Accuracy and relevance of Digital Elevation Models for Geomatics applications - A case study of Makkah Municipality, Saudi Arabia

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ABSTRACT

Several geomatics applications depend on utilizing Digital Elevation Models (DEMs), such as geomorphologic applications of watershed management and flood hazard determination. Additionally, DEMs play a crucial role in geodetic applications, particularly for the determination of topographic effects in quasi-geoid modelling. This study aims to investigate the accuracy performance of several global and national DEMs in order to define the suitability of them in engineering applications in Kingdom of Saudi Arabia (KSA). Two global DEMs have been exploited, namely the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and the Shuttle Radar Topographic Mission (SRTM3), along with two national DEMs, belong to the center of research excellence in Hajj and Omrah, with 5 and 10 meter resolution. A dataset of 200 first-order Global Positioning System (GPS) ground control points, that covers the Makkah (Mecca) metropolitan area in the western region of KSA, has been compiled and employed to judge the accuracy of all DEMs in a Geographic Information Systems (GIS) environment. The attained results showed that the 5-meter resolution national DEM is the most accurate one, that produces mean height difference and standard deviations equal 0.01 ± 2.95 m respectively. That national DEM is more accurate by factors of 3 and 2 over the global ASTER and SRTM3 DEMs respectively. Guidelines have been drawn to apply each DEM in geodetic, topographic mapping, and geomorphologic studies in KSA.

Keywords: DEM, Accuracy analysis, GPS controls, Geomatics activities, Saudi Arabia.

1. Introduction

Digital Elevation Models (DEMs) are essential for both geodetic and geomorphologic applications. DEMs are utilized in gravity data processing and geoid model development, particularly for the computation of terrain corrections at observed terrestrial gravity data, and for downward continuation computations. Watersheds management and flood hazard assessment are typical morphometry and geomorphologic activities utilize DEMs (Subyani et al. 2010, and Mendas 2010). In the last few decades, several global DEMs have been compiled and released. This study aims to investigate the accuracy

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performance of several global and national DEMs in order to define the suitability of them in engineering and geomatics applications in Kingdom of Saudi Arabia (KSA).

2. Study Area

Makkah city is located in the south-west part of KSA, about 80 Km east of the Red Sea (Figure.1). It extends from 39° $35^{'}$ E to 40° $02^{'}$ E, and from 21° $09^{'}$ N to 21° $37^{'}$ N. The area of the metropolitan region (the study area) equals 1593 square kilometers. The topography of Makkah is complex in nature, and several mountainous areas exist inside its metropolitan area.
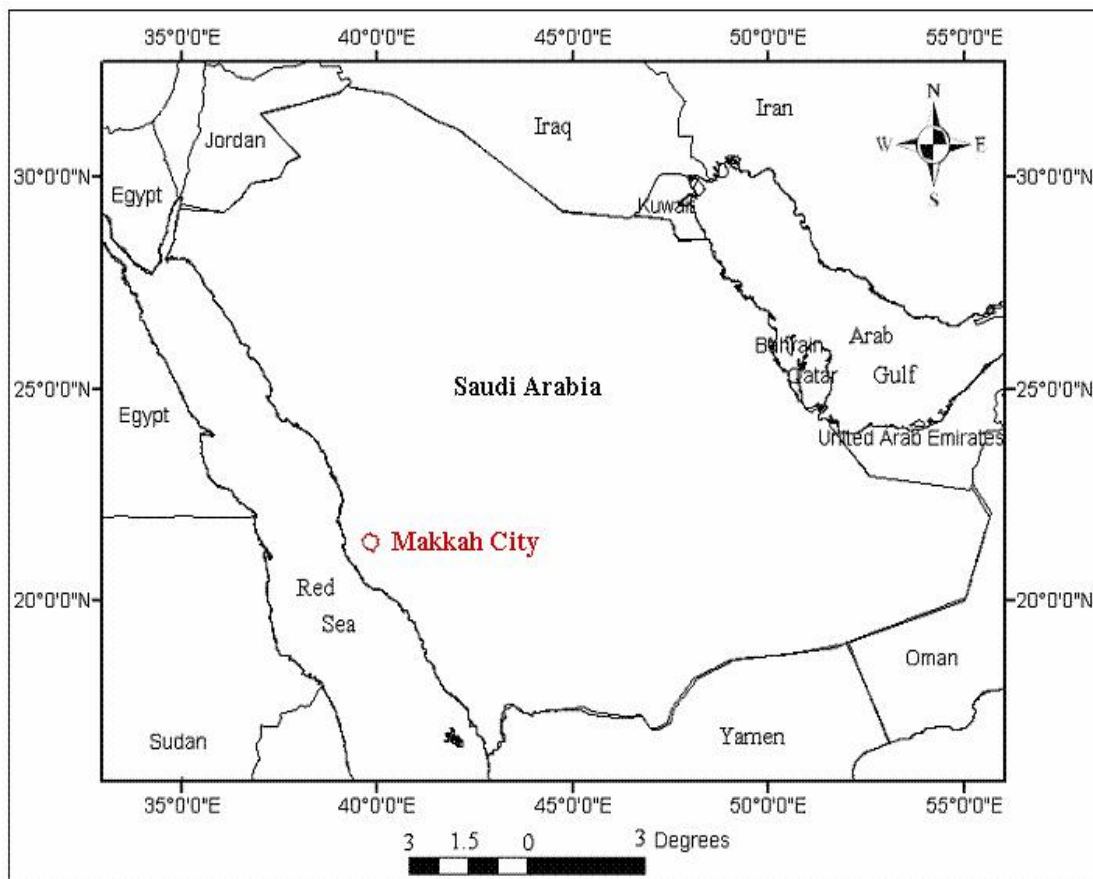

Figure 1: Study Area

2.1 Digital Elevation Models (DEMs)

Two global DEMs, along with two KSA national DEMs, have been exploited in this research, and they will be briefly described.

2.2 Global DEMs

The Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA) have jointly released Version 1 of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM). ASTER horizontal resolution equals 1 arc second, that is 30 meters approximately, and it is available free of charge. ASTER DEM has been utilized in many research studies (Dowerah 2010, Abdeen et al. 2009, and Mousavi et al. 2007). The window of the ASTER DEM corresponding to Makkah metropolitan area has been downloaded (http://www.gdem.aster.ersdac.or.jp/) and has been considered in this study (Figure. 2).
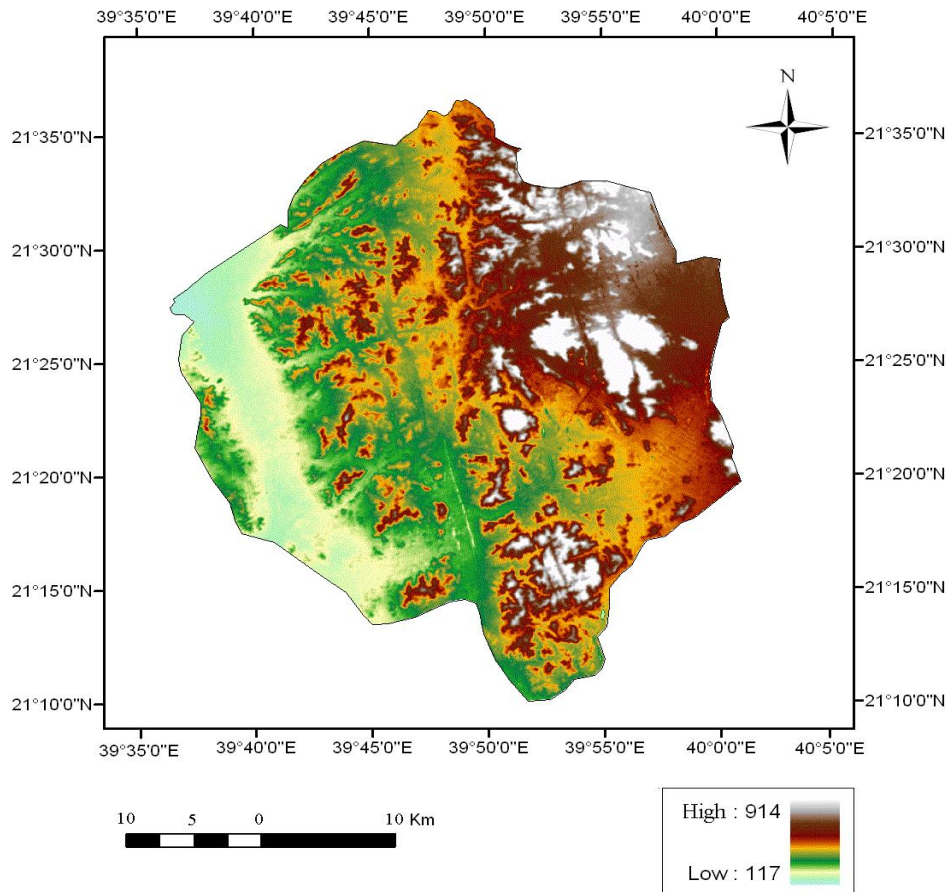
Figure 2: ASTER DEM for Makkah

The Shuttle Radar Topography Mission (SRTM) global DTM is a joint project between the U.S. National Imagery and Mapping Agency (NIMA) and the National Aeronautics and Space Administration (NASA). A 90 meters (3 arc seconds) SRTM DTM for many parts of the world has been compiled and released (Called SRTM3) and being available free of charge. SRTM3 has been used in geoid   odeling for several regions, particularly

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for topographic and downward continuation corrections (Kiamehr and Sjöberg 2005) and also for morphometric studies (Bubenzer and Bolten 2008, and El Bastawesy 2007). The window of the SRTM DEM corresponding to Makkah territories has been downloaded (http://www2.jpl.nasa.gov/strm/) and has been considered in this study (Figure. 3).
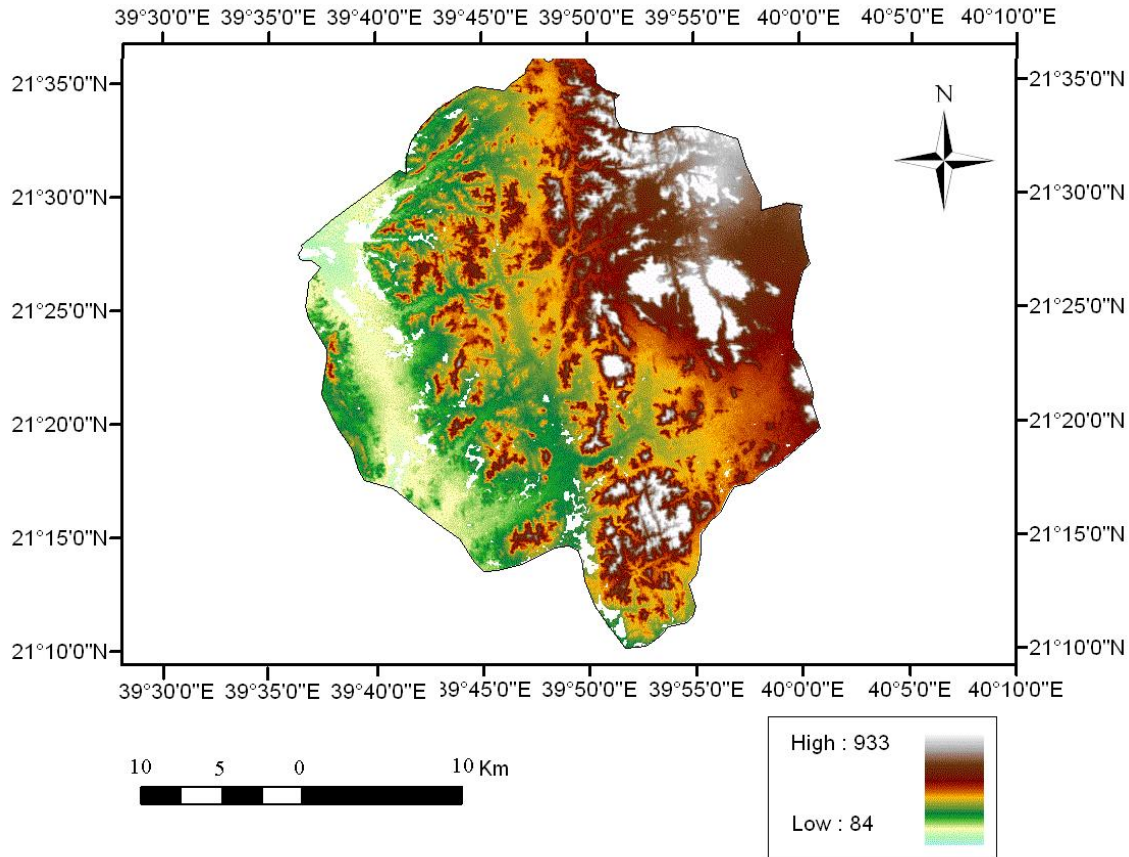
Figure 3: SRTM3 DEM for Makkah

2.3 National DEMs

Two national DEMs have been acquired, with resolution of 5 and 10 meters, developed by King Abdulaziz City of Sciences and Technology (KACST). Windows cover Makkah metropolitan area has been provided through the Center of Excellence in Hajj and Omrah, Umm Al-Qura University. The ASTER and SRTM3 are rectified relative to the World Geodetic System 1984 (WGS84). Since the available GPS data are relative to that geodetic datum too, the national 5-m (Figure. 4) and 10-m DEM has been projected from the national Saudi geodetic datum (Ain El-Abd 1970) to WGS84. That process, and consecutive procedures, has been performed using the Arc GIS software.
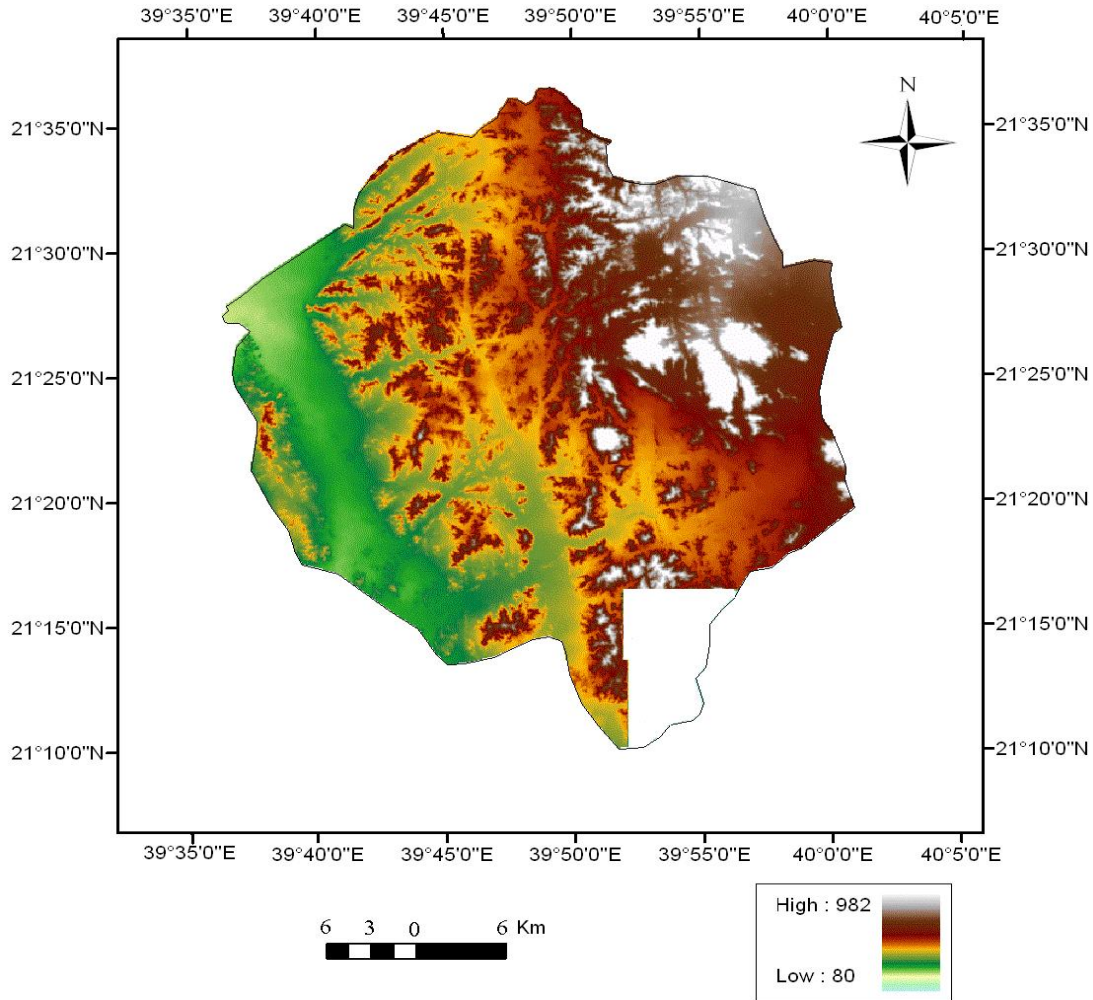
**Figure 4:** National 5-m DEM for Makkah

3. Data and Processing

3.1 Available data

A dataset of 200 first-order Global Positioning System (GPS) terrestrial control points, with known orthometric heights, has been compiled and used to judge the accuracy of DEMs. That dataset covers the entire Makkah metropolitan region as seen in Figure 5.

3.2 Processing methodology

GIS provides an efficient technical tool for spatial and attribute data storage, manipulation, processing and analysis. Utilizing GIS technology in GPS surveying activities facilitate the data processing for a number of applications (Dawod and

Mohamed 2009). The GIS processing procedures, carried out in this research, consist of several steps (Figure. 6).
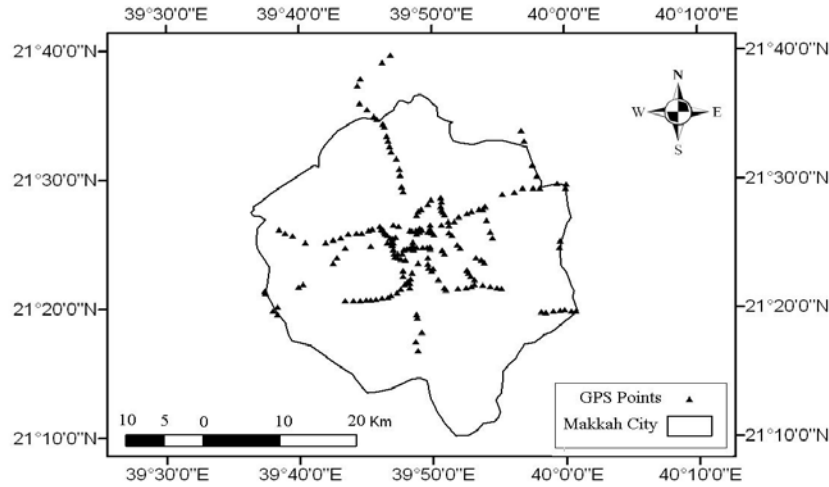
Figure 5: Available GPS Stations

Firstly, all available DEMs and the GPS dataset have been imported within the Arc GIS software. That program has a lot of spatial analysis tools within its Arc Toolbox component. That component, in the second procedure, has been utilized to interpolate the DEMs' heights of the available GPS points. Thirdly, the obtained DEMs' heights have been compared against the known heights of the 200 terrestrial control points cover the Makkah metropolitan area. Finally, statistical analysis has been performed to investigate the accomplished results.
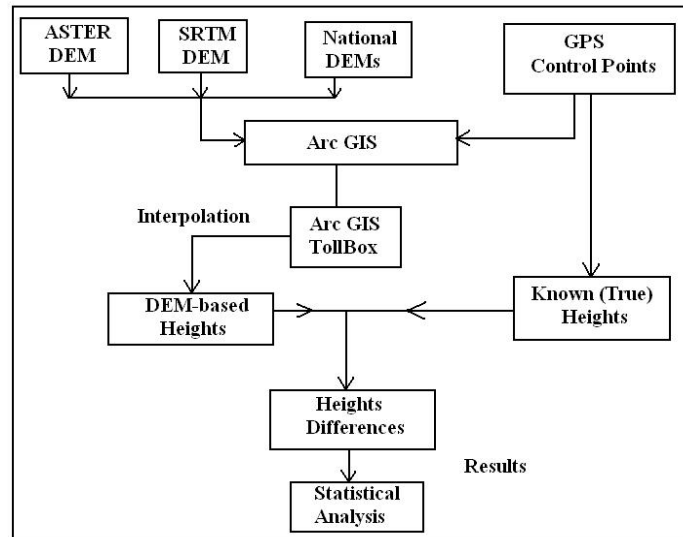
Figure 6: GIS Processing Steps

4. Results, discussion, and conclusions

4.1 DEM accuracy

For the global DEMs, the published accuracy levels are 7-14 and 6-10 meters for ASTER and SRTM3 respectively (Abrams et al. 2008 and Rodriguez et al. 2005 respectively). These accuracy levels are on a global scale, hence, the main task of the current research is to assess their accuracy within Makkah metropolitan area. DEMs accuracy assessment studies have been performed in several regions in the world (Denker 2005, Kiser and Kelly 2010, and Dawod 2008). Clearly, it can be noticed from figures 1 and 2 that there are some differences between ASTER and SRTM3 DEMs over Makkah. ASTER produces height values range from 117 to 914 meters, while the SRTM3's heights range vary from 84 to 933 meters. From Figure 3, the corresponding heights of the 5-m national DEM range from 80 to 982 meters.

Tables 1 and 2 present the accomplished results of heights comparison. From Table 1, it can be seen that the ASTER DEM yields height differences range from -20.34 m to 19.30 m, with a mean value of 2.59 m and a standard deviations equals ± 8.66 m. On the other hand, the SRTM3 DEM produces height differences vary from -20.12 m to 9.07 m, with an average of -5.20 m and standard deviations equals ± 5.85 m. Therefore, it can be concluded that the 90-m resolution SRTM3 DEM is more accurate than the 30-m resolution ASTER DEM by a factor of 1.5 approximately, over Makkah city. Comparable results over Australia have been reported (Hirt et al. 2010).

Table 1: Statistics of Global DEMs' Height Differences over Check Points

	Heights Differences of ASTER	Heights Differences of SRTM3
Minimum	-20.34	-20.12
Maximum	19.30	9.07
Mean	2.59	-5.20
Standard Deviation	8.66	5.85

Regarding the available national DEMs, it can be seen, from Table 2, that the 10-m resolution DEM generates height differences range from -7.60 m to 7.36 m, with a mean value of 0.01 m and a standard deviations equals ± 2.96 m. Conversely, the 5-m resolution DEM produces height differences vary from -7.54 m to 7.07 m, with an average of 0.01 m and standard deviations equals ± 2.95 m. Therefore, it can be concluded that there are no significant differences between the accuracy of both DEMs even though their horizontal resolutions are different. This conclusion is quite important in computer data processing since the file size of the 5-m resolution DEM is almost twice that of the 10-m DEM. Hence, utilizing the 10-m DEM will be faster in performing processing tasks of surveying, mapping, and geomorphologic studies.

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Table 2: Statistics of National DEMs' Height Differences over Check Points

	Heights Differences of National 10m-DEM	Heights Differences of National 5m-DEM
Minimum	-7.60	-7.54
Maximum	7.36	7.07
Mean	0.01	0.01
Standard Deviation	2.96	2.95

Another comparison between global and national DEMs reveals that both national DEMs are more accurate, in representing the topography of Makkah city, by factors of 3 and 2 over the global ASTER and SRTM3 DEMs respectively.

4.2 DEM relevance

A chief concern in utilizing DEMs is to select a DEM that is appropriate, in terms of precision, for a specific geodetic, mapping, or morphometric task. Three example issues, in this regard, will be considered. Firstly, creating contour maps from a DEM mainly depends on the DEM accuracy. The United States Geological Survey (USGS) standards state that: "for topographic maps, the vertical accuracy standard, for all map scales, requires that the elevation of 90 percent of all points tested must be correct within half of the contour interval" (USGS 1999). Hence, the tested two national DEMs can be used to develop topographic maps with a contour interval equals 6 m, while SRTM3 and ASTER DEMs can yield 12-m and 18-m interval contour maps, respectively. Secondly, the rigid topography of Makkah metropolitan area emphasis the fact that a precise DEM is needed in estimating the terrain corrections in quasi-geoid modelling. Hence, the 5-m resolution national DEM is the optimum candidate in developing gravimetric co-geoid of Makkah city. Thirdly, for hydrological analysis and water resources management, DEM spatial resolution affects flood simulation and the computations of inundation areas from flood simulations (Li and Wong 2010 and Dixon and Earls 2009).

5. Conclusions

DEMs play a crucial role in geodetic, geomorphologic, and mapping applications. This study has investigated the accuracy of two national DEMs, with 5m and 10m resolutions, along with the ASTER and SRTM3 global DEMs. A dataset of 200 first-order GPS ground control points, that covers the Makkah (Mecca) metropolitan area in the western region of Saudi Arabia, has been utilized to judge the accuracy of these DEMs. The attained results showed that the 5-meter resolution national DEM is the most accurate one and produces mean height difference and standard deviations equal 0.01 ± 2.95 m respectively. That national DEM is more accurate by factors of 3 and 2 over the global ASTER and SRTM3 DEMs respectively. Recommendations have been drawn to apply each DEM in the geodetic, topographic mapping, and geomorphologic activities in Saudi Arabia.

Acknowledgements

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