COMPARISON OF SATELLITE IMAGES FOR ESTIMATION OF RESERVOIR CHARACTERISTICS USING GIS BASED TECHNIQUES (A CASE STUDY OF THREE DAMS I.E. DOMLI, BARAL (LEHRI) AND CHAMAK MIRA IN PAKISTAN)

***Ehtesham Ahmed[1], Ghulam Nabi[2], Moien Ahsan[1], Arslan Arshad[1]**

[1]Student, Centre of Excellence in Water Resources Engineering, University Of Engineering and Technology, Lahore

[2]Assistant Professor, Centre of Excellence in Water Resources Engineering, University Of Engineering and Technology, Lahore

[*]Corresponding Author's email: ehtesham3094@yahoo.com

ABSTRACT: *Dams are designed to irrigate the maximum command area and hydropower generation. In this Study two types of satellite images (Digital Elevation Models SRTM and ATER) were used to determine the area and capacity of existing and proposed dams. Three dam sites were selected for checking the suitability of DEM for capacity and area calculations. Using SRTM DEM for Domel, Baral (Lehri) and Chamak Mira Dams showed -9.14%, -10.80% and -40.42% deviation from the reported reservoir capacities respectively. On the other hand, ASTER DEM overestimated capacity for Domeli 34.17%, Baral (Lehri) 27.98% and underestimated for Chamak Mira dam up to 4.58%. In case of estimating area, SRTM underestimated the area while ASTER DEM overestimated the area. SRTM showed -41.52%, -31.47% and 52.47% for Domeli, Baral (Lehri) and Chamak Mira dam respectively, whereas ASTER showed 20.02%, 2.33% and -20.45% for Domeli, Baral (Lehri) and Chamak Mira dam respectively. The heights of the dams calculated by SRTM DEM were 365.01m, 310.00m, and 935.26m in addition calculated by ASTER DEM were 351.70m, 305.61m, 305.61m and 932.17m for Domeli, Baral (Lehri) and Chamak Mira dam respectively. It is concluded that ASTER data is more feasible for developing area-storage-elevation relationships and relating dam height against it.*

Key Words: SRTM, ASTER, DEM, GIS, Dam Height, Reservoir Capacity, Reservoir Area

INTRODUCTION

Water is essential for the survival of every living being. Water usage is going to be increased day by day due to increasing demand of water for irrigation, drinking, hydropower and industries. According to the future scenario of water shortage, there is a need to make surveys for new sites for building the new reservoirs. Before recognising suitable new locations, it is essential to identify the amount of water that can be stored within the reservoir against different crest levels. This can be determined by surveying the reservoir site. However, undulating topographical features and exhaustive field data measurements often limit the frequency of these surveys. Recently, advancement in computer technology, use of Geographical Information Systems (GIS) has become essential tools for analysing optimum reservoir locations [1]. GIS are simply processed, analyses, and presentation of spatial data [2]. DEMs are widely used for hydrological modelling [3], to determine flow directions, slope steepness, stream orders, areas and capacities. ArcGIS provides accurate calculations of reservoir volumes and water surface areas through contouring and surface mapping rather than other traditional methods. The volume under each contour can be found and thus reservoir capacity at crest level's contour can be easily determined. This considerably reduces economic burdens, time and workload in calculating the reservoir capacities and areas.

Capacity calculation is a very convenient approach by using Digital Elevation Model (DEM) which enables to have a range of reservoir volumes and surface areas of reservoir at different crest heights. Reservoirs capacities are based on Direct Methods, i.e. i. Mid Area Method, ii. Prismoidal Method and Indirect Methods by using topographic maps or satellite images, from which a power relationship between surface area and capacity of a reservoir is used to estimate reservoir capacity. In Ghana [5] used the remote sensing data to measure the storage capacity of small reservoirs and showed that there exist relationships between areas, depth and volume for the reservoirs.

The area can be obtained in GIS i.e. the area under water at specified contour. Wide contours indicate a gently sloping flat valley area and closed spaced contours indicate steeply sloping cliff sides. Others [4] used 1:50,000 topographical maps to estimate surface areas of the small farm reservoirs on the study of finding the impact of small farm reservoirs on urban water supplies in Botswana. Variation in volumes and surface areas can be seen through the elevation-volume-area relationship of a reservoir at different elevations. This relationship is determined from the elevation contour map of the reservoir area. In [5] authors studied that SRTM and ASTER DEMs are two types of elevation datasets that are frequently used for a wide range of applications due to their near-global coverage. [6] stated that DEMs can be produced from optical satellite images using similar elevation extraction methods.

The height of any dam above the lowest level in the river channel is determined by the gross storage (live storage + dead storage) capacity of the reservoir plus the free board. Reservoir live storage capacity is required to regulate the river flows for the future purposes. To ensure that reservoir live storage capacity remains available for long time, additional capacity is provided to store the sediment load which is termed as dead storage capacity. Abnormal and

severe actions of a wave due to wind action are controlled by the provision of free board to prevent overtopping of the embankment. Height of dam through geospatial techniques is very handy and easy method of feasibility survey without the physical presence of dam engineers/hydrologists at dam sites.

STUDY AREA

The study was focused on 2 existing dam sites on Pothwar area and 1 proposed dam site near Abbottabad. Pothwar area, about 58 small dams has constructed by Small Dams Organization, Irrigation and Power Department and a number of dams are proposed for future development. Pothwar region lies parallel to the Himalaya hills and between the rivers Jhelum and Indus. It includes Attock and Rawalpindi districts and some part of the Murree zone. 75% of Chakwal, 15% of Jhelum and 20% of the Mianwali district also contribute in Pothwar plateau. Pothwar area consists of many small water storage reservoirs for irrigation, drinking and other purposes. Two existing dams, i.e. Domeli dam and Baral (Lehri) dam are present in Pothwar region. Domeli dam lies in the Jhelum district having annual rainfall of 780mm. It is built specially for irrigation purpose which irrigates about 3000 acres of land. Baral dam is also constructed for irrigation, which give benefits to about 2200 acres of land located in Jhelum district.

Study for the proposed dam site was done on Chamak Mira dam site, which is located near Abbottabad city having latitude and longitude 34.114600° and 73.109759° respectively. Construction of Chamak Mira dam will provide floodwater storage for irrigation supplies to the land downstream of the marked location. Figure 1 shows the location map of the study area dams.

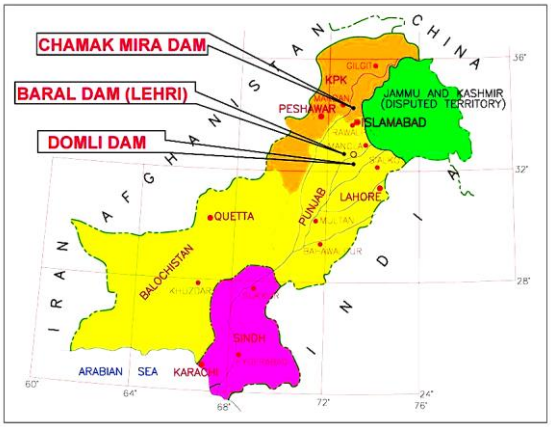


Figure 1: Location Map of the Study Area Dams

MATERIALS AND METHODS

Reservoir Capacity at Different Levels through GIS

Capacities through GIS is a very quick approach for dam engineers. ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and SRTM (Shuttle Radar Topography Mission) DEMs were used in this research to check which was more suitable for storage/area estimation.

Drew the contours of the study area exploring the contour command from Spatial Analyst Tools > Surface > Contours and provide the contour interval of 1 m as seen in Figure 2.

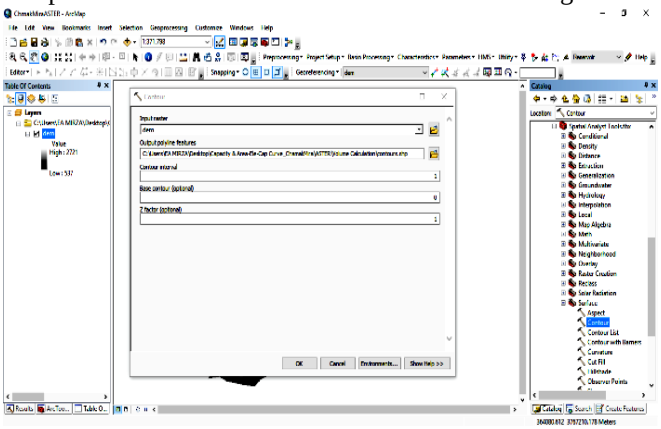


Figure 2: Contour of the Study Area

After making the contours, selected the arbitrary maximum crest height for dam to draw area elevation curve after finding out capacities at different levels of the dam. Selected and exported this contour to the directory. This exported contour was then converted into polygon by using the command "Feature To Polygon" tool present in Data Management Tools > Features > Features To Raster as shown in Figure 3. Closed any open space before converting it into polygon by starting the edits of contour layer. Extracted the DEM against this polygon at the end.

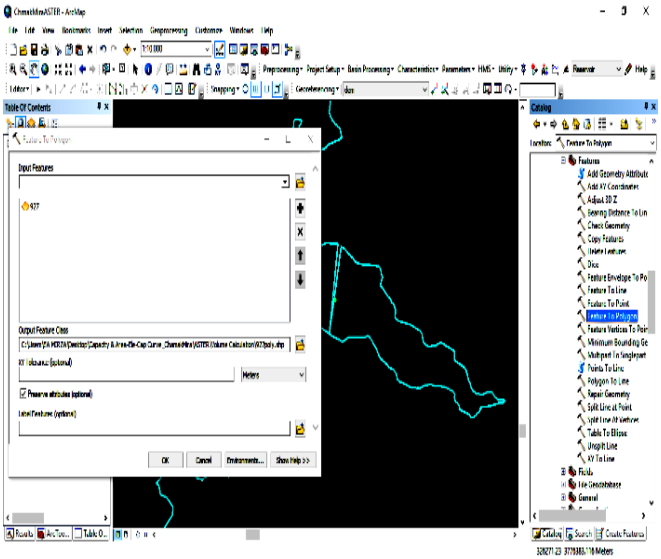


Figure 3: Feature To Polygon

Volume and area against each contour was estimated by "Surface Volume" tool present in 3D Analyst tools > Functional Surface > Surface Volume as shown in Figure 4. By using this tool, volume can be estimated below any specified contour. Repeated the above methodology for all dams and proposed dam site.

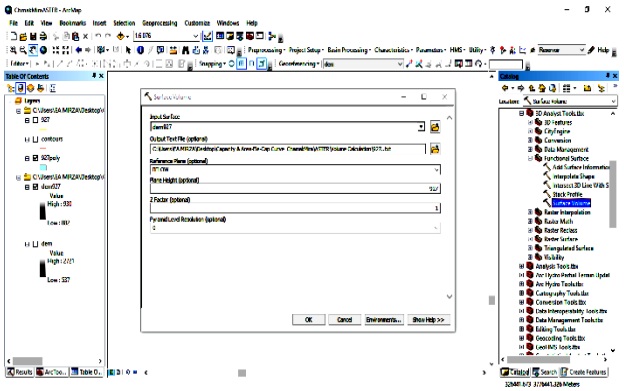


Figure 4: "Surface Volume" tool for Calculating Volume and Area against Specified Contour

Reservoir Storage-Area-Elevation Relationship

Reservoir storage-area-elevation relationship was obtained by obtaining a series of capacities and areas at different levels of the dam. Capacities and areas obtained in the previous section are further used in excel sheet to develop relationship among them.

Height of Dams using Geo-Spatial Techniques

Ripple mass curve can be used to obtain the live storage capacity of the reservoir as well as dead storage capacity can be obtained through reservoir sedimentation studies. Got the estimated Gross Storage Capacities Domeli, Baral (Lehri) and Chamak Mira dams from Small Dams Organization, Irrigation and Power Department.

Obtained storage capacities was the first planning criteria which is used to determine appropriate dam crest height using the GIS based algorithm. As the storage-area-elevation relationship has been developed in the previous step, acquire the elevation against gross storage capacity i.e. live + dead storage. This is the spill level or Normal Conservation Level (NCL) of the reservoir.

RESULTS AND DISCUSSIONS

Reservoir Areas

Reservoir areas through GIS is a very convenient approach. Table 1 consists of the pond areas get through the reservoirs' survey by Small Dams Organization, Irrigation and Power Department and pond areas generated by ArcGIS. Pond areas at gross storage levels were estimated through GIS by using ASTER and SRTM DEMs. As ASTER data has more pixel values than the SRTM data, area generated through ASTER DEM has more values than the SRTM DEM. From the table it is clearly seen that Domeli dam has 121.47 Ha area for ASTER and 59.19 Ha for SRTM at Gross Storage Level (GSL) while its original value is 101.21 Ha. This can be noticed that SRTM DEM underestimates the pond area and this trend was observed for Domeli and Baral (Lehri) dams. In the last row, pond area calculated through reservoir survey for Chamak Mira is slightly higher than the area determined by ASTER. Trend showed that ASTER DEM calculated much closer values with respect to reported values. This shows the validation of ASTER DEM for estimation of pond areas at different levels.

Table 1: Reservoir Pond Areas at Gross Storage Levels of Dams

Dams	Gross Storage Level-GSL (m)	Reported Pond Area (Ha) - Reservoir Survey	Pond Area (Ha) In This Study	
			SRTM	ASTER
Domeli	358.23	101.21	59.19	121.47
Baral (Lehri)	292.3	68.79	47.14	70.39
Chamak Mira	926.59	15.4	7.32	12.25

Table 2 shows the percentage increase or decrease in pond areas with respect to reported values obtained from the department.

Table 2: Percentage Increase or Decrease in Reservoir Pond Areas From Reference Value

Dams	Percentage Increase or Decrease from Reference Values (%)	
	SRTM	ASTER
Domeli	-41.52	20.02
Baral (Lehri)	-31.47	2.33
Chamak Mira (Proposed)	-52.47	-20.45

Figure 5 to 7 shows the graphical representation of the reservoir areas for 4 dams at different levels from the crest level to minimum level of the dam.

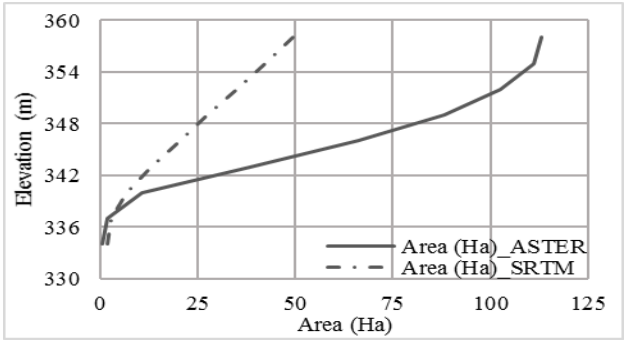


Figure 5: Graph of Reservoir Pond Areas at Different Levels for Domeli Dam

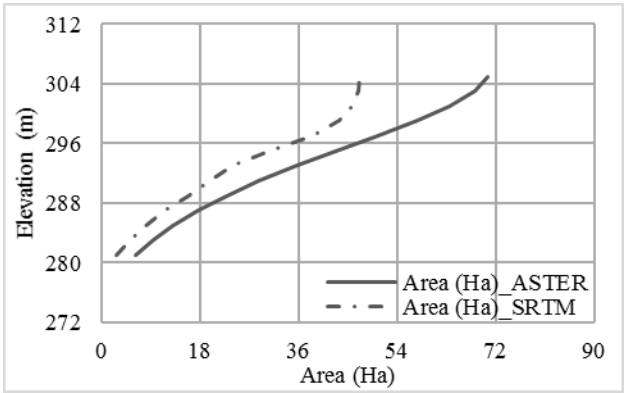


Figure 6: Graph of Reservoir Pond Areas at Different Levels for Baral (Lehri) Dam

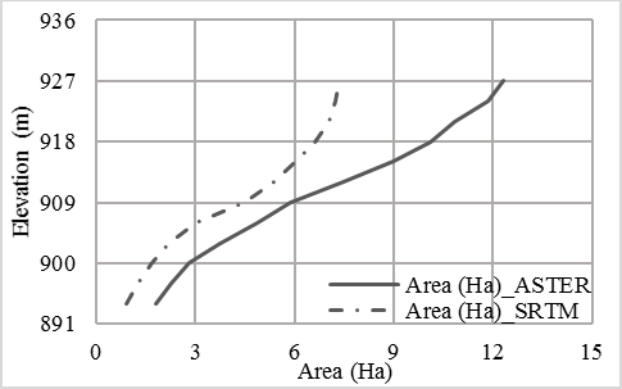


Figure 7: Graph of Reservoir Pond Areas at Different Levels for Chamak Mira Dam

Above graphs show that SRTM DEM is poor estimator of reservoir pond areas than ASTER DEM.

Reservoir Capacities

Table 3 shows the storage capacities given by Small Dam Organization, Irrigation and Power Department, and through SRTM and ASTER DEMs at a gross storage level of the reservoirs. It can be seen, ASTER DEM generated more values than SRTM DEM. It is clear from Table 4 that there is a percentage decrease from reported values in storage capacities by using SRTM DEM while percentage increase occurs in calculating the capacity by using ASTER DEM. So, it is concluded in this study that ASTER DEM calculates the reservoir storage capacities more sensitively than SRTM DEM.

Table 3: Reservoir Storage Capacities at Gross Storage Levels of Dams

Dams	Gross Storage Level-GSL (m)	Storage Capacities (MCM) Original Value	Storage Capacities (MCM) In This Study	
			SRTM	ASTER
Domeli	358.23	10.72	9.74	14.44
Baral (Lehri)	292.3	7.04	6.28	9.01
Chamak Mira	926.59	2.4	1.43	2.29

Table 4: Percentage Increase or Decrease in Gross Storage Capacities from Reference Value

Dams	Percentage Increase or Decrease from Reference Values (%)	
	SRTM	ASTER
Domeli	-9.14	34.70
Baral (Lehri)	-10.80	27.98
Chamak Mira (Proposed)	-40.42	-4.58

Figure 8 to Figure 10 shows the resulting graphs developed for capacity versus elevation from top to bottom of the dam.

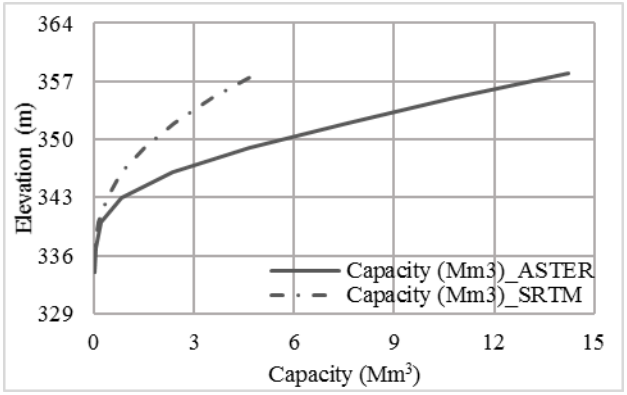


Figure 8: Graph of Reservoir Capacities at Different Levels for Domeli Dam

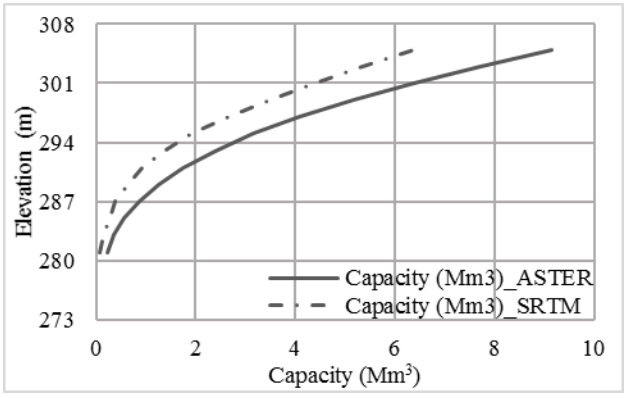


Figure 9: Graph of Reservoir Capacities at Different Levels for Baral (Lehri) Dam

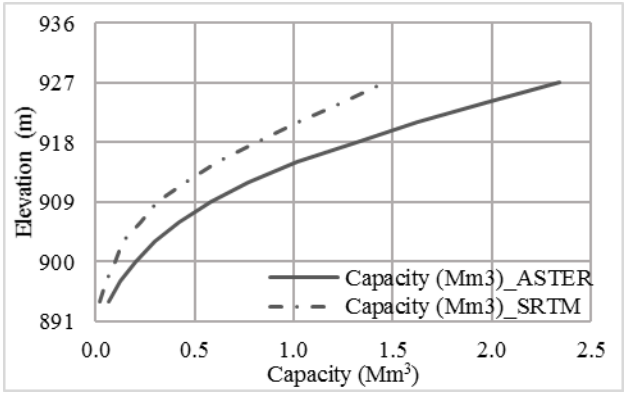
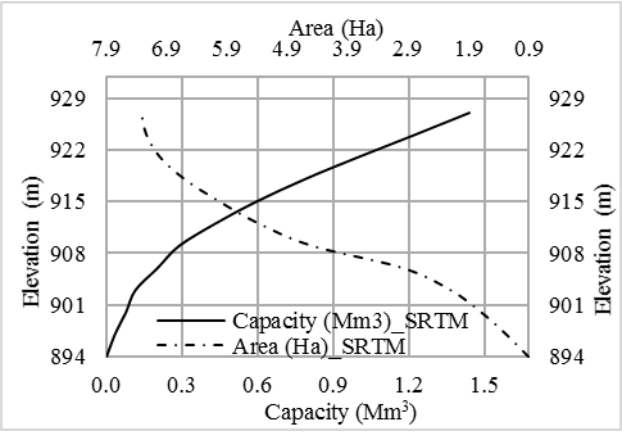


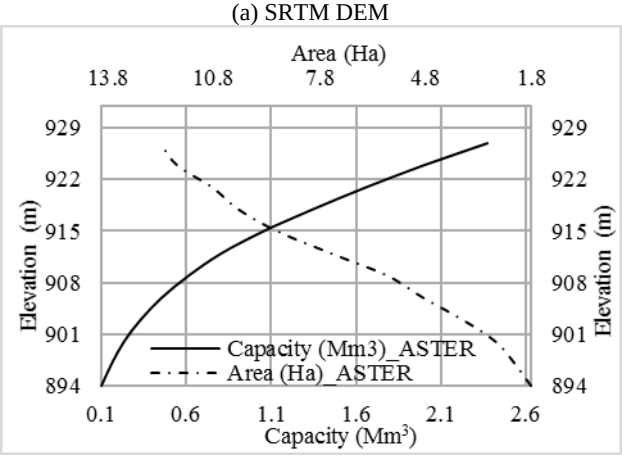
Figure 10: Graph of Reservoir Capacities at Different Levels for Chamak Mira Dam

Storage-Area-Elevation Relationship

Storage-area-elevation curves are plotted for all dams using SRTM and ASTER DEMs. Result for Chamak Mira dam is shown in Figure 11.



(a) SRTM DEM



(b) ASTER DEM

Figure 11: Storage-Area-Elevation for Chamak Mira Dam

Height of the Dam

Obtained reservoir storage-area-elevation is further used to relate the dam height against the capacity obtained from Small Dams Organization, Irrigation and Power Department. Interpolate the Gross Storage Level (GSL) from estimated gross storage capacity of the reservoir. The results for each dam is given in below Table 5. It can be seen from the table that the ASTER DEM shows less height than SRTM DEM. This is due to the large capacity value at the lower level of the dam calculated by ASTER DEM. As we discussed earlier, ASTER shows better results for estimation of capacity. So, it is recommended to use the results generated by the ASTER DEM.

Table 5: Height of Dams Corresponding to Gross Storage Capacities

Dams	Height of Dam at NCL (m) By Department	Height of Dam at NCL (m)	
		SRTM	ASTER
Domeli	358.14	359.222	345.906
Baral (Lehri)	304.80	306.340	301.957
Chamak Mira (Proposed)	926.59	930.699	927.605

CONCULSIONS

Geo-spatial techniques, i.e. GIS enables the user to develop Area-Elevation-Storage relationship without physically visiting of the proposed dam site. From the study, it is concluded that SRTM DEM underestimates the pond areas than ASTER DEM due to low pixel values. From the above discussion, it is also concluded that ASTER DEM is more suitable due to its precise inclusion of all hidden ground features as well as the height of the dam obtained from ASTER DEM proves best for any dam site because it shows much closer values to reported values of Small Dams Organization.

REFRENCES

[1] Baban, S.M.J., and K. Wan-Yusof, "*Modelling optimum sites for locating reservoirs in tropical environments,"* **Water Resources Management 17**: 1-17(2003)

[2] Yomralıoğlu, T., "*Geographic Information Systems*," **Basic Concepts and Applications, 2nd Edition Istanbul: 479s** (2002)

[3] Garbrecht, J., and L. V. Martz, "*Digital elevation model issues in water resources modeling*" **19th ESRI International user conference, Environmental Systems Research Institute, San Diego, California**: (1999)

[4] Meigh, J. "*The impact of small farm reservoirs on urban water supplies in Botswana*," **Natural Resources Forum, Vol. 1**: 71-83(1995)

[5] Nikolakopoulos, K. G. and Chrysoulakis, N., "*Updating the 1:50.000 topographic maps using ASTER and SRTM DEM: the case of Athens, Greece*," **Remote Sensing for Environmental Monitoring, GIS Applications, and Geology VI, edited by Manfred Ehlers, Ulrich Michel, Proc. of SPIE Vol. 6366 636606-1**: (2006)

[6] Jacobson, K., DEM Generation from Satellite data. Available online at: http://www.earsel.org/tutorials/Jac_03DEMGhent_red.pdf, (2003)