

Reduction of the Storage Capacity of two Small Reservoirs in Jordan

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Abstract

Scarcity of water resources in the Middle East represents a prime factor in the stability of the region and its economic development and prosperity. Accordingly, augmenting water is considered very important. Therefore, building of dams is an important mean to achieve such a goal. Despite the fact that number of dams had been built but maintenance operations and reduction of siltation rates are still not up the standards.

Two small reservoirs, north West Jordan, were investigated. Sad Wadi Alarab reservoir constructed in 1986 (storage capacity of 20×10^6 m³). The second, Alghadeer Alabyadh, was constructed 1966 (storage capacity 7×10^5 m³).

The actual storage capacities of these reservoirs were calculated using echo-sounding traverses. Data obtained were used in special computer software to construct the bathymetric maps and calculate the existing storage volume. The results showed that the reservoir storage capacities were reduced at an average annual rate of 0.3×10^6 and 1.7×10^4 m³ respectively. This implies that Sad Wadi Alarab reservoir will be filled with sediment within 38 years, while Alghadeer Alabyadh reservoir is already filled with sediment now.

Bottom sediments of the reservoirs were collected and analyzed. In all the cases, sand, silt and clay were the dominant sediment components.

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1 Introduction

Jordan among other Arab countries is very poor in its water resources [1,2,3 and 4]. Consequently, water availability is a serious and urgent issue. One of the means of augmenting water budgets is to control surface flows by building reservoirs. To maintain long life operation of these reservoirs, it is evident that siltation problems should be carefully monitored. High rates of sedimentation will eventually lead to reduction of the storage capacity of the reservoirs. In such a case, they are no longer economically feasible in river basins where water is scarce.

Effective use of water requires sustainability of the reservoir. To achieve this goal, minimizing sedimentation problems and in consequence keeping high storage capacity is a must. In this investigation Wadi Arab and Alghadeer Alabyadh reservoirs (Figure 1) have been studied to monitor the amount and nature of sediment deposited within them. This can help decision-makers to put best solutions into practice.



Figure 1: Location map of Wadi Al-Arab and Alghadeer Alabyadh dams

2 Field techniques

2.1 Storage Capacity

Echo-sounding traverses were made between known points, to cover the entire area of the reservoir (see Figure 2a and b). All traverses were perpendicular to the longest axis of the reservoirs. A Traverse Total Station (Model SOKKIA SET F6) was used to carry out the land survey while two echo sounding devices (Models Eagle Ultra III 3D and Sonarlite SL2.0 OHMEX) mounted on an inflatable boat were used to survey the water depth. All end points of the surveyed traverses were connected to a well-known Benchmark. A Note pad computer was connected to the echo sounder so that all survey points could be recorded. The survey data were fed to Arc View®3.1 and WMS®5.0 software. The former is produced by Environmental Systems Research Institute (ESRI), the makers of ARC/INFO, the leading geographic information system (GIS) software. WMS® version 5.0 (Watershed Modeling System) was developed by the Engineering Computer Graphics Laboratory of Brigham Young University in cooperation with the U.S. Army Corps of Engineers Waterways Experiment Station (for more details see[5]). WMS® 5.0 was used to create terrain models from Triangulated Irregular Networks, or TINs. The TIN was in turn used for delineating the data. Both software packages have been utilized for the construction of the bathymetric chart of each reservoir (see Figures 7 and 14).

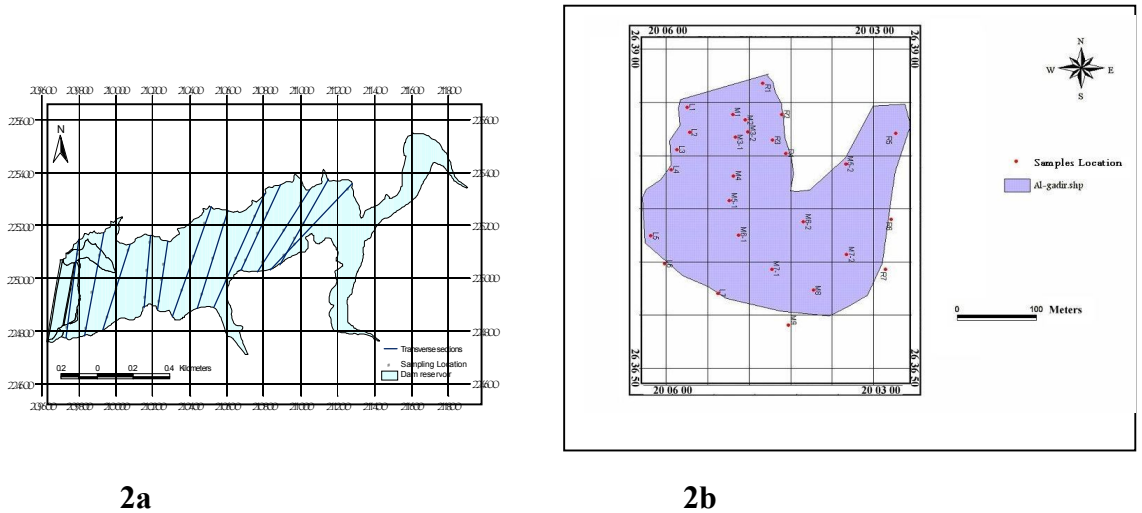


Figure 2: Transverse sections and sampling locations of bottom sediments within reservoirs of (a) Wadi Al-Arab and (b) Alghadeer Alabyadh dams.

2.2 Bottom Sediment

To study the nature of bottom sediment of the two reservoirs, a van veen grab was used to collect the samples (Table 1). The exact location of each sample was fixed using GPS. Samples were collected covering the entire bottom of the reservoir (see figure 2). The samples were dried and sieved to estimate the sand content. The fine portions (silt and clay) were determined by pipette analysis. Folk's [6] procedure was used for in the evaluation of the statistical parameters of the sediment samples. This was applicable only for samples having cumulative curves percentages more than 95% of the total sample

Table 1: Number of bottom sediment samples collected from the two reservoirs.

Reservoir	No. of Samples
Wadi Sad Al-Arab dam	40
Alghadeer Alabyadh	27

3 Wadi Sad Al-Arab Dam

Wadi Al-Arab dam is a rock fill dam located at the south of Yarmouk River in the northern parts of Jordan. It drains an area of 267 km² and has a maximum storage capacity of 20MCM. Wadi Zaher, trending north north-west toward the south south-east, is the main area providing water for the main tributary within the basin. The Catchment area is mostly covered by undifferentiated plateau gravels. The Upper and Lower Terrace deposits are mainly of Quaternary age. The latter sediments are mainly composed of sand, silt, clay and debris of chalky marl and basalt. The basalts are of Quaternary to Neogen in age. Talus deposits are also present in the catchment area and overlay the Upper and Lower Terrace deposits. In addition, the Belqa Group is mainly covered by the Lower Terrace deposits and is consisting of medium to light weathered chalky marl stones ranging in color from light to dark yellow [7].

The average annual rainfall reaches 400 mm. Rainfall season is normally extending from October to April, but most of the rain (> 60%) is confined to the period from December to February. Meteorological records show wide variation of temperature values between summer and winter. Daily maximum temperature reaches up to 40°C during summer and drops to lower than 10°C in winter. The mean monthly temperature however, ranges between 31°C (maximum) and 14°C

(minimum). In addition the daily temperature variation is also large, reaching about 16°C in daily difference. Potential evaporation ranges from 2mm to 6mm during winter and summer respectively.

Daily sunshine hours in the area may reach 12 hours in summer and drops to 5 hours during winter. In consequence the solar radiation rays vary from 600cal/cm²/day to 220cal/cm²/day for summer and winter periods respectively. Furthermore, the relative humidity reaches 50% during summer while it goes up to 65% during winter. The average annual monthly wind speed is of the order of 2.4m/sec.

Nippon Koei and Naigai Eng. Companies estimated runoff values in 1978 [8]. They stated that the average annual runoff of Wadi Arab is about 1.05m³/sec. It was also noted that the past maximum flood was estimated to be of the order 170m³/sec (as observed at a bridge down stream from the dam). Furthermore, they considered that the estimated probable maximum flood discharge was 900 m³ /s.

3.1 Nature of Bottom Sediment

Forty samples were collected covering the entire bottom of the reservoir (see Figure 2 a). The analysis indicates that the reservoir bed is mainly covered by sand (81%), silt (14%) and clay (5%). Curves of cumulative percentage versus diameter were constructed on logarithmic probability paper (Figure 3). The curves were similar containing two straight segments round 0.0625mm. All the curves showed relatively gentler slope beyond 0.0625mm. The steepness of the curve is a reflection of scales. The change of gradient of the curves indicates a bimodality of the sediment. The inflection occurs at the boundary between sand and silt. Each straight segment reflects specific process or mode of deposition. In the case of Wadi Arab sediment it is believed that the sand was transported by saltation while the silt and clay fractions were transported by suspension in the water.

Sand covers the entire bottom area of the reservoir (Figure 4). There is no major change in sand percent distribution, but the southern parts of the reservoir have

relatively higher sand percentages. This may be attributed to agricultural and human activities on the southern slopes of the reservoir, in addition to the valley's contribution of sediment. The silt and clay distribution (Figures 5&6) indicates deposition from suspension, with a relatively higher percentage on the northern parts of the reservoir.

The average mean grain size diameter (0.01mm) falls within fine sand indicating that most of the bottom sediments are of a very fine nature. The data showed that very fine sand covers more than 80% of the bottom area of the reservoir while medium to fine sand covers near shore areas. Patches of finer material (more than 0.088mm in diameter) are restricted in distribution. This is believed to be due to the nature of deposition and the topography of the bed of the reservoir.

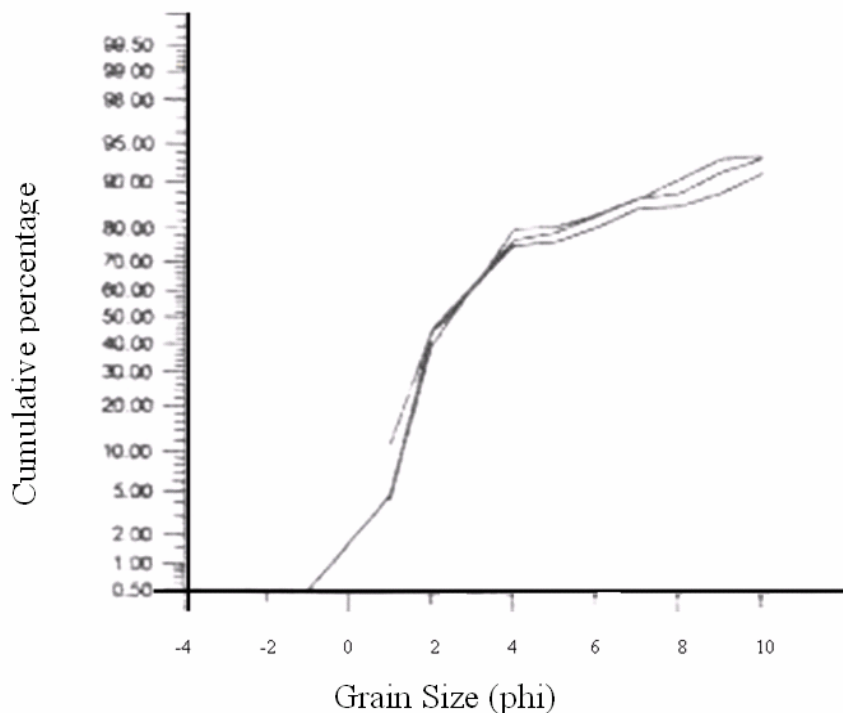


Figure 3: Example of cumulative percentage versus diameter for two selected bottom samples of Wadi Al-Arab dam reservoir.

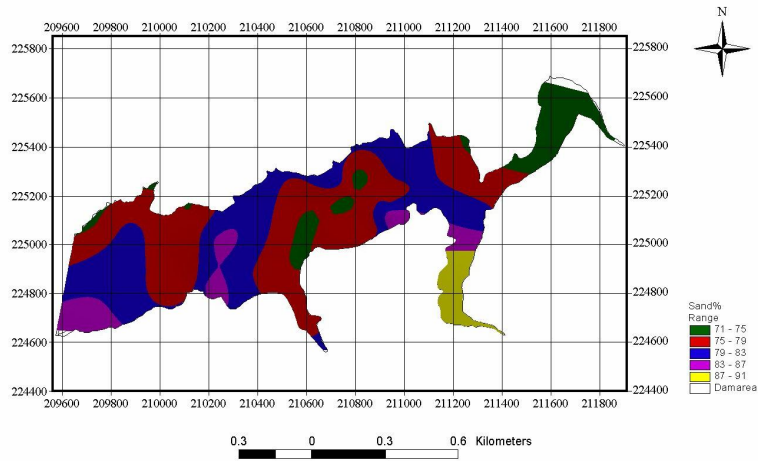


Figure 4: Sand percentage in Wadi Al-Arab dam reservoir

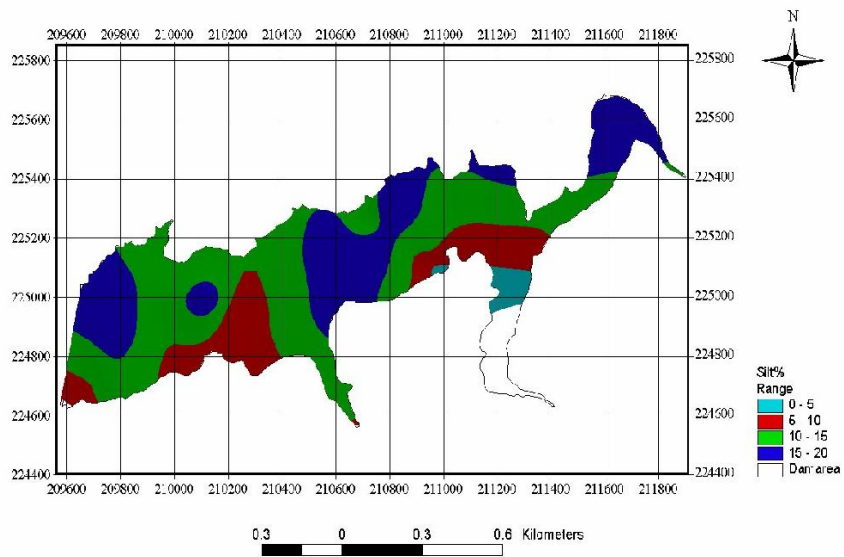


Figure 5: Silt percentage in Wadi Al-Arab dam reservoir.

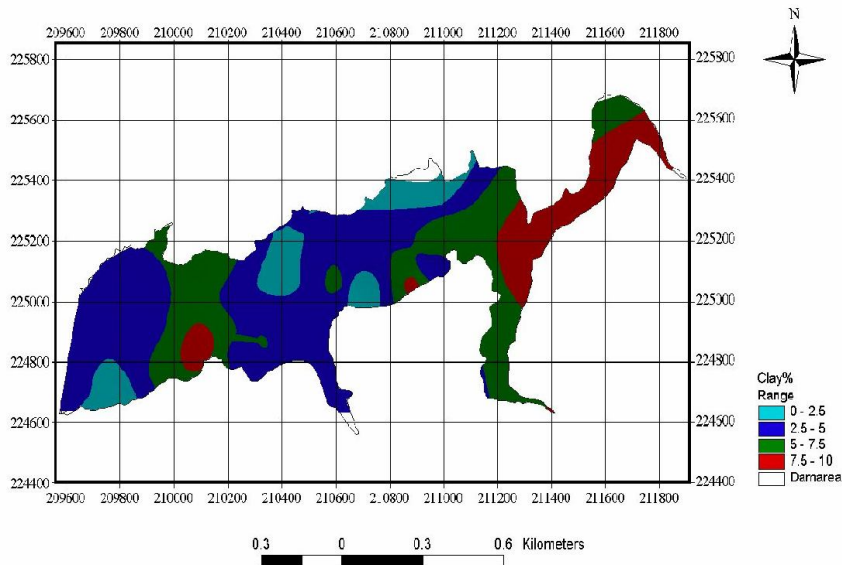


Figure 6: Clay percentage in Wadi Al-Arab dam reservoir.

3.2 Storage Capacity

The dam has been designed so that its effective storage capacity is $16.9 \times 10^6 \text{ m}^3$ while its dead storage is $3.1 \times 10^6 \text{ m}^3$. This gives a gross storage capacity of $20 \times 10^6 \text{ m}^3$. The rock fill dam has a crest length of 82.5m at a crest elevation of 101.5m below mean sea level. The dam has a spillway, which is a side overflow weir with channel. The spillway crest length is 85m with a 193m long chute ranging in width from 14-20m. The designed discharge of the spillway equals $840 \text{ m}^3/\text{sec}$. The plunge pool length extends 140m [9].

The maximum length of the reservoir is about 1700m extending west-east with a width ranging between 350 to 500m. Water enters the reservoir from two main valleys from the east and number of smaller valleys from the north and south. The northern part of the reservoir is characterized by much steeper slopes than the southern slopes.

In 1999, Al-Ansari and Al-Alami [5] surveyed the reservoir. They found that the rate of sedimentation was of the order of $0.446857 \times 10^6 \text{ m}^3$ per year.

Thirteen echo-sounding traverses were made between known points during the

period of November 2006, to cover the entire area of the reservoir (see Figure 2 a). The water level was 120m below mean sea level. It should be mentioned however that the traverses used were on the same location executed by Al-Ansari and Al-Alami in 2003[5] for the purpose of comparison.

The new bathymetric chart (see Figure 7) is more or less similar in shape to the original topographic maps of the area. The exception is the effect of sedimentation within the body of the reservoir. As far as the map produced by Al-Ansari and Al-Alami in 2003 [5], there was almost no differences apart of some small deviations in the depths of some points. The deepest point recorded was -151.5 meters below mean sea level. It is evident that the slope of the bed of the reservoir gradually drops toward the dam.

The deepest area lies directly east of the dam. Both sides (northern and southern) of the reservoir are characterized by their steep slopes near the dam site. Moving toward the east, the slopes become relatively gentler. The bed of the reservoir, however, is more or less gentle in its slope. It seems that sediments were deposited in the main valley course causing a generally flat bed shape. The results are shown in figure (7).

This indicates that the maximum storage capacity of Wadi Al-Arab dam reservoir is $11.996 \times 10^6 \text{ m}^3$ after the last survey. This figure suggests that the average annual sediment deposition rate is of the order of $0.313546 \times 10^6 \text{ m}^3$ per year for the period 1999 to 2006. This rate is less than that calculated by Al-Ansari and Al-Alami in 2003 [5] ($0.446857 \times 10^6 \text{ m}^3$ per year). It is believed that the scarcity of rainfall during after 1999 is responsible for the reduction in the sediment volumes transported to the reservoir. As a consequence, the long term siltation rate is $0.4002 \times 10^6 \text{ m}^3$ per year. Using the data obtained from the survey the area-depth relationship in Wadi Al-Arab dam reservoir was established (Figure 8). In view of the above, it seems that the life span of the reservoir will be of the range 26 (when using the rates of siltation calculated by Al-Ansari and Al-Alami [5]) to 38 years (using present rates of siltation) depending on the rates of sedimentation

deposition.

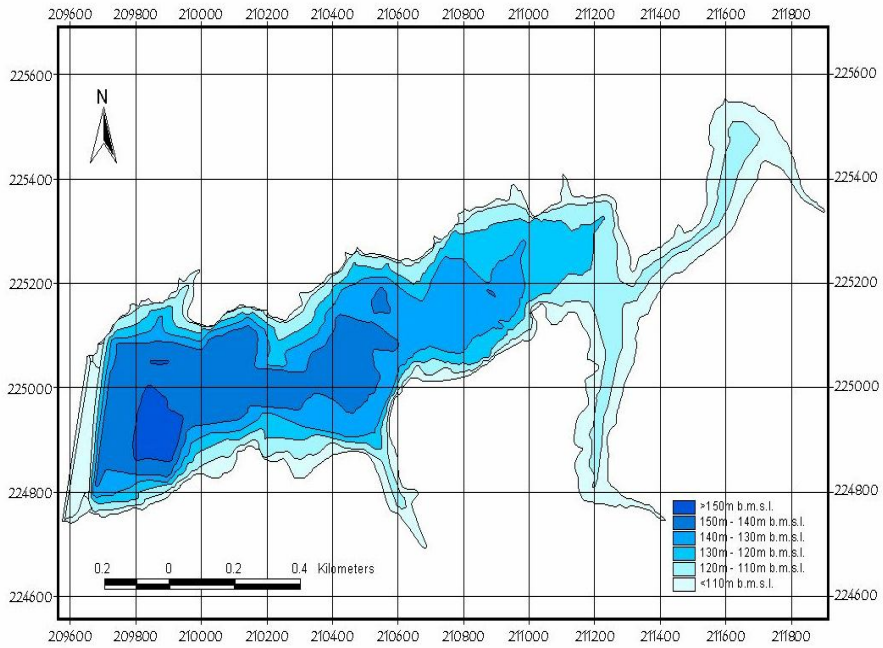


Figure 7: Bathymetric chart of Wadi Al-Arab dam reservoir.

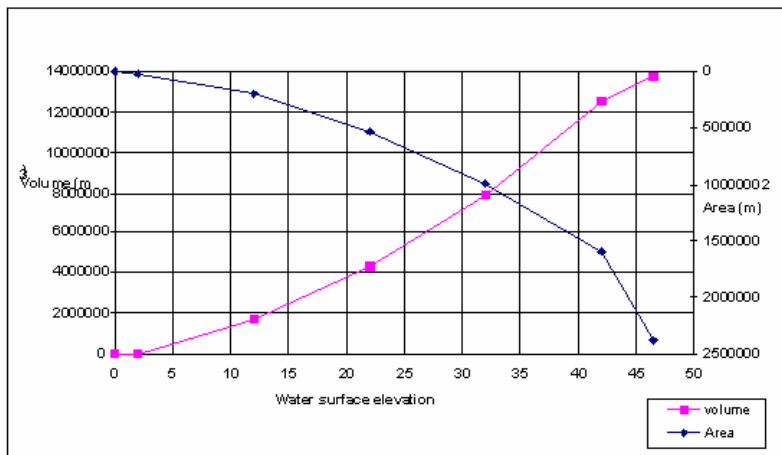


Figure 8: Area-depth relationship in Wadi Al-Arab dam reservoir.

4 Alghadeer Alabyadh dam

Alghadeer Alabyadh dam is a concrete dam located at the north west of Mafraq city in the northern parts of Jordan. The dam drains a catchment area of about 50 square kilometers. The designed maximum storage capacity is $0.7 \times 10^6 \text{ m}^3$ [10]. Wadi Alghadeer, trending south-east toward the north-west, is the main tributary within the basin. The catchment area is mostly covered by soil. The Upper and Lower Terrace deposits are mainly of Quaternary age. The latter sediments are mainly composed of sand, silt, clay and debris of chalky marl and basalt. The basalts are of Quaternary to Neogen in age. In addition the northwestern part of the catchment area Amman silicified Limestone and Al-Hisa Phosphorite is the dominant rock units. It consists of alternating beds of micritic limestone with chert varying thickness in addition to alternating beds of phosphatic chert, phosphatic limestone with chert and phosphate. The micritic limestone percent is increasing towards the top. The depositional environment of these beds is marine shelf type [11]. In Southeast, Wadi es Sir Limestone Formation is the dominant rock unit. This formation is considered as the top of Ajlun group. It is well exposed in the south west, west and central parts. Its thickness rang from 90 to 110 m.

The average annual rainfall is less than 100 mm. Rainfall period extends from October to May, but most of the rain ($> 60\%$) is confined to the period from December to February. Meteorological records show wide variation of temperature values between summer and winter. Daily maximum temperature reaches up to 37.3°C during summer and drops to less than 5°C in winter. The mean monthly temperature however, ranges between 32°C (maximum) and 6°C (minimum). In addition, the daily temperature variation is also large, reaching about 17.5°C in daily difference. Potential evaporation ranges from 3.5mm to 21.7mm during winter and summer respectively. Daily sunshine hours in the area may reach 12 hours in summer and drops to 5.6 hours during winter. Furthermore, the relative humidity reaches 41% during summer while it goes up to 71% during winter. The average annual monthly wind speed is of the order of 200km/day.

Runoff value is estimated to be around 3.08 % [12].

4.1 Nature of Bottom Sediment

Twenty seven samples were collected covering the entire bottom of the reservoir (see Figure 2b). The analysis indicates that the reservoir bed is mainly covered by sand (74.8%), gravel (17.3%), silt (4.7%) and clay (3.2%). Curves of cumulative percentage versus diameter were constructed on logarithmic probability paper (Figure 9). The curves were similar containing two straight segments round 0.0625mm. All the curves showed relatively gentler slope beyond 0.0625mm. The steepness of the curve is a reflection of scales. The change of gradient of the curves indicates a bimodality of the sediment. The inflection occurs at the boundary between sand and silt. Each straight segment reflects specific process or mode of deposition. In the case of Alghadeer Alabyadh dam sediment it is believed that the sand was transported by saltation while the silt and clay fractions were transported by suspension in the water.

Sand covers the entire bottom area of the reservoir (Figure 10). There is no major change in sand percent distribution, but within the southern parts and northeastern parts of the reservoir have relatively a high percent of gravel reaches 23% (see Figure 11). This may be attributed to agricultural and human activities, in addition to the valley's contribution of sediment. The silt and clay distribution (Figures 12&13) indicates deposition from suspension, with a relatively higher percentage on the middle northern parts of the reservoir.

The average mean grain size diameter distribution shows that fine sand covers more than 70% of the bottom area of the reservoir while medium to fine sand covers near shore areas. Patches of finer material (more than 0.09mm in diameter) are restricted in distribution. This is believed to be due to the nature of deposition and the topography of the bed reservoir. The above figures and facts reflect the nature of sediments and their transport mechanism. The sediments within the source area are of a very fine nature. Furthermore, almost all the sediments are

transported by dragging, saltation and suspension. The nature of the sediments and their distribution mode is similar to many other reservoirs in the world [13] [14].

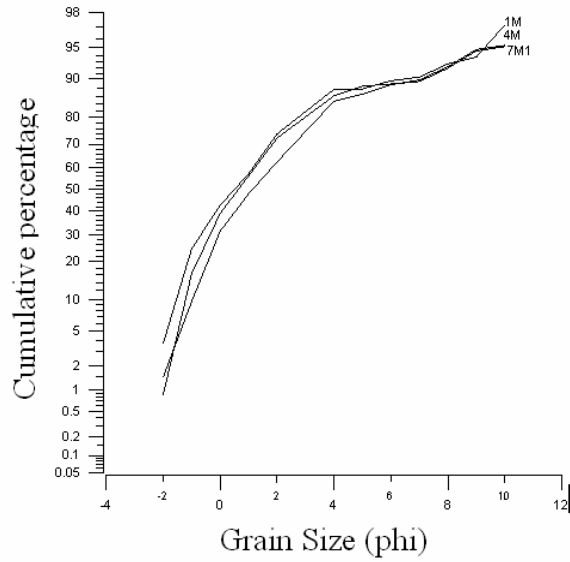


Figure 9: Example of cumulative percentage versus diameter for two selected bottom samples of Alghadeer Alabyadh dam reservoir.

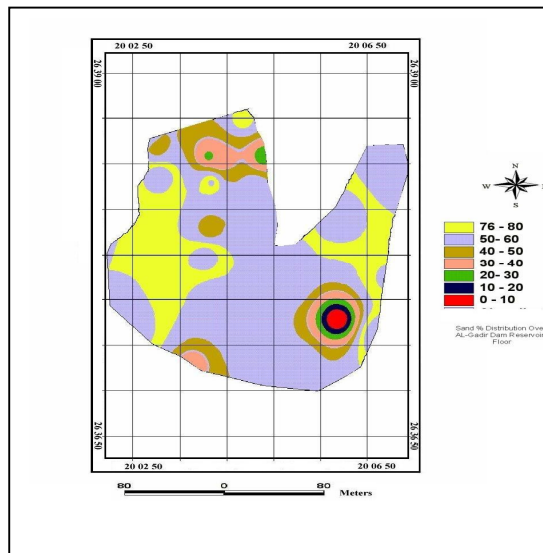


Figure 10: Sand percentage in Alghadeer Alabyadh Dam reservoir's floor.

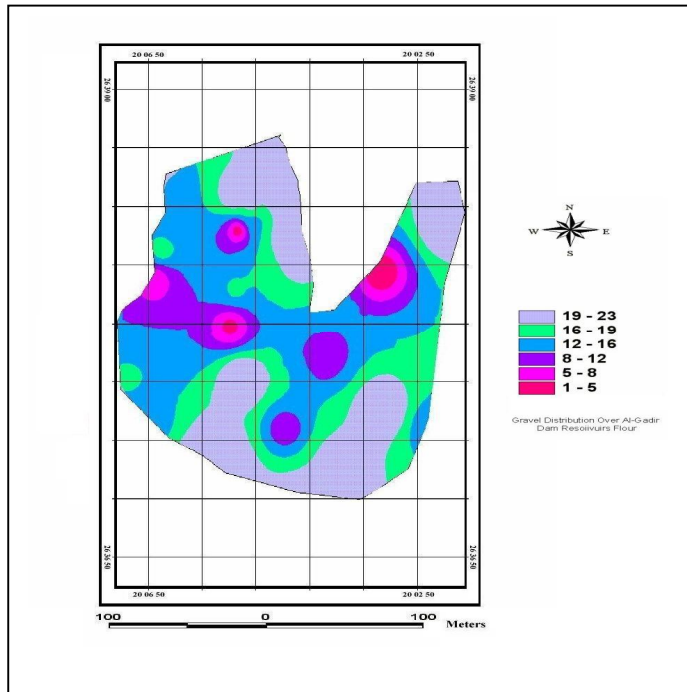


Figure 11: Gravel percentage in Alghadeer Alabyadh Dam reservoir's floor.

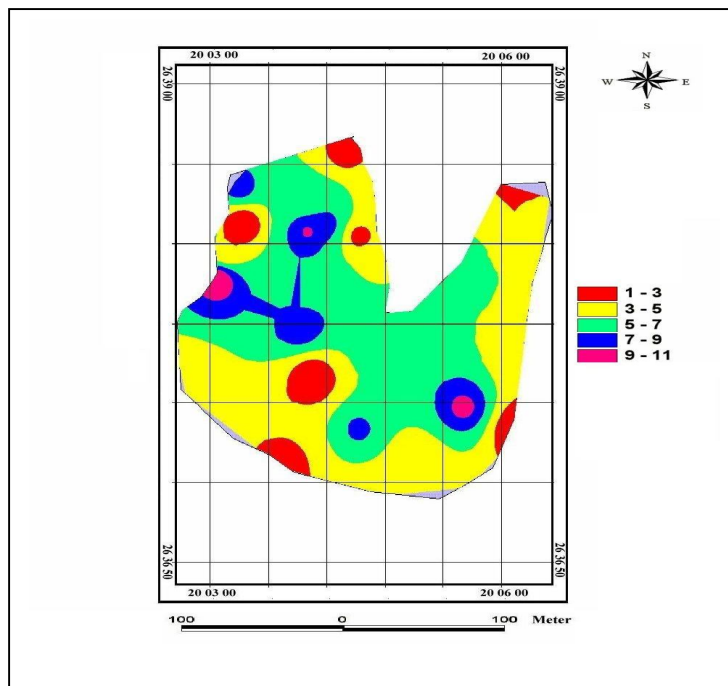


Figure 12: Silt percentage in Alghadeer Alabyadh Dam reservoir's floor.

4.2 Storage Capacity

The dam had been designed so that its effective storage capacity is 0.7×10^6 m³. The concrete dam has a crest length of 100 m at a crest elevation of 665m above mean sea level. The dam has an outlet, which is a side overflow weir without channel. The outlet elevation is 663.5 m.

The maximum length of the reservoir is about 500m extending west-east with a mean width of about 400m. Water enters the reservoir from an only main southeastern valley. The western part of the reservoir is characterized by steeper slopes compared to the southern part which are relatively flat.

Nine echo-sounding traverses were made between known points during the period of November 2004, to cover the entire area of the reservoir (see Figure 2b). The water level was 662 m above mean sea level.

The new bathymetric chart (see Figure 14) shows the huge amount of sediment accumulation within the reservoir. The deepest point recorded was 661.6meters above mean sea level. It is evident that the slope of the bed of the reservoir gradually drops down in elevation from the south toward the north where the Alghadeer Alabyadh dam is situated.

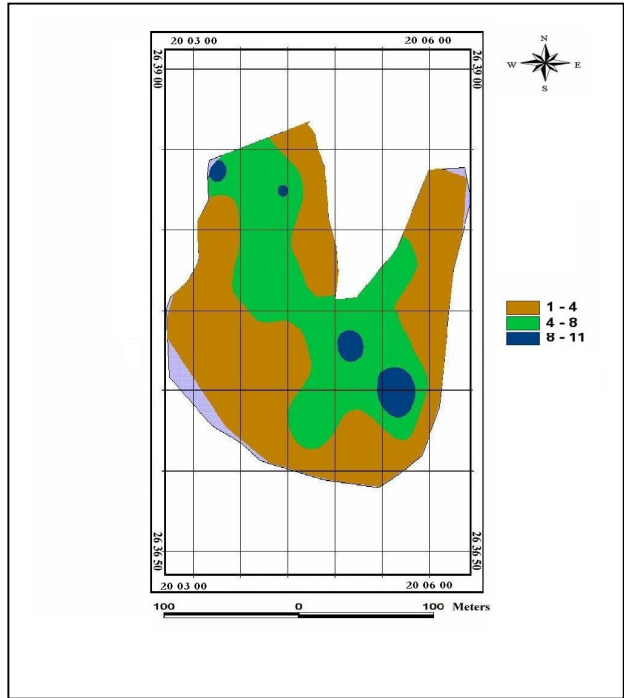


Figure 13: Clay percentage in Alghadeer Alabyadh Dam reservoir's floor.

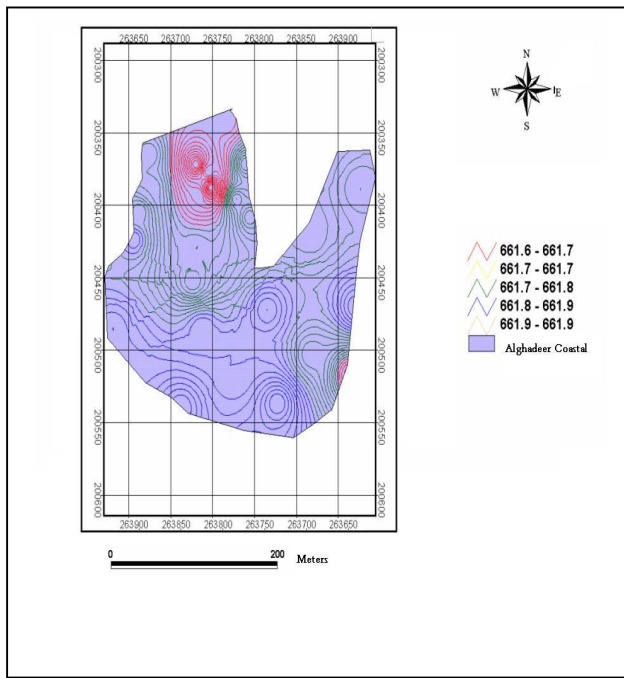


Figure 14: Bathymetric chart of Alghadeer Alabyadh Dam reservoir

The deepest area lies directly south of the dam. Northern parts of the reservoir are characterized by its steep slopes near the dam site. Moving towards the southeastern parts of the reservoir the slopes are much gentler. The bed of the reservoir, however, is more or less gentle in its slope. Comparing the new bathymetric map with all topographic maps of the area, it is evident that sediment was deposited all over the reservoir area forming a generally flat bed shape. The results are shown in figure (14).

The present storage capacity for Alghadeer Alabyadh dam reservoir has been calculated to be about $0.028965 \times 10^6 \text{ m}^3$ indicating huge reduction in storage capacity of the reservoir. The comparison of this value with the designed storage capacity suggests that $0.671034 \times 10^6 \text{ m}^3$ of sediments have been deposited during the life span of the reservoir. Consequently, the average annual sediment deposition rate is of the order of $0.017206 \times 10^6 \text{ m}^3$ per year. Walling et al [15] calculated the rate of erosion within the area using Cs137. The calculations were based on one point sample and it showed a high sedimentation rate. This might be due to the fact that sediment composed of fine particles will generally have higher ^{137}Cs content than sediment composed of coarser particles from the same source (cf. [16]; [17]). According to the calculated rates of deposition the reservoir is filled with sediments and can not be of any value now.

5 Conclusions

Fine sand was the dominant sediment covering the bed of both reservoirs. It seems that the sediment was mainly transported by suspension and saltation.

The rate of siltation in Wadi Al-Arab dam reservoir was of the order of $0.4002 \times 10^{-6} \text{ m}^3$ while it was $0.017206 \times 10^{-6} \text{ m}^3$ per year in Alghadeer Alabyadh dam reservoir. This difference reflects the differences in the geology, topography and meteorology of the two catchments. The catchment of the former is mountainous with relatively high amount of rain when compared with Alghadeer Alabyadh Catchment which is a plain area lying on the verge of the desert.

Wadi Alarab reservoir will be filled with sediment within 38 years maximum, while Alghadeer Alabyadh reservoir is already filled with sediment now.

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