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Optimal Route Assessment of Oil and Gas Pipelines using Geographic Information System (GIS)

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Abstract

Oil and Gas pipelines constitute an essential part of infrastructure investment in petroleum projects. It is essential; therefore, pipeline route selection must be cost-effective because an optimal route influences the lifespan of the pipeline, from design and planning to construction and operation. Geographic Information System (GIS) is the cornerstone of well-managed spatial analysis. GIS is integrated into the study for terrain evaluation and the identification and assessment of the optimal pipeline routes. The application of GIS enables routing the pipeline through the most appropriate terrain that possesses the minimum risk for geo-hazards. The present research identifies the optimal routes for the pipelines in contrast to the existing pipeline network in Khyber Pakhtoon Khwa (KPK) Province of Pakistan. The extreme effects of a geological hazard on the pipeline are the case of rupture and it is this event that terrain evaluation and risk analysis seeks to avoid by assisting in the decision-making progress used in selecting the most appropriate route for the pipeline.

Keywords: Oil and gas industry, optimal route assessment, geographic information system (GIS), petroleum projects, construction and operation

INTRODUCTION

Pakistan officially the Islamic Republic of Pakistan is a South Asian country which is also the 33rd largest country and fifth most populous country in the world. Pakistan has four administrative provinces amongst which Khyber Pakhtunkhwa (KPK) province is located in the northwestern region of the country. KPK province shares its international border with Afghanistan. Geographically, KPK province is the smallest province but it is the third largest province in terms of population and economy. The province is divided into two zones: northern one extending from ranges of Hindu Kush to the borders of Peshawar basin and southern one extending from Peshawar to Derajat basin. The KPK province has mountainous terrain having sub mountains areas and plains surrounded by hills. The highest peak of Hindu Kush ranges has an elevation of about 25,230 ft which is called Tirich Mir. Half of the province's population lies in the fertile valley of Peshawar. The elevation of the region greatly influences the climate. The climate is primarily frost while the region becomes warmer in the south as the elevation declines (Figure 1) [1].

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On a global scale, there exists a vast network of pipelines for the transportation of petroleum resources from one location to another. The significant impact of these transported commodities requires an efficient and reliable transportation system. Pipelines provide the most cost effective and efficient means of transportation of petroleum products. They help in minimizing the cost and

avoid unforeseen dangerous incidents, such as spill and highway congestion. The oil and gas industry faces a lot of risk if there is an accident or ignition in the petroleum infrastructure [2]. Therefore, it is imperative to put extra efforts on careful planning and management of pipeline routes so that all the precursor concerns could be satisfied [3, 4]. The most serious problems in pipeline routing are related to geological factors, such as slope and elevation that could help in the determination of least cost routing. GIS finds a lot of its application in various fields and plays a big role in geographical studies including pipeline route assessment [5, 6]. ArcGIS software package has been used for the implementation of GIS in the present study. The least cost path analysis is a useful technique in planning pipelines routes using linear features [7]. The traditional techniques used for the development of the shortest possible route have been suitable for wide plain areas, but they did not produce satisfying results when used for undulated land and rugged terrain. A lot of difficulty is faced in planning pipeline routes in undulating regions, some of which are mentioned as follows:

1. In a mountainous region, it is difficult to plan straight or shortest routes for the pipelines and longer route is followed.
2. A lot of time is spent in preliminary surveys on mountainous areas than in plains.
3. It is worth mentioning that pipeline routes are taken along gentle slopes since it is safer and convenient for trucks to carry construction material.

Therefore, GIS provides a holistic approach towards the optimal route assessment by minimizing the challenges towards planning pipeline routes and it has also become the sole purpose of this study to investigate the pipeline's routes in KPK province.

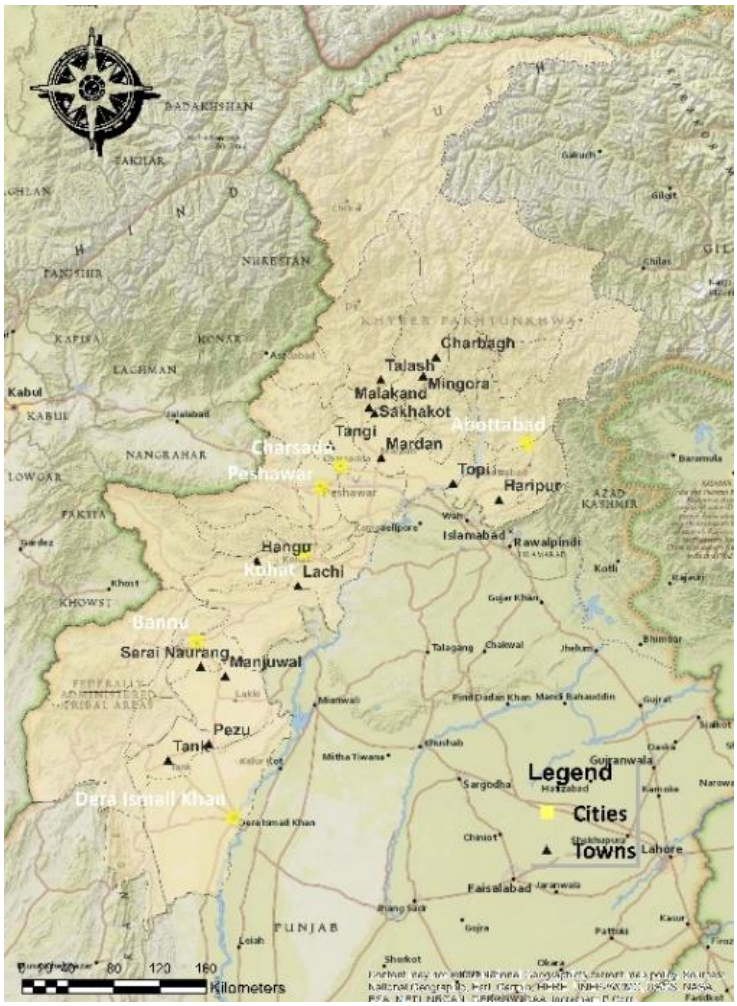

Figure 1. Area of Research (Khyber Pakhtunkhwa Province (KPK), Pakistan).

METHODOLOGY

For the evaluation of the most appropriate routes, it is necessary to consider closest possible geographic paths between the concerned locations whilst considering the geologic conditions. Geographic Information System (GIS) is the corner stone of well-managed spatial analysis. GIS is involved into the study for terrain evaluation, and identification and assessment of optimal pipeline routes [8]. Terrain evaluation has been emphasized in the research as to avoid expensive site restoration in case of surgency and to ensure normal operations of the pipelines. For achieving the research objectives, the spatial as well as non-spatial data was incorporated into the geo-database.

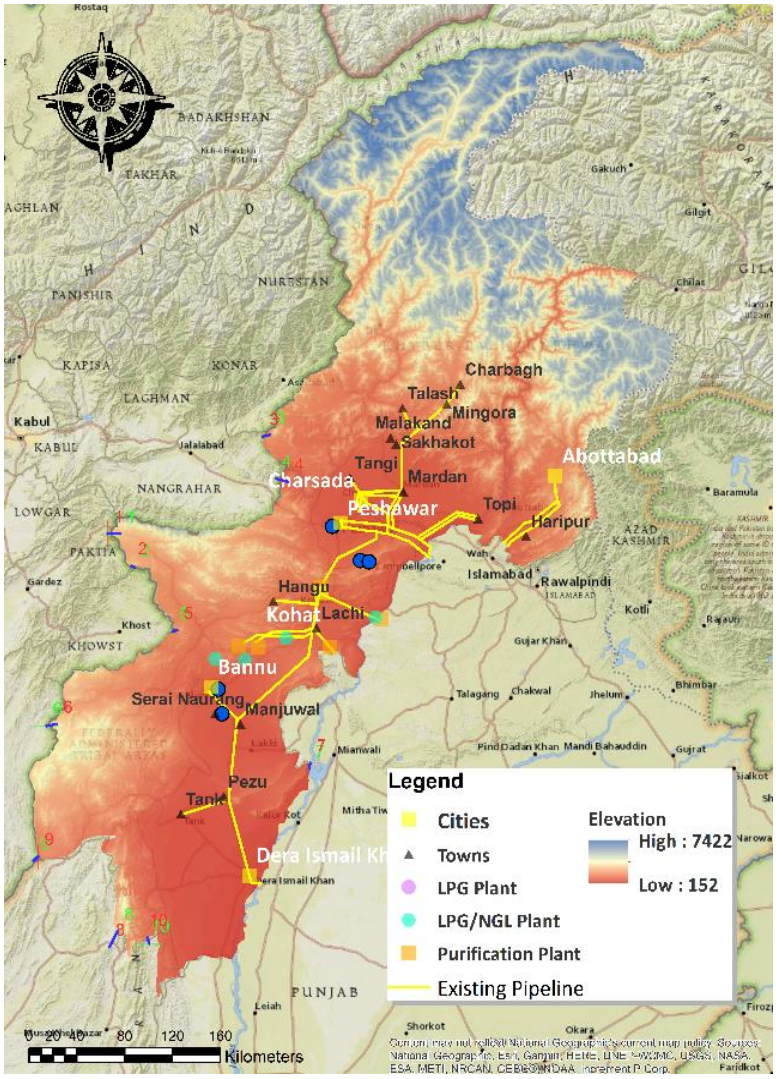

Figure 2. Incorporated datasets.

A number of factors influence the routing of the pipelines. However, the choice of factors was on the basis of availability of data and computational capacity. The elevation raster (grid) dataset of the area of interest was also involved. The oil and gas (OG) projects including processing plants, compression stations etc. were mapped in their respective shapefiles [9]. All the remaining datasets were converted to raster datasets. Figures 2 and 3 illustrate the datasets utilized in the study.

Pipeline routing is a complex process involving simultaneous evaluation of numerous criteria. It could be in the form of factor or constriction. For instance, routing a pipeline in close proximity to the roads would be more suitable than routing it far from the roads. However, constriction would limit the alternatives under considerations, for example, water bodies encountered during the routes is highly

discouraged and it is preferred that pipelines are not routed across them. Therefore, pipeline route evaluation is a complex task which is not limited to just routing them to the final destination from the oil or gas refinery. Natural barriers would also be a constriction in the routing process.

The research involved a criteria-based approach. Due to the rugged terrain of the study area, the gentle slopes were preferred as the provide solid foundations for laying the pipelines. Steep slopes require levelling and support and hence they were regarded as less suitable.

Initially, a spatial geo-database was established in ArcGIS. The DEM (Digital elevation map) for the KPK province was added into the geo-database. A new set of tools was designed in the model builder of ArcMap. It constituted of a series of tools in stepwise order as displayed in the flowchart Figure 2. The spatial analyst extension being enabled, the slope for the whole area of interest was evaluated using Slope tool. Reclassify tool was processed for the re-distribution of the data into broader groups according to the median of the slope data. Subsequently, the cost distance analysis was carried out, in which the least cost path is determined to reach the prescribed source. Finally, Cost Path tool is run for the determination and illustration of the cost-effective path from the source to the target. The iteration of this custom-build tool led to the determination of the optimal pipeline network throughout the KPK province of Pakistan. Thus, the processed optimal route of the pipelines is demonstrated in Figure 4 and its derived results are discussed in the subsequent section of this paper.

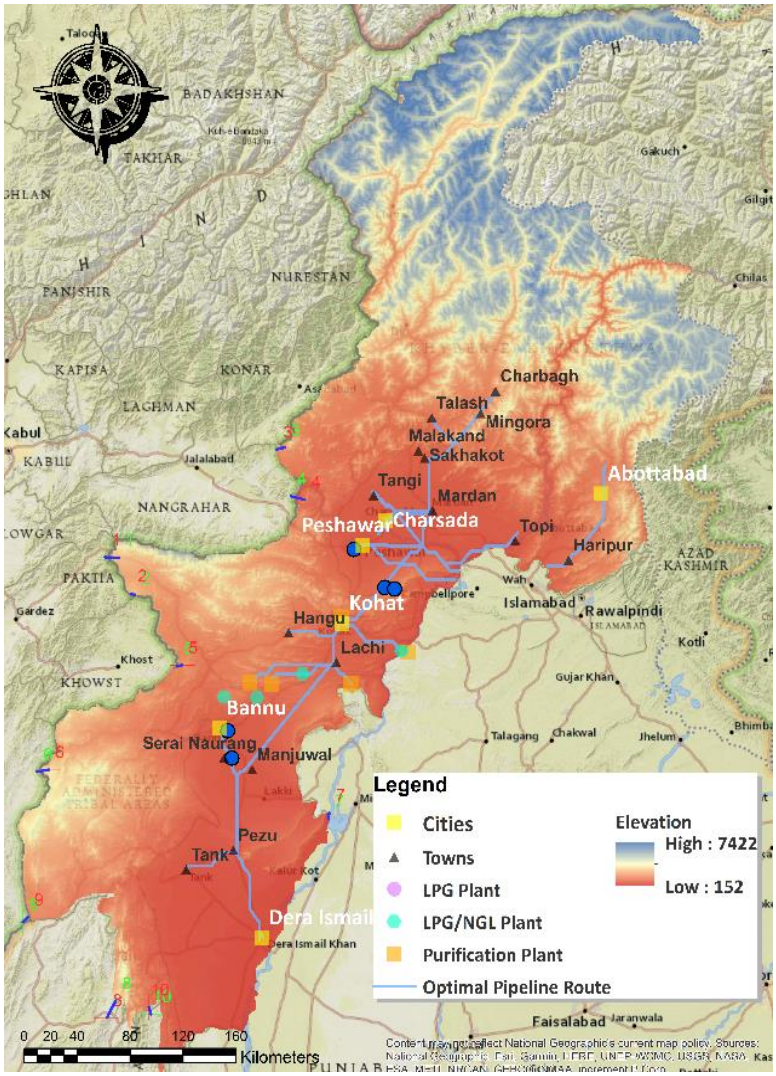

Figure 3. Computed optimal pipeline.

RESULTS AND DISCUSSION

Once the optimal routes have been identified and all inputs have been provided into the process, the final optimal routes map was classified. Terrain evaluation has been the major emphasis of this study as to avoid the expensive site restoration in case of surgency and the pipelines' smooth operation is ensured by considering the terrain conditions. KPK province is a mountainous region and has a rugged terrain. It hosts one of the world's largest mountain ranges, Himalayas. Natural gas is primarily used in the homes in Pakistan for cooking purposes and it is necessary to ensure the proper deliverability of natural gas. The results included the detailed GIS database, from which imperative conclusions were drawn. The developed pipeline routes network, having connected to all the regions and facilities in the manner similar to the existing pipelines, covered 46.3741% less than the length of the existing pipeline network.

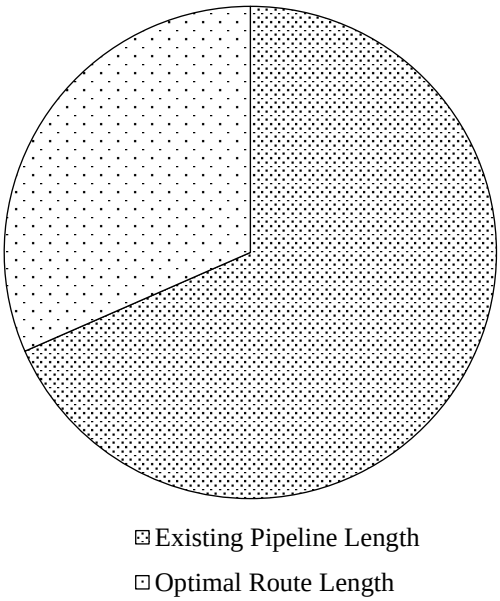

Figure 4. Comparison of existing and optimal pipelines covering distance.

Figure 5 illustrates the optimal routes map derived using the present proposed techniques. Through the visual inspection of the produced results, it was distinctly identified that most of the existing pipeline routes corresponded to the optimal solution while the rest of the routes deviated from it which could be due to the presence of water resources and forestry etc. The major deviations from optimal solutions between the cities has also been studied. GIS method is more environmentally effective and cheaper than traditional one [10]. The extreme effects of a geological hazard on the pipeline is a rupture and it is this event that terrain evaluation and risk analysis seeks to avoid by improving the decision-making progress used in selecting the most appropriate route for the pipeline (Tables 1 and 2).

Table 1. Length covered by pipelines.

Pipeline	Length in km	Length in m	Percentage Optimal
Existing	1335	2894138	46.37 %
Optimal	2894	1342130	

Table 2. Significantly optimized routes.

Target Locations		Length in km	Length in Meter
From	*To*		
Manjuwal	Lachi	110.26	967.41
Kohat	Mardan	129.96	130.59

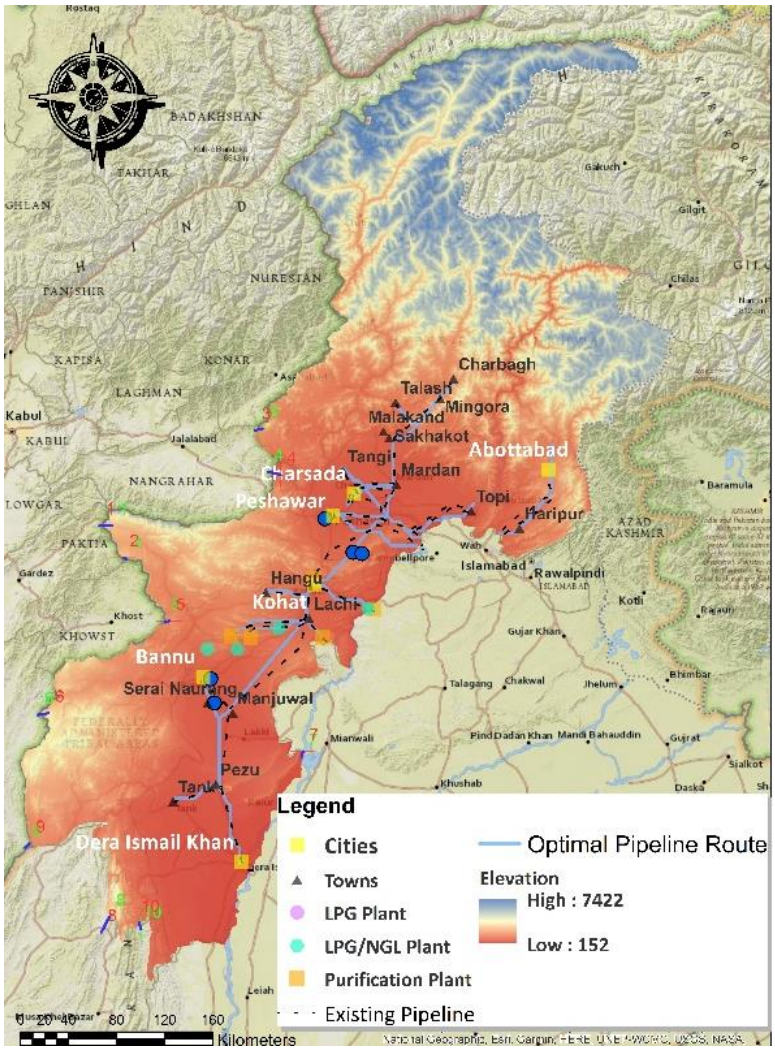

Figure 5. Optimal route in contrast to the existing pipeline network

The proposed pipeline network optimized the distance covered by the pipelines up to 46.37% reducing the covered length by 1,552,008 meters. Out of the overall length span, a significant reduction in the length was observed in two different routes as mentioned in the following table.

The limitations encountered during the research were related to the acquisition of data, more specifically spatial information. The unavailability of data required for considering other environmental factors has led to only focus on the factors that are related to terrain conditions. It is highly suggested that there is a dire need for an organization which could provide open-source data for the sole purpose of GIS incorporated research.

CONCLUSION

This paper provided a GIS-based methodology for determining the most cost-effective and optimal routes for the pipelines whilst considering the environmental factors. It is highly envisioned that the proposed GIS integrated assessment model would provide a holistic approach towards the routing activity of the pipelines while considering the effects of associated concerns.

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