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Research Article

Hydrologic Analysis of the Outflow Channels on the Martian Surface

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Abstract

The main objective of this report is to explore and apply GIS in a radically new way that studies extraterrestrial features.

Traditionally, geography with the GIS tools was bound to modeling the surface of Earth. However, exploration of the extraterrestrial planets by various missions have led to creation of databases storing the models of extraterrestrial relief, images, and thematic maps. This data can be used for conducting GIS analysis using variety of tools provided by ArcGIS software package. This case study is focused on creating the thematic map of the surface of the Mars, which outlines the hydrological features such as ancient river channels.

Keywords: Hydrologic Analysis; Outflow Channels; Martian Surface

Introduction

One of the phenomena that have been puzzling astronomers for centuries is the visible valley networks, which resembled the river channels on Earth. They were first observed by an Italian astronomer Giovanni Schiapelli, which lead to a widespread belief that these channels are formed by the liquid water on the surface. However, the recent missions to Mars and the surface exploration with rovers have proven that currently water can be found only in form of atmospheric water vapour and in form of ice in the Northern polar cap with smaller quantities in the southern polar cap, which primarily consists of solid carbon dioxide. One way of measuring the water content is with neutron spectroscopy, which measures the hydrogen content of the surface, as seen in figure 1.

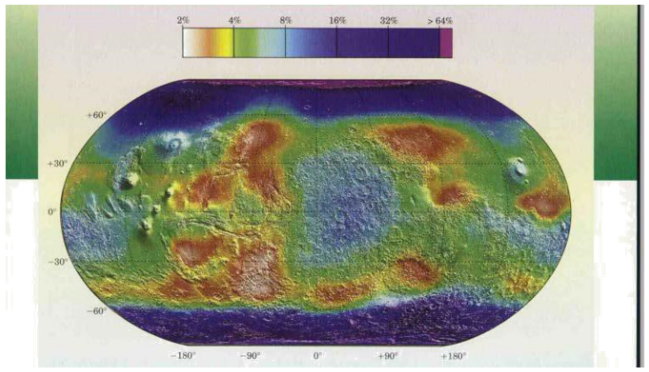

Figure 1: Variation of water content on the Martian Surface obtained by the Mars Odyssey spacecraft [1]. The spectroscopy shows the water content (in solid form) in the polar ice caps.

The neutron spectroscopy method, however, shows that there is no liquid water between the poles, where majority of the Martian channels are located. These channels are the key to understanding the hydrologic past of the planet, since they visually resemble the channels on Earth and can explain the distribution of sediments and the geomorphology of their surrounding features. In order to understand the geomorphology of the Mars further, these channels have to be geographically located and identified throughout

the planet and mapped. The topography of the Mars will help to remotely locate these channels, which will be mapped in order to relate to the ancient fluvial processes.

Methodology

Proposed methods

In order to map the channels of the surface of the Mars there are two proposed methods of capturing the geographic data. The first method was to analyze the surface visually and to manually digitize the proposed outflow channels. The second method of mapping the outflow channel is using the GIS software, which should be a faster method that uses the quantitative methods in order to calculate the locations of the river channels.

Study area

Due to the complexity of the topography across the planet, the sample study region was selected in order to test the two proposed methods above. The study region consists of the section of Kasei Valles, which is a giant system of canyons that have been identified as the biggest known outflow channel system on the Martian surface [2]. The geomorphology of the channel indicates that the outflow valleys have experienced a variety of flooding episodes, which is evident by the layered rock structures at the delta of the channel indicating the presence of sedimentary rocks which are deposited and formed by the water. Another evidence for the outflow valleys of the Kasei Valles is the anastomosing channel pattern of the study region, which can be seen from the figure 2 below. Anastomosing channels, such as the ones in Kasei Valles form the series of islands (bars) and are considered a low-gradient channels which are capable of moving massive loads of sediment [3].

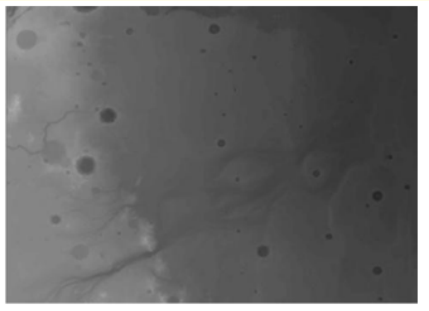

Figure 2: Anastomosing channel pattern of the Kasei Valles, which is characterized by the channel splitting around the geographic features along the floodplain.

These factors indicate the studied valleys in the region are of the fluvial origin, as opposed to tectonic, which is an important consideration for both of proposed methods.

Data sources

In order to conduct the analysis of the outflow channels on the surface, two different types of data were used. The first type was the Google Mars imagery of the selected study area, which is developed by the University of Arizona and is collected by the Mars Orbiter Laser Altimeter (MOLA) from the Mars Global Surveyor spacecraft. It depicts colour-coded elevation, which shows the differences in surface elevation and allow for accurate interpretation of the outflow channels. The second data type is the DEM of the surface of the Mars, which was also collected by the MOLA from the Mars Global Surveyor. The DEM was provided by the USGS Astrogeology Division, which is a 1.96 GB raster file with a cell resolution of 463 meters.

The data gathered by the MGS has an uncertainty in elevation of ± 3 meters, which is not too significant considering that the raster cell resolution is 463 meters. The data is projected on a custom Mars2000 Equidistant Projection, which uses a datum and allows for a geospatial analysis to be conducted by ArcGIS.

Method 1: Digitizing the data using adobe illustrator

The first method requires for the data to be extracted from Google Mars, which was done by screenshotting the desired region and saving it in order to be analyzed in Adobe Illustrator. Then the proposed outflow channels were digitized by creating the vector lines along the channels. This method was relatively straight forward and requires very little skill to digitize the outflow channels.

Method 2: Digitizing the data using ArcGIS

The second proposed method requires the use of GIS Software in order to conduct the hydrologic analysis on the raster dataset. The first step is to import the DEM into the ArcMap by selecting "Add Data feature". Then the selected geographic region had to be extracted, by selecting "Extract dataset" feature within the map extent. The dataset then was saved and added once again to ArcMap in order to be analyzed with the Hydrology toolset.

In order to remove the surface imperfections of the DEM dataset "Fill" tool was used, which identifies and creates a network of "sinks". These are raster cells with an undefined drainage direc-

tions which are lower in elevation in comparison to their neighboring cells. Next step is to use "Flow Accumulation tool", which creates a raster network of accumulated flow determined by the number of the downslope cells. The input of the Flow Accumulation is the output of the Fill tool used previously. Lastly, the "Flow Direction" tool is used to create the raster dataset with the proposed river channels. Each cell receives the value from 1 to 255 and the cells with the lower value than its neighboring cells receive the "flow" direction.

Results

Discussion

The results of the analysis have revealed that both methods are useful in analyzing and mapping the outflow valleys in the study area of the Kasei Valles. The first method consists of interpretation of the topographic surface visually and manually digitizing the outflow valleys. This method is entirely subjective and relies on the interpretation of the surface by the analyst. The advantage of this method is that it is relatively quick and simple and does not require too much of a technical knowledge of the software to create the maps. The data can be easily accessed from GoogleMars, which is

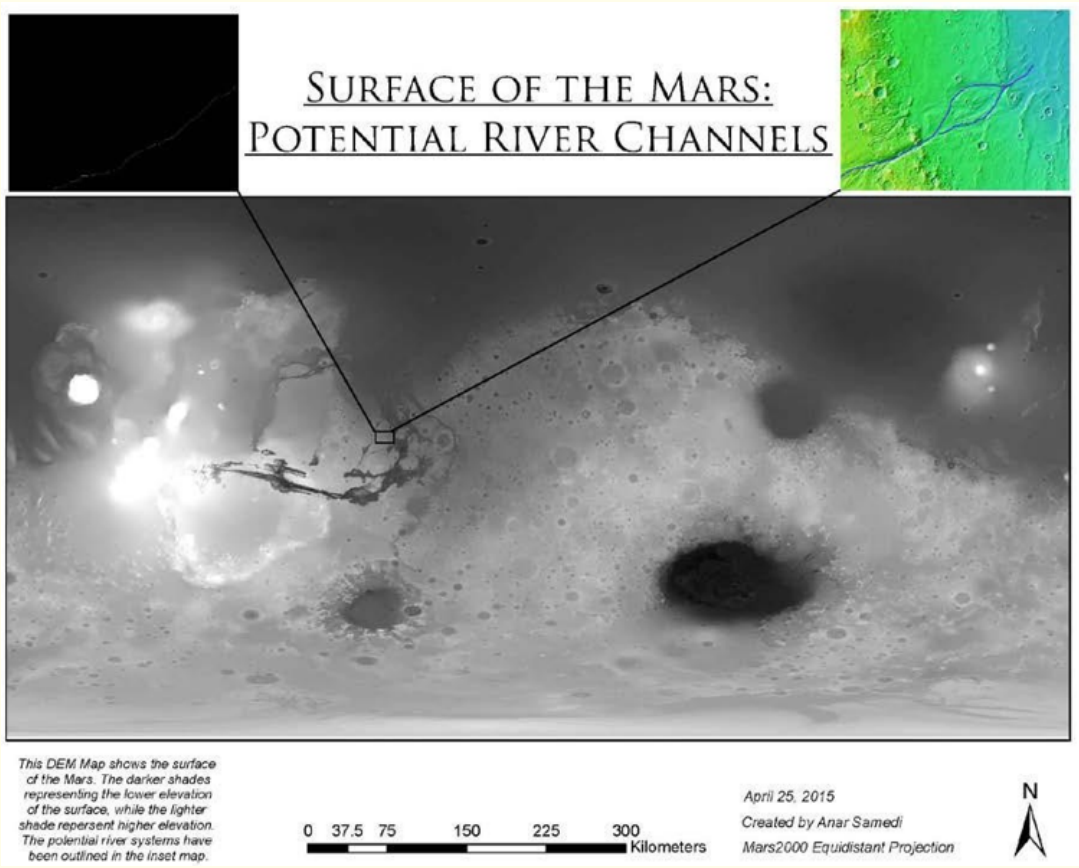

Figure 3: The following cartographic product depicts the Digital Elevation Model of the Mars that was collected by the MOLA MGS Spacecraft. The inset map on the left shows the product of the Flow Direction tool, which depicts the proposed outflow valley of the ancient river system. The inset map on the right shows the manually digitized outflow valleys, which was based on the GoogleMars image.

a secondary type of data, and digitized using any Photoshop software. This method, however, also relies on the knowledge of the basic geomorphology and aerial interpretation of the geomorphic feature by the analyst, which is its main limitation.

The second method requires working on a primary data obtained directly by the MGS Spacecraft from the USGS website. The obtained DEM data contains the network of raster cells with a spatial component and the z-value (elevation). The DEM data is optimal for predicting the flow patterns over the surface, because the water flows from areas of higher elevation to areas of lower elevation. ArcGIS calculates the flow using the rook's case of defining the cell routing across the surface, as seen in figure 4 [4].

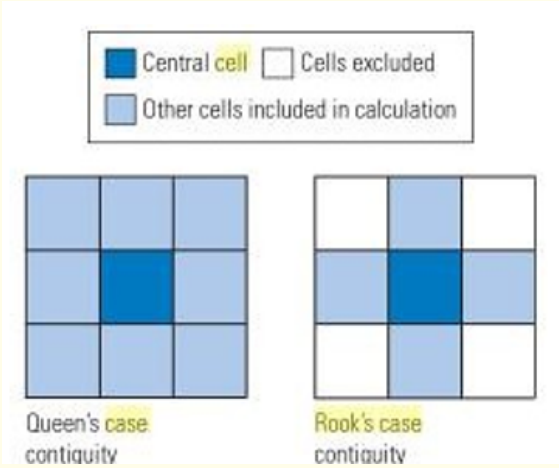

Figure 4: Raster operation using the Queen's case, which uses 8 of the neighboring cells surrounding the central cell.

The purpose of using the Fill tool, was to fill in the imperfections of the surface such as the closed depressions. The flow accumulation and flow direction tools, conceptually all follow the same computational principle, which is assigning the flow to the neighboring cells with lower slopes [5].

The advantage of this method is that it produces the outflow channels that are calculated using quantitative methods using the GIS. This method is a lot faster than manually digitizing the surfaces and can be used to calculate the outflow valleys over the larger geographic areas. The disadvantage of this method is that it is dependent on the spatial resolution of the DEM. The resolution of 463

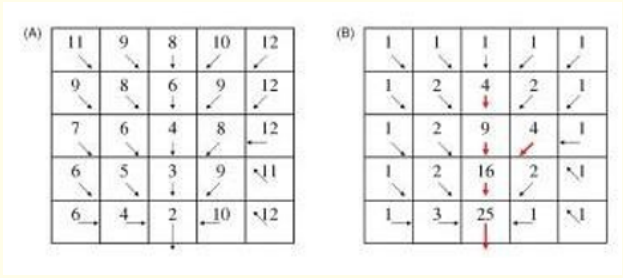

Figure 5: The diagram A shows the inferred flow directions and diagram B shows accumulated flows from each of the neighboring cells [5].

meters is inadequate to perform raster analysis because there are fewer cells within the geographic area. The second method works primarily on the neighboring cells and if they are assigned the same value over a large geographic area (low spatial resolution) then the outcomes of the analysis will be greatly affected. This is the reason as to why the outcomes of the first and the second method are not exactly matching. Therefore, the limitation of the second method is the spatial resolution of the DEM. However, given the higher spatial resolution of the DEM, this method will yield more accurate results and can be used to efficiently analyze large geographic areas.

Conclusion

The surface of the Mars contains numerous evidence of the past hydrologic activities, such as the outflow channels which indicate the downslope flow of the water. Capturing these channels in Kassei Valles was done using the digitizing method 1 and flow accumulation method 2 using the GIS software. Both methods have their own limitations, although given the higher spatial resolution the second method should produce more accurate results. Both methods rely on the concept of water flowing from areas of higher elevation to areas of lower elevation. Creating the hydrologic maps containing the outflow channels of the Martian surface using the improved version of the second method will allow for further understanding of the ancient fluvial processes that shaped the surface of the planet.

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