



**BUSITEMA
UNIVERSITY**
Pursuing Excellence

FACULTY OF ENGINEERING

DEPARTMENT OF WATER RESOURCES AND MINING ENGINEERING

APPLICATION OF GIS IN OPTIMAL PIPELINE ROUTING

CASE STUDY-MANAFWA District-Eastern Uganda.

BY

TEBUGULWA DAN

BU/UP/2014/634

Email: dantebtd67@gmail.com

Tel: 0704983580/0785419870

Supervisors

Main supervisor: Mr. Oketcho Yoronimo

Co-supervisor: Mr. Mugisha Moses.



A project report submitted to the department of water resources and mining Engineering in partial fulfillment of the requirements for the award of Bachelor of Science in water resources engineering degree of Busitema University.

MAY,2018

ABSTRACT

This report shows how the Geographical Information Systems (GIS) techniques were applied in generating an optimal pipeline route in Manafwa District from J. Quarters water point(source) to Bunambale village(destination). The project aims to ensure the generated route has the highest utility to the public, in addition to minimizing harmful impacts to people and the natural environment. Inputs from pipeline host communities where the pipelines will pass were seriously considered when determining the relative preferences of the various factors affecting the route (Weightings).

This involved deriving weights for the variables using Analytical Hierarchy Process (AHP) and modeling the routing process using them. A model developed incorporating topography, geology, soil types, roads, land use, and protected areas to identify an optimal route. GIS was used for spatial modeling, analysis and data overlay. The variables were weighted using AHP to determine their relative preferences This approach significantly increases the reliability and acceptability of the generated route. ESRI's ArcGIS spatial analyst tool was deployed for data analysis and interpretation.

DECLARATION

I TEBUGULWA DAN declare that the work presented in this project is as a result of my own research and has never been submitted to any institution of higher learning for any award whatsoever.

Signature.....*Handwritten*.....

Date.....*31/05/2018*.....



APPROVAL

This project on the **APPLICATION OF GIS IN OPTIMAL PIPELINE ROUTING**
CASE STUDY-MANAFWA District-Eastern Uganda has been written under the supervision
of;

Main supervisor

Mr. OKETCHO YORONIMO

Signature

Date.....

Co-supervisor

Mr. MUGISHA MOSES

Signature


Date..... 31/05/18

ACKNOWLEDGEMENT

I thank the Almighty God for the far that he has brought me, the gift of life, protection and his provision to me during and throughout the writing of this project.

I extend my deep sense of gratitude to my academic supervisors, **Mr. Oketcho Yoronimo and Mr. Mugisha Moses** for their kind attitude, keen interest, immense help, inspiration and encouragement which helped me throughout this project. My heart pulsates with the thrill for tendering gratitude to the entire staff of the department of Mining and Water Resources Engineering Busitema University for providing all kind of possible assistances throughout this project. Let me also convey my heartfelt appreciation to the management of EARTH CONSULT (UG) ltd for thee great opportunity you gave me to train with you and acquire special skills which I have deeply applied in this project.

Great thanks to my beloved uncle Mr. Musoke Disan for his financial and moral support and I promise him that as long as I live, he will live.

It would be great injustice if I omit the role played by my dear friends especially Oyuki Godfrey, Niringiye Ernest, Nakkomo Joanitah, and Butita Simon in directing me, their tremendous tireless support and guidance given to me during the writing of this and the entire team of class 2014. May the good Lord reward you all!

Table of Contents

ABSTRACT	i
DECLARATION	ii
APPROVAL.....	iii
ACKNOWLEDGEMENT	iv
LIST OF FIGURES.....	viii
LIST OF TABLES	ix
LIST OF ACRONYMS.....	x
CHAPTER ONE	1
1.0 Background	1
1.1 Problem statement	2
1.2 Justification of the study	2
1.3 Objectives.....	3
1.3.1 Main objective	3
1.3.2 Specific objectives	3
1.4 Scope of the study	3
1.5 Project Area.....	3
CHAPTER TWO: LITERATURE REVIEW	5
2.0 Pipeline routing	5
Geographic information system (GIS)	8
2.0.1 View-shed analysis	9
2.1 Cost surface.....	10
2.2 Cost Distance tool	11
2.2.1 Mathematical algorithm underlying the cost distance tool	11
2.3 Cost Back Link.....	13
2.3.1 Mathematical algorithm underlying the cost back link tool	13
2.3.2 Path distance	14
2.3.3 Cost path tool	14
2.4 Weighted overlay	15
2.4.1 Mathematical algorithm underlying the weighted overlay tool	15

2.5	Optimization Techniques	17
2.5.1	Fuzzy AHP	17
2.5.2	Analytical Hierarchy Process.....	17
2.5.3	Implementation of the AHP	20
2.5.4	Procedure: Estimating Consistency Ratio.....	22
2.6	Geotechnical Considerations for Pipeline.....	23
CHAPTER THREE: METHODOLOGY		27
3.0	Developing relevant thematic maps for the datasets.....	27
3.1	Generating an accumulated cost surface map	28
3.1.1	Rasterisation.....	28
3.1.2	Reclassification	29
3.2	Analyzing and interpolating GIS layers and maps.....	29
3.3	Weightage calculation	30
3.3.1	Procedure for Estimating Consistency Ratio	32
3.4	Computing the least cost path for the pipeline.....	33
3.4.1	Cost distance raster.....	33
3.4.2	Cost back link raster.....	33
3.4.3	Least cost path.....	34
CHAPTER FOUR: PRESENTATION AND DISCUSSIONS OF RESULTS.....		36
4.0	Thematic layers	36
4.1	Soil map.....	36
4.1.1	Analysis of Soil layer.....	37
4.2	Lithology map	37
4.2.1	Analysis of lithology layer.....	38
4.3	Slope map.....	39
4.3.1	Analysis of Slope layer	40
4.4	Land use/Land cover map	40
4.4.1	Analysis of land cover layer	41
4.5	Roads.....	42
4.5.1	Analysis of Roads Layer.....	42

4.6	Protected areas.....	44
4.6.1	Analysis of protected area layer.....	44
4.7	Model development.....	45
4.7.1	Accumulative Cost Surface map.....	45
4.8	Least Cost Path Routing.....	47
4.8.1	Overlaying the paths on thematic layers for comparison.....	50
CHAPTER FIVE: CHALLENGES FACED, CONCLUSION AND RECOMMENDATIONS.		55
5.0	Challenges Faced.....	55
5.1	Conclusion.....	55
5.2	Recommendations.	56
References.....		57
APPENDICES.....		59
APPENDIX 1: A DIGITAL ELEVATION MODEL OF UGANDA		59
APPENDIX 2: A LITHOLOGY MAP OF UGANDA		60
APPENDIX 3: A LAND COVER MAP OF UGANDA.....		61
APPENDIX 3: GRAPH OF AREA AGAINST LAND COVER OF UGANDA.....		62

LIST OF FIGURES

Figure 1.1: The location of study area	4
Figure 2.0: Basic Pipeline Optimization.....	7
Figure 2.1 (b): Algorithm underlying the cost distance tool for Diagonal nodes.....	12
Figure 2.1(c): Principal of determining the cost distance raster	13
Figure 2.2(a): Algorithm underlying the cost back link raster.....	13
Figure 2.2(b): Principal of determining the cost back link raster	14
Figure 2.3: Algorithm underlying the weighted overlay tool	16
Figure 2.4: The three major steps of Saaty AHP	18
Figure 3.1: Developing thematic maps	28
Figure 3.2: Major steps in generating an accumulated cost surface map	28
Figure 3.2.1 Rasterisation	29
Figure 3.2.2: Reclassification	29
Figure 3.3.1: Methodology for cost distance raster	33
Figure 3.3.2: Methodology for cost back link raster.....	33
Figure 3.3.4: Methodology for determining the Least cost path.....	34
Figure 3.4: Flowchart for the optimal pipeline routing.....	35
Figure 4.1.1: A thematic layer showing the soils of Manafwa District	36
Figure 4.1.2: A thematic layer showing the lithology of Manafwa District	38
Figure 4.1.3: A thematic layer showing the slope of Manafwa District	40
Figure 4.1.4: A thematic layer showing the Land Cover of Manafwa District	41
Figure 4.1.6: A thematic layer showing the Protected area of Manafwa District.....	44
Figure 4.2: The general model used to overlay all the factors of optimal pipeline routing.....	45
Figure 4.2.1: Accumulative Cost Surface map basing on different effectiveness percentage.....	46
Figure 4.2.2: Accumulative Cost Surface map basing on equal effectiveness percentage.....	46
Figure 4.3.1: Cost distance raster map.....	47
Figure 4.3.2: Cost back link raster map	48
Figure 4.4: The least cost path on the cost surface raster map	49
Figure 4.4.1: The sensitivity analysis path obtained from equal effectiveness percentage.	50
Figure 4.4.2: Overlaying the paths on land cover thematic layer for comparison.....	51
Figure 4.4.3: Overlaying the paths on thematic layers for comparison	51
Figure 4.4.4: A graph of environmental aspect consideration against different techniques.....	52
Figure 4.4.5: A pie chart showing the total cost in using different pipeline routing criteria	53
Figure 4.4.6: A graph showing the cost variation with parameters of different routing techniques	54

LIST OF TABLES

Table 2.1: Weighting system for AHP.....	19
Table 2.2: Relative scores in AHP.....	21
Table 2.3: Random Indices (RI) n=1, 2....15	23
Table 2.4: Moh's scale of hardness.....	24
Table 3.1 Showing different data sources and functions.....	27
Table 3.2: Pairwise Comparison Matrix	30
Table 3.3: Normalized Pairwise Comparison Matrix	31
Table 3.4: Consistency ratio	32
Table 4.1: Soil reclassification.....	37
Table 4.2: Rocks reclassification	39
Table 4.3: Slope reclassification	40
Table 4.4: Land cover reclassification	42
Table 4.5: Roads reclassification	43
Table 4.6: Protected area reclassification	44
Table 4.7: Consideration of different parameters by different pipeline routing techniques.....	52
Table 4.8: Cost of using different routing techniques.....	53

LIST OF ACRONYMS

- AHP – Analytical hierarchy process
- DEM – Digital Elevation Model
- DGSM – Directorate of Geological Survey and Mines
- DWD – Directorate of Water Development
- DWRM – Directorate of Water Resources Management
- UBOS - Uganda Bureau of Statistics
- GIS – Geographical Information System
- MWE – Ministry of Water and Environment
- NARO – National Agricultural Research Organization
- SRTM - Shuttle Radar Topography Mission
- NFA – National Forestry Authority
- USGS – United States Geological Survey
- UTM – Universal Transverse Mercator
- WIOA – Weighted Index Overlay Analysis
- GA – Genetic Algorithm
- VTDT – Variable Topography Distance Transform

CHAPTER ONE

This chapter outlines the following; background to the study, problem statement, justification, objectives of the study, purpose of the study and the scope of the study.

1.0 Background

Water is a basic human right. Without it societies wither and people die (Joanne, 2000). The major problem affecting developing countries is the inadequate supply of safe water to its natives.

There can be no state of positive health and well-being without safe water (Aderibigbe, 2008). The various purposes of water to man include, drinking, cooking, bathing, recreation, irrigation, and industrial uses amongst uses. A study in 1990 estimated that more than 1 billion people in developing countries lacked access to safe drinking water (WHO, 1995). Washing hands after visiting the latrine and before preparing food is of particular importance in reducing disease transmission, but without abundant water in or near homes, hygiene becomes difficult or impossible (Park, 2002). Many cities and municipalities are facing steady population increases and community growth which, as a result, exerts greater strain on these cities' resources. Affordable municipal water strategies are necessary to meet the growing water demand. Some of these strategies include large-scale projects that involve pumping water through a series of pipelines spanning large tracts of land and requiring an extensive infrastructure of reservoirs and pumping stations. Indeed, siting the route of a pipeline is a crucial component that will later influence its design, construction and maintenance which will then determine some of the environmental impacts (Marshall, 1983). Cross et al (2007) noted that it is important that these environmental consequences of pipeline construction are clearly defined and understood to better assess the effectiveness and drawbacks of its construction.

A major objective in selecting a pipeline route is to ensure the chosen route has the highest utility to the public, in addition to minimizing harmful impacts to people and the natural environment. (C.N. Nonis, 2007)

Manual pipeline route planning uses available maps, surveys and experience and is seriously constrained due to lack of updated data and quantitative approach. This is inadequate for complex

References

- Aderibigbe, S. A. (2008). Availability, Adequacy and Quality of Water Supply in Ilorin Metropolis, Nigeria. *Nigeria. European Journal of Scientific Research*, 23(4):528-536.
- Adewumi., R. (2006). Developing Nigerian Oil and Gas Pipeline Using MCDA. *Nigerian Engineering Conference and Annual General Meeting (Gateway)*. Abuja,: Technological and National Content Development for Economic Self-Reliance. .
- Aissi, C. a. (2012). GIS-based Multicriteria Evaluation Approach for Corridor Siting. *Environment and Planning B-Planning & Design* 39 (2), 287–307.
- Barron, R. J. (2005). *Site selection of Petroleum Pipelines*. Retrieved from A GIS Approach to Minimize Environmental : <http://gis2.esri.com/library/userconf/proc99/proceed/papers/pap350/p350.htm>, ESRI
- Berger, J. a. (2004). A parallel hybrid genetic algorithm for the vehicle routing problem with time windows. *Comput. Operat. Res*, 2037-2053.
- Bevilacqua, M. A. (2004). A Multi-Criteria Decision Approach to Choosing The Optimal Blanching-Freezing System. *Journal of Food Engineering*, 63, 253-263.
- Bouyssou, D. M. (2000). *Evaluation Models: A Critical Perspective*. Boston: Kluwer.
- C.N. Nonis, K. V. (2007). Investigation of an AHP based Multi Criteria Weighting Scheme for GIS. *24th International Symposium on Automation & Robotics in Construction (ISARC)*.
- Chang, D. Y. (1992). Extent Analysis and Synthetic Decision. In *Optimization Techniques and Applications* (pp. 1, 352). Singapore: World Scientific.
- Cheng, C. H. (1999). Evaluating Attack Helicopters by AHP Based on Linguistic Variable Weight. *European Journal of Operational Research*, 116, 423-435.
- Collischonn, W. J. (2000). A Direction Dependent Least-costpath Algorithm for Roads and Canals. *International Journal of Geographical Information Science*.
- De Smith, M. (2004). Distance transforms as a new tool in spatial analysis, urban planning, and GIS. *Environment and Planning, B: Planning and design*, 85-104.
- Dijkstra, E. W. (1959). A Note on Two Problems in Connexion with Graphs. *Numerische Mathematik* 1, 269–71.

- Dubey, R. (2005, 07 24). *A remote Sensing and GIS based least cost routing of pipelines*. Retrieved from <http://www.gisdevelopment.net/application/Utility/transport/utilitytr0025pf.htm>.
- Feldman, S. C. (1995). A Prototype for Pipeline Routing Using Remotely Sensed Data and Geographic Information System Analysis. *Remote Sensing of Environment*.
- Ghose, M. A. (2006). A GIS based transportation model for solid waste disposal: A case study on Asansol municipality. *Waste Manage*, 1287-1293.
- Goodchild, M. (1976). An evaluation of lattice solutions to the problem of corridor location.
- Gupta., P. D. (1999). Decision Support System for Pipeline Route Selection. *International Journal of Project.*, 41(10): 29-35 .
- Joanne, G. (2000). Global Environment Outlook. *United Nations Environment Programme (UNEP)*.
- Lee, Jay, Dan Stucky. (1998). On Applying View-shed Analysis for Determining Leastcost Paths on Digital Elevation Models. *International Journal of Geographical Information Science*.
- Leung, L. C. (2000). On Consistency and Ranking of Alternatives in Fuzzy AHP. *European Journal of Operational Research*, 124, 102-113.
- Luettinger, C. (2005). Geographic Information System-based Pipeline Route Selection Process. *Journal of Water Resources Planning & Management*.
- Maheen Iqbal, F. S. (2006). IEEE, Planning a Least Cost Gas Pipeline Route A GIS & SDSS Integration Approach.
- Marshall, R. a. (1983). Geotechnical aspects of pipeline construction in Alberta. *Canadian Geotechnical Journal*, 20: 1-10.
- Özdağoğlu, A. (2007). Comparison of AHP and fuzzy AHP for the Multi- Criteria Decision making processes with Linguistic Evaluations. 65-85.
- Park. (2002). Environment and Health in: Park's Textbook of Preventive and Social Medicine. *Eds. (17)*.
- Peters, T. a. (2003). *Plant Design and Economics for Chemical Engineers*. McGraw-Hill Companies Inc.
- Rees, W.G. (2004). Least-cost Paths in Mountainous Terrain. *Computers & Geosciences*.2003.
- Saaty, T. L. (1980). *The Analytic Hierarchy Process*. New York: McGraw Hill.
- Saha, A. K. (2005). GIS-based Route Planning in Landslide Prone Areas. (*International Journal of Geographical Information Science 19 (10)*), 1149–1175.