Open Journal of Safety Science and Technology, 2024, 14, 136-146
https://www.scirp.org/journal/ojsst
ISSN Online: 2162-6006
ISSN Print: 2162-5999

Spatial Risk Assessment for the Proposed East African Crude Oil Pipeline (EACOP)

Luwaga Denis[1,2,3]*, Siriba N. David[1], Ssekandi Joseph[2], Zaabwe Thaddeus[4,5], Nababi Joyce[6], Nakawoombe Milliam[4], Nansamba Phionah[2]

[1]Department of Geospatial and Space Technology, School of Engineering, University of Nairobi, Nairobi, Kenya
[2]Department of Environmental Sciences, Faculty of Agriculture, Uganda Martyrs University, Nkozi, Uganda
[3]Department of the Built Environment, Faculty of Environmental Sciences, Mzuzu University, Mzuzu, Malawi
[4]Department of Fisheries and Aquatic Sciences, Faculty of Environmental Sciences, Mzuzu University, Mzuzu, Malawi
[5]National Agricultural Research Organization, Bulindi Zonal Agricultural Research and Development Institute, Hoima, Uganda
[6]Department of Chemistry, Faculty of Science Technology and Innovations, Mzuzu University, Mzuzu, Malawi
Email: *luwagadenis@gmail.com

How to cite this paper: Denis, L., David, S.N., Joseph, S., Thaddeus, Z., Joyce, N., Milliam, N. and Phionah, N. (2024) Spatial Risk Assessment for the Proposed East African Crude Oil Pipeline (EACOP). *Open Journal of Safety Science and Technology*, **14**, 136-146.
https://doi.org/10.4236/ojsst.2024.144010

Received: February 8, 2021
Accepted: November 2, 2024
Published: November 5, 2024

Abstract

A well thought out risk assessment process enables asset owners and stakeholders to carry out effective and efficient risk management through specific actions that minimize the likelihood of risk occurrence. The intention is to reduce risk to the lowest practical level possible. Whereas an impact assessment was carried out for the proposed East African Crude Oil Pipeline (EACOP), it does not exhaustively point out all the potential risks associated with the pipeline establishment. This article therefore, focuses on the use of geospatial technologies in the development of a spatial risk assessment model for enhancing the security and safety of the proposed pipeline and the surrounding environment. This was achieved through identifying and incorporating other potential risk factors such as terrorist attacks, political violence, social unrest, theft, floods and earthquake. These factors can paralyze pipeline operations which may lead to gross loss of revenue, destruction of property and livelihood. The risk assessment model was developed using the Multi-Criteria Decision Analysis (MCDA) approach. The input factors were independently assessed depending on their relative influence on pipeline security and safety based on the history of their occurrence in the study area. These were proportionally assigned relative weights depending on their proximity to the pipeline. The study modeled risk based on Cova's proposed approach, which considers risk to be a product of hazard and vulnerability (Risk = hazard * vulnerability). The results of the study indicate that the section of the pipeline that traverses through Uganda is more at risk than its Tanzanian counterpart. This can be attributed to the presence of terror threats and political unrest in Uganda. The quantitative results further revealed that approximately

265,504 hectares of vegetation cover and 9,149 households are at risk of being destroyed and displaced by pipeline operations respectively. To effectively enhance the security of the pipeline, the article proposes a collaboration between different stakeholders in the oil and gas sector, including investors, researchers, biodiversity conservationists, industry professionals, technology developers, the private sector, Government, NGOs and Civil Society Organizations. This will facilitate integrated knowledge and expertise sharing on various methodologies to ensure that all spheres of the economy, including biodiversity conservation, are strongly considered.

Keywords

Spatial Risk Assessment, MCDA, Hazard, Vulnerability, EACOP

1. Introduction

The Ugandan Government, together with other stakeholders, discovered and confirmed the existence of commercial quantities of oil and gas resources in the Albertine region in 2006 [1]. The exploration phase was done by stakeholders, including oil companies such as China National Offshore Oil Cooperation (CNOOC) Ltd., Total Ltd. and Tullow Oil; after which the development phase preceded. At this point, it is expected that a considerable amount of oil and gas resources shall be produced for commercial purposes [1]. Once extracted, the crude oil shall be partly refined in Uganda to supply the local market and the surplus will be exported to the international market through a proposed pipeline known as the East African Crude Oil Pipeline (EACOP).

The EACOP (**Figure 1**) is a 1443 km crude oil export pipeline that was selected by the government of Uganda as the most cost-effective, optimal and efficient route to transport Uganda's crude oil resources from Hoima District in Uganda to the Chongoleani peninsula near Tanga port in Tanzania [2].

Pipelines are one of the key mechanisms in the transportation of oil and gas resources and are expected to operate continuously at all times. They provide effective and cost-effective means to transport crude oil resources to refinery plants both on and offshore [3]. It is, therefore, vital that they operate as safely and efficiently as possible. When incidents like attacks or theft occur, they must be expeditiously restored to normal operation in order to meet industry, environmental, safety, quality, and production demands [4].

The use of an integrated risk assessment index method to produce individual hazard and vulnerability maps from which the final risk map can be derived is important. The indexing method can be used to assess gas pipeline risks [5]. GIS and overlay analysis can be used to quantitatively evaluate the risk along the gas pipeline through integrating location information for accident incidents with land use and demographic information to depict the spatial distribution of occurrences and potential areas susceptible to risk [6].

Whereas the above studies were undertaken using different methodologies, the current study models risk as a product of Hazard and Vulnerability (Risk = Hazard * Vulnerability). In addition, these studies squarely consider terrorist attacks and theft as the major risk factors overwhelming the safety of oil and gas pipeline systems yet other factors, such as floods and earthquakes may present significant damage and sabotage to pipeline operations. Furthermore, the Environmental and Social Impact Assessment (ESIA) that was carried out for the EACOP focused on the impact of the pipeline on the communities and the environment, but it doesn't exhaustively highlight the potential risks associated with the pipeline itself.

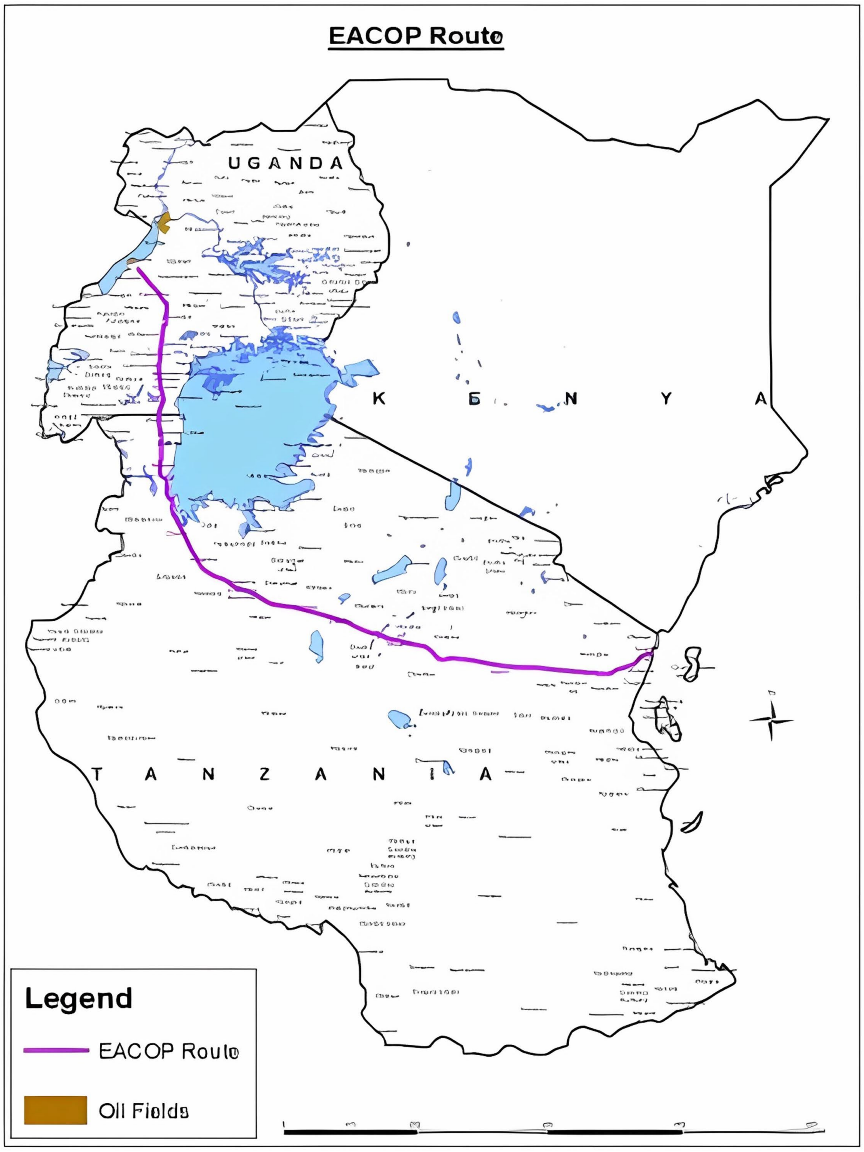


Figure 1. Map showing the EACOP Route.

1.1. Objective of the Study

The study aimed at using geospatial technologies to develop a risk assessment model for the proposed EACOP. The study also estimated and quantified the potential damages along the proposed pipeline in case of hazard occurrence. Specifically, the study identified other potential risk factors associated with oil and gas pipeline systems which are unique to the EACOP.

1.2. GIS and Risk Assessment

Geospatial technologies are available to enhance planning, design, management, operation, and maintenance of pipeline systems [7]. Remote sensing techniques integrated with GIS capabilities can be leveraged to assist in pipeline risk assessment and boost the safety of pipeline facilities. GIS has the capacity to help by mapping and monitoring existing infrastructure, including the pipeline [8]. Knowing and understanding the geographic context of the infrastructure helps in predicting and examining effective measures to prevent such attacks [9]. GIS analysis can be used to predict where these attacks are most likely to occur. This helps to reduce future attacks and also equip rescue teams with situational and incidence awareness, as well as improving in response time once an attack or theft takes place [10].

1.3. Risk Modeling

Although different mechanisms like foot patrols, aerial surveillance and leak detection systems can be employed to ensure the protection and safety of pipelines, the baseline should be to identify the risks to which pipelines are exposed to, identify their causes and determine optimal and effective measures for risk mitigation [11]. Risk assessment is therefore, needed to give weight to a specific occurrence depending on its likelihood. GIS is gaining considerable favor compared to traditional approaches of risk analysis [12]. GIS can be employed to examine and analyze risk from a spatial perspective relevant to the current study [13]. The parameters involved in the process of risk modeling can therefore, be grouped into hazard and vulnerability, as shown in **Figure 2**.

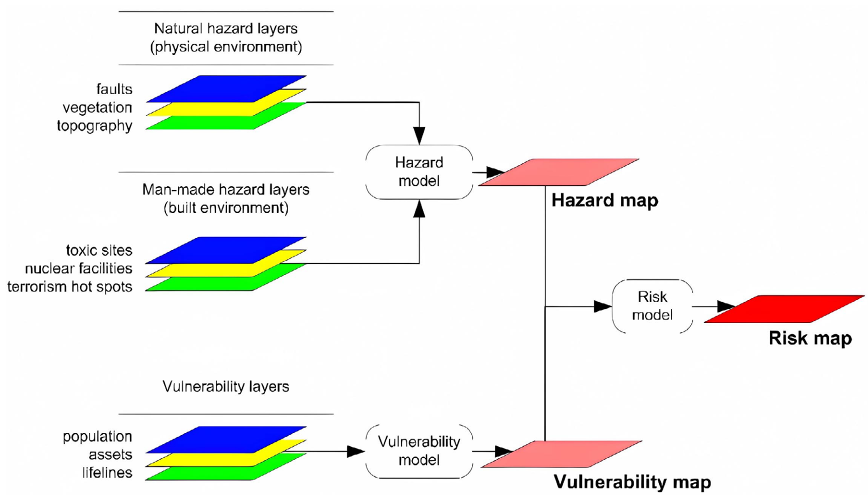


Figure 2. Cova's risk assessment model (1999).

In the above model, Cova [14] combined the natural hazard layers (Physical environment), man-made layers (Built environment) and vulnerability layers to assess the risk associated with people's livelihood. This study used the same approach where hazard and vulnerability layers were examined to determine the risk associated with the EACOP. The study assesses risk by assigning weights to each of the variables based on an integrated risk assessment of multi-hazards. Hazard and vulnerability maps were produced by describing ordinal classes of intensity in the range of 1 - 5 (**Table 1**).

Table 1. Risk assessment matrix.

Likelihood		Very Likely 5	Likely 4	Unlikely 3	Very Unlikely 2	Not Likely 1
Consequence	Fatality - 5	25	20	15	10	5
	Major Injuries - 4	20	16	12	8	4
	Moderate Injuries - 3	15	12	9	6	3
	Minor Injuries - 2	10	8	6	4	2
	Negligible Injuries - 1	5	4	3	2	1

In reference to this study, the risk assessment matrix was generated by multiplying the likelihood of the hazards identified occurring by their estimated consequence or impact. Basing on the literature, the probable risk factors were prioritized and independently assigned relative likelihood and impact values depending on the level of severity realized previously when such events occurred in the study area. The values were assigned weights on a Likert scale of 1 - 5 with 5 being the highest level of likelihood and severity on both the likelihood and consequence axes respectively. Furthermore, terrorism and political violence were identified to be the most probable risk factors associated with the pipeline and also cause significant damage in case they do take place.

2. Methodology

The first aspect was to identify potential risk factors associated with oil and gas pipelines after which the relevant spatial data was acquired and organized into a geodatabase for easy access and usability.

The input datasets required to undertake the study included the EACOP Pipeline, international, national and administrative boundaries, populated areas and urban centers, elevation data, vegetation cover, land use/land cover and transportation networks, which were acquired from the Ministry of Energy and Mineral Development (Uganda) at https://www.energyandminerals.go.ug/. The terrorism data was acquired from the Global Terrorism Database (GTD) at https://www.start.umd.edu/research-projects/global-terrorism-database-gtd while the Social Conflict data was acquired from the Social Conflict in Africa Database (SCAD) at https://worldmap.harvard.edu/data/geonode:scad_pt2_fr8.

The methodology used was based on the concept developed by Cova in 1999 where Hazard and Vulnerability were spatially intersected to generate the Risk component (Risk = Hazard * Vulnerability). Hazards were identified depending significantly on the history of past events and the following hazards were singled out; terrorist attacks, political violence and social unrest, floods, earthquakes, and theft.

Using different GIS tools and processes like reclassification, intersection, validation, weighting, and overlaying, the input features were reclassified into 5 classes using the natural breaks classification algorithm. The risk assessment model was developed using the Multi-Criteria Decision Analysis approach, in which the input factors were independently assessed. This was dependent on their relative influence on pipeline security and safety basing on the history of their occurrence in the study area. They were then proportionally assigned relative weights (1 - 5) depending on their proximity to the pipeline with the nearest features having a bigger weight (5) and the furthest (1) as indicated in **Figure 4**.

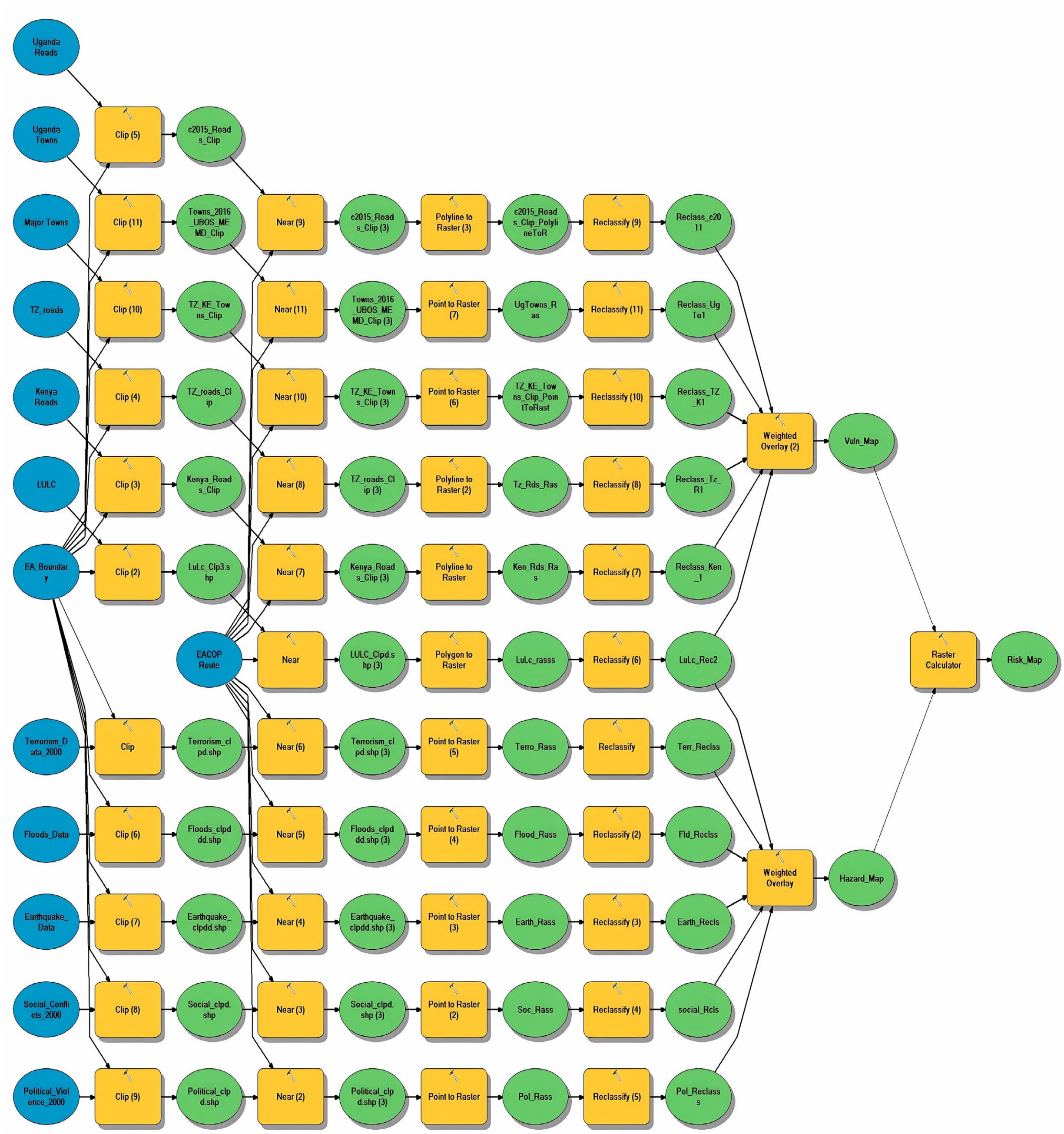
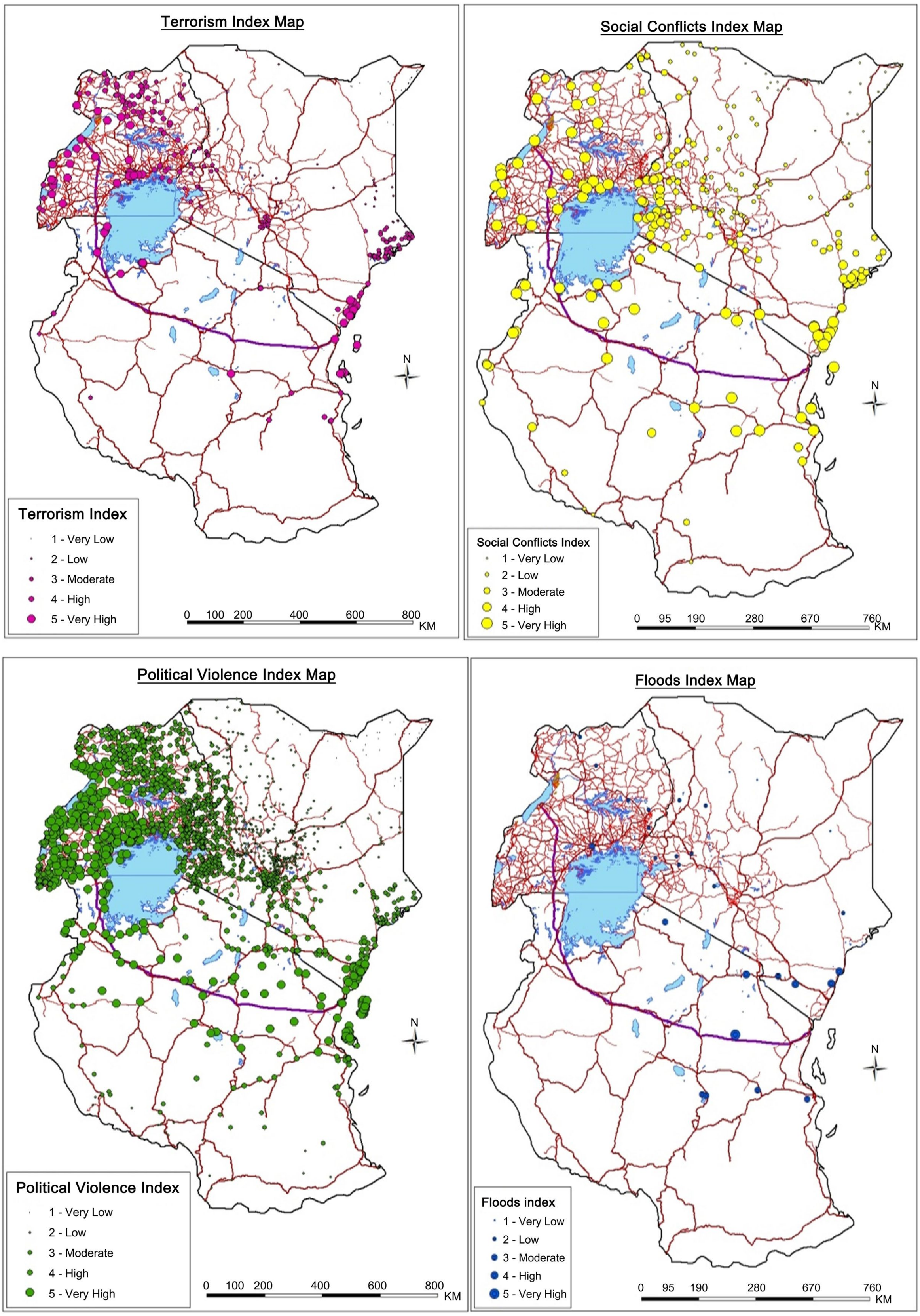


Figure 3. The GIS model from which the final hazard map was derived.

3. Results and Interpretation



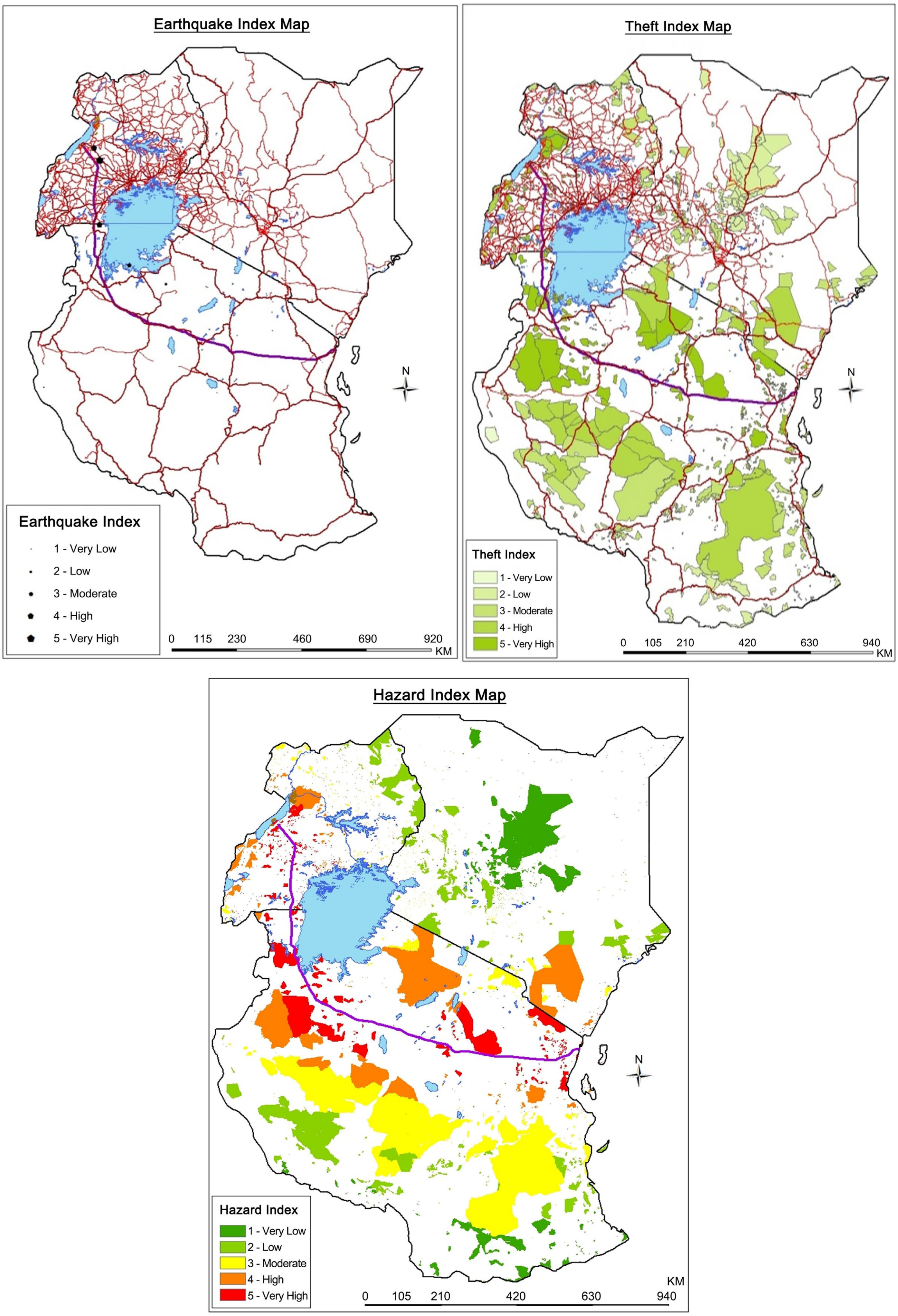


Figure 4. Final Hazard Index Map displaying risk levels associated with the EACOP.

As visualized from the hazard maps above; it is envisioned that the section of the pipeline that traverses through Uganda is at high risk (4) of terrorist attacks, political violence and social conflicts than in Tanzania (2). This could be attributed to power struggles and political instabilities in the region. The results also reveal that the section of the pipeline that traverses through the western part of Uganda especially in the districts of Hoima, Kikuube, Kyankwanzi and Kakumiro is at moderate risk (3) of earthquake due to major faults associated with the East African Rift System. Moreover, the section of the pipeline that traverses through the eastern part of Tanzania in the districts of Kiteto, Kilindi, Kologwe and Tanga is prone to floods (3) due to the low underlying elevation influenced by the Indian Ocean. Furthermore, the section of the pipeline that traverses through the western and central regions of Tanzania is at risk (3) of theft and vandalism of petroleum products due to thick vegetation cover in form of forests and wetlands that exist in the area.

The study also estimated the potential damage along the pipeline in case of hazards. This was done by quantifying elements at risk in both Uganda and Tanzania. This was accomplished using the calculate geometry and tabulate areas tools where the area calculated was normalized based on the number of known occurrences of hazardous events in the study area. It is estimated that approximately 9,149 households, of which 3,155 from Uganda and 5,994 from Tanzania are at risk, 96 intersections of highways and major roads in both Uganda (58) and Tanzania (38) are at risk. It is also estimated that approximately 265,504 hectares of vegetation cover in both Uganda and Tanzania are at risk of being destroyed by pipeline operations.

4. Conclusions

The model used in this study is reliable in identifying, predicting and visualizing where probable hazards can occur along the pipeline system. The results of the study concur with the Environmental Social Impact Assessment (ESIA) report for the EACOP although other potential risk factors like soil erosion, fire outbreak, volcanoes, and vehicle collisions among others need to be further investigated and mitigation measures be devised.

Furthermore, the results from the model indicated that the section of the pipeline that traverses through Uganda is more at risk than the Tanzanian counterpart. This may be due to the increased establishment of oil and gas infrastructure, presence of terror networks in the country, social unrest and political violence, uncontrolled urbanization resulting from population pressure in cities like Kampala, Jinja, Masaka and Mbarara. We can use similarly, the section that traverses through Tanzania may also be at risk since the establishment of the pipeline may result into the construction of new oil and gas infrastructure. This therefore, calls for a concerted effort between the governments of Uganda and Tanzania fostered at safeguarding the pipeline since it will generate revenue for both governments hence enhancing economic growth.

Recommendation

Since the pipeline shall traverse through local communities and several ecological zones, the article proposes that the following measures be undertaken to boost the security of local communities and the pipeline: 1) Collaboration between different stakeholders in the oil and gas sector including investors, researchers, biodiversity conservationists, industry professionals, technology developers, the private sector, Government, NGOs and Civil Society Organizations to share knowledge and expertise to facilitate the integration of various methodologies to ensure that all spheres of the economy including biodiversity conservation are put into consideration, 2) To identify other optimal sites where the affected biodiversity areas can be re-established, 3) Timely compensation of stakeholders for loss of land and property while acquiring the EACOP route to enable and foster resettlement plans, 4) An in-migration plan has to be developed for urban centers like Hoima, Mbirizi and Kinoni that are directly traversed by the pipeline as people may be attracted for both direct and indirect project opportunities, 5) A community health, safety and security plan to be developed to mitigate concerns over noise from pipeline construction, pollution, impact on water quality, soil productivity and spread of communicable diseases by project staff.

Other general mitigation measures in order to avoid or reduce on the likelihood of potential hazards may include 1) Establishment of police posts in critical areas along the pipeline, like towns that are at high risk, 2) Regular monitoring of the pipeline using ground patrols and UAVs, 3) Insuring the pipeline, 4) Introducing better hazard warning systems such as encouraging people to conserve and protect wetlands which keep hold of surface water, restore river courses, among others to avoid hazards like floods.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Mawejje, J. (2019) The Oil Discovery in Uganda's Albertine Region: Local Expectations, Involvement, and Impacts. *The Extractive Industries and Society*, **6**, 129-135. https://doi.org/10.1016/j.exis.2018.09.007

[2] Butijn, H. (2018) Profile of the East African Crude Oil Pipeline. https://www.banktrack.org/project/east_african_crude_oil_pipeline

[3] Burgherr, P.E. (2010) Security Risks of Critical Infrastructures in the Oil and Gas Sectors. Davos: Paul Scherrer Institute. https://www.slideshare.net/slideshow/security-risks-of-critical-infrastructures-in-the-oil-and-gas-sectors/4466108

[4] Farrell, A.E., Zerriffi, H. and Dowlatabadi, H. (2004) Energy Infrastructure and Security. *Annual Review of Environment and Resources*, **29**, 421-469. https://doi.org/10.1146/annurev.energy.29.062403.102238

[5] Vanessa, A., Libriati, B.Z. and Norhazilan, B.M.D.N. (2022) Risk Assessment of Underground Gas Pipeline Leakage Incorporating Geographical Information System

(GIS).
https://technoaretepublication.org/book/smart-environmental-science-technology-management/paper/15.pdf

[6] Clemonds, M.A. and Isaacs, R. (2010) GIS in Pipeline Management. https://www.researchgate.net/profile/Epuh-Emeka/publication/335394096_Application_of_GIS_to_Oil_and_Gas_Pipeline_Management_A_Case_Study_of_South-South_Nigeria/links/5fa6c6cca6fdcc06241d5a8e/Application-of-GIS-to-Oil-and-Gas-Pipeline-Management-A-Case-Study-of-South-South-Nigeria.pdf

[7] Monica, P., Marcelo, M. and Annalia, B. (2008) Geographic Information Systems and Risk Assessment. https://core.ac.uk/download/pdf/38613171.pdf

[8] Kaur, H., Gupta, S., Parkash, S. and Thapa, R. (2018) Application of Geospatial Technologies for Multi-Hazard Mapping and Characterization of Associated Risk at Local Scale. *Annals of GIS*, **24**, 33-46. https://doi.org/10.1080/19475683.2018.1424739

[9] William, E.R. and Subijoy, D. (2017) Remote Sensing and GIS Applications for Pipeline Security Assessment. https://proceedings.esri.com/library/userconf/proc05/papers/pap1762.pdf

[10] Oleg, S. and Solomon, T. (2017) Risk Assessment of Oil and Gas Pipelines with Consideration of Induced Seismicity and Internal Corrosion.

[11] Hamlin, J. (2014) A Spatial Analysis of African Oil and Gas Infrastructure Security. https://inspire.redlands.edu/work/ns/7d341fa4-c657-403f-9e15-ec01e4b8f41d

[12] World Bank Global Facility for Disaster Reduction and Recovery Report (2014) Understanding Risk; Review of Open Source and Open Access Software Packages Available to Quantify Risk from Natural Hazards.

[13] Cordner, L. (2011) Managing Regional Risk: Offshore Oil and Gas Safety and Security in the Asia-Pacific Region. *Australian Journal of Maritime & Ocean Affairs*, **3**, 15-24. https://doi.org/10.1080/18366503.2011.10815672

[14] Cova, T. (1999) GIS in Emergency Management: Geographical Information Systems: Principles, Techniques, Applications, and Management. https://www.researchgate.net/publication/305347817_GIS_in_Emergency_Management