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The ultimate vertical accuracy assessment of the third generation Turkish 1:25000 quad maps; under canopy vs. no canopy

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Abstract

Elevation, vertical accuracy of any topographic Earth representation, e. g. stereo surface models, topo maps, DEMs, etc., is important if such data will be the base of further projects or development plans. The main form of these types of data in Türkiye is "1:25000" scaled quad maps. The third generation such maps were produced via digital stereo air-photo capture and photogrammetry capabilities as opposed to the previous two analogue based releases. Through this long-adapted scale, land cover types, hydrological formations, surface features, down to house rooftops, can be depicted in these maps. Elevation integration are also provided through the contour lines drawn in 10 m elevation difference showing intervals. They are the most frequently addressed topographic data type in forestry education as well as in profession. With the establishment of county-wide active GNSS network, very high precision elevation verification has become available for multitude of purposes. In this study, four dam reservoirs intensively surveyed using CORS-GPS were used to assess the vertical accuracies of the corresponding quad-map based DEMs produced in different resolutions. RMSEs ranged from 5.49 m to 14.22 m when the entire quad sheets were used while they ranged from 2.58 m to 8.95 m when the quads were purposely cut. Canopy closure apparently worsened the results.

1. Introduction

Although there were earlier attempts in site-specific (Sahin et al. 2022) or country-wide (Dagdas and Bilge 2015) scales, depicting target land cover type, forests, topography related map production, undertaken by Turkish Mapping Command in Türkiye started revealing the first country-wide coverage around 1959-1960.

Relatively similar to 7.5 minute, 1:24000 US quadrangle maps, 1:25000 Turkish quads can be considered as the country's main elevation integrated, forest cover and type prioritizing topographic maps. Repeated with a second coverage around 1992-1993, they were produced via stereo air-photo capture and photogrammetric analyses and interpretation capabilities. These two coverages were produced with analogue means.

Since elevation has been embedded into such maps in contour line fashion, they have been accepted as the first set of reliable datasets to produce surface models, DEMs, in cartographic studies using GIS software(s), starting from the 1980s onward (Taud et al. 1999; Ardiansyah and Yokoyama 2002; Guth 1999).

Although everybody has started using them in all sorts of projects, reports, theses, etc. to generate surface models and their inherent derivatives e.g., slope, aspect, hillshade, roughness, hydrology, etc. not very many studies looking into the actual vertical accuracy of those maps surfaced until the late 2000s. Based on a verification established over 1:16000 stereo air photo driven models, Ozturk and Kocak (2007) found out that 1:25000 Turkish quad maps had RMSEs in the range of ±2 m. Then, Bildirici et al. (2009) used them to assess the practicality of the newly released 3 arc-second SRTM and showed that SRTM's absolute height error was actually better than the mission stated 16 m.

Although there have been even more subsequent coverages in places where frequent land-cover/land-use changes occur, finally, the third and current country-wide coverage produced with digital means, was started to be released around 2009-2010. Around the same in 2009, Türkiye also established and started effectively using the indigenous active GNSS system, TUSAGA-Active (TA) network (Yildirim et al. 2011). Using this new achievement, it's been possible to acquire positional coordinates, x, y, z, in millimeter accuracy in much of the country as well as in Northern Cyprus.

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In the scope of this study, four dam reservoirs, two to be transformed from agricultural fields, one to be transformed from >%90 forest cover and one to be transformed from <%30 forest cover were surveyed utilizing CORS GPS constantly communicating with TA network, and the results were compared to those extracted from quad map(s) generated different resolution DEMs; purpose-cut, entire sheet, 10 m resampled, 30 m resampled.

2. Study Area and Methodology

2.1. Study Area

Four dam reservoirs chosen previously by the State Hydraulic Works (DSI) for hydro-electric and irrigation purposes in Kastamonu province, were meticulously surveyed in 2014-2015 period by independent surveyors for engineering and hydrologic calculations, yet to come in the following years (Figure 1). Two of the dam reservoirs (Incebogaz and Hasanli) were planned over agricultural areas with occasional single-story dwellings for living and livestock storage. One of them (Arac) had <%30 forest cover with human habitation signs and the last one (Obrucak) had >90% forest cover with no habitations.

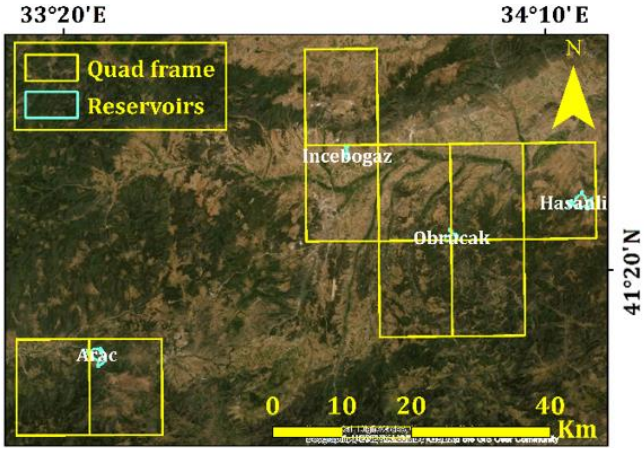

Figure 1. Locations of the studied dam reservoirs

2.2. Methodology

GCPs were recorded using ITRF-96 coordinate system meaning 3^0 Transverse Mercator projection. An illustration of GCP set acquired in Obrucak Reservoir can be seen in Figure 2. Elevation measurements were based upon GRS80 vertical datum. Elevation readings were subsequently transformed into orthometric heights by subtracting the respective geoid heights from the recorded ellipsoidal heights (Simav et al. 2015). After the elevation correction, all GCP records were transformed into 6^0 Universal Transvers Mercator projection over WGS84 datum for easier comparison with the elevations to be extracted from different versions of the quad map generated DEMs. Tested quad coverage was also produced adopting the same projection and datum. ArcGIS 10.8 was used in the analyses.

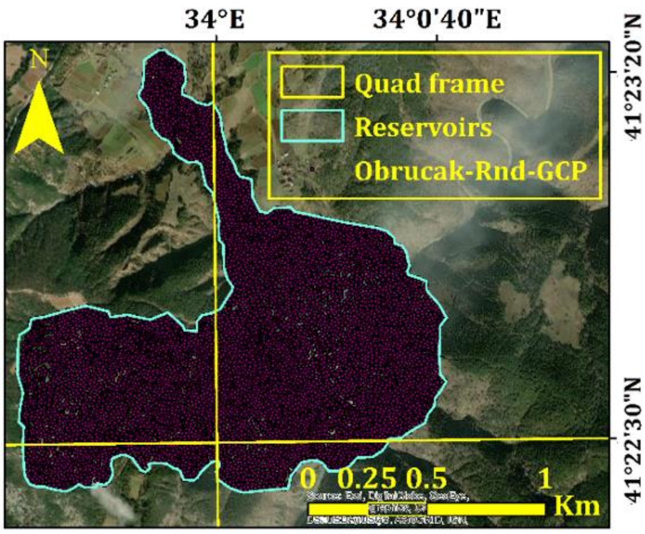

Figure 2. Random GCPs within Obrucak dam reservoir

Vectorized quad sheets were used. Sheets were first purposely cut using the polygons housing the GCPs, Second, TIN surfaces were generated for each site within the designated polygons. Then, a TIN to raster conversion was performed for each site preserving the ArcGIS recommended default cell sizes. Thus, four site-specific DEM datasets, "Purpose-Cut Quad Sheet" were generated.

The same sequence was repeated to create four more DEM datasets utilizing the quad sheets as whole, "Entire Quad Sheet". 10 m and 30 m cell size preferences were dictated during entire sheet TIN to raster conversion phases of the third and fourth DEM dataset creations, "10 and 30 m Resampled Entire Quad Sheet" (Table 1).

Table 1. Summary statistics

Raster Resolution	Arac Dam Reservoir	Obrucak Dam Reservoir	Hasanli Dam Reservoir	Incebogaz Dam Reservoir
From Purpose-cut Quad Sheet (m)	11.2	7.5	12.3	7.5
From Entire Quad Sheet (m)	84.4	112.4	56.3	111.8
From 10 m Resampled Entire Quad Sheet (m)	10	10	10	10
From 30 m Resampled Entire Quad Sheet (m)	30	30	30	30
Number of GCPs	41181	26716	14894	11226
Acreage (ha)	339.7	160.5	394.9	64.1
Number of quad sheets per site (tying)	2	4	1	2
Quad sheed line-up sequence	West-East	All around	None	North-South

A total of 16 DEM datasets was generated to test how quad sheet generated DEM resolution would differ in elevation accuracy against precisely measured GPS GCPs. To do this, each random GCP dataset was placed on the generated DEM(s) and the respective elevation record of each GCP was extracted from four different DEM datasets. Root mean square error (RMSE), mean error (ME), mean absolute error (MAE) and standard deviation

(STD) were calculated (Satge et al. 2016). They were then placed as input into Poudel and Cao (2013) approach to get a collective comparison result. The respective equations are as followed;

$$RMSE = \sqrt{\frac{\sum_{i=1}^{i=n}(x_i - y_i)^2}{n}} \quad (1)$$

$$ME = \frac{\sum_{i=1}^{i=n}(x_i - y_i)}{n} \quad (2)$$

$$MAE = \frac{\sum_{i=1}^{i=n}(|x_i - y_i|)}{n} \quad (3)$$

$$STD = \sqrt{\frac{1}{n-1}\sum_{i=1}^{i=n}[(x_i - y_i) - ME]^2} \quad (4)$$

where n is the number of GCPs, x is the measured elevation value (m) of the GCPs, while y is the elevation value extracted from DEM datasets.

$$R_i = 1 + \frac{(m-1)(S_i - S_{min})}{(S_{max} - S_{min})} \quad (5)$$

where R_i is the relative rank of the DEM datasets (i=purpose-cut, entire sheet, 10 m resampled and 30 m resampled), S_i is the basis of error values produced by each DEM dataset, S_{min} is the minimum value of Si and S_{max} is the maximum value S_i, m is the number of questioned DEM datasets. The equation produced a ranking score ranging from 1 to m. The remaining ranks were produced in real numbers between 1 and m.

3. Results and Discussion

As apparent from many studies based on both active and passive-sensor produced surface models, DEMs, the vertical accuracy performance of the end product is highly correlated with the land cover type and topographic uncertainties within the target during the actual image acquisition (Shortridge 2006; Wechsler and Kroll 2006; Hebeler and Purves 2009; Altunel 2018; Gonzalez and Rizzoli 2018;). Although smaller in caliber in terms of investment, coverage and know-how, aerial stereo image capture, today, is not entirely different from those of the satellite-based ones. Tested third generation quad coverage was produced from stereo captured color infrared air-photos, better defined as air-imagery. Imagery-wise, Yilmaz and Erdogan (2018) showed that RMSE of DEMs produced from new stereo air-photos captured at 45 cm ground sampling distance were ±2.51 m, ±1.38 m and ±1.3 m within Uşak, Aksaray and Dogu Beyazit designated quad sheets. They said a 5 m GRID spaced DEM could very well be produced for the entire country, utilizing the new generation air-photos.

While the building blocks of the third and later version(s) country-wide quad sheets have been this strong, it is perfectly logical to think that elevation accuracy of the quad sheets must also be close to above mentioned figures.

Arac, Obrucak, Hasanli and Incegogaz reservoir areas extended across 435-1710 m, 580-1750 m, 555-1280 m and 680-1375 m elevations, respectively. In Arac, Hasanli and Incebogaz reservoirs, bulk of the slope facades was on sloping to very steep slopes, 5%< - <150%, whereas in Obrucak they were on moderately steep to very steep slopes, 15%< - <200% (FAO, 2006). These figures amounted to 93% of Arac reservoir, 99.6% of Hasanli reservoir, 95% of Incebogaz reservoir and 91% of Obrucak reservoir land area being on steep topography. This could be understood when water storage was intended. Random, but rather tightly, recorded GCPs allowed us to reach the results presented in this study.

RMSE-wise, the results were as followed: in Arac reservoir, purpose-cut and 10 m resampled DEMs were clearly similar and better than 30 m resampled DEM, entire sheet-based DEM produced the least favorable elevation performance; in Hasanli reservoir, the situation was the same, but the gain was marginal; Incebogaz reservoir, same results with better gain were observable and in Obrucak reservoir, same results again with more than 2 times better gain was obvious (Table 2).

Table 2. Ranking results based on individually calculated errors

Reservoir	Canopy Closure	Raster Making Method	RMSE	ME	MAE	STD	Total Rank	Overall Rank
Arac	Partial canopy (<%30)	Purpose-cut Quad Sheet	4.73 (1.00)	-0.77 (1.26)	3.42 (1.00)	4.67 (1.00)	4.26	1.07
		Entire Quadrangle Sheet	7.02 (4.00)	-1.08 (4.00)	5.13 (4.00)	6.94 (4.00)	16.00	4.00
		10 m Resampled Entire Quad Sheet	4.73 (1.00)	-0.74 (1.00)	3.42 (1.00)	4.67 (1.00)	4.00	1.00
		30 m Resampled Entire Quad Sheet	5.08 (1.46)	-0.77 (1.26)	3.70 (1.49)	5.02 (1.46)	5.68	1.42
Obrucak	Full canopy (>%90)	Purpose-cut Quad Sheet	6.77 (1.03)	0.07 (1.28)	4.95 (1.00)	6.67 (1.00)	4.31	1.00
		Entire Quadrangle Sheet	14.22 (4.00)	-0.56 (4.00)	10.6 (4.00)	14.21 (4.00)	16.00	4.00
		10 m Resampled Entire Quad Sheet	6.70 (1.00)	0.07 (1.28)	4.98 (1.02)	6.70 (1.01)	4.31	1.00
		30 m Resampled Entire Quad Sheet	7.54 (1.34)	0.02 (1.00)	5.54 (1.31)	7.54 (1.35)	4.99	1.18
Hasanli	Agriculture (no canopy)	Purpose-cut Quad Sheet	8.95 (1.32)	-0.14 (1.00)	4.25 (1.29)	8.91 (1.29)	4.78	1.00
		Entire Quadrangle Sheet	9.12 (4.00)	-0.19 (4.00)	4.53 (4.00)	9.07 (4.00)	16.00	4.00
		10 m Resampled Entire Quad Sheet	8.93 (1.00)	-0.18 (3.40)	4.22 (1.00)	8.90 (1.00)	6.40	1.43
		30 m Resampled Entire Quad Sheet	8.97 (1.63)	-0.18 (3.40)	4.30 (1.77)	8.92 (1.77)	8.34	1.95
Incebogaz	Agriculture (no canopy)	Purpose-cut Quad Sheet	2.58 (1.00)	0.81(4.00)	2.05 (1.00)	2.45 (1.00)	7.00	1.22
		Entire Quadrangle Sheet	5.49 (4.00)	0.08 (1.00)	4.04 (4.00)	5.49 (4.00)	13.00	4.00
		10 m Resampled Entire Quad Sheet	2.59 (1.01)	0.68 (3.47)	2.05 (1.00)	2.49 (1.04)	6.52	1.00
		30 m Resampled Entire Quad Sheet	2.94 (1.37)	0.61 (3.18)	2.32 (1.41)	2.88 (1.42)	7.38	1.40

Although the tendency in terms of elevation performance was towards purpose-cut and 10 m resampled DEMs in all reservoirs, the results were not the same one another despite the fact that they were all located within same geographical region. Location-wise, Incebogaz reservoir produced nearly the same results of Ozturk and Kocak (2007) and Yilmaz and Erdogan (2018), however the rest was worse. Even though their results were basing upon direct air photography photogrammetric calculations, it was nice to see that a secondary product fabricated using the same photography would match their original precision. Closed canopy in Obrucak reservoir must have been the reason that entire sheet-based DEM produced the overall worse RMSE, 14.2 m. Besides, this high RMSE was also triggered by the DEM acquired, combining four quad sheets together. Partial canopy closure in Arac reservoir did not tarnish the RMSE as much as that of Obrucak reservoir. Additionally, MAE values calculated over all questioned DEMs were the overall highest just like those of the RMSEs in the same reservoir.

In three out of four reservoirs, Arac, Obrucak, Incebogaz, purpose cutting the quad map clearly improved the DEM making performance of the quad maps compared to that of the entire sheet-based DEM. The gains were close to more than two times. However, the fact that no such improvement was observed in Hasanli reservoir convinced us that it would be impossible to get the same elevation precision from all quad maps. Nevertheless, it is possible to say that a less than 10 m quad specified contour interval precision can be achieved in the third generation 1:25000 Turkish quad maps.

Resampling clearly improved the DEM making performance of the quad maps. Both of the tested GRID spacing, 10 m and 30 m, were better in Arac, Obrucak and Incebogaz reservoirs, 10 m DEM being the better one in each, than the entire sheet-based DEM, but no noticeable difference was observed in Hasanli reservoir. Sorensen and Seibert (2007) showed that high resolution DEM provided better TWI distribution while Tan et al. (2015) said the most sensitive SWAT model DEM parameter was DEM resolution so higher the resolution better the outcome. Quad line-up sequence did not have any detectable effect over the calculated error values, however, although not certainly conclusive, it was obvious that quad tying worsened the error values.

The remaining error calculations, ME, MAE and STD behaved the same so detailed explanations were deemed unnecessary to elaborate, however they were nice additions to achieve the overall ranking results for each reservoir area.

4. Conclusion

Quad, topographic, maps are important geographical assets of a country. Türkiye has long had a meticulous tradition of producing them systematically. Three nation-wide coverages have been released as of 2022, and they have been produced through photogrammetric calculations performed over tens of thousands of stereo-captured air photos. Topography is depicted via elevation embedded contour lines, which yielded the above results for the third and current coverage in four dam reservoirs in Kastamonu province. This study showed that a less than 10 m vertical accuracy can be attained directly from 1:25000 Turkish national quads, and the results can be further improved if secondary products such as resampled DEMs, are produced.

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