Combining historical cartography and GIS to unravel the mysteries of the Isabel II dam in Níjar (Almería)

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Resumen

La presa de Isabel II, también conocida como Pantano de Níjar, es una de las obras hidráulicas más impresionantes del siglo XIX en la Península Ibérica, pero también es un excelente ejemplo de cómo al ignorar los condicionantes climáticos y geológicos, grandes obras de ingeniería pueden ser económicamente desastrosas. Después de ser inaugurado en el año 1850, los altos niveles de erosión de la cuenca inutilizaron la presa en un período muy corto de tiempo, durante el cual el embalse se llenó de depósitos sedimentarios en lugar de agua. Este colmatamiento rápido de la presa ha sido estudiado a fondo por varios investigadores pero, debido a que ésta ha estado llena de sedimentos durante más de 100 años, ha sido imposible saber cómo era la cuenca antes de que fuera construida o exactamente cuánto material hay retenido. Sin embargo, los planos históricos del embalse, así como vistas y mapas de la zona siguen siendo accesibles, lo que permite tener una idea exacta de cómo era el paisaje antes de su construcción. Cuando esta información histórica se combina con el uso de técnicas de SIG y de trabajo de campo es posible lograr mejores niveles de comprensión sobre por qué la presa se colmató tan rápido y qué cantidad de sedimentos contiene el embalse. Al recrear en 3D la antigua cuenca del embalse de hace 160 años y compararla con la actual se obtienen respuestas a algunas de estas preguntas, mientras que surgen nuevas cuestiones no consideradas aún.

Palabras clave: Sedimentología; Cartografía Histórica; Pantano de Isabel II; Níjar; 3D; Recreación Histórica;

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Abstract

The Isabel II dam or Pantano de Níjar is one of the most impressive 19th century hydraulic works in the Iberian Peninsula, but it is also a prime example of how by ignoring the climatic and geological conditionings major engineering works can be economically disastrous. After being inaugurated in the year 1850, high levels of sediment yield caused the dam to become useless in a very short period of time as the lake progressively became filled with sedimentary deposits instead of water. This quick filling of the dam has been thoroughly studied by many current researchers, but since the dam has been full of sediment for over 150 years it has been impossible for them to know how the basin was like before the dam was built or exactly how much material is retained by the dam. However, the plans of the dam, together with views and maps of the area have survived the test of time and are still accessible, which allows having an accurate idea of how the previous landscape of the area was. When this historical information is combined with the use of modern GIS techniques and fieldwork it is possible to achieve better levels of understanding of why the dam got filled so fast, how did it happen and how much sediment the dam holds. By recreating in 3D how this area was like 160 years ago and how it is now this research provides answers to some of these questions, while rising new issues which had not been considered yet.

Keywords: Sedimentology; Historical Cartography; Isabel II Dam; Níjar; 3D; Historic Recreation;

1. Introduction

During the early 19th century plans to improve the agricultural production and enhance the population density of the Campo de Níjar were drawn (Paniagua Mazorra, 1992). The area, back then scarcely populated (Molina, Provansal, & Instituto de Estudios Almerienses, 1991), lies East of the Andalusian city of Almería and it is located in one of the driest places of Europe with very low levels of precipitation and very high insolation (Garmendia, Tomás, Labajo, Universidad de Salamanca, & Asociación Meteorológica de España, 1989). Such climatic conditionings made farming an arduous task and most locals had to resort to subsistence agriculture, a relatively unproductive means of life with resulted in the area being deprived, with periodic hunger episodes occurring during those years with a more adverse meteorology (Pérez Cuadrado, 2010). In order to increase the productivity and population of the area, a group of private entrepreneurs started a campaign to raise money to build a dam and a canal which would irrigate and consequently increase the value of the land downstream (Vázquez Guzmán, 2011). These capitalists managed to convince around a thousand stockholders (Vázquez Guzmán, 2011) who willingly invested in the venture; most of them were however not local, with many of them being from Málaga or even as far as Madrid (Vázquez Guzmán, 2011). Once the money was put together they started the construction of the dam which would feed the canal and secure the water for irrigation.

The selected stream were the dam was built was the Rambla del Carrizal – also known as ‘del Pantano’ (Instituto de Cartografía de Andalucía, 2000) and ‘de los Colectores’ (Roquero, 1991) -, an intermittent stream located at the piedmont of the mountains which surround the Campo de Níjar but which only carries water during very wet years or when torrential thunderstorms suddenly pour water creating flash floods (Fernández Bolea, 2007). At one point the Rambla passes through a very narrow gorge and it was decided that that would be an ideal place to build the dam, so works started. By the year 1850, during the reign of Isabel II of Spain (Cowsans, 2003) and after some financial difficulties, the dam was finished and inaugurated (Vázquez Guzmán, 2011). After the completion of the dam, the investment company established to build the dam and the canal went bust and stopped operations (Vázquez Guzmán, 2011), so the canal which was supposed to irrigate the fields downstream was never completed and the dam was left unattended (Vázquez Guzmán, 2011).
The abandonment of the dam meant that sediment carried downstream by the Rambla was never cleared, which lead to the progressive deposition and accumulation of layer after layer of sediments at surprising rates due to the area’s semi-desertic climate (Langbein & Schumm, 1955). Reports about the speed in which the dam was filled with sediments are not clear and vary depending on the sources, but it appears that the dam became filled in around 20 years (Fernández Bolea, 2007), so the sediment yield was unusually high, leading to the present situation of a lake of earth instead of water (see Fig. 1). This intense erosion rate has been noticed by several geomorphologists who have tried to measure it and have consequently become interested in the dam (Roquero, 1991).

![Fig. 1. The Isabel II dam nowadays, with the contained sediment on the right side. Source: Author’s work.](image)

One of the parameters needed in order to calculate the sediment yield is how much sediment does the dam hold, an unknown figure as it became filled in a time when measurements or graphical work were not commonly used. The amount of sediment which the dam can hold is crucial for geomorphologists in order to perform calculations about erosion rates, so an accurate figure should be sought, but so far only approximate estimates have been used and no accurate figure has been given (Roquero, 1991). In this paper a method to identify the amount of sediment contained by the dam is designed, applied and an accurate figure is given.
2. Methodology

Since the dam was built over 150 years ago and it became filled with sediment shortly after its conclusion the amount of quantitative data about it is almost non-existent. Since the exact shape of the basin before the dam was built is not known it is necessary to virtually recreate it as the alternative would imply emptying the lake from sediments, an expensive and arduous task. In order to overcome these limitations the proposed method uses a combination of desk based work, archival and on site fieldwork with its corresponding datasets:

Current datasets:
- 5m resolution Digital Terrain Model (Instituto Geográfico Nacional)
- 0.5m PNOA orthophotograph (Instituto Geográfico Nacional)
- Topographic maps of the area at different scales (Instituto Geográfico Nacional)

Historic data:
- Original plans of the dam (Ministerio de Fomento)
- Historic aerial imagery of the area (Instituto Geográfico Nacional)

Fieldwork data:
- Maximum sediment perimeter height
- Maximum height of dam

Without knowing the original shape of the valley it is not possible to calculate the volume of the dam, so the first step is to look for historic cartographic information of the area. In this case the Ministerio de Fomento has the original documents and plans of the engineering project of the dam, which once digitised and overlaid on top of current cartography where used to identify the original shape and size of the valley. Secondly, and by using historic aerial pictures, the evolution of the sediment surface extension was analysed. By combining images from different times it was observed that the current surface occupied by sediments was not the maximum level it had had, some sediment was being lost. It was later found that this was due to the lower doors of the dam being bust, but it meant that it was necessary to measure the current sediment surface but the preterit one, as that was the maximum sediment the dam accumulated when it filled the first time around.

In order to precisely measure the maximum sediment extent historic aerial imagery is not detailed enough, so field measurements were deemed necessary. Initial observation showed that the current loss of sediment was indeed a reality, as figure 2 shows. Fortunately for this research, the extreme margins of the top sediment layer had clung to the rock and are still clearly visible, which allowed creating a perimeter using GPS measurements which followed the highest sediment level. This perimeter allowed knowing the maximum surface which the sediment bulk ever reached. At this point, the top surface of the sediment and the primitive river channel were known, so in order to calculate the actual volume of the collected sediment only the profiles of the original mountainsides were needed, a datum which was not recorded in any of the historic documentation.
The calculation of the slopes was done by interpolation using the Natural Neighbour method as it gave the most adequate results. Other methods were tested but results did not comply with what it would be expected from the area. The points used in the interpolation were:

- Elevations recorded every 5m from the maximum sediment height perimeter
- Elevations of the primitive river’s channel path every 5m -assuming that it flowed at a steady gradient
- A cloud of random elevation points from the current DTM covering the slopes of the basin

Once the interpolation surface from these points was created the original basin shape was obtained as a result, so in order to find out the exact volume of the dam is was just necessary to subtract the maximum sediment surface to it.
3. Results

The application of the method provided relevant results which lead to the discovery of the maximum amount of sediment held by the dam, but not only. For example, by applying standard hydrology analysis and using the very detailed DTM available it was revealed that the exact watershed surface of the basin upstream from the dam is 18.3803 km$^2$. This figure is similar but more precise than the value used in previous research, which was of only 18 km$^2$ (Roquero, 1991). The surface and perimeter length of the maximum sediment contained by the dam was also calculated at 13.031ha and 21111.58m respectively. All these figures can help geomorphologists calculate the sediment yield of the basin more precisely, therefore attaining better results.

The proposed method also allowed creating a reconstruction of how the valley was before the year 1850, when the dam was completed and the sediment began accumulating, as figure 3 shows. The shape of the bottom of the valley was established by what the old plans of the dam stated, while the rest of the recreation used the methods and datasets described in the previous section.

![Fig. 3. Recreation of the valley before the dam was built. The red line represents the perimeter of the maximum sediment level held by the dam and the purple dots the top of the dam. Source: Author’s work.](image)

Finally, the last result was the actual volume of sediment stored by the dam at its peak, a figure not known before. By substracting the maximum sediment surface and the recreated valley shape it was possible to calculate the volume which has been filled by sediments, as illustrated by figure 4. In this case it was found that the maximum amount of sediment stored by the dam was of 1 hm$^3$, a value which halves the volume estimated by previous researchers (Roquero, 1991).
4. Discussion and conclusions

Results have proven that the described method is very powerful and successful as by combining information from different sources new data which was not available before can be obtained. When compared with previously existing papers about the Isabel II dam, it can be observed that the extremely high erosion rates (Roquero, 1991), while being significant, were not accurate due to the fact that nobody knew how much sediment was held by the dam and estimations doubled the results obtained by this paper (Roquero de Lamburu, 1964). This means that thanks to the application of this method geomorphologists can now make more accurate sediment yield calculations without having to use expensive destructive methods.

As a result, the proposed method can be replicated and used in other filled up dams of unknown capacity, but it should be noted that it has several limitations. The biggest one is that information about the original shape of the dam could not be accessible or not even exist. In this case, knowing the path in which the primitive river channel flowed would be impossible, something which would greatly hinder the final results. Not all areas or projects have had bespoke detailed cartography created, and even if they had it could be the case that historic documentation has been lost or destroyed. In those cases the method could still be used, but results would be coarser and more inaccurate.

The other great limitation the present method has is that it makes several assumptions which may or may not be totally accurate all the time. The first assumption is that the original river flowed on a constant gradient, so slope remained the same along the area which is currently covered by sediment. This assumption results from the lack of information about how the river was before the dam was built and it could be minimised by replicating the characteristics of similar neighbouring streams into the model. The second assumption is related to the first one, as it is presumed that the slope of the mountains covered by sediment is
constant. Even if this supposition is somehow minimised by the interpolation method used is may be a source of error which should be taken into account when presenting the result.

In any case, all these limitations do not hinder the validity of the results as even if some error is introduced by the model it will under most circumstances be minor and will in any case be better than the previously existing crude suppositions. This method should therefore be considered as a good way of recreating how currently covered valleys used to be. Moreover, the method described here could be used to recreate any type of covered surface and know how much material is contained in it, be it sediments or liquids. Therefore it could be concluded that, if the aforementioned limitations are taken into account, the proposed method could be used not only for the Isabel II dam, where it has been successful, but in other similar cases anywhere else.

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