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A Geospatial Approach to Irrigation Route Determination in Mountainous Areas: A Case Study of Zimbabwe's Eastern Highlands

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Abstract

Geospatial methods such as remote sensing and Geographic Information Systems (GIS) can be used in planning irrigation routes in mountainous areas. Compared to the traditional methods such as ground survey, use of geospatial techniques is quicker, cheaper and less burdening. This study proposes the use of remote sensing and GIS techniques in planning irrigation routes in mountainous regions. The study adopts the hydrological modeling process outlined in ArcGIS Arc Hydro Toolset and uses Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) Version 2 to delineate an irrigation route in the study area. The area of study is located in Zimbabwe's Eastern highlands. Results show that ASTER GDEM can be applied for irrigation route delineation in mountainous regions using Arc Hydro. An irrigation route of approximately 4.45 km was delineated from a dam which is the irrigation water source. The maximum and minimum elevations above sea level of the route are 1047m and 978m respectively. The maximum and average slope are 18.5% and 3.2% respectively. The results were validated through comparison with Google Earth elevation data. A correlation coefficient of 0.991923 was found between the ASTER GDEM and Google Earth elevations. The study concluded that GIS methods such as Arc Hydro and Remote Sensing data such as ASTER GDEM are suitable tools for determining irrigation routes in mountainous regions

Keywords: *Arc Hydro, ASTER Imagery, Geospatial methods, Irrigation*

INTRODUCTION

Irrigation plays an important role in attaining food security as well as ensuring sustainable agriculture (Kumar 2014).Geospatial techniques such as Remote Sensing (RS) and Geographic Information Systems (GIS) are used in lieu of the time consuming, tiring and costly conventional method of locating irrigation routes by ground surveys(Ramos 2003). In addition, the use of geospatial methods in irrigation planning is even more convenient in hilly regions. This is due to the fact that irrigation planning in hilly areas presents its own unique challenges.

For an efficient irrigation planning in hilly regions geospatial methods can be employed to determine spatial distribution of fields suitable for gravity irrigation and the location of optimum contours. In a terrain of such undulating topography geospatial methods are also suitable in ascertaining the availability of surface and groundwater resources(Basak, Narasimha, and Nazimuddin 1989).

Space remote sensing is a source of objective data on the agricultural and hydrological conditions of irrigated regions(Kumar 2014).There are two main types of irrigation which are Drip and Gravity (Surface) irrigation. Drip irrigation refers to the application of water to the root zone with the aid of an emitter. Gravity irrigation which is the focus of this study is the capitalizing of the earth's gravitational force to water the surface from higher to lower sloping regions(Panda et al. 2014). The objective of this study is to propose and assess the suitability of GIS and Remote Sensing techniques in planning and determining irrigation routes in mountainous areas.

In particular, GIS methods through ArcGIS Arc Hydro toolset and remote sensed ASTER GDEM are used to determine the irrigation route. This is because using ground survey methods to optimally determine irrigation routes is time consuming and taxing due to the highly undulating hills that characterize mountainous regions. However, the use of GIS and remote sensing methods is quicker and less exhaustive than traditional ground survey methods.

In1989 Basak et.al identified the distribution of irrigable lands in the basin of Kerala State, India using remote sensing. The delineation of irrigable lands in the basin was done through the studying of black and white aerial photographs of 1:60 000 scale.

The interpretation was based on visual observations using a stereoscope(Basak, Narasimha, and Nazimuddin 1989).Topography and slope have an influence on gravity or surface run-off(Panda et al. 2014). Hydrologic models attempt to illustrate a watershed run-off process. The watershed run-off process is implicitly spatial; hence GIS tools can be employed to arrange the data and devise hydrologic models. The availability of Digital Elevation Models (DEMs) and the geospatial software to process it has heightened the awareness of the spatial distribution of hydrologic processes. DEMs are composed of elevation values and can be used to assess terrain characteristics using customized algorithms and GIS visualizations. Due to the extensive availability of DEMs, as a result many surface –water hydrologic applications start with the raster data of the terrain.

Terrain features such as slope, aspect, flow length and channel network can be quickly and reliably ascertained from DEMs despite the size of the watershed. Automated retrieval of surface drainage, channel network and other hydrographic data has recently progressed admirably to an extent that it is mandatorily a part of most GIS software. The major drawbacks with DEM-derived hydrographic data are related to the resolution and quality of the DEM.

DEMs are used to determine flow direction in distributed hydrological models for stream flow simulation. Lately various techniques for flow direction determination have been applied successfully to mountainous areas. The DEM's characteristic of efficiently representing the spatial variability of the earth's surface makes it the appropriate input data for flow direction determination. (Zhao et al., n.d.).Various GIS based tools have been developed for DEM processing and stream delineation. Arc Hydro, an Arc GIS based toolset is applied in water resources monitoring and analysis. It is a collection of data models and tools used in hydrological information modeling, simulation and supporting geospatial and temporal water resources data analysis. Using Arc Hydro, topological variables can be extracted from a DEM raster and then applied in delineating, building and analyzing hydro geometric networks for hydrological analysis(Khan et al. 2016).

The ASTER GDEM version 2, was released in October 2011 with its coverage spanning from 83 degrees north latitude to 83 degrees south. ASTER data offers better resolution than SRTM with a resolution of 30m(Rusli, Majid, and Din 2014). The ASTER GDEM's water body detection ability has improved to 1 km2 in version 2 from 12 km2 in version 1(Tachikawa et al. 2011).

2. MATERIALS AND METHODS

2.1 Study area

The study area is located in Zimbabwe's Eastern Highlands near the country's border with Mozambique. It is an agricultural area with the major crops being bananas, coffee, maize, potatoes and lychees. The hilly nature of the region makes it suitable for gravity irrigation. The Figure 1 below is a map of the study area.

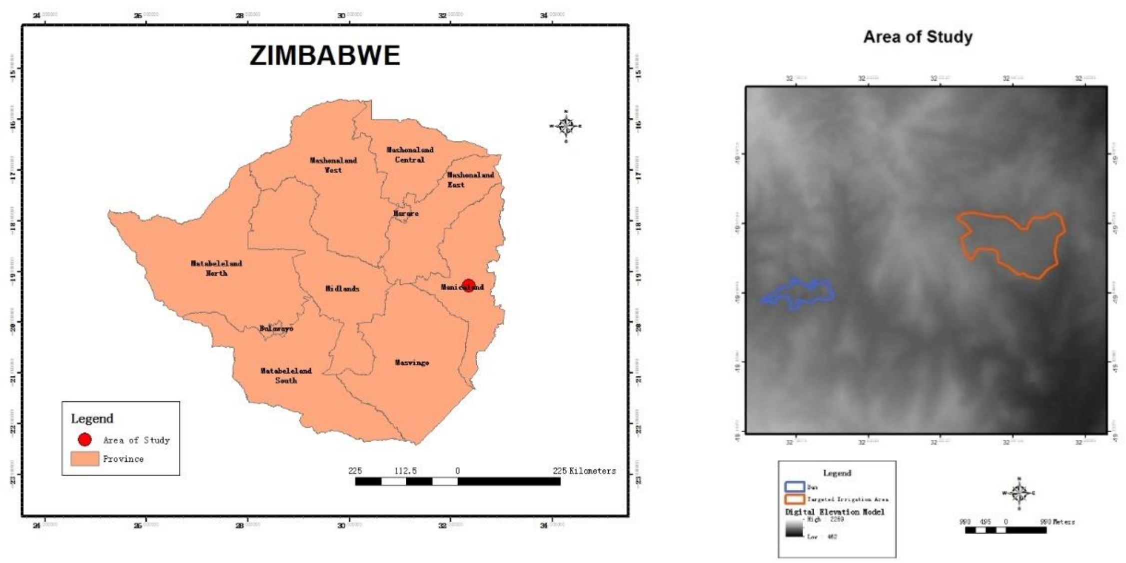

Fig. 1: map of study area

2.2 Data and Methodology

ASTER GDEM Version 2 DEM of the area of interest was used as the input data. The hydro-processing procedure was performed using ArcGIS 10.2 in combination with Arc Hydro Tools 2.0. The methodology followed the procedure shown in the Fig. 2 below:

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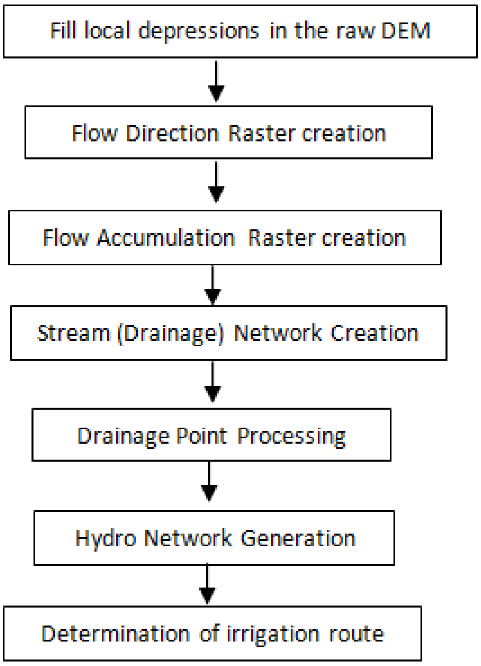

Fig. 2: Irrigation route determination procedure

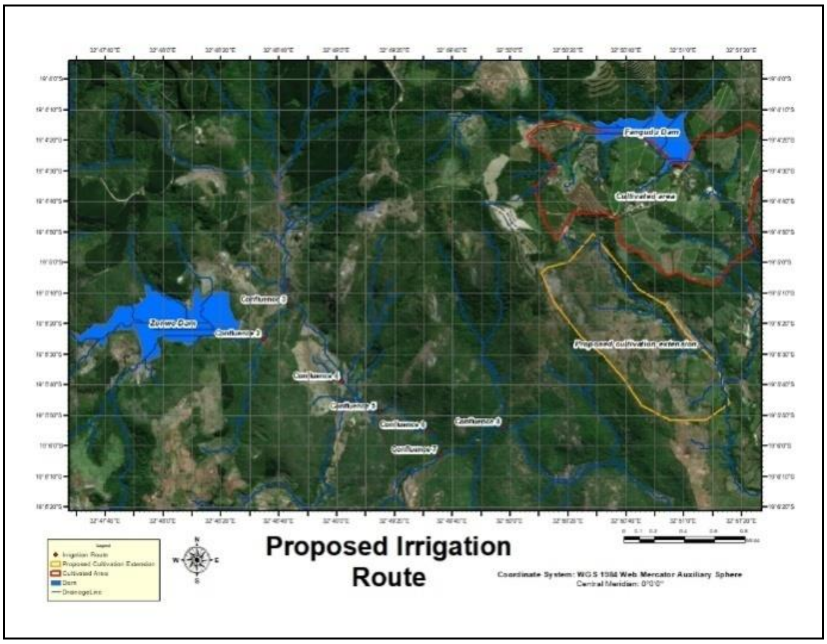

Fig. 3: Proposed Irrigation Route

3. RESULTS

3.1 Irrigation route

Below is the proposed irrigation which runs from the stream confluences, confluence 1 to confluence 8 through the drainage network. The delineated irrigation route is approximately 4.45 km of length and starts from a dam which is the irrigation water source and approximately 1.2 km away from the targeted cultivation area. The maximum and minimum elevations above sea level of the route are 1047m and 978m respectively. The maximum and average slope is 18.5% and 3.2% respectively.

Table 1: Geographic coordinates of irrigation route confluences

Confluence		Location	
4.	5.	6. E	7. S
8. 1	9.	10. 32°48'19.909"	11. 19°5'23.706"
12. 2	13.	14. 32°48'35.054"	15. 19°5'24.919"
16. 3	17.	18. 32°48'43.781"	19. 19°5'13.76"
20. 4	21.	22. 32°49'2.006"	23. 19°5'39.231"
24. 5	25.	26. 32°49'15.098"	27. 19°5'49.176"
28. 6	29.	30. 32°49'31.783"	31. 19°5'54.755"
32. 7	33.	34. 32°49'36.147"	35. 19°6'3.002"
36. 8	37.	38. 32°49'57.452"	39. 19°5'54.028"

3.2 Results Validation

The results were validated through comparison with Google Earth elevation data. A correlation coefficient of 0.991923 was found between the ASTER GDEM and Google Earth elevations.

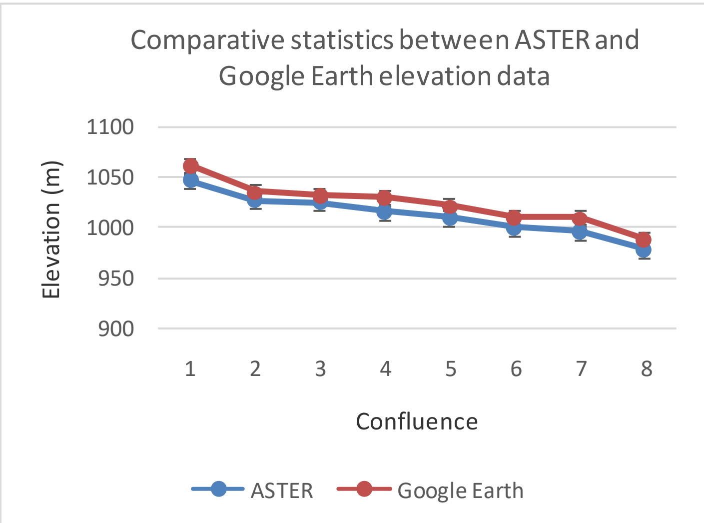

Fig. 4: Correlation between ASTER GDEM and Google Earth elevation data

DISCUSSION

The results show that an irrigation route can be determined using GIS and remote sensing methods. The significantly strong positive correlation between the ASTER GDEM and Google Earth elevation data confirms the suitability of ASTER data as input for hydrological processing and modeling in mountainous areas. The ASTER GDEM version 2 has an elevation error standard deviation of 12.6 m (Tachikawa et al. 2011), hence this influences the degree of accuracy of elevation data of the irrigation route. To improve accuracy of the irrigation route, a high spatial resolution DEM, of up cm level and acquired from flying an Unmanned Aerial Vehicle (UAV)(Barry and Coakley, n.d.) can be used as an input DEM in Arc Hydro for hydrological processing. The determined irrigation route of this case study ended about 1.2 km way from the targeted cultivation area. This is because there is no natural flow from the last node of the irrigation route to the targeted cultivation area. In such a situation, it is recommended that mechanical methods such as trenching and excavation with the aid of topographical field surveys be employed to determine the most economical route to the intended cultivation area.

CONCLUSION

This study has shown that geospatial techniques in the form of GIS and remote sensing can be employed to determine and plan irrigation routes especially in hilly or mountainous. This is made possible through hydrological processing tools such as Arc Hydro where a DEM is used as an input data to derive hydrological models and simulations from. The study recommends ASTER GDEM's latest version as the best suitable elevation data source for irrigation route planning and determination in mountainous areas. Geospatial techniques such as remote sensing and GIS can be a cheaper and quicker alternative to traditional methods of determining and planning irrigation routes such as ground surveys.

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