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AVALIAÇÃO COMPARATIVA DA QUALIDADE DOS DADOS DE ELEVAÇÃO OBTIDOS COM GNSS, GOOGLE EARTH E SRTM PARA PROJETOS DE ESTRADAS

COMPARATIVE ASSESSMENT OF ELEVATION DATA QUALITY FOR ROAD PROJECTS: A GNSS, GOOGLE EARTH, AND SRTM EVALUATION

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RESUMO – Obter dados precisos de elevação do terreno é de extrema importância para diversas aplicações na engenharia. No entanto, independentemente da técnica utilizada para obter tais dados, erros inerentes surgem devido a limitações dos instrumentos, técnicas de medição e o modelo escolhido para representação da Terra – seja ele plano, esférico ou elipsoidal. Nesse contexto, este estudo propõe uma análise comparativa abrangente dos dados de elevação derivados das coordenadas geodésicas fornecidas pelo *Global Navigation Satellite System* (GNSS), assim como os dados obtidos pelo Google Earth (GE) e *Shuttle Radar Topography Mission* (SRTM). A coleta de dados foi realizada no trecho urbano que abrange do km 125 ao km 145,500 da Rodovia Dom Pedro I (SP-065) no estado de São Paulo, Brasil.Para avaliar a qualidade dos resultados, é utilizado o Erro Quadrático Médio (RMSE) como referência. Os resultados apontam que os dados de elevação do SRTM apresentam um nível mais elevado de concordância e precisão em comparação com os dados do GNSS. Além disso, os dados do SRTM demonstram uma qualidade superior, com valores de RMSE menores e uma maior proximidade com as elevações médias calculadas para o trecho específico da rodovia, indicando menor variação. No entanto, vale ressaltar que, a utilização do GE pode ser uma boa alternativa para estudos preliminares de baixo custo.
Palavras-chave: elevação; GNSS, SRTM, Google Earth, projetos rodoviários.

ABSTRACT – Obtaining terrain elevation data is essential for numerous engineering applications. However, regardless of the technique used to obtain the elevation data, there will be errors intrinsic to the instruments and to the measurement technique used, as well as depending on the model of Earth representation, which are plane, spherical or ellipsoidal. In this perspective, this work proposes a comparative approach between the elevation data obtained from the geodesic coordinates, provided by Global Navigation Satellite System (GNSS), and those obtained from Google Earth (GE) and Shuttle Radar Topography Mission (SRTM). The data collection was carried out in the urban section between km 125 to km 145,500 of Dom Pedro-I Highway (SP-065), State of São Paulo, Brazil. The quality of the results is evaluated based on the Mean Quadratic Error (RMSE). The main results showed that the elevation data obtained through the SRTM show greater agreement or adjustment to the GNSS data when compared to the higher quality and less variation than those obtained through the GE, since they have smaller RMSE and are closer to the average elevations calculated for the highway segment

analyzed. However, it is worth noting that the use of GE can be a good alternative for low-cost preliminary studies.
Keywords: elevation; GNSS; SRTM; Google Earth; road projects.

1. INTRODUCTION

Obtaining terrain elevation data is essential for numerous engineering applications, including bridges, dams, transportation infrastructure, hydraulic systems, urban planning, and more. These data enable the creation of features such as Digital Elevation Models (DEM), relief maps, and slope maps, which are frequently utilized in georeferenced databases like Geographic Information Systems (GIS).

The methods for acquiring elevation data can be classified as either local or global, depending on the sampling scope. Local methods rely on traditional topographic surveys (EL-ASHMAWY, 2016), employing tools such as total stations, auto levels, and GNSS receivers. These techniques allow for accurate determination of elevation. On the other hand, global methods refer to data obtained through sensors capable of generating point clouds, such as LIDAR and SRTM (AGÜERA-VEGA *et al.,* 2018). However, it is important to emphasize that regardless of the technique used to obtain elevation data, intrinsic errors exist in the instruments and measurement techniques employed, as well as in the Earth representation model chosen. For instance, measurements conducted using GNSS technology are subject to limitations caused by atmospheric factors, while measurements obtained through SRTM and Light Detection and Ranging (LIDAR) technologies depend on terrain irregularities, vegetation coverage, and artificial obstacles for their accuracy. Therefore, it is crucial to assess the impact of these factors on the quality of elevation data generated by different techniques and models, based on the specific requirements of each application.

Google Earth (GE) offers several advantages for topographic studies compared to GNSS and SRTM (GOOGLE, 2020):

- Accessibility and Cost-effectiveness: GE provides free access to high-resolution satellite imagery and elevation data, making it easily accessible and cost-effective for preliminary studies.
- User-Friendly Interface: GE has an intuitive interface with interactive mapping capabilities, allowing easy exploration and analysis of terrain features.
- Broad Coverage: GE offers global coverage, making it suitable for conducting preliminary assessments and feasibility studies in various locations.
- Visualization and 3D Modeling: GE allows the creation of 3D models for better visualization and understanding of topographic features.
- Integration with Other Data: GE can be integrated with other data sources and software applications, enhancing the analysis by overlaying additional spatial data layers.
- Rapid Data Acquisition: GE provides a quick and efficient way to obtain elevation data and imagery without the need for time-consuming field surveys.
- Availability of Historical Imagery: GE offers access to historical imagery, enabling the analysis of landscape changes over time.

While GE has advantages, its accuracy may vary, and for detailed studies, GNSS and SRTM data are recommended. GE serves as a valuable tool for initial assessments, mapping, and visualization, complementing more accurate data from GNSS and SRTM.

Hence, this study aims to evaluate the quality of topographic elevation measurements obtained through GNSS receivers, Google Earth Professional (GOOGLE, 2020) software, and SRTM data (NASA, 2018). Additionally, these methodologies are applied to geodetic data surveys related to highway projects. The research adopts a comparative approach, comparing elevation data derived from geodetic coordinates provided by GNSS with those obtained from Google Earth (GE) and SRTM. The case study focuses on data collection conducted in the urban segment spanning from km 125.0 to km 145.5 of the Dom Pedro-I Highway (SP-065) in the state of São Paulo, Brazil. The quality of the results is assessed using the Root Mean Square Error (RMSE).

Section 2 provides background information, including a literature review and the presentation of fundamental concepts related to the preparation of this work. Section 3 outlines the methodological procedures employed to conduct the study, while Section 4 presents the results and discussions of the performed experiments. Lastly, Section 5 presents the main conclusions and offers suggestions for future work.

2. BACKGROUND

In the literature, several studies have been conducted on this topic. One notable example is the work by Wang et al. (2018), which presents a method for extracting elevation data using Google Earth (GE) for highway applications in transportation. In their study, they achieved a root mean square error (RMSE) of approximately 2.27m between GE elevations and reference elevations obtained with GNSS receivers. The authors emphasize that this level of accuracy is satisfactory for a wide range of transportation applications and highlight the importance and availability of elevation data obtained through GE. However, they also acknowledge that GE may provide inaccurate elevation values in areas near bridges, viaducts, overpasses, and other structures, which need to be carefully evaluated in accordance with project norms and guidelines.

Ashraf, Ahmad and Iqbal (2012) developed regression models to assess the quality of Digital Elevation Models (DEM) in relation to positioning data obtained with GNSS. Their study involved collecting 30 points in the city of Dera Ismail Khan, Pakistan, and resulted in an RMSE of approximately 4m. They concluded that the measured elevation values did not exhibit a normal distribution of errors, with higher RMSE values observed in areas with dense vegetation. Furthermore, they found that the elevation data extracted from SRTM with a resolution of 90m showed better agreement with the GNSS-obtained elevation data compared to other DEMs (ELKHRACHY, 2016). The authors suggest that the elevation data obtained from SRTM are primarily suitable for preliminary design stages, situation mapping, geomorphological and ecological studies, as well as planning and management of watershed areas.

Mohammed, Ghazi and Mustafa (2013) conducted a test of horizontal and vertical positional accuracy based on the GE model in the city of Khartoum, Sudan. Their study involved comparing the coordinates of 16 points measured in GE with geodetic coordinates collected using GNSS. The results indicated a horizontal positional accuracy with an RMSE value of approximately 1.59m and a vertical RMSE of around 1.70m. According to the authors, these accuracies allow for the production of maps at a scale of 1:50,000 or smaller. Therefore, these cited studies, along with others consulted, underscore the significance of accurately evaluating the quality of elevation data before employing it in engineering projects, given its fundamental importance.

In a study conducted by Wang *et al*. (2017), GE elevation data were compared with terrestrial data from national GPS references and road monuments in the United States. The overall RMSE value for these points was determined to be 22.31 meters. Another comparison between GE data and road monument data from six states in the US resulted in an RMSE of 2.27 meters, representing a significant improvement over the GPS data.

In a comprehensive study conducted by Moura-Bueno *et al.* (2016) in Giruá, a municipality in the state of Rio Grande do Sul (RS), Brazil, different digital elevation models were assessed, yielding varying RMSE values. Specifically, the TOPODATA model exhibited an error of 9.78 meters, while the SRTM method showed a lower RMSE of 5.95 meters. The author concluded that the SRTM and TOPODATA models provided results that were relatively closer to the actual terrain and presented lower RMSE values. However, they acknowledged that these models were not suitable for accurately representing small-scale details due to their limited resolution.

The use of contour lines in data acquisition also involved incorporating Google Earth, which had a discernible impact on data accuracy, leading to higher errors.

2.1 Digital Elevation Model – DEM

Modeling terrain numerically involves creating a mathematical representation of its surface using one or more mathematical functions in a specific reference system. The mathematical interpolation models used to generate a Digital Elevation Model (DEM) can be categorized as punctual or regional.

Punctual models estimate the elevation of an unknown point based on the elevation values of its neighboring points. Popular interpolation algorithms for punctual models include nearest neighbor and weighted inverse distance methods (CHEN *et al.,* 2017). Regional interpolation methods utilize information from the entire dataset to estimate the elevation of the unknown point. Common algorithms for regional interpolation include Kriging and polynomial methods (BASCETTA, 2013).

Most modern interpolation models are based on triangular structures that form a finite element network, where each triangle has a unique polynomial interpolation equation. Therefore, the elevation of the unknown point is determined based on its location within the triangle and the chosen interpolation function.

2.2 Global Navigation Satellite System – GNSS

GNSS integrates various artificial satellite positioning systems such as GPS, Glonass, Galileo, and COMPASS. These systems provide elevation information in point form, based on transmitted or precise ephemerides, and with respect to reference ellipsoids like WGS84, PZ90, GTRF, and CGCS2000 used by GPS, Glonass, Galileo, and Beidou respectively.

GNSS positioning methods can be absolute or relative. In absolute positioning, coordinates are directly determined relative to the Earth's center of mass using distance measurements between the receiver antenna and satellites, based on transmitted ephemerides. This approach achieves metric accuracy. For higher-quality positioning, data can be post-processed with precise ephemerides, typically available within 48 hours after tracking. This method, known as Precise Point Positioning, can achieve accuracy within a few centimeters.

When post-processing data with precise ephemerides provided by organizations like the International GNSS Service (IGS), the determined coordinates are linked to the International Terrestrial Reference Frame (ITRF) geodetic reference at a specific time, usually 2008. The reference ellipsoid used is typically GRS80. In practical terms, the geodetic references mentioned are compatible with each other, with discrepancies of less than 1 cm based on the International Terrestrial Reference System (ITRS).

In the relative positioning method, the desired coordinates are determined in relation to one or more points with known coordinates. This approach eliminates or minimizes highly correlated errors, such as satellite and receiver clocks. The effectiveness of error minimization depends on the baseline length, and for baselines greater than 100 km, other sources of error must also be considered.

When using GNSS technology for positioning, the obtained elevations correspond to geometric altitudes, which are purely geometric and referenced to one of the mentioned reference ellipsoids (WGS84, PZ90, etc). To obtain elevations associated with gravity, known as orthometric altitudes, a transformation is required using geoidal models such as EGM96, EGM2008, and MAPGEO2015. This transformation provides elevations with physical meaning.

2.3 SRTM

SRTM primarily involves capturing the reflectance of objects on the Earth's surface in the microwave band of the electromagnetic spectrum using the radar sensor of the mission (NASA, 2018). It adopts the WGS84 horizontal geodetic reference system and the EGM96 global geoidal model for vertical reference. Unlike the GNSS system, SRTM does not generate information on a point-by-point basis. Quantitatively, SRTM products are sampled on a grid with arc lengths of 1" or 3" in latitude and longitude, corresponding to an area of 30 m x 30 m or 90 m x 90 m, respectively (FARR *et al.,* 2007; NASA, 2018).

The altitudes determined by SRTM represent average values obtained through the integration of heights within the analyzed grid. In regions with rugged terrain, the discrepancies between SRTM and GNSS elevations tend to be greater in relative positioning compared to flat regions.

Cartographic products derived from SRTM data generally exhibit an absolute height error lower than 16 m and a relative height error lower than 10 m, both at a 90% confidence level. The absolute and relative geographic location errors are typically below 20 m and 15 m, respectively (RODRIGUEZ *et al*., 2005). Elevations obtained using SRTM technology vary across different regions of the globe, being less accurate in areas with steep terrain and dense vegetation cover. Studies by Farr *et al*. (2007) revealed the following errors for South America: an absolute geographic location error of approximately 9.0 m, an absolute height error of 6.2 m, a relative height error of 5.5 m, and a height error due to the long-wavelength radar of 4.9 m.

2.4 Google Earth – GE

GE integrates and provides a comprehensive database of high-resolution orbital images covering the entire world, along with digital elevation models for various regions. This geospatial information can be exported in the KML format, allowing compatibility with various applications (MOHAMMED; GHAZI; MUSTAFA 2013).

The orbital images in GE are orthorectified and sourced from the QuickBird satellite, offering a spatial resolution ranging from approximately 61 cm to 72 cm in panchromatic mode and from 2.4 m to 2.8 m in multispectral mode (DIGITAL GLOBE, 2018). Geodetic coordinates in GE are referenced to WGS84, while altitudes are referenced to the EGM96 geoid model (MOHAMMED; GHAZI; MUSTAFA, 2013). GE utilizes a derived DEM from NASA's SRTM radar data, enabling land resource mapping, three-dimensional rendering of physical objects, and applications focused on urban planning, such as traffic monitoring (MOHAMMED; GHAZI; MUSTAFA *et al.*,2013). For linear measurements, GE employs the Universal Transverse Mercator (UTM) projection, while in polar regions, it uses the stereographic polar projection since the UTM projection is not suitable for representing the poles.

Furthermore, GE allows for the conversion between geographic and plane coordinates. This means that plane or geographic coordinates can be obtained from any location on the globe using UTM or stereographic projection zones. However, users should be aware of the inherent distortions in these projections before utilizing them in their projects. Additional details on this topic can be found in references such as Richardus and Adler (1972).

3.MATERIALS AND METHODS

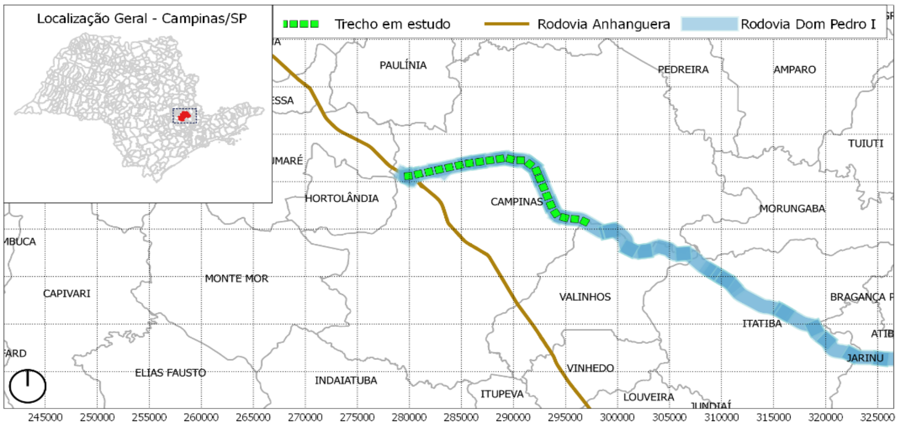
3.1. Initial data and study area characterization

The methodology employed in this study focused on collecting geo-referenced information on topographic elevation from a specific section of a highway in Brazil. The targeted area was between km 125.0 and 145.5 of Dom Pedro I Highway (SP-065) in Campinas, São Paulo (SP), Brazil (Figure 1). To obtain elevation data, a combination of data sources was utilized, including GNSS receivers, satellite images from GE, official orthophotos, and topographic maps. The static and kinematic relative positioning technique was utilized, involving two dual-frequency GNSS receivers (Leica System 1200 GX1230 GG model). One receiver served as a reference point and was installed at the Operations Control Center (CCO) of Rota das Bandeiras, the company responsible for managing the road section. The other receiver was installed on a vehicle that traversed the studied road (Figures 2a and 2b).

Both GNSS receivers, positioned at the CCO base and on the vehicle, simultaneously collected data at a rate of 0.5 seconds, with an elevation mask of 0°. This configuration enabled recording data from all available satellites during the tracking period using the kinematic relative positioning method. As a result, observations were recorded every 0.5 seconds, generating a comprehensive point cloud for both directions of the road.

Following data collection, the collected points were processed using Leica Geo Office software (LEICA GEOSYSTEMS, 2005). Initially, the coordinates were transformed to estimate the reference coordinates of the base through static relative positioning, aligning them with the Brazilian Geodetic System, which adopts SIRGAS 2000 as its geocentric reference. This transformation was performed using nearby stations from the Brazilian Network of Continuous Monitoring of GNSS Systems (RBMC), specifically the SPC-1, SPBP, and POLI stations.

Figure 1. Localization of the studied road section.



Source: Chuerubim (2019).

Figure 2. (a) Base station defined in the CCO of the "Rota das Bandeiras"; (b) GNSS receiver antenna installed on top of vehicle.

Source: Chuerubim (2019).

During the processing and coordinate transformation, precise GPS and Glonass orbits were utilized, provided by IBGE (2018). To minimize or eliminate tropospheric and ionospheric refraction, a cut-off angle of 15°, the Hopfield tropospheric model, and the ion-free linear combination were applied. Once control coordinates were estimated for the CCO base, the collected data was processed in kinematic mode for both directions of the road. To explore the collected point cloud using the proposed methodology, a subset of 58 points was selected.

To indirectly extract elevation information, Quickbird satellite images obtained from GE and SRTM data were utilized. The Quickbird satellite images, available through GE, provided valuable data for the analysis. Additionally, the SRTM data, sourced from the digital elevation model (DTM), were obtained from EMBRAPA. Based on the SRTM data, contour lines were generated at 10-meter intervals to represent the elevation variations in the study area.

3.2 Acquisition of elevation data through GE and SRTM

With the available data, the elevation of the 58 points in the study section was determined using both GE and SRTM. For GE, the elevation calculation was automated within the software through the "elevation profile" feature. Initially, the 58 points were imported into GE's digital graphical interface. Then, by selecting the "show elevation profile" option, an elevation graph representing the trajectory of the study section was automatically generated, encompassing all 58 points.

To calculate elevations using SRTM, the previously mentioned contour lines (Figure 5) were employed. The coordinates of each desired point were established using the same set of 58 points selected in the Google Earth Pro method. In cases where the desired point fell between two contour lines, interpolation techniques were applied to estimate the closest elevation value. Linear interpolation was specifically employed for this purpose. The results of the elevation values obtained through this process will be presented in the subsequent section of this study.

4 RESULTS AND DISCUSSION

Based on the described methodology, the elevation of the 58 reference points situated between km 125.0 and km 145.5 of SP-065 highway was calculated in both the north and south directions, using data from GE and SRTM. The corresponding elevation values are presented in Tables 1 and 2. To assess the accuracy of the calculated elevations, the Root Mean Squared Error (RMSE) value was computed using equation 1, as shown below:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}[o_i - m_i]^2} \quad (1)$$

Where: i = identifier of each observation; n = quantity of observed points; o = observed SRTM or GE values; and, m = model values that correspond to GNSS.

To summarize the data obtained from Tables 1 and 2, we created Table 3, which presents the RMSE (Root Mean Squared Error) and Standard Deviation (σ) values. As we are dealing with elevation values, the RMSE is the most appropriate index for comparing the three methods. The RMSE values for the comparison between SRTM and GNSS, as well as between Google Earth and GNSS, were around 10 meters. The standard deviation showed acceptable values, averaging 5 meters for the four mentioned values. To assess the normality of the errors, we performed the Shapiro-Wilk Test using SPSS, and the resulting p-values were greater than 0.05, indicating a normal distribution with a 95% confidence interval.

Table 1. Elevation values for North direction of the Highway.

METHOD				ERROR ANALYSIS		
KM	**GNSS (m)**	**SRTM (m)**	**GE (m)**	**Average elevation (m)**	**SRTM Error (m)**	**GE Error (m)**
125	659.915	663.310	660.000	661.075	3.395	0.085
126	708.314	730.450	733.000	723.921	22.136	24.686
126.6	733.038	750.000	753.000	745.346	16.962	19.962
127	721.778	738.130	734.000	731.303	16.352	12.222
128	678.769	688.370	689.000	685.380	9.601	10.231
129	654.218	655.330	658.000	655.849	1.112	3.782
130	674.585	690.600	685.000	683.395	16.015	10.415
130.5	685.618	700.000	698.000	694.539	14.382	12.382
131	663.974	670.440	669.000	667.805	6.466	5.026
132	656.260	666.630	661.000	661.297	10.370	4.740
133	638.439	655.310	640.000	644.583	16.871	1.561
133.8	617.685	620.000	618.000	618.562	2.315	0.315
134	621.771	620.000	622.000	621.257	1.771	0.229
135	637.189	642.090	648.000	642.426	4.901	10.811
136	654.014	666.440	666.000	662.151	12.426	11.986
137	626.253	633.680	633.000	630.978	7.427	6.747
137.6	622.356	620.950	626.000	623.102	1.406	3.644
138	634.743	643.120	650.000	642.621	8.377	15.257
138.4	644.567	660.000	660.000	654.856	15.433	15.433
139	632.042	637.450	638.000	635.831	5.408	5.958
140	611.896	616.870	617.000	615.255	4.974	5.104
141	600.842	616.810	615.000	610.884	15.968	14.158
142	589.115	600.000	599.000	596.038	10.885	9.885
143	592.609	598.550	598.000	596.386	5.941	5.391
143.4	586.934	593.120	597.000	592.351	6.186	10.066
144	592.328	602.800	604.000	599.709	10.472	11.672
144.5	583.783	592.310	594.000	590.031	8.527	10.218
145	603.913	614.620	616.000	611.511	10.707	12.087
145.5	628.283	637.730	639.000	635.004	9.447	10.717
Minimum	583.783	592.310	594.000	590.031	1.112	0.085
Maximum	733.038	750.000	753.000	745.346	22.136	24.686
Mean	639.836	649.142	648.966	645.981	9.525	9.130
Standard Deviation	39.966	43.034	42.449	41.722	5.529	5.834
RMSE (m)					**10.965**	**10.780**

Table 2. Elevation values for South direction of the Highway

METHOD				ERROR ANALYSIS		
KM	**GNSS (m)**	**SRTM (m)**	**GE (m)**	**Average elevation (m)**	**SRTM Error (m)**	**GE Error (m)**
125	662.388	668.010	660.000	663.466	5.622	2.388
126	710.286	728.760	720.000	719.682	18.474	9.714
126.6	734.205	756.240	753.000	747.815	22.036	18.795
127	720.805	735.420	732.000	729.408	14.615	11.195
128	679.310	691.520	696.000	688.943	12.210	16.690
129	654.007	660.000	656.000	656.669	5.993	1.993
130	674.922	687.960	683.000	681.961	13.038	8.078
130.5	685.058	698.900	700.000	694.653	13.842	14.942
131	662.263	666.020	670.000	666.094	3.757	7.737
132	657.842	665.040	666.000	662.961	7.198	8.159
133	639.116	650.650	643.000	644.255	11.534	3.884
133.8	618.126	611.780	619.000	616.302	6.346	0.874
134	622.239	616.430	625.000	621.223	5.809	2.761
135	639.795	643.190	652.000	644.995	3.395	12.205
136	653.785	667.390	671.000	664.058	13.605	17.215
137	624.161	633.850	634.000	630.670	9.689	9.839
137.6	622.024	624.640	627.000	624.555	2.616	4.976
138	635.073	643.090	645.000	641.054	8.017	9.927
138.4	645.793	660.000	663.000	656.264	14.207	17.207
139	631.107	637.160	637.000	635.089	6.053	5.893
140	611.949	612.090	616.000	613.346	0.141	4.051
141	606.721	617.420	618.000	614.047	10.699	11.279
142	591.219	595.380	597.000	594.533	4.161	5.781
143	590.905	598.320	599.000	596.075	7.415	8.095
143.4	586.903	593.570	594.000	591.491	6.667	7.097
144	590.667	600.000	603.000	597.889	9.333	12.333
144.5	583.565	592.220	593.000	589.595	8.656	9.436
145	606.722	615.390	615.000	612.371	8.668	8.279
145.5	628.683	638.670	638.000	635.118	9.987	9.317
Minimum	583.565	592.220	593.000	589.595	0.141	0.874
Maximum	734.205	756.240	753.000	747.815	22.036	18.795
Mean	640.332	648.590	649.138	646.020	9.096	8.970
Standard Deviation	39.956	43.854	42.041	41.868	4.857	4.825
RMSE (m)					**10.103**	**10.146**

Table 3. RMSE and Standard Deviation values

Method	**RMSE (m)**	**σ (m)**
SRTM North	10.965	5.529
SRTM South	10.103	4.857
Google Earth North	10.780	5.834
Google Earth South	10.146	4.825

To facilitate the comparison of elevation models, boxplot graphics were utilized to compare the SRTM and Google Earth models against the GNSS as the reference. Figures 3 and 4 present the obtained graphs for the north and south directions, respectively.

Boxplots are commonly employed to visually assess data distribution using quartiles and to identify outliers. They summarize the data by displaying the median, quartiles, and extreme values, offering insights into the level, spread, and symmetry of the distribution (WILLIAMSON; PARKER;KENDRICK, 1989).

Analyzing Figure 3, we observe that both the SRTM and Google Earth models exhibit similar ranges of residuals, indicating comparable results. However, the SRTM data show greater variability. Notably, the Google Earth median line is positioned closer to the first quartile, suggesting a positively skewed distribution.

The use of boxplots allowed us to analyze altitude residuals, revealing a symmetrical distribution for the SRTM model as indicated by the median aligning with the center of the box. This implies better values compared to Google Earth.

Turning to the south direction in Figure 4, we can observe that both models demonstrate similar variability in altitude residuals, with the median aligning with the center of the box, indicating a symmetrical data distribution.

Figure 3. Variation of the North elevations in relation to the analysis method.

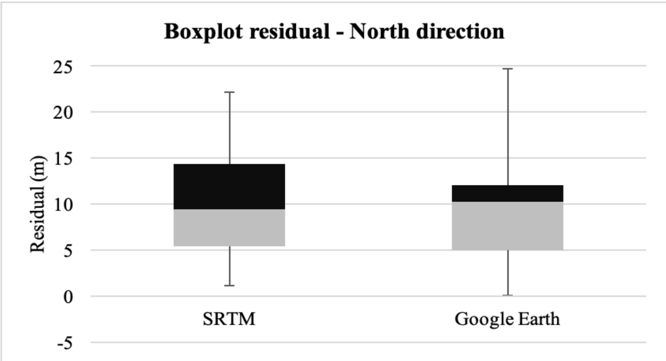
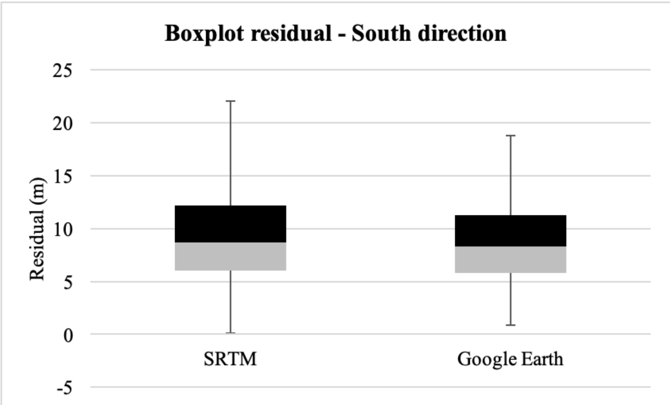


Figure 4. Variation of the South elevations in relation to the analysis method.



Considering the study's geographical extent of 20 kilometers, the obtained data's accuracy was deemed satisfactory, despite potential variations when measuring distances. The variable terrain along the road profile further influenced the model's performance, potentially resulting in reduced accuracy. Additionally, alongside the GE and SRTM data, GNSS receivers automatically recorded elevation values at various points along the route. These GNSS-derived values served as a reference for evaluating the quality of measurements obtained through GE and SRTM. Figures 5 and 6 illustrate the graphical representation of the variation in elevation values obtained using these respective methods.

In both graphs (Figures 5 and 6), the red line represents the elevation values obtained from the GNSS receivers, serving as the standard reference for elevation measurements in the analysis. The green line represents the elevation values derived from the SRTM methodology, while the yellow line represents the elevation values obtained from GE.

Figure 5. Variation of elevations in the north direction regarding to the method of analysis.

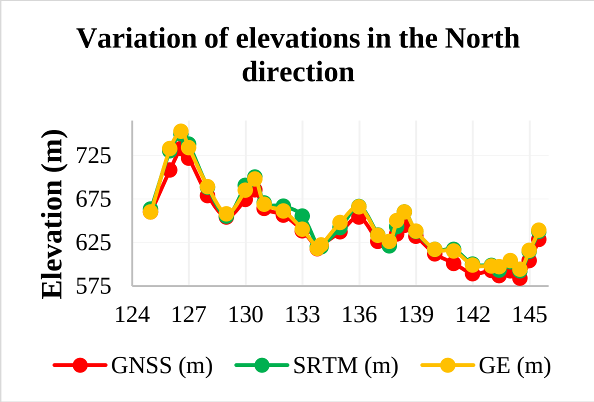
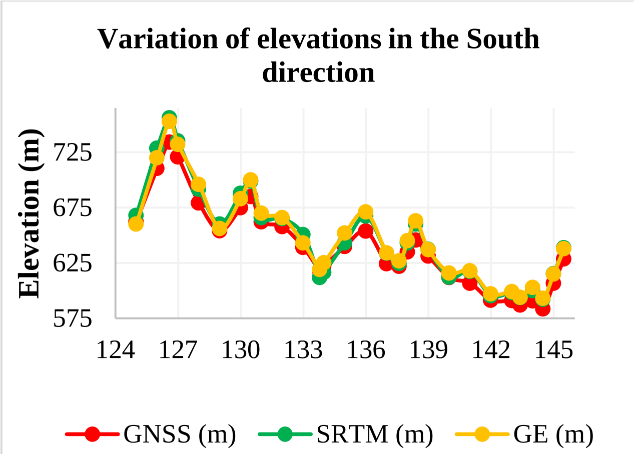


Figure 6. Variation of elevations in the south direction regarding to the method of analysis.



In Figures 5 and 6, it is evident that, in both the North and South directions of the surveyed section, the elevation values obtained through GE are generally higher compared to those obtained from the GNSS receiver and SRTM.

Upon analyzing the graphs (Figures 5 and 6) and Tables 3 to 5, it is observed that, on average, the mean squared error values for elevations derived from SRTM are smaller than those obtained through GE. This indicates that SRTM yields more accurate and higher-quality results for topographical elevations.

Furthermore, the standard deviation of the SRTM values is also lower than that of the GE values. Therefore, it can be concluded that the SRTM methodology provides elevation values with greater accuracy and consistency compared to those obtained from GE.

Additionally, four scatter plots were created to compare the values obtained from the three aforementioned methods, with the GNSS values serving as the reference. The scatter plots depict the correlation between altitude values derived from GNSS versus SRTM (Figures 7 and 8), as well as the correlation between altitude values obtained from GNSS versus GE (Figures 9 and 10).

Each scatter plot includes the regression equation and the coefficient of determination (R^2) of the model, as presented in Table 4.

Table 4. The equation of the line and R^2 coefficient

Method	**y**	**R^2**
SRTM North	0.922x + 41.431	0.985
SRTM South	0.905x + 53.348	0.987
Google Earth North	0.934x + 33.845	0.984
Google Earth South	0.944x + 27.431	0.987

In Figures 7 and 8, the x-axis represents the values obtained from SRTM (Figure 7) and Google Earth (Figure 8), while the y-axis represents the GNSS values. When comparing the altitude discrepancies between the GNSS and SRTM data, we observe a strong alignment of the data with the model in both directions of the highway. The determination coefficients, R^2=0.985 and R^2=0.9857, respectively, indicate a high degree of correlation and a good fit between the GNSS and SRTM values, as depicted in Figures 7 and 8.

Figure 7. Relation between SRTM and GNSS values in the North direction.

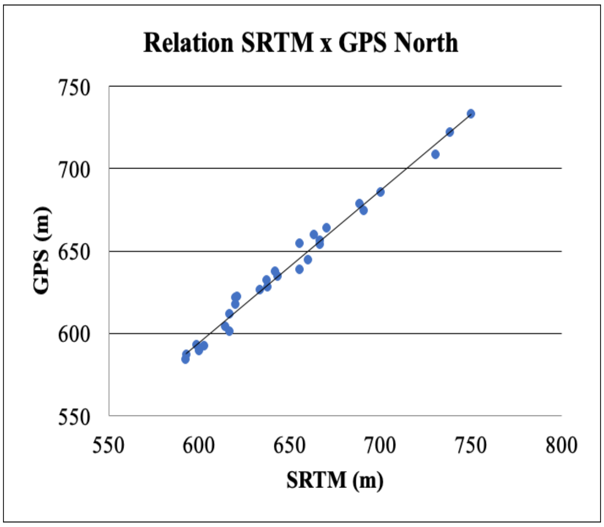
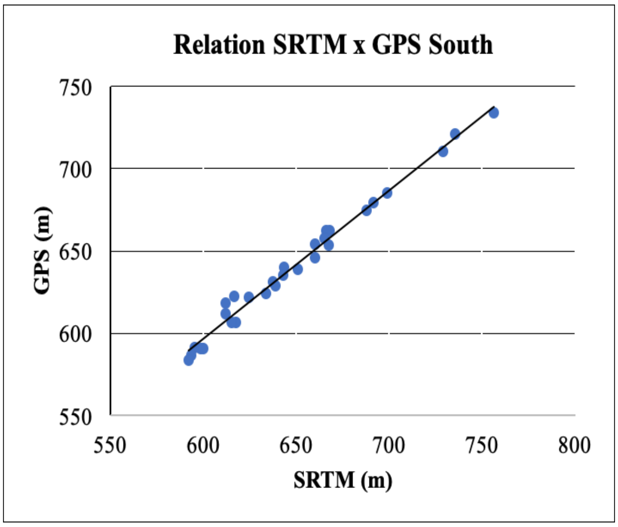


Figure 8. Relation between SRTM and GNSS values in the South direction.



However, when examining the altitude discrepancies between the GNSS and Google Earth data, we observe a slight dispersion in the values, despite the high determination coefficients indicating a good overall fit between the data. The determination coefficients for both directions of the highway are approximately R^2=0.984 and R^2=0.987, as shown in Figures 9 and 10, respectively. This indicates a reasonably strong correlation between the GNSS and Google Earth values, but with some scattered points that deviate slightly from the overall trend.

Figure 9. Relation between Google Earth and GNSS values in the North direction.

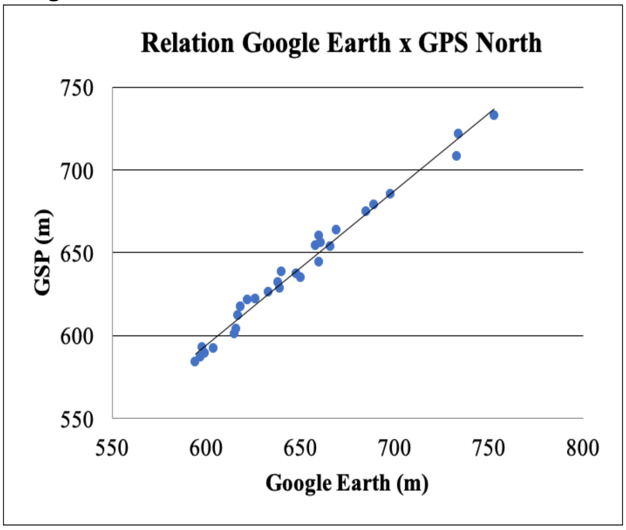
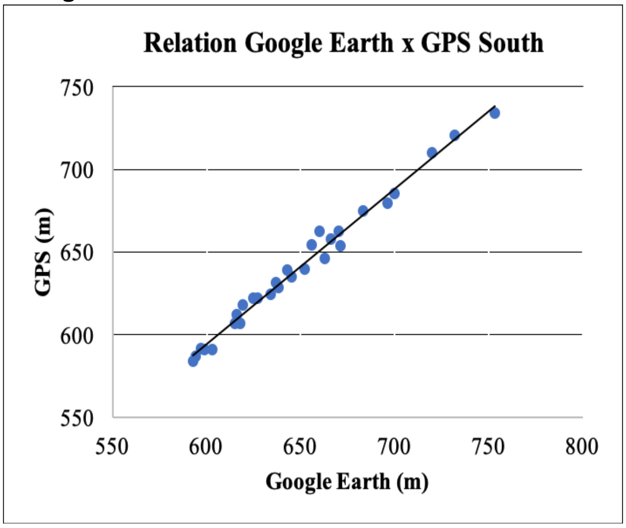


Figure 10. Relation between Google Earth and GNSS values in the South direction.



The obtained determination coefficients (R^2 values) exceeding 0.98 align with findings in the literature, particularly studies that compare GNSS data directly collected with data indirectly acquired through digital terrain elevation models (ASHRAF; AHMAD; IQBAL, 2012). These results indicate a strong correlation and agreement between the methods, with minimal data dispersion. Thus, the applied approach in the road environment demonstrates its efficiency.

Considering road projects, both methodologies for elevation data collection can be considered valid and efficient. However, due to its higher accuracy, SRTM is more suitable for projects requiring detailed and precise information. On the other hand, GE can be utilized for preliminary applications, initial studies, and tasks that do not demand high positional accuracy.

In addition, it is important to note that the availability of multiple methodologies does not exclude the use of others. In this context, GE and SRTM can be employed in a complementary manner, capitalizing on their respective strengths and yielding benefits for comprehensive applications in the field of road engineering.

Furthermore, a study conducted by K. Malarvizhi, Vasantha Kumar e Porchelvan (2016) highlights one of the key advantages of Google Earth, which is the availability of images captured at different time periods. This feature proves highly beneficial for urban planners as it allows for the detection of land use changes and facilitates better monitoring of rapid urbanization. Additionally, Google Earth offers real-time traffic visualization on major avenues and high-traffic roads, adding another valuable aspect to its functionality (SZTUTMAN, 2014).

Overall, the combination of SRTM and GE methodologies provides a comprehensive approach to obtaining topographic elevation values, catering to the diverse needs of road engineering projects.

In addition to data extraction and visualization capabilities, Google Earth (GE) offers valuable insights into the effects of elevation changes on vehicle fuel efficiency, congestion, and route choices in transportation planning. Wang *et al.* (2017) explored GE's potential in evaluating the impacts of elevation change on non-motorized transportation modes and optimizing energy-efficient route alternatives, thus highlighting its wider applicability.

The Root Mean Square Error (RMSE) serves as an excellent parameter for assessing the accuracy of a dataset. Its application in transportation projects is crucial, especially when proximity to real-world conditions is essential and the occurrence of errors should be minimized. For instance, in road staking or sign location projects, both in urban and rural areas, the RMSE aids in ensuring the collected data is suitable for use. It becomes particularly significant during road maintenance or initial planning stages, where the accuracy of collected information directly impacts the project's cost and execution efficiency. As road construction projects involve substantial resources and labor, minimizing data extraction errors becomes economically important.

The calculated RMSE between different approaches for obtaining elevation values was approximately 10 meters. This finding aligns with literature results ranging from 4 to 9 meters, as reported by Ashraf, Ahmad and Iqbal (2012). It is worth noting that in this study, GNSS receivers were used with the kinematic relative positioning method, collecting data at a rate of 0.5 seconds. Differential corrections were applied to each tracked point based on a minimum number of observations within this interval. Consequently, the magnitude of the error is influenced by the positioning technique employed. However, for road engineering applications that do not require centimeter-level accuracy, this level of error is generally tolerable. For instance, it can be acceptable when locating sections of ascending or descending ramps for road safety analysis.

5. FINAL CONSIDERATIONS

In conclusion, it is evident that both the SRTM and GE methodologies are widely used for obtaining topographic elevation values in road engineering projects. These methods effectively enable the remote acquisition of precise and efficient positional attributes.

Upon analysis, it was observed that the elevation values obtained through SRTM exhibited greater precision and accuracy compared to those obtained using GE. The SRTM calculations showed a closer alignment with the reference measurements obtained from GNSS receivers, indicating their reliability. Therefore, it is recommended to prioritize the use of SRTM for road projects that require higher positional quality and accuracy. On the other hand, GE can still be utilized as a supplementary resource to complement measurements acquired through GNSS and SRTM.

For future research, it is recommended to conduct a comparative analysis of altitude accuracy using the static relative positioning technique. This technique involves determining altitudes for passive occupation landmarks on the ground in relation to one or more reference stations. In altimetry, it is crucial to minimize discrepancies to a few meters or even centimeters. Furthermore, it is important to consider the impact of baseline length on error propagation, particularly due to factors such as ionosphere and troposphere. Longer baselines tend to introduce larger errors. However, given the dynamic nature of the environment and the challenges of data collection, the kinematic positioning method has proven to be efficient, meeting the objectives of this study while ensuring the safety of the team, especially in high-traffic sections analyzed that involve passenger and cargo vehicles.

Additonaly, for future investigations, it is highly recommended to assess additional highway sections in Brazil to validate the findings of this study. Moreover, the integration of other geotechnologies, such as drones and interferometric surveys, should be explored. By comparing different methodologies for georeferenced data acquisition, these studies can contribute to advancing knowledge in the field of Geosciences and foster the comprehensive development of Highway Engineering and its applications to society.

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