded soil is the largest pollutant of the surface waters in the world, since sediments affect water quality and suitability for consumption and industrial use. Soil eroded from upland areas, e.g. Ethiopia Highlands, from where 85% of River Nile waters come, is the source of most sediment transported by the rivers to the reservoirs; Roseires , Sennar, Gash el Girba, Aswan High Dam (AHD), in Egypt, and irrigated system. Problems associated with sediments deposition are varied; in stream channels reduces flood carrying capacity, resulting in greater flood damage to adjacent properties. Reservoir not only trap the incoming sediment load bur reservoir sedimentation also increases the flooding risk because of aggradations upstream of the reservoir i.e. reservoir sedimentation result in loss of storage capacity for flood control and/or irrigation. Upstream aggradations depend on the stream slope, the sediment size distribution and water – level fluctuations in the reservoir. Streams with low slope carrying large quantities of sediment may result in aggradations many kilometers upstream of the reservoir.

Figure (2), shows the formations of some islands in the Main Nile and in the vicinity of the Dongola station. It is believed that the formation of these islands due to the sedimentation problem in the Main Nile diverts part of the flow away from the gauged station at Dongola. This diverted water will reduce the measured discharge at Dongola and consequently will affect the computations of the water losses from Aswan Lake as estimated by the water balance method.

3.2 Available Data at Dongola Station

The available hydrological data to calculate the losses from Nasser Lake by the water balance method totals 46 years from the water year 1964/1965 to the water year 2009/2010. Table (1) shows the water losses of Nasser Lake from the water year 1964/1965 to the water year 2009/2010 as calculated by the water balance method. Also Figure (3) shows the change of the water losses over a period of 46 years. It is clear from Table (1) and Figure (3) that there is a significant decrease of the water losses in some years; which is not practical. From Figure (3), it can be seen that the water losses from Nasser Lake as calculated by the water balance method is not consistent. For example, the water losses decreases significantly in the period (1988-1992) then starts to increase in the period (1996-1999) then decreases again in recent years. This inconsistency in the water losses of Nasser Lake is not realistic. The annual water losses from Nasser Lake range from 10 to 16 BCM (Moslem Shaltout & El Housry, 1997), but it can be seen from Figure (3) that the annual water losses could be less than 5 BCM which is unrealistic. So, it is crucial to investigate the discharges at Dongola which affect the water losses from Nasser Lake as calculated by the water balance method. The discharge at Dongola is affected by the formation of some islands in the vicinity of the measuring station due to the sedimentation problem. This formation of these islands might divert part of the discharge away from the Main Nile.

Table 1: Water Losses from Nasser Lake as Calculated by the Water Balance Method

Water Year	Dongola Discharge (BCM)	Flow Arriving the Lake (BCM)	Water Level of the Lake (m)	Water Storage of the Lake BCM)(	Change in Water Storage of the Lake (BCM)	Discharge Downstream HAD (BCM)	Flow Arriving HAD (BCM)	Water Losses (BCM)
1964/1965	120.36	119.51	117.89	3.33	2.42	116.76	119.18	0.33
1965/1966	81.79	81.06	119.02	4.60	1.27	78.80	80.06	1.00
1966/1967	71.58	70.88	133.73	14.54	9.94	58.77	68.71	2.17
1967/1968	93.60	92.84	145.54	29.26	14.72	72.17	86.90	5.94
1968/1969	71.76	71.06	151.10	39.97	10.71	53.12	63.83	7.23
1969/1970	71.06	70.36	153.83	46.43	6.46	54.85	61.31	9.05
1970/1971	80.10	79.38	159.68	61.36	14.93	55.36	70.30	9.08
1971/1972	78.21	77.49	162.49	69.82	8.46	55.96	64.42	13.07
1972/1973	53.36	52.71	158.20	57.24	-12.58	55.24	42.66	10.06
1973/1974	76.59	75.88	161.71	66.70	9.46	56.30	65.76	10.12
1974/1975	82.49	81.76	165.60	80.06	13.36	55.80	69.16	12.61
1975/1976	102.74	101.95	172.42	108.37	28.31	53.22	81.53	20.42
1976/1977	67.79	67.10	171.70	105.05	-3.32	56.14	52.82	14.28
1977/1978	77.13	76.41	172.52	108.84	3.79	61.78	65.57	10.85
1978/1979	73.41	72.70	173.04	111.30	2.46	59.72	62.18	10.52
1979/1980	56.58	55.93	171.27	103.12	-8.19	56.71	48.53	7.40
1980/1981	66.69	66.01	171.13	102.49	-0.63	56.60	55.97	10.04
1981/1982	68.03	67.34	170.36	99.15	-3.34	59.00	55.66	11.68
1982/1983	50.73	50.09	165.87	81.03	-18.12	58.73	40.61	9.48
1983/1984	58.53	57.87	163.60	72.94	-8.09	57.06	48.96	8.91
1984/1985	42.07	41.45	156.37	51.46	-21.48	56.28	34.80	6.65
1985/1986	64.44	63.76	157.23	53.70	2.24	55.52	57.76	6.00
1986/1987	53.48	52.83	154.65	47.26	-6.44	55.27	48.83	4.00

Table 1: Continue

Water Year	Dongola Discharge (BCM)	Flow Arriving the Lake (BCM)	Water Level of the Lake (m)	Water Storage of the Lake BCM)(	Change in Water Storage of the Lake (BCM)	Discharge Downstream HAD (BCM)	Flow Arriving HAD (BCM)	Water Losses (BCM)
1987/1988	48.89	48.26	151.70	40.67	-6.59	52.89	46.30	1.96
1988/1989	97.14	96.36	164.41	75.78	35.11	53.39	88.49	7.87
1989/1990	60.62	59.96	163.77	73.52	-2.26	54.00	51.74	8.22
1990/1991	58.69	58.03	162.50	69.25	-4.27	53.80	49.53	8.50
1991/1992	65.61	64.93	163.98	74.23	4.98	54.25	59.23	5.71
1992/1993	71.96	71.26	167.45	87.06	12.82	55.30	68.12	3.14
1993/1994	75.46	74.75	169.64	96.05	9.00	55.47	64.46	10.29
1994/1995	78.40	77.68	172.34	108.00	11.95	55.50	67.45	10.24
1995/1996	66.22	65.54	172.76	109.97	1.97	55.50	57.47	8.07
1996/1997	79.65	78.93	175.48	123.80	13.82	55.97	69.79	9.14
1997/1998	62.53	61.86	174.75	120.00	-3.80	55.58	51.78	10.08
1998/1999	89.01	88.26	174.75	120.00	0.00	71.44	71.44	16.82
1999/2000	83.87	83.13	175.79	125.41	5.41	67.06	72.46	10.67
2000/2001	74.43	73.72	175.85	125.72	0.31	61.98	62.29	11.44
2001/2002	76.71	76.00	175.70	124.94	-0.78	68.13	67.35	8.65
2002/2003	66.23	65.54	175.14	122.03	-2.91	57.14	54.23	11.31
2003/2004	49.78	49.15	172.06	106.68	-15.35	57.71	42.36	6.79
2004/2005	55.26	54.61	169.59	95.84	-10.85	56.95	46.11	8.50
2005/2006	61.18	60.51	168.65	91.87	-3.97	57.50	53.52	6.99
2006/2007	88.78	88.03	173.42	113.20	21.34	59.09	80.42	7.61
2007/2008	84.89	84.15	174.80	120.26	7.06	68.86	75.92	8.23
2008/2009	69.58	68.89	173.30	112.60	-7.66	62.79	55.13	13.76
2009/2010	53.62	52.97	169.79	96.70	-15.90	58.04	42.13	10.84

4. STUDY OF DONGOLA DISCHARGES

The discharges at Dongola have been investigated by establishing the stage-discharge relationship or the rating curves for the entire period of the study. From these rating curves, it can be seen that:

- Figure (4) shows the rating curves for the water years from 1970 to 1974. It can be seen from this figure that the difference in the discharges from one year to another as estimated by the rating curve at the same level is small and can be neglected particularly in low flows.
- Figure (5) shows the rating curves for the water years from 1988 to 1992. It is clear from these curves that the difference between the estimated discharges at the same level from one year to another is very small and can be neglected.
- By comparing the discharges at the same level for the water years (1970-1974) and (1988-1992), it can be seen that there is a significant decrease in the discharges in the later one and this decrease extends in recent years. The reduction in the discharges at Dongola station ranges from 16 to 19% in recent years. Table (2) shows a comparison between the discharges in the period from 1970/1974 and the discharges in the period from 1988/1992. It can be seen from Table (2) that there is a significant decrease in the discharges recently than before.
- This decrease in the discharges at Dongola can be realized in very recent years as shown in Figure (6).

Table 2: The Change of Discharges at Dongola Station

Water level (m)	Average discharges (mm^3/day)		Change of Discharge (mm^3/day)
	(1970-1974)	(1988-1992)	
12.00	345	285	60
13.00	525	425	100
14.00	725	605	120

As the discharges at Dongola are estimated by the rating curve that relates the discharge with the water level; so it is imperative to be certain that the water levels as measured at Dongola station are accurate. A double mass curve that relates the water levels at Dongola and the water levels at Atbara was established. Figure (7) shows the double mass curves between the water levels at both Dongola and Atbara within the entire period of this study. It can be realized from Figure (7) that the relation is constant which means that the change in the discharges at Dongola stations from one year to another has nothing to do with the water level measuring station at Dongola. Investigations show that that change in the discharge at Dongola station could be due to the followings:

1. Part of these discharges is used by the Sudanese government for irrigation, industrial or domestic use.
2. A new channel has been formed recently due to morphological changes and discharges downstream the location of Dongola station and this channel is not gauged.
3. There is another channel that divert part of the discharges of Dongola to adjacent swamps and never return back again to the main Nile.
4. All of the above.

Figure (8) shows a relation between the water level and the cross – sectional area at Dongola. It can be seen from this figure that the cross-sectional area reduced in recent years than before. The percentage of reduction ranges from 2.5 to 6 % which means that, sedimentation occurred in the vicinity of the measuring station at Dongola. Also, a relation between the water levels and the average depth of water at Dongola was established. It can be seen from Figure (9) that the average depth decreases with the increase of the water level in recent years than before. The sedimentation at the vicinity of the measuring station at Dongola formed an island that created another channel that draw part of the water away from the measuring point and this channel is not gauged and this will affect the discharge at Dongola and consequently will affect the water losses from Nasser Lake as computed by the water balance method.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- Estimating the water losses from Nasser Lake by the water balance method will be affected by the accuracy of the discharges measured or estimated at Dongola station, about 782 km from Aswan Dam.
- The study showed that sedimentation occurred in the vicinity of the measuring station at Dongola created another channel that diverts part of the discharge at Dongola consequently this will affect the computation of the water losses of Nasser Lake.

5.2 Recommendations

- The new channel that formed due to the sedimentation at Dongola should be gauged and it discharge should be added to the discharge of Dongola.
- Another new location should be used to measure the discharges of the Main Nile to alleviate the sedimentation problems at Dongola.

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AUTHORS BIOGRAPHY

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Dr Mansour is a senior researcher in the Drainage Research Institute and currently is the Head of the Technical office of the Central Directorate for Egyptian Irrigation in Sudan. His main experience involves irrigation and drainage, water resources management and engineering. He gained his experience through his long involvement in projects in the Irrigation Department of the Ministry of Water Resources and Irrigation in Egypt or drainage projects in the Drainage Research Institute in Egypt as well.

Figure 1: shows the location of Dongola and Atbara on the Main Nile

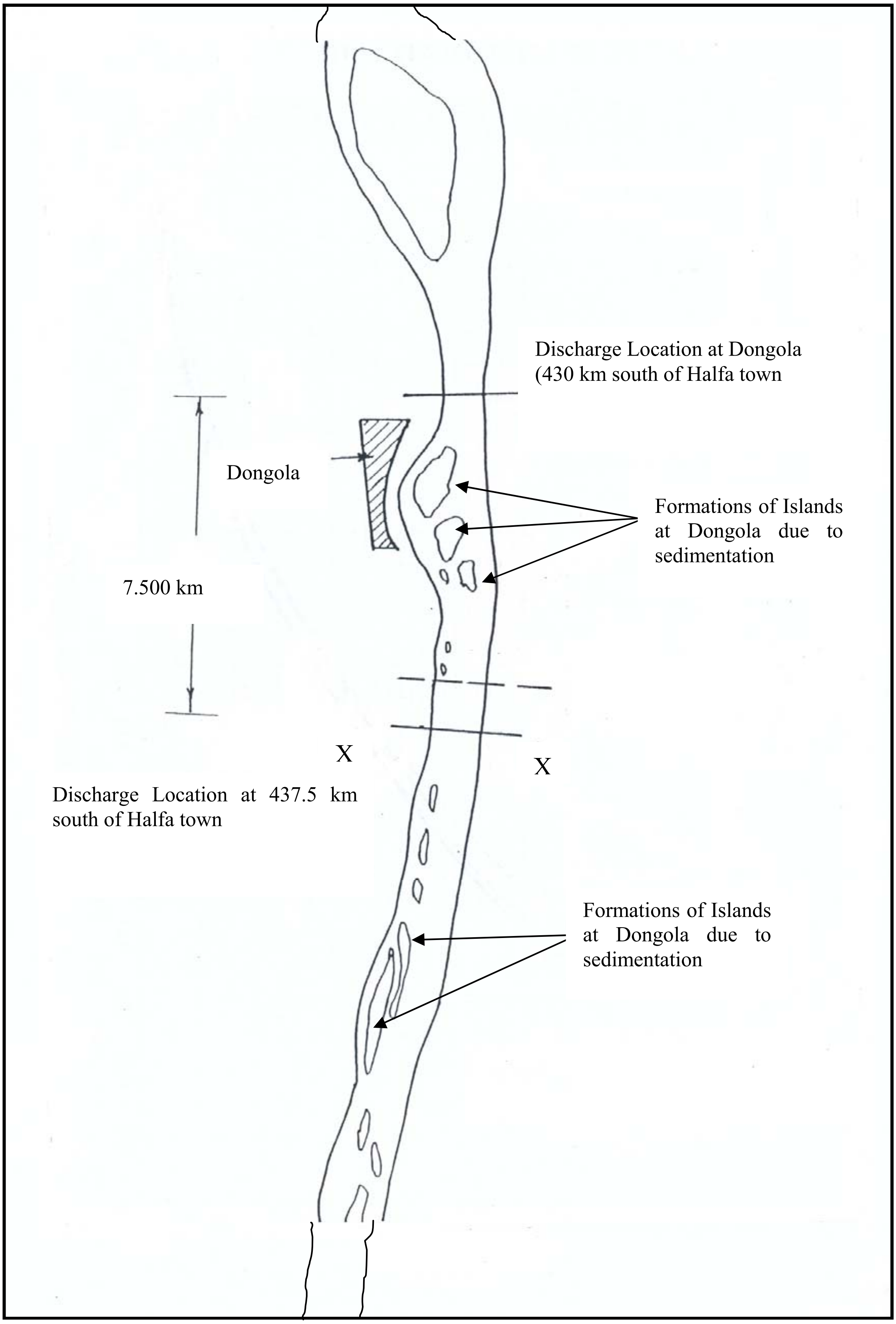

Figure 2: shows the locations of Islands in the Main Nile north and south Dongola

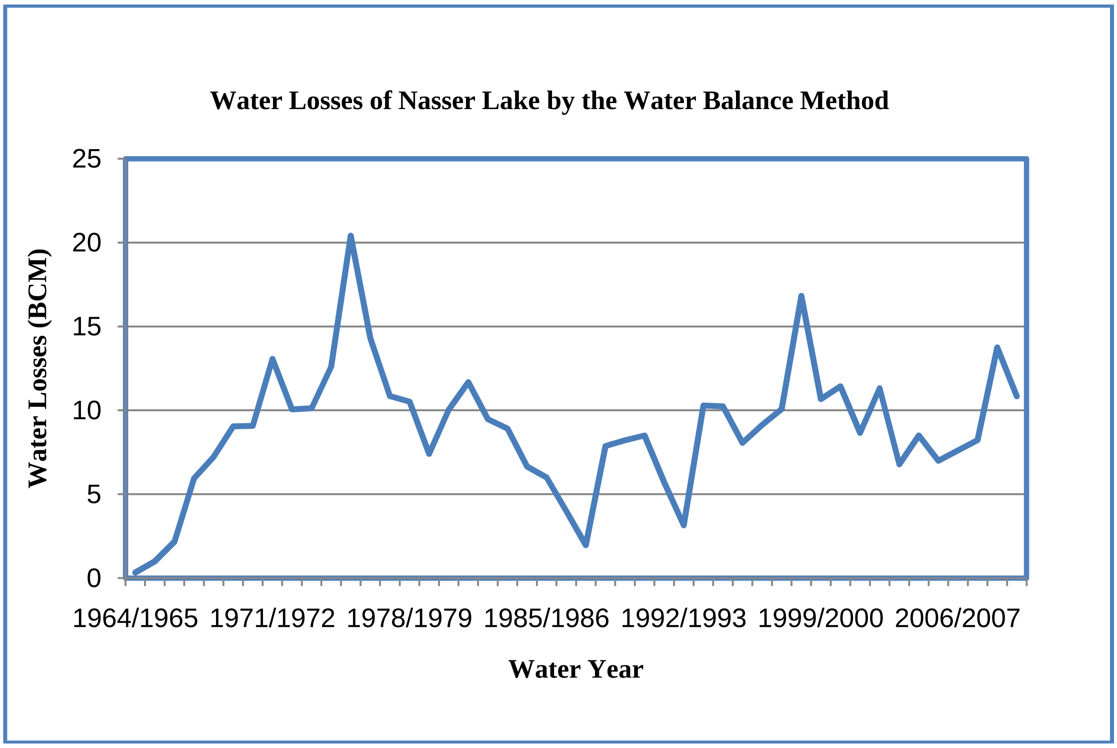

Figure 3: Water Losses from Nasser Lake as Computed by the Water Balance Method

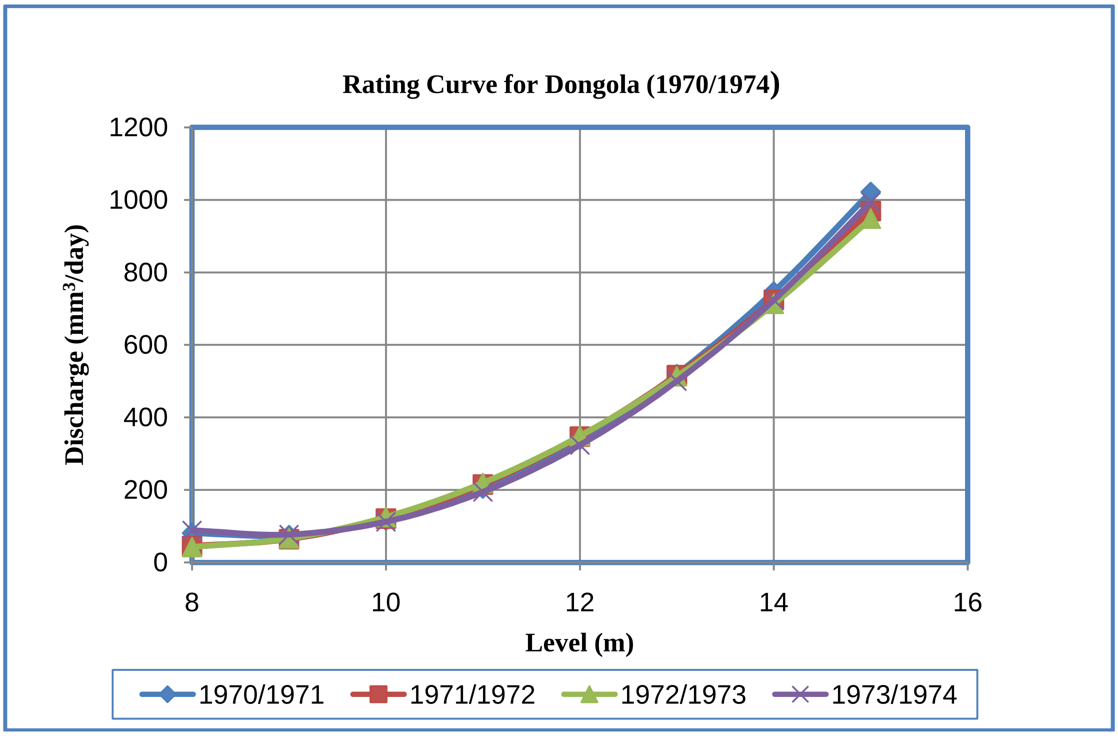

Figure 4: Rating Curves for the Discharges at Dongola Station in the Period (1970/1974)

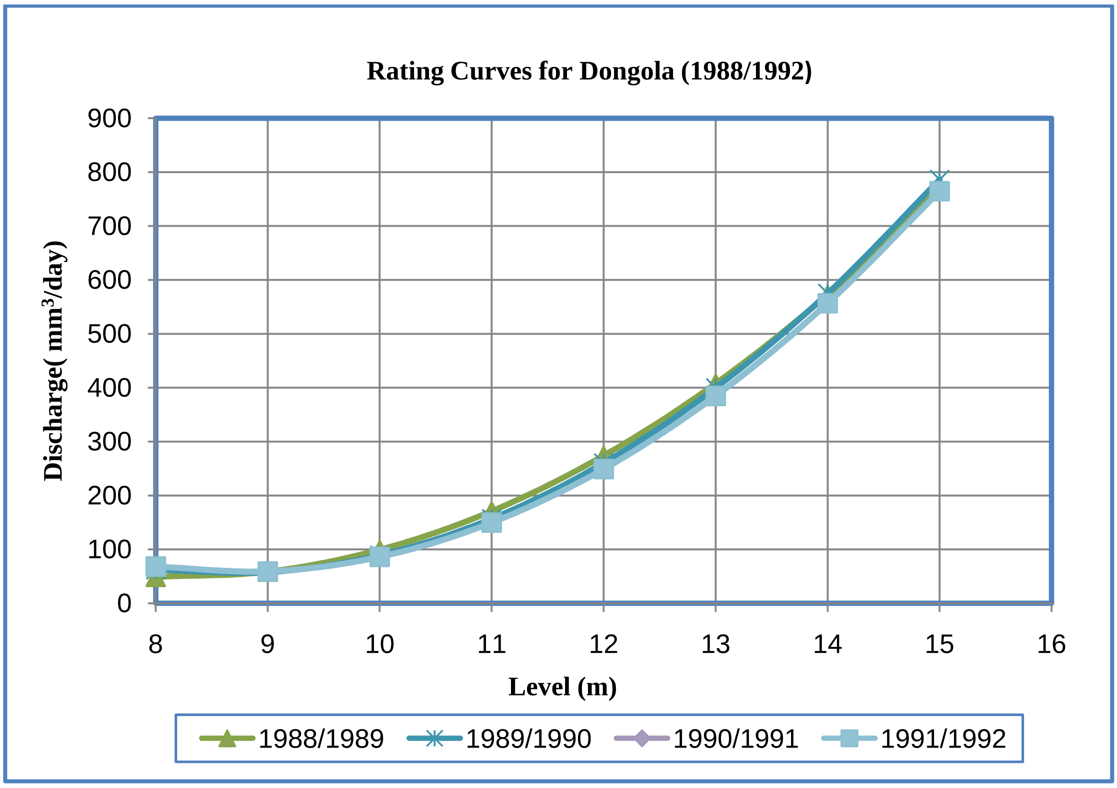

Figure5: Rating Curves for the Discharges at Dongola Station in the Period (1988/1999)

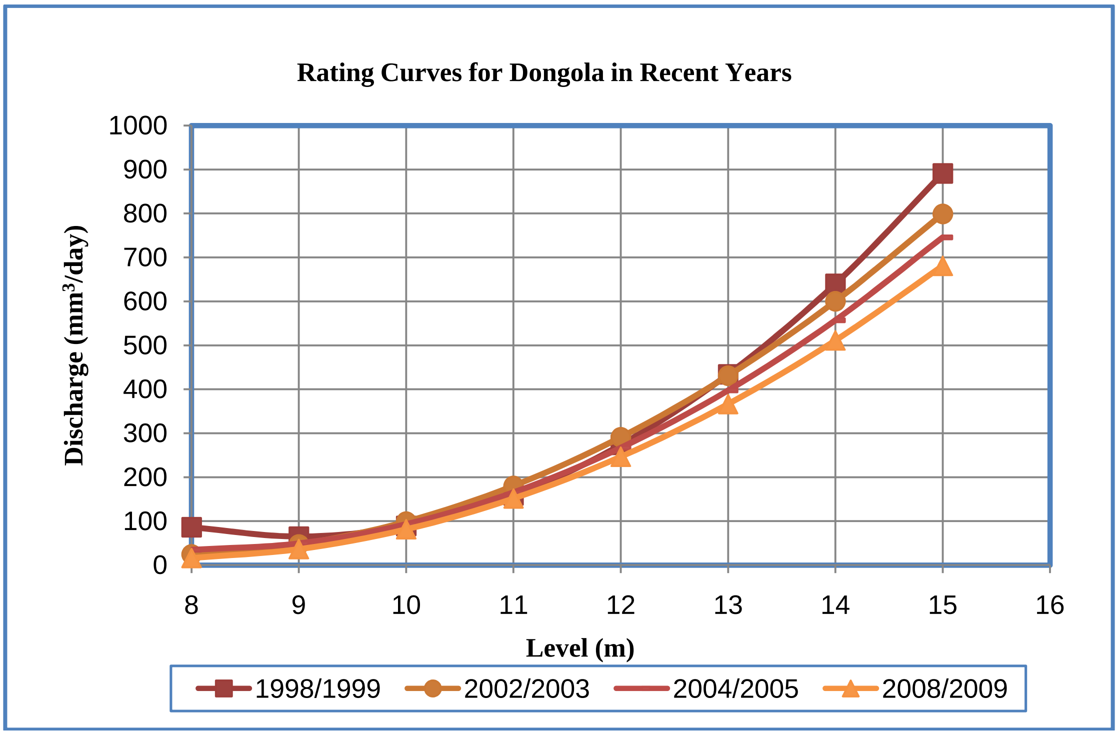

Figure 6: Rating Curves for the Discharges at Dongola Station in Recent Years

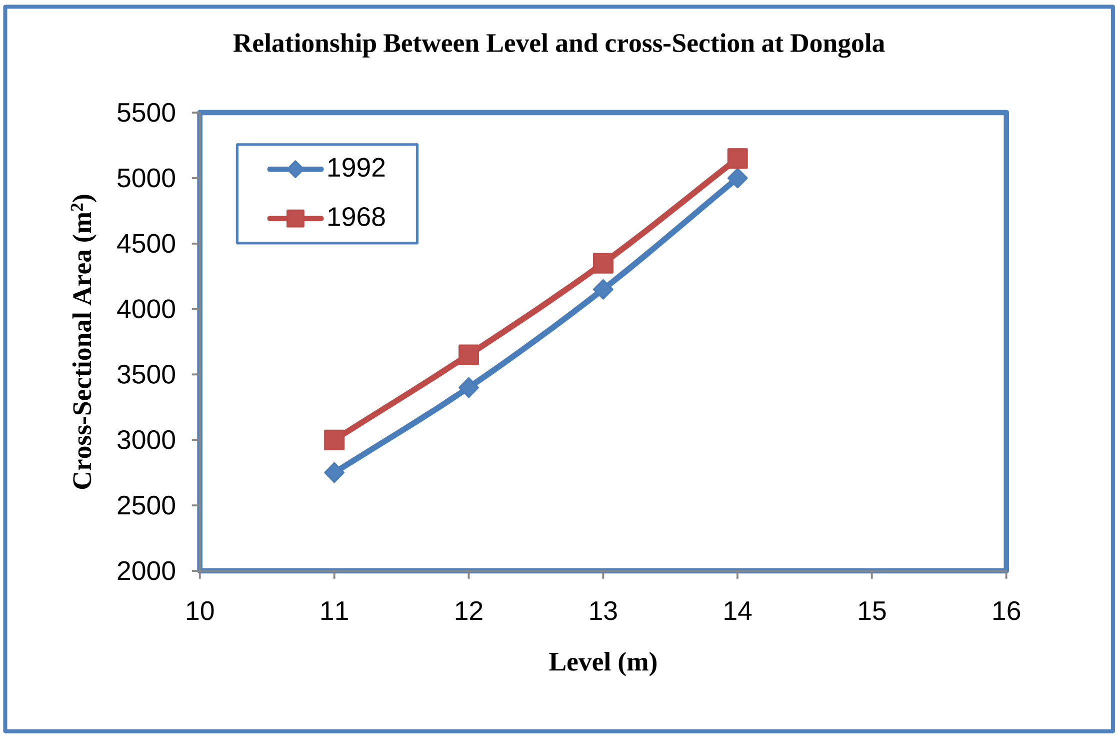

Figure 7: Relationship between Water Level and Cross Sectional Area at Dongola Station

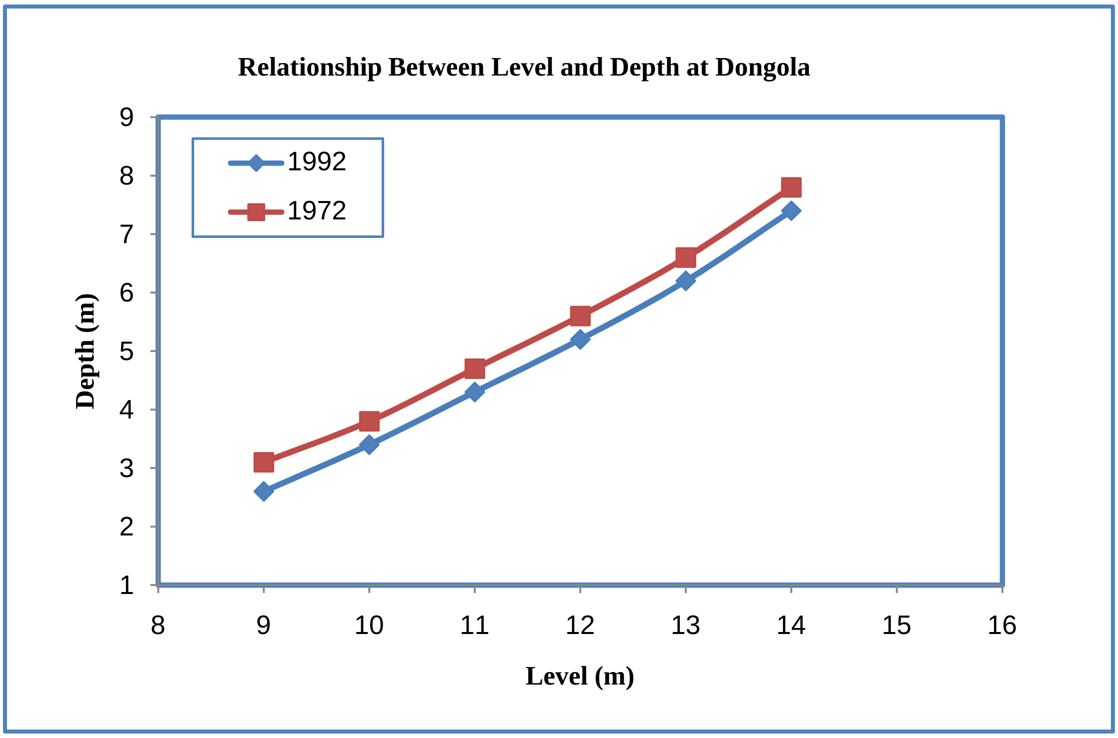

Figure 8: Relationship between Water Level and Water Depth at Dongola Station

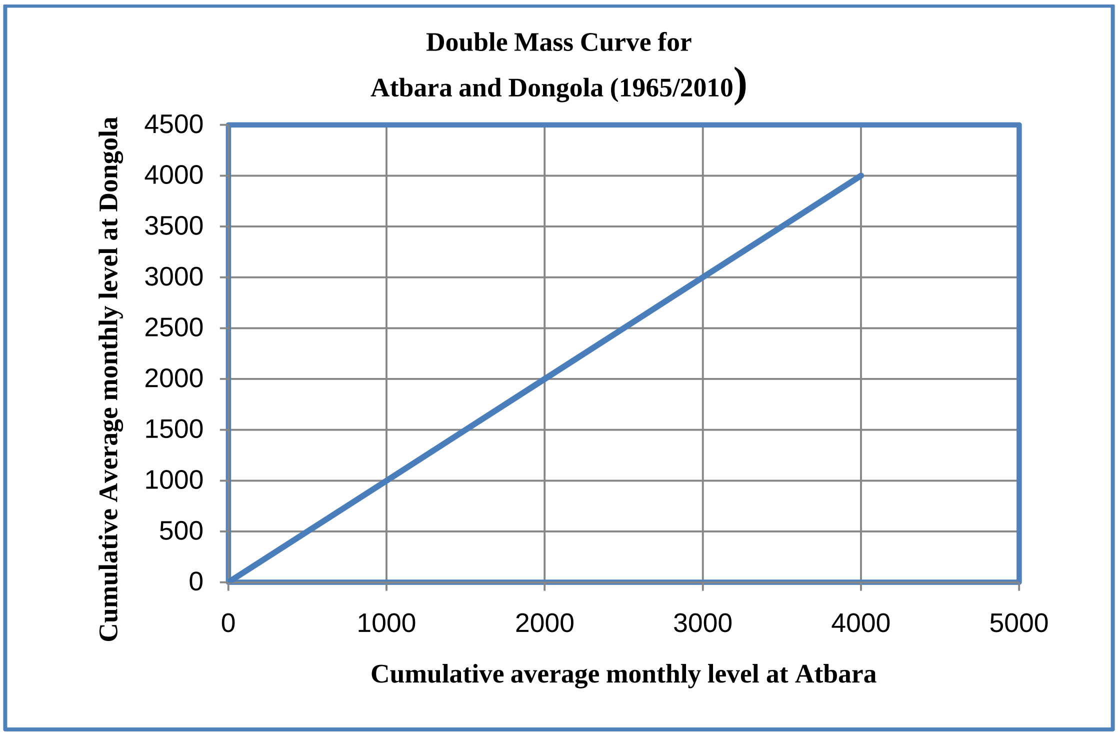

Figure 9: Double Mass Curve for Average Monthly Levels at Both Dongola and Atbara