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Evaluation of "GIS" related tools and their applications in the rivers hydraulic modeling

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Abstract: The research work presented was carried out with the purpose of evaluating GIS Water and HECgeoRAS Geographic Information System (GIS) related tools, which function as a connection node between the HEC-RAS model and the QGIS and ArcGIS software respectively. Here the conditions of creation of the digital model of the land are leveled, with the purpose of obtaining a final result from a parity of circumstances. The case study chosen to obtain the results was the Quebrada Borure located in the city of Barquisimeto, State of Lara, Venezuela. Once both solutions provided by the HEC-RAS hydraulic modeler were obtained, the correlation between both products was determined, being high, close to the value of the unit. Therefore, it could be concluded that both tools are applicable in the data processing for the HEC-RAS model, with the advantage that GISWater is a free license and works under the geographic information system QGIS with the same characteristics.

Key words: GISWater; HECGEORAS; HEC-RAS; hydraulic modeler; GIS tool; geographic information system

1 Introduction

Programs or software designed for hydraulic modeling of rivers or canals along natural or artificial channels can often be found. For rivers in natural state, information about their topographic configuration must be provided in advance. For these cases, topographic survey must be carried out to collect all information about their configuration, but this is not enough for hydraulic modeling. In order to enable hydraulic software to process the above information quickly, it is necessary to make use of other types of software, such as Geographic Information Systems (GIS), which aim to combine basic geographic information to obtain other derived information [1].

It is very common that many hydraulic modelers and users of such tools prefer to use HEC-RAS software for analysis. It is a free modeler developed by the U.S. Navy Corps of Engineers for one-dimensional hydraulic calculations of natural or artificial channel systems [2]. Additionally, it is a software capable of reading the geometric information of the river from a GIS and use it in the modeling or analysis process. Historically, the most widely used tool has been ArcGIS, which can interact with HEC-RAS through its HECgeoRAS extension, although the latter is a paid license, which could be an excluding factor for certain users [3].

In 2015, a tool that works as a connection node between free license GIS environment software and HEC-RAS software called GISWater, which is used as a bridge or link between both programs, was launched on the Web and is also free to download [4]. According to the features provided by the group that created the tool, you can use HEC-RAS to connect to the free access GIS software named QGIS. This will be novel, because a new line will be generated, which can conduct the hydraulic modeling process based on the geographic information processed by GIS without any monetary investment.

Usually, when users do not know the reliability of the new tool at first, they will show some resistance to using it, which will certainly lead them to question how reliable it is to use Giswater tool and QGIS software in the data preprocessing of HEC-RAS software. But to answer this question, we need to study and verify it, because we can't answer it dichotomy.

Researchers from the Department of Water Conservancy and Sanitation Engineering, Department of Civil Engineering of Lisandro Alvarado Central Western University, Venezuela, are responsible for verifying the process involved in this modeling line, using only freely accessible software, namely QGIS, Giswater, Hecras, and when obtaining the results, compare them with the lines in the traditional or most trusted hydraulic modeler environment, such as ArcGIS, HECgeoRAS, and HECRAS. For this reason, the researchers referred to a case study, namely the Quebrada Borure in Iribarren, Venezuela, of which a topographic survey of approximately 675 m of the river in the longitudinal direction was available, including a hydraulic structure (bridge) located on the trunk road 7 (Lara - Zulia).

2 Methodology

2.1 Collect topographic and hydrological information

In order to start the research process, it is necessary to carry out topographic and hydrological research on the study area, including a section of canyon named "Borure" in Iribarren municipality of Lara State in Venezuela. The purpose of selecting it as a research case is to validate the Giswater tool based on its interaction with QGIS and HECRAS. In terms of topographic survey, a topographic survey of approximately 675 m of the stream in CAD format was available [5], but it is suggested that the basic information formed by digital elevation model is through the points measured on site, rather than through a series of lines or horizontal curves in order to avoid errors in the interpolation process by the GIS programmes.

Considering that the hydraulic modelling was carried out for a return period of 50 years, its magnitude was taken from the hydrological study, being equal to 32.03 m^3/s. For this particular case, there was the presence of a bridge located transversely to the bed of the stream, so it was essential to take readings of certain dimensions of the bridge that would be necessary later. Subsequently, the auxiliary files used during the development of the process were created, which referred to the creation of a contour that would allow the delimitation of the study area, the demarcation of the main channel of the stream, the banks and flood plains of the same, as well as the cross sections where it was intended to take a reading of the flow. For the use of the ArcGIS - HECgeoRAS tool, the files must be stored in DXF format. While for the use of the QGIS - GISWater tool, they must be stored in shape file format.

2.2 Digital elevation model (DEM) in the geographic information systems QGIS and ArcGIS

The next step in the hydraulic modelling of rivers with the support of GIS tools is the creation of the digital elevation model. The hydraulic response depends to a large extent on the quality of the model, which is why it is of utmost importance to have an adequate point cloud from the topographic survey, choosing the right interpolation method to be used. In relation to QGIS, only two interpolation methods are available, the triangle irregular network method, better known as TIN, and the inverse of the weighted distance (IDW); while ArcGIS has a wider range of interpolation methods in addition to these two, which is why only those mentioned were selected for the subsequent evaluation.

The TIN method consists of the construction of a triangle network covering the entire surface. Each is constructed by vertices corresponding to points with known heights arranged relatively close to each other. With the grid arranged, it is possible to calculate the points of estimated height from the equation 1 of the plane subtending each triangle:

$$Z = A \times X + B \times Y + C \qquad (1)$$

This is a parametric equation, and the values of A, B and C are determined according to the known values X, Y and Z of the triangle vertices that compose the plane. Therefore, for any point in the calculation plane, its height Z can be derived from its position X, Y [6]. For the IDW method, the Z-value estimation of the unknown height point is calculated by statistically determining the weighted average height of the surrounding points (see Equation 2), and its weighted weight is obtained according to the reciprocal distance between each known point and the unknown point (see Equation 3) [6].

$$Z_i = \frac{\Sigma(z_j \times w_{ij})}{\Sigma(w_{ij})} \qquad (2)$$

$$W_{ij} = \frac{1}{D_{ij}^{p}} \qquad (3)$$

Where:

Zi Estimated value of height at point i, weighted average of known point heights

Zj Known height value of all j points

Wij Weight, inverse distance between i point and other j points

D_{ij} Distance between point i and point j of other known heights

p Exponential factor ranging from a value of 1 and upwards

As the value of the exponential increases, the influence of the height of the furthest points is considerably reduced, giving prevalence to the known heights closest to the point at which the calculation is made.

The procedure for generating the DEM in QGIS is detailed below:

From the point cloud coming from the topographic survey in shape file format, the QGIS interpolation complement window was opened, assigning the size of the interpolation unit (0.10 x 0.10) m, and the attribute to be interpolated. In this particular case, elevation was selected, so it was necessary to verify the correspondence of the type field together with the option points. If the IDW method is chosen as the predictive method for the interpolation values, the same window used for the TIN must be invoked, but this time with the exception of defining an additional parameter, the exponential factor "p", which, as indicated above, will define the influence of the predicted values with respect to the already known nearby values.

At this point, it is relevant to highlight that QGIS displays DEMs in grid mode, since it groups the information in grids, i.e., although the interpolation method is a triangle network, as in the first case, internally, it then transforms the DEM into a raster file, based on a set of pixels with specific elevation attributes. In the same vein, for the creation of the digital elevation model in ArcGIS software, it describes a sequence similar to that of QGIS. But this software incorporates other interpolation methods in addition to TIN and IDW. However, here it was limited to the use of the two mentioned above, in addition to the fact that the DEMs provided by this software are not presented under raster images, so it is necessary to make the transformation, because it is intended to match the conditions with QGIS.

For the creation of the DEM in ArcGIS using the TIN method, it was necessary to have the contour lines in CAD format, which would be transformed to raster later, following the path ArcToolBox / Coversion Tools / To Raster / Polyline to Raster. It was possible to define the output files of the DEM, which alludes to the storage path of the DEM and the size of the interpolation cell. The created file was then transformed to point format, which was possible by taking the ArcToolBox / Coversion Tools / From Raster to Point route. Once the file was in point format and raster type, the DEM was created through 3D Analyst Tools / Data Management / TIN / Create TIN. Finally the DEM was available under the required conditions.

Then the transformation to Raster format was carried out to equalise the conditions with respect to QGIS as indicated in the previous paragraph. For the creation of the DEM using the IDW interpolation method, unlike the TIN, the route of ArcToolBox / 3D Analyst Tools / 3D Interpolation / IDW is selected. 3D Interpolation / IDW. Fig. 1 shows the DEM obtained by the TIN method.

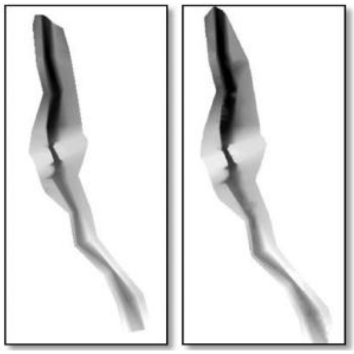

Fig. 1. Digital terrain elevation model raster created in: a) ArcGIS; b) QGIS

2.3 Preparation of the HEC-RAS geometric data file via ArcGIS-HECgeoRAS and QGIS-GISWater

In the case of ArcGIS, once the DEM was created, the HECgeoRAS extension was used to create the attributes of the river, which were given from the superimposition of the auxiliary files, i.e. the creation of the channel line, banks, flood plains and cross sections were digitised using these files as a background. During the same step, the Manning's roughness coefficient was also assigned to the terrain of the study area. Subsequently, the geometric data of the river was exported to the HECRAS modeler, the format was given the *.sdf* extension.

As far as it is concerned, QGIS does not have the integrated tool for loading river attributes as ArcGIS has. In this regard, it is necessary to use the GisWater tool to interact with QGIS and HECRAS. Because GisWater works outside the QGIS interface, it is called to start the program. Once the tool is started, some necessary parameters must be set on its main interface, such as selecting the program that you want to connect with GisWater. For this study, in addition to selecting the database you want to cooperate with, you also selected HECRAS, because the program belongs to the validation line. The database was used to connect PostgreSQL database to PostGIS 2.0 or later.

Next, on the same main interface, but in the "Project Data Management" section, the identification of the new project was defined when redirected to the Create Project, where the identification referred to the name of the project, creation date, authors and coordinate system to be used. Subsequently, the path of DEM created in QGIS was included, for which it is important to point out that GISWater is compatible with different DEM formats, such as geoTIF, img, asc, txt.

In the main interface window, the creation of a new GIS project was defined, which is noted in Create Gis Project, where the data such as the name of the GIS project, storage path, etc. were specified. On successful completion of this step, the tool automatically creates the new GIS project, where the QGIS software is opened immediately, showing the creation of the layers or attributes of the river, including the bank layer, flood plains, cross sections and the main river channel. The auxiliary files that will serve as a background for digitising the aforementioned attributes must then be loaded.

Once all the layers had been digitised, a file had to be generated within QGIS that the HECRAS programme would recognize. To do this, the GISWater tool had to be used again to invoke the storage path of the file in SDF format (Standard Data File) created in QGIS that would be read by HECRAS for the hydraulic modelling, because GISWater can dictate certain orders for QGIS to execute, as in the case of the latter.

2.4 Hydraulic modelling of the Borure stream

The hydraulic software used for the hydraulic modelling of both files was HEC-RAS in its version 5.0.3 and the data input in HEC-RAS was done by means of a graphical interface which contemplates the creation of files, where the unit system and geometric data must be selected. In this case, these data are created outside the software, and the flow type data and boundary conditions of the model are imported. In the geometric aspect, the bridge belonging to the case study was included. In addition, the Manning's roughness value was assigned for the file generated by QGIS-GISWater, since it is not yet possible to assign this value directly from the QGIS-GISWater interaction as ArcGIS - HECgeoRAS does.

Having made necessary changes to the river geometry, a file was created containing the flow, peak flow for Tr=50 years, and boundary conditions which were assumed to be uniform flow for both upstream and downstream. Once the necessary files for the modelling were available, the modelling run was carried out.

3 Analysis of results

3.1 Selection of the interpolation method for digital elevation models

For the selection of the digital terrain model, it was necessary to choose the interpolation method that best suited the terrain configuration. For both GIS programmes, two digital models were created, one using the IDW interpolation method and the other using the TIN method. For this purpose, a visual assessment was made, which consisted of comparing typical sections and determining which of them showed a result more in line with the terrain (see Fig. 2).

As can be seen in Fig. 3b, in the IDW method, the typical sections generated by the QGIS software showed marked irregularities, which were not in accordance with the real configuration of the surface, as they showed certain jumps of up to 200m difference in an area where the cross slope does not have a pronounced sinuosity. The same method used in ArcGIS software showed results closer to the real terrain surface. Meanwhile, for the TIN method, in both geographic information systems, QGIS and ArcGIS, the results were consistent with the terrain. For this reason, the IDW method was discarded and the following analysis is based on the digital elevation models obtained by the TIN method.

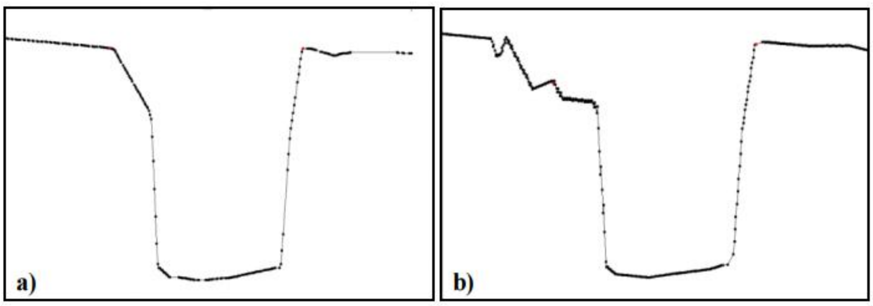

Fig. 2. The bridge upstream cross section created in ArcGIS by the following methods: (a) TIN; (b) IDW

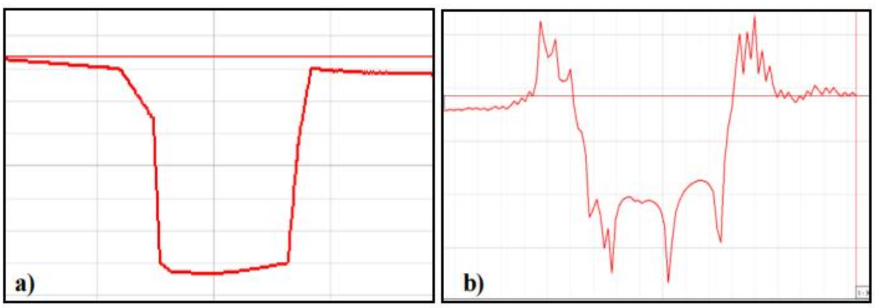

Fig. 3. The bridge upstream cross section created in QGIS by the following methods: (a) TIN; (b) IDW

3.2 "Canal bottom elevation" variable analysis

Considering that geometric shape is the main feature of DEM, this attribute included in DEM has been studied, including the graphical comparison of the longitudinal section of the river axis and the cross section of the canyon obtained by each GIS, as shown in Fig. 4 and Fig. 5.

The similarity between the longitudinal section and the cross section shown in Fig. 5 is proved. However, in order to numerically compare the variability presented in the results from both GIS programmes together with their respective connection nodes in the processing of geometric data, a graph was made where the abscissa axis represents the background elevation of each cross-section created and exported to Hec-RAS through QGIS -GISWater. The same variables are represented on the ordinate axis, but they are obtained through ArcGIS-HecGeoras, and then statistical parameters called correlation coefficients, also known as R2, are used. Its special feature is that when they are close to the unit, that is, the value equal to 1, they infer that the correlation between the data is increasing.

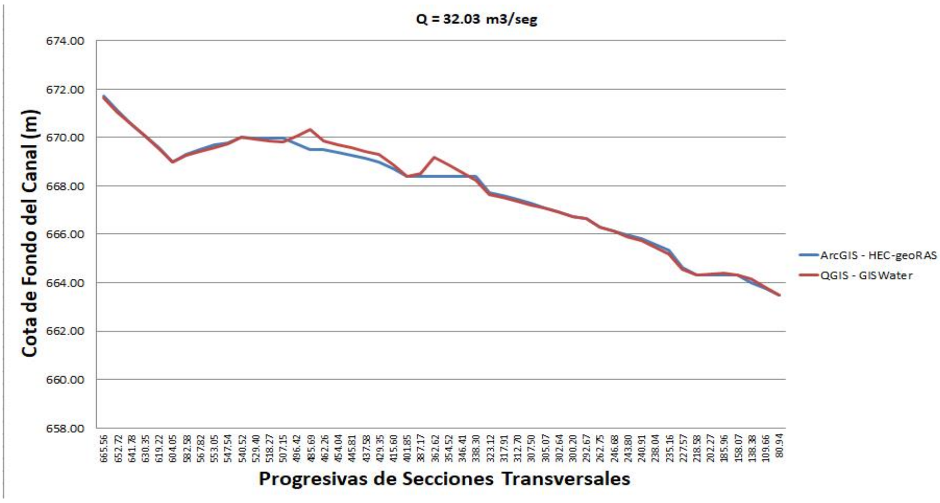

Fig. 4. Longitudinal profile of the stream under study

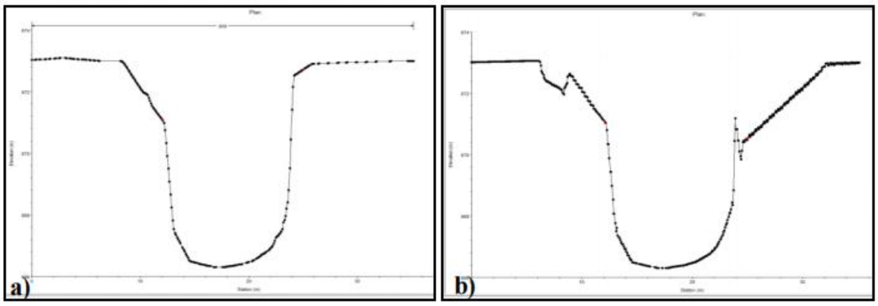

Fig. 5. Downstream cross-section of the bridge created in: a) ArcGIS-HEC-geoRAS; b) QGIS-GIS Water

In this sense, it can be seen from Fig. 6 that the variable canal bottom elevation is highly correlated and very close to unity, indicating that the two results are very close to each other, which translates into the reliability of the profile created in any program used.

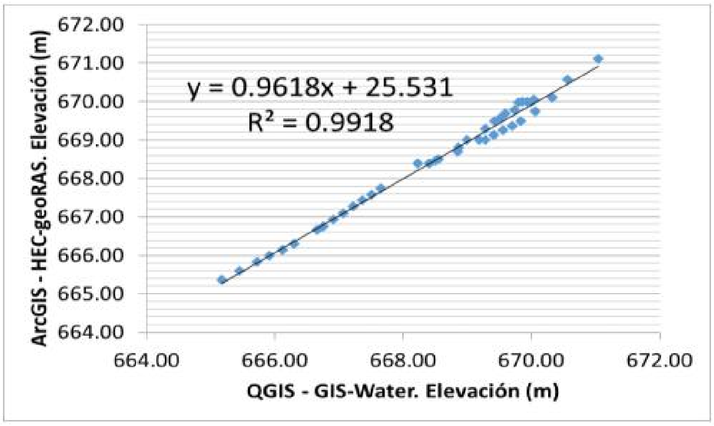

Fig. 6. Data correlation of variable "canal bottom elevation"

3.3 Analysis of the results generated from HEC-RAS

The first component to be evaluated was the geometric component, linked to the data input to the Hec-RAS hydraulic model, followed by the analysis of the most representative hydraulic variables, such as the flow rate, the average velocity and the Froude number. The latter is related to the results obtained by the software according to the geometric configuration created in each GIS. For comparison, the same procedure described for the variable canal bottom elevation was followed.

Tension: Fig. 7. shows the water surface profile. As can be seen in the graph, the profiles were very similar, as they depend to a large extent on the geometric input information, and having obtained a high correlation in this aspect, as indicated in the previous item, this result was to be expected.

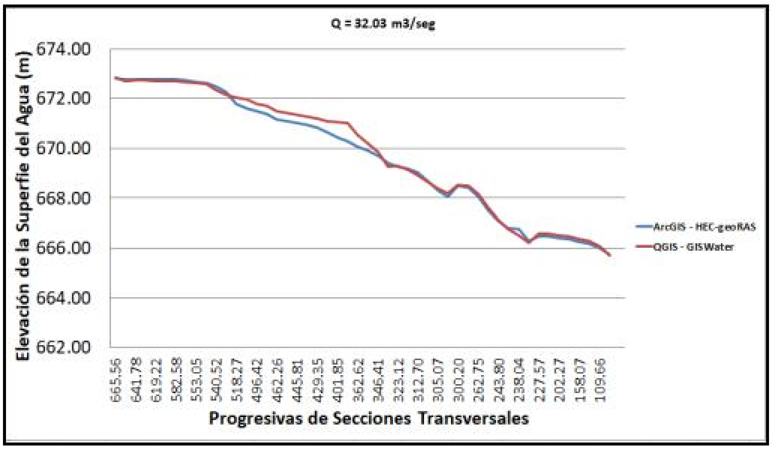

Fig. 7. Elevation of water surface or suspender

The statement in the previous paragraph is digitally verified by crossing the suspender variables and calculating the correlation coefficient. In this sense, the correlation between the two running results can be accepted, because the value of 0.95 is higher than 0.8, so it is considered very high, which can be seen from Fig. 8.

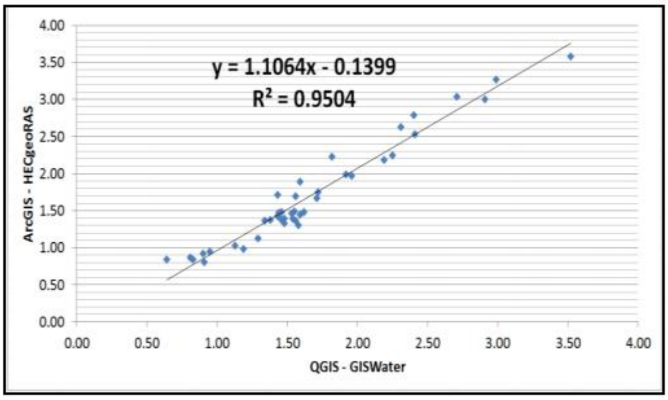

Fig. 8. Correlation of data for the variable "flow rate" with Q=32.03m^3 /s

The suspender variable is very important in the hydraulic analysis study. In order to seek the closest verification of the results, this value is conducive to determining the approval of the tool under study.

Average velocity: with respect to this parameter, the values continue to maintain strong correlation, and these results can be observed in Fig. 9. However, compared to the value obtained for the Tirante, the correlation coefficient decreases from 0.95 to 0.93, and the points on the right side of the chart are more scattered, which means that the velocity variable is more sensitive to the geometric variations involved in using different GIS for the creation of the digital elevation model, and in general the geometric data file, but they are not significant.

Like the Tirante, the average speed is directly related to the configuration of the cross section. In a wider cross section, the suspender tends to decline, so the speed will increase, because each cross section is unique to each DEM. When two elevation models are used to simulate the same flow, there will be small differences, so the correlation coefficient is not uniform.

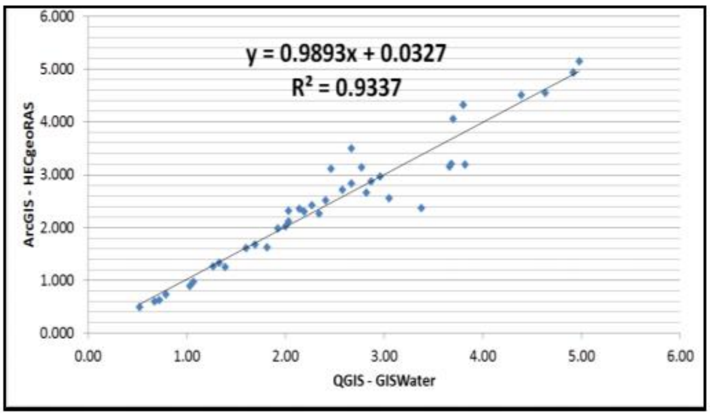

Fig. 9. Correlation of data for the variable "Average velocity" with Q=32.03m^3 /s

For comparison, a maximum and minimum speed table (see Table 1) is made for the two files generated from the GIS program, and their similarities can be clearly seen.

Table 1. Maximum and minimum speed of each GIS model

Tr: 50 years		
GIS program	Maximum speed (m/s)	Maximum speed (m/s)
ArcGIS-HECgeoRAS	5,15	0,50
QGIS-GISWater	4,98	0,52

Froude number: The correlation of this variable is similar to that of the average speed, because Froude number is proportional to the speed. In the same order, as described in the previous paragraph, correlation values higher than 0.80 indicate high correlation, as shown in Fig. 10.

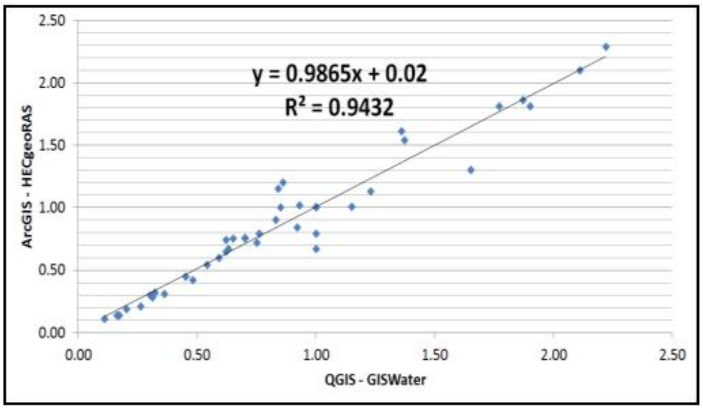

Fig. 10. Data correlation of variable "Froude number" with Q=32.03m^3/s

In relation to the visualisation of results, ArcGIS under the HECgeoRAS extension has a great advantage over QGIS-GISWater, as the ArcGIS connection node behaves in a bidirectional manner, i.e. it is possible to export the results to the GIS to generate flood-spot type results, while Giswater is only applicable to hydraulic analysis under the Hec-Ras software, Therefore, it is impossible to compare the results in this respect.

4 Conclusion

• It was found that for both GIS models the TIN method of surface interpolation was the best suited to the reality of the channel geometry. The IDW method in QGIS presented irregularities in the cross sections.

• In the case of the TIN method, QGIS internally converts the digital elevation model into raster format. While in ArcGIS it is possible to work in raster format or convert it into raster format manually.

• The method route of creating digital model in QGIS is shorter than that in ArcGIS, and the application is more practical, that is, it needs to call more commands to reach the final result, but the speed of creating and executing digital model in ArcGIS is faster than that in QGIS.

• QGIS-GISWater processes the data to HEC-RAS without the need to execute a route for the extraction of attributes, since the changes that are produced in the QGIS interface are registered in the GISWater database. Once it is identified as fields of . sdf format for HEC-RAS, an instant storage cloud will allow changes to be saved as soon as a modification is made to the file in question, so at the end of creating the file that HECRAS will use for modelling, it will already be updated in GISWater without having to perform any additional export. Unlike HECgeoRAS, it does this only if the user executes it via commands.

• The high correlations of the results obtained through the implementation of the two GISs statistically validate the joint work of the GISWater connection node and the QGIS software, which leads to the conclusion that this freely licensed tool can be used with confidence in the same way as HECGeoRAS in Arc-GIS, with the limitation that the latter is a commercial licence.

• In the QGIS software, it is recommended not to keep the digital elevation model layer selected in order not to make spontaneous edits or modifications to the DTM created by GISWater in QGIS, as this causes updates and registrations of the database in very short times, resulting in a crash of the QGIS runner, which causes unexpected exits and sudden loss of the work done.

• GIS tools are undoubtedly important sources for the creation of these types of projects, allowing the ease of handling large numbers of geo-referenced data and at the same time graphing results for easy interpretation.

• It is recommended that the developers of the GISWater tool incorporate the option to make it a bi-directional tool, i.e. to allow the export of results from HEC-RAS to QGIS.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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