An Automated Procedure to Assist Site Selection of Water Harvesting Structures

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Summary

A novel procedure is presented for identifying water harvesting sites and their potential storage capacities from spatial data of water scarce regions. Via analysis of Digital Terrain Models, the procedure identifies appropriate sites, applies barriers (representing dams etc.) and combines these with topographic contours to create polygons representing areas impounded by the barriers. These polygons are then intersected with elevation data to obtain the potential storage volume created by each barrier. Vegetation cover within each polygon is also extracted, from spectral-based rasters. This improves on existing water harvesting site selection techniques which consider parameters (e.g. slope) on a cell-by-cell basis.

KEYWORDS: Water Harvesting, Automated Site Selection, GIS, Digital Elevation Model

1. Introduction

Water harvesting has several definitions, one of which is "the process of concentrating rainfall as runoff from a larger area for use in a smaller target area" (Oweis et al., 1999, p.V). Typically, water harvesting is undertaken in arid and semi-arid regions, for a number of different purposes. Often structures consist of bunds aimed at promoting the growth of trees or crops. Other schemes are intended to reduce erosion, increase aquifer recharge, or to store water.

Information acquired by remote sensing and GIS analysis, is often used to help locate sites for water harvesting structures. In a review of approximately 50 research papers focussed on siting water harvesting structures, Adham et al. (2016) found that slope, land use/cover, soil type, rainfall, distance to settlements/streams, and cost were the most common parameters used as part of site selection processes. A noticeable shortcoming in such processes is that, since parameter values are gathered on a cell-by-cell basis, no overall information on the entire water harvesting 'wetted zone' created by the structure is gathered. Cell-by-cell studies of slope, for example, do not allow decision makers to compare the volume impounded by a barrier to the size of the barrier itself, and thus identify the best value option. Neither do they allow judgments of whether sites are more suited to impoundment for cultivation or storage based on the synoptic topography.

Selecting sites manually is a time-consuming. The procedure described here automates this process via a Python script within an ArcGIS Pro environment. A key feature of the procedure is that the direction of the barrier is estimated by creating an axis perpendicular to the flow direction.

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2. Process

The procedure operates on a raster format Digital Elevation Model (DEM), which is added to ArcGIS Pro Contents before the script is run. Ideally, the DEM should be a terrain model that represents the ground surface – rather than a surface model which incorporates vegetation – in order to more realistically model the surface runoff flow paths. The first step is to create a 'filled' DEM raster. **Figure 1** shows this step in a simplified manner, together with the other parts of the process explained in this section.

Using the 'filled' DEM as the input raster, a flow direction raster is produced. The flow direction is in D8 format, meaning the flow from any cell has one of eight directions (north, north east, east, etc.). The flow direction raster is then used to create a flow accumulation raster.

A Points Feature Class (FC) is created from the raster containing the extracted flow accumulation cells. It is these points ("siting points" hereafter) that will be assessed for their suitability for water harvesting structures. Within the Points FC table the flow direction raster is used to obtain the direction of stream flow for each siting point. For each siting point, a line is now created, centred on the point and perpendicular to its flow direction. The length of the line can be altered by the user. This line represents the barrier axis.

A Triangular Irregular Network (TIN) is then built from the DEM, and from the TIN, contour lines are produced. An intersect tool is applied to the contour line and the barrier line which results in intersect points. Often, due to topographic complexity, the axis strikes a single contour line at more than one place on one side of a siting point. Thus, if not removed, some intersect points will create erroneous polygon areas. For every intersect point, the distance and position relative to the siting point is found and script commands used to search for intersect points with the same relative position. If found, the intersect point(s) furthest away from the siting point are removed.

A polyline is then created connecting the pair of intersect points either side of each siting point. The line represents the barrier (specifically the crest) that would impound and harvest water flowing into the siting point, as shown in **Figure 2**. Using a loop, the first barrier is selected, and its corresponding contour line found. The polygon enclosed by the barrier and contour is created. The polygon represents the enclosed area at the elevation of the barrier crest. The volume of storage that would be created by the barrier is then found by combining the polygon and the TIN. The script then loops and repeats this set of steps for each barrier.

The volume of the barrier itself is estimated using a formula which considers the increased width of the barrier base as the height of the barrier increases.

Should the topography allow, a siting point may have up to three barriers.

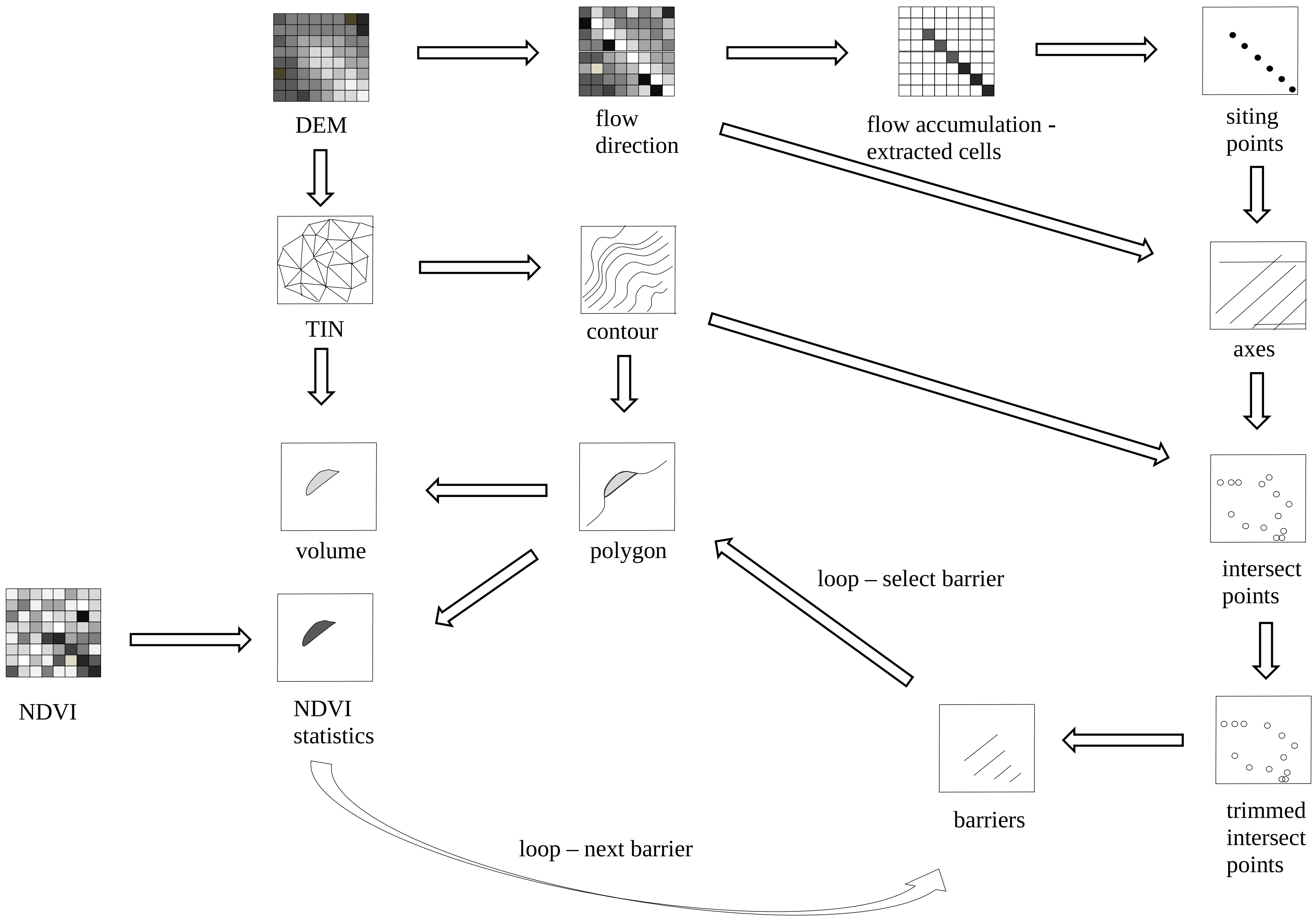

Figure 1 Principal processing steps described in the text

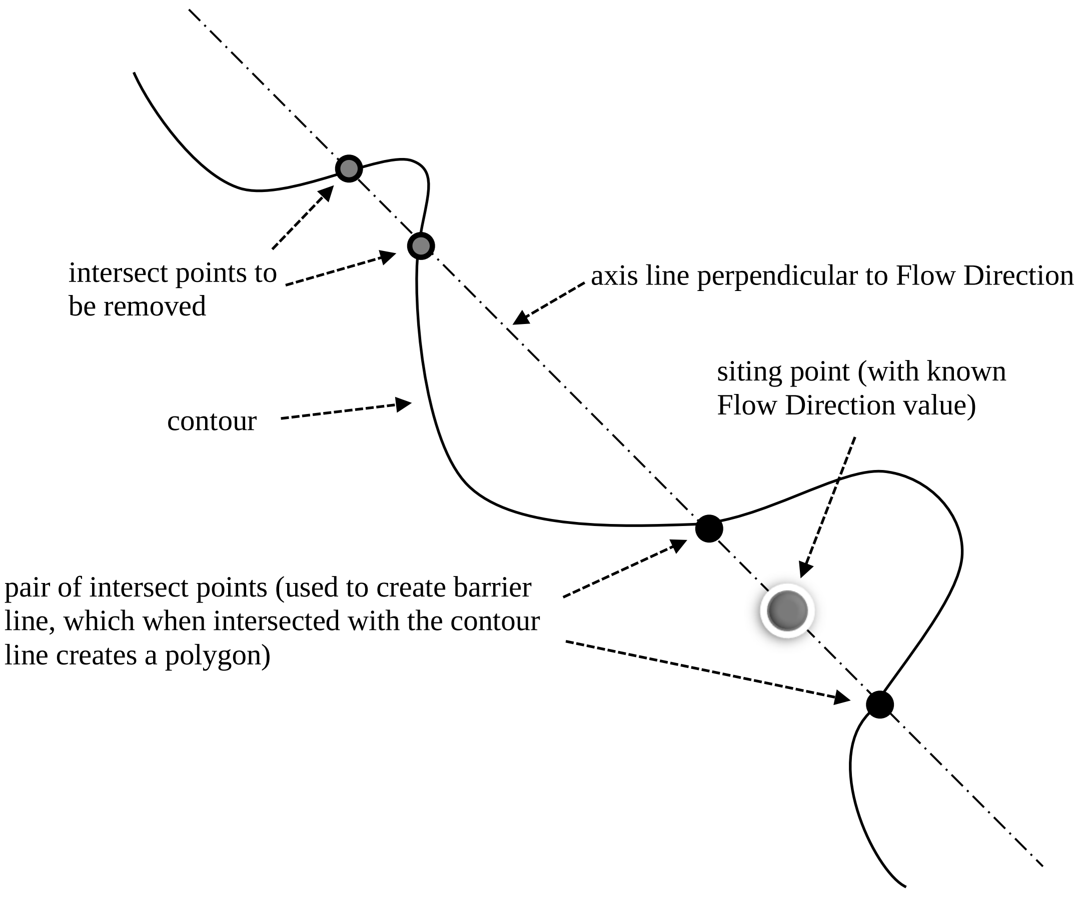

Figure 2 Schematic of trimming points

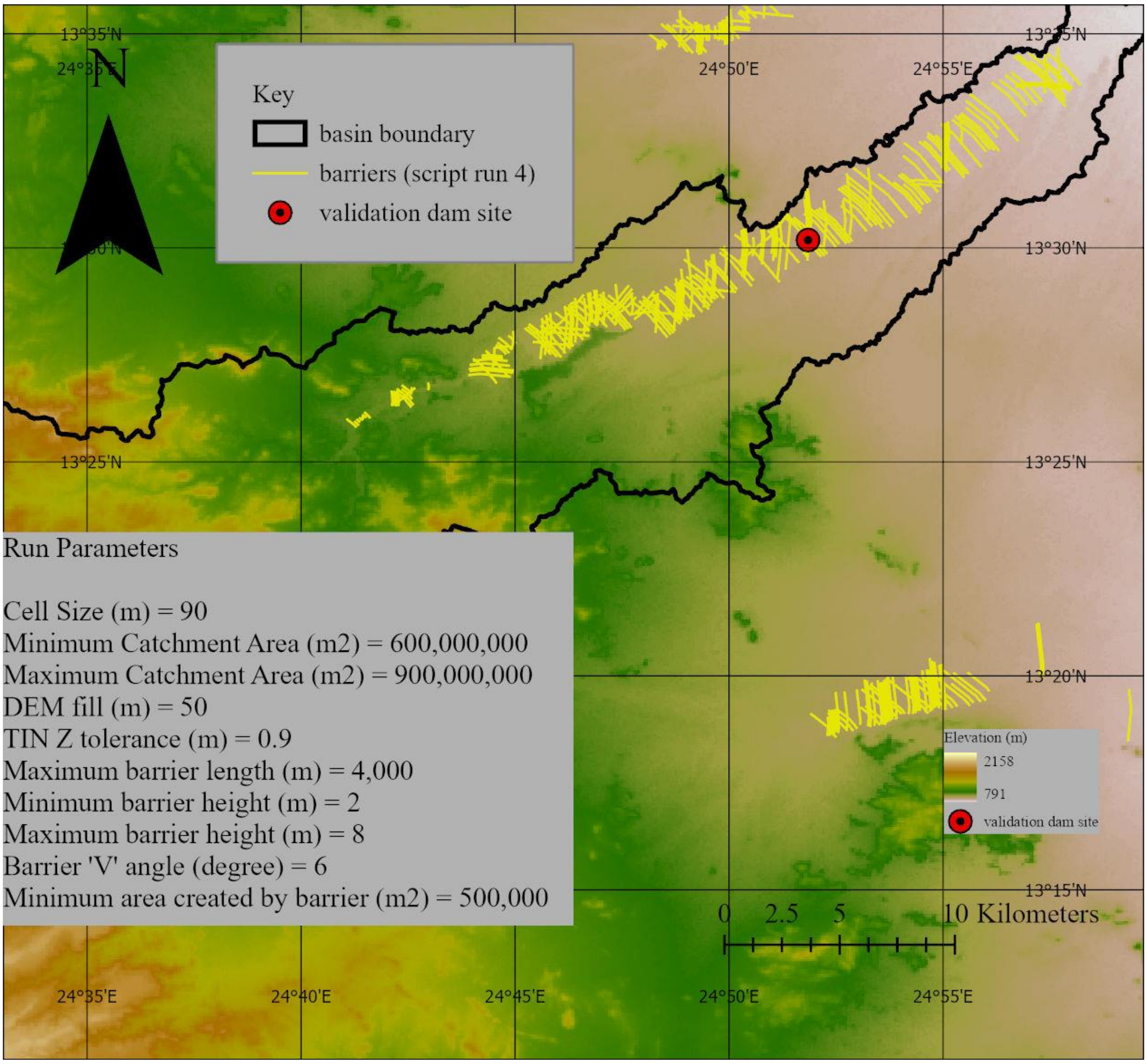

Figure 3 Script run results for Sudan basin

3. Validation

A dam in Sudan was chosen for the purposes of validation as a topographic survey, undertaken using a Differential Global Positioning System, was available.

Figure 3 provides the location of the site, part of the basin boundary, script parameters and the barriers generated by the water harvesting tool. **Figure 4** shows the location of this point, the alignment of the barriers linked to the siting point and the polygons associated with each barrier. The number inside each polygon refers to the elevation, in metres.

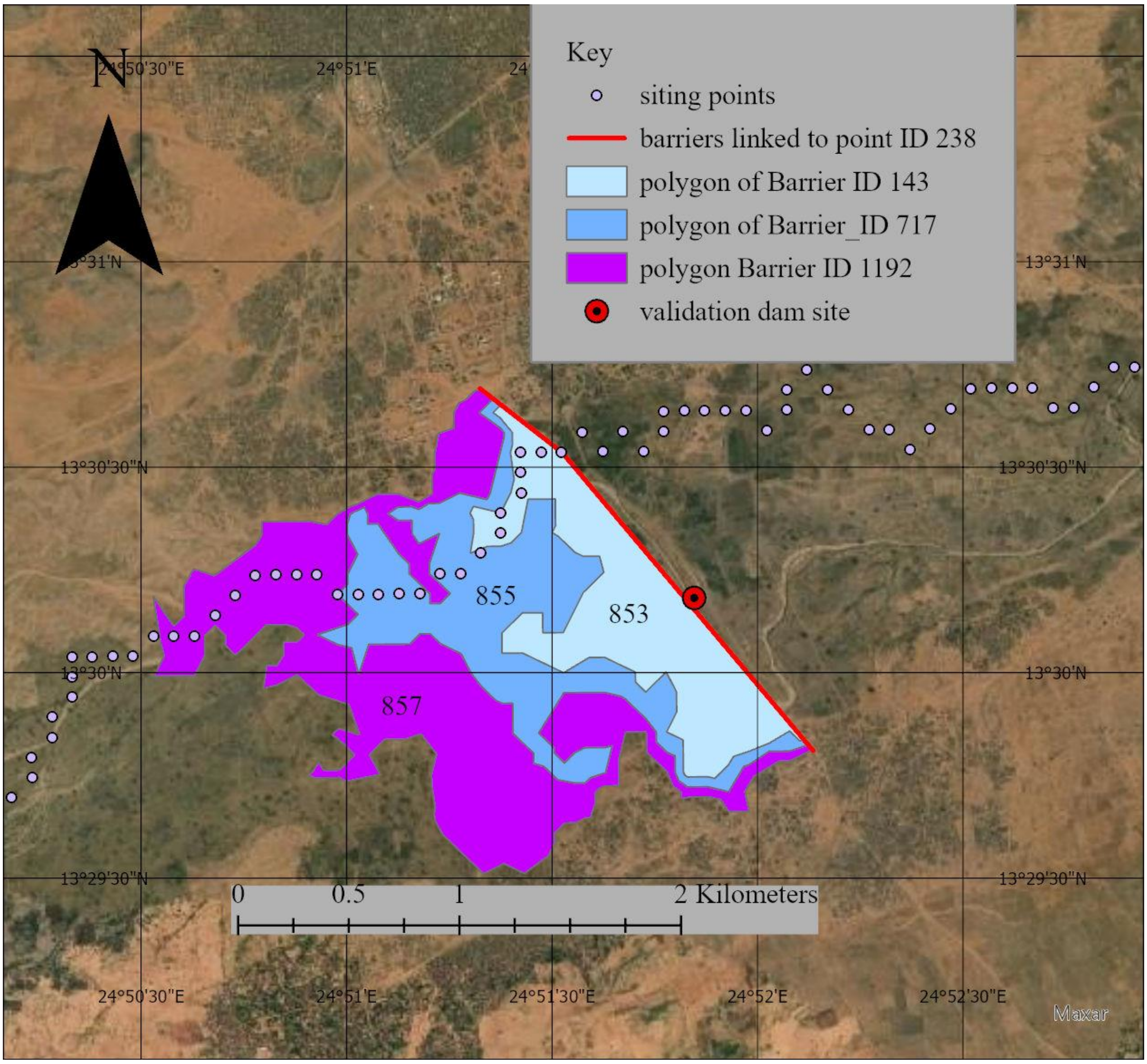

Figure 4 Script run results showing the barriers and associated polygons for siting point ID 238

The crest of the actual embankment dam was traced and then intersected with contours generated using data from the topographic ground survey (**Figure 5**).

Figure 6 provides a comparison of elevation-area for the two methods, one using SRTM 90m resolution data and processed using the water harvesting script and the other using data collected by hand as part of a topographic survey and processed within a GIS environment using standard tools.

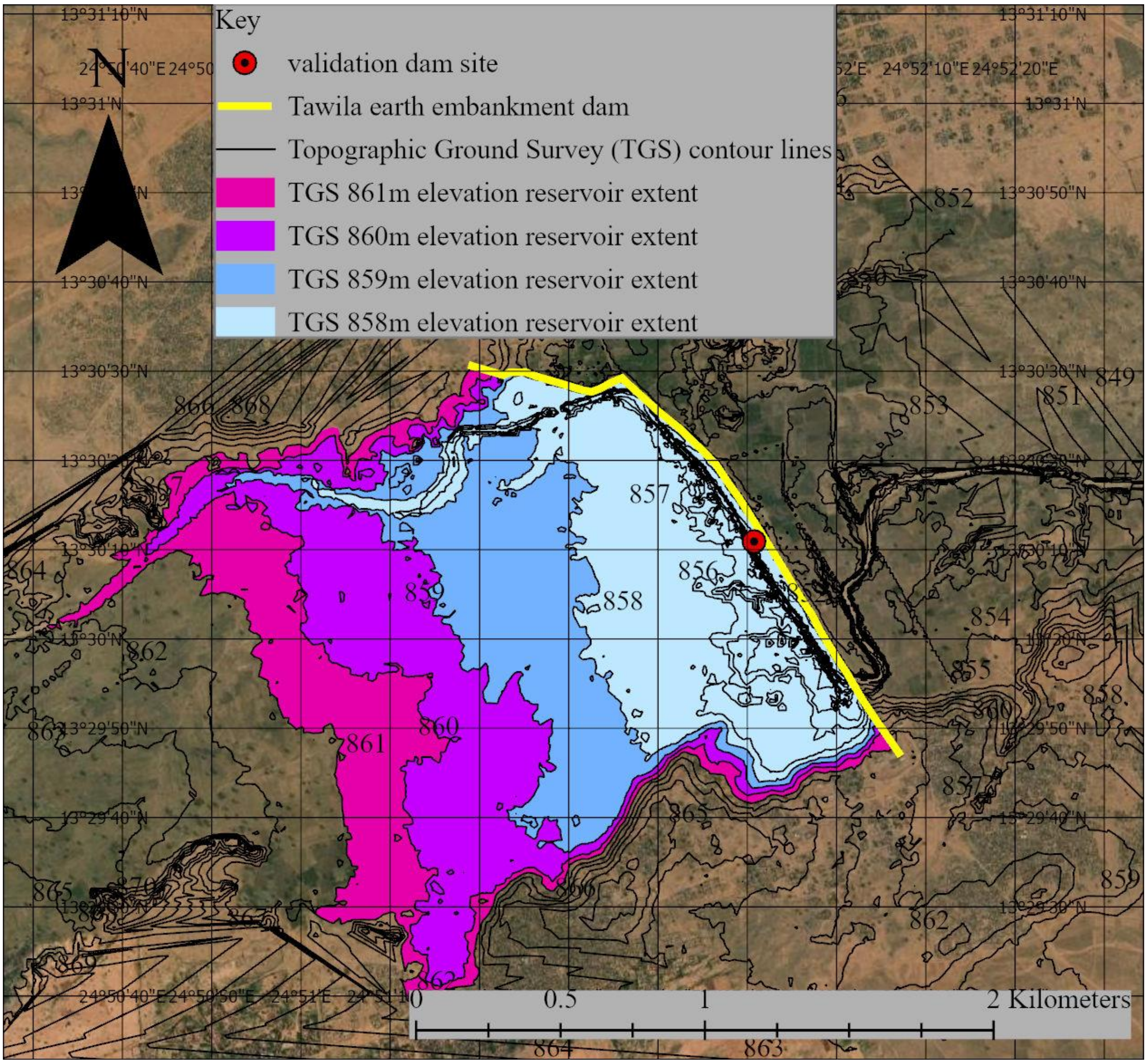

Figure 5 Reservoir elevations and areas using DGPS ground survey

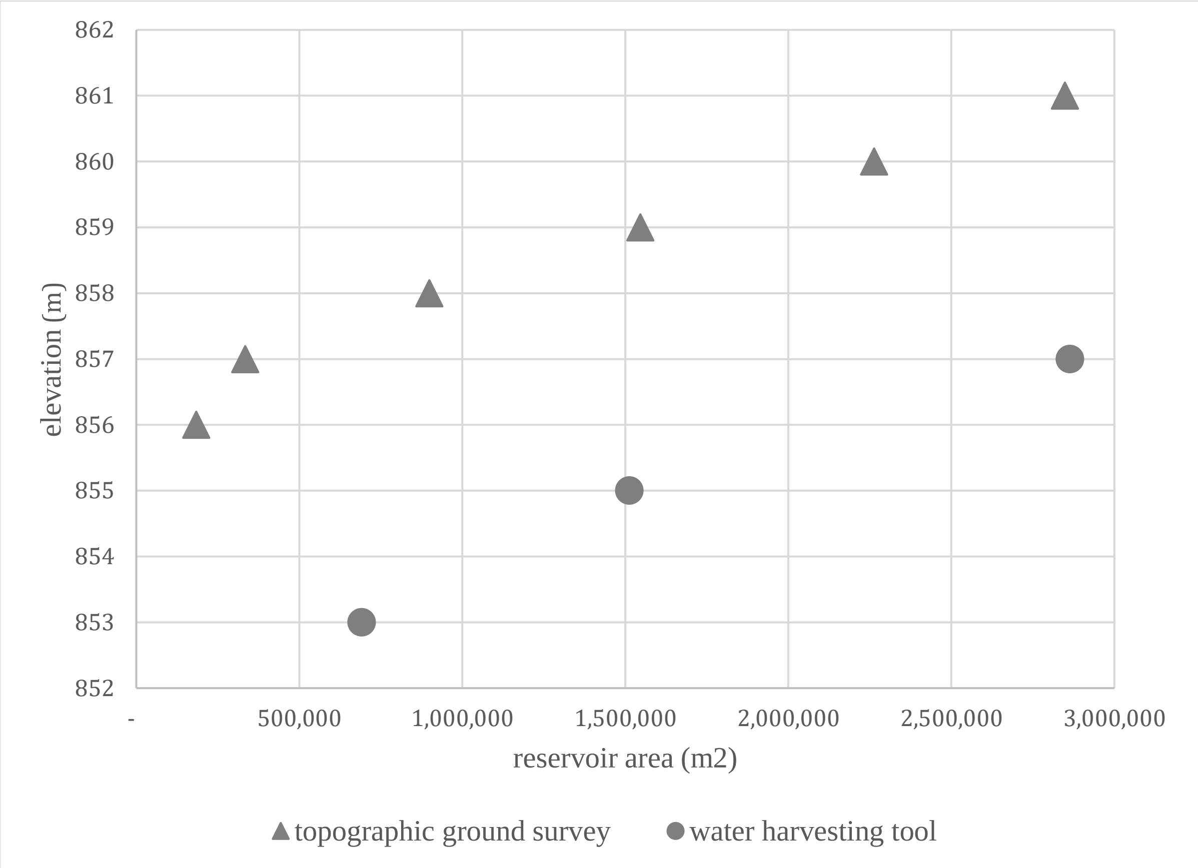

Figure 6 Elevation-Area Chart: Comparison between ground survey and tool

4. Discussion

Figure 6 shows a good correlation between how the reservoir area increases as the crest height of the dam increases. There is an off set between the two sets of figures presumably due the two difference sets of elevation data used (STRM and DGPS ground survey). The embankment dam used to validate the water harvesting tool is approximately 1,700m in length so the while a 90m resolution SRTM elevation data may be suitable to scope out large water harvesting structures this can not be assumed to be the case for smaller structures.

The procedure described could be part of a scoping exercise. The validation process found four additional sites with a storage to barrier volume ratio seven times greater the actual dam site.

The direction of the barrier axis is perpendicular to the flow direction and so has a limited number of directions and so is unlikely to be optimum. As such the water harvesting scoping script described can not be considered as a final decision-making tool.

5. Conclusion

The use of the procedure described would mark a change in direction for water harvesting site selection, moving away from analysis using single raster cells to the study of the 'wetted zone' created by the barrier. The outputs of the script provide additional parameters compared to those currently obtainable using ArcGIS tools. These parameters include barrier volume, barrier length, barrier height, cultivation area and storage capacity. An important parameter for any water harvesting scheme for food production is the ratio of catchment area to cultivation area which can be found using the procedure described.

By creating shape files of every barrier and its corresponding enclosed area, the script allows information from other data sources to be extracted. Knowing the degree of vegetation cover of sites could lead to research studying linkages between NDVI and water harvesting.

The procedure described here was developed for the purpose of finding good sites for water harvesting structures, primarily in drylands. However, since the structures (barriers) hold back runoff, the same script could be applied to small scale flood attenuation schemes in temperate regions.

Acknowledgements

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Biographies

Alan Blackburn is a Professor of remote sensing at Lancaster University with research interest in developing remote sensing and GIS techniques for environmental applications.

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