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Research Article

Evaluation of Open Source Dems for Regional Hydrology Analysis in a Medium-Large Basin

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Abstract

Nowadays exist a variety of topographic source with different spatial resolution obtained by using distinct methodologies. Choosing a data source that is the more accurately possible in area relief, has become fundamental in hydrological studies. The aim of this study is to compare the accuracy of four open source DEMs (TOPO_IGN, SRTM_30m, SRTM_90m and ASTER-GDEM) in the Quequen Grande River Catchment (QGRC), in the south-west of Buenos Aires Province in Argentina, in two different ways. Determining the vertical error of four source DEMs using geodesic points established by the National Geographic Institute of Argentina (GCP_IGN); and examining the association of DEMs error with hydrological parameters associated to drainage network obtained in each case. The results confirmed differences between GCP_IGN and open source DEMs elevation values. The Root-Mean-Square Error (RMSE) value shows that the uncertainty of elevation measurement is bigger in high altitudinal zones. This is due to two factors (i) the complex landscape pattern in areas characterized by high elevation values within flat study area; and (ii) the level of precision and spatial resolution of each open source DEM. The calculated slope is overestimated in all DEMs, indicating a positive bias and due to this, that slope accuracy is influenced by terrain roughness and pixel size of DEM, mainly. The extract catchments and drainage information from all DEMs area also affect the outcome. The terrain morphology strongly influences the DEM accuracy. So, coming to a conclusion, as in a QGRC, that include zones with high slopes and flat areas, SRTM_30m can be used to obtain height data. SRTM_90m can be used to obtain automatic drainage and catchment delineation. Both DEMs are similar to the obtained by using IGN topographic data. Lastly, the ASTER-GDEM model although possessing a high spatial resolution, turned out giving the lesser appropriate topographic information. These results can be useful for further hydrological, agronomical and environmental studies that employ these DEMs in modeling exercises.

Keywords: ASTER-GDEM; DEM accuracy; SRTM; TOPO_IGN

Introduction

Topography is one of the main factors in controlling hydrological processes [1]. In particular, topography defined (i) hydrological and meteorological characteristics, which control hydrological and thermal regimes of the soils; and (ii) parameters for lateral transport of water and other substances in the subsoil and overland [2]. Choosing a data source that is the more accurately possible in area relief has become fundamental in hydrological studies, involving investment of both time and cash.

Actually, quantitative techniques have been developed in order to automate the interpretation of topography parameters from a Digital Elevation Model (DEM) [3] and various morphometric parameters were developed in an attempt to characterize the landscape [4]. DEM consist of a two dimensional digital array of numbers that represent the spatial distribution elevation on a regular grid [5]. Generally, DEM-derived attributes (such as slope, aspect, curvature and topographic index, etc) are important properties for hydrological terrain analysis [2,6,7]. Therefore, this analysis depends principally on an accurate and spatial resolution of elevation data [8].

Elevation data requisites to carry out DEM can be obtained by topographical survey, photogrammetry or through remote sensing [9]. DEM´s performed in regional projects, frequently used elevation data obtained by using radar interferometry-optical stereo images [9]. Raster maps are obtained through this process, including a value of height for each pixel. On the other hand, local DEM can be created by using contours lines from topographical maps, issued by government agencies. These contour lines are digitalized and interpolated onto a grid [10]. In all cases, the altimetry surveying and principle techniques behind DEM are different [11,12]. This can generate various kinds of errors in the performance of DEM, both to what marginal of error in magnitude and spatial distributions at whatever location, is unknown. Obviously, a better quality of input elevation data is important in the successful use of DEM. Keeping this in mind, the determination of the utility of input elevation data regionally and locally is imperative.

Automatic methods of analysis of DEM can provide hydrological parameters such as drainage networks, generation of surface and sub-surface runoff, definition of flow paths, flow accumulation areas and catchment boundaries [13]. The hydrological modeling from DEM is more cost-effective and objective than traditional field-

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based methods [14]. However, the accuracy of open source DEM for hydrological modeling depends on the topographical conditions in a particular region [2]. Although open source DEM are available for large regions of the earth's surface, it is pertinent, the evaluation of their applicability in hydrological modeling at every particular region.

For intermountain plain region in the south-west of the Buenos Aires Province, the official altimetry data is provide by the Argentina National Geographic Institute (IGN), through from topographical maps at different scales. The use of this information has as disadvantages, regarding the map scale and inherent problems in normal digitalization processing. In the last years, according to technological advances and smoother accessibility to data, the use of altimetry data is more frequent since remote sensing. This data is the result from topographic survey on a global level carried out by aero-spatial agencies from different countries. Such models offer DEM with a different processing degree and have been used as basic input in different hydrologic investigations. However, a comparative analysis that permits the setting of a fit grade and representation that these models have over area with the geological, geomorphological and topographical particularities that the Bonaerense intermountain plain hold is not available at present. These models have been used to obtain altitude of different stations, automatic extraction of height profiles, drainage network generation, runoff definition, geomorphological analysis among others [15-21].

The aim of this study is to produce a comparative assessment of the accuracy of four open source DEMs in two different ways; first, by determining the vertical error of four source DEMs using geodesic points established by IGN; and second, by examining the association of DEMs error with hydrological parameters associated to drainage network obtained from each case. We expect that this study will serve as an orientation tool for the use of different DEMs in areas with similar geological and geomorphologic characteristics.

Methodology

Study area

The Quequen Grande River Catchment (QGRC) is located in a sedimentary basin between two range systems in the Pampa Plain; Tandilia and Ventania in the southeast of the Buenos Aires province (Figure 1). The Surface runoff network of QGRC is asymmetrical and is recognized as one of the major tributaries creeks Pescado Castigado, Quelacinta, Quequen Chico, Calaveras, El Chancho and Tamangueyu (Figure 1). All tributaries situated on the left bank, in what Martinez [22] associated to a neotectonic control. The QGRC at its outlet into the Atlantic Ocean has an average flow rate of $22m^3/s$ with peaks reaching $300m^3/s$ and a maximum historical record of $1942m^3/s$ during September 1998. Discharge is quite constant through the year, but strong peaks as a consequence of heavy rains usually occur during summer months.

This catchment constitutes a portion of the Wet Pampa Plain territory, very representative of this type of geomorphological environment, comprising of the southern slopes of the Tandilia range, important cities such as Necochea, Quequen and Loberia are located within it. In the study area, the Tandilia system has a maximum altitude of about 410m asl. It consists of two big geological units: a Precambrian crystalline bedrock called Complejo Buenos Aires [23] and a set of sedimentary rocks of Precambrian-Lower Paleozoic origin, grouped under the name of Balcarce Formation [24].

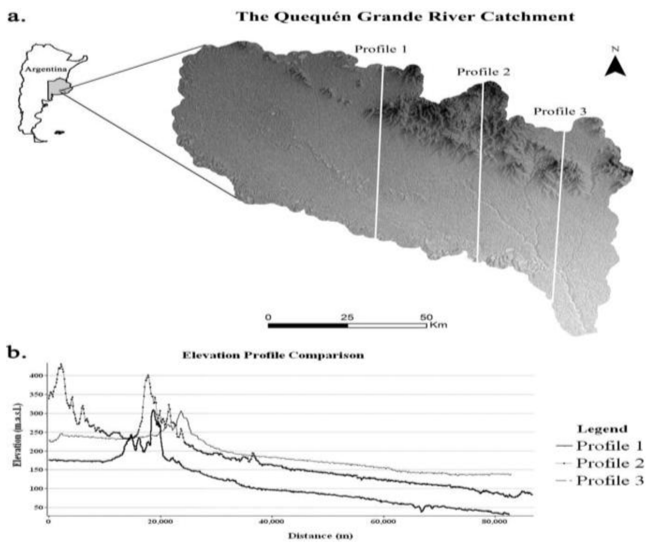

Figure 1: Digital Elevation Model of study area using 90m grid resolution. (a.) The lower part is the Bonaerense intermountain plain, whereas the highly part comprising of the southern slopes of the Tandilia range; (b.) Plot of elevation comparison on three profiles with direction north-south.

The upper Pleistocene-Holocene cover of the area is a sequence of silt, silt-clayed and fine sand sediments of Aeolian and fluvial origin that constitute an aquifer system known as Pampeano Aquifer [25]. It is an unconfined aquifer with a thin unsaturated zone ranging from 0.50 to 25m. The more typical values of unsaturated zone thickness are in the range of 2 to 10m. Groundwater flow path is generally aligned with surface water flow direction. Most of the drainage network shows a gaining behavior in the major proportion of the stream courses [26].

Open source DEMs acquisition and characteristics

For this study, we used four open source DEMs: (i) TOPO_IGN (derived from IGN toposheets); (ii) ASTER-GDEM; (iii) SRTM 90 m elevation data; and (iv) SRTM 30m elevation data.

TOPO-IGN was performed by using hypsographic (river, stream, wetlands) in the 1:25,000 - 1:50,000 map series produced by IGN. The contours used had an interval and accuracy of 2, 5y 10m. The Topo to Raster function in the ArcGis 9.2 software [27] was used to interpolate the transformed contour data into a DEM. Topo to Raster function is based on the ANUDEM program developed by Hutchinson [28] and Hutchinson [29]. Topo to Raster function uses an interpolation technique specifically designed to create a surface that more closely represents a natural drainage surface and better preserves both ridgelines and stream networks from input contour data. The grid size chosen for the TOPO_IGN DEM using Topo to Raster function was based on the following equation:

$$\Delta s = A/2\Sigma L$$

Where "A" is the area of the study site (km^2) and "L" is the accumulative length of all contour lines (km). A complete description of this methodology can be found in Hengl and Evans [30].

The Advance Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) or ASTER-GDEM was developed by the METI (Ministry of Economy, Trade and Industry) of Japan and the NASA [31]. The vertical relative error and circular relative geolocation error of GDEM2 elevation data is less than 17 and 71m, respectively [32]. ASTER-GDEM2 is used for various applications such as geomorphometric analysis [33], volcano topographic mapping [34], watershed boundary delineation [35], glacial studies [36] and rock glaciers [6]. Their application in hydrological modeling is less common. ASTER-GDEM2 are known to be accurate in near-flat regions and smoothly sloped areas and inaccurate in areas covered by forest, snow and limited solar exposure [37]. Errors as a few as a hundred meters can be encountered in areas with deep valleys [38]. These error sources should be evaluated on a regional level. The ASTER-GDEM with spatial resolution 16 m were downloaded from a website of Japan Space Systems (http://gdem.ersdac.jspacesystems.or.jp/).

Shuttle Radar Topography Mission (SRTM) was a joint mission by National Imagery and Mapping Agency (NIMA) and NASA to collect global elevation data set. The SRTM elevation data are derived from X-band and C-band Interferometric Synthetic Aperture Radar (InSAR) sensor (5.6cm wavelength and 5.3 GHz frequency) [12,39]. SRTM elevation data is readily available at three different resolutions; 30m (1 arc-second), 90m (3 arc-second) and 1km (30 arc-second). The vertical relative error and circular relative geolocation error of SRTM elevation data was less than 10 and 15m, respectively. From 2003, SRTM elevation data have been used for various applications [40]. Unfortunately, the original SRTM elevation data contain error from various sources. SRTM elevation data were influenced by natural and man-made features. Therefore, they provide heights of the earth's surface including objects such as vegetation, buildings, etc. These error sources reduce its reliability for hydrological applications. [41]. The SRTM elevation data with 90m used in this study, was downloaded from the website of the Consultative Group on International Agricultural Research consortium for Spatial Information (CGIAR-CSI-http://srtm.csi.cgiar.org). Data available from this site has been upgraded to version 4, which was obtained using new interpolation algorithms and better auxiliary DEMs. SRTM v4 representing a noticeable improvement from previous ones. The data of SRTM with 30m used in this study was downloaded from a website of USGS (http://earthexplorer.usgs.gov/). This data was released in November of 2014.

GIS analysis

The four open source DEMs (TOPO_IGN, ASTER-GDEM, SRTM_30m and SRTM_90m) were reprojected in Argentine Gauss Krüger system, zone 5 to Campo Inchauspe Datum (EPSG: 22195). The entire open source DEMs were corrected for hydrological terrain analysis by creating an elevation grid without any sinks for each basin. Sink occurs when all neighboring cells are higher than the processing cell, which has no down slope flow path to a neighbor cell. Generally, sinks cause obstacles to the calculation of flow direction, leading to inaccurate representation of flow accumulation and drainage networks [42]. Sinks could be real components of the terrain or the result of input errors generated during DEM production [37]. Hence, the sinks have been removed by grid filling function in ArcGis 9.2 software [27].

Open source DEMs accuracy assessment

Two approaches were used to determinate the accuracy of the four open source DEMs (TOPO_IGN, ASTER-GDEM, SRTM_30m and SRTM_90m) in the study area: (i) absolute accuracy and (ii) relative assessment.

Absolute accuracy assessment

Absolute accuracy refers to the closeness of an elevation data from open source DEM and true value [39]. Absolute accuracy was computed by a comparison of elevation data from open source DEM and 115 ground control points (GCP_IGN), which we assumed as reference values. These GCP_IGN were established by IGN and are part of the national geodesic network of Argentina. GCP_IGN were downloaded from the IGN website (http://www.ign.gob.ar).

In this work, the main goal of absolute accuracy assessment was to answer the following question: Which is the absolute vertical accuracy of each open source DEMs within the study area?

The question at hand, absolute errors between open source DEMs elevation data and corresponding GCP_IGN elevation value, were analyzed. On this, a scatter plot was performed and the corresponding determination coefficient (R2) was also reported. Also, Root Mean Square Error (RMSE) was performed to derive elevation error in each open source DEM. RMSE is widely used as an overall indicator for vertical accuracy assessment of DEMs [37,43]. Generally, RMSE exhibits on average how far open source DEM elevation values differ from GCO_IGN elevation values. RMSE was defined as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(GCP\_IGN_i - OS\_DEM_i)^2}$$

Where, GCP_IGNi is the reference elevation of i location, OS_DEMi is the elevation obtained from open source DEM for i location.

Then, the magnitude of absolute errors in the open source DEM elevation data with respect to GCP_IGN elevation data was analyzed from box-plots. This analysis was performed using the “ggplot2” package in R v3.1.2. [44].

Finally, the spatial distribution of absolute errors was analyzed using ArcGIS v.9.2. [27].

Relative assessment

The open source DEM should reproduce as close as possible the terrain shape. Therefore, relative accuracy refers to the reproduction of terrain shape [45].

In this work, the main goal of relative accuracy assessment was to answer the following questions:

(1) What is the difference of relative accuracy between open source DEMs within the study area? (Profile and slope analysis)

(2) What is the effect of relative accuracy of each open source DEM in the simulation of real hydrological processes?

Addressing the first question, the distributions of open source DEM elevation data in segments of 40km in a transect of 132km, were compared and analyzed. This analysis was performed using the “ggplot2” and “grid” packages in R v3.1.2. [44] and ArcGIS v.9.2. [27]. Thus, the spatial distribution of slope derived from open source DEMs were calculated and analyzed. Slope represents the magnitude of the

Table 1: Statistical characteristics elevation derived from each DEM and ground control points of national geodesic network established by Argentina Geographic National Institute (GCP_IGN).

Source	Elevation				
	Pixel size (m)	Media (m)	CV (%)	Min (m)	Max (m)
GCP_IGN	-	189.34	54.76	21.4	524
TOPO_IGN	101	182.22	51.18	20.41	443.2
ASTER-GDEM	15	182.25	52.33	22.64	477.54
SRTM_30m	30	184.98	51.16	26	476.96
SRTM_90m	90	171.69	44.62	16.8	410.34

Table 2: Error histogram analysis of each DEM.

DEM	Error frequency (%)	Interval Error (*m*)	Range Error (*m*)
TOPO_IGN	67.8	-8.0-5.0	13
ASTER-GDEM	63.5	-3.4-6.6	10
SRTM_30m	85.2	-7.9-2.6	10.5
SRTM_90m	67.3	-19.2	19.2

terrain inclination. The ArcInfo method was used for computing slopes [27]. Generally, slope at a given point in a terrain is a function of elevation values. It is a first derivative of elevation describing rate of change of elevation. Together, the slope in the x direction and the slope in the y direction (partial derivatives of d with respect to the x and y directions) define gradient vector of the surface.

$$Slope = \sqrt{\left(\frac{dH}{dx}\right)^2 + \left(\frac{dH}{dy}\right)^2}$$

To address the second question, the accuracy of hydrological behavior of each open source DEMs was evaluated. To this, a simulation of real hydrological processes in each open source DEM was performed using the Soil and Water Assessment Tool Model (SWAT) [46].

SWAT is a physically based and continuous time model developed to predict the long-term impact management on water and sediment in watersheds with varying soils, land-use and management conditions [7,47]. Several studies have determined that SWAT is capable of simulating hydrological processes with reasonable accuracy and can be applied to a large basin [7,48]. However, SWAT depends on the DEM quality and resolution. A complete description of SWAT equations can be found in Arnold, Srinivasan [49] and Douglas-Mankin, Srinivasan [50].

At each open source DEM, the watershed was divided into multiple sub-basing based on topographic features of the watershed calculated applying open source DEM data. The terrain attributes (such as the sub-basins area, slope and slope length) and hydrological processes (such as drainage patters of each watershed), were calculated using the SWAT extension (USDA-Agricultural Research Service, 1998) of ArcGIS v.9.2. [27]. Specifically for this work, the hydrological parameters analyzed and compared were: number of sub catchments, area, perimeter, slope, drainage density, total order number, general order of catchment and stream frequency [51]. Several studies have determined that the accuracy of this hydrological parameters in SWAT depend on the DEM quality and resolution [47,50].

Results and Discussion

Open source DEMs data accuracy

Tables 1 & 2 & Figures 2-4 show the results of absolute accuracy

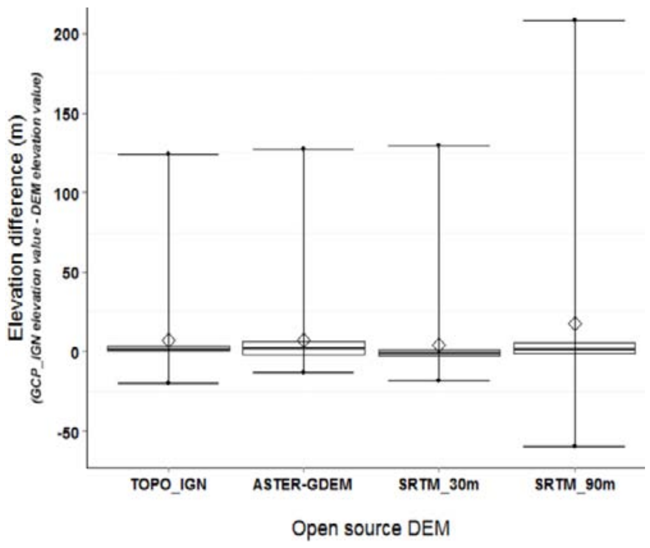

Figure 2: Comparison of absolute differences between open source DEMs and ground control points of national geodesic network established by Argentina Geographic National Institute (GCP_IGN).

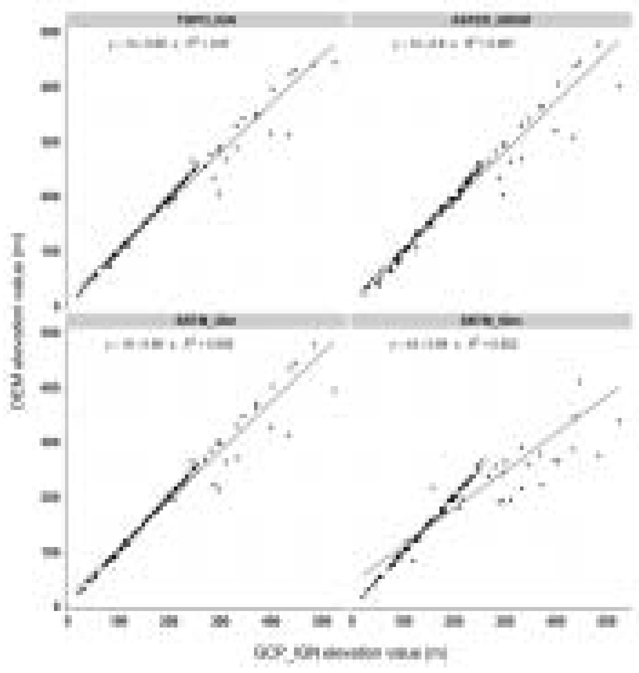

Figure 3: Level of agreement among DEMs and ground control points of national geodesic network established by Argentina Geographic National Institute (GCP_IGN).

assessment.

Our results confirm differences between GCP_IGN and open source DEMs elevation values (Table 1) (Figure 2). The mean, Coefficient of Variation (CV) and elevation Minimum (Min) were similar between GCP_IGN and all open source DEMs, except to SRTM_90m. The elevation Maximum (Max) were dissimilar between GCP_IGN and all open source DEMs. The average of differences of mean elevation values between GCP_IGN and all open source DEMs was 9.05m. The lower difference of mean elevation was between GCP_

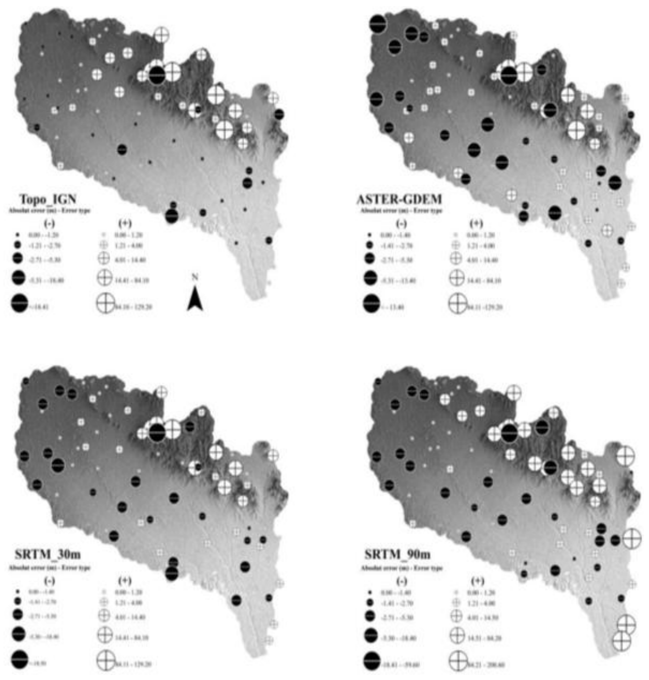

Figure 4: Analysis of the spatial distribution of errors absolute between DEMs and ground control points of national geodesic network established by Argentina Geographic National Institute (GCP_IGN). The size of the symbol is according to the difference of error absolute.

IGN and SRTM_30m (4.36m), whereas the larger difference was between GCP_IGN and SRTM_90m (17.65m). On the other hand, the average of the differences of minimum elevation value between GCP_IGN and open source DEMs was 0.06m, whereas the average of the differences of maximum elevation value between GCP_IGN and open source DEMs was 71.99m. The large differences of elevation values on terrain characterized by high elevation values of GCP_IGN and all open source DEMs could be due to two factors (i) the complex landscape pattern in areas characterized by high elevation values within flat study area [14], in this case as a result of high angle fault interaction, with dominant vertical displacement [52,53]; (ii) the level of precision and spatial resolution of each open source DEM [7,54].

On the other hand, linear regression analysis reveals strong correlation between GCP_IGN and open source DEMs elevation values (Figure 3). This correlation was highly significant ($p<0.001$). It is important to note that in all cases the value of the slope of the regression line was very close to 1. In general, SRTM_90m showed the minor fit with GCP_IGN elevation values (R2=0.852), whereas TOPO_IGN showed the best fit (R2=0.97), followed by ASTER-GDEM and SRTM_30 DEM (R2=0.957 and R2=0.959 respectively). RMSE confirmed important differences between GCP_IGN and SRTM_90m elevation values. Analysis confirmed and revealed a significant decrease in accuracy of all open source DEMs in terrain characterized by high elevation values. Our results indicate that error is minimized for the plain areas (elevation value <300m) and maximized for the sloping regions (elevation value >300m), except to SRTM_90m.

Table 2 shows the results of error histogram analysis, recognizing the peak of error frequency in each open source DEM. In all open source DEMs, most of the 63% of the data have an error lower to 20m. The minor range-error found corresponded to ASTER-GDEM, followed by SRTM_30m and TOPO_IGM, the error frequency value of SRTM_30m DEM being considerably major to ASTER-GDEM.

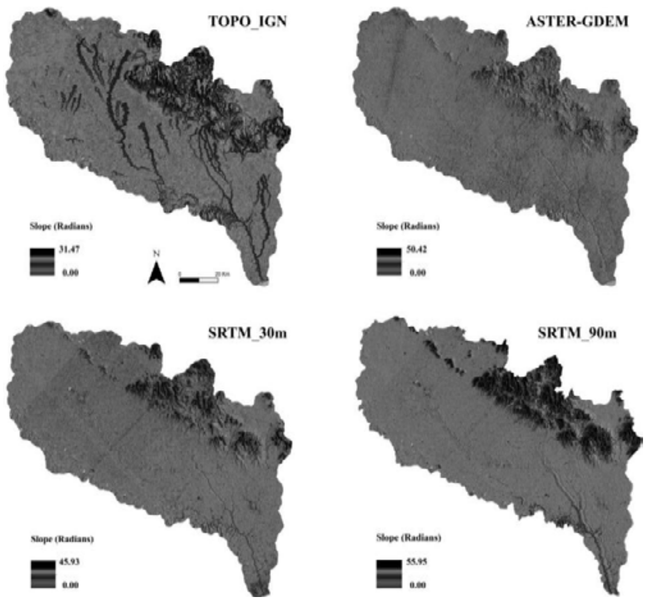

Figure 5: Spatial distribution of the calculated slope from each DEM.

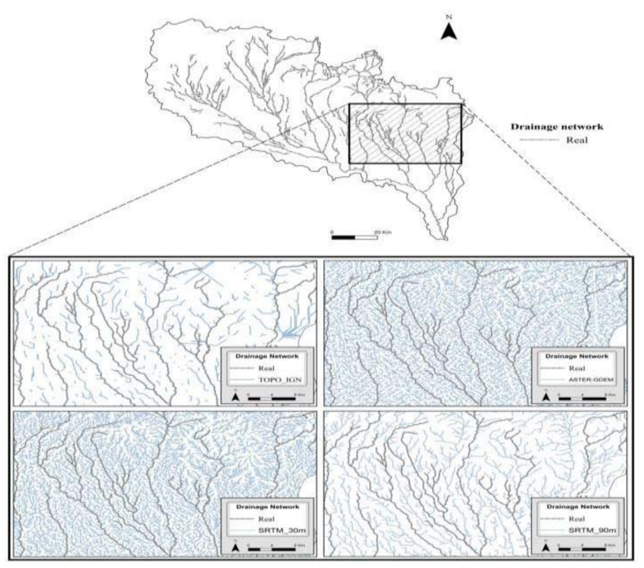

Figure 6: Drainage network extracted from each DEM in a common zone in the central area of the Quequen Grande River Catchment (QGRC).

Figure 4 shows the spatial distribution of errors absolute between GCP_IGN elevation data and open source DEM elevation data. Symbol size is accordance to the difference of error absolute. Also, two symbols were used to differentiate if the error absolute is positive (white symbol) or negative (black symbol). The higher absolute errors correspond to positive values (DEM elevation values larger that GPC_IGN elevation values), establishing that all open source DEMs tend to exaggerate the elevation values. Although TOPO_IGN, ASTER-GDEM and SRTM_30m DEM showed similar RMSE values, ASTER-

Table 3: RMS error of elevation from each DEM relatives to each altitudinal zone.

Altitudinal zone (*m*)[†]	TOPO_IGN	Aster	SRTM_30m	SRTM_90m
	RMSE (m)[††]			
<100	4.61	7.47	1.98	2.75
100-200	8.23	5.33	2.72	11.95
200-300	20.87	19.52	18.95	28.63
>300	78.54	58.4	57.46	128.36

[†]Altitudinal zone with respect to GCP_IGN elevation values.
[††]Root mean square error (RMSE) between GCP_IGN and open source DEMs elevation values.

GDEM showed higher absolute errors distributed throughout the basin, whereas TOPO_IGN and SRTM_30m DEM showed higher absolute errors only in areas with high elevation (>250m). In all cases, larger errors were found in the north of the study area, coinciding with the Tandilia Range system Area. This is more noticeable in SRTM_90m DEM. The latter with a bigger absolute error.

Effect of terrain irregularity on the open source DEMs accuracy

Figures 5 and 6 & Table 3 show the effect of terrain irregularity on the open source DEMs accuracy.

Terrain irregularity is one of the major influencing factors for relative accuracy of open source DEM [55]. In order to evaluate this, the terrain was divided into 4 altitudinal zones (<100m, 100-200m, 200-300m, >300m) with respect to GPC_IGN elevation values. The RMSE values between GCP_IGN and open source DEMs elevation in each altitudinal zone were derived (Table 3).

The RMSE can be an indicator of the effect of the terrain irregularity on the relative accuracy of open source DEMs [14]. A high RMSE indicates important differences between GCP_IGN and open source DEMs elevation values within each altitudinal zone (Table 3). SRTM_30m DEM provides the more accuracy when compared to others open source DEMs, whereas SRTM_90m provides less accuracy. However, SRTM_90m provides slightly less accuracy in the altitudinal zone <100m compared to SRTM_30m. In general, open source DEMs are more erroneous in high elevation zones where the terrain is more irregular and this was also found in the study of Gorokhovich and Voustianiouk [39], Mukherjee, Joshi [14] and AL Harbi [56]. Abrupt changes of slope are frequent in altitudinal zones >300m in the study area. Therefore, the RMSE value shows that the uncertainty of elevation measurement is larger in high altimetry zones. Our results indicate that the error depends on pixel size of open source DEM grid and of terrain irregularity.

The calculated slope from all DEMs is compared with TOPO_IGN slope calculated (Figure 5). The calculated slope is overestimated in all DEMs, indicating a positive bias. The bias increased in DEM with higher spatial resolution. Due to this, the SRTM_90m has higher overestimation of the slope than that of ASTER-GDEM and SRTM_30m. The general slope maps have different extreme values. Also, the distributions are very different between all DEMs (Figure 5). The mean slope value obtained is minimum from TOPO_IGN (0.57 Radians) and maximum from ASTER-GDEM (4.95 Radians). The maximum slope gradients found correspond to SRTM_90m (55.95 Radians) and ASTER-GDEM (50.42 Radians). On the other hand, the maximum value of slope in the TOPO_IGN and SRTM_30m were 31.47 and 45.93 Radians, respectively. These results suggest that the decrease of slope accuracy is influenced by terrain roughness and pixel size of DEM, mainly. Respectively, Mukherjee, Joshi [14] demonstrated that due to coarser resolution of ASTER-GDEM and SRTM, the representation of surface slopes have higher error.

Table 4: Comparison of catchment and drainage parameters calculated from each DEM.

Parameter	Open Source DEM			
	TOPO_ IGN	ASTER-GDEM	SRTM_30m	SRTM_90m
Minimum area for subcatchment (Km²)	1.96	1.85	1.86	1.84
Subcatchments (Units)	36	36	32	40
Area (Km²)	10,228.3	9,808.2	9,776.1	9,460
Perimeter (Km)	771.5	1,216.5	1,062.7	952.8
Mean slope (Radians)	0.57	4.95	1.92	0.93
Cumulative lenght of stream (∑L) (Km)	8,035.1	29,680.2	30,559	11,438.1
Drainage density (Dd)	0.8	3	3.1	1.2
Total Orden Number (∑N)	4,945	81,245	81,365	8,11
General Order of catchment	7	9	8	7

Table 4 shows the hydro-processing to extract catchments and drainage information from all DEMs.

Area and perimeter are important because they directly affect the size of storm hydrograph, the magnitude of peak and mean runoff [57]. SRTM_90m shows the lowest minimum area for sub catchment, whereas TOPO_IGN shows the highest. The lowest minimum area for sub catchment is induces to generate a greater number of sub catchments.

The Drainage density (Dd) determines the time travel by water in a catchment [58]. The measure of Dd is a useful numerical measurement of landscape dissection and runoff potential. A high drainage density reflects a highly dissected drainage basin with a relatively rapid hydrological response to rainfall events, while a low drainage density portrays a poorly drained basin with a slow hydrological response [59].

The Dd values show a high variability in all DEMs (Table 4). The Dd obtained from TOPO_IGN indicates a catchment with a high permeability surface, good conditions for infiltration and suitable conditions as to recharge to the aquifer. To the contrary, the Dd values from SRTM_90m indicate a catchment with a low permeability and suitable conditions for runoff potential, therefore lowering the infiltration and consequently a low recharge is given to the aquifer.

The ordering network system was defined by Horton (1945) and modified by Strahler (1952). This methodology is useful because it provides a rapid method of quantitavely, therefore designating any stream or stream segment anywhere in the world, Gregory and walling (1973). Stream ordering provided the touchstone by which drainage net characteristics could be related to each other hydrological [60]. SRTM_90m and TOPO_IGN show the lowest general order of catchment, whereas ASTER-GDEM shows the highest. In general, these results suggest that in the general order drainage network, the catchment has an 8 value.

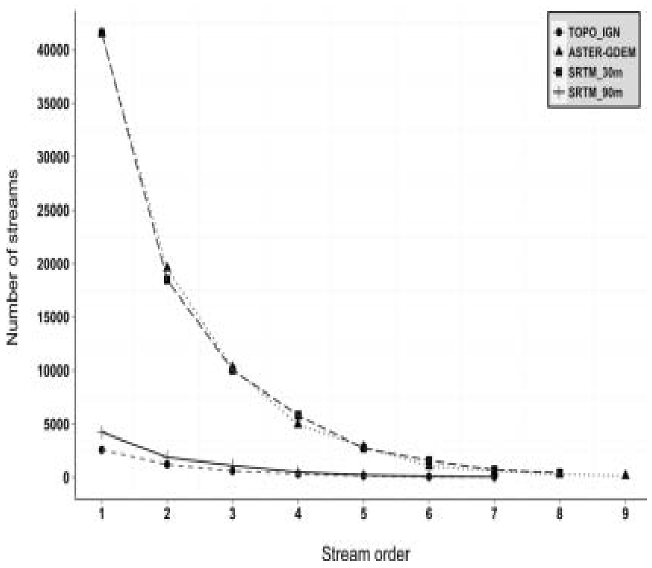

Figure 7: Distribution of different drainage orders from each DEM.

Figure 6 shows different drainage network obtained from all DEMs in a common zone in the central area of QGRC. In each window were compared drainage network from each DEM were compared to real drainage network digitalized from satellite images and cartography. SRTM_30m and ASTER-GDEM, or the low spatial resolution DEMs, generated a high number of low grade drainage and a high drainage density. In one particularly case of drainage network obtained from ASTER-GDEN, can be observed a strong linearity could be observed that suggest geological and geomorphological characteristics associated with igneous and metamorphic formations with structural controls. The drainage network obtained from TOPO_IGN shows confluences drainage zones. These zones can be associated to low flooding areas; the straight configuration of drainage into these areas would indicate an interpolation problem of elevation values. It can be fixed by the inclusion of more levels of topographic contours obtained from higher spatial resolutions maps.

Drainage network obtained from SRTM_90m exhibited the major fit to hydrological cartography, showing a good similarity of confluences between different rivers and the creek. The general drainage density obtained from SRTM_90m is coherent with the evident in the field and in the remote sensing.

Figure 7 shows the distribution of different drainage orders from all DEMs. SRTM_30m and ASTER-GDEM or the high spatial resolution DEMs, present an exponential distribution; being very similar to each other. In the case of the TOPO_IGN and SRTM_90m, a lineal distribution was shown. In both cases, the low number of drainage of first and second orders is significant.

Conclusion

In this contribution, an absolute and relative accuracy of four Open sources DEM in the intermountain Pampa plain were validated. To obtain this absolute accuracy 115 points as ground control points obtained through IGN were used. In this sense, the SRTM_30m has a higher vertical accuracy (in terms of RMSE) followed by ASTER-GDEM and TOPO_IGN. The RMSE of SRTM_90m showed the worst fit to GCP_IGN coinciding with the major absolutes errors within Tandilia Range System. The horizontal profiles allowed us to identify the fit between different models. A high variation of ASTER-GDEM was in evidence along all the profile. Meanwhile, SRTM_90m DEM overestimates and underestimates topographic values in high and low areas respectively.

The Geographical Information Systems offer one the possibility of the use of different topographic data source, depending on the main project objective or specific activity into project. In the case of areas with geomorphologic characteristics as Quequen Grande River Catchment, SRTM_30m DEM can be used to obtain height data. Regarding obtained automatic drainage and catchment delineation the model SRTM_90m can be used. Both results are similar to those obtained by using IGN topographic data, with the advantage that by using SRTM models, there is free access and we can avoid the contour topographic digitization process. In this sense, the ASTER-GDEM model, although possessing low spatial resolution, gave the less appropriate topographical information.

The varied results conclude that the surface representation is highly influenced by DEM position. The vertical accuracy of the DEMs is affected by the morphological characteristics and terrain roughness negatively, having a strong influence on the vertical accuracy. In the higher altitude (>300m) where the variance of elevation is high, height error is also increased.

The best part of the information used in this contribution was downloaded free of charge. Our current study strongly suggests the need to analyze the accuracy of the DEM with a sensitivity test prior to its use in hydrological applications.

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