Route Alignment using GIS, Remote Sensing and Deep Learning

B. Tech. Project Report

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Abstract

Route alignment involves a number of steps, from assessing various factors to optimizing the route. This study aims to align an optimized route between Pune and Mumbai that minimizes environmental harm, reduces travel time and construction and maintenance costs. Route alignment involves the positioning of the route centerline based on factors such as topography, geospatial features, social implications, climatic conditions, obstructions, the cost of the plan and the presence of other features. As a result, Deep Learning, Remote Sensing, and GIS are used to achieve the results. Remote sensing and Geographic Information Systems (GIS) are extremely important for facilitating route alignment. Deep learning techniques have surged in use in GIS and Remote Sensing applications in recent years. In this study, two deep learning models are employed to apply pixel-wise Land Use Land Cover Classification to Sentinel-2 images. Each pixel is assigned a weight based on its importance for aligning for which AHP is used. Finally, different algorithms are used to determine different routes. Hence, the final result will provide the optimal alignment area between the two given locations among the different routes

KEYWORDS : Route alignment, Geographical Information System, Remote Sensing, Route planning, Route selection, Route Optimization, Optimal Path

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Chapter 1

Introduction

Route alignment refers to how a route or road's centre line is positioned on the ground[3]. Aligning routes requires consideration of a variety of factors. These various factors that need to be considered for route alignment include, but are not limited to, the type of vehicle traffic, gradient, climate, topography, obstructions, economic constraints, social implications of the alignment plan, reduction of harm caused to the environment by the plan etc. Route alignment is imperative because incorrect alignment of a route can increase the number of accidents, road construction costs, vehicles operation cost, and road maintenance costs[35]. It can also cause discomfort to road users, and reduce the road's durability. It is important to carefully analyze the alignment of a new route since it impacts the cost of construction,cost of maintenance, safety, and simplicity of travel. The following factors should also be taken into account while aligning routes:[14].

1. The Optimal route should have the lowest construction and maintenance costs.

2. The operational costs should be as low as possible.

3. The maximum degree of comfort and safety must be maintained.

4. Aesthetic considerations.

Because of the consideration and analysis of various datasets, selecting the best route alignment is a complex process. It is possible to model these datasets easily using GIS [14]. Thus, In order to facilitate route alignment, GIS and Remote Sensing can play a very crucial role when used together. Remote sensing began in the 1840s. In remote sensing, information is obtained from a distance, usually from satellites, about different areas and entities. The field of geographic information systems (GIS) started in the 1960s and is a database that contains geographic data and software tools for organizing, analyzing, and displaying that data. As a result of the use of GIS and remote sensing, route alignment is less time-consuming, less costly, and requires less manpower. GIS is a collection of geospatial data, and deep learning methods can be used to create models from this data. Deep learning is critical for highway alignment because it consists of models, algorithms and techniques that can simplify and accelerate the process. A deep learning algorithm was first implemented in the 1960s, and since then it has been used to power a variety of applications around the world. It is widely recognized that deep learning has numerous applications, including speech recognition, image recognition, recommendation systems, natural language processing, image reconstruction among others.Deep learning is essentially a subset of machine learning, and both are considered forms of artificial intelligence. Recent years have seen an explosion of applications of Machine Learning algorithms in GIS and Remote Sensing. GIS and remote sensing applications can use a variety of supervised and non-parametric machine learning models. GIS and remote sensing have found use for machine learning methods including Naive Bayes, Support Vector Machine, Random Forest, and Decision Trees. Thus, the availability of machine learning and deep learning algorithms makes the deployment of Artificial Intelligence for route alignment possible. Several Artificial Intelligence concepts and algorithms are being used for route alignment purposes, such as Genetic Algorithm, Fuzzy Logic, and Swarm Intelligence. Genetic algorithms are adaptive heuristic search methods that fall under the broader category of evolutionary algorithms. Natural selection and genetics are the foundations of genetic algorithms[10]. The concept of swarm intelligence comprises the use of the collective knowledge of a number of objects (people, insects, etc.) for the purpose of finding the optimal solution to a specific problem. [36]. Fuzzy logic, a type of many-valued logic, permits variables' truth values to be any real number between 0 and 1[3].

1.1 Study Area

Our project involves optimizing the route alignment of the distance between Pune and Mumbai cities of Maharashtra. The present distance of the Pune-Mumbai Expressway is 97.2 km which currently stays overloaded due to traffic and accident prone too. The construction also adversely affected the forest areas, environment and also the communities involved. By using machine learning and deep learning based models, we aim to improve the Pune-Mumbai Expressway's route, suggest alternate routes, and reduce economic, social, and environmental costs. We also aim to increase the road's usefulness by making it safer and more connected to other highway networks. For this, we have used the Sentinel-2 image of the Pune-Mumbai region which is then processed in further steps to predict optimized routes to connect the 2 cities. Sentinel-2 images are multi-spectral images with a maximum width of 290 km and a spatial resolution of 12 bits. They comprise of 13 spectral bands with 4 bands at 10 m, 6 bands at 20 m, and 3 bands at 60 m spatial resolution. A Sentinel-2 image tile of Pune-Mumbai region is processed in the further steps using image processing and deep learning techniques and optimal route alignments are predicted.

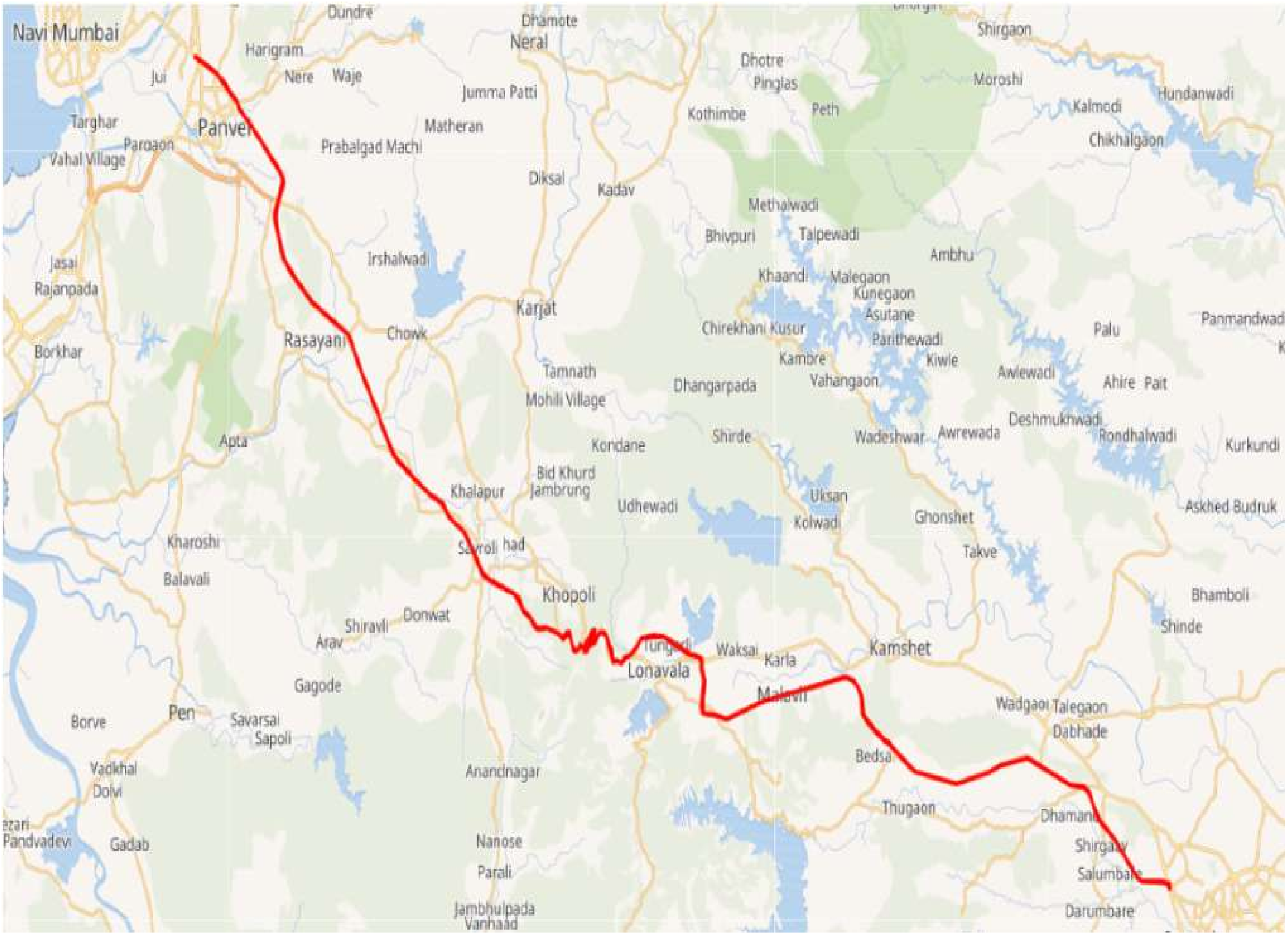

Figure 1.1: Map of the existing Pune-Mumbai Expressway

Chapter 2

Literature Review

2.1 Review Process

The systematic review was conducted by reading research papers. In order to retrieve the papers for our systematic review, we conducted keyword searches in Google Scholar, Scopus, Science Direct, ACM, ASCE and IEEE using the terms:

1. Road Route Alignment
2. Route Planning System
3. Route Selection System

The research papers were downloaded after reading the titles. On October 23, 2022, a search was conducted and 180 research papers based on their titles were downloaded. Based on the inclusion and exclusion criteria for our systematic literature evaluation, a total of 35 papers were selected. Our assessment of the literature did not include papers that used hyperspectral images, were written in languages other than English, or performed route selection and alignment for pipelines, railroad networks, and road networks. We gathered the following categories of data by reading the whole texts of the

Table 2.1: The number of papers found on a particular site for a particular topic.

Name	Google Scholar	Scopus	Science Direct	IEEE	ASCE	ACM
Road Route Alignment	194000	2517	8815	15	2224	606736
Route Planning System	2840000	17400	211638	4585	19973	611490
Route Selection System	3430000	19793	232979	1645	15734	625772

remaining pertinent studies that may be helpful for performing a systematic literature review:

Procedure of route alignment of roads and highways, different algorithms used for route selection and alignment including - Dijkstra, A star and other shortest path algorithms; Genetic algorithms, Swarm intelligence, Fuzzy logic and other DL/ML based algorithms; details of cost functions and factors involved in route selection considering economic, social and environmental implications, and analyzing the type and features of study area using various approaches and creating corresponding maps.

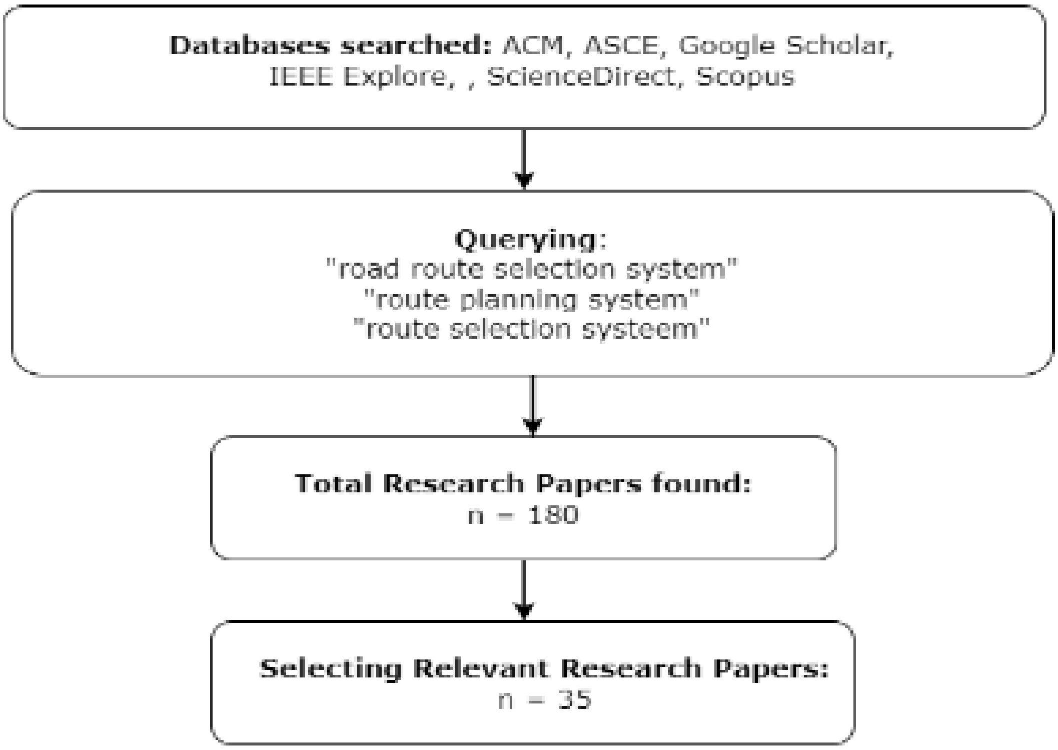

Figure 2.1: Process of Selection of papers for Systematic Literature Review using PRISMA analysis

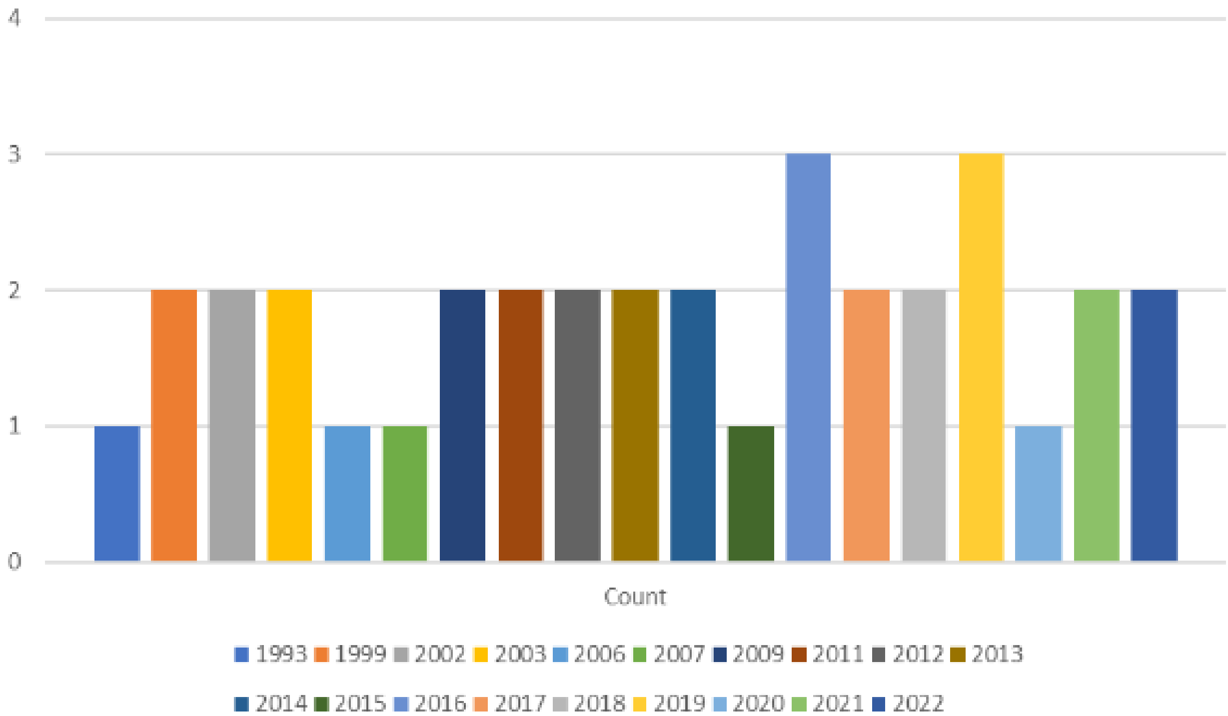

Figure 2.2: Year wise count of included papers

2.2 Stages involved in Route Alignment :

Categories	Techniques used
Land Use Land Cover Classification(LULC)	• ArcGIS - Support Vector Machines, Mahalanobis Distance (ArcView Extension). • QGIS - Artificial Neural Network, Random Forest, Mahalanobis Distance.
Weight Assignment to variables affecting Route Alignment	• Analytic Hierarchy Process • Analytic Network Process • Rank Sum • Rank Reciprocal • Rank Exponent • Ratio Estimation • Entropy weight theory • VIKOR Method • TOPSIS
Route Alignment Optimization	• Manual techniques • Dijkstra's Algorithm • A* Algorithm • Pythagorean theorem • Least Cost Path Algorithm (LCP) • Fuzzy Influence Diagrams • Genetic Algorithm. • Swarm Intelligence based algorithms - Ant colony optimization algorithm • Bellman-Ford Algorithm • Floyd–Warshall algorithm • Grey Incidence Analysis • GIS based tools - ArcGIS Spatial Analyst module

2.3 Literature Survey

2.4 Factors affecting Route Alignment of Roads

A correct plan for route alignment requires consideration of a number of factors or variables for construction of a function or model [3] . These factors include topography, environment, contour, geomorphology, geology, drainage, climate, cost, social, landuse and landcover. Topographic maps, aerial photographs, geological maps, soil maps, as well as various surveys can be used to analyze these factors[4].

Different types of factors can be measured via various cost functions , such as:

- Economic factors: can be calculated considering highway alignment and construction costs.
- Social and cultural factors: can be measured considering accessibility cost, utility costs and proximity costs.
- Environmental factors: can be estimated using Environmental Impact Assessment(EIA). It estimates the impact of route construction on the environment (soil, water, forests, climate) using penalty functions, and assigns corresponding values to alternative alignments.

The variables are then represented in software like ArcGIS to create web maps and analyze geospatial data necessary for route alignment.The alignment plan is selected based on further studies performed with ArcGIS.

2.5 Techniques for Assigning Weights to Factors affecting Route alignment

2.5.1 Formal Decision Analysis

Formal decision analysis is used to examine the total impact of various route alignments and determine the ideal alignments by rating their influence on economic, social, environmental, and utilitarian variables. An initially used process from earlier times, it involved manually deciding the highway alignments, and then using decision analysis to rank them[18]. Initially, the decision problem is structured by identifying the impact factors (land use, relocation, cultural & biological resources involved etc.), attributes to measure those impact factors, and selecting the alternative alignments possible by the stakeholders. Then, for every alignment, the attributes are assigned values depending on their impact levels, and trade offs (considering penalty and cost functions)[22]. It is an effective process to evaluate alignments rationally and consider all multiple attributes involved in route alignment optimization but is time consuming due to manual intervention involved. Hence, further GIS tools including ArcGIS, Spatial Modules are developed to ease the process based on formal decision analysis techniques.

Multi Criteria Evaluation or Multi Criteria Decision Analysis methods are also based on similar concepts, used to select important attributes or factors as per given area maps and purpose involved, which is then used to calculate the cost matrix for optimization[22]. In this, various alternative attributes involved are ranked manually by the stakeholders, and the attributes are decided[29]. It is simple but less efficient, and can be optimized using different GIS tools for decision making.

2.5.2 Weight ranking methods

Multi-criteria weight methods are used to assign weights to input parameters/ factors affecting route alignment (as discussed in section 1). In each of the maps, the weight cost matrix is generated by weight assignment to the attributes and corresponding direction maps are plotted to visualize different factors involved in route alignment optimization. [14] Five weight assignment methods are discussed as follows:

- **Analytic Hierarchy Process (AHP) Technique:**

  This approach creates a pairwise comparison matrix taking into account all input variables. By analysing the components' relative relevance to an aim, each attribute is assigned a score between 1 and 10, and the resulting matrix is known as the importance matrix.

The total weight of the qualities, which represents their contribution to the identification of the optimum path, is shown in the importance matrix. The more crucial the factor, the higher the weight in the matrix.

- **Rank Sum Technique:**

  A non-parametric method used in random sampling is rank sum. In this, the rank of a parameter is determined by the total of its weights.

- **Rank Reciprocal Technique:**

  The normalised reciprocals of a criterion's rank are used in this method to create rank reciprocal weights. Ranking is based on the parameter's weight.

- **Rank Exponent Technique:**

  In this method, the decision-makers first identify the weights of the most significant element or criterion on a scale of 0–1, and only then do they determine the weights of the other factors relative to earlier parameter considered.

- **Ratio Estimation Technique:**

  In this approach, an arbitrary weight is assigned to the most important aspect on a scale of 0-100. Less significant components are given smaller weights and the remaining factors' estimated weights. Up until the weight for the least important criterion is assigned, the process is repeated. Finally, in order to compare the relative importance of the various components, ratios of each element are determined in relation to the least important factor.

2.5.3 Entropy Weight Theory

The concept of entropy weight theory is used to assign weights to different decision making variables involved in highway route alignment. Initially, an evaluation matrix of the route plan is created considering multiple attributes, objectives and indexes, and these are combined to generate a single synthesis index using entropy and entropy weight theory. Indexes can be classified as qualitative or quantitative, depending upon their impact and are assigned an index value using a 10 point system.Then the entropy weight decision making model is applied, which includes the following steps:

1. Scheme of evaluation, and indexes are decided, and a matrix is constructed considering cost and benefit of each scheme (or factor)

2. The entropy of each evaluation index is determined. As a result, the index's entropy weight is calculated. Entropy theory states that a given index is more significant for decision-making if it has a lower entropy weight and a greater difference between the same index for various schemes.

3. For each evaluation index, a weighted matrix is built, and factors' importance is estimated using metrics like distance (the difference between the ideal point and the one being evaluated point) and fidelity (the separation between the ideal point and the evaluation point / the distance between the ideal point and the negative point).

4. Schemes (or factors) are selected according to their fidelity values. A scheme having smaller fidelity is considered more important for optimization[21].

In the end, synthesis index values can be compared to determine which road alignment design is optimal. This decision making model is based on objective, hence the results are more realistic. Moreover, it also considers relationships between different factors involved in highway construction using their entropy, hence optimal routes can be selected.

2.6 Techniques for Route alignment Optimization

2.6.1 Least Cost Path Algorithm (LCP)

The least cost and most optimal path connecting the starting and ending points of a highway route is determined using the least cost path algorithm. With the help of the spatial analyst extension, ArcGIS software can generate the Least Cost Path Algorithm. Initially, a cost function is decided which considers the cost of construction (avoiding slopes, swampy areas), environmental area covered (water, forests etc.), social and cultural impact costs(damage to agricultural lands, moving of communities), via estimating multiple attributes involved using GIS based tools[37]. Once the cost parameters are decided, To find the cheapest path between a source and a destination, LCPA employs the cost-weighted distance and direction surfaces for the region. The procedure is repeated until there is a low-cost route connecting the source and destination points. LCP analysis is used to improve the social, environmental, economic, and technical aspects of the route alignment. GIS-based tools can also be utilised to apply LCP analysis efficiently using different plugins and modules present[29].

2.6.2 Fuzzy Logic

Fuzzy logic is a type of many-valued logic in which the truth values of variables could correspond to any real number between 0 and 1.A fuzzy logic approach can be useful when route alignment is being considered, since the results are not always accurate for any particular plan of route alignment[3]. Fuzzy logic has also found applications in influence diagrams which can be used for constructing route alignment models. A model can be built using a fuzzy influence diagram to describe the risk of a route alignment plan and to achieve a risk-based conclusion.[8]. It is advantageous to use fuzzy logic when precise inputs are not required.

2.6.3 Genetic algorithms and Swarm Intelligence

Genetic algorithm is used for both constrained and unconstrained optimization that is inspired by natural selection, a process that drives biological evolution. GAs were first utilized for highway alignment optimization by Jong (1998)[36].It uses the principle of orthogonal cutting planes,in which the straight line joining start and end points is divided into intervals(number of intervals decides the precision of optimization), and each plane passes through an interval. Additionally, it claims that the ideal highway alignment will always pass exactly one point along each plane (created by passing through each line interval).
There are 3 steps involved in route optimization using Genetic algorithms :

1. Genetic encoding and initial population is decided: The encoded solution has 2n genes when n intersection points are aligned in the intervals. As a result, genes on chromosomes are mapped along with the coordinates of intersection locations (as: (lambda)2i-1 = di... for all i = 1, 2,... n).

2. Genetic operators are applied to solved the optimization problem - it includes mutation based and crossover based operators - designed to work on the decoded intersection points.

3. Optimal search is performed - Initially, the initial population is generated, and further generations, better solutions are searched by applying the genetic algorithm to minimize the objective function/cost function. Cost function is decided considering the length dependent costs (construction, maintenance) and location dependent (right of way) costs. By using curve fitting, this stage connects the start and finish points and creates optimised route alignments.

The search for optimised route(s) using GAs takes longer, and the difference in cost functions gets smaller with each subsequent generation. The swarm intelligence algorithm, which takes its cues from the cooperative behaviour of social insect colonies, can improve GA even further. It decides the evolution of genes in further generations, by selecting the intermediate planes for optimal search randomly. Hence, using SI with GA, reduces the computational efficiency and reaches optimal path quicker, although it is harder to apply SI for route optimization in regions with greater land variability, and route network optimization[17]. A combined GIS-GA model has also been created in order to find the best horizontal highway alignment using station locations.

2.6.4 Other Techniques

Hand drawn alignment sketches are also being used. In one study, all alignment coordinates and element data were kept in a data bank, making it simple to convert hand-drawn alignment sketches on maps into vector drawings. The cost model (GMAPS-GCARS), which is used to evaluate the generated vector representation of alignments based on various criteria, is actually formed by joining the nodes of a cost-model matrix, where each node is given a cost of traversing it using the Dijkstra algorithm and Genetic Algorithm. Dijkstra's algorithm is commonly used for optimizing route alignments and finding shortest routes in many studies[13].

2.6.5 GIS tools for Route Alignment

The alignment of routes has also been accomplished through the use of a variety of tools. ArcGIS, ArcInfo and ArcView are primarily used to digitize the land use, road networks and other variables within the given area. In these tools, initially the satellite images obtained are converted to vector layers. Then the layers are stacked onto each other, to obtain different cost criterion maps for land use/land cover, physical features, slope, forest, water areas, which are further converted to raster form and used to calculate cost matrix involved in alignment optimization. A Quantum computer-based planning tool was utilized for alignment optimization, which is capable of performing cost-based alignment optimization, generating low cost road alignments automatically. As an alternative to a single least cost path, it provides a set of alternatives that take into consideration different social and economic factors and allow people to select their preferred alignment, resulting in lower costs. ArcGIS provides various tools for route alignment optimization, some of the tools used for route alignment include:

- **Weighted Overlay Analysis (WOA) tool:** used for surface cost analysis to find out important factors involved in cost estimation using multi criteria evaluation/ multi attribute decision making[29].
- **Spatial Module:** used to perform alignment optimization by minimiz-

ing cost of path from source to destination.

- **Polyline feature conversion tools:** used to convert optimum route alignment(s) calculated in raster form to polyline features for better visualization of path(s).

GIS based tools can be utilized to perform overlays of maps, create buffers and rasters, analyze datasets of images through visualization, and cost optimization using various techniques. It provides a simple and efficient way to implement route alignment optimization through different modules available.

Chapter 3

Research Gaps and Problem Statement

After performing the literature review we analyzed the research gaps involved in existing techniques used in road alignment which helped to define our problem statement

3.1 Research Gap

- Unavailability of 0 cloud coverage images for performing analysis of the research area.
- Unavailability of high resolution images of the research area.
- Sentinel 2 images are large and require a large amount of storage and memory for processing.
- The approach of physically analysing the research region for factors influencing route alignment is typically time consuming and may involve human errors, which may result in future economic, social, and environmental consequences.
- The present methods for route alignment often do not take into account

the environmental and social factors that are significantly impacted by road construction. This harms both the environment and the society.

3.2 Problem Statement

To develop model that will align optimized route between the given two locations Pune and Mumbai which considers different factors affecting the alignment. This can further be generalized on any study area.

Chapter 4

Proposed Methodology/ Solution

Our proposed solution is broadly a 3-step procedure involving the following steps:

1. Land Use Land Cover Classification
2. Weight Assignment and Ranking
3. Route alignment Optimization

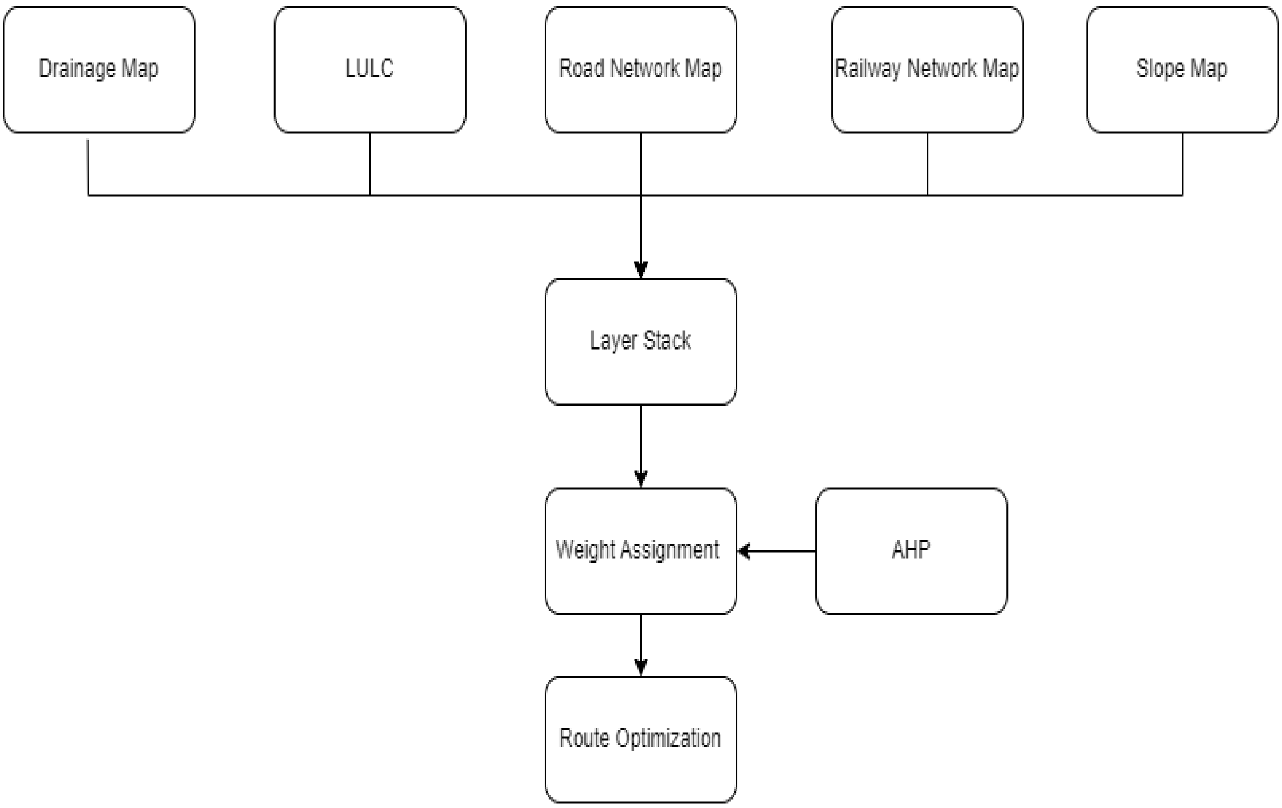

Figure 4.1: Methodology

4.1 Land Use Land Cover Classification

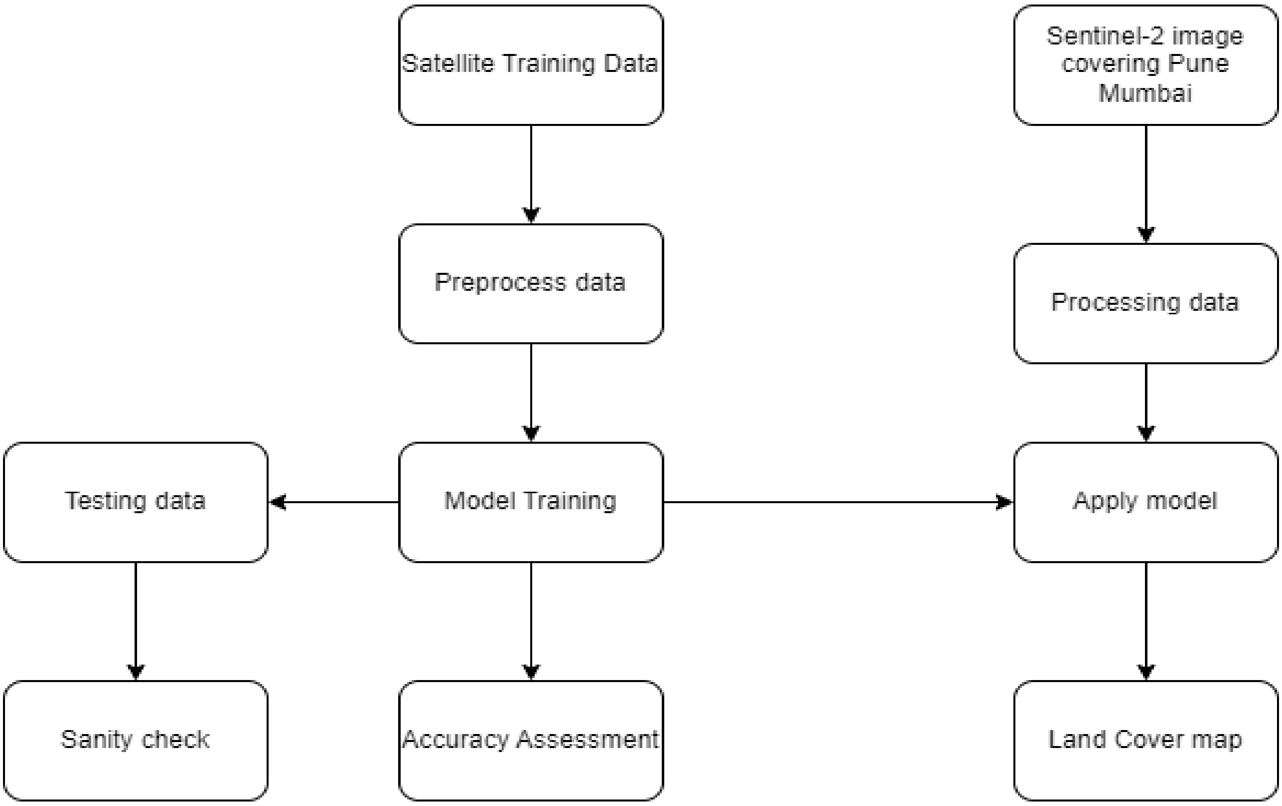

Figure 4.2: LULC Process

4.1.1 Using Deep Learning Techniques

Deep learning based models are used to perform land cover classification of the research area. For this, a Sentinel 2 image in the form of four overlapping tiles is acquired from the USGS Earth Explorer website. The tiles are merged to single image using QGIS software and the Sentinel 2 image of the Pune Mumbai region is obtained, which has 30m resolution and 10 bands. Pixelwise classification is performed using Unet and Resnet_50_Unet models. ResNet stands for Residual Network which is a neural network that uses residual connections to learn the differences between input and output in each layers. UNet has an advanced CNN architecture specifically used for semantic segmentation in image processing. The models were trained on the DeepGlobe Land Cover Classification dataset obtained from Kaggle which

consists of 803 images having their corresponding mask images classified into 7 classes, that are further split into training and testing data. The training of the models resulted in dice-coefficient of 98% and 96% for UNet and ResNet50__UNet respectively. Further, sanity check is also performed on the mask images so that the original and predicted images appear to be nearly accurate. The classes or categories considered for classfication included water, urban area, agricultural land, range land, forest land, barren land, unknown area(clouds and others).
Further various maps such as Slope map and Drainage map were prepared after downloading DEM (Digital Elevation Model) datasets for the specified study area from the USGS earth explorer. Roads and railway networks maps were prepared using open source datasets downloaded using OpenStreetMap API. The layers of each of these maps are clipped according to the shapefile of study area, and stacked to obtain find land cover utilization.

4.1.2 Using QGIS software

A free and open-source GIS programme called QGIS (Quantum GIS) is used to analyse spatial data. To perform the analysis of the study area using QGIS software, several maps were prepared, and analysed according to the priority of factors decided further. Following maps were prepared using various modules, plugins and tools present in QGIS:

1. Land Use Land Cover Map: LULC map is prepared using ESRI's Land Cover datasets, and clipping the regions according to the administrative areas shapefiles of Pune-Mumbai region

2. Road network and Railroads Map: Road and railway network maps are downloaded using OpenStreetMap's plugin called QuickOSM from QGIS

and the regions are clipped according to study area to obtain the final map.

3. Slope Map: DEM dataset is downloaded from USGS Earth Explorer, covering 30m height regions, in which 4 tiles were obtained. The tiles were merged and the slope map is obtained using functions of Processing Toolbox module of QGIS.

4. Drainage or Water Network Map: The USGS Earth Explorer website's dataset for water bodies is downloaded, and the shapefile is further studied using the vector layer analysis modules that are available.

Further, the maps prepared were analyzed manually with respect to different criteria such as: water bodies present, utilization of land for agriculture, buildings and barren land etc. The layers of each of the maps were clipped according to the shapefile of the administrative areas of the study region and the final output of the land use and land cover categorization was obtained by additional layer stacking, which will be used for route optimisation in the further steps.

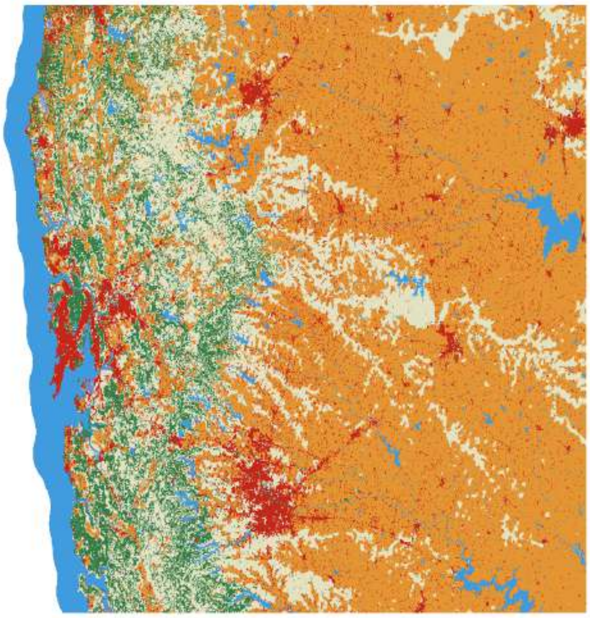

Figure 4.3: Land Use Land Cover Map

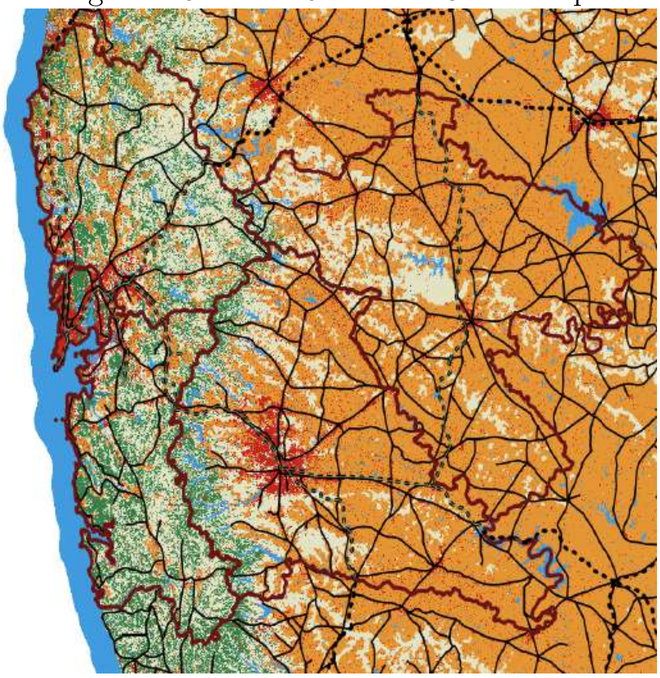

Figure 4.4: Roads and Railway Network Map

4.2 Weight Assignment and Ranking

The 7 factors or classes were considered for assigning weights and ranking which includes: water, agricultural land, forest, buildings, vegetation, bar-

ren land and range land. Weight assignment was performed using Analytical Hierarchy Process, for which a pairwise importance matrix is created based on the relative importance of each of the factors for route alignment. For example, the route designed should not pass through water bodies and dams (as it would lead to environmental damage as well as increase in construction cost), hence water was assigned the highest weight while ranking, and the weight of other factors were decided relative to it. In AHP, the higher the weight of the factor considered, more is its importance. The accuracy of weight ranking using AHP is determined using Consistency ratio, which is obtained as this method Consistency ratio, the weights, their standard deviation are calculated which shows whether the weights assigned are consistent or not. According to standards, for the pairwise comparison matrix to be consistent, consistency weight should be less than 0.1. We performed the weight ranking using AHP in Python and have obtained a consistency ratio of 0.1, concluding the weight assignment is consistent.
Further, in the final stage of route optimization, optimal routes are obtained using specified criteria and different algorithms for the specified study area.

4.3 Route alignment Optimization

4.3.1 Using Machine Learning and Shortest Path Algorithms

For this purpose we attempt to use 4 different approaches which include: Genetic Algorithm, Dijshtra's, Bellman ford and A* algorithms. From this, GAs and A* algorithms are AI based, which aim to minimize the heuristic or cost function considering all ways possible. Dijkstra's is a greedy approach to find shortest path between 2 points whereas Bellman ford uses dynamic programming for route optimization between the source and destination. These algorithms, provide different routes for minimizing the cost function. Further, the routes are analysed for suitability according to pre-decided criteria and most optimal route is selected.

4.3.2 Using QGIS software

To perform route alignment optimization between Pune and Mumbai using QGIS software, the road and railway networks map obtained from OpenStreetMap is utilized. For this QuickWebServices plugin is used, which provides facility to access OpenStreetMap vector layers in QGIS software. Then, the layer is clipped using tools in Processing toolbox to the size of the study area taken as a shapefile. The route optimization and analysis is performed on the clipped road network layer stacked on top of land cover map layers. To find the optimized route between Pune and Mumbai, the start and end points were considered to be Kiwale (in Pune) and Kamanboli(in Mumbai) respectively which were also the start and end coordinates of Old Pune Mumbai Highway.

The route is optimized considering the criteria that it should be cost effective, time efficient and should not pass through agricultural land, water bodies and minimizes environmental degradation caused. For this, ORS tools (Open Route Service tools) plugin and its corresponding API is utilized, are the shortest path between Pune and Mumbai is calculated using Dijkstra and A* algorithms and optimized path is produced as output. Further, the fastest route (for driving car) is calculated using the ORS tools plugin considering the road and railways present, as well as the natural factors considered. A map considering the shortest and fastest routes avoid the roads with tolls, ferries is also prepared which provides a cost effective and faster way to design for the benefit of people travelling from Pune to Mumbai and vice versa.

Chapter 5

Experimental Setup

The training of the UNet and ResNet-50 models is conducted on an Nvidia-DGX system which is equipped with 4 Tesla v100 cards with each card having 32GB. Additionally, the system memory is 256GB. This version of CUDA on the system is 11.00. The version of the system driver is 450.80.02. For training purposes, Kaggle's DeepGlobe dataset is used which has Sentinel-2 images with 3 RGB (Red, Green, Blue) masks. With each image size of 2448x2448 pixels, this training data contains 723 satellite images in RGB bands. There is a 50cm pixel resolution on the images collected by DigitalGlobe's satellites. The dataset contains 80 validation and 343 test images (without masks). The UNet model is trained for 12 epochs. To execute this model, a Docker container was built with the image available at Docker Image. Our model was trained in a day with a GPU. Due to the earlystop callback, UNet was trained for 10 epochs as the results remained constant after 10 epochs. The average epoch time was 1.5 hours The ResNet-50-Unet model was trained for 12 epochs with an average time of 15 minutes per epoch. QGIS software is also used for imposing and analysing various maps and finding optimal routes from source to destination. DIVA-GIS software was used to download shapefiles of the railway network, road network, and water bodies in the research region. DEM has been downloaded from the USGS EarthExplorer.

Chapter 6

Results and Discussion

Land Use Land Cover classification resulted in generation of 7 classes for the given study area. We obtained a dice coefficient of 98.5% for the UNet model and 96.89% for the ResNet-50_UNet model. An accuracy of 85% was obtanied using the QGIS software. In the further steps, AHP was used to assign weights to different criteria involved in route alignment, with a consistency ratio less than 0.1. Final route optimisation results show that the fastest route developed is 113 km long and the shortest route achieved is 107 km long, which is optimized than the length of Old Pune Mumbai Highway, as well as covering more places and minimizing passage through water bodies and agricultural lands. The results of various stages involved in route alignment are added below.

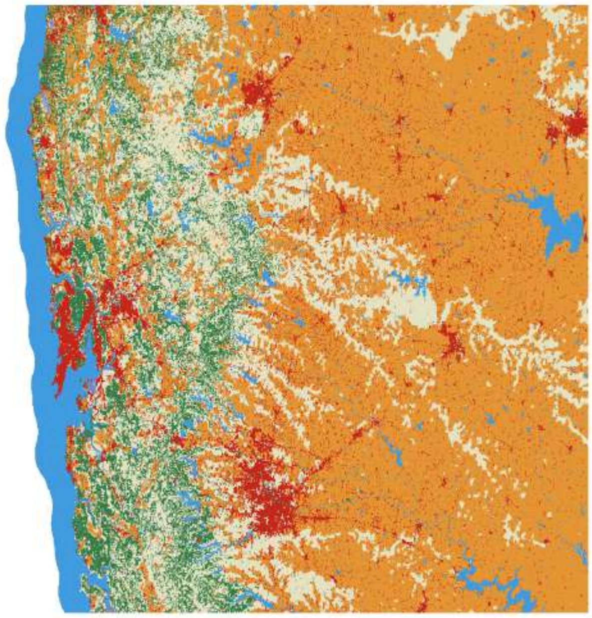

Figure 6.1: Land Use Land Cover Map of Pune-Mumbai Region

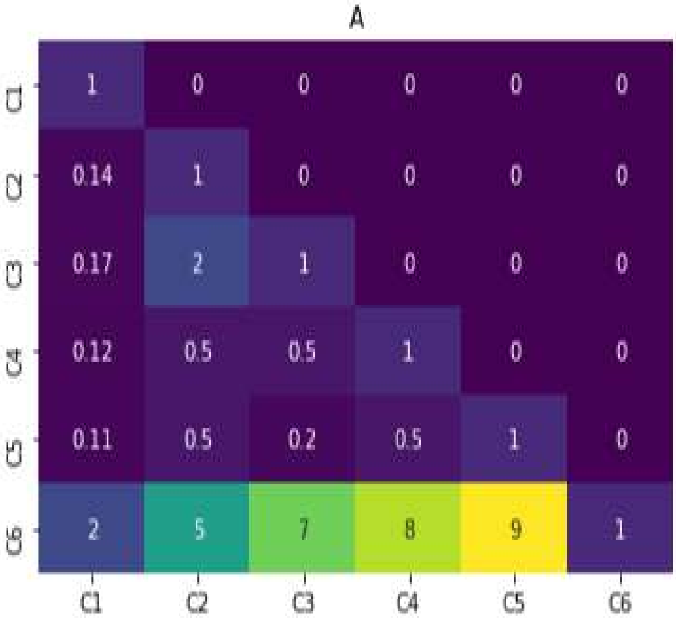

Figure 6.2: AHP Pairwise comparison matrix

	Weights	Weights +/-	RGMM	+/-
Crit-1	34.50%	11.41%	34.51%	11.25%
Crit-2	6.20%	1.71%	6.21%	1.70%
Crit-3	9.10%	3.42%	9.14%	3.33%
Crit-4	4.40%	0.93%	4.39%	0.92%
Crit-5	3.00%	1.02%	2.98%	0.99%
Crit-6	42.80%	16.91%	42.77%	15.46%

Consistency Ratio: 5.08% & Consistency Ratio of Weighted: 4.40%

Figure 6.3: Criterion weight heatmap obtained using AHP

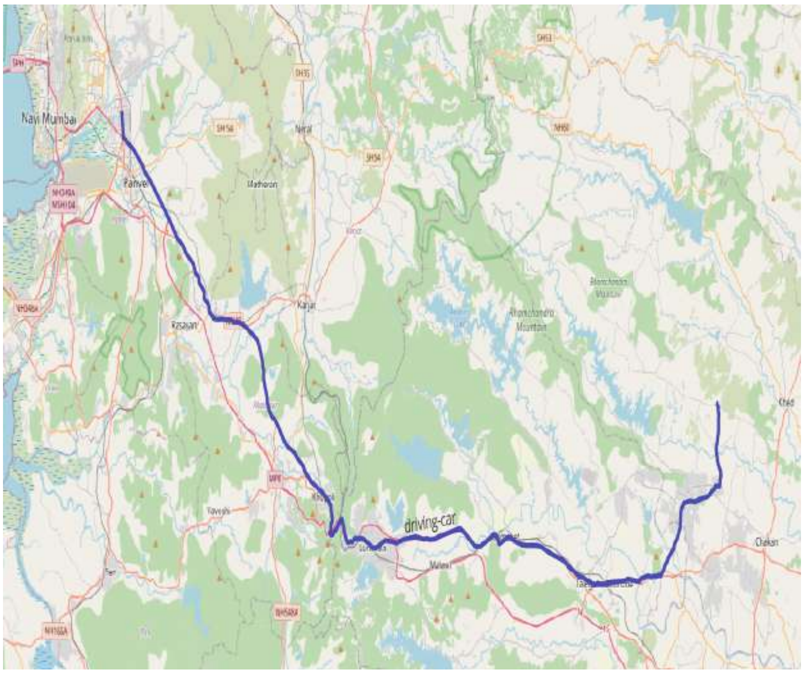

Figure 6.4: Shortest route of 107Km

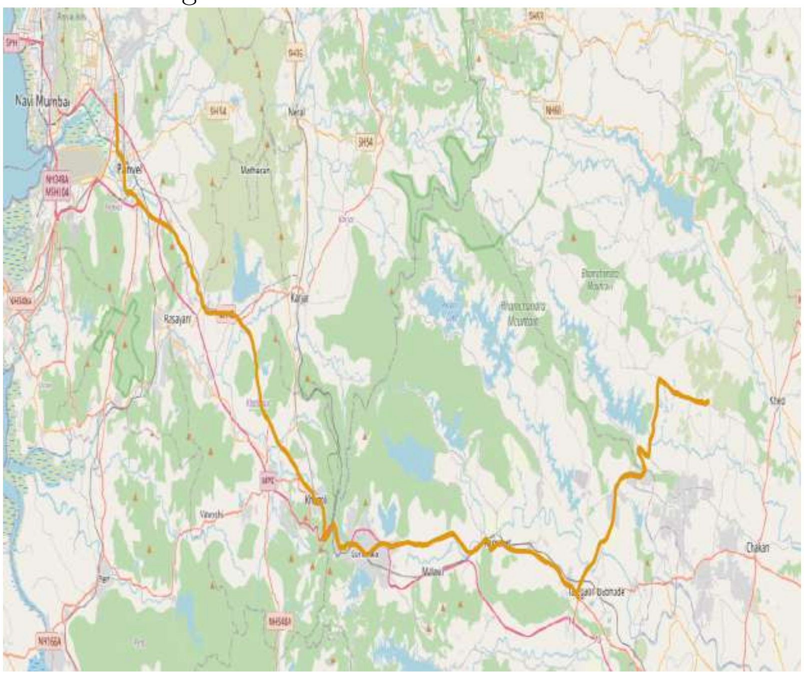

Figure 6.5: Fastest route of 113Km

Chapter 7

Conclusion

The goal is to develop an optimal route alignment between Pune and Mumbai. During whole process GIS, RS and deep learning techniques played an important role. The main challenge behind this process is the large processing power required to train the models and handle such huge images. Furthermore, because additional bands' datasets were unavailable, the selection was limited to three bands. It was difficult to acquire data such as shapefiles for certain locations since we wanted to cover two cities. It covered a total of four tiles that were blended into one another, thus cutting and merging was required. Our model required a long time to train because of the large image size. In LULC, two models were trained out of which UNet has an accuracy of 98%. AHP is determined to be the best for weight assignment throughout the multicriteria decision making phase. Genetic algorithm proved to be most suitable for route optimization. Finally these results are also obtained from QGIS to perform a comparative study of deep learning techniques and existing GIS softwares. The final route is **107 Km** which covers more places in between while minimizing environmental harm.

Further this study can be generalized to any study area depending on criterion that is being considered.Dataset of Sentinel-2 image can be generated using GAN.

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