INNSPUB

International Journal of Agronomy and Agricultural Research (IJAAR)

ISSN: 2223-7054 (Print) 2225-3610 (Online)

http://www.innspub.net

Vol. 12, No. 2, p. 38-45, 2018

RESEARCH PAPER

OPEN ACCESS

Development of an optimum irrigation scheme using least-cost path analysis and digital elevation modeling

Aaftab Ahmad*[1], Burhan A. M Niyazi[1], Chaabani Anis[1]

[1] *Department of Hydrology and Water Resources Management, King Abdul Aziz University, Jeddah, Saudi Arabia*

Article published on February 12, 2018

Key words: Irrigation, GIS, DEM, LCPA, Water resources.

Abstract

Irrigation suffices crop water requirements for optimum crop production in arid regions. It consumes about 72% of available fresh water in the world while contributing 40% of the world food supply. As the global population increasing rapidly and the available fresh water per capita is decreasing, so scarce natural resources (such as land and water) must be used wisely. Development of an optimum water supply and on farm distribution system for irrigated lands will increase water use efficiency and will reduce water supply cost. Different techniques of GIS have been used in irrigated agriculture to increase water use efficiency and yield in farm lands. In this study, the combination of digital elevation modelling (DEM) and least cost path analysis (LCPA) was used to develop an optimum irrigation scheme. Digital elevation model was used to generate the complete topography of the irrigated farms to determine water flow path from Haddah sewerage water treatment plant (Makah Province Saudi Arabia) to farm fields(date palm) near Bahrah town (in downstream of Wadi Fatima, Makkah province). Least-cost path analysis was used to find cheapest water supply path between source and the irrigated lands to decrease construction cost and water losses. The combination of least-cost path analysis and digital elevation model in water allocation for irrigated lands was efficient and cost effective as compared to the existing unlined water allocation channel. Construction and material cost was more as compared to unlined channel but it saved more than 50% water for development of an optimum irrigation scheme.

* **Corresponding Author:** Aaftab Ahmad ✉ aftabagri@yahoo.com

Introduction

Irrigated lands contribute 40% of world food supply chain therefore; more investments should be pumped in irrigation sector to cope up with increasing human food demand (Hugh and Jean, 2010). Irrigation consumes 72% of the world available fresh water, yet the production is low due to poor management and low water use efficiency in farm lands (Hugh Turral, 1995).Manually designed and operated irrigation schemes and water supply paths are costly and inefficient because water loss reaches up to 50% of the water supplied to fields (Kemal *et al.*, 2002). Evapotranspiration is the main issue of arid regions and it becomes very crucial in hot summer days when the water supply line is an open channel network. High efficiency irrigation systems along with efficient water allocation system (pipeline) can increase production and water use efficiency in hot arid regions (Muhammad *et al*, 2010; Hector, 2012).

Geographic Information System (GIS) can give precise information about a path between two places, such as distance, degree of slope, speed limit, estimated reach time, terrain features, type of surface, and level of difficulty during travelling (Rong *et al.*, 2012). Digital Elevation Models (DEMs) are essential in hydrological modelling as the geography determines the water flow patterns. DEM has many other valuable applications in much discipline like in telecommunications, Hydrology, reservoirs locations and determining landslide probability. In irrigation, DEM is used in watershed delineation, water management, and distribution of water and flow of water in the water channels and in the fields channels (Sulebak, 2000). DEM is used to find slopes and possible water flow paths under gravity for irrigated areas. Least cost path analysis (LCPA) is a tool used in GIS to create the shortest travel path between source and destination. LCPA allows user to create cheapest path between source and destination over cost surface (Bagli *et al.*, 2011).LCPA has been successfully used by many researches to find the cheapest and easiest path between two specific points. LCPA was used to identify the moving corridors for wild animals using GIS (Adriaensen *et al.*, 2003).

In oil and gas industry LCPA has been used for path routing and pipeline routing to limit the costs and production materials (Feldman *et al.*, 1995; Rees 2004; Aissi *et al.*, 2012).

The pipeline network is the most reliable and controlled method to allocate water. If the route is designed carefully it lowers construction and operational costs. Comparing to old routing methods, LCPA is very reliable and cost effective method can be used in irrigation water supply networks. Water is the limiting recourse for agricultural sector in arid lands of Saudi Arabia, so efficient water use and reduction in water conveyance losses by reducing evaporation and percolation is very critical issue of the country. Thus, irrigation water should be allocated through pipelines.

Therefore, it is obligatory to develop an optimum water supply network for irrigated fields to increase water use efficiency. Optimum irrigation scheme increases water use efficiency and production capacity to prevent future famine in the world (Lucina *et al.*, 2010).In this study DEM and LCPA were used to develop least cast path from water source to the irrigated date palm area to develop an optimum irrigation scheme using high efficiency irrigation methods in Wadi Fatima near Makkah province Saudi Arabia.

Material and methods

Study area and scope

To deliver the treated water from Haddah sewage treatment plant (Makah Province Saudi Arabia) to farm fields (date palm) near Bahrah town (in downstream of Wadi Fatima, Makkah province) LCPA function of GIS was used. Haddah Sewer Treatment Plant (HSTP) is located at 21º26´30.26"N and 39º33´52.27"E, and it receives 130,000 cubic meter of sewage water per day from Makkah city for three stages treatment. During Hajj, pilgrimage season, coming sewage water increases to 180,000 cubic meters per day (Sami, 2015). An unlined existing channel was being used to allocate the treated water from the HSTP to date palm fields downstream of Wadi Fatima 80 km away from Makkah city.

Due to severe aridity, high temperature and sandy soil, the unlined water channel wastes more than50% of treated water in the way due to evaporation and deep percolation. If this treated water is transported by pipeline these losses will be eliminated. Fig. 1 shows the HSTP in working condition.

Digital elevation modeling (DEM)

Terrain modeling is one of the key methods that can be used to assess the spatial variability of agricultural fields and their surrounding ecologies (Franklin *et al*., 2000; Mackey *et al*., 2000; Fried *et al*., 2000). The illustration of terrain in the form of digital elevation models (DEMs) can be used to help the execution of the applications of precision conservation management practices. For example, terrain analysis models can use DEM-based topography to identify runoff-contributing areas and calculate slopes for use in field-runoff and buffer-filtration models (Dosskey *et al*., 2005).

Commonly available data sources such as 30-m digital elevation models from government agencies such as United State Geological Survey (USGS) provide a starting point, but more accurate data can yield much better results for a broader range of applications. In this study the DEM raw data was downloaded from USGS website and DEM was used to calculate the slope, topography and hydrologic analysis of the study area. Slope of area determined the terrain features and water flow patterns. The DEM data provided the basis for LCPA.

Least cost path analysis (LCPA)

LCPA is often used in planning infrastructure such as roads, pipelines, canals, and power transmission lines as well as for recreational uses. The terrain features of soil along the pipeline specify the construction cost of pipeline such as cut and fill, operations, machinery, geotechnical, environmental impact and labour cost. For LCPA, different types of data are used in a raster format in the GIS software. Source point and the destination points are specified then raster cells are weighted by considering different weighted parameters such as slope, roads, mountain, urban areas, forest area and railways tracks. Raster cells are then evaluated and path moves to the least accumulated values cells, and this process continues until the source is connected to the destination. Completed path shows the cells with least accumulated values. When using least cost path analysis in GIS, the eight neighbours of a raster cell were evaluated and the generated path moved to the cells with the smallest accumulated or cost value ("Distance Analysis Using Arc GIS"). This process repeated multiple times until the source and destination were connected.

The completed path was the smallest sum of raster cell values between the two points and it has the lowest cost. The procedure moves like the layers 1) source raster, 2) cost raster, 3) cost distance measures and 4) an algorithm for deriving the least cost path were developed. The source was Haddah sewage treatment plant and destination was date palm field. In the source raster layer, only the source cell was given a value and all others cells were given a "no data" value. Any combination can be a part of LCPA It may be from one source to many destinations or from many sources to only one destination. If shortest path between source and destination is straight path, this is the least resistance path. Fig. 2 shows part of the unlined water channel to transport water from HSTP to the remote date palms farms in Wadi Fatima.

Results

Slope of the area

Using DEM data layer the slope of whole study area was calculated using GIS software 10.2. The calculated slope was used in LCPA generation. The whole area was categorized into two categories 1) high slop and 2) low slop.

The high slope was 50% and low slope was 0%. The high slope area is not suitable to construct LCPA. Fig. 3 shows the slope of the area, the green areas shows high slope and brown area with low slope. With HSTP as source and date palm as destination points. The source point is at higher elevation which permits water flow under gravity.

Fig. 1. Haddah Sewer Treatment Plant (HSTP) in working condition.

Least cast path analysis (LCPA)

Cost distance and cost direction analysis

With the help of slope, the cost distance and cost direction layers were generated using spatial analysis tool of GIS. The surface model increases costs depending on the direction we are traveling from. Both of these surfaces act as inputs to calculate the LCPA. When combined, these layers acts like an obstacle course. The farther away you are, the more it costs you in time, money, or effort to reach the goal. Fig. 4 shows the cost distance and cost direction surfaces with weighted parameters along source and destination points.

Fig. 2. Unlined water channel and date palm farms in Wadi Fatima.

With the help of cost distance and cost direction surfaces, using spatial analysis tool of GIS the least cost path was constructed between HSTP and the date palm farms in wadi Fatima, Makkah Province. This was efficient pipeline route passing from rural areas along the decreasing slope which enables water flow under gravity reducing pumping cost. This is a prototype path analysis. By constructing pipeline following this route, the construction cost per meter will be very low due to avoiding steep slope and other factors that contribute in construction cost. Fig. 5 shows the least cost path beween source and destination.

The straight line path is the shortest distance between source and destination. The incremental costs resulting from terrain, geology, and land use were accumulated for these routes along the cost surface. The study concentrated on many different weighted overlays options and demonstrated with different least cost paths routes which helped to determine least hazardous route for the study area.

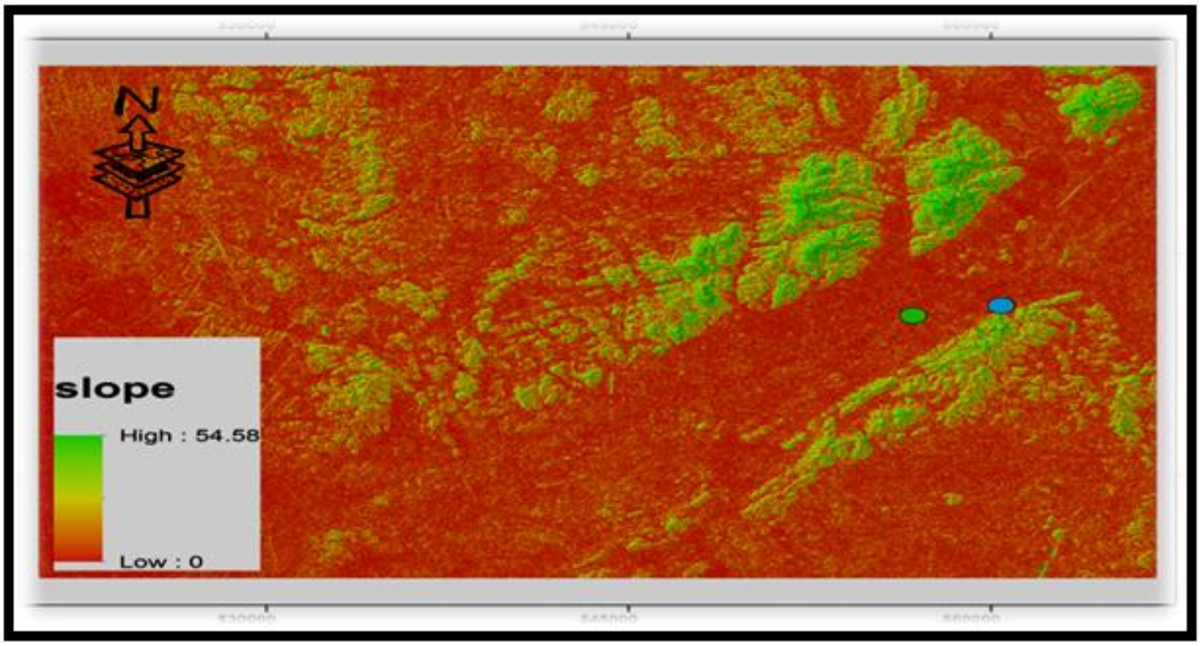

Fig. 3. Slope of research area with two classes (High & low) (blue dot is source and green shows destination).

Discussion

Using a GIS-based least cost path analysis we explored the connectivity among source and destination in the study area. The LCPA finds the cheapest way to get from one point to another using the least amount of efforts. In this study the Hada water plant was considered as source point and the remote date palm fields were classified as destination point. For the cost layer, we classified the slope into two categories: 0 (low) and 50% (high).

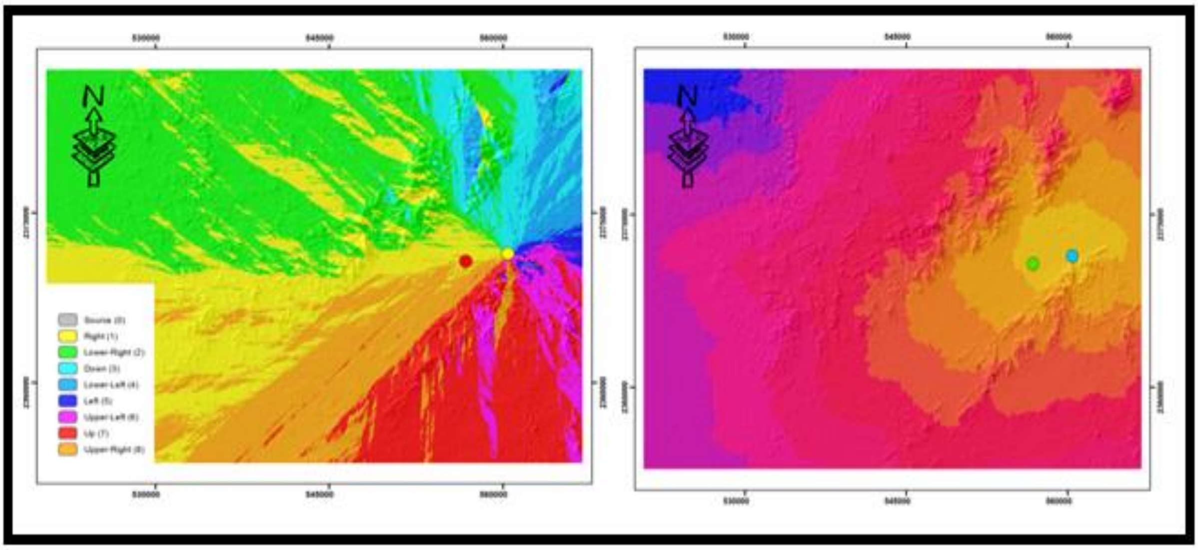

Fig. 4. Cost direction surface and cost distance surface as weighted parameter (in both pictures the right dot is source and left dot is destination).

The resulting pathway was influenced by the main geological structures like hilly areas and slope. This initial analysis gave the first idea about the connectivity of source and destination (Chang, 2012).

A route selection process that is well documented, uses the best available data, and allows early input from stake holders will in the end save in design costs. The success of this project was significantly increased by the use of the GIS tools throughout the route selection process.

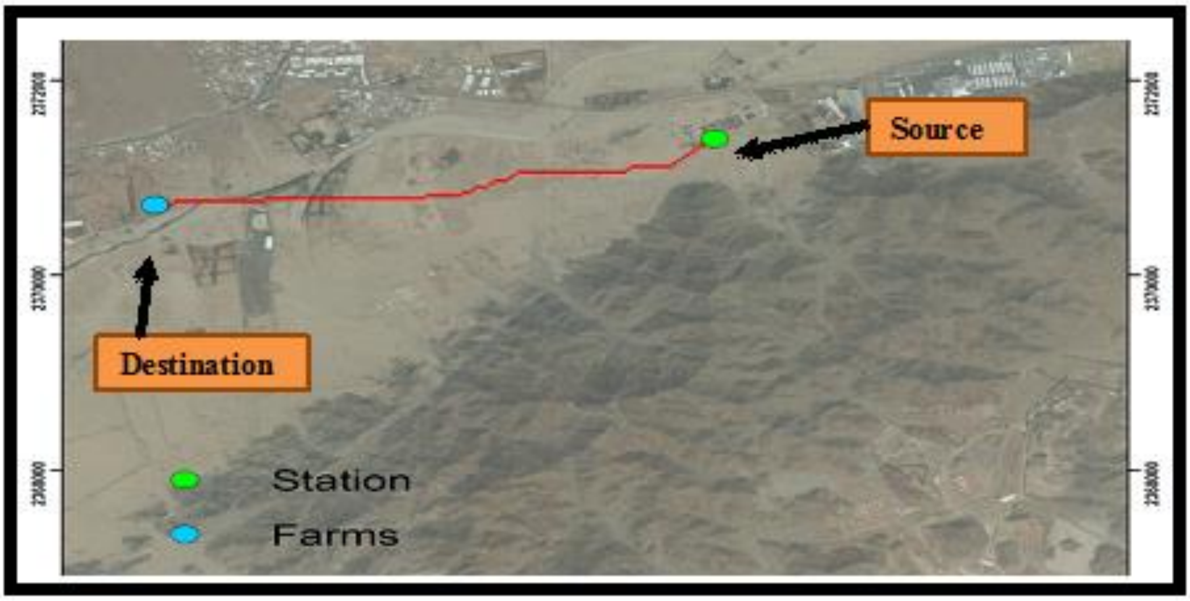

Fig. 5. Least cost path between source and destination showing in red color.

Conclusion

This is a prototypical analysis and practices cost data from other pipeline projects. To be most effective, the least cost path analysis must be fine-tuned on this study and on a project by project basis to account for actual project costs in the geographic area under consideration. The created least cost path from this study provides the least hazardous pipeline routes by using the available data that covers the Makkah region Saudi Arabia. When comparing the created route to the existing unlined water channel, the proposed least cast path accurately detail route that is almost similar and effective in providing a path from the source to the destination points. If the unlined open channel is replaced with the pipeline, the conveyance losses will be minimized by more than 50% by reducing the evaporation, seepage, leakage and deep percolation. Conveyance efficiency will increased which ultimately will increase the production. Additionally, running water in the Wadi main channel close to urban area can cause mosquito growth and breeding forming a threaten to human health can be cured.

Acknowledgement

The authors are thankful to Ministry of Higher Education and King Abdulaziz University of Saudi Arabia for providing Scholarship and facilities to complete this study.

References

Adriaensen FJP. 2003. The application of 'least-cost' modeling as a functional landscape model. Landscape and Urban Planning **64,** 233-247.

Aissi H, Salem C, Vincent M. 2012. GIS-based Multicriteria Evaluation Approach for Corridor Siting. (Environment and Planning B-Planning & Design **39(2),** 287–307.
http://dx.doi.org/10.1068/b37085).

Burrough PA. 1995. Spatial aspects of ecological data. In Data Analysis in Community andLandscape Ecology, 213–251.

RH, Jongman CJF, Ter Braak OFR, Van Tongeren eds. Wagenigen, The Netherlands: Cambridge University Press.

Chang KS. 2012. Introduction to Geographic Information Systems. McGraw-Hill: New York, 6th Edition.

Chyi RC, Wei LT, Yu FL. 2012. A GIS-dynamic segmentation approach to planning travel routes on forest trail networks in Central Taiwan. Landscape and Urban Planning **97,** 221-228.

Dosskey MG, Eisenhauer DE, Helmers MJ. 2005. Establishing conservation buffers using precision information. Soil and Water Conservation. **60(6),** 349-354.

Feldman SC, Ramona E, Pelletier EW, James C, Smoot, Douglas A. 1995. A Prototype for Pipeline Routing Using Remotely Sensed Data and Geographic Information System Analysis. Remote Sensing of Environment **53(2),** 123-131.

Franklin JP, Mc Cullough, Gray C. 2000. Terrain Variables Used for Predictive.

Fried JS, Brown DG, Zweifler MO, Gold MA. 2000. Mapping contributing areas for storm water discharge to streams using terrain analysis. In Terrain Analysis: Principles and Applications 183-203. J. P. Wilson and J. C. Gallant, eds., New York, John Wiley & Sons.

Guy F, Eric L. 2004. Online article GIS-based Management system for irrigation Districts. Website
www.newidea\FtCollins.htm.

Hector Valenzuela. 2012. (Online article on crop production guidelines and efficiency of localized irrigation methods. Website University of Hawaii, Hither. Last visited on 18/06/2012.
www.extento.edu/kbase/reports/dripirrigation.htm.

Hugh Turral. 1995. Recent trends in irrigation management changing directions for the public sector. Natural Resource Perspectives No **5,** September 1995.

Hugh T, Mark S, Jean MF. 2010. Investing in irrigation: Reviewing the past and looking to the future. Agricultural Water Management **97,** 551-560.

Kemal SG, Hasan D, Cigdem D. 2002. Creation of GIS supported database in irrigation Project Management. Agro environmental conference, 26-29 October 2002, Cairo, Egypt.

Knox JW, Kay MG, Weatherhead EK. 2012. Water regulation, crop production, and agricultural water management-Understanding farmer perspectives on irrigation efficiency. Agricultural Water Management **108,** 3-8.

Lucina S, Isidor D, Playan E, Aragues R. 2010. Irrigation modernization and water conservation in Spain: The case of Riegosdel Alto Aragón. Agricultural Water Management **97**, 1663-1675.

Mackey BG, Mullen IC, Baldwin KA, Gallant JC, Sims RA, Mckenney DW. 2000. Toward a Spatial Model of Boreal Forest Ecosystems: The Role of Digital Terrain Analysis. In Terrain Analysis: Principles and Applications 391-423. J. P. Wilson and J. C. Gallant, eds., New York, John Wiley & Sons. Mapping of Vegetation Communities in Southern California. In Terrain Analysis: Principles and Applications 331-53. J. P. Wilson and J. C. Gallant, eds., New York, John Wiley & Sons.

Mohammad A, Ali S, Majid B, Abd AN, Saeed BN, Mona G. 2010. Comparison of different irrigation methods based on the parametric evaluation approach in Dosalegh plain: Iran. Agricultural Water Management **97,** 1093-1098.

Negash W. 2004. GIS Based Irrigation Suitability Analysis. (A Case Study of Abaya-Chambo Basin, Southern Rift Valley of Ethiopia). FWU, Vol. **4,** Lake Abaya Research Symposium 2004.Page 79-89. Proceedings.

Rees WG. 2004. Least-cost Paths in Mountainous Terrain. Computers and Geosciences. **30(3),** 203-209.

Sami AS. 2015. Evaluation of soil efficiency in wastewater treatment and simulating its transport: field and lab studies on the soil of waste water treatment at the downstream site of wadi Fatima Makkah province. (Master thesis, department of Hydrology King Abdul-Aziz University Jeddah Saudi Arabia.

Stefano B, Divide G, Francesco O. 2011. Routing of Power lines through least-cost path analysis and multicriteria evaluation to minimize environmental impacts. Environmental Impact Assessment Review **31,** 234-239.

Sulebak JR. 2000. Applications of Digital Elevation Models. SINTEF Institute of Applied Mathematics. Department of Geographic Information Technology, White paper 2000.

Toriman ME, Mokhtar M. 2012. Irrigation: Types, Sources and Problems in Malaysia. Irrigation Systems and Practices in Challenging Environments, Dr. Teang Shui Lee (Ed.), ISBN: 978-953-51-0420-9
In Tech, Available from:
www.intechopen.com/books/irrigation-systems-and-practices-in-challenging-environments/irrigation-types-sources-andproblems-in-malaysia.