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Siltation of Alghadeer Alabyadh Reservoir

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ABSTRACT

Siltation of Alghadeer Alabyadh dam in the northern part of Jordan was investigated. Alghadeer Alabyadh dam was constructed 45 years ago (1966). The designed total reservoir storage capacity of this damwas 0.7 million cubic meters. The actual storage capacity of the reservoir was calculated using echo-sounding traverses. The data obtained were used in special computer software to construct the bathymetric mapof the reservoir and consequently calculate the existing storage volume. The obtained results indicated that the reservoir storage capacitywas reduced at an average annual rate of 0.016 MCM.

Bottom sediments of the reservoirwere collected using van-veen grab and analyzed. Sand, silt and clay were the main sediment components.

KEYWORDS: Siltation, Alghadeer Alabyadh, Storage capacity, Echo-sounding traverses, Bathymetric map.

INTRODUCTION

Jordan is one of the most Arab countries suffering from water scarcity. Therefore, water availability is a serious and urgent issue. One of the means of augmenting water budgets is to control surface flow by building reservoirs. To maintain long life operation of reservoirs, it is evident that siltation problems should be carefully monitored. High rates of sedimentation will eventually lead to such reservoirs being 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 consequently keeping high storage capacity is a must. In this investigation, Alghadeer Alabyadh reservoir (Fig. 1) has been studied to monitor the amount and nature of sediment deposited.

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INVESTIGATED SITE

Alghadeer Alabyadh dam is a concrete dam located north west of Al-Mafraq city in the northern part of Jordan (Fig. 1). The dam drains a catchment area of about 50 square kilometers. According to Arger (1997), the designed maximum storage capacity is about 0.7 MCM. Wadi Alghadeer trends from south-east towards north-west and is the main tributary within this basin. The catchment area is mostly covered by soil, while the Upper and Lower Terrace deposits are mainly of Quaternary age according to (Smadi, 2000). 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 according to (Smadi, 2000). The dominant rock units in the north western part of the catchment area are the Amman Silicified Limestone Formation and Al-Hisa Phosphorite Formation. Amman Silicified Limestone consists

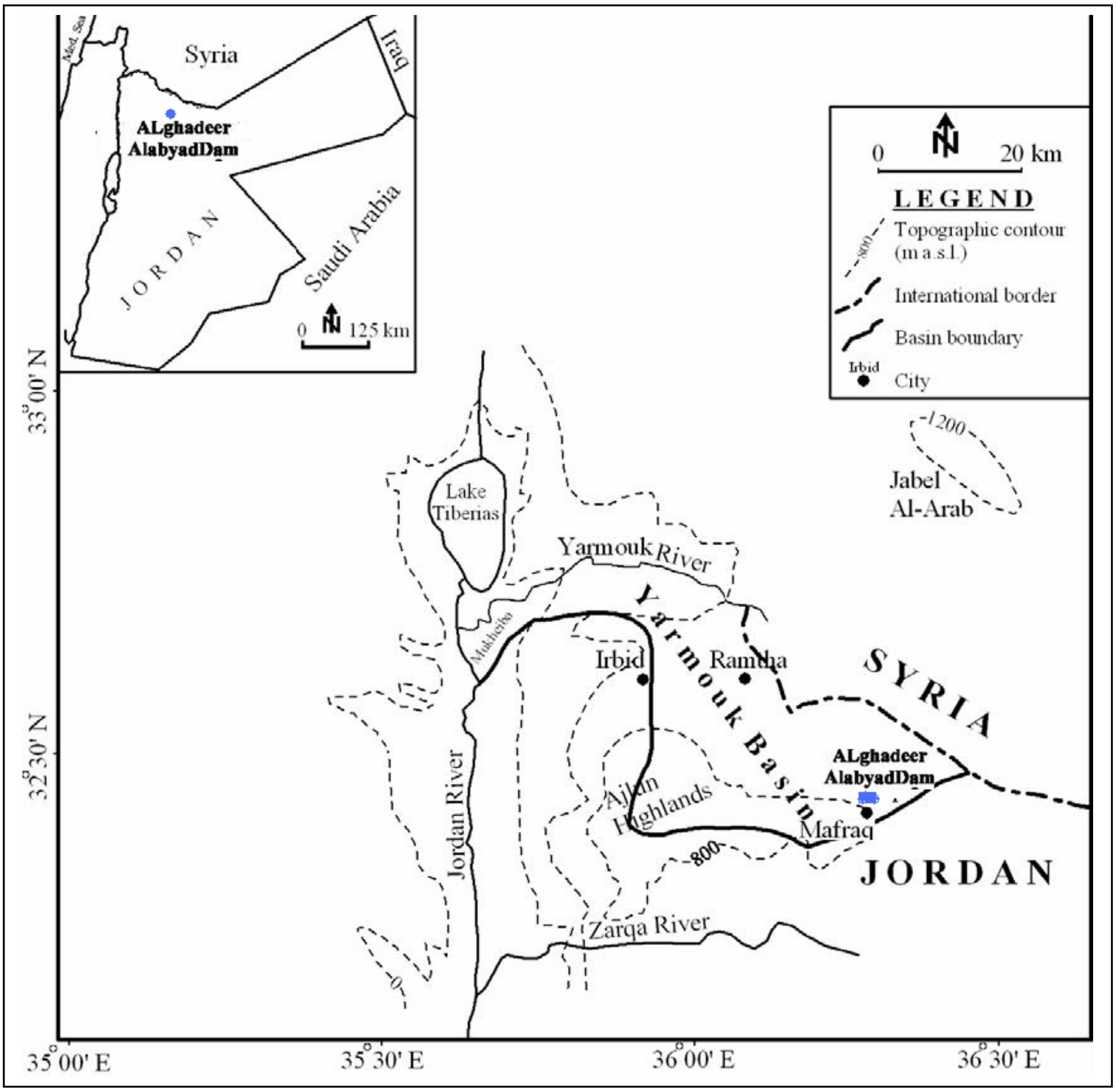

Figure 1: Location map of Alghadeer Alabyadh dam modified after (Ta"any, 2007)

predominantly of massive chert and limestone beds, which exhibit a variety of textures ranging from homogenous to brecciated. Al-Hisa Phosphorite is heterogeneous in lithology, consists of 10-15 m thick phosphates, phosphaticchert, limestone, oyster coquina limestone, marl and chalky marl (Shinaq, 2006). The depositional environment of these beds is marine shelf type (Smadi, 2000). Wadi es Sir Limestone Formation is well exposed in the south west, west and central parts of the catchment area. This formation is considered as the top of Ajlun group. Its thickness ranges from 90 to 110m according to (Smadi, 2000). It consists of well-bedded, hard massive, fine to medium crystalline limestone, dolomitic limestone and dolomite of Turonian age (Shinaq, 2006).

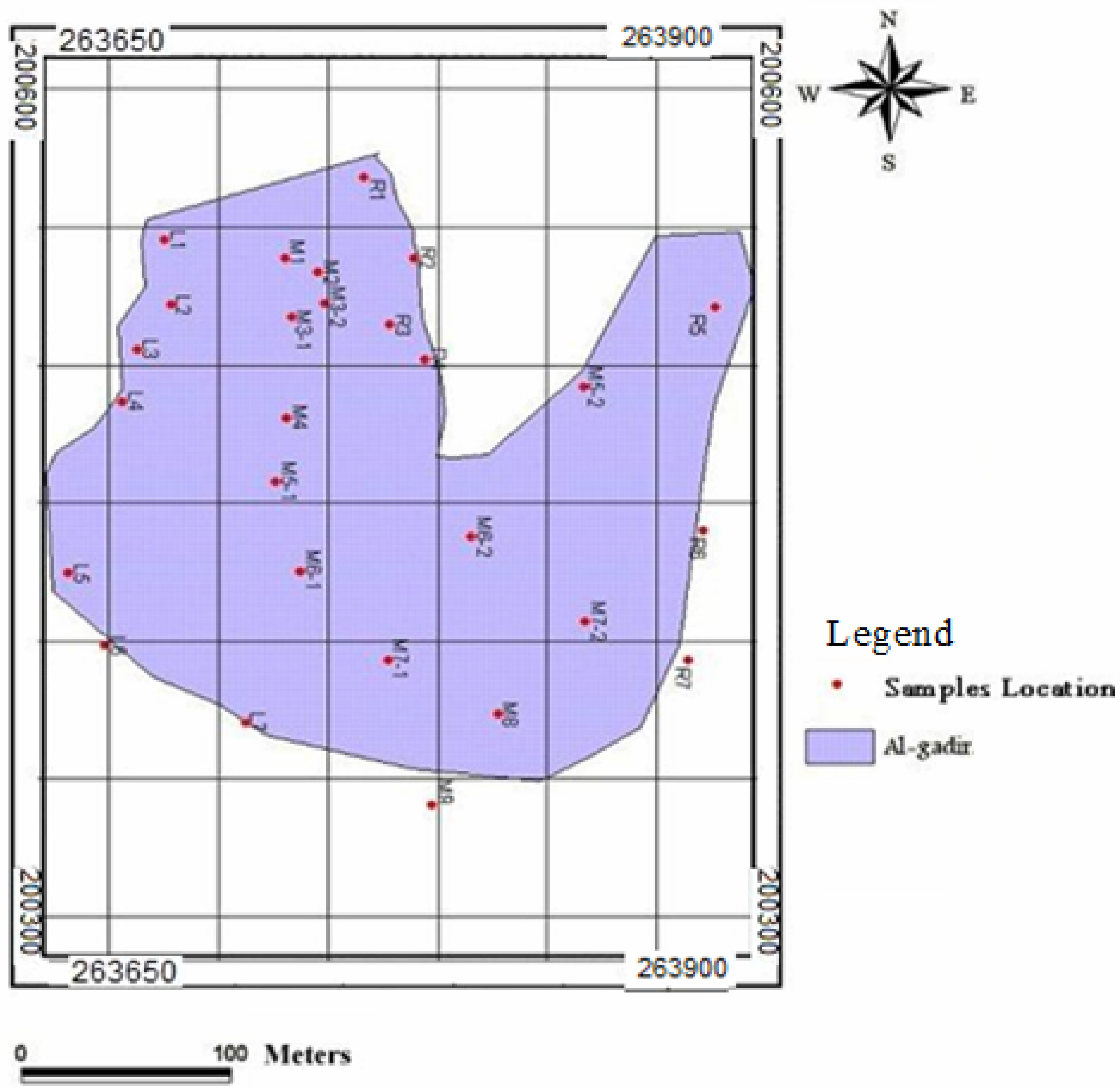

Figure 2: Transverse sections and sampling locations of bottom sediments within Alghadeer Alabyadh dam reservoir

The average annual rainfall is less than 100 mm. Rainfall is restricted to the period extending from October to May, but most of the rain (> 60%) is confined to the period from December to February. Meteorological records collected by the Jordan Meteorological Department (JMD) at Al-Mafraq station during the years 1970 to 2010 show wide variations of temperature values between summer and winter. Daily maximum temperature reaches up to 37.3^{o}C during summer and drops to less than 5^{o}C in winter. The mean monthly temperature, however, ranges between 32^{o}C (maximum) and 6^{o}C (minimum). In addition, the daily temperature variation is also large, reaching about 17.5^{o}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 20 km/day. Runoff coefficient is estimated to be around 3. 08% (Salameh et al. , 1997).

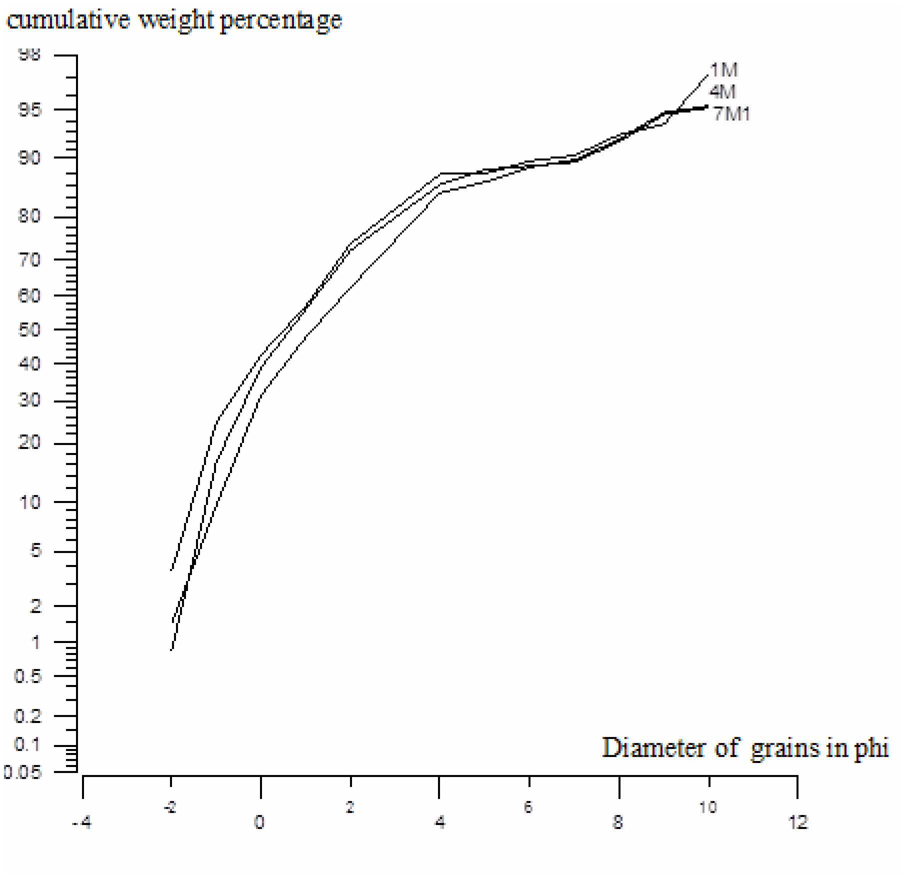

Figure 3: Example of cumulative percentage *vs.* diameter for three selected bottom samples of Alghadeer Alabyadh dam reservoir

Alghadeer Alabyadh reservoir had been designed so that its effective storage capacity is 0.7 MCM. The concrete dam has a crest length of 100 m at a crest elevation of 665 m above mean sea level. The dam has an outlet, which is a side overflow weir without channel which has an elevation of 663. 5 ma. s. l. The maximum length of the reservoir is about 500m extending west-east with a mean width of about 400m. Water enters the reservoir only from a main southeastern valley. The western part of the reservoir is characterized by steeper slopes compared to the southern part which is relatively flat.

METHODOLOGY

The adopted methodology in this research includes data collection, field and lab works, processing and analyzing the collected data.

Estimates of siltation rates in small reservoirs can be obtained using several methods, indirectly by measurements of suspended sediment fluxes, sediment traps or runoff/sediment yield estimations and more directly by sediment coring of deposited bottom sediments or bathymetric surveys (Foster, 2006).

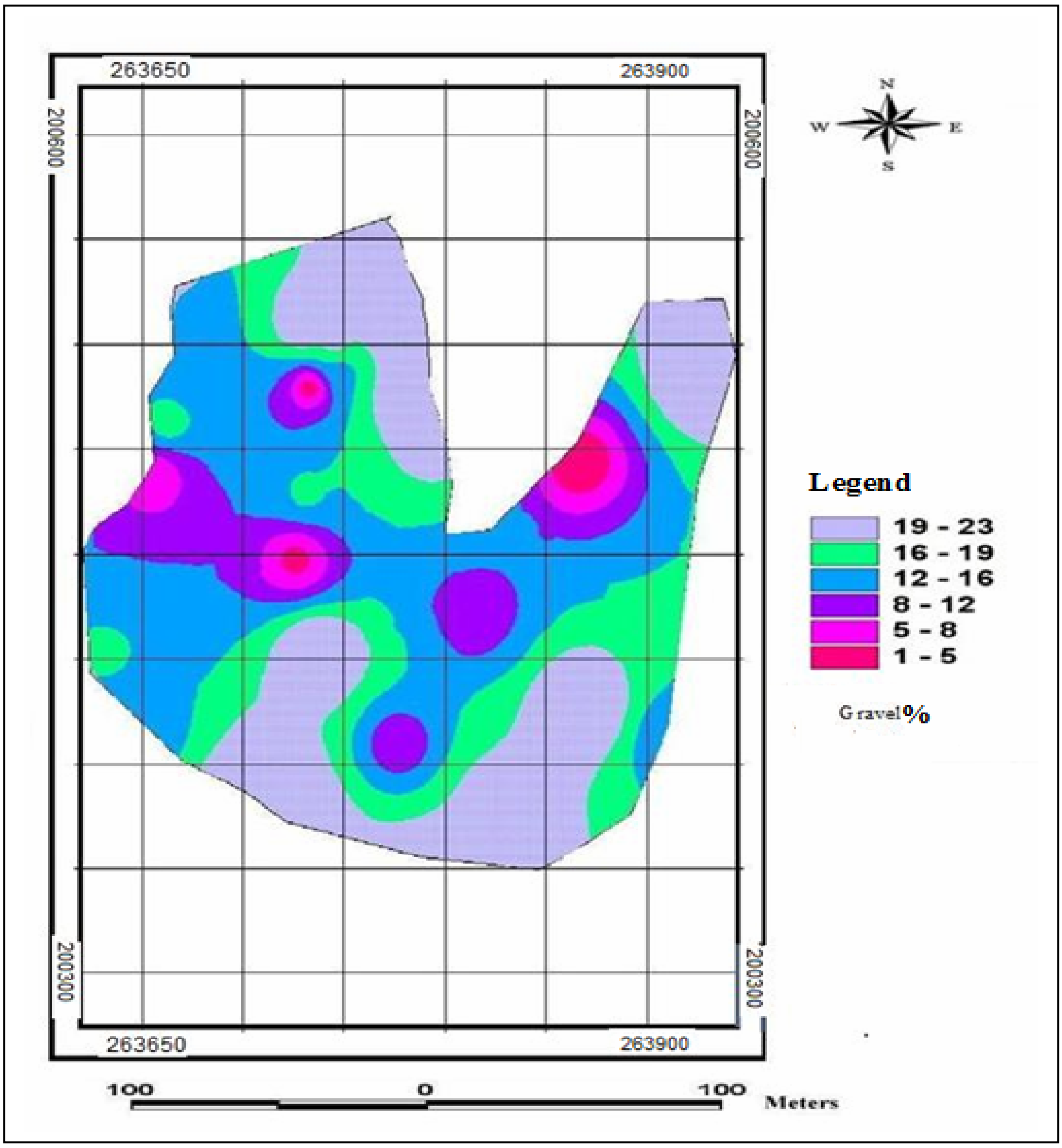

Figure 4: Gravel percentage in Alghadeer Alabyadh dam reservoir's floor

The bathymetric approach is based on a simple comparison of the reservoir's morphology at two different time periods; first at the time of the construction of the dam and second at the time of the survey, which should be at least 10 years later to detect any significant changes. The initial topographical map of the reservoir (Scale 1: 1000) and the corresponding geotechnical report are required to get information about area-volume curves, potential water storage capacity, water surface and catchment area, spillway, overflow and runoff data. Moreover, construction details of the dam, the degree of surface soil disturbed and sediments removed are needed. Additionally, a clear elevation point should be selected (e.g. at the spillway), which serves later as a fixed point for comparative analysis. By using inflatable boat, water depths were taken

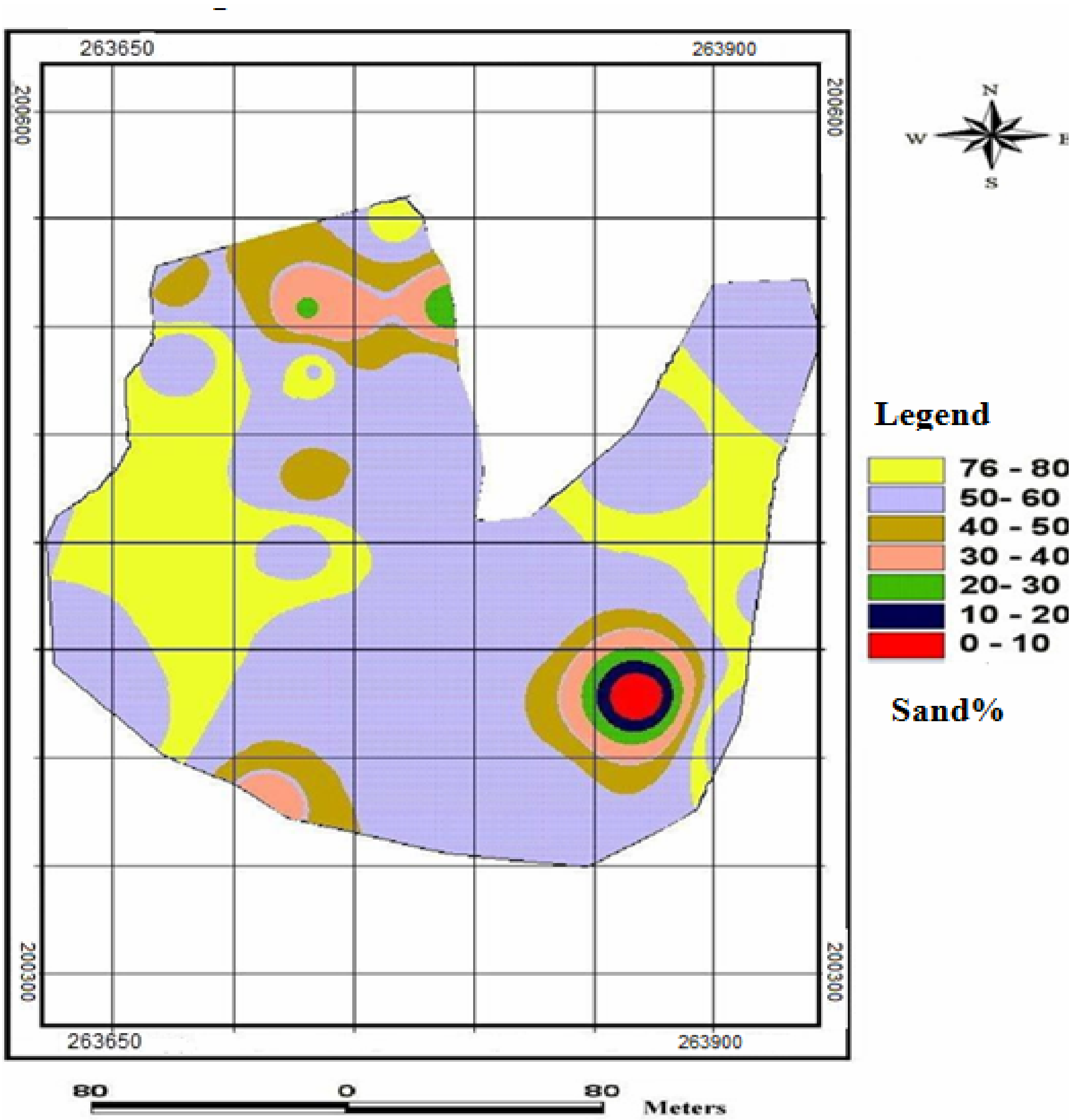

Figure 5: Sand percentage in Alghadeer Alabyadh dam reservoir's floor

point by point in a sampling grid fine enough to yield a map of resolution similar to the baseline information with which it will be compared. The sampling design depends on the size of the reservoir as well as on the number and density of the elevation points in the initial topographical map. The collected water-depth points and the corresponding GPS-coordinates will be processed by a geographical information system (e. g. ArcView, ArcGIS) or grid-based graphic software (e. g. Surfer). For the interpolation of the survey points, known interpolation routines (such as linear triangulation, kriging and inverse distance to a power) can be used. Sampling points should be limited to the bottom surface of the reservoir, because bank area points might generate large variations in the digital elevation model. The same procedure is repeated with the initial topographical map. A second digital elevation model is derived based on the original elevation points and/or contour lines. By overlaying the two elevation models, differences in elevation can be calculated and the volume contained between the modeled surfaces estimated. The resulting volume is an estimate of the quantity of sediment that has been accumulated (Foster, 2006).

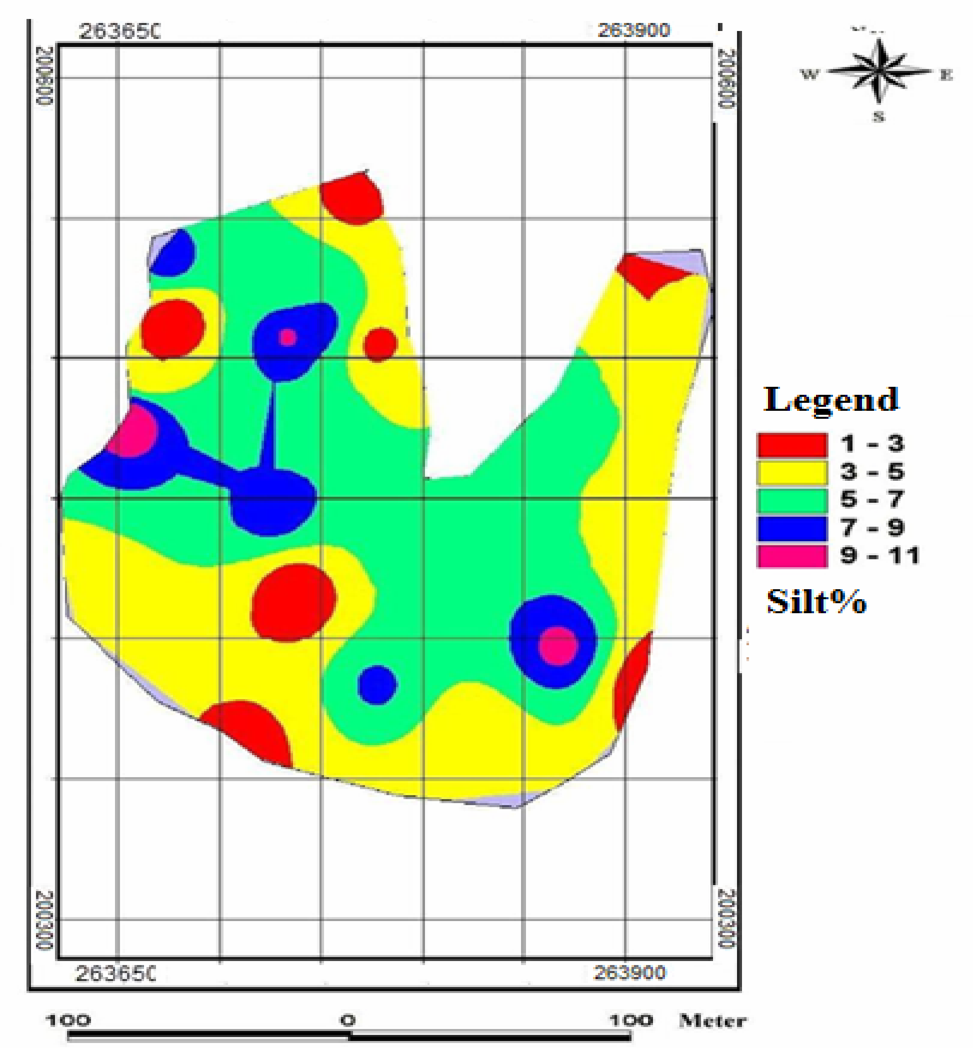

Figure 6: Silt percentage in Alghadeer Alabyadh dam reservoir's floor

In order to study the nature of bottom sediment of the reservoir, a van-veen grab was used to collect twenty seven samples covering the entire bottom of the reservoir (Figure 2). The exact location of each sample was fixed using GPS. Samples were collected covering the entire bottom of the reservoir (Figure 2). The samples were dried and sieved to estimate the sand content. The fine portions (silt and clay) were subjected to pipette analysis if they form more than 5% of the total sample. Folk's (1973) procedure was used during laboratory analysis and in the evaluation of the statistical parameters of the sediment samples.

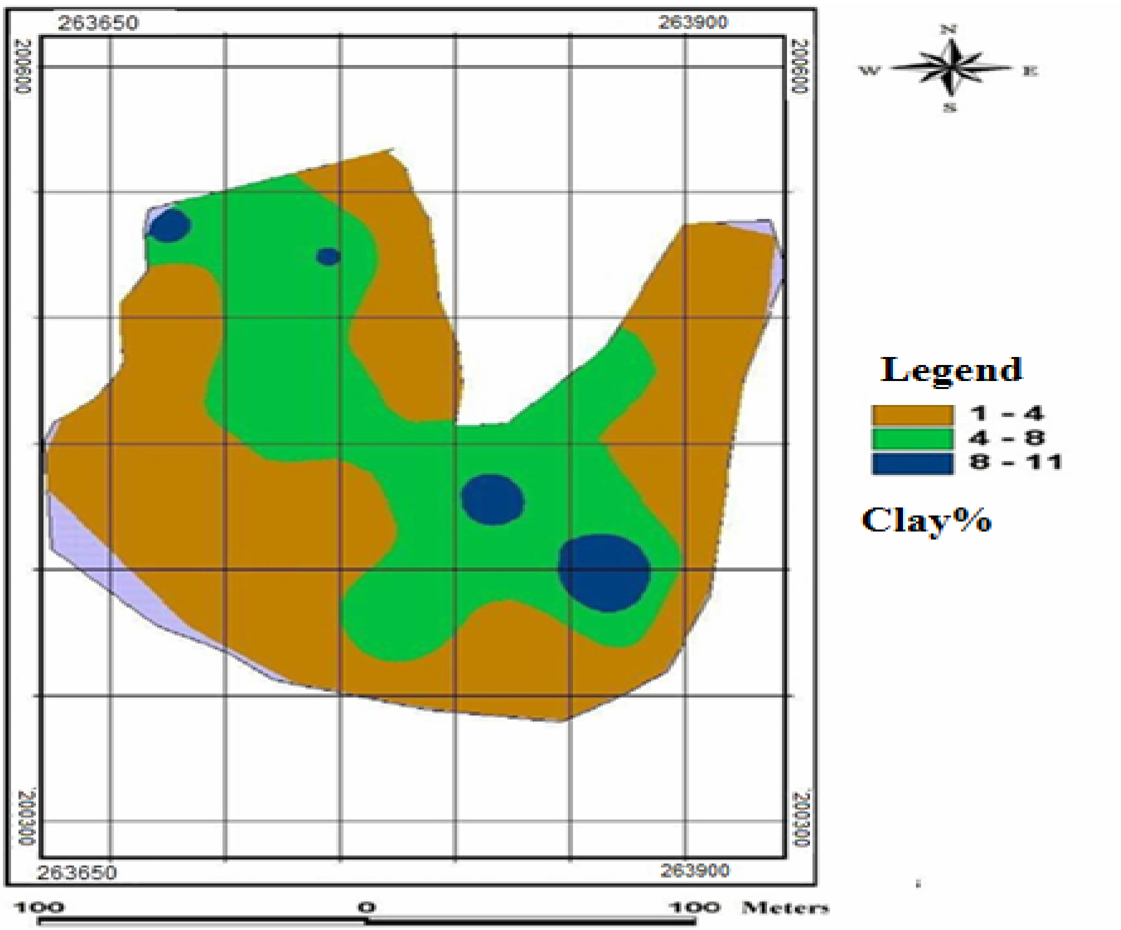

Figure 7: Clay percentage in Alghadeer Alabyadh dam reservoir's floor

DATA ANALYSIS AND RESULTS

Nine echo-sounding traverses were made between known points during the period of November 2009, to cover the entire area of the reservoir (Figure 2). The water level was 662 m above mean sea level. All the traverses were perpendicular to the longest axis of the reservoir. A Traverse Total Station (TTS) (Model SOKKIA SET F6) was used to carry out the land survey, while two echosounding 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 notebook computer was connected to the echosounder so that all survey points could be recorded. The survey data were fed to ArcMap®9.1 and WMS®5.0 software. The former is produced by the 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. WMS® 5.0 was used to create terrain models from Triangulated Irregular Networks, or TINs. The TIN was then used for delineating the data. Both software packages have been utilized for the construction of the bathymetric chart of the reservoir (Figure 8).

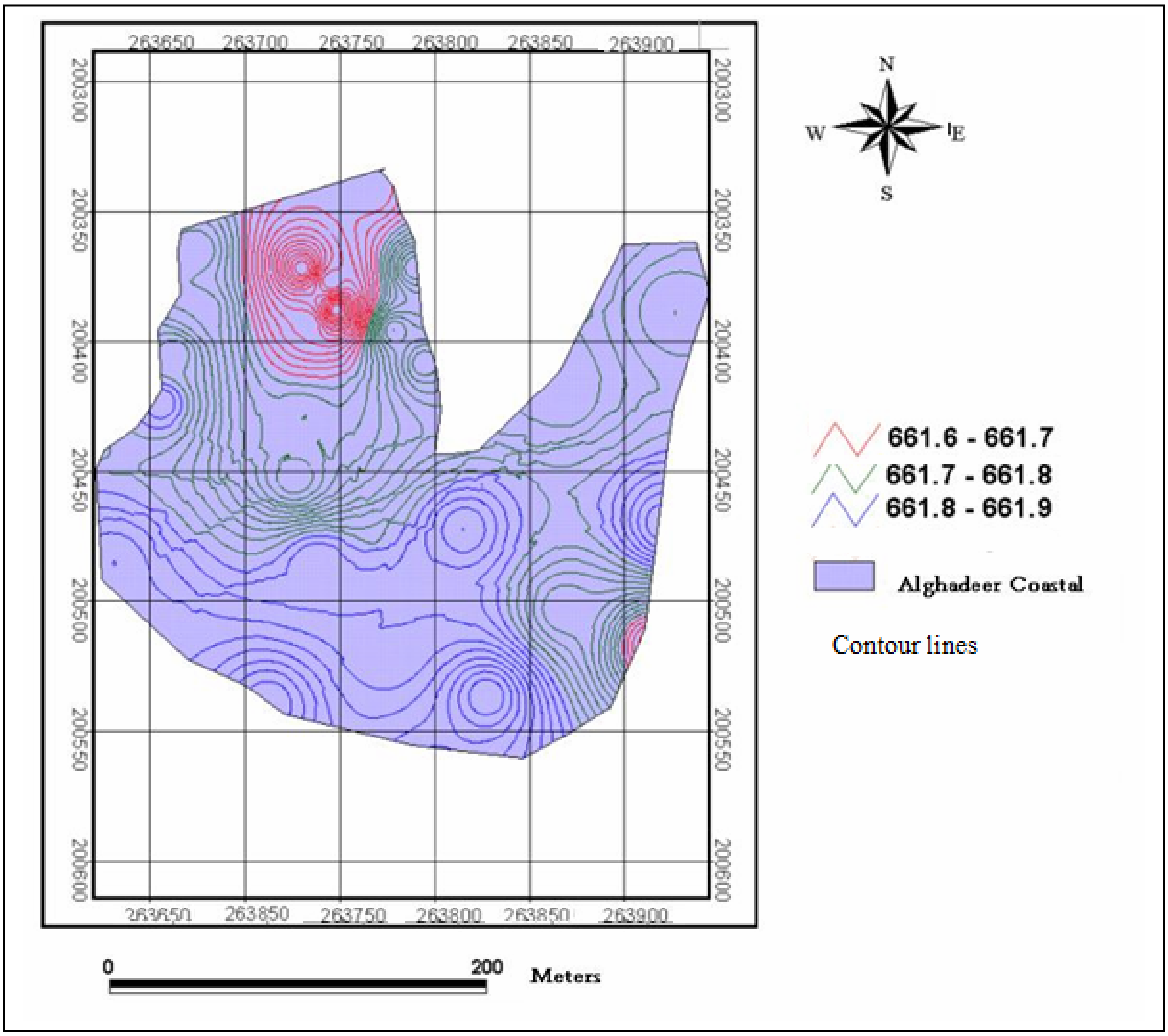

Figure 8: Bathymetric chart of Alghadeer Alabyadh dam reservoir

The new bathymetric chart (Figure 8) shows the huge amount of sediment accumulation within the reservoir. The deepest point is recorded at 661.6 meters above mean sea level. It is evident that the slope of the bed of the reservoir gradually drops down in elevation from the south direction towards the north direction, where Alghadeer Alabyadh dam is situated.

The deepest area lies directly south of the dam. The northern parts of the reservoir are characterized by 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. Results are shown in Figure (8).

The analysis of the collected sediment samples 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 3). They indicate straight segments around 0.0625 mm. All the curves are characterized by a relatively gentler slope beyond 0.0625 mm. The steepness of the curve is thought to be 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 a specific process or mode of deposition.

Sand covers the entire bottom area of the reservoir (Figure 4). There is no major change in sand distribution. The southern parts and northeastern parts of the reservoir are characterized by a high percent of gravel reaching about 23% (Figure 5). This may be attributed to agricultural and human activities, in addition to the valley’s contribution of sediment. The distribution of silt and clay (Figures 6 and 7) indicates deposition from suspension, with a relatively higher percentage on the middle northern parts of the reservoir.

CONCLUSIONS AND RECOMMENDATIONS

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 is distributed near the shore areas. Patches of finer material (more than 0.09 mm in diameter) are restricted in distribution. This is believed to be due to the nature of deposition and to 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, approximately all the sediments were transported by dragging, saltation and suspension. The nature of the sediments and their distribution mode are similar to those of many other reservoirs in the world (Al-Ansari, 1987; McManus and Duck, 1993).

The present storage capacity for Alghadeer Alabyadh dam reservoir has been calculated to be about 0.029 MCM, indicating a huge reduction in the storage capacity of the reservoir. The comparison of this value with the designed storage capacity suggests that 0. 671 MCM of sediments have been deposited during the life span of the reservoir. Consequently, the average annual sediment deposition rate is in the order of 0.016 MCM per year.

Erodible soil cover, young and weak geologic formations, floods during relatively heavy torrential rainfalls, urbanization activities, livestock productivity and improper cultivation and land uses are factors contributing to the frequent occurrence of erosion in the catchment area.

The annual loss of Alghadeer Alabyadh dam reservoir's capacity due to siltation is about 2.5%, this is nearly twice the rate of Sharhabiel Bin Hasnaha (Zeglab) dam located in the Jordan Valley (Shatnawi, 2002). This can be attributed to the easily erodible nature of the soil and sediment covering most of the catchment area of Alghadeer Alabyadh dam. According to Ludwig (2008), the annual loss in reservoir capacity in the Mediterranean region reaches about 1.5%. However, every year 0.5-1.0% of the world’s reservoir capacity is lost due to sedimentation (White, 2000).

The bathymetric survey provides a useful tool to get an overview of sediment storage in reservoirs. The fieldwork requires a comparatively small commitment of time and does not involve permanent monitoring and/or maintenance of sediment yield/runoff devices. However, the technical equipment is relatively costly and some expertise is needed for data processing and the construction of a digital elevation model. A limitation of the described sonar device is that depth-measurements can be taken only in 10 cm depth intervals and shallow depths below 0.5 m cannot be considered. Therefore, the water depth was crosschecked with a simple stadia rod, which is still a very good and low-cost tool.

The remarkable increase in rainfall intensity due to global warming will cause an increase in sediment load in turn. The sediment load will increase as the area of arable land will decrease adding a new dimension to this issue which requires further investigation.

It is obvious that it is not possible to totally avoid or stop siltation. An approach to reduce siltation of reservoirs is to conduct Catchment Area Treatment (CAT). This suggests the application of various techniques such as plantation, gully plugging and check dams within the degraded portions of the catchment area to reduce the silt coming into the reservoirs. Catchment Area Treatment plans are expected to be implemented before the project construction is completed, so that there is minimum siltation of the reservoirs once water storage in the reservoir is started.

Since erosion process occurring in the watershed is believed to be the major source of sediment load, it is important to pay due attention for appropriate watershed development or soil and water conservation, especially for those places which are major causes of higher sediment yield.

Since the reservoir becomes dry in late summer, it is recommended to remove the accumulated sediments by trucking as they can be used in cultivation due to their versatility.

Also, it is recommended to collect regularly primary data. The data collection includes bathymetry, flow into the reservoir and the sediment transport rate. Moreover, data on sediment gradation should also be collected for all water reservoirs in the country.

REFERENCES

Al-Ansari, N. A. (Ed.). 1987. Hemrin Reservoir: Geological and Hydrological Investigation, *J. Water Res.*, Special Pub., No. 2.

Agrar and Hydrotechnik. 1997. National Water Resources Master Plan of Jordan. 8 Volumes, Essen, Hannover.

Baban, S. and Al-Ansari, N. A. (Eds.). 2001. Living with Water Scarcity, Water Resources in the Jordanian Badia Region. The Way Forward, Al al-Bayt Univ. Publications, Jordan.

Bender, F. 1974. Geology of Jordan, Borntraeger, Berlin.

Folk, R.L. 1973. Petrology of Sedimentary Rocks, Hemphill’s, Austin, Texas.

Foster, I. D. L. 2006. Lakes and Reservoirs in the Sediment Delivery System: Reconstructing Sediment Yields. In: Owns, P. N. and Collins, A. J. (Eds.): Soil Erosion and Sediment Redistribution in River Catchments. CAB International, Wallingford, 128-142.

Ludwig, W. 2008. http://www.cnrm.meteo.fr/hymex/global/documents/Presentations_janvier_2007/Session_E/Rivers_input_Ludwig_Wolfgang. pdf.

Marakawi, M. 1995. Managing Water for Peace in The Middle East: Alternative Strategies, UN University Press, N.Y.

McManus, J. and Duck, R.W. 1993. Geomorphology and Sedimentology of Lakes and Reservoirs, John Wiley and Sons, New York.

Rogers, P. and Lydon, P. (Eds.). 1993. Water in the Arab World: Perspectives and Prognoses, Harvard Univ. Press.

Salameh, E., Al-Ansari, N. and El-Naqa, A. 1997. Scientific Guide Book to Al-Mafraq Governorate, Al al-Bayt University, Jordan.

Shatnawi, A. 2002. Hydrological and Hydrochemical Study for Zeglab Dam, MSc. Thesis, Al al-Bayt University, Jordan.

Shinaq, R., Sherideh, S. and Saifuldin, N. 2006. Microfacies and Depositional Environment of the Upper Cretaceous Phosphorites in Northern Jordan. Freiberger Forschungshefte C511; 45-58.

Sloff, C. J. 2005. Modeling Reservoir Sedimentation Processes for Sediment Management Studies, Delft University, The Netherlands.

Smadi, A. A. 2000. The Geology of Al-Mafraq Area, Natural Resources Authority, Amman, Jordan.

Ta"any, R., Batayneh, A. and Jaradat. 2007. Groundwater Quality, Yarmouk Basin, Jordan, *Journal of Environmental Hydrology*, 15: 28.

Water Authority. 1989. The North Jordan Water Resources Investigation Project, Amman, Jordan.

White, W. R. 2000. Contributing Paper: Flushing of Sediments from Reservoirs, Prepared for Thematic Review IV. 5: Operation, Monitoring and Decommissioning of Dams. HR Wallingford, UK.