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Sedimentological study of Lake Nasser; Egypt, using integrated improved techniques of core sampling, X-ray diffraction and GIS platform

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Sedimentological study of Lake Nasser; Egypt, using integrated improved techniques of core sampling, X-ray diffraction and GIS platform

Hussien ElKobtan¹, Mohamed Salem², Karima Attia³, Sayed Ahmed² and Islam Abou El-Magd⁴*

Abstract: Lake Nasser is one of the largest man-made reservoirs, that is located on the Nile River. To understand the sedimentation process of the lake, bottom sediments from the bottom-surface of the lake core samples from the top 1.25 m of the bottom layer were collected. These samples were mechanically analysed in the laboratory. The analysis of statistical parameters of the sediment samples has generally classified the lake into two depositional environments that reflect the sedimentation process; (1) the riverine environment that exist at the entrance of the lake between El-Daka and CC stations, (2) the lacustrine environment that extend along the rest of the lake to the High Aswan Dam. Along the riverine environment, the river processes were the prevailing, which being reflected on the bottom sediments that are nearly free from clay and composed mainly of sand (>87%) mixed with small ratios of silt (<10%). Further downstream to the end of the lake the lacustrine environment is dominant with slow deposition from quite water with bottom sediments free of sand and the bottom sediments composed mainly of clay (>57%). X-ray analysis indicated that montmorillonite, kaolinite and illite are the dominant clay minerals. GIS was used to spatially simulate the bottom sediment distribution at the bottom of the lake.

Subjects: Geology-Earth Sciences; Geomorphology; GIS, Remote Sensing & Cartography; Sedimentology & Stratigraphy

Keywords: sedimentation process; X-ray diffraction; core sampling; grain size analysis; GIS; Lake Nasser

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1. Introduction

Egypt has constructed a huge human controlled structure “High Aswan Dam” to manage the Nile water and rescue the Nile Delta and flood plain from flooding. At the upstream side of this dam a huge reservoir was formed, which is called Lake Nasser. The lake stores water budget of Egypt (55.5 BCM per year), to secure the water usage in the country (Abul-Atta, 1978). It also receives huge amount of sediments that carried with the water flow from the catchments of the Nile River. The tunnels of the High Aswan Dam allow water to drain downstream into the Nile River, however sediments continuously settle down and accumulate in the lake deforming and reducing the storage capacity.

It is estimated that more than 134 million tons of Nile sediments are deposited annually in Lake Nasser (Shalash, 1980). Depending on this estimation, it could be estimated that there were about 6.8 Milliard tons of sediments deposited along the lake since the construction of the dam till 2015. Owing to the strategic importance of the preservation of the lake storage capacity and the priority of sediments as an essential component of the lake system, there is an essential need for understanding the sedimentation processes. Up till now, there is no precise information about the material beneath the surface of the sediments of Lake Nasser.

For accurate representation of the lake sediments, sampling and measuring processes took place. The locations in respect to the cross section’s vertex were determined earlier based on optical survey instruments like Levels and Total Station (Dahab & EL-Moattassem, 1994; Makary, 1982; Shalash, 1980). However, El-Kobtan (2007) used global positioning system (GPS) technique to accurately position the sampling-measuring stations. The bottom sediment samples were mechanically analysed in order to determine their graphical grain size statistical parameters and their significances, mineralogical and chemical composition (Abdel-Aziz, 1997; Dahab & EL-Moattassem, 1994; El-Kobtan, 2007; El-Manadely, 1991; Makary, 1982; Philip, Hassan, & Khalil, 1978; Shalash, 1980). Minerology of sand fraction included in the bottom sediments was investigated using the polarized light microscopic technique (Philip et al., 1978). Whereas, the clay mineralogy was investigated using X-ray Florescence Diffraction Technique (XRFD) (El-Kobtan, 2007; Makary, 1982).

In this research, an integrated approach of using improved techniques: (1) core sampler to collect core samples from the bottom sediments of Lake Nasser, (2) X-ray diffraction and laboratory analysis and (3) geographic information systems to provide comprehensive knowledge and understanding of the sedimentation processes in Lake Nasser.

1.1. Description of the study area

Lake Nasser is located on the border between Egypt and Sudan, lies between Latitudes 20°27′–23°58′ N and Longitudes 30°07′–33°15′ E. Its northern two-third part is located in Egypt (always called Lake Nasser) whereas the southern one-third part is located in Sudan (sometimes called Lake Nubia).

In the case of full storage capacity, the water level reaches 182 m (ASL), and the lake extends from the Aswan High Dam in Egypt to Dal Cataract in Sudan with length of about 500 km (Figure 1). At this level, the lake occupies an area of about 6,500 km² whereas its storage capacity reaches about 162 billion m³ (Abul-Atta, 1978). This creates a maximum width of about 24 km and a maximum depth of about 110 m.

Lake Nasser is located in the Nubian Desert that surrounded by barren desert and hilly areas. The climatic condition is typical arid environment with high temperature that reaches as high as 45°C in June and as low as 5°C in January. It also has nearly no precipitation that classified this region as one of the driest areas in the world. Such conditions have classified this region as hyper-arid (Springuel, Hassan, Sheded, El-Soghir, & Ali, 1991).
Lake Nasser is located in a complex geological area; therefore, it is underlain and surrounded by a wide variety of lithology like granite, granitoids, gneisses, schists, sandstones, conglomerates and shales. The area is highly affected by structural elements like folds, faults and fractures, which highly controlled the lake path. The lithological variation around the lake body controlled the differentiation of the lake into its southern and northern parts around Gomay. The hard basement rocks surrounding the lake along the southern part may be responsible for the narrowing of the lake course. However, the softer sedimentary rocks surrounding the lake along the northern part may be responsible for the widening of the lake course. Therefore, the changes in the hydro-morphologic features (depth, width and hence, profile area), to a large extent, appear to be litho-structurally controlled.

2. Materials and methods
Some measuring and sampling processes were carried out through two field trips. The first field trip was of two phases covered almost by the lake. The first phase between 1 and 18 December 2006 covered the Egyptian part of the lake, whereas, the second phase between 2 and 14 February 2007 covered the Sudanese part. Through this field trip, the measurements included some bathymetric and hydro-morphologic measurements in addition to some hydrographic (physicochemical) measurements. The collected bottom sediments and surface water samples were analysed in the laboratory.

The second field trip was carried out during November 2011 to collect core samples between Latitudes 30°58′31.64″ E & 31°26′25.10″ E and Longitudes 21°27′42.07″ N & 22°10′15.11″ N. The hydro-morphologic and bathymetric measurements were carried out using a combination of GPS
and the Ecosounding system. This technique was used throughout 32 horizontal cross sections. These cross sections were selected to geographically cover most of the lake.

Some hydrographic (physicochemical) measurements were carried out at three main levels (surface, middle and near bottom). The current velocity was measured using a currentmeter model VALEPORT BFM 108 MK11. The TDS and EC were measured using a portable electrical conductivity-meter (WTW Model LF 197). The pH was also measured using a portable pH meter (WTW Model pH 197). The temperature was measured using a portable instrument (WTW Model Oxi 197). The turbidity was measured using a Hach 2100P portable turbidity meter. In addition, 93 water samples were collected from the lake and were filtered to determine the suspended sediments concentration.

Eighty-eight grab sediment samples were collected from the bottom of Lake Nasser that comprises 32 profiles (cross sections) (Figure 1). The samples are geographically representing the eastern, middle and western parts of each profile. The exact location of the sampling stations was carried out using the GPS.

The lack of advanced resources and fund to obtain such equipment to collect core samples has challenged to design and produce a low-cost local core sampler. A core sampler (gravity corer) was designed and manufactured for this research to collect bottom sediments samples from the lake. The core sampler was made of a 1.50 m length and 3” diameter steel pipe with a plastic (PVC) liner. Using this corer, 13 cores were collected along the distance between Atiry (30°58′31.64″ E–21°27′42.07″ N) and Adendan (31°26′25.10″ E–22°10′15.11″) to represent the mid-line of the lake.

### 2.1. Laboratory analysis

The collected bottom samples were air-dried, which consequently fractionated into two main types according to their texture; coarser than 0.0625 mm (less than 4Ø) and finer than 0.0625 mm (more than 4Ø). For the first type, wet and dry sieving were applied using standard set of sieves with mesh opening 1, 0.5, 0.25, 0.125 and 0.0625 mm. However, pipette analysis was carried out upon the second type applying the method described by Krumbein and Pettijohn (1938). Na hexameta phosphate and Na carbonate with concentrations of 1.65 and 0.35 gm/L, respectively, were used as peptizer. In this method, 20 gm of washed dried sediment sample is flocculated in a 1,000 ml measuring cylinder charged with peptizer. Suctions at intervals of time according to stokes law were taken and the weight per cent for each suction was calculated in weight per cent and cumulative per cents.

Histograms and cumulative curves were constructed. Depending on these histograms, sand, silt and clay components were calculated in percentage using Wentworth (1922) that modified by Friedman and Sanders (1978). Depending on the cumulative curves, key statistical parameters included median diameter (MdØ), mean size (MzØ), inclusive sorting (σ₁), skewness (Sk₁) and kurtosis (K₁) were calculated according to the equations proposed by Folk and Ward (1957).

In addition to the above analysis, the collected cores were divided into sub-core samples based on depths ranged 0–25, 25–50, 50–75, 75–100 and 100–125 cm. The produced 47 core samples were air-dried and analysed to determine the grain size distribution and mineralogical composition. The grain size distribution indicated that silt and clay sized particles are the main component.

### 2.2. X-ray diffraction analysis

X-ray diffraction is an efficient tool for the mineralogical analysis of fine-grained sediments (Worden & Morad, 2003). Therefore, the mineralogical composition of the bottom sediments was determined for 19 selected core samples of the bottom sediment using the X-ray diffraction technique. The selected core samples were grinded to less than 63 μm grain sized powder and investigated using Philips X-ray Vertical diffractometer (type PW 1373, Holland). For studying the clay mineralogical composition, the clay fraction of each sample (particle size < 2 μm) was separated by sedimentation using glass slide method (Bish & Reynolds, 1989; Hughes, Moore, & Glass, 1994), after the removal of carbonate, iron oxide, organic matter and soluble salts. The clay fraction on the glass slides was
analysed in each of the air-dried, heated and ethylene glycol-solvated conditions. Figure 2 shows the typical X-ray diffraction patterns of a powdered, clay oriented, heated and glycolated core sample.

The relative abundance of each mineral was estimated from the intensities of the diffraction peaks, measured by the peak heights or peak areas (Ruhe & Olson, 1979; Tucker, 1988). Semi-quantitative comparisons were made between samples by means of various ratios of peak heights or peak areas (Biscaye, 1965).

A simple mathematical procedure was applied for roughly calculating the relative proportion of each of the composing non-clay minerals as a part of the unit using the following equation:

$$P_{M1} = \left( \frac{I_{M1}}{I_{M1} + I_{M2} + I_{M3}} \right), \quad P_{M2} = \left( \frac{I_{M2}}{I_{M1} + I_{M2} + I_{M3}} \right), \quad P_{M3} = \left( \frac{I_{M3}}{I_{M1} + I_{M2} + I_{M3}} \right)$$

(1)

whereas

$$P_{M1} + P_{M2} + P_{M3} = 1$$

(2)

where $P_{M1}$, $P_{M2}$, and $P_{M3}$ are the proportions of the non-clay minerals 1, 2 and 3, respectively. $I_{M1}$, $I_{M2}$ and $I_{M3}$ are the peak intensities of the non-clay minerals 1, 2 and 3, respectively.

2.3. GIS

GIS was used for spatial representation and analysis of the data. The sampling locations were converted into a point layer with all the results of the laboratory analysis embedded attributes. It enabled for simulating the data spatially to understand the spatial distribution of the sediments and then understand the sedimentological processes influenced the deposition of these sediments. It also enabled for understanding the hydro-morphology of the lake.

3. Results

The bottom sediment samples were mechanical analysed to be statistically represented. The statistical parameters determined found to be widely varied along the lake.

MdØ ranges between 1.66Ø (medium sand) and 11.36Ø (clay) with an average of 8.14Ø (very fine silt). MzØ ranged between 1.65Ø (medium sand) and 10.84Ø (clay) with an average of 7.97Ø (fine silt). $\sigma_1$ between 0.29Ø (very well sorted) and 3.64Ø (very poorly sorted) with an average of about 1.94Ø (poorly sorted). Sk ranged between −0.76 (strongly coarse skewed) and 0.75 (strongly fine skewed) with an average of −0.10 (coarse skewed). $K_0$ ranged between 0.58 (very platykurtic) and 4.41 (extremely leptokurtic) with an average of about 1.28 (leptokurtic).

To understand the mechanisms of deposition along the lake, bivariant plots between the average values of median diameter MdØ and each of the inclusive sorting $\sigma_1$ were illustrated in Figure 3 and...
skewness Sk, in Figure 4. The study of the bivariant plot diagrams allows us to distinguish between two main depositional mechanisms, river processes and slow deposition from quiet water (Stewart, 1958).

Distribution of statistical parameters of the bottom sediments along the lake was represented in Figure 5. It proved the occurrence of two depositional environments of riverine (the most upstream 50 km at the entrance of the lake) and lacustrine (the rest of the lake). In turn, the lacustrine environment was differentiated at the 2nd Cataract into two distinctive sedimentological regions, southern and northern.

Along the riverine environment, the average values of MdØ increased northward from 1.79Ø (medium sand) at El-Daka to 2.85Ø (fine sand) at CC with an average of 2.53Ø (fine sand). MzØ increased northward ($R = -0.767$) from 1.08Ø (medium sand) to 2.88Ø (fine sand). However, $\sigma_i$ abruptly increased from 0.36Ø (well sorted) at AA to 1.13Ø (poorly sorted) at Okma, then decreased northward to 0.31Ø (very well sorted) at the site CC. Meanwhile, Sk ranged between 0.14 (fine skewed) and 0.65 (strongly fine skewed) with no direction to change (i.e.) the sediments tend to skew towards the fine fraction. $K_G$ decreased northward from 0.86 (platykurtic) at AA to 2.29 (very leptokurtic) at CC.

Along the southern part of the lacustrine environment (which is the transitional from riverine to lacustrine), the average value of MdØ increased northward from 5.83Ø (coarse silt) at El Dowishat to 9.26Ø (clay) at the Second Cataract. MzØ increased northward from 6.16Ø (medium silt) to 9.07Ø (clay). $\sigma_i$ ranged between 2.3 and 2.75Ø (very poorly sorted) with no direction for change. Sk decreased northward from 0.28 (fine skewed) to −0.17 (coarse skewed). $K_G$ ranged between 0.75 and 0.85 (platykurtic) with no direction for change.

Along the northern part of the lacustrine environment, the average value of MdØ slightly decreased northward from 10.76Ø (clay) at Abdel Kader to 9.45Ø (clay) at Kalabsha. MzØ slightly decreased from 10.29Ø (clay) to 9Ø (clay). $\sigma_i$ increased from 1.88Ø (poorly sorted) to 2.57Ø (very poorly sorted). Sk sharply decreased to range between −0.48 and −0.66 (strongly coarse skewed) between Abdel Kader and Dabarosa, then decreased to range between −0.16 (coarse skewed) and −0.32 (strongly coarse skewed) further north, with nearly no direction for change. $K_G$ ranged between 1.11 and 1.50 (leptokurtic) with no direction for change.

Figure 3. Bivariant plot between MdØ and $\sigma_i$. 

![Bivariant plot between MdØ and $\sigma_i$.](image)
To understand the factors affecting the sediments distribution along the lake, a correlation between the mean diameter (MzØ) of the bottom sediments and each of the current velocities, total dissolved salts TDS, pH and each of the hydro-morphologic features was illustrated (Figure 6).

The interrelation between MzØ and the suspended sediments concentration (Figure 6(A)) showed a reverse relation along the part of the lake south of the site WW \((R = -0.94)\), i.e. the riverine environment and the entrance of the lacustrine environment. This indicates the northward decrease in the grain size of the bottom sediments with the continuity of settlement of the suspended sediments. Along the distance between the site WW and Abu Simbil, MzØ continued to show inverse relation with the suspended sediments concentration \((R = -0.90)\). This indicates the continuity of the northward decrease in the grain size of the bottom sediments with the continuity of settlement of the suspended sediments. North of Abu Simbil, MzØ showed a direct relation with the suspended sediments concentration \((R = 0.93)\). This indicates that the grain size of the bottom sediments increased northward with the continuity of the settlement of the suspended sediments from the water column. This may indicate, in turn, the northward increase in the grain size of the sediments in suspension to be coagulated to settle down.

The interrelation between MzØ and TDS (Figure 6(C)) showed no distinct correlation along the riverine and southern part of lacustrine environment. However, it showed a reverse correlation along the northern part of the lacustrine environment indicating the increase in the grain size with the increase in the TDS concentration. This may be due to the increase in the clay particle size in suspension which coagulate to settle down with the increase in the TDS concentration along the northern part of the lacustrine environment.

The interrelation between MzØ and pH (Figure 6(D)) showed no distinct correlation along the riverine environment and along the upstream entrance of the southern part of the lacustrine environment (till reaching Atiry). North of Atiry, as the MzØ value exceeded 8 (i.e. clay content was more than 45% of the bottom sediment), there was a direct relationship between the MzØ and pH. This means that the grain size of the clay bottom sediments decreases with increasing pH. This may be due to the decrease in the clay particles size in suspension to coagulate and settle down with the increase in pH values.
The interrelation between MzØ and hydro-morphologic features including the width, depth and profile area (Figure 6(E)–(G), respectively) showed no distinct relation. There was an exception for the depth that showed an inverse relation with MzØ along the northern part of the lacustrine environment \( (R = -0.736) \) meaning that the grain size of the bottom sediments increased with the increase in depth.

Sediment types strongly control the mineralogical distribution along the lakes. Such distribution of sediment types in reservoirs (lakes) is required to be evaluated before studying the mineralogical or elemental distribution (Horowitz, 1991). Therefore, the core samples were mechanically analysed to determine the grain size distribution. It indicated that the core sampled sediments composed of...
mixed sand, silt and clay grain mixture. The part of the lake that was sampled during the coring process located in the lacustrine environment. The riverine environment has not included; therefore, there was no sample classified as sand.

For more understanding of the vertical distribution of the bottom sediment of the lake, the vertical distribution of 125 cm depth of the bottom sediments below the water-bottom sediments interface is shown in Figure 7. The figure shows the realistic sediment distribution that respond to the depositional environment. The sandy silt and silty sand classes were limited to the most southern part of the studied area (at Atiry). Northward, reaching Halfa, the investigated thickness of the bottom sediments composed of inter-bedded silt and clayey silt classes. North of Halfa, the silt variety
withdrawn to lower depths giving rise to the clayey silt, silty clay and clay varieties to spread out in this area. This completely reflects the two depositional environments of riverine to the south with coarse sediments and lacustrine environment downstream where the sediment getting finer.

X-ray diffraction patterns of the samples’ powder showed that the bottom sediments along the studied locality are composed mainly of clay minerals including montmorillonite, kaolinite and illite in addition to some non-clay minerals including quartz, feldspar and calcite.

### Table 1. Peak height of the non-clay minerals and its relative peak height proportions in the analysed core samples along the studied area

| Site name       | Sample no. | Peak height in counts | Relative peak height proportions |
|-----------------|------------|------------------------|----------------------------------|
|                 |            | Quartz | Feldspar | Calcite | Quartz | Feldspar | Calcite |
| Atiry           | 2          | 333    | 85       | 15      | 0.77   | 0.20     | 0.03    |
|                 | 3          | 167    | 57       | 30      | 0.66   | 0.22     | 0.12    |
| Semna           | 5          | 36     | 16       | 14      | 0.55   | 0.24     | 0.21    |
|                 | 8          | 22     | 11       | 5       | 0.58   | 0.29     | 0.13    |
|                 | 10         | 51     | 30       | 16      | 0.53   | 0.31     | 0.16    |
| Kajnarity       | 12         | 24     | 10       | 14      | 0.50   | 0.21     | 0.29    |
|                 | 15         | 18     | 11       | 6       | 0.51   | 0.31     | 0.17    |
| Marshed         | 17         | 55     | 83       | 18      | 0.35   | 0.53     | 0.12    |
|                 | 20         | 22     | 12       | 9       | 0.51   | 0.28     | 0.21    |
| 2nd Cataract    | 25         | 43     | 18       | 9       | 0.61   | 0.26     | 0.13    |
|                 | 26         | 25     | 14       | 10      | 0.51   | 0.29     | 0.20    |
| Abdel Kader     | 31         | 21     | 11       | 13      | 0.47   | 0.24     | 0.29    |
| Haifa           | 34         | 88     | 35       | 17      | 0.63   | 0.25     | 0.12    |
| Dabarasa        | 35         | 12     | 6        | 5       | 0.52   | 0.26     | 0.22    |
|                 | 37         | 52     | 13       | 9       | 0.70   | 0.18     | 0.12    |
| Arqeen          | 38         | 15     | 11       | 7       | 0.45   | 0.33     | 0.21    |
|                 | 40         | 26     | 12       | 10      | 0.54   | 0.25     | 0.21    |
| Sara            | 44         | 22     | 12       | 13      | 0.47   | 0.26     | 0.28    |
| Adendan         | 47         | 27     | 12       | 8       | 0.57   | 0.26     | 0.17    |
The peak height of the non-clay minerals and its relative peak height proportions is listed in Table 1. The peak height was used as the measure of peak intensity. Applying this simplified procedure, used not to quantify the mineral content in each sample, but significantly to look for the trends of the changes in the minerals relative abundance.

Velde and Meunier (2008) specified the X-ray diffraction as the most important analytical technique used to identify and quantify the clay minerals present in a sample. Peaks created by clay minerals in the X-ray diffraction patterns, especially mixed-layer varieties, are often very broad. Therefore, a clay mineral present is more closely related to peak area than to peak height because of the natural variation in clay mineral peak shapes and widths (Klug & Alexander, 1954). The X-ray diffraction patterns of the glycolated oriented clay fraction were used in this aspect.

Montmorillonite, kaolinite and illite are the main constituent clay minerals. The quantification of the abundance of each clay mineral constituent was carried out through two steps. The first is the semi-quantitative estimation of the relative abundance of the clay minerals using Equations (1) and (2). In these equations, the variants $P_{M1}$, $P_{M2}$ and $P_{M3}$ are the proportions of the peak intensities of clay minerals 1, 2 and 3, respectively; whereas, the variants $I_{M1}$, $I_{M2}$ and $I_{M3}$ are the peak intensities of the clay minerals 1, 2 and 3, respectively. The peak intensity is calculated by multiplying the mineral’s peak area by its specific power factor (1 for montmorillonite, 2 for kaolinite and 4 for illite). The second step is the quantitative estimation based on calculating the percentage of each of the clay minerals in a sediment sample. The second step was carried out by considering that the clay minerals integrated together to form the percentage of the clay sized portion in a sediment sample. The relative proportions (semi-quantitative) and the percentage (quantitative) of the composing clay minerals along the studied locality were listed in Table 2.

| Site name      | Sample no. | Relative proportions | Percentage from total clay |
|----------------|------------|----------------------|----------------------------|
|                | M          | K                    | I                          | M          | K          | I          |
| Atiry          | 2          | 0.858                | 0.041                      | 0.101      | 2.81       | 0.14       | 0.33       |
|                | 3          | 0.819                | 0.090                      | 0.090      | 8.89       | 0.98       | 0.98       |
| Semna          | 5          | 0.887                | 0.075                      | 0.038      | 21.95      | 1.86       | 0.93       |
| Kajnarity      | 8          | 0.864                | 0.101                      | 0.058      | 29.15      | 2.59       | 1.82       |
|                | 10         | 0.869                | 0.077                      | 0.054      | 16.39      | 1.98       | 1.13       |
| Morshed        | 12         | 0.881                | 0.062                      | 0.057      | 36.81      | 2.04       | 4.49       |
|                | 15         | 0.849                | 0.047                      | 0.104      | 28.93      | 2.04       | 1.86       |
| Gomay          | 17         | 0.875                | 0.054                      | 0.072      | 15.84      | 0.97       | 1.30       |
| Amaka          | 20         | 0.881                | 0.068                      | 0.051      | 32.62      | 2.51       | 1.88       |
| 2nd Cataract   | 25         | 0.873                | 0.101                      | 0.025      | 29.61      | 2.88       | 1.20       |
|                | 26         | 0.879                | 0.085                      | 0.036      | 27.67      | 3.21       | 0.80       |
| Abdel Kader    | 31         | 0.857                | 0.070                      | 0.073      | 34.39      | 2.79       | 2.92       |
| Halfa          | 34         | 0.839                | 0.078                      | 0.083      | 16.27      | 1.52       | 1.60       |
| Dabarosa       | 35         | 0.917                | 0.064                      | 0.020      | 23.79      | 1.66       | 0.51       |
|                | 37         | 0.816                | 0.076                      | 0.109      | 41.65      | 3.87       | 5.55       |
| Arqeen         | 38         | 0.685                | 0.107                      | 0.207      | 46.36      | 7.27       | 14.02      |
|                | 40         | 0.872                | 0.040                      | 0.087      | 64.97      | 3.00       | 6.51       |
| Sara           | 44         | 0.874                | 0.069                      | 0.057      | 41.87      | 3.30       | 2.75       |
| Adendan        | 47         | 0.724                | 0.142                      | 0.134      | 39.35      | 7.72       | 7.27       |
Depending on the peak area of the X-ray diffraction patterns of the glycolated oriented clay samples, montmorillonite, was estimated as the main constituent clay mineral (0.685–0.917 parts of the unit) followed by kaolinite (0.040–0.142) and illite (0.025–0.207).

4. Discussion
The variation of sediment characteristics and composition along the lake provided information about the efficiency of the transporting agent and the depositional environment along Lake Nasser. Figure 8 shows GIS simulation of the spatial distribution of the sediment types along the bottom layer of the lake.

The river processes prevailed along the riverine environment at the entrance of the lake (Figures 3 and 4). Therefore, the bottom sediments are nearly free from clay and composed mainly of coarse sediments including sand (87–100%) (Figure 8(A)) mixed with small ratios of silt (0–10%) (Figure 8(B)). MzØ of the bottom sediments mainly exceeded the limit of MdØ (Figure 5(A) and (B)) that influenced with its skewness towards the fine fraction (Figure 5(D)). The distribution of each of the median and mean diameter values (MdØ and MzØ) described the capability of the sedimentation processes to deposit sediments grains like coarse, medium and fine sand. In addition, the well sorting, the fine skewness and the leptokurtic grain size distribution represent a high degree of texture maturity along this part.

The transitional part between riverine and lacustrine environment (the southern part of the lacustrine environment) was partially influenced by the riverine processes with gradual increase in the slow deposition from quite water to operate (Figures 3 and 4). Accordingly, sand composed 83 and 61% at the middle part of El-Dowishat and HH and 78% at the western part of Atiry, north of which it formed no more than 5% of the bottom sediments (Figure 8(A)). Along this segment of the lacustrine environment, silt composed 36–58% as average values (Figure 8(B)), whereas clay composed 18–59% of the bottom sediments (Figure 8(C)). The continuity of the fine skewness (Figure 5(D)) caused the MzØ to exceed MdØ till reaching the site W-W (Figure 5(A) and (B)). North of W-W, the MdØ exceeded MzØ influencing with the change towards the coarse skewing.

Along the southern part of the lacustrine environment (Figures 3 and 4), the distribution of the MdØ and MzØ described the decrease in the sedimentation processes capability which deposited sediment particles as fine as silt and clay (Figure 5(A) and (B)). In addition, the very poorly sorting (Figure 5(C)), coarse to strongly coarse skewness (Figure 5(D)), platykurtic kurtosis (Figure 5(E)) represented a textural immaturity. North of Atiry, as the MzØ value exceeded 8 (i.e. clay composed more than 45% of the bottom sediment), the grain size of the bottom sediments decreased with the increase in pH (Figure 6(D)). Along this portion of the lacustrine environment, the very poorly sorting and the platykurtic particle size distribution indicate a textural immaturity.

Along the northern part of the lacustrine environment, the slow deposition from quite water prevailed (Figures 3 and 4); therefore, the bottom sediments were sand free (Figure 8(A)). Along this segment of the lacustrine environment, the bottom sediments composed mainly of clay, which shared with (57–84%) (Figure 8(C)), in addition to some silt which shared with (14–37%) (Figure 8(B)). However, MdØ exceeded MzØ, the distribution of the MdØ and MzØ described that silt and clay particle size were the main components of sediments (Figure 5(A) and (B)). This indicates the continuity of the deterioration of the sedimentation processes capability. The abundance of clay fraction in addition to the very poorly sorting and coarse skewness indicates a textural immaturity. The leptokurtic distribution along this segment is due to the narrowing of the grain size range to the clay class, indicating the severely decrease in the capability of the transporting agent. Along this segment of the lacustrine environment, the grain size of the clay particles increased with the increase in each of bottom depth and the total dissolved salts concentration and decreases with the increase in pH.
The mineralogical composition of the bottom sediments may provide stratigraphic and sedimentological indicators. Interrelation was plotted between the mean grain size MzØ and the calculated relative peak height of each of quartz, feldspar and calcite along the studied locality.

The relative peak height of quartz decreased with the increase in MzØ (Figure 9(A)) indicating a reverse relation ($R = -0.883$). In other words, the abundance of quartz decreased with the decrease in grain size of the bottom sediments along the studied area.

The interrelation between relative peak height of calcite and MzØ (Figure 9(B)) showed that the studied locality may be distinguished into two regions; Atiry-Dabarosa and Arqeen-Adendan.
Figure 9. Interrelation between $Mz\bar{\Omega}$ and the relative peak height of (A) quartz, (B) calcite and (C) feldspar along the studied part of the lake.

Figure 10. Interrelation between the estimated percentage of the montmorillonite concentration and total clay size content along the studied locality.
regions. Along the two regions, the relative peak height of calcite increased with the increase in MzØ indicating a direct relation ($R = 0.922$ and $0.967$, respectively). In other words, the abundance of
calcite increased with the decrease in grain size of the bottom sediments along the studied area of
the lake.

The interrelation between relative peak height of feldspar and MzØ (Figure 9(C)) showed that the
studied locality may be classified into its southern and northern parts of lacustrine environment
around Gomay. Along the southern part, the relative peak height of feldspar increased with the in-
crease in MzØ indicating a direct relation ($R = 0.831$). Conversely, along the southern part, the rela-
tive peak height decreased with the increase in MzØ indicating a reverse relation ($R = -0.832$). In
other words, the abundance of feldspar increased along the southern part with the decrease in grain
size of the bottom sediments. However, the feldspar abundance decreased with the decrease in
grain size along the northern part.

The montmorillonite content found to increase with the increase in the total clay content
($R^2 = 0.99$) along the studied area (Figures 10 and 11) through the correlation equation:

$$y = -0.0066 x^2 + 1.1878 x - 2.8838$$

(3)
where $x$ is the total clay content in percentage and $y$ is the montmorillonite concentration in percentage.

The illite content found to increase with the increase in the total clay content ($R^2 = 0.97$) along the distance between Atiry and Gomay (Figure 12(A)) through the correlation equation:

$$y = -0.0007x^2 + 0.072x + 0.151$$

(4)

where $x$ is the total clay size content and $y$ is the illite concentration in percentage.

However, north of Gomay (Figure 12(B)), the illite content increased with the increase in the $Mz\bar{O}$ ($R^2 = 0.99$) through the equation:

$$y = 3.0369x^2 - 46.716x + 180.41$$

(5)

where $x$ is the $Mz\bar{O}$ value and $y$ is the illite concentration in percentage.

Applying Equations (3)–(5) on each of the collected core samples, the percentages of montmorillonite, kaolinite and illite content were estimated. The margins of error were repaired depending on the proportion of each mineral in a sample. The vertical distribution of the abundance of each of the clay minerals along 1.25 m depth of the bottom sediments was illustrated in the Figures (13–15).

5. Conclusion

In-situ measurements and sampling processes were carried out along Lake Nasser between latitudes $21^\circ 02' 33''$ N and $23^\circ 38' 55''$ N and longitudes $30^\circ 38' 42''$ E and $32^\circ 54' 23''$ E. The integration between some improved techniques, Core Sampling, X-ray diffraction and GIS, was used to comprehensively study the sedimentation processes and its relation to the hydrographic physicochemical conditions.

The grain size analysis and mineralogical composition of the core sediments reflect the linkage between the sedimentation process and the depositional environment with the river morphology and both water and sediment flow. This has enabled to understand that Lake Nasser could be classified into two main sedimentation processes and two depositional environments (riverine and lacustrine) each of them has its specific sedimentological properties and sedimentation process.
(1) The riverine environment, located between latitudes 21°01′ 54″ and 21°18′ 57.92″ and longitudes 30°36′ 50″ and 30°53′ 12.99″. It occupies the first part of the lake where the river processes are still the dominant mechanism of deposition. The lake is narrow and its morphology is controlled by the geology of geomorphology of the surrounding area enabling for such sedimentation process which reflected in the relatively coarse bottom sediment grain size (fine to medium sand) compared with the rest of the lake. With the distance northward as the lake get wider and bigger the grain size of the bottom sediments decreased as the current velocity and the suspended sediments concentration decreased. This created a transitional sedimentation process between the riverine and the lacustrine. The cross-sectional area, pH, TDS and EC increased in the same direction.

(2) The lacustrine environment located between latitudes 21°18′ 57.92″ and 23°38′ 55″ and longitudes 30°53′ 12.99″ and 32°54′ 23″. It occupies the larger area of the lake that is more wide and calm. The sedimentation process of this area was sub-categorized into two main parts (Southern and Northern). Along this lacustrine environment, the grain size of the bottom sediments decreased northward as each of the current velocity and suspended sediment concentration decreased; whereas, each of the profile area, TDS and EC increased in the same direction. As MdØ gradually elevated compared with MzØ to exceed it by Gomay, the slow deposition from quite water became the prevailing mechanism. Along this part of the lacustrine environment, as the particle size decreased, the abundance of quartz decreased, feldspar increased, whereas, calcite and clay minerals (montmorillonite, kaolinite and illite) increased.

Along the northern part of the lacustrine environment, the bottom sediments composed mainly of clay size particles, MdØ continued to exceed MzØ and the slow deposition from quite water continued to be the prevailing mechanism. Along this segment of the lacustrine environment, the grain size of the clay particles increased with the increase in each of bottom depth and the total dissolved salts concentration and decreases with the increase in pH. Along this part of the lake, with the increase in grain size of the bottom sediments, the abundance of quartz and feldspar increased, whereas, each of the feldspar and clay minerals (montmorillonite, kaolinite and illite) decreased.

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