Creating a Digital Elevation Model (DEM) from SPOT 4 Satellite Stereo-Pair Images for Wadi Watier - Sinai Peninsula, Egypt

Moustafa El-Sammany[1], Islam H. Abou El-Magd[2], El-Sayed A. Hermas[2]

[1]Water Resources Research Institute, National Water Research Center, Egypt.
[2]National Authority for Remote Sensing and Space Sciences, Egypt.

Abstract
Flash Floods are one of the most damaging and costly natural hazards in Egypt, particularly in Sinai Peninsula and the Eastern Desert. Therefore, hydrological modelling and hydrodynamic simulations, to understand and forecast flash flood events, are highly needed. Digital Elevation Model (DEM) is the key component in such hydrological and hydrodynamic modeling, which can be used to derive a wealth of information about the morphology and drainage network of a watershed. Unfortunately, limited precise geographical and topographical information in the form of high resolution DEMs, in developing countries, constrain such advanced hydrological and hydrodynamic modelling applications. This paper describes the strategy of extracting high resolution and accurate DEMs from SPOT 4 stereo-pair satellite images. The main objective of generating the DEM was for hydrological and hydrodynamic simulation models for flash flood forecasting and as a significant component of an early warning system. The research developed a methodology for generating 10 meter resolution DEM that was calibrated against accurate land survey measurements.

Key words: DEM, SPOT Image, Flash Floods, Sinai Peninsula, Egypt.

1. INTRODUCTION

Water resource management commonly requires investigation of landscape and hydrological features such as terrain slope, drainage networks, drainage divides, and catchment boundaries. Digital Elevation Model (DEM) is very useful for many of water related applications, more effectively when integrated with hydrologic and hydrodynamic models to analyze and forecast variable scenarios for the interaction between the water, its power and motion, and the surrounding environment. For example, small scale hydrological and hydrodynamic applications require precise and high resolution of Digital Terrain Models (DTM). Conceptually, DTMs is mathematical simulations in space of heights (Baltsavias et al., 1995), which is consequently generates digital elevation model (DEM). DEM is traditionally created from topographic maps, field survey and/or photographic interpretations (Garbrecht & Martz, 1999).

Recently, a large number of satellites provided imagery with high potential applications in various geomatic fields, particularly the capability to produce data for DEMs generation (Gruen et al., 2004, Baltsavias et al., 2006). In the last few decades, pushbroom satellite (such as SPOT 4) with the motion of along track or an across track acquire stereo pair images that could be utilized to generate DEMs. Precisely, along track stereo images are acquired on the same orbital pass by a satellite which usually has more than one sensor looking at the Earth from different angles. Across track stereo images are those taken by the same sensor on multiple orbits such as SPOT 4 which was used in this research.SPOT 4 provided across-track stereo images of 10m and 20m ground resolution. DEMs with sub-pixel accuracy were extracted (Baltsavias et al., 1992, Gugan & Dowman, 1988) and used for GIS applications (Welch, 1990, Baltsavias & Stallmann, 1992).

For many remote regions within the developing countries there are missing of adequate and/or reliable topographic data. The lack of this basic information hinders the ability to apply GIS spatial analysis in many applications, such as hydrological and hydrodynamic modelling, and can be a significant gap in the required knowledge base for selection and design of new nature reserves. The digitizing of high relief mountain topographic data for producing an adequately scaled DEM, can be time consuming and expensive. This, indeed, challenged scientists and researchers to explore the generation of DEMs from remotely sensed data. The advantages of extracting DEMs from satellite images are: 1) the wide coverage of the scene rather restricted area, 2) the digital data that ease the automation process, and 3) regular temporal coverage of satellite sensors that made it easier to get in hands. Despite of these advantages, generating DEMs from satellite images suffers from shortcomings – accuracy, coverage and computation time (Lee et al., 2000).

DEM is offering the virtual reality of the earth features and mitigation measures to most of the natural hazards such as flash floods. Nevertheless, DEM accuracy still plays a significant role in such applications. DEM accuracy is usually quantified using the RMSE statistically. Sources of DEM errors have been described by Burrough (1986), Wise (1998) and Heuvelink (1998). For example, DEM resolution has been shown a direct impact on the hydrological and hydrodynamic modeling for a flash flood event forecasting (Wolock & Price, 1994, Zhang & Montgomery, 1994, Band & Moore, 1995, Quinn et al., 1995). Previous literatures have shown that the grid cell size of a raster DEM significantly affects the derived terrain attributes (Kienzle, 2004). The impact of grid cell resolution on terrain parameters has been related to both topographic complexity and the nature of the algorithms used to compute terrain attributes.

In this paper, due to the lack of accurate and reliable DEMs for Wadi Watier, which can be used for hydrological and hydrodynamic simulations for flash flood forecasting, an approach was adopted to check the feasibility to generate a DEM at 10m resolution from SPOT 4 stereo-pair images.Table 1: Selected water discharge stations

2. STUDY AREA

Wadi Watier is located in the south eastern part of Sinai Peninsula, Egypt between 33° 50′ E to 34° 40′ E and 28° 50′ N to 29° 30′ N as shown in Figure 1. The study area is a part of the arid climate, where the rates of evaporation exceed the rates of precipitations. The summer is hot and the winter displays lower temperatures. The majority of the precipitation events occur in autumn and winter seasons. However the rainfall is limited, the total accumulated rainfall in few consecutive hours might create potential flash flood hazards. The area is classified as rugged mountainous topography constitutes the drainage basin of Wadi Watier and end up with a delta at Nuweiba City on Gulf of Aqaba. This delta is almost flat with infrastructures and development areas such as tourism hubs, commercial harbour, oil tanks and other human activities.

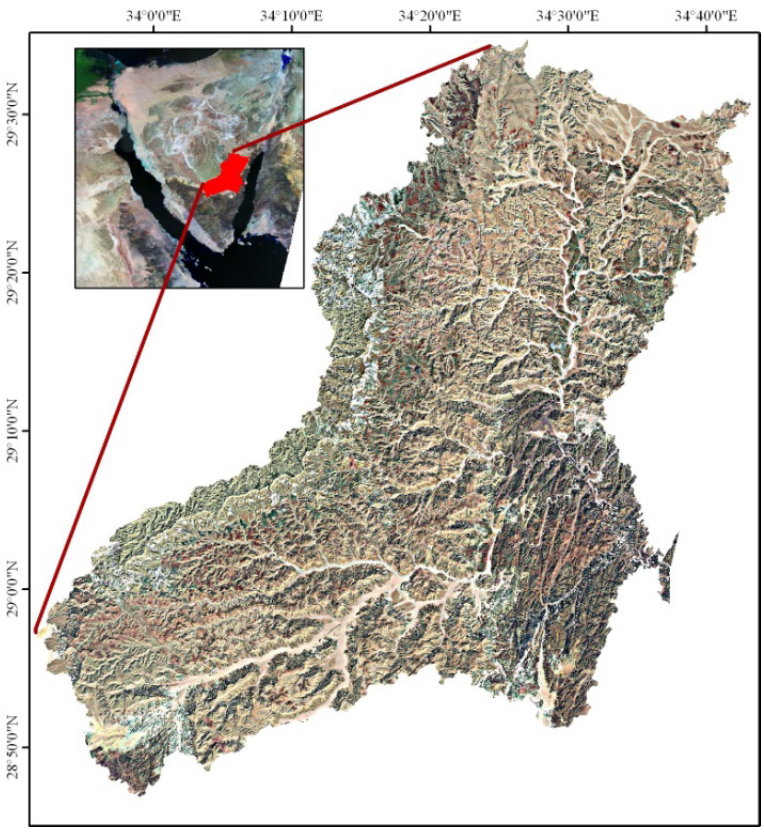


Figure 1: Catchment of Wadi Watier (the study area)

3. MATERIALS AND METHODS

The following data were used and processed to generate a DEM for Wadi Watier:

- SPOT 4 stereo-pair images that were acquired in January 2008. Table 1 lists the properties of the selected stereo-pair images. The reason behind using SPOT 4 images is the availability of receiving station at the National Authority for Remote Sensing and Space Sciences (NARSS) that allow receiving of the satellite images.
- Topographic maps at scale 1:50,000 together with the stream network which were used for obtaining and optimizing the Ground Control Points (GCPs).
- Real Time Kinematic (RTK) survey data which yield nearly absolute positions (sub-centimetres position accuracy). Theses points were used as GCPs to improve the accuracy of X, Y, and Z positions of the resulted DEM.

Table 1: List of the characteristics of the selected stereo-pair images

Item	Left Image	Right Image
K/ J	120/292	119/292
Scene size (Pixels)	7177 * 6008	6679 * 5997
Viewing angle	-21.3	+14.1
Acquisition Date	24/01/2008	25/01/2008
Acquisition Time	10:38 am	10:19 am

The process of generating a DEM is quite complex and requires more accuracy in the data handling and input. The conceptual framework model of the methodology used in generating the DEM from stereo-pair satellite images is shown in Figure 2.

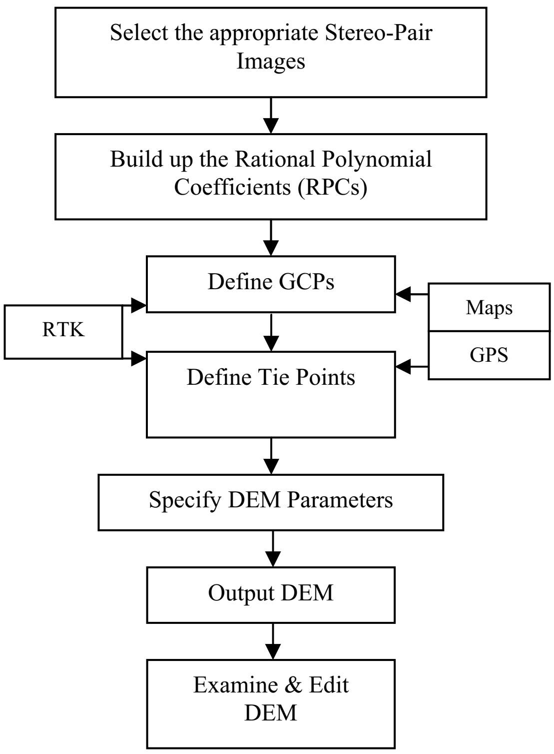


Figure 2: Conceptual framework model of the methodology used for extracting the DEM

3.1. Select of the Stereo-Pair Images

Initially, selection of the stereo-pair images is a fundamental step for both matching the coverage area and the accuracy. The key selection criteria of the stereo-pair images are:

a) **Base Height Ratio (B/H)**
The B/H ratio between the observation base B (distance between two satellite positions, variable up to 850 km) and the height H (satellite elevation, about 832 km) can be estimated using two values of the angle of incidence as indicated in equation (1) and shown in Figure 3.

$$B/H = \tan\alpha g + \tan\alpha d \quad (1)$$

Because of the not fixed view direction across the orbit, the base-height relation can reach 1.0, which has a direct implication on the matching accuracy. This ratio is optimal for open and flat area (Borner et al., 1997). However, in other topographical landscapes, it is tested that, if the value of the B/H ratio is around 0.8, the stereo-pairs are applicable for all applications, however if it went down to 0.6 they are applicable for digital processing (Gugan & Dowman, 1988, SPOT, 2006). In this research the B/H ratio of the selected stereo pairs was 0.69 which is applicable for digital processing.

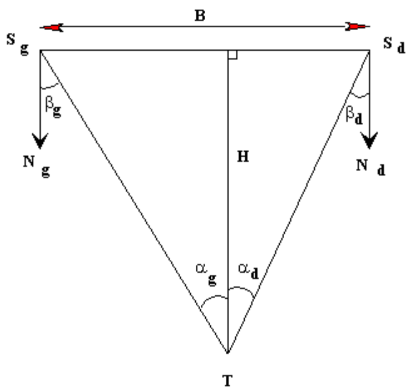


Figure 3: Geometrical view of the stereo-pair images

Where,
α = angle of incidence; β = viewing angle; T = point on ground; N = nadir;
S = view vertex; B = view base; H = view height

b) Time Lag
It is important that the time lag between the two images to be as short as possible to avoid any excessive radiometric differences that reduce the accuracy. The time lag of the selected pairs in this research was just one day that maintained minimal radiometric differences.

c) Degree of Overlap
Normally, the common part between the two stereo-pairs depends particularly on the difference in orientation of the two images and always evaluated by the geographic coordinates of the two scenes. In this research the overlap area between the two selected pairs was up to 75%.

3.2. Build Rational Polynomial Coefficients (RPCs)

First of all, the generation of a DEM from stereo-pair images requires rational polynomial coefficients (RPCs) positioning from the Pushbroom satellite sensor. These RPCs would be used to generate the tie points and calculate the stereo-pair images relationship. Therefore, computing the RPCs is essential to construct sensor geometry, where the object point, perspective center, and image point are all on the same space line. Since SPOT 4 images have no built in RPCs, so it is essential to create RPCs coefficients for both left and right scenes. The technique involves a series of transformations involving pixel, camera, image-space, and ground coordinate systems. Building RPCs for SPOT 4 images required accurately few parameters which are:

a) Principal Point Coordinates; which is assumed to be the centre of the image and were set to be 0.0, 0.0.
b) Focal Length which is the orthogonal distance from the perspective centre to the image focal plane, which is 1082.
c) Pixel sizes which correspond to the CCD cells (detectors of the camera that captured the images). Typically, aerial digital cameras and satellite pushbroom sensors have square pixels, which means

that the pixel size is the same in the x and y dimension; the pixel size in millimetre is defined at 0.013.

d) Incidence angles; It is quite important for pushbroom sensors to know the across track incidence angle in degrees which known at the angle between the vertical position of the satellite and its side-viewing direction when the sensor is scanning along the side. This angle has a negative value if viewing direction is eastward to the ground point corresponding to the centre of the scene. It is set to -21.3 for the left scene and +14.1 for the right scene.

e) Build exterior orientation; which is the process of obtaining GCPs to compute the exterior orientation parameters of XS, YS, ZS, Omega, Phi, and Kappa (ENVI, 2006). This important to determine the Root Mean Square Error (RMSE) for each GCP, and then the total cumulative RMSE. The total obtained RMSE, in the pixel size and for this particular step, was 0.04604572 in X axis and 0.03534746 in Y axis.

3.3. Define the Ground Control Points (GCPs)

Ground control points (GCPs) were determined from maps and handheld GPS to georeference the stereo-pair images. The obtained RMSE was varied from 42cm to 35cm with an average of 38.5cm in the X&Y. However, the RMSE of the Z was varied from 108 cm to 62cm with an average of 85cm. When RTK positions were used, in the Delta of Wadi Watier and the end part of the main road, the accuracy was improved to be 20cm in X & Y plane and 28cm in the Z direction.

3.4. Collecting Tie Points for Creating Epipolar

Generating epipolar geometry between the selected stereo-pair images is required for creating the DEM, which based on tie points between the two scenes. Viewer to viewer approach was used to obtain these tie points, in which 27 tie points were selected along the two scenes as shown in Figure 4. Then automatic image matching technique was used to extract the elevation for matching pixels within the respective datasets based on mathematical model that was generated from the satellite orbit data associated with each scene and the tie points. This model was then used to create an epipolar projection for the selected SPOT 4 stereo-pair images. The epipolar projection removes the y-parallax between left and right stereo-pair images which produced the DEM for the area of overlap between the images. The generated epipolar images remove one dimension of variability, thus greatly increasing the speed of image-matching processing as well as the reliability of the matching results. Figure 5 illustrates the left and right epipolar images that have been created.

3.5. Setting up the DEM Parameters

The basic parameters of output projection were determined to Universal Transverse Mercator (UTM, Z 36N), the horizontal datum of WGS84, the measuring units are in meters and the cell size is the same as the SPOT image at 10x10 meter. However, the correlation coefficient threshold used to determine whether or not the points within the Moving Windows are in a good match is considered to be between 0.65 and 0.85 and in this research 0.7 was used as the minimum correlation in a moving window of 5 by 5 (ENVI, 2006). Background colour was set to be 0 as a black colour background. But, edge trimming of the coast line was used beyond the study area.

3.6. Extracting the DEM

Once steps from one to six are carried out and the parameters of the output DEM are set up, the final step of extracting the DEM is conducted. This is the accumulation of the above steps of creating the epipolar stereo-pair image, identifying the GCPs with the DEM parameters which would produce the final output product of the DEM. It is an automatic step that has been generated using ENVI package, however, the algorithm of creating the DEM is the well known method of triangulation discussed in the literatures (e.g. Raper, 1989, Raper & Kelk, 1991, Turner, 1991).

3.7. Examine and Edit the DEM

Sometimes the triangulation algorithm produces anomalies either due to data missing, mismatched values or correlation in altitudes. Therefore, it is important to examine the resulted DEM against other data sources to ensure the accuracy and harmony of the simulation models. Thus, rectifying any of these anomalies and fine tuning of the DEM is necessary. In our study case, editing the resulted DEM was done based on the field survey data obtained by RTK survey which was conducted in the field for the delta of Wadi Watier and a part of the main wadi as shown in Figure 6. The final rectified DEM is shown in Figure 7.

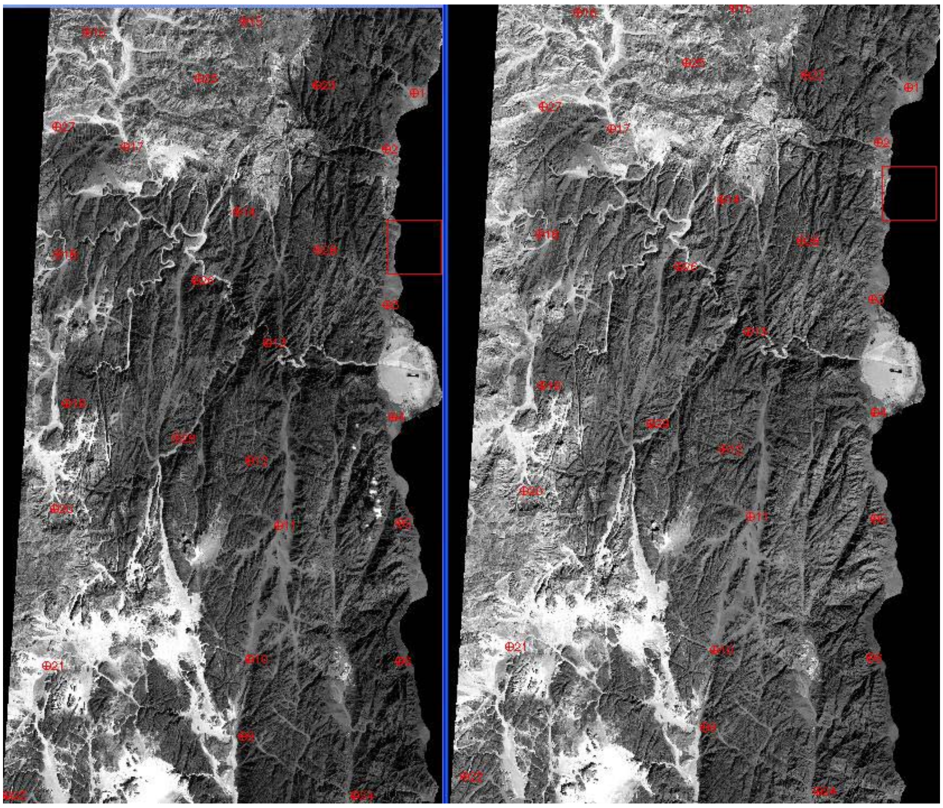
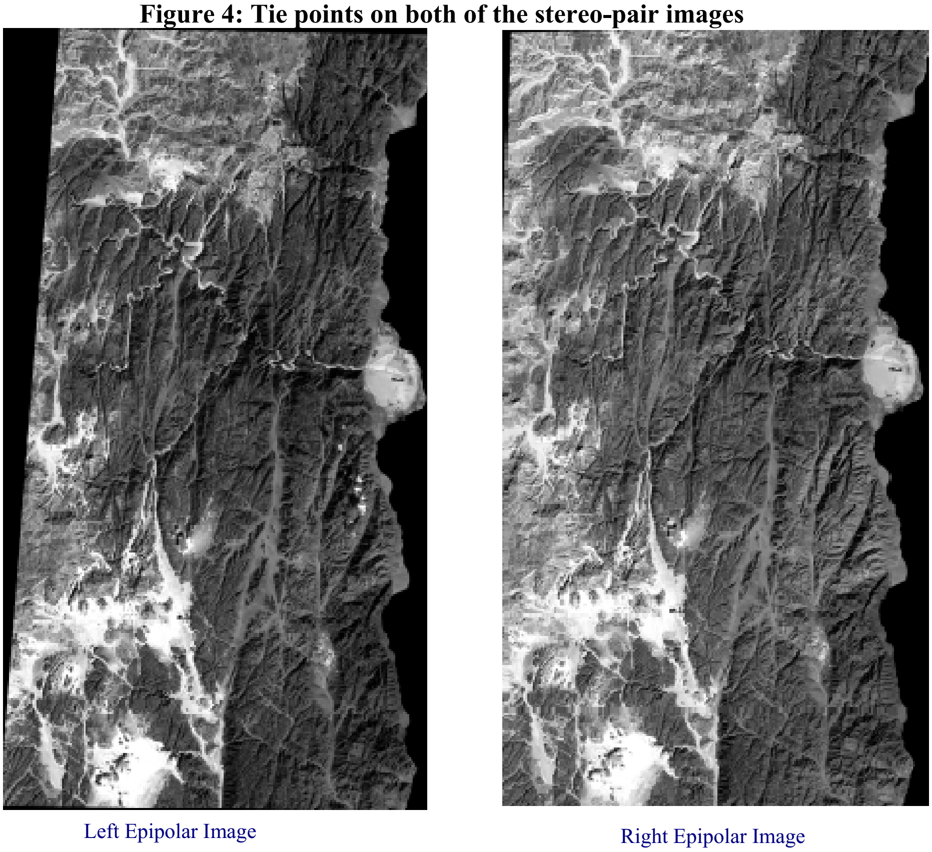


Figure 4: Tie points on both of the stereo-pair images



Left Epipolar Image Right Epipolar Image

Figure 5: The resulted epipolar images

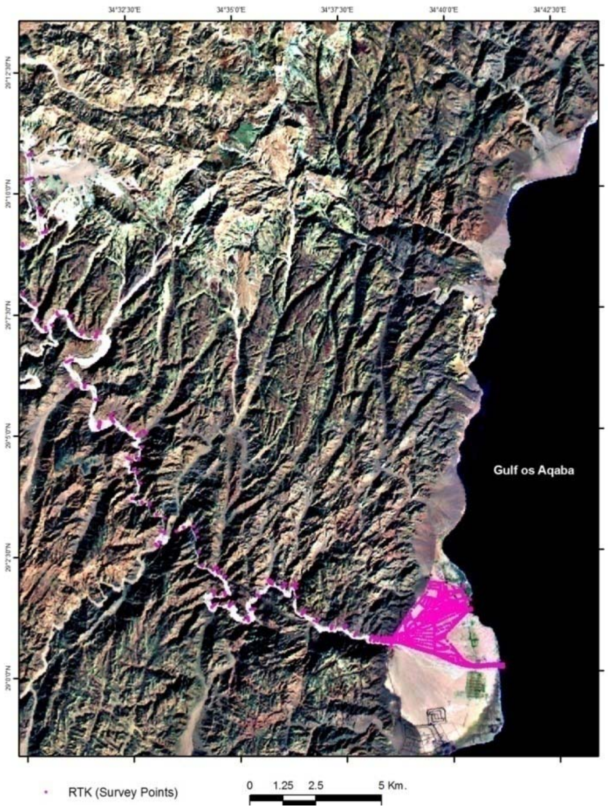


Figure 6: RTK survey data points for the delta and the main wadi

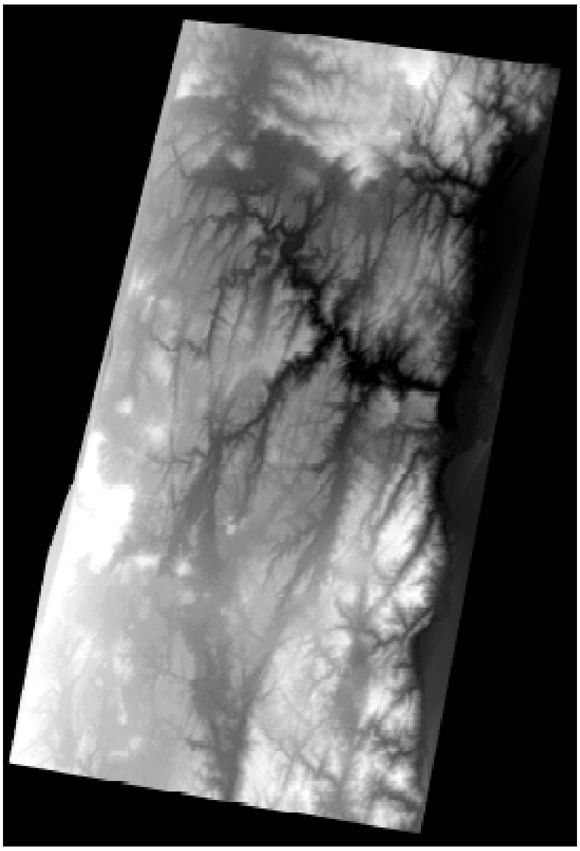


Figure 7: The resulted DEM

4. RESULTS

In this research it was attempt to create a high resolution DEM (i.e. 10 by 10 meter grid resolution). The above described methodology aided producing 60×60 km2 DEM of Wadi Watier (See figures 5 and 6). Initially, GCPs were collected using topographic maps supported by the coarse 90m resolution DEM from Shuttle Radar Topography Mission (SRTM) and handheld GPS receivers whose positioning accuracy was between 1-3 meters. The complexity of the process of creating the DEM cumulatively generates errors at several stages. A measure of horizontal displacement was calculated using the selected GCP's (n = 27) before the actual extraction process based upon the RMS residual error, estimated at 24 m, for the actual versus estimated x, y coordinates of these GCP's. Residual error in this case refers to the mean difference between the conventionally produced and the stereo-imagery produced DEM. Upon the completion of the extraction of the DEM, the difference in actual elevation, particularly in the delta of Wadi Watier, was calculated as a RMSE of about 11 m. The 27 GCP's were located within the extracted overlap between the stereo-pairs, and were compared with pixels which were successfully classified by the extraction matching procedure.

Once extra accurate points obtained the RMSE matrix of the X & Y displacement shows a realistic accuracy for both directions. The X shift was about 40cm however; Y was about 30cm with an average of 35cm in the horizontal dimension, which is more than adequate for the hydrologic and hydraulic applications. However, the maximum accuracy of the Z at the mountainous area was about 108cm and the minimum was 62cm with an average of 85cm. Nevertheless, this level of accuracy was about the double of the horizontal accuracy. The accuracy of Z was not optimistic in the delta area where the coastline that should be at 0 level illustrated higher elevation of up to 17 meter. Cross section of the delta of Wadi Watier showed no consistency of topography (i.e. z values) in comparison with the elevation from coarse DEM of the SRTM, or in reflexion of reality as shown in Figure 8. These high discrepancies in the accuracy of z values are due to the low level of accuracy of the GCPs in the delta.

Therefore, an enhancement of the DEM accuracy within the delta is necessary. The resulted DEM was rectified using the integration of the high accuracy RTK topographic survey data, which was conducted for the delta of Wadi Watier and a part of the main wadi, with the triangulation process of the SPOT4 images to generate the final DEM. The cross section of the delta after this rectification showed a consistent topography level with nearly 0 level at the coast line as shown in Figure 9. Moreover, the updated GCPs of the final DEM show an improved accuracy in both of the delta and mountainous terrain. So, it is clearly shown that the accuracy of the final DEM was improved once accurate points from the field were used.

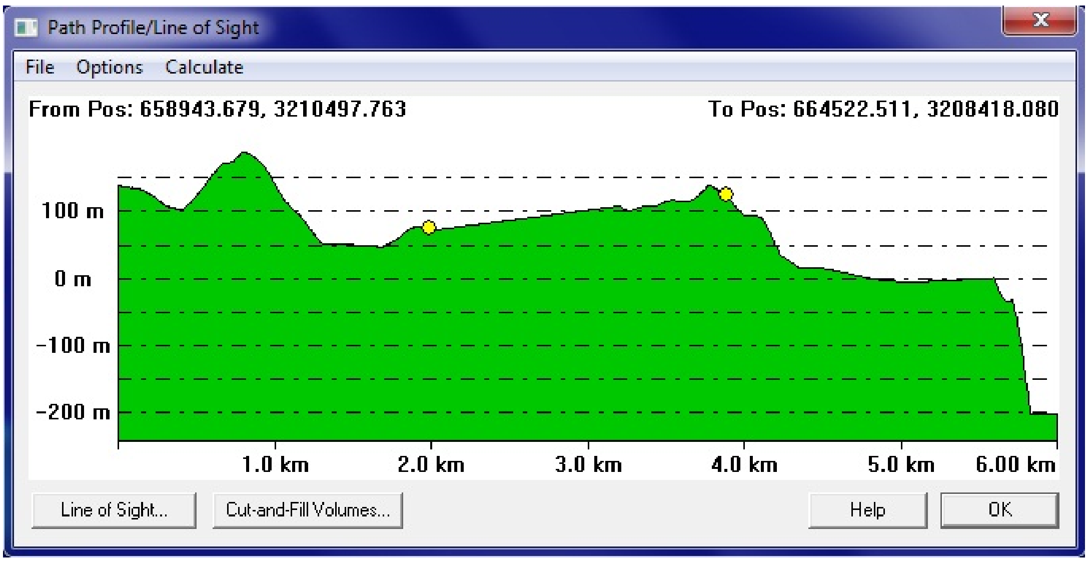


Figure 8: Longitudinal section of the delta of Wadi Watier as the first resulted DEM

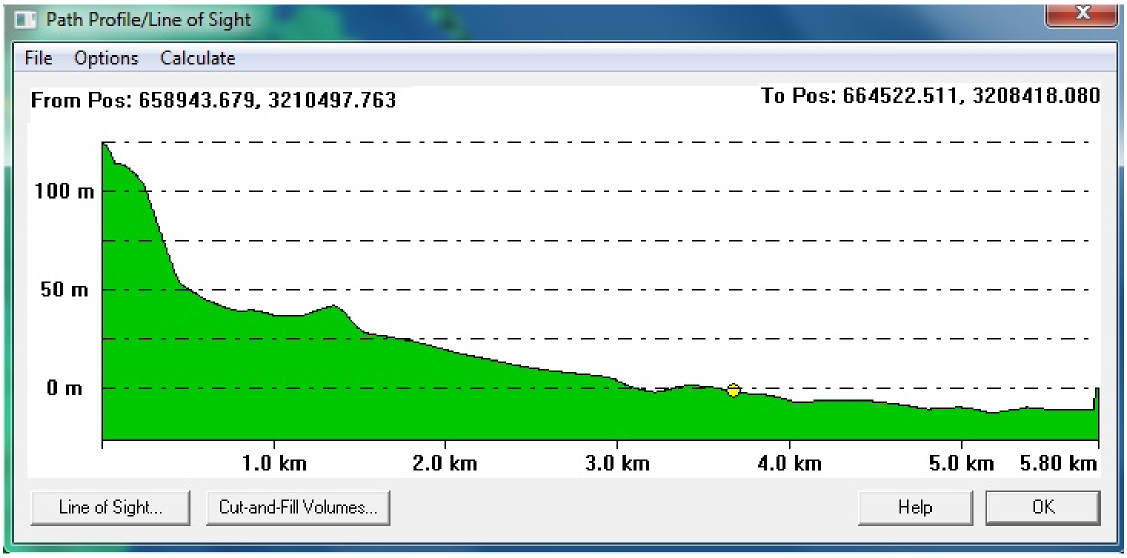


Figure 9: Longitudinal section of the delta of Wadi Watier after rectifying the DEM

5. DISCUSSION

Accuracies attained in this study did not approach the precise and highly accurate results normally associated with the automated DEM extraction and orthoimage generation process, when based upon stereo SPOT imagery. For example, under nearly ideal circumstances, a large-scale mapping project in the rugged mountainous areas of Sinai Peninsula reported sub-pixel accuracies of ± 3 to 4 m. However, an assessment of the suitability of SPOT 4 stereo data for DEM generation proved accuracy of the Z to about 85cm in the mountainous area and up to 11m in the flat area of the delta. Although the elevation accuracy in the mountains area was desirable, the two and three-dimensional cross sections of the delta of Wadi Watier provided undesirable accuracy level. This initiated for the obtaining GCPs using high level of accuracy using RTK survey equipments that reach few millimetres in accuracy. When integrating in the process of creating the DEM in the nearly flat area of the delta of Wadi Watier and the RTK survey data, the accuracy was improved to be 20-80cm in the delta. Therefore, the extracted DEM proved extremely useful as a terrain base for subsequent orthorectification of the SPOT 4 stereo-pair images. Some degree of error is likely to be propagated from the DEM through to the orthorectification process and GCPs, DEM accuracy proved sufficient to remove the major sources of distortion and displacement associated with the terrain surface. The ability to use an SPOT 4 stereo-pair images to extract DEM allowed for a complete remote sensing based solution to the production of a satellite ortho-map image and base of topographical terrain models particularly in developing countries where there are gaps in such data availability.

Overall, the resulted DEM of this study showed that remote sensing-based DEM extraction can provide essential geographic information and a basis for analysis of rugged mountainous areas, especially in the absence of such basic topographical data. Advantages attributed to this methodology include: cost-effectiveness, timeliness, and equal access to high spatial resolution data. This methodology can quickly provide a basis for building an accurate and powerful GIS analysis for hydrological, hydrodynamic applications and/or any other earth surface processing applications.

6. CONCLUSION AND RECOMMENDATIONS

It could be concluded that the Digital Elevation Model (DEM) is representing the reality of the earth's terrain, which becomes nowadays highly demanded from engineers, scientists and researchers in many of the applications particularly hydrological and hydrodynamic applications. DEMs are effectively offer sensible problem-solution results when integrated with other models. The accuracy and time reliability of acquiring such a DEM is becoming a hot issue, particularly in developing countries where there is a lack in the availability and reliability of accurate DEMs. The development of space science and satellite sensors offered new techniques to capture the earth's terrain, for 3-dimenions, from stereo-

pair images. This, indeed, offered a time reliability and variable resolution to generate DEMs on a regular basis. Nevertheless, the accuracy is still a challenge in generating a DEM. This research demonstrated the extraction of a 10m resolution DEM from SPOT 4 stereo-pair images and that is not available before for hydrological and hydrodynamic modelling in Sinai, Egypt.
The paper outlined the methodology of extracting the DEM for the catchment area of Wadi Watier from SPOT 4 satellite stereo-pair images. Also, it could be recommended that the generation of an accurate DEM at a cost effective and timely manner in remote inaccessible areas, in developing countries where there is no available topographic data, should take into consideration the following points:

- Use the Pushbroom satellite images in the form of stereo-pair images which are proved to be an effective source of information for the extraction of DEM,
- Identify appropriate time interval between the two images to be less than 28 days to minimize the radiometric differences,
- Implement RTK survey to obtain highly accurate GCPs, which will significantly improve both of 2-dimensions and 3-dimensions data.

7. ACKNOWLEDGMENT

The authors gratefully acknowledge all the facilities, resources and support offered by Water Resources Research Institute (WRRI), National Water Research Center (NWRC), Egypt and the National Authority for Remote Sensing and Space Sciences (NARSS), Egypt, to conduct this research.

8. REFERENCES

1. Baltsavias E. P., Stallmann D. (1992), *From Satellite Images to GIS with Digital Photogrammetry Using SPOT Data*, In Proc. of EGIS 92, 23-26. March, Munich, Germany, Vol. 2, pp. 945 - 946.
2. Baltsavias, E. P., Gruen , A. and Meister, M. (1992), *DOW-A system for generation of digital orthophotos from aerial and SPOT images,* EARSeL Adv. Remote Sensing **1** 3 (1992), pp. 105–112.
3. Baltsavias, E. P., Mason, S. and Stallmann, D. (1995), *Use of DTMs/DSMs and Orthoimages to Support Building Extraction*, In: A. Gr¨un, O. K¨ubler and P. Agouris (eds), Automatic Extraction of Man-Made Objects from Aerial and Space Images, Birkh¨auser, Basel, pp. 199–210.
4. Baltsavias, E. P., Gruen A., Küchler, M., Thee P., Waser L.T. and Zhang L. (2006), *Tree height measurements and tree growth estimation in a mire environment using digital surface models,* Workshop on 3D Remote Sensing in Forestry, 14th . 15th Feb. 2006, Vienna . Session 2a.
5. Band, L. and Moore, I. (1995), *Scale: Landscape Attributes And Geographical Information Systems,* Hydrol. Processes, 9, 401–422.
6. Borner, A., Hilliger, E., Reulke, R. (1997), *The Optimization of the Stereo Angle of CCD-Line-Sensors with end to end Simulation Systems,* Sensors and Mapping from Space“, University of Hannover.
7. Burrough, P. A. (1986), *Principles of Geographical Information Systems for Land Resources Assessment,* 194 pp., Oxford University Press, New York, NY.
8. Environment for Visualizing Images (ENVI), (2006), *ENVI Tutorials: The DEM extraction module.*
9. Garbrecht, J., and Martz, L. W. (1999), *TOPAZ: An Automated Digital Landscape Analysis Tool for Topographic Evaluation, Drainage Identification, Watershed Segmentation and Subcatchment Parameterization; TOPAZ Overview,* U.S. Department of Agriculture, Agricultural Research Service, Grazinglands Research Laboratory, El Reno, Oklahoma, USDA, ARS Publication No. GRL 99-1, 26 pp., April 1999.
10. Gruen, A. Baltsavias, E. P., and Meister, M. (1994), *Digitale Orthobilder and Terrain-Visualisierung (in German),* Oesterr. Z. Vermessung Geoinformation **82** 3, pp. 220–232.
11. Gruen, A., Remondino, F. and Zhang, L. (2004), *The Bamiyan Valley: Landscape Modeling for Cultural Heritage Visualization and Documentation. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences,* Vol. XXXVI-5/W1. International Workshop on Processing and Visualization using High Resolution Imagery, Pitsanulok, Thailand.
12. Gugan, D.G. and Dowman, I.J. (1988), *Accuracy and Completeness of Topographic Mapping from SPOT Imagery,* Photogrammetric Record, 12 (72), pp.787-796.
13. Heuvelink, G. B. M. (1998), *Error Propagation in Environmental Modeling with GIS,* 127 pp., Taylor & Francis Ltd, London, England.

14. Kienzle, S. (2004), *the effect of DEM raster resolution on first order, second order and compound terrain derivatives,* Transactions in GIS, 8(1), 83-111.
15. Lee, H., Kim, T., Park, W., and Kim T. (2000), *The development of an accurate DEM extraction strategy for satellite Image pairs using epipolarity of linear pushbroom sensors and Intelligent interpolation scheme,* International Archives of Photogrammetry and Remote Sensing, Vol. XXXIII, Part B3, Amsterdam, Netherland.
16. Quinn, P., Beven, K., and Lamb, R. (1995), *The ln(a/TanB) index: how to calculate it and how to use it 15 within the TOPMODEL framework,* Hydrol. Processes, 9, 161–182.
17. Raper, J. F. (1989), *Three Dimensional applications in geographical information systems,* London: Taylor and Francis.
18. Raper, J. F. and Kelk, B. (1991), *Three dimensional GIS,* In Maguire, D Goodchild, M. and Rhind, D. (eds) Geographic Information Systems: Principles and Applications, Harlow: Longman, pp299-317.
19. SPOT (2006), Spot Manual and data user handbook.
20. Turner, K. (1991), *Three dimensional modelling with geoscientific information systems*, Dordrecht: Kluwer.
21. Welch, R. (1990), *3-D terrain modeling for GIS applications,* GIS World 3 (5), 26–30.
22. Wise, S. (1998), *The Effect of GIS Interpolation Errors on the Use of Digital Elevation Models in Geomorphology, in: Landform Monitoring, Modeling and Analysis,* edited by: Lane, S. N., Richards, K. S., and Chandler, J. H., p. 300, John Wiley and Sons.
23. Wolock, D. and Price, C. (1994), *Effects of digital elevation model map scale and data resolution on a topography-based watershed model,* Water Resour. Res., 30(11), 3041–3052.
24. Zhang, W. and Montgomery, D. (1994), *Digital elevation model grid size, landscape representation and hydrologic simulations,* Water Resources Research, 30(4), 1019–1028.

AUTHORS BIOGRAPHY

Moustafa S. EL-Sammany joined the Nile Research Institute, National Water Research Center, in 1991, as Assistant Researcher. In 1995, He got his M.Sc. from Irrigation and Hydraulics Dept., Faculty of Engineering, Cairo University, and he was promoted to be Research Assistant. In 2002, He got his Ph.D. from Irrigation and Hydraulics Dept., Faculty of Engineering, Cairo University, and he was promoted to be Researcher. In 2004, EL-Sammany joined Water Resources Research Institute and got the responsibilities of many technical projects. The last position was the Technical and Regional Coordinator of FlaFloM project which was co-funded by the European Commission under the LIFE Third Countries Fund (project number LIFE/TCY/ET/000232) from January 2007 to December 2009.

Islam Abou El-Magd is an Assistant Professor working for the National Authority for Remote Sensing and Space Sciences in the Environmental Studies Department. Dr. Abou El-Magd has just over 20 years experience in remote sensing and GIS applications and modelling in environmental management and water resources management. He has obtained his Ph.D. from the school of Civil Engineering and the Environment, University of Southampton, UK on the application of GIS and remote sensing in irrigation water management. He is also a Chartered Scientist from the Council of Science, UK and Chartered Environmentalist from the Council of Environment, UK. He is a peer reviewer to many of the international journals in these fields.

ElSayed Hermas is research scientists at the Division of the Geology and Mineral Resources, the National Authority for Remote Sensing and Space Sciences, Cairo, Egypt. Dr. Hermas has broad experiences in the field of remote sensing and GIS applications in geomorphology and environmental sciences. Dr. Hermas had obtained his PhD from Texas A&M University, College Station, Texas in the application of remote sensing and GIS for studying the dynamic of earth surface processes. The current research focus of Dr. Hermas is the application of innovative techniques for understanding and modelling the fluvial and aeolian surface processes in the arid lands