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Automated Alignment of Infrastructure Corridors Using Geospatial and Web Technologies

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Abstract
Infrastructure corridors such as gas/oil pipelines, roadways, railways, and power lines require careful alignment considering multiple conditions. Traditionally, this process relies on geo-spatial data with heavy manual involvement, making it tedious and subject-specific. With advancements in geospatial and information technologies, data creation, processing, and visualization have become easier and more affordable. However, domain experts still require specialized technical skills for effective analysis and corridor alignment.To address this, a geo-web application integrated with server-side processing has been designed and developed. The application allows users to provide inputs such as origin and destination points, along with class-wise weights for thematic layers. Based on these inputs, the system automatically prepares, processes, and delivers customized outputs online. This enables officials to utilize geospatial data available with nodal agencies without requiring in-depth spatial expertise.The application further supports generating multiple alignment scenarios, allowing users to compare and select the most suitable option. As a demonstration, a road corridor alignment derived using the tool closely matches an existing road, validating its effectiveness.

Key words*: corridor alignment, thematic geo- spatial data, cost-path analysis, multiple criteria, client – server architecture*

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I. Introduction

The infrastructure sector is a key driver of the Indian economy, propelling overall development and receiving strong policy focus from the Government to ensure time-bound creation of world-class facilities. This sector encompasses power, bridges, dams, roads, and urban infrastructure. India ranked 44th out of 167 countries in the World Bank's Logistics Performance Index (2018) and second in the 2019 Agility Emerging Markets Logistics Index. In FY19, 10,855 km of highways were constructed, with a target of 12,000 km in FY20 (IBEF, 2020). The pipeline industry is also expanding, with Engineers India Limited (EIL) executing projects to lay about 9,000 km of pipeline networks as of 2020, while Power Grid commissioned 8,468 circuit km of transmission lines in 2019 (Powergrid, 2019). Additionally, new railway lines are being developed across the country.

For building such infrastructure, corridors must be aligned optimally to minimize cost and ensure efficiency. This requires multiple datasets, broadly categorized as topographical and thematic. With advances in digital data collection and processing, the integration of Remote Sensing, Geographic Information Systems (GIS), and Information & Communication Technology has transformed corridor planning. Corridor planning plays a crucial role in aligning infrastructure expansion with future housing and employment needs, thereby supporting sustainable growth.

Geospatial data and processing software are essential for deriving corridors. However, most executing agencies in the infrastructure sector are engineering-focused and have limited expertise in thematic data generation. At NRSC, such datasets are developed under various projects and can be leveraged for this purpose. Thus, an application enabling users to utilize available geospatial data without requiring deep technical expertise would be highly beneficial. Against this background, the scope includes developing an automated methodology for deriving least-cost corridors between specified origin and destination points.

II. Literature Review

For laying new pipelines, power lines, or highways between specified origin and destination points, multiple alternative routes must be evaluated. Each route is constrained by several physical and environmental factors, as well as associated costs—both financial and resource-based. Therefore, identifying the optimum path, i.e., the least-cost path, is a prerequisite before initiating detailed design and construction activities.

Highway and corridor alignment optimization is a complex process that aims to determine the most economical and feasible path connecting specified points. The task is challenging due to the numerous variables involved. Geographic Information Systems (GIS) play a vital role in this process by integrating spatial data to identify shorter, safer, and more comfortable routes, thereby reducing travel distance and operational costs. Advanced approaches, such as the integration of GIS with genetic algorithms, have also been explored for optimizing alignments under constrained conditions, especially in mountainous and geologically complex terrains (Shanmugam et al., 2017).

A cornerstone of semi-automatic corridor (SAC) methodologies is the generation of a cost surface, followed by route analysis. The cost surface integrates thematic factors such as slope, soil, land use/land cover, geology, streams, and transportation networks, using a system of ranks and weights. This approach balances the trade-off between the minimum (straight-line) distance and real-world terrain constraints. Cost rankings and weights are typically assigned through expert knowledge, general recommendations, and domain-specific considerations (Dubey, 2009).

Pipelines, in particular, are regarded as efficient, cost-effective, and environmentally friendly means of fluid transport, reducing congestion, pollution, and spill risks compared to highways. Careful alignment can significantly reduce construction and operational costs while mitigating environmental impacts. GIS-based analysis supports this by applying cost-weighted distance and direction functions, which, when integrated with shortest path algorithms, enable reliable route optimization (Iqbal et al., 2006).

A review of literature (Ashish Verma et al., 2011; Ferit Yakar et al., 2014; Bailey, 2003; Rajadurai et al., 2015; Sampath Kumar et al., 2019) shows that GIS has been extensively used for corridor alignment across domains such as road and rail, with some adopting multi-criteria approaches. Building upon these studies, the present work emphasizes automatic/semi-automatic corridor alignment methods over internet-based platforms, integrating image processing and GIS. This makes the proposed methodology distinct by offering cost-effective, scalable, and user-friendly solutions for infrastructure planning.

III. Data and tools used

The following details consist of input data and tools and technologies used. The area of interest considered is part of Odisha state, India as shown in the figure 1. The thematic data used consists of Landuse/Landcover, Soils, Geomorphology and slope in raster format, which are used at the server end to process the data. The original datasets were both in raster and vector formats at various scales and resolutions. These datasets were normalized for 50m spatial resolution and made pixel to pixel matching suitable for image processing through developed software.

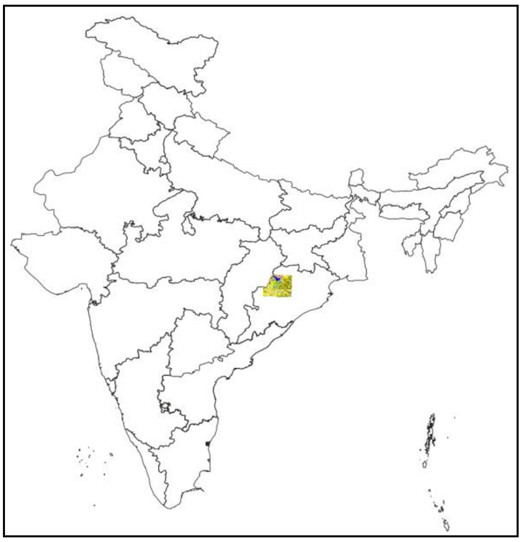


Fig 1 Study area consists of Part of Odisha State

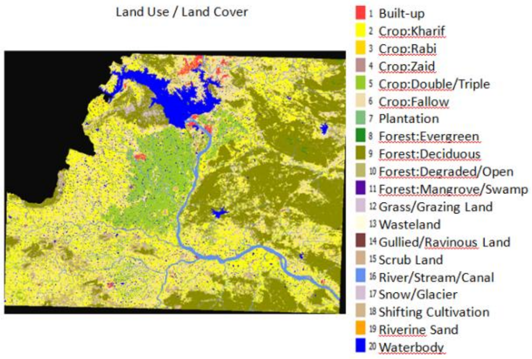


Fig 2.1 Input data : LULC

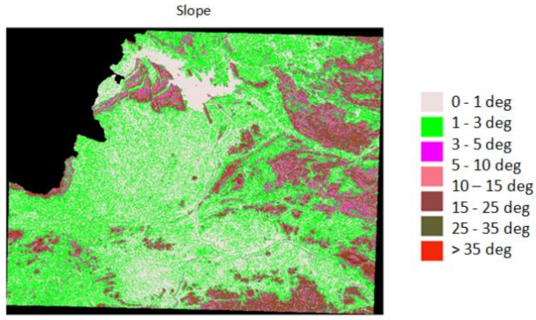


Fig 2.3 Input Data: Slope

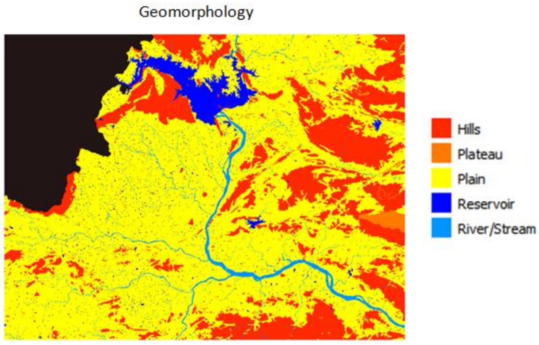


Fig 2.2 Input Data: Geomorphology

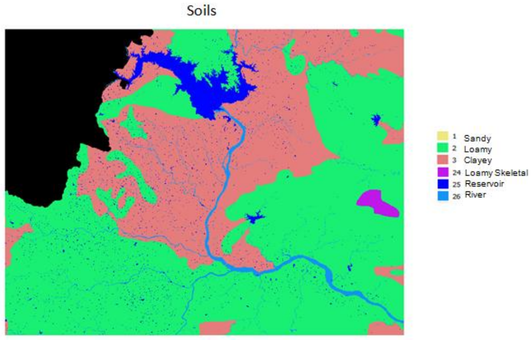


Fig 2.4 Input Data: Soils

The following are the tools and technologies used for various technical aspects for developing and deploying the application.
Emergence of new technologies and knowledge in open source has given boost to the web based GIS. Web GIS programming environment are also now rich with easy-to-use development tools like Browser-side GIS APIs, such as the JavaScript, openlayer API, etc have greatly simplified Web GIS application development. Geospatial technology is now converging with information technologies to communicate spatial information. The present web based GIS application is developed using open-source software tools given in table1.

Table1. Tools and Technologies

Functionality	**Software**
Geospatial Server	Geoserver
Programming/Scripting	PHP,javascript, Python
Geospatial Database	PostGreSQL,PostGIS
Geospatial Data Visualization	OpenLayers
Map serving online	Geoserver
Python Libraries	GDAL,OGR,OSR,Shutil, Zipfile

IV. Methodology

The methodology consists of developing algorithm and implementing the same using client and server programs by integrating each other. The application is accessible through authentication module, which allows providing Inputs such as origin and destination of corridor and the weights for each class of various thematic maps shall be submitted by the user. Subsequently a file is prepared at server end. This file will be utilized by the server side program and processes in PyQGIS to arrive a suitable corridor in terms of a shape file, which in turn shall be provided to access by client for both visualization and downloading by the user.

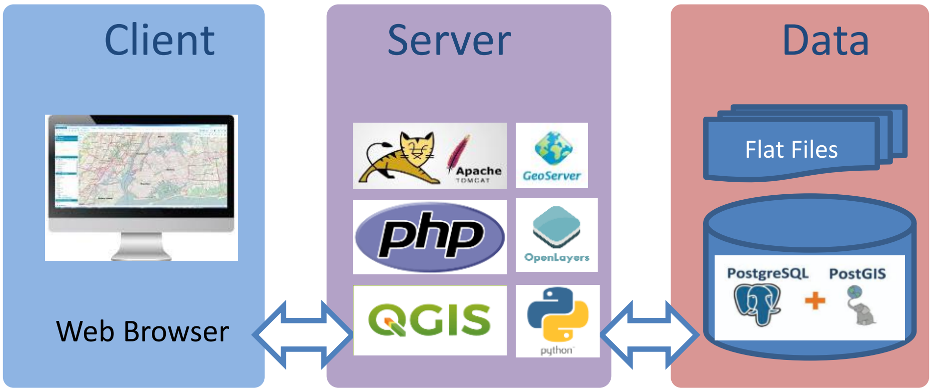


Fig 3.Application architecture

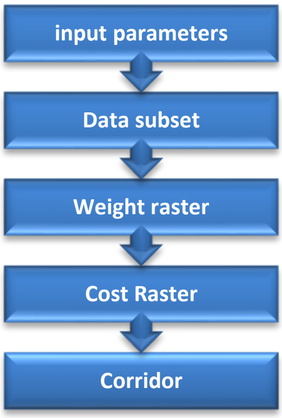


Fig 4 Core Methodology Flowchart

4.1 Input Parameters:

Corridor alignment requires the origin and destination coordinates, specified either by manual entry or by selecting locations on the satellite image. The application supports multiple thematic datasets, with Land Use/Land Cover (LULC) being mandatory and others optional. For each selected theme, class values are displayed, and users assign weights (0–9) to reflect their relative importance. Once inputs are provided, the request is submitted and stored in the server database, triggering automated corridor computation and result generation.

4.2 Data Subset:

Once the request is received by the server the programme of computing corridor is invoked. The first step at the server is to subset the data from the national level data for efficient processing. The subsets for all the thematic data are computed and then used for the computation of weight raster.

4.3 Computation of weight raster:

The weight raster is computed by adding the weights multiples theme class values for subset region. The weight value ranges 1-9. The weight value 0 of a particular class is completely ignored. For example reservoir weight value is assigned 0 then that class is not considered for route alignment. The weight raster is further used for computation of cost raster. The sample weight raster is shown in the figure 5. The origin location for path is shown in red colour.

58	71	19	19
40	37	16	28
49	46	16	16
49	49	31	28

Figure 5. Sample Weight Raster

4.4 Computation of Cost Raster:

The cost raster is computed using the weight raster. The computation begins from the location where origin of the corridor is assigned. The cost at the origin is taken as 0.0 and further the cost is computed using the surrounding cells in the weight raster. Computation of cost around a given cell is computed in two cases, one is adjacent cells which is shown in figure 6, and second is for diagonal cells which shown in figure 7. The computation is described in case1 and case two with computation equations.

Case 1: cost computation for adjacent cells

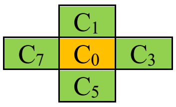
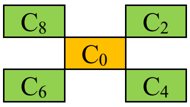


Figure 6. Adjacent cell location.

Cumulative cost at (C_1) = cost at C_0 + (weight at C_0 + weight at C_1)/2

Case 2: Cost computation for diagonal cells

Figure 7. cell locations in 4 diagonals



Cumulative cost at (C_2) = cost at C_0 + 1.4142* (weight at C_0 + weight at C_2)/2

108.67	95.50	61.34	68.59
60.81	41.50	43.84	62.11
47.50	0.00	31.00	47.00
67.17	47.50	54.45	62.11

Figure 8. Sample Cost Raster

The cost raster shown in Figure 8, which is computed using the weight raster shown in Figure 5. The red colour cell represents the origin location for the corridor whose cost value is represented as 0.00 and the other cells cost value is computed using the weights and directions as described above.

4.5 Aligning corridor:

Once the cost raster is generated, it contains the 0.0 cost at the location of origin of corridor and the cost at each cell get increased as moving away from the origin location. Resulting the cost at the cell location of destination of corridor will be much higher than the cost at the origin location of the corridor. Alignment of corridor begins from the destination location to the origin by finding out the cells relatively lower than the current cell location up to the origin location. The path of all the cells from the destination location by identifying the lower cost value of the cell surrounding to the given cell and reaching to the origin location, resulting the effective corridor path. The center coordinates of each of the cell is used to generate the shape file, which is used for displaying in the web application or allowed to download by the user for further analysis in GIS environment.

V. Results and Discussion:

Based on the objectives, the algorithm was developed using which the methodology is formed and implemented as an integrated web and server-side applications using the open source tools and technologies.

Since it is a secured application the user authentication page is given as shown in figure 9. Upon successful login user is directed to user interactive input page having a map to provide the origin and destination locations and thematic class weights as shown in figure 10. It also has a brief help for the user and the list of paths computed using the application. Once user has submitted the results are displayed in the map portion of input page shown in Fig 12.

Figure 9. Authentication user interface of Web application.

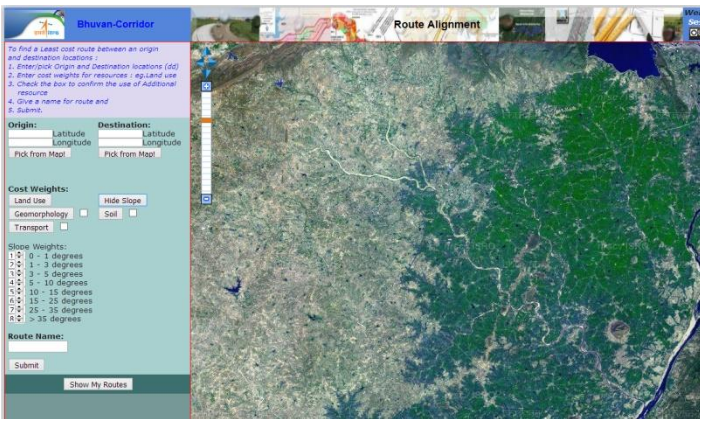


Figure 10. interactive Geo Spatial user-interface page of web application.

The following description will show and analyse the result/output, which is an aligned corridor. For understanding the functionality and analysis of the process three cases has been considered for aligning a road feature.
Case 1: in this case a road is to be aligned between the source/origin to destination where it should not cross a reservoir. The output is given in Figure 11, where the red line represents the alignment given by the application where the corridor is circumvent the reservoir/water body.

Some sample outputs are given below with unique features such as

- Path will not cross reservoirs
- Path will cross rivers
- Paths will be different if the input thematic weights are modified

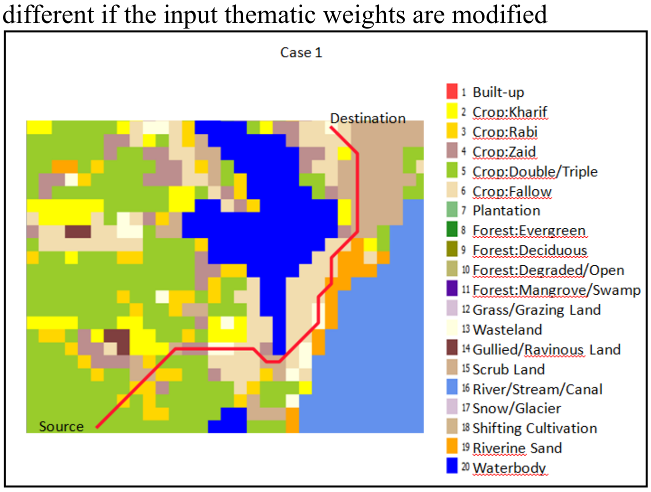


Fig 11: path attained without crossing Reservoir

Case 2: in this case a road is to be aligned between the source/origin to destination where it should cross river/stream/canal. The output is given in Figure 12 and Figure 13, where the red line represents the alignment given by the application where the corridor crosses the river/stream/canal feature.

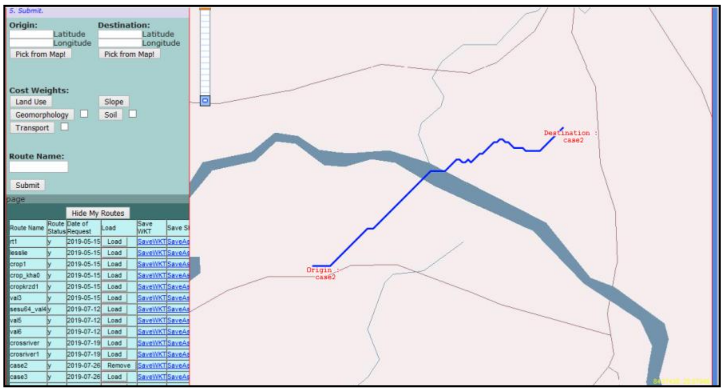


Figure 12: Path of case2 is shown in web environment

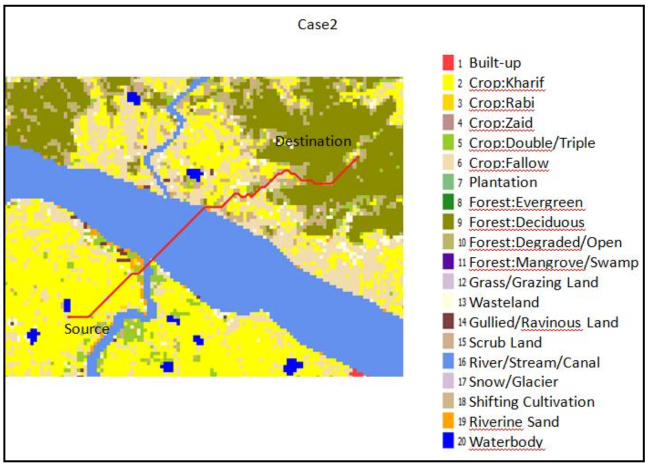
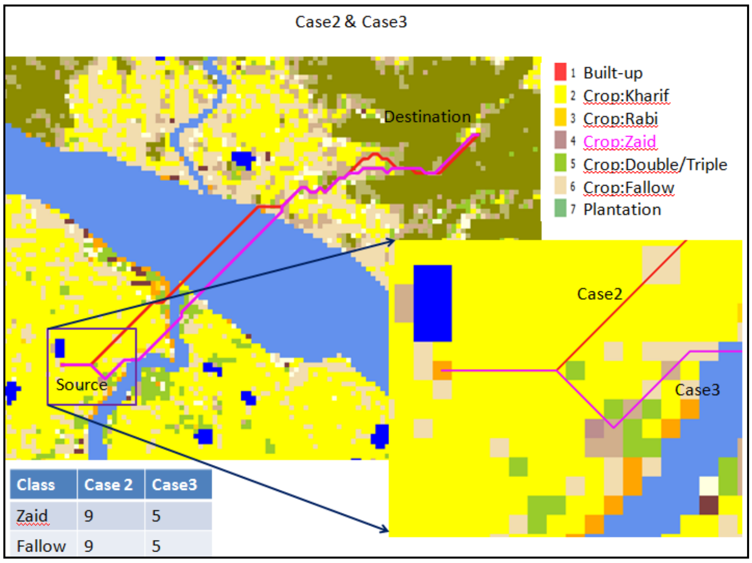


Figure 13: Path obtained with crossing River

Case 3: It is similar to case2 i.e. a road is to be aligned between the same source/origin to destination, but the weights for Zaid and Fallow classes of LULC theme are changed. The output is given in Figure 14, where the pink line represents the alignment given by the application where the corridor crosses the river/stream/canal feature.



Class	Case 2	Case3
Zaid	9	5
Fallow	9	5

Figure 14: difference of paths due to change of weights

The robustness of the algorithm and developed application is demonstrated by varying the weights assigned to different classes, which results in alternative corridor outputs. This flexibility allows users to adjust weights based on local conditions, thereby reflecting higher or lower costs for specific classes. Figure 14 illustrates a comparison of the alternative paths.

For validation, a road section between Kainsir and Lapanga settlements was selected (Figure 15). When the generated output shapefile was overlaid on open-source maps, the results closely aligned with the existing Sambalpur–Rourkela Highway (Figure 16). Minor deviations were observed, which may be attributed to the use of 1:250,000 scale data and other ground parameters that are critical in actual road construction.

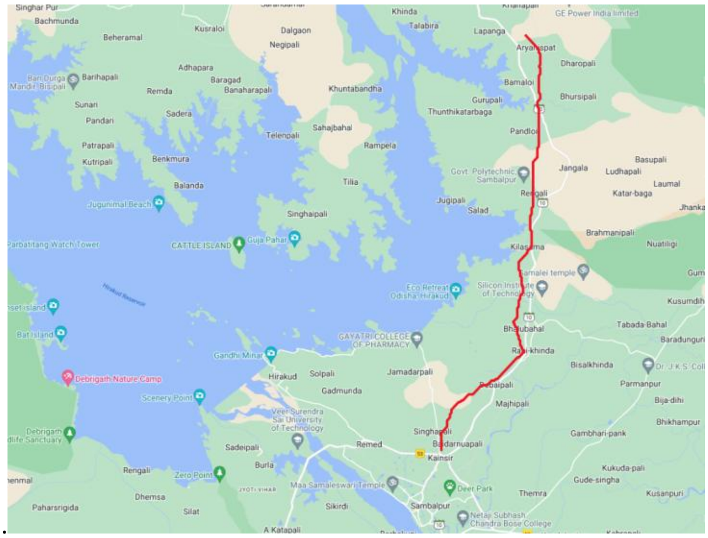


Fig 16. Validation of Study output with the existing Road

VI. Conclusion

This work represents an attempt to develop an integrated application leveraging both web and server-side processing. The experience highlights the significant potential for further development of such applications, particularly in enabling communication between web pages and Python in QGIS open-source software. The methodology demonstrates that corridor alignment can be achieved with minimal user expertise and inputs, provided there is a strong technical and processing framework at the server end. The study area, located in Odisha state, is largely characterized by gently undulating terrain; hence, the application's performance in highly rugged or complex terrain remains an important area for further evaluation.

A key strength of the proposed methodology is its versatility. The application allows incorporation of thematic datasets with higher spatial resolution and more detailed classifications, and the user interface can be further customized. The study area can also be extended to larger regions, including state or national scales, depending on data availability. Moreover, the application is adaptable for planning different types of infrastructure corridors such as roads, railways, pipelines, and power lines. The output is generated as a shapefile, enabling seamless integration into a GIS environment for further spatial analysis and decision support.

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