TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF CIVIL ENGINEERING

FINAL YEAR PROJECT REPORT ON STUDY OF ALTERNATIVE ALIGNMENTS OF KATHMANDU-POKHARA HIGHWAY

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Supervisor:

Dr. Pradeep Kumar Shrestha

April 2022

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IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR DEGREE IN CIVIL ENGINEERING (Course Code: CE755)

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CERTIFICATE

This is to certify that this project work entitled "STUDY OF ALTERNATIVE ALIGNMENTS OF KATHMANDU-POKHARA HIGHWAY" has been examined and declared successful for the fulfilment of academic requirement towards the completion of Bachelor Degree in Civil Engineering.

Project Supervisor	HOD, Department of Civil Engineering
Dr. Pradeep Kumar Shrestha	Dr. Gokarna Bahadur Motra
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ABSTRACT

This study focuses on the alternative alignments of highways to link Kathmandu and Pokhara. For the purpose of this study, the highway linking Kathmandu and Pokhara is termed as "Kathmandu-Pokhara Highway". The present alignment has severe problems of sharp bends and high grades, mostly in Naubise to Nagdhunga section. The alignment lacks proper sight distance throughout the alignment. This study aims to solve these problems by selecting the best alignment from a collection of different unique alternatives. Data is collected from online sites like OpenStreetMap, GoogleEarth etc.

Overall five alignments are selected and analysed. Firstly, the current alignment is studied under different technical aspects. Second alignment is designed using Dijkstra's Shortest Path algorithm. This alignment is found to be similar to the current alignment. So third alignment is designed by modifying current alignment at several locations to make it shorter, faster and safer by decreasing the deflection angles and grades with addition of bridges and tunnels along with cutting and filling in some critical sections. Fourth alignment is based on economic principle, i.e., it consists of no tunnels. Fifth alignment is designed as an expressway with less deflection angle of curves, low grades and high speed throughout the alignment.

These alternatives are then evaluated under different technical aspects like length, radius of curves, grades etc as well as economical aspects and given insightful scores to compete against one another, and the best alignment is proposed.

This project can be accessed online @ https://bit.ly/project74KtmPkr

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

Nepal lies basically in the foothill of the Himalayas, which extends throughout the northern part of the country from east to west. The southern part however is relatively flat and consists of plain land.

There is an elevation difference of more than 8500 metres within a short north-south stretch of about 200 kilometres. Also this land offers great diversity in caste, culture, tradition, ethnicity, etc. The country can be categorised either from southern part to northern or from eastern part to western and in every prospect, the difference of communities and societies can be observed distinctively. Such a geographic and socio-cultural diversity makes Nepal a peculiar country.

Nepal is a landlocked country surrounded by India in the east, west and south while China in the north. The main occupation of people is agriculture. The majority of the population live in villages. However, in recent times people have migrated from villages to cities. Towns are also being developed in the sub-urban areas while the cities are being populated. Main reason for this migration being lack of infrastructure and opportunities outside the capital.

Only after the restoration of multiparty democracy in 1990, it was realised that the main factor inhibiting the development was the lack of transport facilities in the country. Among the different modes of transport, Road is the most promising and economical approach to transportation in underdeveloped countries like Nepal. Since then, the concept of Strategic Road Network (SRN) and Local Road Network (LRN) have developed which have guided the Engineers to build roads into every corner of the nation. SRN consists of National Highways and Feeder Roads which are under Department of Roads (DOR) while LRN consists of District Roads and Urban Roads which are under Department of Local Infrastructure Development and Agriculture Roads (DoLIDAR), recently renamed as Department of Local Infrastructure (DoLI). Recently the roads are classified as National roads which are under jurisdiction of the Department of Road of central government, Provincial highways and roads under provincial government and Local roads under Municipalities and rural municipalities. Today, almost 13,500 km of SRNs exist in the country (Road Network Data 2017/18, DOR) along with thousands of kilometres of LRNs. Simultaneously, the need for upgrading existing Roads has been realised and various Road extension projects are also underway to accommodate the existing Traffic Volume and to provide alternate paths.

This landslide-prone and heavily congested highway passes through five districts: Kathmandu, Dhading, Chitwan, Tanahu and Kaski. This highway has a junction with Tribhuvan Highway at Naubise. The Bharatpur-Mugling section connects this highway to Mahendra Highway, the longest highway in Nepal. The highway also connects Nuwakot District via a newly constructed road in Galchhi and connects to the district headquarter of Dhading District at Phurke Khola, Malekhu. Until 2011 opening of the B.P. Highway, this highway was the only improved land route from Kathmandu Valley to all points south, and as such the main artery for heavy trucks into Kathmandu Valley and into Pokhara.

A 25 km (16 mi) road off the main highway connecting Pokhara and Kathmandu links to the historical town of Gorkha. Apart from these historic points of interest, the highway is lined with modern townships that have sprung up around important road junctions and river crossings. The scenery along the highway is dramatic as it follows a series of deep river valleys. On clear days, most of the way to Pokhara there are views of Machapuchare and the Annapurna massif.

The importance of the highway was reflected as three major highway bridges, near Mahadevbesi, Belkhu, and Malekhu were washed out by flood by the tributaries of the Trishuli River in 1993. But now major issues with some bridges have been arising because of human encroachment near the foundations of the bridges as well as weak maintenance. The 370m (1,210 ft) bridge over the Madi River at Damauli may collapse due to a weakened foundation, as it was constructed at the same time as the highway with Chinese assistance. Sand and rock extraction nearby have weakened the pillars on a crucial bridge of Nepal's busiest highway. The bridge near Mugling faces maintenance problems from time to time.

The Krishna Bhir is a cliff located in Dhading District by the side of Prithivi Highway, approximately 83 km from Kathmandu Valley. It was one of the most landslide prone parts of the highway, Jogimara area being first to affect the traffic largely as the highway was opened to the public. The steep elevation of the cliff compounded with the loose mud constituent of the cliff creates the vulnerability of landslide in monsoons. In 2004, the Department of Roads, Nepal and a team of Nepalese bio-engineers managed to prevent the landslide over a season which is considered as an achievement in modern Nepalese engineering.

There are some major issues faced by the highway. The traffic capacity of the highway, safety and grade issue of the road alignment in some locations. The traffic numbers on the road are increasing but not the service. Speeding and unawareness of other road users are creating hazards for both of the parties, however new road safety furniture has been installed along the highway. Some extensive studies are being done to address the problem faced by the highway at Naubise - Nagdhunga Section. For example, a Thankot - Naubise Road and Sitapaila - Dharke Road, which will reduce operation and maintenance cost of road and vehicle, after completion.

1.2 OBJECTIVES OF THE PROJECT

The objectives of the given project are as follows:

1. To analyse the present condition of Kathmandu-Pokhara highway.
2. To find the alternative alignments for current alignment of Kathmandu-Pokhara highway.
3. To select the best alternative such that we can reduce travel time, cost, grade, etc.
4. To select the alignment so that it connects major settlements, consists of the least number of horizontal and vertical curves, avoid landslide prone areas etc.

1.3 SCOPE OF THE PROJECT

The scope of the project comprises:

- Review and analysis of the present condition of Kathmandu-Pokhara highway
- Finding the shortcomings of present highway alignment

- Finding different alternative alignments of Kathmandu-Pokhara highway using different software like GIS, and manual coding to reduce the travel time from current alignment
- Feasibility study of each alternative alignment
- Comparing alternative alignments using different parameters like travel time, overall gradient, number of bridges, horizontal and vertical curves etc
- Selection of environmentally, economically, geometrically feasible alignment

1.4 LIMITATIONS OF THE PROJECT

And, the limitations are:

- Low resolution of elevation data
  - GPS visualizer did not give elevation for exact road coordinates
  - Constraints of time and computational resources
- Lack of detailed benefit analysis from factors such as reduction in
  - Fuel consumption due to grade reduction
  - Greenhouse gases emission
  - vehicle maintenance cost
  - congestion, etc
- Absence of a rigorous method of scoring of the alternative alignments

1.5 ORGANISATION OF REPORT

Chapter 1 depicts the present scenario of transportation facilities in the study area and introduces the existing Kathmandu-Pokhara highway with its shortcomings. The objectives, scope, and limitations of the project are discussed.

Chapter 2 reviews the existing literature (design codes) for design guidelines. GIS knowledge from lectures of Elective III course (CE 78501) are realised. Modified Dijkstra algorithm is explained.

Chapter 3 explains the methodology of the project, incorporating the process of data collection and processing using the tools GIS and computer codes.

Chapter 4 is the main focus of the report, which is about technical details of the current and proposed alternative alignments. Four alternatives are proposed with various unique features. It then performs the technical and economic analysis of the alternatives using simple scoring parameters to find the best one.
Chapter 5 presents the social and environmental conditions and impacts of the study area.
Chapter 6 is about the economical aspects of the study area.
Then the report is concluded and recommendations are given. Appendices are listed at the end of the report.

Draft Report

After studying the different alternative alignment possible to link two major cities of Nepal, i.e., Kathmandu and Pokhara using different tools and techniques, the initial report (draft report) is submitted to our supervisor sir for review and comments on the selected alternatives along with their features. The draft report consisted of followings:

- Method of selection of alternatives
- Extraction of data and their sources
- Features of different alternative alignments
- Evaluation criteria of the alternatives

Final Report

With the suggestions from our supervisor, the report is continued and the final report is completed with the following additions.

- Technical evaluation of the alignments based on length, number of bridges and tunnels, length of bridges and tunnels, speed, grade, travel time etc
- Economic evaluation based on cost benefits of time saving and decrease in fuel consumption.
- Social, economical and environmental aspects of the study area
- Conclusion and recommendations

CHAPTER 2: LITERATURE REVIEW

The project team members gathered as much as information from written materials, reports, studies of the proposed road/sections and road norms, which were particularly knowledgeable about the specified study.

The students made full use of existing materials such as:

- Nepal Road Standards-2070
- Pavement Design Guidelines
- Traffic Manuals
- IRC Hill Road Manuals

2.1 FACTORS AFFECTING ALIGNMENT SELECTION

The factors considered for selection of the alignments are:

- Distance: The route between any two points is made as short as possible
- Comfort: The alignment is designed with easy curves and small gradients.
- Economy: Some alignments are made with some modifications to current alignment which saves the construction cost.
- Safety: The alignment is made to satisfy the safety requirements

2.2 ROAD CLASSIFICATION

2.2.1 Administrative Classification

NRS 2070 classifies roads into 4 administrative subgroups based on national importance and level of government responsible for overall management and financing. It includes:

- National Highways
- Feeder Roads
- District Roads
- Urban Roads

Our scope of study is the Prithivi Highway (**H04**) + Tribhuwan Highway (**H02**) and to design its alternative route.

2.2.2 Technical/ Functional Classification

For assigning various geometric and technical parameters for design, roads are categorised into classes as follows:

Class -I

Class I roads are the highest standard roads with divided carriageway and access control.

(Expressways) with an ADT of 20,000 PCU or more in 20 yrs. perspective period. Design speed adopted for the design of this class of roads in plain terrain is 120 km/h.

Class II

Class II roads are those with ADT of 5000-20000 PCU in 20 yrs. perspective period. Design speed adopted for the design of this class of roads in plain terrain is 100 km/hr.

Class III

Class III roads are those with ADT of 2000-5000 PCU in 20 yrs. perspective period. Design speed adopted for the design of this class of roads in plain terrain is 80 km/hr.

Class IV

Class IV roads are those with ADT of less than 2000 PCU in 20 yrs. perspective period. Design speed adopted for the design of this class of roads in plain terrain is 60 km/hr.

2.3. GEOMETRIC DESIGN

Geometric design of roads is an important aspect to be considered while selecting alignment. Cross-section elements and sight distance are the functions of design speed which influences alignment parameters like radius of horizontal curves, deflection angle between tangent lines. Important geometric design parameters regarding selection of alignment are:

2.3.1 Design Speed

The design speed of the road is 100 km/hr.

The Design Speed table as per NRS 2070 is given below.

Road Class	Plain	Rolling	Mountain	Steep
I	120	100	80	60
II	100	80	60	40
III	80	60	40	30
IV	60	40	30	20

Table 2.3.1 Design speed as per NRS 2070

2.3.2 Horizontal Alignment

Minimum Radius of curve

The minimum radius of the horizontal curve adopted in the design is 50 metres. As far as possible the curves are designed to maintain the speed. As far as possible a larger radius is favoured to provide comfort for the drivers and passengers.

Basic equation for finding the radius of horizontal curve from the condition of equilibrium of centrifugal force, super elevation and friction is given below:

$$R = \frac{V^2}{127(e+f)} \qquad [4.1]$$

Where, R is the radius of horizontal curves in metres, V is the design speed in km/h, e is the superelevation provided and f is the coefficient of lateral friction which depends on the speed.

According to NRS 2070,

<table>
<tr><th colspan="4" rowspan="2">Road Class</th><th rowspan="2">Design Speed km/hr</th><th colspan="3">Minimum Recommended Radius, m</th></tr>
<tr><th>When no superelevation provided (2.5% Camber i.e. negative superelevation)</th><th>When maximum superelevation of 10% provided</th><th>From the comfort criteria of passengers (Max. lateral force 15% of vertical force)</th></tr>
<tr><td rowspan="4">I</td><td></td><td rowspan="2"></td><td rowspan="3"></td><td>120</td><td>1730</td><td>600</td><td>760</td></tr>
<tr><td rowspan="4">II</td><td>100</td><td>870</td><td>370</td><td>530</td></tr>
<tr><td rowspan="4">III</td><td>80</td><td>440</td><td>210</td><td>340</td></tr>
<tr><td rowspan="4">IV</td><td>60</td><td>200</td><td>110</td><td>190</td></tr>
<tr><td rowspan="3"></td><td>40</td><td>70</td><td>40</td><td>90</td></tr>
<tr><td rowspan="2"></td><td>30</td><td>30</td><td>20</td><td>50</td></tr>
<tr><td></td><td>20</td><td>20</td><td>10</td><td>30</td></tr>
</table>

Table 2.3.2: Minimum Radius of Horizontal Curves as per NRS 2070

Superelevation

Super elevation has been provided at the curves to avoid overturning of the vehicles and provide comfortable playing of the vehicles. Values adopted for maximum super elevations of the carriageway are 5% for horizontal curves and 10% for hairpin bend.

Value of superelevation is calculated using following formula:

$$e = (\frac{V^2}{127R}) - f$$

[4.2]

Where, e is the value of superelevation, f is the coefficient of lateral friction, V is the design speed in kmph and R is the radius of the horizontal curve.

According to NRS 2070, maximum super elevation to be provided is limited to 7% in plain and rolling terrain, 7% in snow bound areas and 10% in hilly areas not bound by snow.

When a vehicle traverses a horizontal curve, the centrifugal force acts as horizontal outward through the Centre of gravity of the vehicle, the centrifugal force developed depends on the radius of the horizontal curves. The super-elevation that is provided should not be less than the camber from the surface because of the drainage point of view.

The superelevation is introduced by raising the outer edge or the pavement at a specified rate by rotating the pavement about the centre line.

2.3.3 Vertical Alignment

The vertical alignment of the road has been designed as smooth as possible. The grade lines are designed with minimum breaks and long lengths of grades as far as possible. Vertical curves are provided where total change of grade from one tangent to the other exceeds 0.5%. Parabolic curves are provided as it is easy to layout and enables a comfortable transition from one grade to another. A minimum of 1% of longitudinal grade is provided for better drainage.

Vertical Curve

Vertical curves are provided for smooth transition of the profile at vertical grade changes. All vertical curves are designed as simple Parabola. These curves are controlled by the sight distance requirements. As far as practicable the large radius of the curve is adopted. If the convexity of the curve is upwards it is called a summit curve otherwise a valley curve.

Design of a vertical curve is controlled by its K-value and length of the curve (L-value). K and L are related as follows:

$$K = \frac{L}{A}$$

[4.4]

Where, K is the maximum radius of curvature i.e. curvature at the vertex of the parabola curve divided by 100, m/%, L is the length of the vertical curve in metres and A is the algebraic difference of longitudinal grades of the vertical alignment in percentage % .

As per NRS-2070, minimum value of K for summit curves is given by below table:

Design Speed, Km/h	**20**	**30**	**40**	**60**	**80**	**100**	**120**
K-value, m/%	2	4	29	94	321	427	807

Table 2.3.3a: Minimum value of K for various design speeds as per NRS 2070

Minimum Length of curve

The minimum length of the vertical curve adopted in the design is 30 metres. As far as possible, flatter vertical curves with sufficient curve lengths have been provided for comfortable plying of the vehicles.

Gradient

The recommended gradient for highway in mountain/steep terrain for design speed of 100 kmph as per Nepal Road Standard 2070 is 5% and minimum longitudinal gradients for longitudinal drainage purpose is 0.5%

As per NRS-2070, maximum gradients for various design speeds shall be as follows:

Design Speed, km/hr	**20**	**30**	**40**	**60**	**80**	**100**	**120**
Maximum gradient, %	12	10	9	7	6	5	4

Table 2.3.3b: Maximum gradients for various design speeds as per NRS 2070

2.3.4 Sight Distance

The Sight distance depends upon the design speed of the road. The safe stopping sight distance for design speed of 100 kmph is adopted as 190 metres.
As per NRS-2070 stopping distance for various speeds are given below:

Speed, km/hr	**20**	**30**	**40**	**60**	**80**	**100**	**120**
Stopping Distance, m	20	30	50	80	130	190	260

Table 2.3.4: Sight Distances for various design speed as per NRS 2070

2.4 GIS and Dijkstra Algorithm

2.4.1 Geographic Information System

Geographic Information System (GIS) is an organised collection of computer hardware, software, geospatial data and users to efficiently capture, store, update, manipulate, analyse and display all forms of geographically referenced information. GIS includes all essential vector and raster analysis functions that enable users to calculate and process geospatial data, construct civil engineering location based plans and display results in the form of maps.

2.4.2 Dijkstra's Algorithm

Dijkstra's algorithm is used to determine the shortest path between two nodes in an interconnected graph. The algorithm begins with the starting node, compares the distances of its connected neighbours and finds the nearest one and marks the node as found. In next iterations, the algorithm calculates the distance from source of all the neighbours of the previously found nodes including the source node using the formula $Dj=Di+dji$ where Di is the least distance from source to previous found node i and dji is the distance between nodes i and j. Among the neighbours considered, one with least value of Dj is marked as found with its least distance from source as Dj. The process is repeated until all nodes are selected one by one in the ascending order of minimum distance from the starting node.

2.4.3 Dijkstra's Algorithm for Raster Data Model

To apply Dijkstra's algorithm to a raster data model, following points are considered:-

1. Each cell of the raster is considered as a node positioned at the midpoint of the cell.
2. Nodes representing each cell of the raster are two ways connected to its 8 neighbouring nodes.
3. The distance between the nodes is unit cell size for nodes connected vertically and horizontally and $\sqrt{2} \times$ cell size for nodes connected diagonally.

2.4.3 Cost Distance Analysis

Cost Distance Analysis is a raster analysis function used to determine the least costly path to reach a source for all cells in the raster. This function takes two inputs: a cost raster and a source layer and returns a cost weighted raster. The function takes the cost raster and evaluates the value for each cell; the evaluated value is the accumulated least cost required to travel from the cell to its nearest source. The function uses Dijkstra's Algorithm for raster model data by replacing distance between two nodes with average cost of the cells to compute the least cost path between source and destination.

CHAPTER 3: METHODOLOGY

3.1 STUDY AREA

3.1.1 Location and Access

The road section is in Kaski, Tanahun, Chitwan, Dhading and Kathmandu. It connects Kathmandu to Pokhara . Primary destinations of this Highway are Naubise, Galchhi, Gajuri, Malekhu, Kurintar, Mungling, Anbukhaireni, Dumre, Damauli, Pokhara.

3.1.2 Geology

The Himalayas were formed due to the collision between the Indian plate and Eurasian plate some 40 million years ago. Of its 2400 km east-west stretch, Nepal occupies the central 800 km. It can be divided into five morpho-tectonic zones from south to north viz. Terai plains, Siwalik range, Mahabharat range and mid-valleys, Higher Himalayas and Tibetan Tethys. Each of these zones are identified by their specific geological features. Among these zones, the proposed study area falls under Mahabharat range. It consists of high hills and deep valleys. From a mineral resources point of view, this lesser Himalaya range is promising for metallic minerals, industrial minerals, marble, gemstones, fuel minerals, construction materials etc.

The proposed road section lies in Mahabharata Range. The rock sequence is represented by meta-sandstone, phyllite, slate, limestone, and dolomites. Owing to intense deformation, the adjacent geography consists of four formations which are repeated and constitute five longitudinal folds.

3.1.3 Soil

There are different types of soil in Nepal. Various factors such as geology, climate and vegetation types have resulted in variations in soil properties. Various types of soil are found in Nepal such as alluvial soil, sandy gravel soil, lacustrine soil, rocky soil and mountain soil. Alluvial soil in Terai and in river basins. It is formed by the materials deposited by rivers and it's very fertile. The sandy gravel and gravel soil are found in Churiya where gravel and conglomerate are predominately found. This is not fertile soil. There are various types of soil in the middle hill. But rocky soil is predominant. The lacustrine soil is found in the Pokhara valley. It is formed by the deposited materials in the lake hence, it is fertile. The mountain soil is formed by where boulders, sands and stone brought by glaciers are found. It is also not fertile soil.

The soil found in this territory is mostly clay. Due to this reason the place gets all muddy during the monsoon. However, in some places the soil varies from silty clay to sandy gravel. Rocky soil is also encountered in some places. The soil has moderate to high bearing capacity on weathered slates and massive limestone. The area has moderate groundwater potential.

3.2 Study Framework

Following flowchart shows the order of execution of alignment selection process

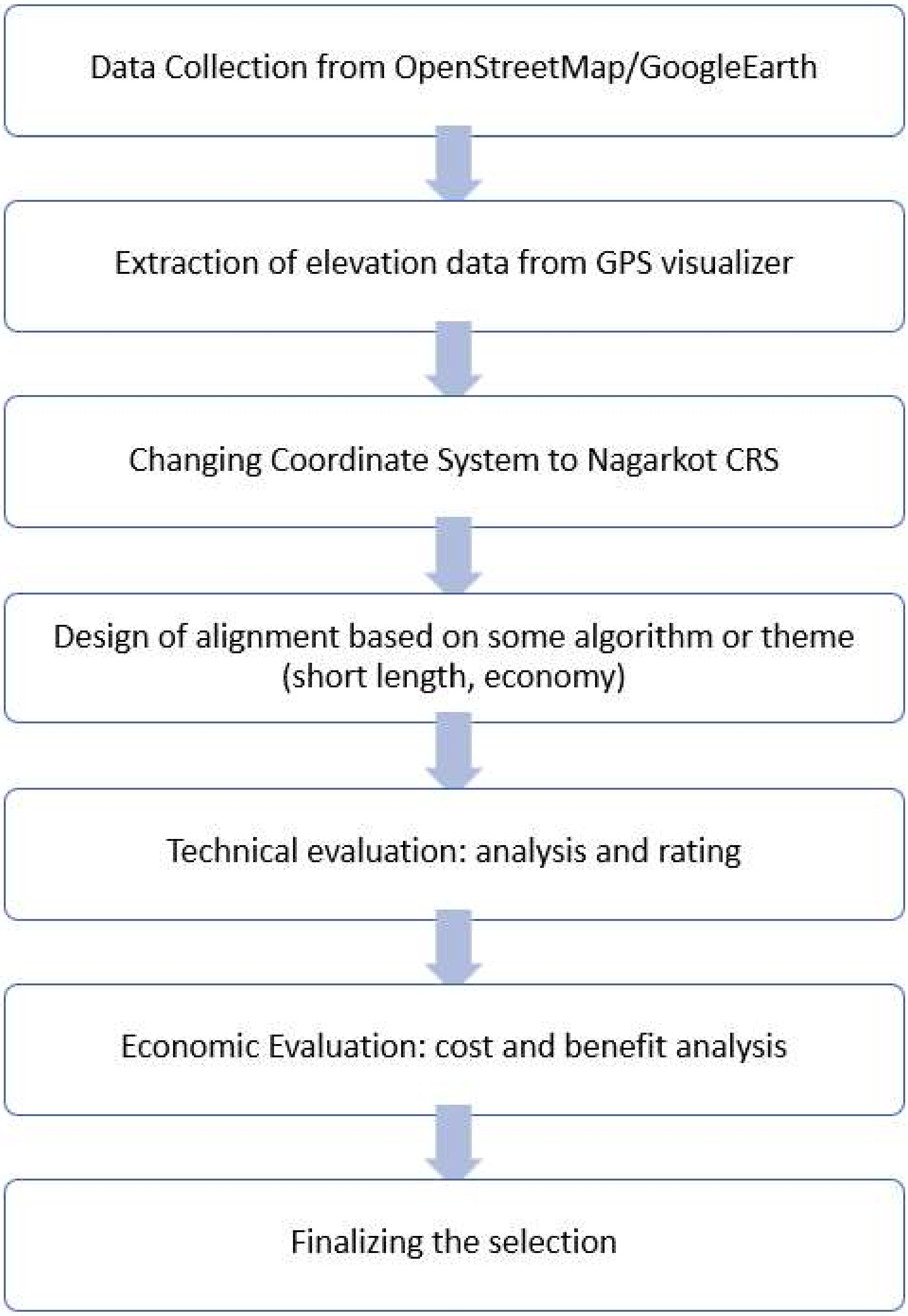


Figure 3.2: Flowchart of alignment design process

First of all, coordinates of current alignment are collected from OpenStreetMap. Then the study area is divided into several rectangular portions and coordinates at certain intervals are taken from QGIS. Elevation for all the data is generated from GPS Visualizer. Then DEM of study data is prepared. All the coordinates are projected to Nagarkot TM.

Alignments are selected based on different themes like shortest path, most economic path, modification to current alignment etc. After that finalised alignments are analysed to get length, statistics of grades and deflection angles etc with analyze.py script and rated with rate.py script based on several factors like alignment length, number of bridges and tunnels, speed, grades, travel time etc. Ranking of the alignments are done based on these factors. Rank 1 is given to the best alignment and 5 to the worst one. Finally the alignment with least ranking score is best alignment in technical evaluation.

Construction cost of the road is computed with reference to similar roads, bridges and tunnels being constructed in the vicinity of Kathmandu-Pokhara highway. Benefit is computed based on saving in fuel consumption due to decrease in highway length and saving in productive time of people due to decrease in travel time. Finally the payback period of each alignment is computed. Technical and financial aspects of the alignments are evaluated for final selection.

3.3 DATA COLLECTION

3.3.1 Sources of Data

Data used in the project are secondary in nature. Although, primary data could have been collected through topographic survey, following two challenges were faced:

1. Since the alignment considered was a national highway (straight aerial distance of 142km), the extent of the area to be surveyed was too large.
2. Due to the COVID-19 pandemic, the nation was under lockdown during most of the project duration eliminating the possibility of physical survey.

Various online archives were studied and inspected before finalising the secondary sources of data. Some considered sources were:

1. The Humanitarian Data Exchange (https://data.humdata.org)
2. ICIMOD (International Centre for Integrated Mountain Development) Regional Database system (https://rds.icimod.org)
3. Open Street Map (https://www.openstreetmap.org)
4. Google Maps Service (https://www.google.com/maps)
5. Google Earth Service (https://earth.google.com)

Among them, some sources were used to obtain archived data to be used in GIS applications. While, some other sources were used indirectly to either obtain elevation data only, or during intermediate analysis. The data used in the final presentation of this report was obtained from the open street map due to community verification and a large amount of data points.

The data required to prepare a whole topographic map of the study area consists of three main attributes, namely latitude, longitude and altitude. Apart from these, other features indicating if a topographic point lies on roads, and on which road, whether it lies on a special feature such as bridge or tunnel were obtained through analysis using GIS application. Since the data obtained from archive (osm) didn't provide altitude of datapoints (Open Elevation API provides elevation data for open street map under https://open-elevation.com, but only for few data points), elevation data was obtained from gps visualizer (https://www.gpsvisualizer.com/elevation).

Although, gps visualizer is an excellent tool for the purpose it was used for, it relies on many other sources. The sources used for the DEM (Digital Elevation Model) database (mentioned as 'Solution 1' in the website) were used for the project based on best availability.

3.3.2 Nature of Data

Data used in the project was obtained from the open street map (referred to as 'osm' hereafter) with elevation data from various sources in GPS Visualizer. The archive of data obtained from osm had the shape files for following cartographic features:

1. buildings
2. land use
3. natural features
4. man made places
5. railways and roadways
6. traffic and transport
7. water and waterways

Since the data points were available for the whole nation, they were clipped for the study area using the GIS application (discussed in 3.4.1) and then used accordingly. The shapefiles had point, line or polygon features based on the nature of data provided. The shapefile of prime concern, that of roads had line features with attributes like name, reference code, class, is bridge or not, is tunnel or not, is one way or not etc. A portion of attributes as seen in the attribute table of QGIS is shown in the picture below.

roads — Features Total: 124637, Filtered: 124637, Selected: 0

	osm_id	code	fclass	name	ref	oneway	maxspeed	layer	bridge	tunnel
1	4825621	5113	primary	NULL	F26	B	0	0	F	F
2	4825630	5113	primary	Kanti Path	NULL	F	0	0	F	F
3	4825671	5115	tertiary	Thabahi Sadak	NULL	F	0	0	F	F
4	4839933	5141	service	NULL	NULL	F	0	0	F	F
5	4839936	5132	trunk_link	NULL	NULL	F	0	0	F	F
6	4839958	5132	trunk_link	NULL	NULL	F	0	0	F	F
7	4840030	5114	secondary	Battisputali Marg	NULL	B	0	0	F	F
8	4840039	5114	secondary	Baburam Achar...	NULL	B	0	0	F	F
9	4840054	5113	primary	NULL	NULL	B	0	0	F	F
10	4840057	5114	secondary	Kamaladi Marg ...	NULL	B	0	0	F	F
11	4840060	5122	residential	Pragya Marg	NULL	B	0	0	F	F
12	4840073	5114	secondary	Tindhara Sadak	NULL	B	0	0	F	F
13	4840092	5113	primary	Jamal Way	NULL	F	0	0	F	F

Figure 3.3.2: Attributes as seen in QGIS Attribute Table of Roads Layer

3.4 DATA PROCESSING AND ANALYSIS

3.4.1 A Short Introduction to QGIS

Most of the data processing and analysis was done using the GIS application, QGIS. It is an open-source software available for a variety of popular operating systems like windows, linux and macOS. It offers various functions required in the processing and analysis of spatial data, both raster and vector. It allows one to see attributes related to all features in a vector shape file and manipulate them as required. It can be, and was, used to generate raster DEM of study area using vector data points with latitude, longitude and altitude. It was used to compute geometric length of line features enabling rough estimate of highway lengths for considered alignments. Apart from manipulating existing data, creation of features from existing data is available allowing the project team to fix new alignments in QGIS itself. Use of QGIS in this project during data processing and analysis is justified in the following headings.

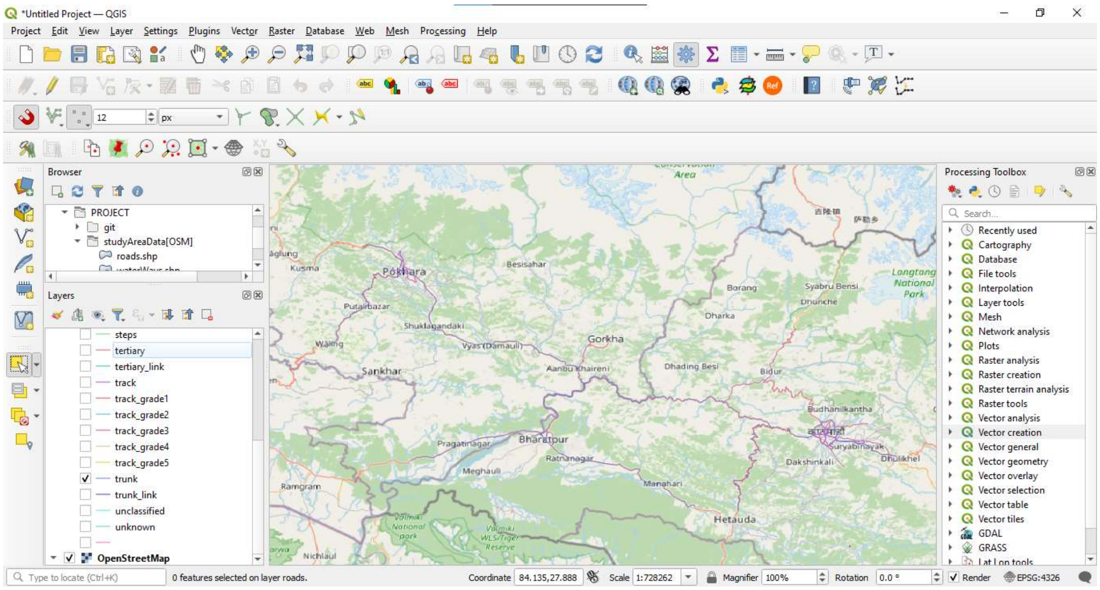


Figure 3.4.1: Roads layer with OpenStreetMap as basemap in QGIS

3.4.2 Obtaining Elevation Data

As mentioned already, data from osm didn't have an altitude attribute. So, it was required to use other sources. A reliable and free website for the very purpose, gps-visualizer was used. Although other methods are listed in its website (https://www.gpsvisualizer.com/elevation), the one named 'Solution 1' was used.

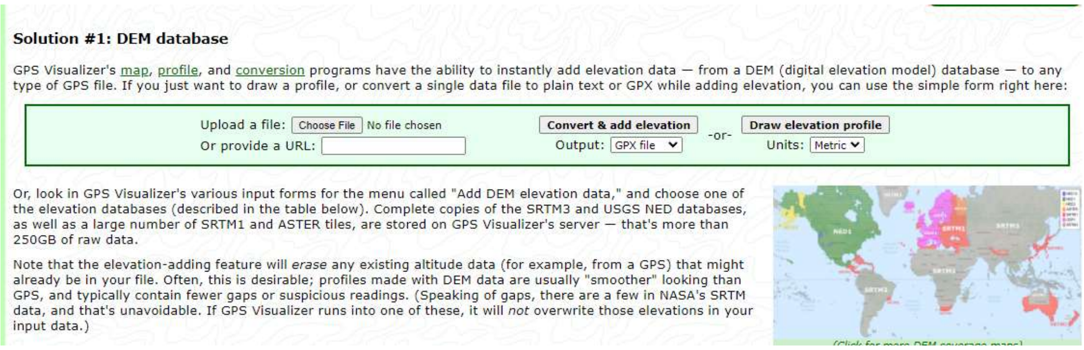


Figure 3.4.2: 'Solution 1' mentioned in gps-visualizer/elevation used to obtain elevation data

The following steps were followed to obtain elevation data:

1. Preparation of a GPX file:

   A GPX file is a special text file representing geographical coordinates in latitude and longitude (along with other attributes) that generally comes from a GPS device. Exporting the geometry of the points layer as a GPX file is available in QGIS which can easily generate GPX files required for GPS-visualizer.

```
</wpt>
<wpt lat="28.2091954" lon="83.9864029">
  <ele>848.8</ele>
</wpt>
<wpt lat="28.2088555" lon="83.9871466">
  <ele>842.6</ele>
</wpt>
<wpt lat="28.2087876" lon="83.9872951">
  <ele>842.0</ele>
</wpt>
<wpt lat="28.2086648" lon="83.9875638">
  <ele>840.2</ele>
</wpt>
<wpt lat="28.2084004" lon="83.9881421">
  <ele>839.6</ele>
```

Figure 3.4.2.1: A portion of a GPX file showing geopoints with latitude and longitude along with elevation as attribute

2. Using GPS Visualizer to add Elevation attribute:

Once a suitable GPX file (with latitude and longitude) is obtained, it can be uploaded in the user form of the website. (See figure 1.4.3) Then, with the click of a single button, a new attribute for altitude is added and updated automatically. The final file (also a GPX file) can be downloaded and used appropriately in QGIS.

3.4.3 Preparing CSV File

The necessary computations like length, grade and deflection were done through python scripts (attached in appendix). The scripts required QGIS to export a csv file in spatial order with all necessary attributes. By spatial order, it means, each row should represent a data point, and the following row should represent a data point that occurs just next to it in space when traversing the considered alignment. This process of preparing geopoints in order was tedious as data from osm was not as required. However, a generalised procedure was developed through different trials and errors:

1. Points were extracted from line features and attributes were copied based on location. This was saved as a new layer.
2. All line features resembling an alignment were dissolved into a single line feature with many points.
3. The dissolved line (that represents the whole alignment) was exploded to reveal points in spatial order.
4. For each point, attributes were copied from the original point layer.

After a new vector layer with points in spatial order was obtained, its attributes along with geometry were exported as a CSV file. It was carefully noted that the elevation obtained from gps-visualizer was present as an attribute. Similarly, geometric computation required spatial coordinates to be in a grid system rather than latitudes and longitudes. For that one of two options could be employed:

1. Using a projected coordinate system that includes study areas in a single grid.
2. Projecting latitude, longitude and altitude to a global grid using mathematical equations.

Both these options seem equally viable and precise. QGIS offered projection to Nagarkot UTM (Universal Transverse Mercator) Coordinates [ESRI: 102306] as the first option. For the second option, a earth-centred, earth-fixed (ECEF) coordinate system was used. The implementation is preserved as a python function in a script named analyse.py, attached in the appendix. However, the first option was preferably used in the project.

3.4.4 Computing Geometric Parameters

The CSV file exported from QGIS has all necessary attributes and completely describes an alignment in data. These data were used to compute following geometric parameters using python script named 'analyze.py':

1. Length: It is geometric length between two 3D points in space. The length is simply computed using the pythagorean relation:

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$$

   Obviously, length was calculated for the second point using first and second points and so on. The sum of lengths for all features gave length of alignment. Similarly, sum of lengths of points for a feature like a bridge or tunnel gave its length too.

2. Grade: It is gradient between two points represented as percent change in altitude per distance between them. In terms of notations previously used,

$$g = 100(z_2 - z_1)/d$$

   The grade for each point (except the first one) represents vertical alignment of the highway cumulatively. However, an unacceptable grade was obtained due to elevation data and latitude-longitude data obtained from different sources. To compensate for this inaccuracy, data greater than third quartile were removed before further analysis.

3. Deflection Angle: It is the angle between two consecutive line segments along an alignment. Deflection angle is important in determining geometry of

horizontal curves. It is the parameter considered to address horizontal alignment of the road. Three points are needed to determine a deflection angle. If three consecutive points are (x_1, y_1), (x_2, y_2) and (x_3, y_3) then the deflection angle at (x_2, y_2) is given by:

$$\Delta = arccos\left(\frac{(x_2-x_1)(x_3-x_2)+(y_2-y_1)(y_3-y_2)}{\sqrt{(x_2-x_1)^2+(y_2-y_1)^2}\cdot\sqrt{(x_3-x_2)^2+(y_3-y_2)^2}}\right) \times \frac{180}{\Pi}$$

These geometric parameters describe an alignment's quality and help in evaluation of alternatives. These are evaluated for each line feature of an alignment and then analysed appropriately.

3.4.5 Speed Calculation and Time of Travel

Although speed and travel time are very important parameters in determining quality of alignment, no reliable secondary data was found to perform appropriate analysis. However, based on a straight reach speed as a maximum limit and, using the following relation, speed (in kmph) was approximated for line features of an alignment.

$$V = 5.292\sqrt{T/tan(\Delta/2)}$$

Here, T is the tangent length of the curve which was taken as a minimum of two legs.

Derivation of this relation is included in the appendix section.

With this speed and length of the line feature, travel time was obtained by dividing length by speed. The travel time of an alignment was obtained by adding all the travel times. The details of this formula are discussed in the appendix.

3.4.6 Statistical Analysis of Data

Geometric parameters like length between consecutive coordinates of alignment can be simply summed to obtain the total length of an alignment. However, parameters like grade and deflection angle should be looked at in greater detail. For example, an alignment with a single grade of 10 degrees is more dangerous than that with two grades each of 5 degrees. However, non zero deflection angles that appear consecutively describe a single turn in the physical road, and thus should be summed. This remains as a limitation of the project as there is no such distinction between exactly zero and slightly zero angles. To generalise the analysis, statistical measures are analysed instead of individual data or the sum of all data. Statistical measures of bridges and tunnels' lengths are also analysed.

Statistical measures include sum, average, sum of squares, standard deviation, variance, the five number summary and frequency distribution. These measures are all rated using the same method and score is provided accordingly. The details of statistical analysis and scoring can be found in 'rate.py' script attached in the appendix. The final output of the whole process consists of a JSON (Javascript Object Notation) file namely, 'score.json'. Evaluation of alternatives is done on the basis of this file. The details of evaluation can be found in section 4.3.

3.4.7 Modified Dijkstra's Algorithm for Raster Data Model

Modified Dijkstra's Algorithm is a cost analysis function to return the least cost path between source and destination where cost between two cells is calculated based on the distance between them and the slope of the distance.

$Cost = Horizontal\,Distance \times (1 + \alpha \times Slope)$ where α is the constant that amplifies the importance of slope in the cost value.

3.4.8 Evaluation of Alignment Alternatives

For all 5 alignments considered, geometric and other parameters as mentioned in section 3.4.6 are evaluated using python script 'analyse.py'. The speed in straight reach is termed 'base speed', which is based on the sum of deflection angles and grades. They are:

I. Alignment 1: 50 kmph
II. Alignment 2: 60 kmph
III. Alignment 3: 80 kmph
IV. Alignment 4: 60 kmph
V. Alignment 5: 80 kmph

As per NRS 2070, for expressway (Class I) roads, the design speed in mountainous terrain is 80kmph.

Since Alignment 2 and Alignment 4 have comparatively higher sum of deflection angles which hinders smooth flow of traffic, thus lower speed (60kmph) is adopted. Furthermore, due to non-uniform road width and quality of Alignment 1, even lower speed (50kmph) is adopted.

Then, the analysed CSV file is taken as input for another script 'rate.py' which would then compute statistical parameters as required. The results can be seen in table 4.3.1. Values of interest were ranked in ascending order from 1 to 5. This rank is considered as a score for each alignment. Then, the overall score is evaluated by adding all scores and the alignment to score least was selected as best alignment.

3.4.9 Economic Evaluation of Alternative Alignments

With reference to similar roads, bridges, and tunnels constructed around the study area, construction cost of road per kilometre is determined. Benefit is determined in financial terms on the basis of reduction in fuel consumption due to reduction in highway length, and productive time saving of people due to reduction in travel time. Finally the payback period of each alignment is computed.

Benefit

Benefit	Reference
Travel time reduction 1. Per capita income = 1191$ per year 2. Daily passenger volume = 104088 Total Benefit per year per hour time reduction (NRS) $= 104088 \times 365 \times 1 \times 4090/(365 \times 8) \times 120$ $= 1859532120$ **= 1.86B NRS per year per hour reduction**	 mof.gov.np Appendix I
Fuel consumption reduction **= 0.144B NRS per year per km length reduction**	Appendix I

Total Benefit in One Year = 1.86T + 0.144L [T and L are reduction in time and length resp.]

Table 3.4.9a: Benefit analysis

Cost

Cost (NRs per km)	**Reference**
Tunnel : 8B	Nagdhunga Tunnel (22B/2.71km) Tunnellingonline.com (6 to 12B/km in South Asia)
Bridge : 1.4B	Chiplegadh Kholda Bridge (185M/130m)
Pavement : 0.09B	Muglin-Narayangarh Road (3B/33.275km road)
Total Cost = 8TN + 1.4B + 0.09P [TN: Tunnel Length, B: Bridge Length, P: Pavement Length]	

Table 3.4.9b: Cost analysis

CHAPTER 4: ENGINEERING ASPECTS OF THE PROJECT

4.1 STUDY OF THE EXISTING ALIGNMENT

4.1.1 Introduction

The existing alignment, referred to as "Alignment 1" hereafter, is 195km long from Prithvi Chowk, Pokhara to Kalanki Chowk, Kathmandu. This length is computed with coordinates from OSM data. The length is shorter than the actual length of the highway as the points along the highway are assumed to be connected with straight lines. According to OSM data, it consists of 40 bridges with a total length of 2.2km. There are no tunnels in this alignment. Currently the construction of Nagdhunga tunnel has been started connecting Sisnekhola of Dhading district and Nagdhunga in Kathmandu.

4.1.2 History

The construction of the highway started in 1967 with the help of the Chinese government. The construction was completed in 1974. The highway is named after King Prithvi Narayan Shah.

4.1.3 Route

The highway passes through five districts: Kathmandu, Dhading, Chitwan, Tanahu and Kaski. This highway has a junction with Tribhuvan Highway at Naubise. The Bharatpur-Mugling section connects this highway to Mahendra Highway, the longest highway in Nepal. The highway also connects Nuwakot District via a newly constructed road in Galchhi and connects to the district headquarter of Dhading District at Phurke Khola, Malekhu. Until 2011 opening of the BP Highway, this highway was the only improved land route from Kathmandu Valley to all points south, and as such the main artery for heavy trucks into Kathmandu Valley and into Pokhara.

4.1.4 Road conditions

The highway is a two-lane single carriageway road with at-grade intersections. There are no major intersections and no traffic lights. No passing lanes are being provided.

Speed limits aren't applied on most of the section, except some warning signs near urban and town areas and a few sharp bends. There are many areas to be treated for high grades, sharp bends and visibility for all road users. Steep and windy sections don't have passing lanes (though some are being implemented in the Naubise - Nagdhunga section).

There are many sections along the highway with roughness and undulation which make the highway unsafe to drive. Road sections near Malekhu and Galchhi need extensive care because of the failure even after maintenance. Rutting, shoving have been the main problems in those areas. Vehicle axle load limit isn't in serious account. Sand trucks are one of the problems in the Gajuri to Nagdhunga section. Sand quarries along and near the highway aren't run in good condition and are hindering the smooth flow of the vehicles.

The local intersections constructed by local residents are one of the new issues to be addressed before they become vital for road safety. No planning on construction of such intersections can be seen.

As the population residing on both sides of the highway are increasing, care should be taken for the safety along the highway. Proper signage and other roadside furniture are to be installed.

4.2 ALTERNATIVES TO THE EXISTING ALIGNMENT

4.2.1 Shortest Path using Dijkstra's algorithm (Alignment 2)

Objective Features of Alignment 2

- Short and Economic
- Least Resisting Length
- Road with gradient below 5%

Working Principles

- Use of shortest path algorithm, Dijkstra's algorithm over DEM raster
- Modification of length parameter to include resisting length

Algorithm Description

A. Data Extraction from QGIS

QGIS provides python IDLE with inbuilt python classes of QGIS commands. This IDLE is used to access layer information and data loaded on the QGIS interface.

```
layer=QgsProject.instance().mapLayersByName('dem_tm')[0]
```

The DEM raster layer named '*dem_tm*' is referenced to the variable *layer*.

```
band = 1

xres = layer.rasterUnitsPerPixelX()

yres = layer.rasterUnitsPerPixelY()

provider = layer.dataProvider()

extent = provider.extent()

raster_band_data=provider.block(band,extent,layer.width(),la
yer.height())
```

Extraction of raster data from layer '*dem_tm*' referred to as layer.

B. Creation of network of neighbour raster cells with slope between the cells in the range of -10% to 10%

```
Network(Cell,Neighbor,Distance) = []
Limiting_Grade = 10%
Slope_Scaling_Factor = 20
For cell in raster:
    For neighbor in neighbors of cell:
        horizontal_distance=sqrt((neighbor_x-cell_x)^2 +
(neighbor_y-cell_y)^2)
        elevation_difference=neighbor_z-cell_z
        slope=elevation_difference/horiontal_distance
        If abs(slope) < Limiting_Grade:
            distance = horizontal_distance * (1 +
            Slope_Scaling_Factor * slope)
            Network.append((cell as Cell,neighbor as
            Neighbor, distance as Distance))
```

C. Running Dijkstra's Algorithm on the Network

```
Shortest_Path_Network(Cell,Nearest_Neighbor)=[]
start_point = (200,250) #Raster Coordinates of Pokhara
end_point = (900,565) #Raster Coordinates of Kathmandu
Search_List(Cell)=[]
Search_List.append(start_point as Cell)
next_point=start_point
While next_point is not end_point:
```

```
Possible_Next_Points(Cell,Nearest_Neighbor,Distance)=[]
```

```
For points in Search_List:

    distances=Network.Distances(point as Cell)

    If size(distances) is 0:

        Search_List.remove(point as Cell)
```

```
    nearest_neighbor=Network.neighbor(point as Cell,
    min(distances) as Distance)

    Possible_Next_Points.append(point as Cell,
    nearest_neighbor as Neighbor,min(distances) as
    distance)
```

```
distances=Possible_Next_Points.Distances()

cell=Possible_Next_Points.Cell(min(distances))

next_point=Possible_Next_Points.Nearest_Neighbor(min(d
istances))

Search_List.append(next_point)

Shortest_Path_Network.append(cell as Cell,next_point
as Nearest_Neighbor)

Network.remove(cell as Cell,next_point as Neighbor,
min(distances) as Distance)
```

D. Extracting Shortest Path between Start and End Point

```
start_point = (200,250) #Raster Coordinates of Pokhara

end_point = (900,565) #Raster Coordinates of Kathmandu

next_point=end_point

Collect_Path_Points(Cell)=[]
```

```
Collect_Path_Points(Cell).append(end_point as Cell)

While next_point is not start_point:

        next_point=Shortest_Path_Network.Cell(next_point as
        Nearest_Neighbor)

        Collect_Path_Points.append(next_point as Cell)
```

E. Load Path to QGIS instance

```
polyline =
QgsGeometry.fromPolyline(Collect_Path_Points.Cells())

feature = QgsFeature()

feature.setGeometry(polyline)

feature.setId(fid)

fields=QgsFields()

fields.append(QgsField('id',QVariant.Int))

loc=r'C:\Users\Admin\Desktop\Project\alignment_2.shp'

writer=QgsVectorFileWriter(loc,'UTF-8',fields,QgsWkbTypes.Li
neString,QgsCoordinateReferenceSystem('ESRI:102306'),'ESRI
Shapefile')

writer.addFeature(geo)

iface.addVectorLayer(loc,'','ogr')
```

Creation of Digital Elevation Model

13,48,704 points with angular resolution of 0.001 degrees covering an extent of region 83.7170E to 85.7170E and 27.6089N to 28.2818N are generated. Elevation of the points are added from the website https://gpsvisualizer.com/elevation. TIN interpolation is performed on the points using QGIS to develop a raster of width 2097 pixels by 801 pixels i.e. horizontal resolution of 94 metres.

```
res=0.001
```

```
extent=np.array([83.7170,85.7245,27.6089,28.2818])
```

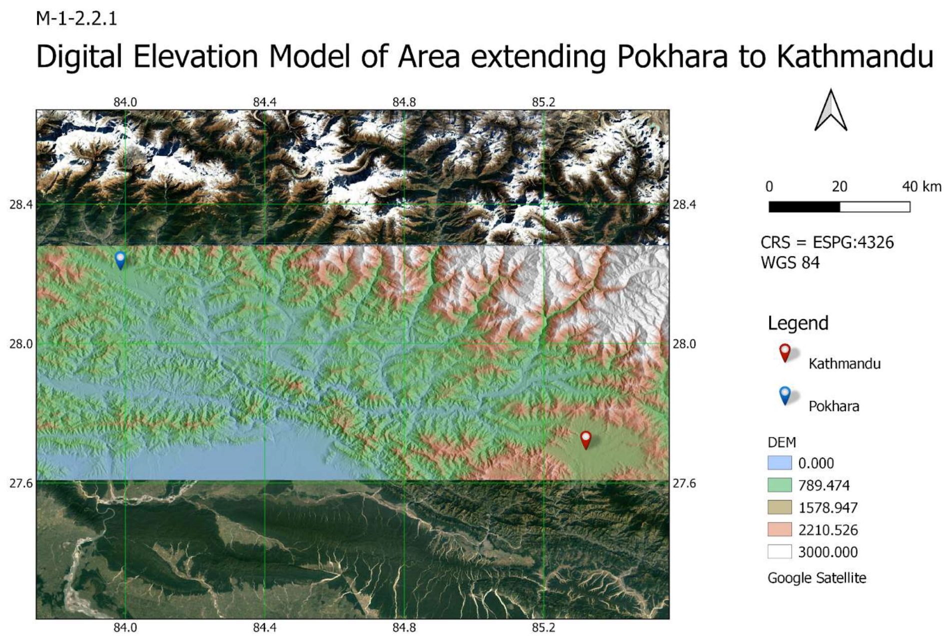


Figure 4.2.1a: Digital Elevation Model of Area extending Pokhara to Kathmandu

Executing the Dijstra's Algorithm

The cost factor while moving between the cells is computed as per the formula mentioned in [3.4.7]

$$Cost \ = Horizontal\,Distance \times (1 + \alpha \times \ Slope)$$

Two trials are performed on the same DEM altering the value of α and the cutoff grade. The cutoff grades used in the trials are greater than the ruling gradient due to formation of large sinks caused by low resolution of DEM. If two neighbour cells in raster have a grade greater than the cutoff grade, the path between them is simply avoided. The avoidance of excessive grades greater than ruling gradient is favoured by the higher value of α >> 1. If still such excessive grades are present, the alignment is refined by manual contouring over that region.

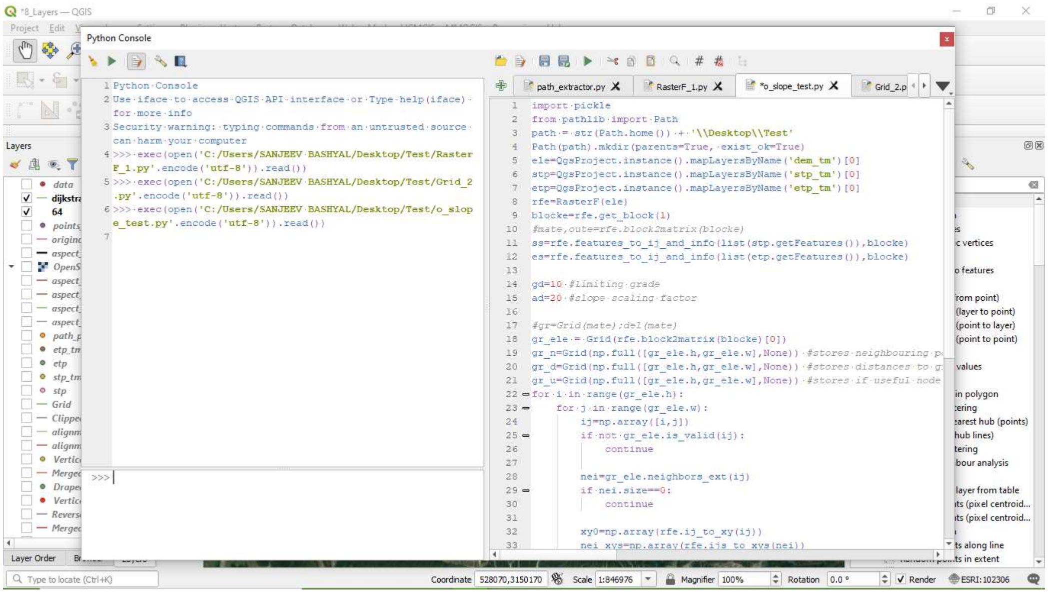


Figure 4.2.1b: Execution of Dijkstra Algorithm

Trial 1

In this trial, the cut off grade is kept 15% and the value for α is kept 25 in the equation: $Cost = Horizontal\ Distance \times (1 + \alpha \times Slope)$ while generating the network of raster cells.

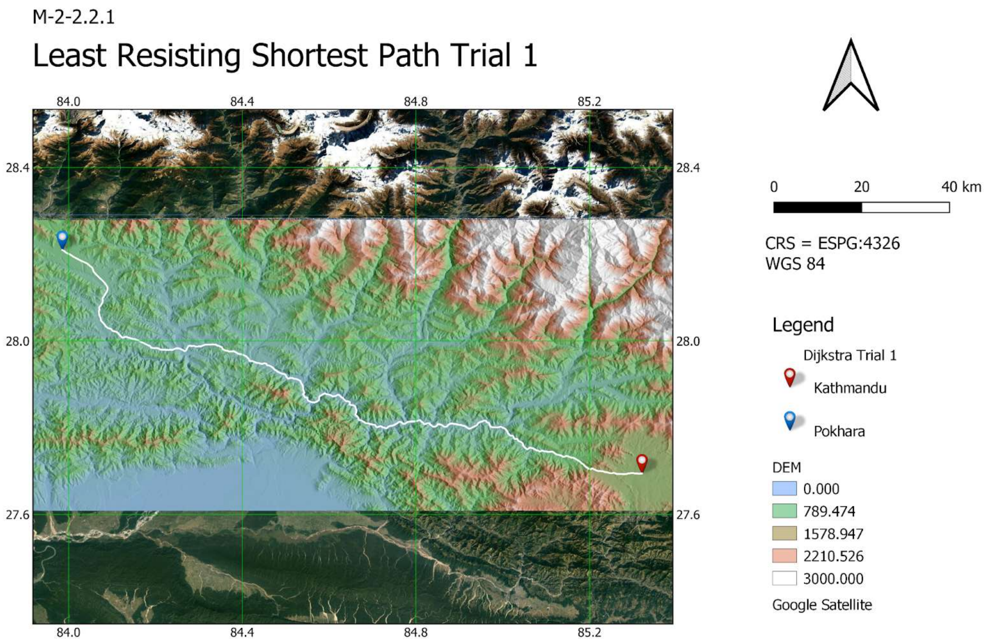


Figure 4.2.1c: Least Resisting Shortest Path Trial 1

Trial 2

In this trial, the cutoff grade is kept 10% and the value for α is kept 50 while generating the network of raster cells. This trial is performed to get milder slope alignment than the previous trial.

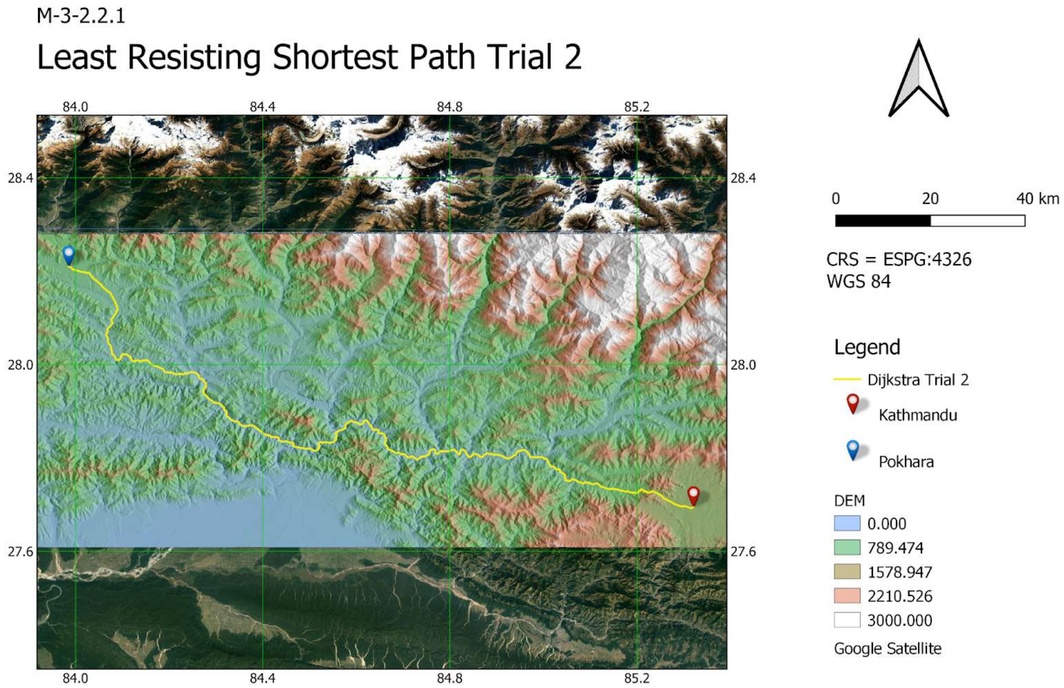


Figure 4.2.1d: Least Resisting Shortest Path Trial 2

Comparison with Current Alignment (195.535 km)		
Alignment Trial	Coincident Length (km)	Coincidence with Current Alignment (%)
1	181	92.57
2	132	67.51

Table 4.2.1 Comparison with Current Alignment

Trial 1 alignment differs with current alignment at Nagdhunga uphill section. Trial 1 is also steep at Nagdhunga uphill section. So, the latter portion is taken from the trial 2 which follows through south of Badritar and Maheshphat.

The final alignment is as follows:

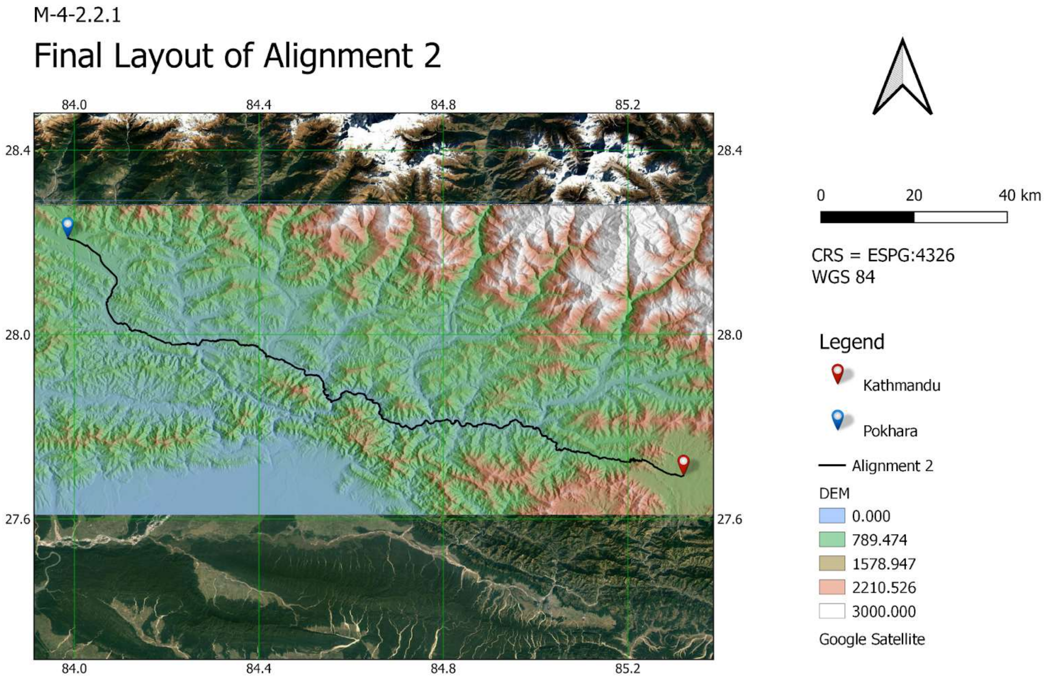


Figure 4.2.1e: Final layout of Alignment 2

The alignment features are studied under evaluation table 4.3.

4.2.2 Modification to current alignment (Alignment 3)

Objective Features of Alignment 3

- Short and Fast
- Least Resisting Length
- Road with gradient below 5%
- Comfort and safety
- Economic in long run

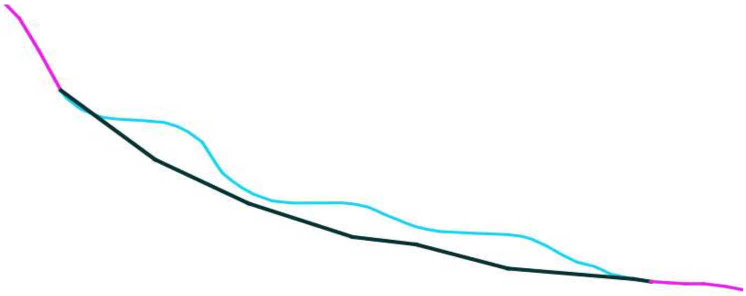
Methodology

After analysing alignment 2, we found out that current alignment is almost similar to the Alignment 2 except in the Naubise - Thankot area. So Alignment 3 is aligned, improving the shortcomings of the current alignment.

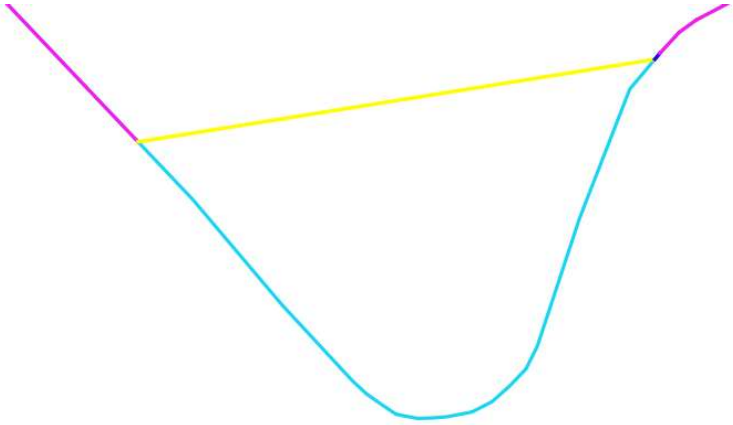
Alignment 3 is prepared in Google Earth changing the features in current alignment. Features in current alignment are analysed with visual examination, and modifications are first drawn in Google Earth wherever necessary and possible in order to make the alignment more shorter and straighter. Then these modifications are exported to QGIS. These modifications are merged with current alignment. Finally this alignment is smoothened in QGIS to get final Alignment 3. Cost components of these modifications are considered as a whole in the economic evaluation section.

Following modifications are done in the current alignment to design Alignment 3.

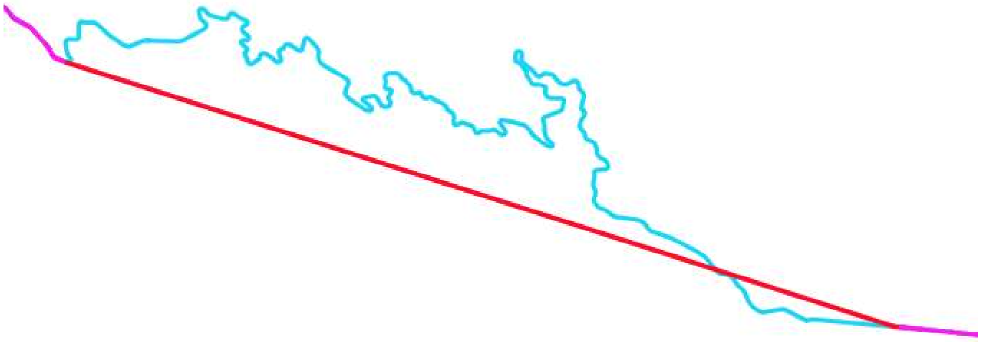
- Consecutive turns in short reach are made shorter and smoother in the alignment with Cut/Fill.



- Long turns around the hills are shortened with addition of new Bridges



- The part of alignment where highway passes around the large hill is directly connected with Tunnels



TUNNELS

Two tunnels are added in Alignment 3. One in Naubise - Nagdhunga area and another in Mugling area.

Naubise - Nagdhunga Tunnel (0+165.3km)

The 17.2km stretch of the highway with quick and complicated turns in Thankot hills is replaced with an 8.6km long tunnel. The beginning point of the tunnel is at an elevation of 935m and the end point is at 1395m. The grade of the tunnel is 5.35%. Current alignment consists of numerous turns with higher grade values which is the main reason for Traffic jams in the Thankot area. Current alignment in this tunnel area, passes from the elevation of 935m to 1500m and again comes back to 1395m but the tunnel passes through elevation of 935m to 1395m. So with the introduction of this tunnel, the length of the road is decreased as well as vehicles have to travel through lesser grade differences.

Figure 4.2.2a: Naubise-Nagdhunga Tunnel

Comparison with under construction Nagdhunga Tunnel

Nagdhunga tunnel is a highway tunnel connecting Sisnekhola of Dhading district and Nagdhunga in Kathmandu. The tunnel will be a part of Tribhuvan Highway.The tunnel has a height of 18m and has a width of 9.5m. The length of the tunnel is 2380 m. The cost estimate of the project is about NPR 22 billion.

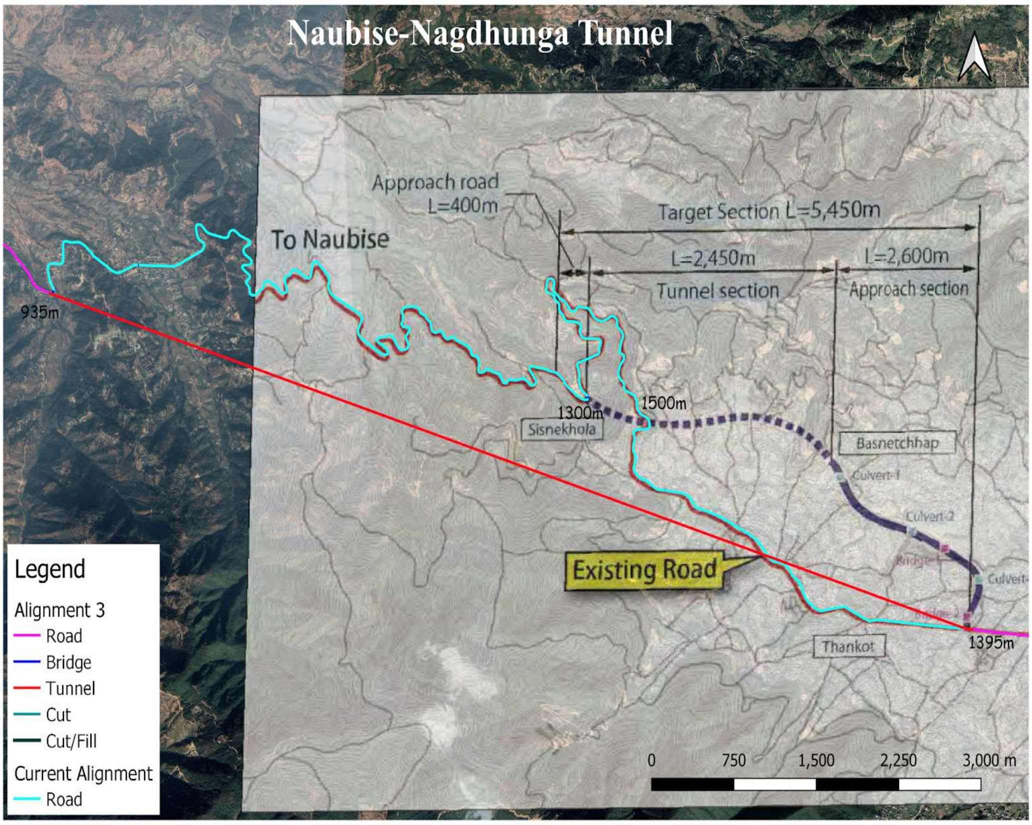


Figure 4.2.2b : Overlay of Nagdhunga Tunnel image over Alignment 3

	Nagdhunga Tunnel	Naubise-Nagdhunga Tunnel
Length	2450m	8600m
Grade	3.5%	5.35%
Problems	Does not solve grade and congestion issues completely	Expensive

Table 4.2.2a: Comparison of Existing and Proposed Tunnels

The Mugling Tunnel (0+82.2km)

The consecutive twists and turns in the Mugling area made the journey in this area quite lengthy and slow. The 12km long road in current alignment is replaced by a 5.6km tunnel.

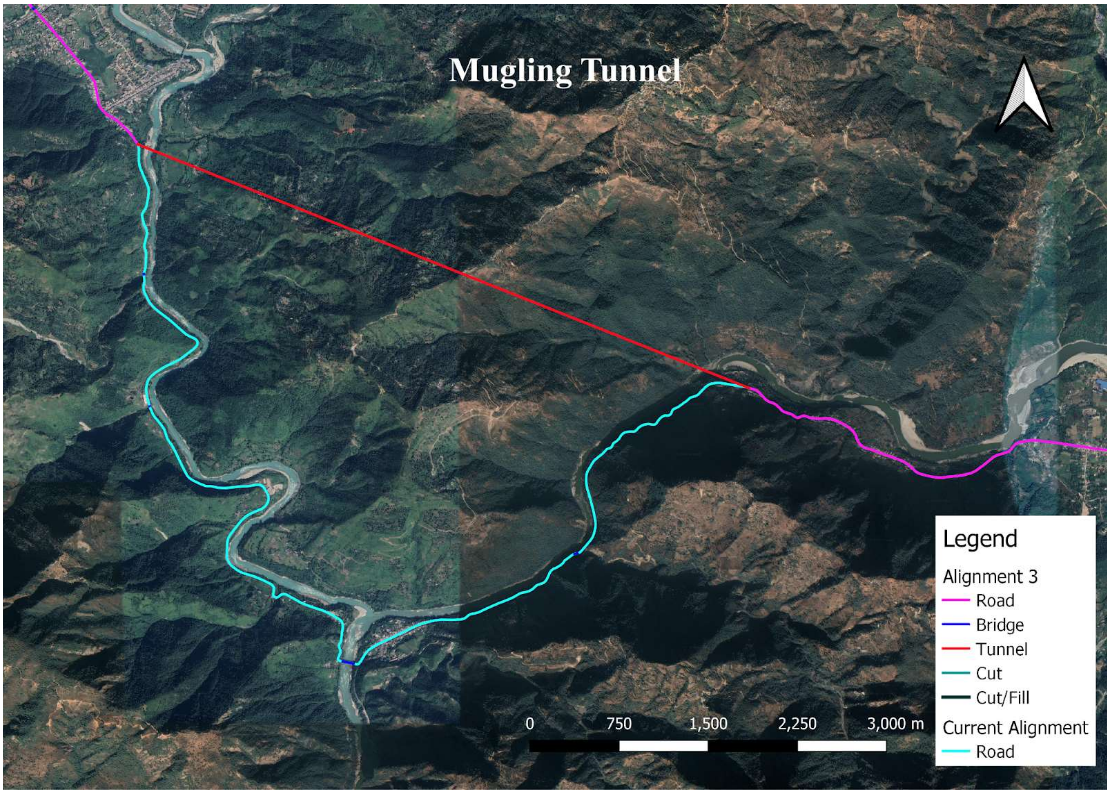
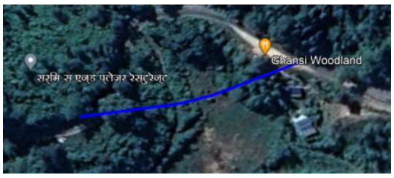


Figure 4.2.2c : Mugling Tunnel

Bridges

Chainage (km) (from Pokhara)	Bridges	Curved Length	Bridge Length
29.1		110	80
52.8		190	110
70.4		390	160
113.5		340	105
120.1		300	102
126		390	85

138.5		140	90

Table 4.2.2b: Bridges in Alignment 3

CUT/FILL

Chainage (km) (from Pokhara)	**Cut/Fill**	**Current length**	**Cut/Fill length**	**Max cut height**
18.2		240	190	10
53.2		600	380	20
57.4		300	270	10
92.6		800	720	15

94.6		150	100	10
111.2		570	490	15

Table 4.2.2c: Cut/Fill in Alignment 3

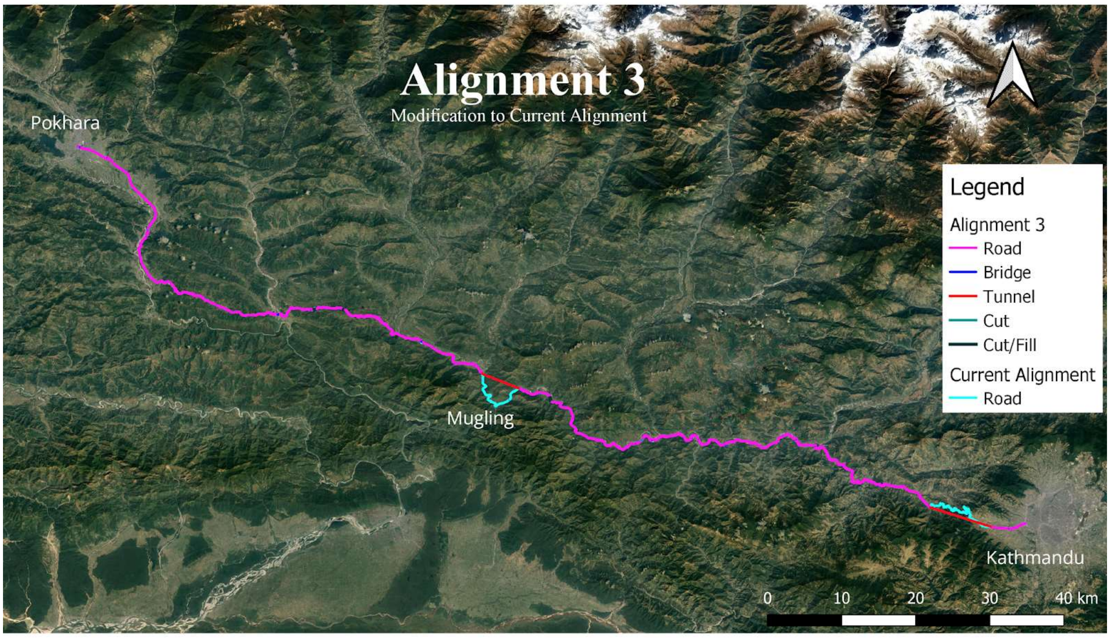


Figure 4.2.2d : Alignment 3

4.2.3 Mid Way Alignment (Alignment 4)

Objective Features of Alignment 4

- Along the straight line joining Pokhara and Kathmandu
- Economic
- No Tunnels in the road
- Road with gradient below 5%

Working Principles

- Working from whole to the part

Phase 1: Preliminary Selection

The entire area of study is taken into consideration. An alignment from end points Pokhara to Kathmandu is selected with 32 Intersection Points. The selection is carried out by visual inspection of the topography of the study area in the software Google Earth.

Points of consideration in the visual inspection are

1. Hills and Steep land morphology are avoided in the line of alignment.
2. Preferred direction is kept as that of shortest path between Kathmandu and Pokhara

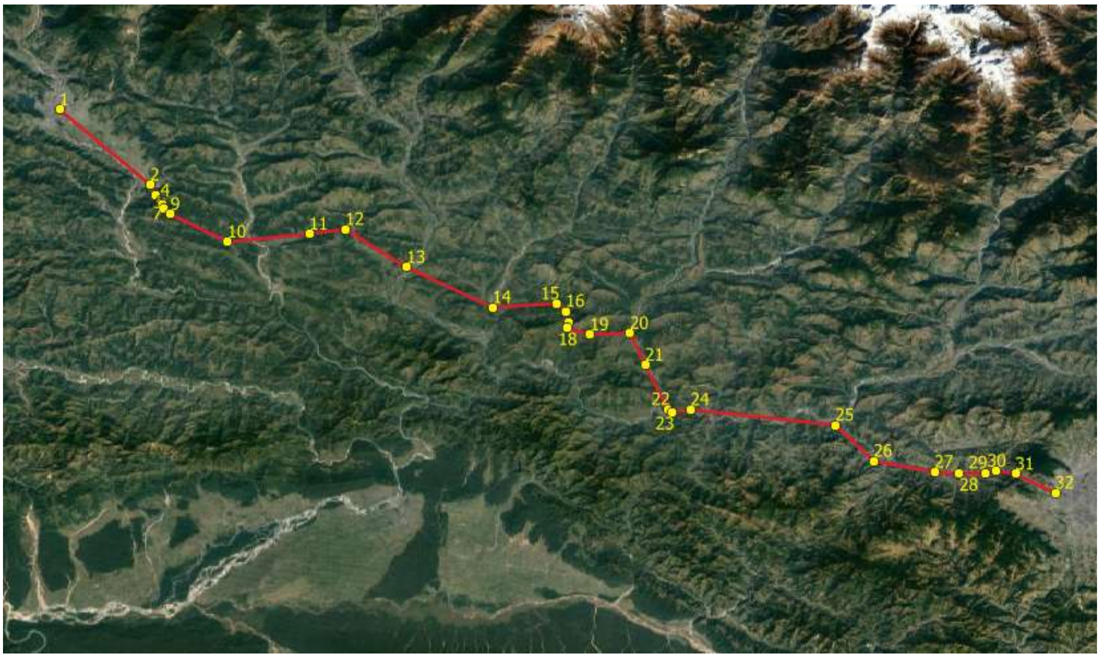


Figure 4.2.3a: Marking of preliminary stations by visual inspection in Google Earth

The selected alignment with 32 IPs is brought to QGIS, first by exporting Google Earth path as kml file and then by importing the kml file as a QGIS vector layer.

Phase 2: Refining Selection

Each of the above 31 tangent line segments have to be developed into a more detailed tangent alignment. This is done by developing a study area for each of the line segments in groups.

The following procedure is followed to refine a portion of alignment over a study area:-

1. Selection of Study Zone

   The extent of the study zone is marked using two diagonal points of a rectangle.

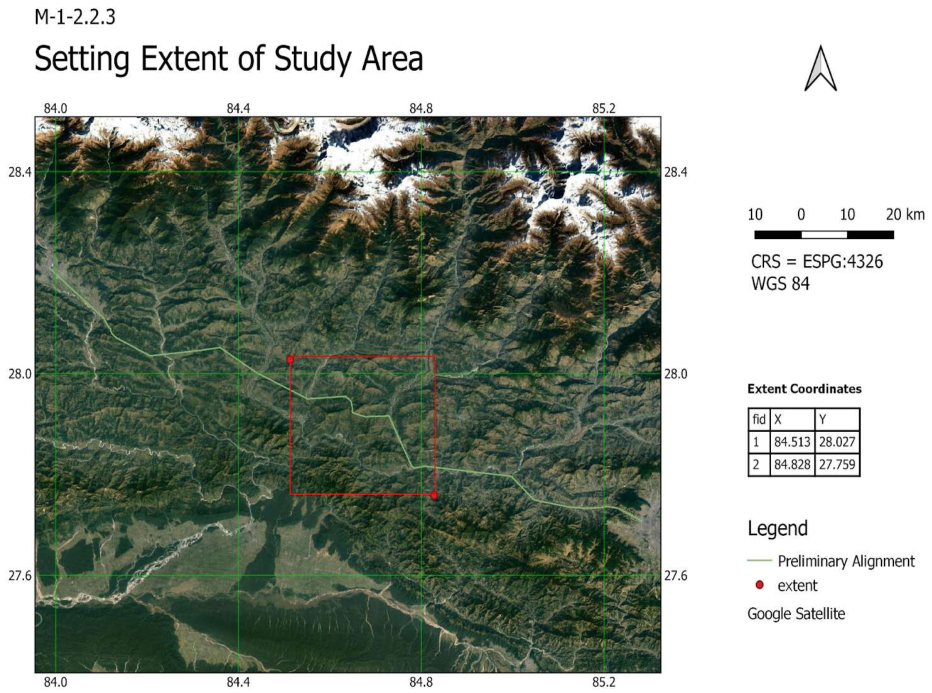


Figure 4.2.3b: Setting Extent of Study Area

2. Selection of sample points of the study area

   Using the extent of study area, a rectangular array of points is created in a kml file format by using a python script *kml_generator.py* [A.6]. These points will be data source points for DEM once after the elevation of ground at that points are added.

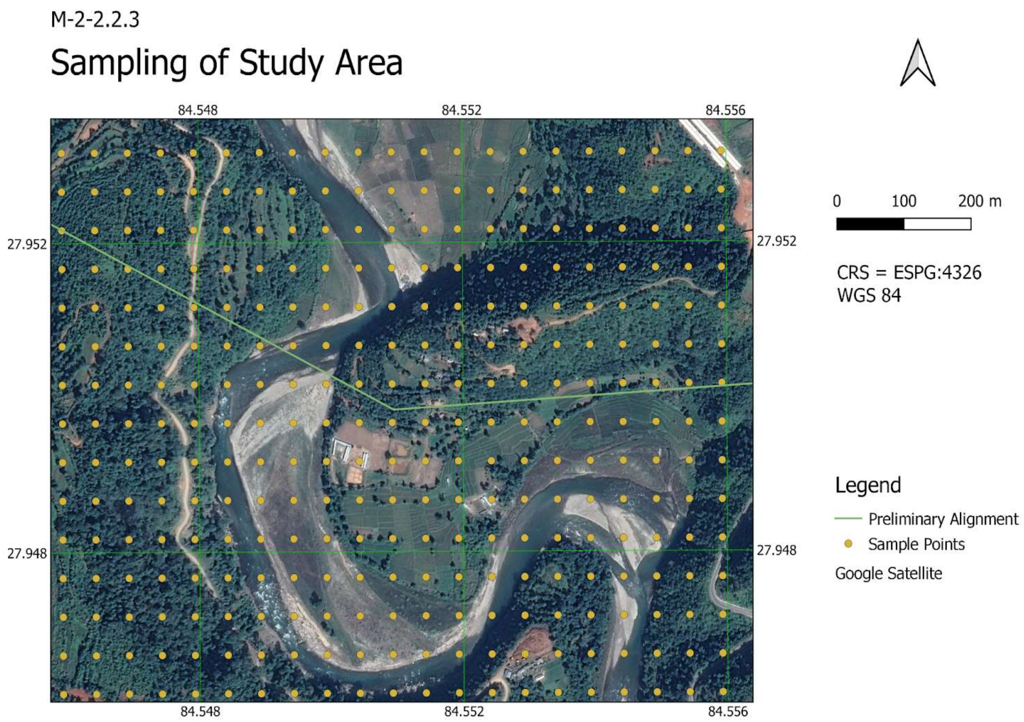


Figure 4.2.3c: Sampling of Study Area

3. Extraction of elevation from GPS Visualizer

   The kml file containing sampling points is fed to the website https://gpsvisualizer.com/elevation as an input which adds elevation of ground level at the given points and returns a gpx file. The file contains (x, y, z) coordinates of the sample points.

4. Creation of DEM (Digital Elevation Model) of study area

   The gpx file is loaded into QGIS software. Digital Elevation Model of the study area is prepared by interpolation of the data source points present in gpx file. For interpolation, Triangulated Irregular Network of the points is used.

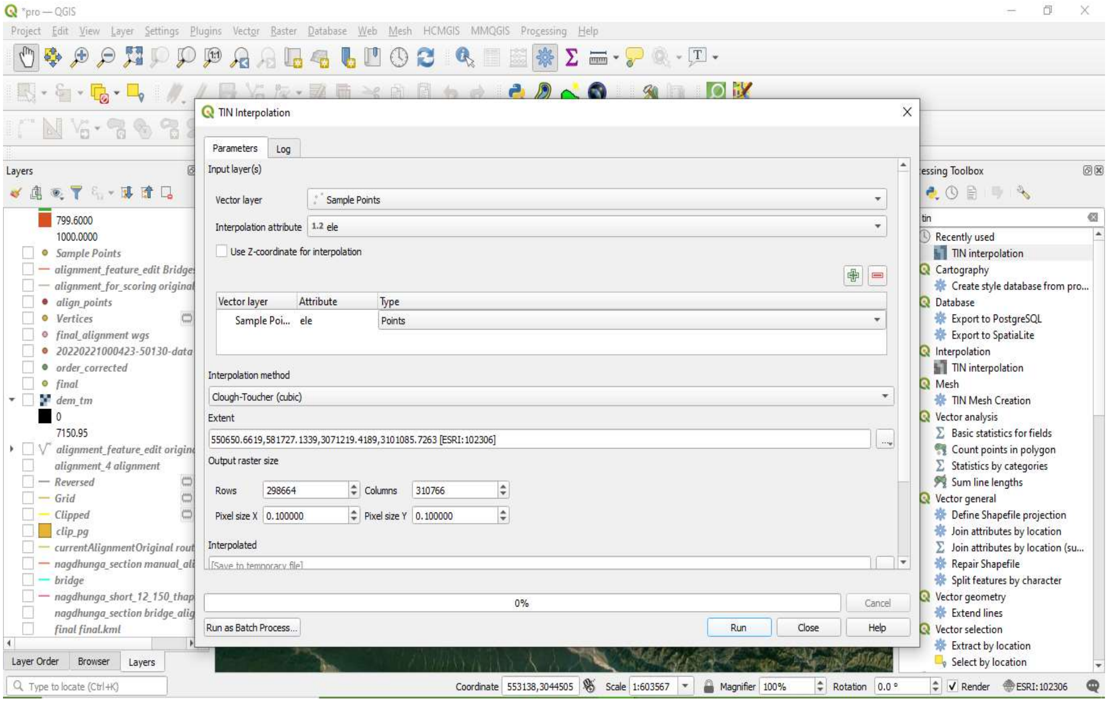


Figure 4.2.3d: Creation of DEM in QGIS

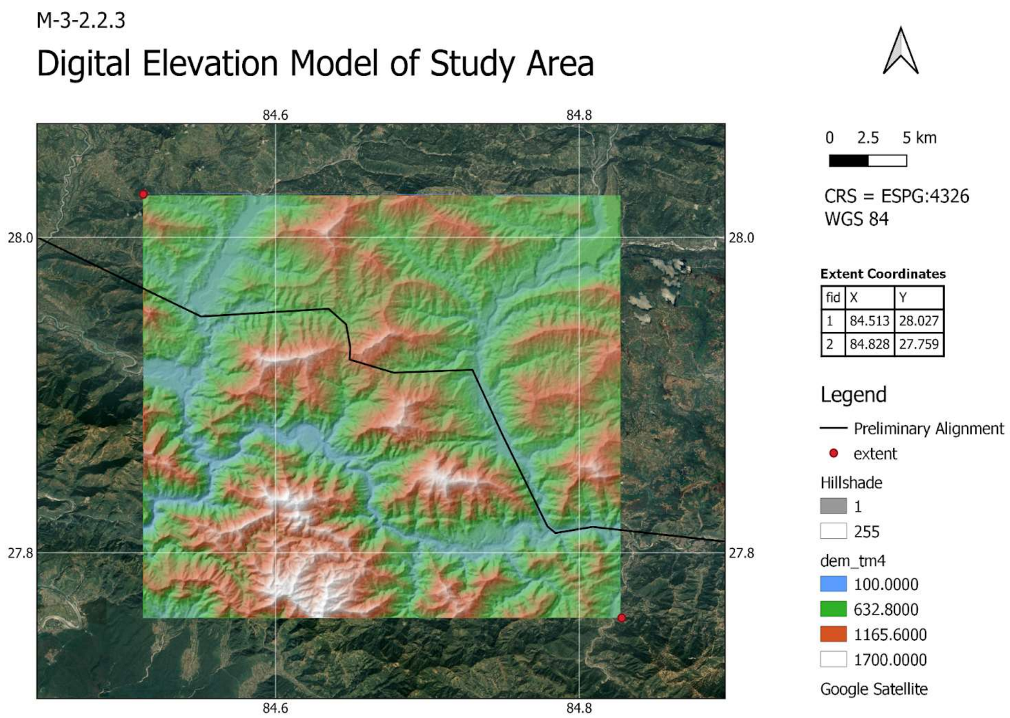


Figure 4.2.3e: DEM of Study Area

5. Contouring of study area at various contour intervals

   Contours at intervals 10m, 20m, 50m, 100m are extracted from the DEM above.

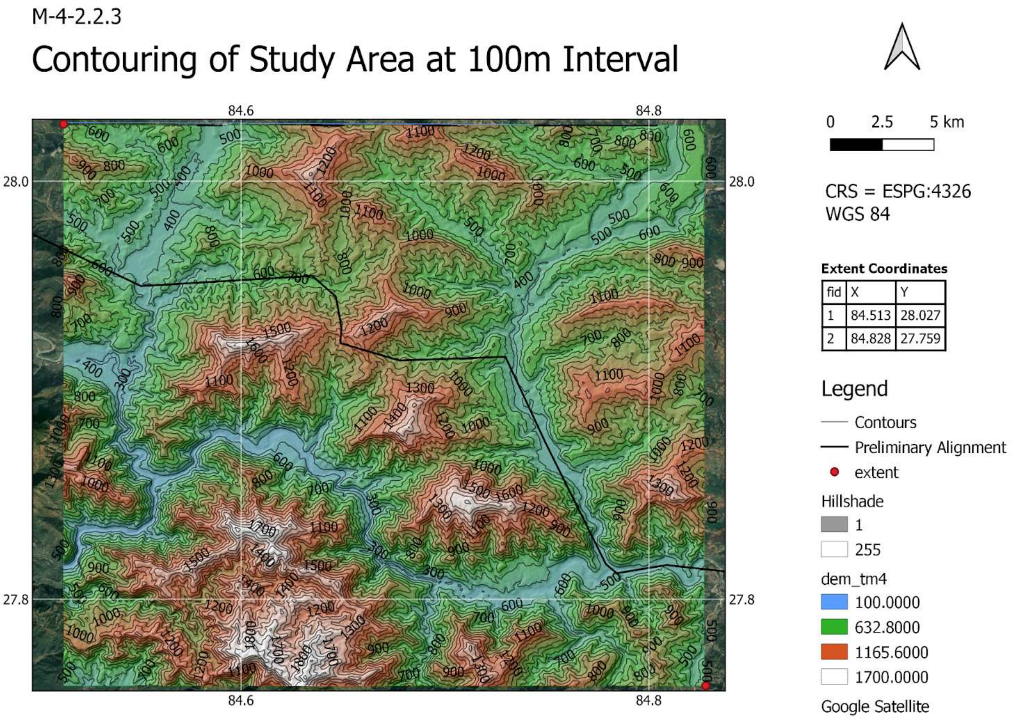


Figure 4.2.3f: Contouring of Study Area at 100m Interval

6. Grid overlay and selection of alignment within permissible grade (i.e. 5%)

   A rectangular grid is overlaid over the contour and DEM layer. This helps the designer to obtain information regarding horizontal distance and slope of the sketch while plotting the alignment.

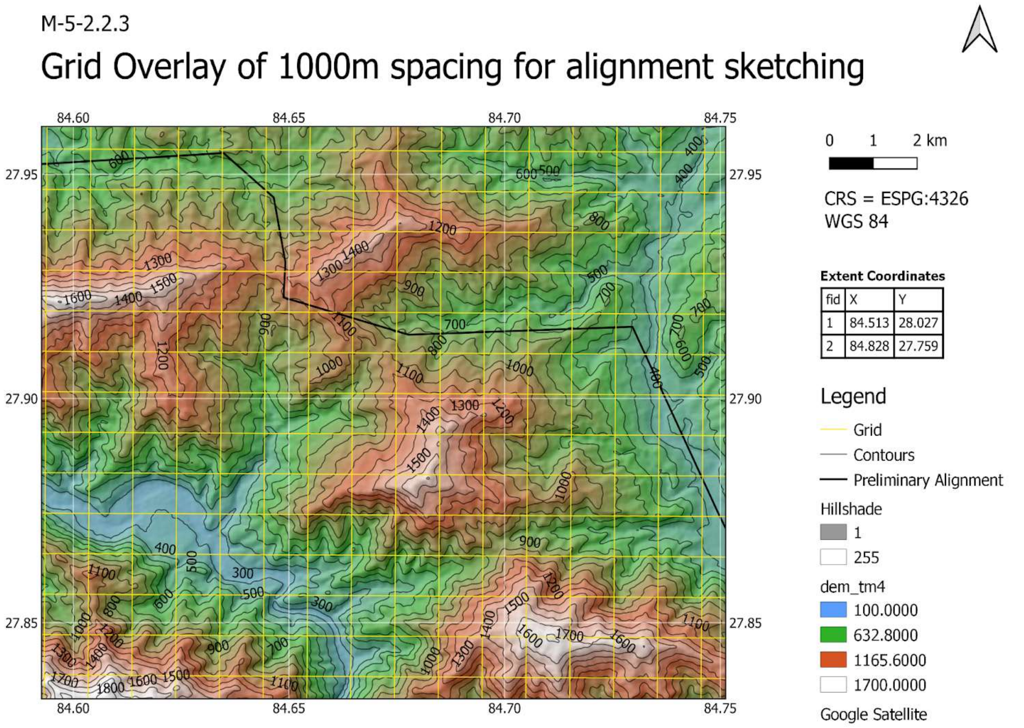


Figure 4.2.3g: Grid Overlay of 1000m spacing for alignment sketching

Sketching of alignment is done with the help of contours and rectangular grid.

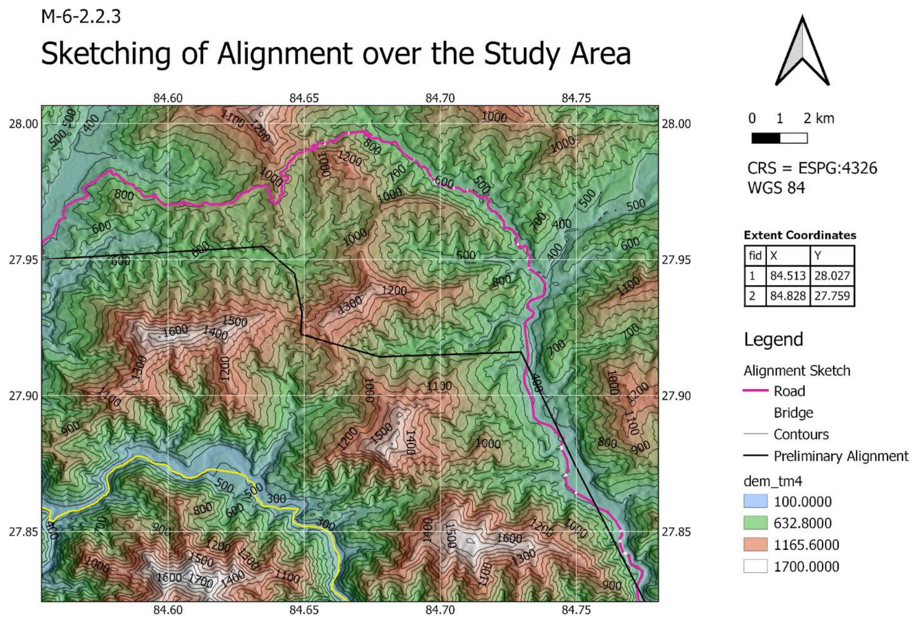


Figure 4.2.3h: Sketching of Alignment over the Study Area

7. Working from whole to the part

Once sketching is done over the study area, the alignment is sketched at a higher resolution by decreasing contour interval and rectangular grid spacing.

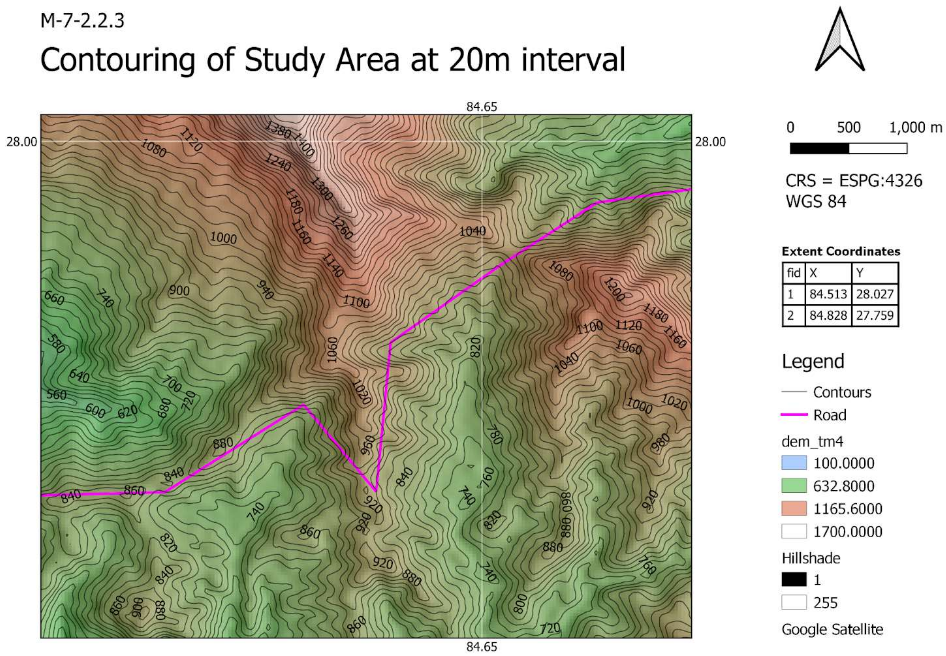


Figure 4.2.3i: Contouring of Study Area at 20 m Interval

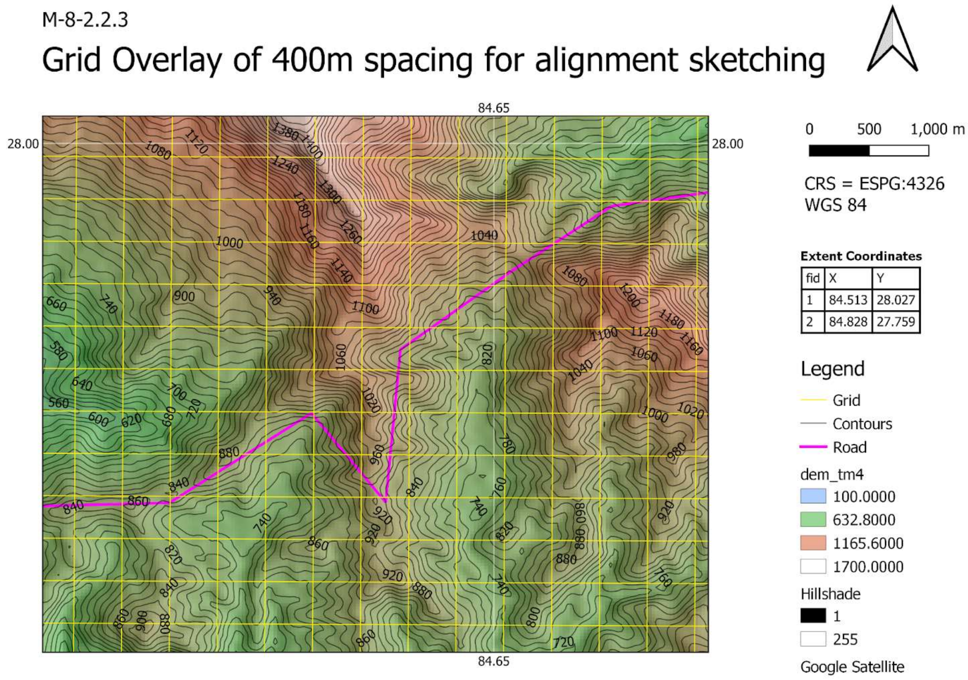


Figure 4.2.3j: Grid Overlay of 400m spacing for alignment sketching

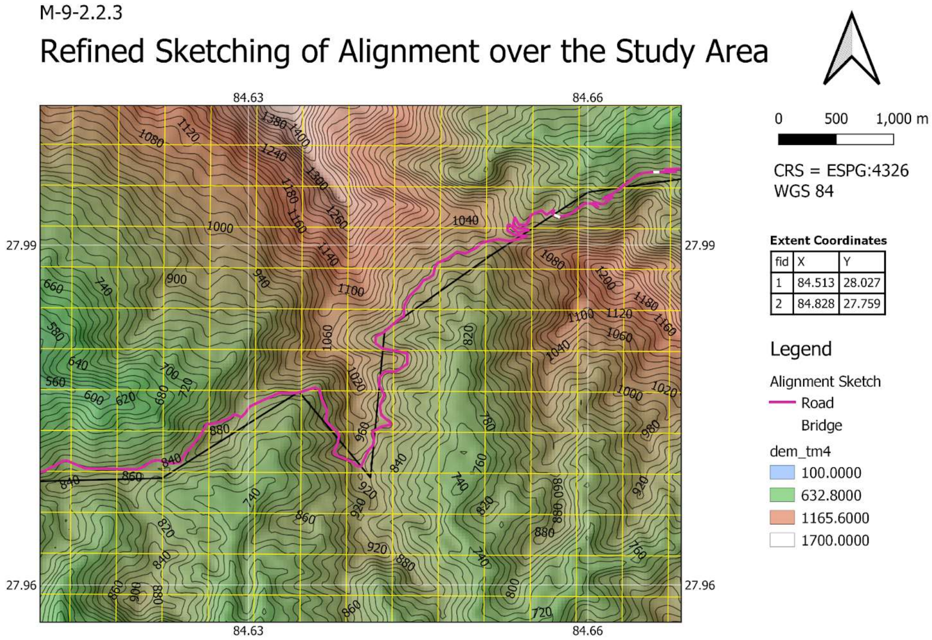


Figure 4.2.3k: Refined Sketching of Alignment over the Study Area

8. Selection of bridge along the alignment

   Bridges are placed along the alignment based on contours and longitudinal profile of selected alignment.

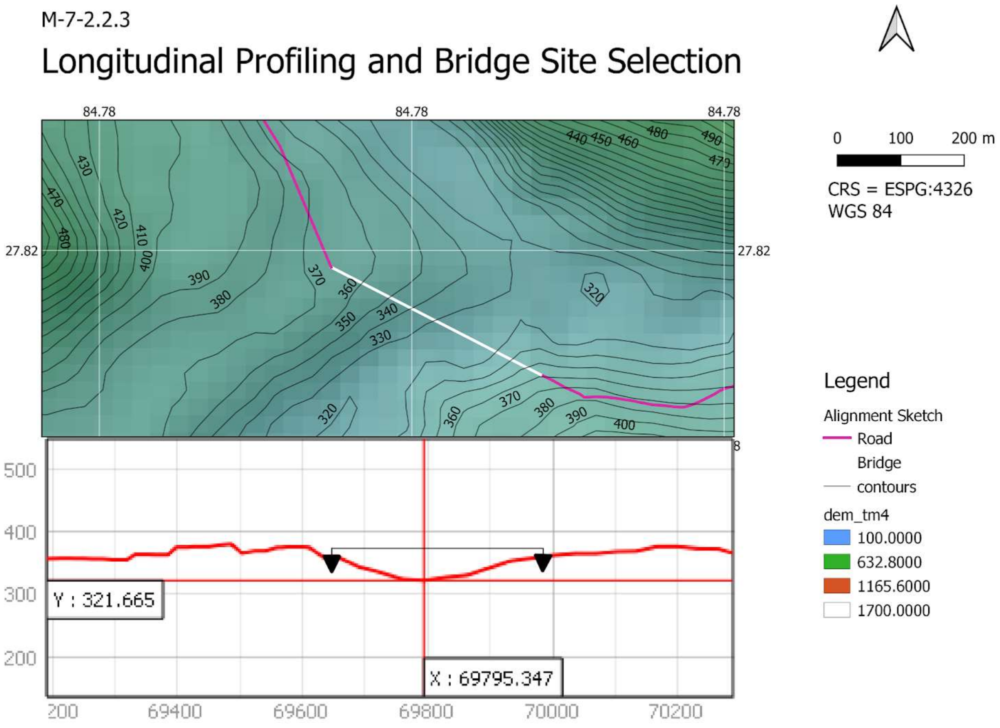


Figure 4.2.3l: Longitudinal Profiling and Bridge Site Selection

9. Repeating the process over different study zones to cover the area of all 31 line segments.

Points of consideration while selecting intersection points (IPs) in a particular reach of study are

The gradient of alignment is within the range of minimum and maximum gradients i.e. 0.5% to the ruling gradient of 4%.

1. Possibility of horizontal curves of radius more than required.
2. Sight Distance required is maintained.

Phase 3: Finalising Selection

Phase 2 of the process completes by providing (x, y) coordinates of intersection points (IPs) of the alignment at the resolution of 100 m. The z values of IPs of the alignment are draped from DEMs of their corresponding area.

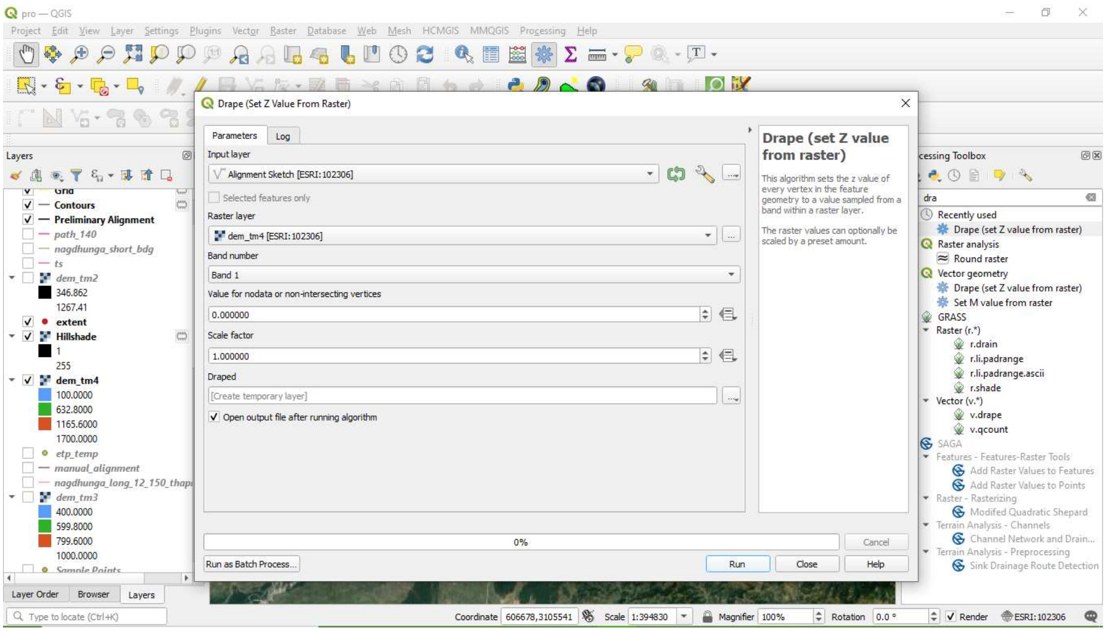


Figure 4.2.3m: Finalising Selection

The alignment layer is exported to projected coordinate reference system ESRI: 102306 known as Nepal Nagarkot Transverse Mercator Projection. The obtained (X, Y, Z) projected coordinates of IPs along with bridge information is analysed and scored.

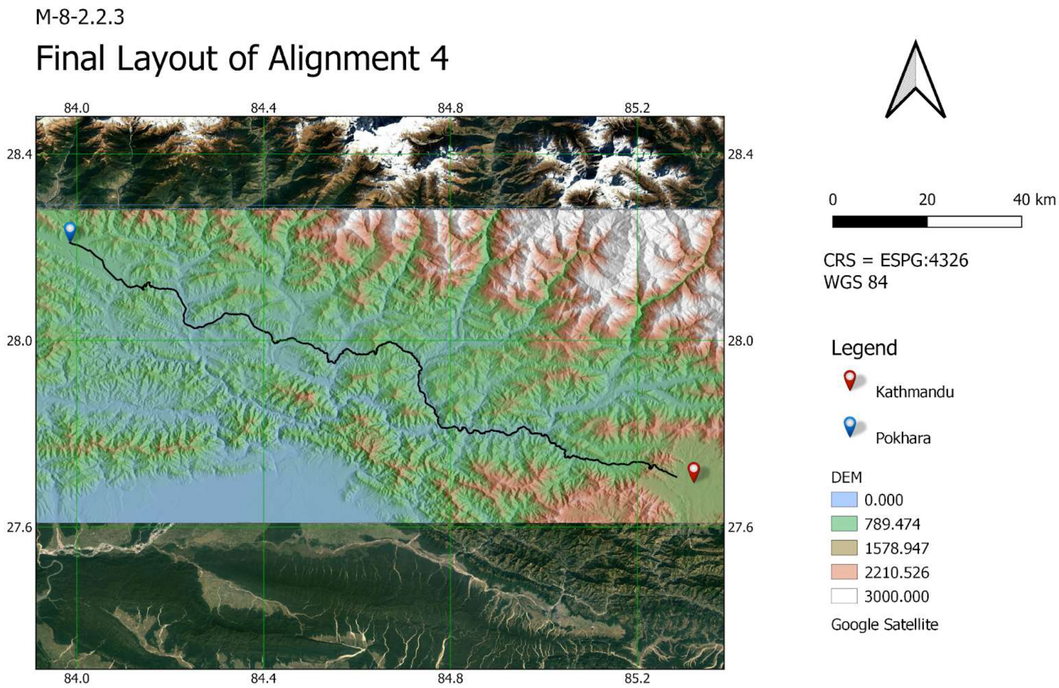


Figure 4.2.3n: Final Layout of Alignment 4

4.2.4 Expressway Alignment (Alignment 5)

Objective Features of Alignment 5

- Short
- Minimum grade change
- Presence of tunnels

Working Principles

- Straight connection from Pokhara to Kathmandu

Phase 1: Rough Sketching of the Alignment

First, a straight line joining Kathmandu and Pokhara is drawn which is the theoretically shortest distance if the ground along the study area was flat.

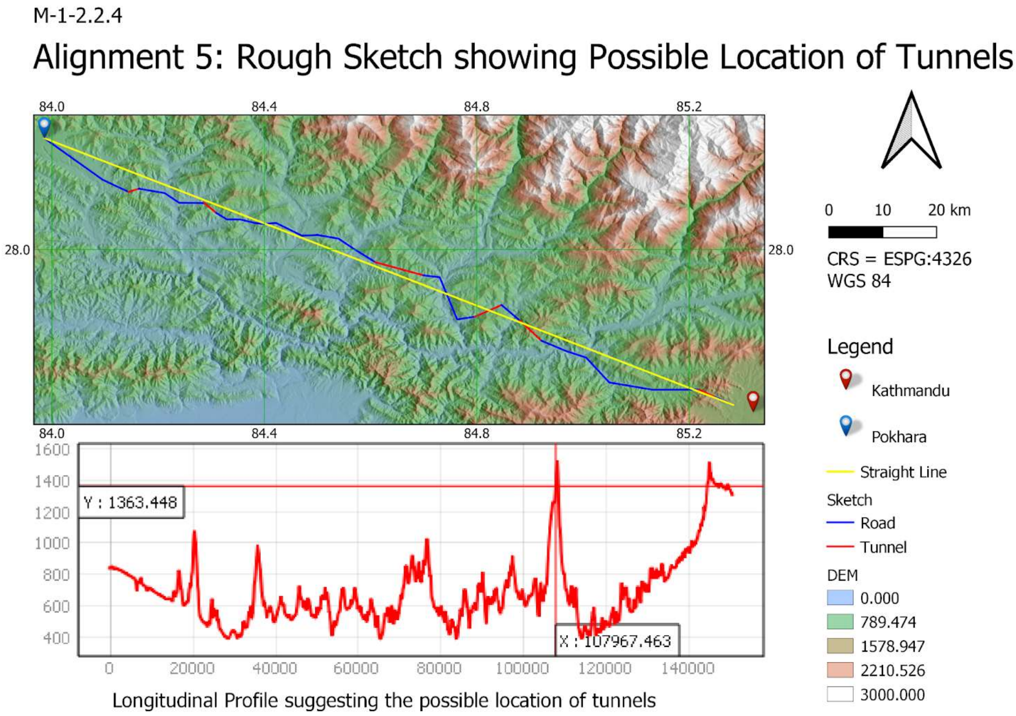


Figure 4.2.4a: Alignment 5: Rough Sketch showing Possible Location of Tunnels

Then, based on the Digital Elevation Model of study area, a rough sketch of the alignment is drawn with tunnels included such that this sketch alignment deviates from the straight line as minimum as possible.

Phase 2: Tunnel Alignment

The possible tunnel sites in the rough sketch are individually examined and the alignment of the tunnel is fixed in position and direction along the ridge where it has a narrow cross section.

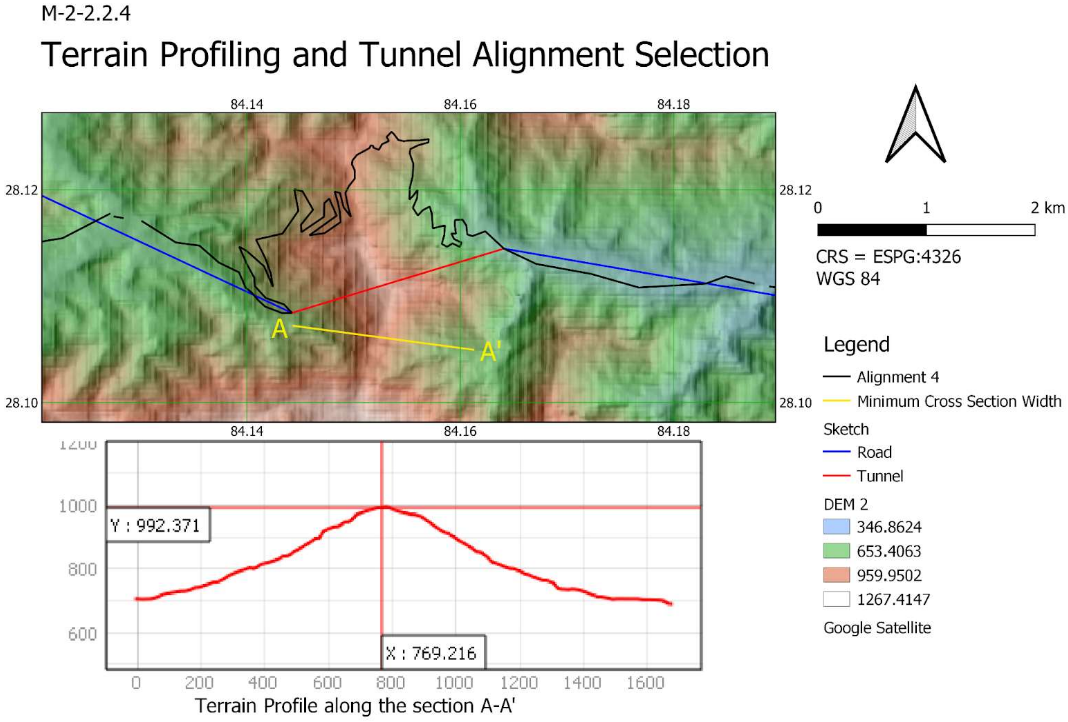


Figure 4.2.4b: Terrain profiling and Tunnel Alignment Selection

Tunnel Entry and Exit Point selection

Then, the start and end point of the tunnel is determined from the study of the cross profile of the ground along the line of proposed tunnel alignment. The tunnel can start at any elevation along the line and can end any elevation along the line. However, high elevated tunnel start and entry points increase the road length before and after the tunnel to gain or lose the elevation in the designed grade. On the other hand, low elevated tunnel start and entry point unnecessarily increase the tunnel length. A sweet spot based on economy has to be determined to find the tunnel start and entry location along the line of proposed tunnel alignment.

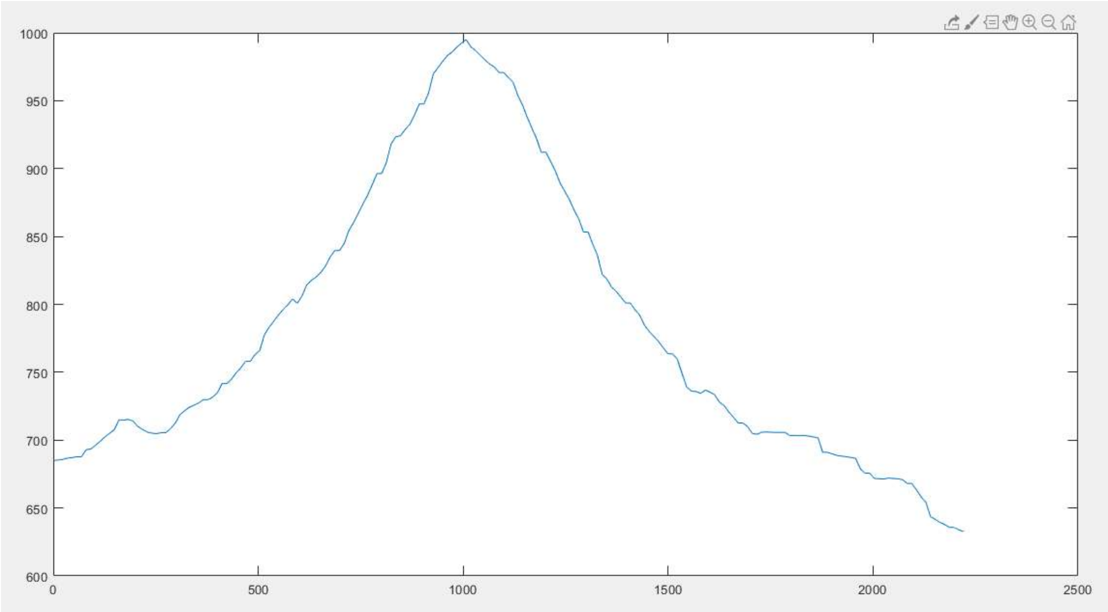


Fig 4.2.4c: Profile Elevation of the ground at proposed tunnel alignment A-A' versus distance in metres

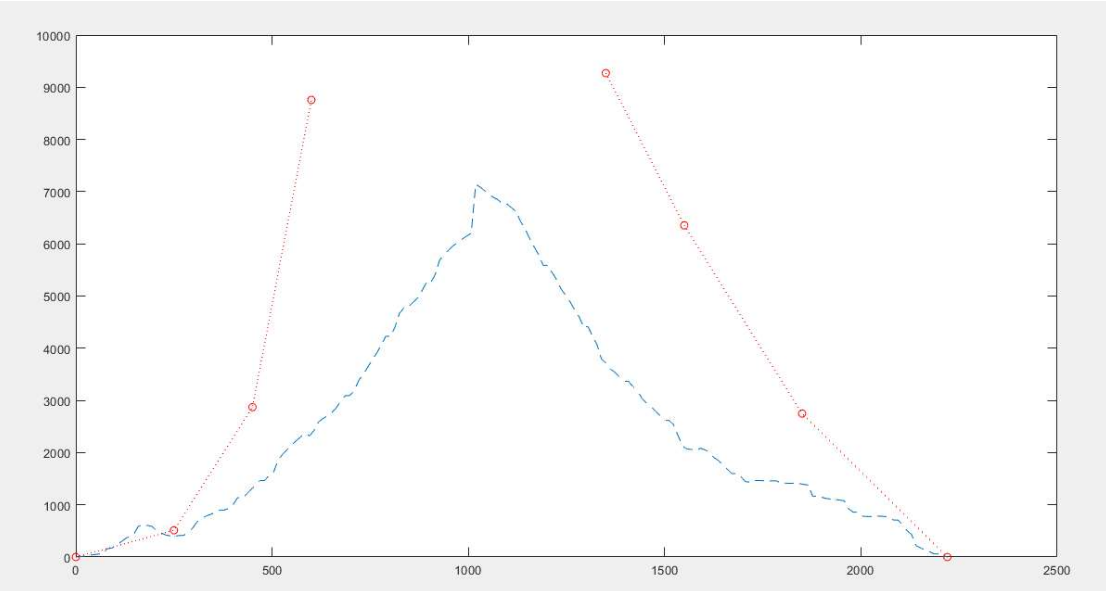


Fig 4.2.4d: Additional length of road with respect to 0 station required to gain the elevation at given length of the proposed tunnel alignment, '--' line indicates theoretical additional distance required at design grade, '......' line indicates the minimum additional distance to be added to the road before and after of the tunnel obtained by modified dijkstra's algorithm

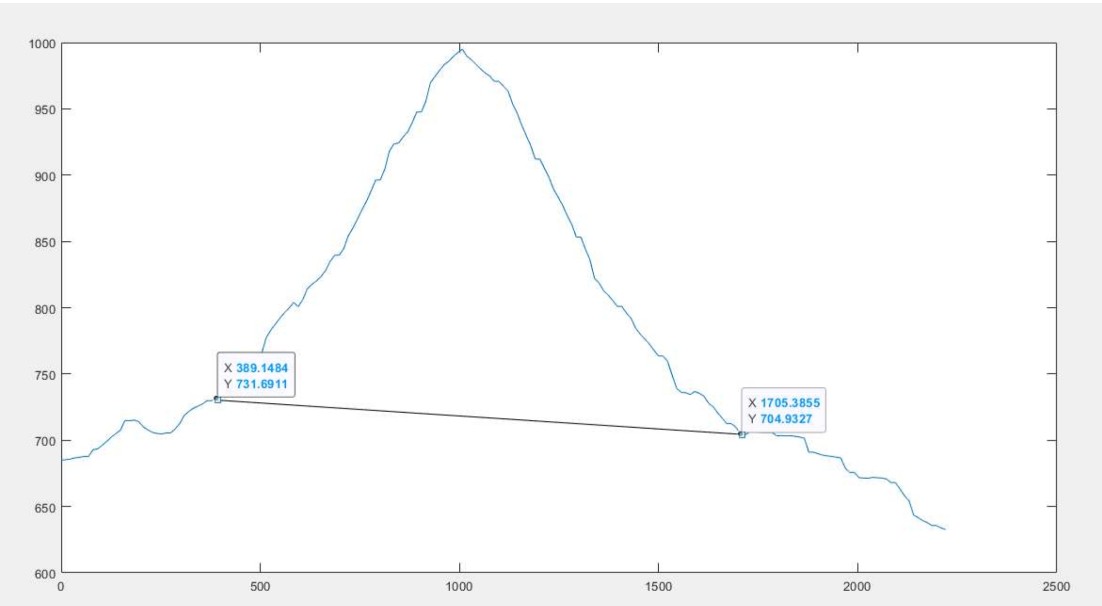


Fig 4.2.4c: Tunnel Entry and Exit Points selection in the cross section view along proposed tunnel alignment

Tunnel	Start Location	End Location	Start Chainage	Length	Grade (%)
1	623974.428, 3066911.542, 1335.338	619760.057, 3068182.455, 1242.875	3094.722	4402.805	-2.10
2	590603.914, 3079563.941, 684.218	587366.185, 3083044.317, 717.615	49011.548	4753.633	0.70
3	581766.563, 3085929.076, 643.930	579716.104, 3084790.392, 674.472	62259.791	2345.616	1.30
4	568488.932, 3092826.230, 578.011	564168.215, 3092339.461, 665.886	86019.295	4348.937	2.02
5	530368.434, 3105780.326, 584.489	528410.667, 3107455.621, 554.790	138814.612	2576.887	-1.15
6	515887.609, 3109520.349, 705.746	514413.162, 3109706.319, 694.125	157038.488	1486.174	-0.26

Table 4.2.4a: Tunnels present in Alignment 5 [Kathmandu - Pokhara] and their information at coordinate reference system Nepal Nagarkot Transverse Mercator [ESRI: 102306]

Phase 3: Alignment between the tunnels

The concept alignment between the tunnels is determined by executing modified dijkstra's algorithm on elevation raster of the area to achieve the least cost path between the endpoint of a tunnel to the start point of the succeeding tunnel. The concept alignment is realigned by contouring the area.

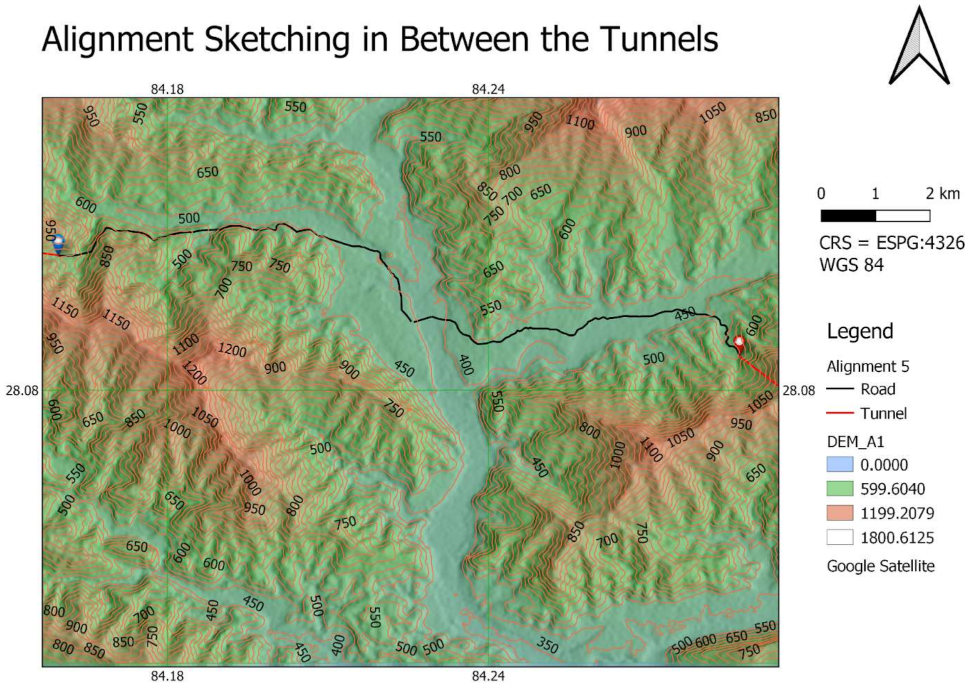


Figure 4.2.4d: Alignment Sketching in between the tunnels

Final layout of Alignment 5

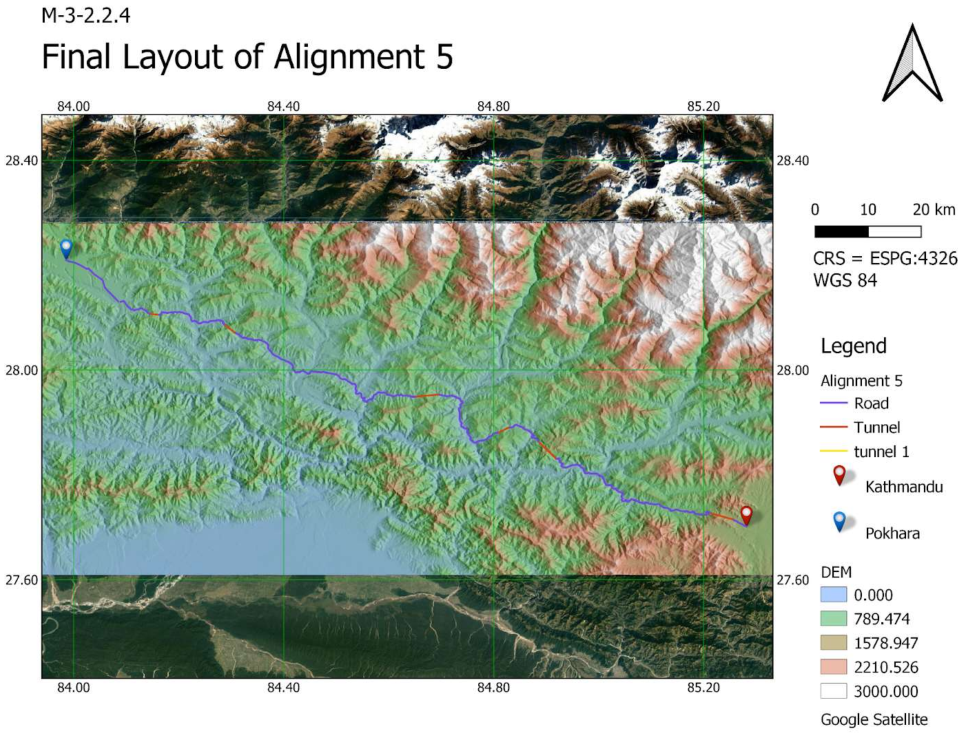


Figure 4.2.4e: Final Layout of Alignment 5

4.3 EVALUATION OF ALTERNATIVES

4.3.1 Technical Evaluation

The following table shows details of technical evaluation.

Alignment features	Alignment 1	Alignment 2	Alignment 3	Alignment 4	Alignment 5
Length (km)	195.535	195.667	179.059	208.241	180.056
	3	4	1	5	2
Bridges (km)					
Number	40	43	33	42	22
	3	5	2	4	1
Total Length	2.202	5.022	2.538	10.623	6.306
	1	3	2	5	4
Tunnels (km)					
Number	0	1	2	0	6
	1	3	4	2	5
Total Length	0	0.277	14.516	0	19.984
	1	3	4	2	5
Grades (%)					
Median	4.466	4.207	3.95	3.81	2.455
Frequency Distribution	36.596, 28.918,	36.608 28.771	35.466, 29.222,	36.464 28.121	42.832, 26.713,

	19.578, 14.908	19.756 14.866	20.01, 15.302	20.537 14.877	18.877, 12.378
	3	2	5	4	1
Deflection Angles (Degrees)					
Sum	48892	43341	35227	43109	35660
	5	4	1	3	2
Median	5.282	7.097	4.791	9.846	10.194
	2	3	1	4	5
Frequency Distribution	93.331, 6.244, 0.396, 0.029	98.215 1.195 0.409 0.180	99.309, 0.403, 0.077, 0.211	88.84 7.659 1.926 1.575	85.832, 11.274, 2.376, 0.518
	3	2	1	4	5
Speeds (kmph)					
Average	40.95	56.63	71.03	57.23	73.93
	5	4	2	3	1
Frequency Distribution	1.294, 5.06, 7.483, 86.163	3.128, 10.382, 12.821, 73.67	0.772, 6.559, 14.390, 78.279	1.882 3.063, 4.595, 90.46	0.086, 1.944, 10.67, 87.30
	3	5	4	1	2
Travel Time (hrs)	4.769	3.364	2.495	3.671	2.538

	5	3	1	4	2
TOTAL	**35**	**41**	**28**	**41**	**35**
Rank	**3**	**4**	**1**	**5**	**2**

Table 4.3.1: Technical Evaluation of Alignments

4.3.2 Economic Evaluation

Benefit Cost Analysis of Alternatives

	Alignment 1	Alignment 2	Alignment 3	Alignment 4	Alignment 5
Length (km)	195.535	195.667	179.059	208.241	180.056
Reduction in Length (km)	0	-0.132	16.476	-12.706	15.479
Bridge Length (km)	2.202	5.022	2.538	10.623	6.306
Tunnel Length (km)	0	0.277	14.516	0	19.984
Pavement Length (km)	193.333	190.368	162.005	197.618	153.766
Travel Time (hrs)	4.769	3.364	2.495	3.671	2.538
Reduction in Time (hrs)	0	1.405	2.274	1.098	2.231
COST	**0**	**26.38**	**134.08**	**32.66**	**182.54**

(Billion NRS)					
BENEFIT (Billion NRS)	**0**	**2.59**	**6.60**	**0.21**	**6.38**
Payback Period (Yrs)	**-**	**10.2**	**20.3**	**155.5**	**28.6**

Table 4.3.2c: Benefit Cost Analysis of Alternatives

CHAPTER 5: SOCIO-ECONOMIC CONDITIONS OF THE STUDY AREA

5.1 GENERAL

The study of socio-economic conditions of the affected population due to the proposed new alignment or modification in the existing alignment is equally important. This includes the settlement area along and around the Kathmandu-Pokhara Highway.

Methods of the study :

Primary method of study is difficult as Kathmandu-Pokhara Highway is a very long route so direct interaction with locals would be a big task and we were bound by the time. Direct interaction was also not possible due to the ongoing pandemic from a long-time.So data was collected from reliable sources on the internet like Pre-Census-Data-of-Nepal-2078. From the data, we observed some places such as extreme ends of the route and places near the extreme of the route are densely populated due to various reasons like developed infrastructure, agriculture, marriage,having good educational institutions, accessibility to other roads, climatic factors while other places are less densely or sparsely populated. The socio-economic status of the people living nearby Kathmandu-Pokhara Highway can be considered as quite good as the highway is connecting two developed and beautiful places of the country with diversified people.

5.2 POPULATION AND DEMOGRAPHIC PICTURE

According to census 2021, population of five districts connecting Kathmandu-Pokhara highway was found as:

- Kathmandu: 20,17,532
- Dhading: 3,22,751
- Chitwan: 7,22,168
- Tanahu: 3,27,620

- Kaski: 5,99,504

5.2.1 Influence area

Before commencement of any road projects, it is important to study the influence area around the road as the people are the one who are going to use the road and they are the affected as well if the road is far away from the settlement area.The road has direct influence along the road and around the road. With the shifting of the road alignment away from the settlement area, there is an increase in the price of accessibility to markets,educational institutions, hospitals, administration etc.

Along with the construction of roads of good condition and less time-taking to reach the destination, there is a high probability of developing other infrastructure along the route and of the accessible places through the road. With the completion of the objectives of the project, the social, cultural and economic status of the people will be better. The area of the influence and the landuse pattern of recent decades was found using qgis application.

5.2.2 Economic Characteristics

The main occupation of the people around the Kathmandu-Pokhara Highway are service sector including tourism,civil services, private jobs, agriculture and the foreign and domestic remittances through trade and business.The places within the Kathmandu-Pokhara Highway have very beautiful eye-catching scenery. The places can be visited for relaxing,religious purpose like visiting temples,monasteries, boating, trekking, rafting and extreme sports like rafting, canoeing, bungee jumping,etc

5.2.3 Structure of Population

According to census 2021, population of five districts connecting Kathmandu-Pokhara highway was found as:

- Kathmandu: 20,17,532 (male : 1025727 and female : 991805)
- Dhading: 3,22,751 (male : 1,57,207 and female : 1,65,544)
- Chitwan: 7,22,168 (male : 3.54,071 and female : 3,68,097)

- Tanahu: 3,27,620(male : 1,52,921 and female : 1,74,699)
- Kaski: 5,99,504 (male : 2.92.764 and female : 3,06,740)

5.2.4 Nature of Migration and Outside Influx

Due to tourism, people are oftenly migrating within our study area. Getting proper and good facilities like urbanisation, education, roads connecting to the capital of the country etc. are also major reasons behind the migration of the people within the area of Kathmandu-Pokhara highway. Due to national and international tourists visiting Pokhara almost everyday, Kathmandu-Pokhara highway seems always busy. Hence if any traffic jams due to any reason occurs,it affects every aspect related to travelling or reaching the destination on time. In this situation our country cannot take any risk of delay in those places. Hence it became our area of study.According to population census 2011,Kathmandu district has the highest percentage of migrants(48%) while Chitwan and Kaski have 32% and 25% migrants respectively.

5.2.5 Land Use Pattern

The land use pattern of the linked districts with the Kathmandu-Pokhara Highway for various purposes like urbanisation, agriculture, deforestation,etc was depicted using MODIS data and gis software as shown in figure below:

Land use type in following figures are coded as:

Code	Land use type
0	Snow
1	Water bodies
2	River soil
3	Barren land
4	Sparse Vegetation
5	Intermediate green vegetation
6	Dense vegetation

Table 5.2.5: Code for land use type

NDVI for year 2011 of state 3 and reclassified image:

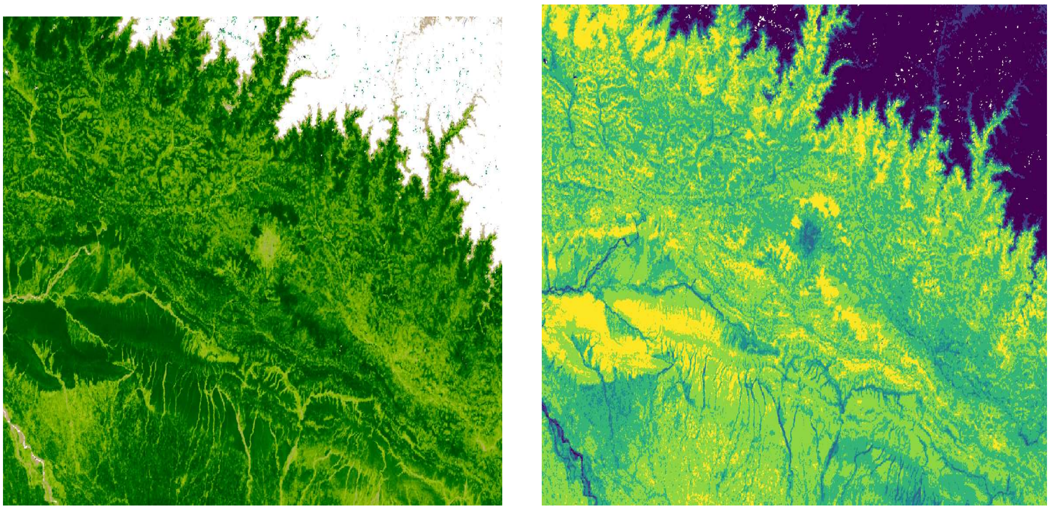


Figure 5.2.5a: NDVI 2011 State 3

NDVI for year 2022 of state 3 and reclassified image:

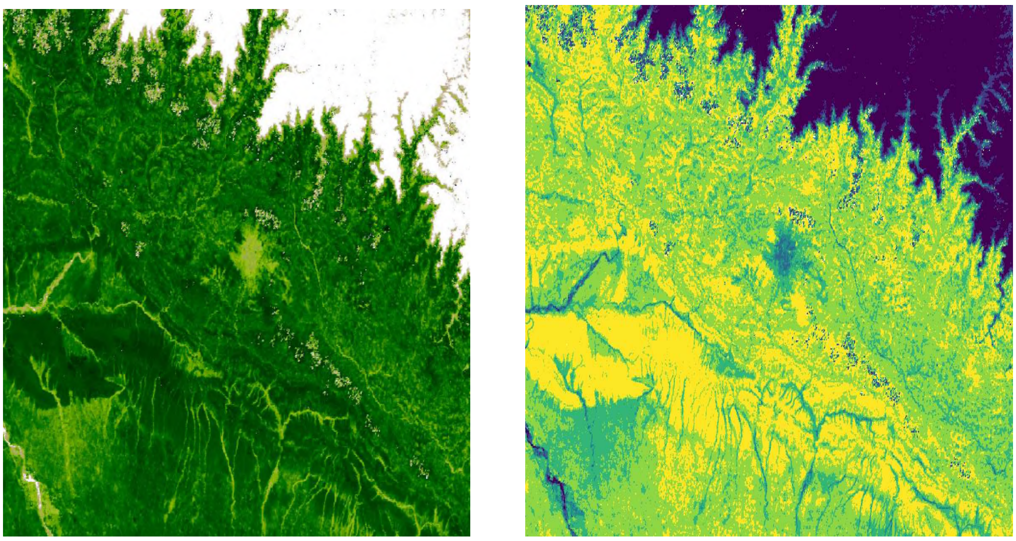


Fig 5.2.5b: NDVI 2022 State 3

Figure 5.2.5c: Land Use change of Kathmandu, Dhading, and Chitwan

These graphs indicate that the land use pattern of some parts have changed significantly as the years passed while there are negligible changes in some parts.

NDVI for year 2011 of state 4

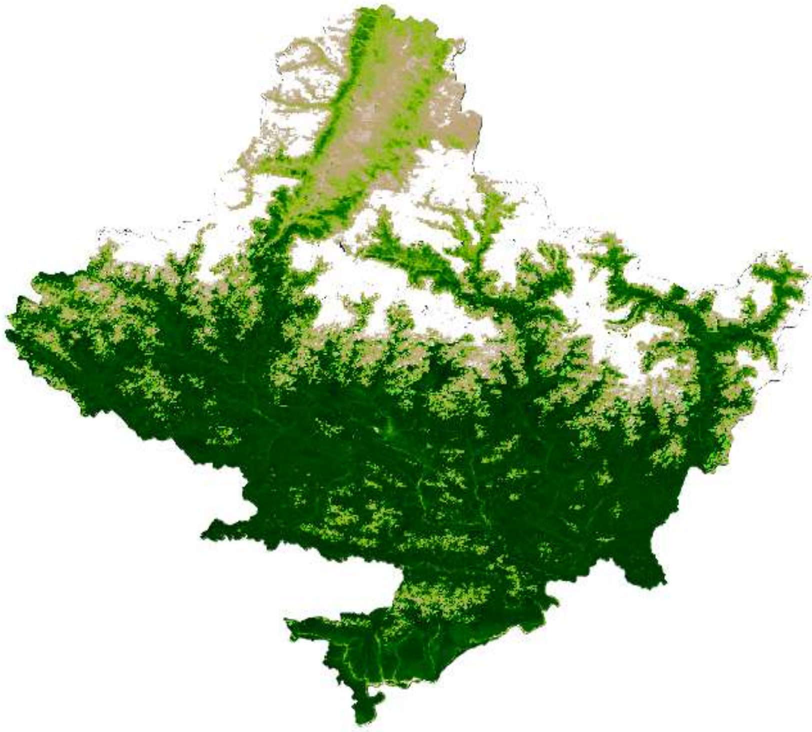


Figure 5.2.5d: NDVI 2011 of State 4

NDVI for year 2022 of state 4

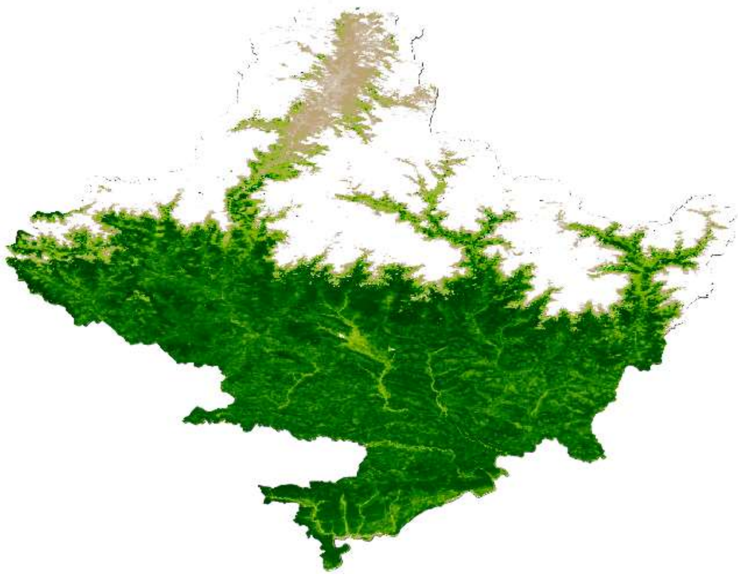


Figure 5.2.5e: NDVI 2022 of State 4

This figure shows that some land parts of the states have changed in their usage. Maybe the land use change is turned into deforested areas or settlement areas by cutting down the trees.

5.2.6 Wild Animals of the Area

During lockdown due to covid epidemic in the country, wild animals have begun to appear on the streets in Tanahun district. According to travellers, wild animals caught their attention on the Muglin-Kotre road section of Kathmandu-Pokhara Highway. Experts said that with vehicles off the roads due to the lockdown, animals must have come out in search of food, among other things.People passing by also stopped to feed the animals. Officials at Devghat Area Development Committee said that as pilgrims stopped coming to Devghat Dham during the lockdown, monkeys have started entering the empty houses in areas nearby while the other times, the road is safe from wild animals as there is no invasion during travelling. So it can be concluded that the road is not disturbed from the wild animals of the area.

5.2.7 Forestry

Around 7,000 trees are to be cut during the widening of the Mugling-Pokhara road section of the Kathmandu-Pokhara Highway. The road is being expanded to four lanes and a total of 6,750 trees along the Tanahu section are to be removed. The permission for cutting down the trees has been granted. With the implementation of the project discussed in this report, there will be minimal cutting down of trees keeping the sustainability of the environment in mind.

5.2.8 Agriculture Production

The Gandaki Province consist of 10 districts and eastern part of the then Nawalparasi district. It is also an agriculture based province. It is estimated that 64% of the population are engaged in agriculture. Tourism and hydropower are the major economic sectors that are expected to flourish in this area.The province has the huge potential of hydro-electricity generation with existing 29 hydro-electricity projects. As almost all kinds of climate is available in this province, it is rich in diversity as well. The province is deficit in fruits and vegetables and is self-sufficient in cereals except for rice. It is highly deficient in onion, garlic, oilseed and pulses. This province collects the highest remittances. The major food crops grown in this province are paddy, maize, millet and wheat. The cash crops include Potatoes, coffee, apples and oranges. Livestock rearing also accounts for a large part of this province's agricultural activity.There is great potential in promoting agro-tourism in this province that can be well incorporated for boosting the economy of the provinces.

5.2.9 Electricity

NEA has awarded the contract to install 50 charging stations to a Chinese company. Of the total number, the NEA has planned to install 20 charging stations in the Kathmandu Valley while among the rest, five each will be located in six provinces.These charging stations will be installed along the East-west Highway, Prithvi Highway, BP Highway and Madan-Bhandari Highway. Super Trishuli hydropower is located at about 100km west of Kathmandu on Prithvi highway.

5.2.10 Tourism Potential

Pokhara valley, with the area of 123 square kilometre is located in the central region of Nepal.The most frequently used road route by tourists in Nepal is probably more than 200 km long Kathmandu-Pokhara Highway leading from Kathmandu to Pokhara.The tectonic depression has created the unique nature of Pokhara, exposing the impressive panoramic view of snow-covered mountains, lakes, gorges of Seti River, caves, green hills, and waterfalls. The spectacular views of scenic Annapurna Himalayan range, the shortest distance of snow-capped mountains, the harmony of exotic mountains, eye catching lakes and the mystical form of Machhapuchhre mountain reflected into Fewa Lake, are the features of Pokhara that have made thousands of tourists, especially from abroad, fascinated. Many hills and villages can be easily accessed and enjoyed while visiting and staying in Pokhara. The names of such famous peaks and spots are Sarangkot, Kaskikot, Naudanda, Dhikurpokhari, Kahun Hill, Kalikastha, Sundari Danda, Armala Kot, Hemja, Austrian Camp, Dhampus-Astham, Mattikhan Hill, Nirmal Pokhari, Bharat Pokhari, Kristi, etc. Pokhara is also the meeting point of migrating Mongoloids and Aryans from the Himalayan mountains and Terai regions of Nepal whose presence has made the Pokhara valley attractive from a cultural point of view. This has made a huge socio-cultural diversity of the region another inevitable mysterious attraction of tourism in Pokhara. The overall population of Pokhara has started from numerous ethnic groups with a number of classes and creeds in a multilingual background, who follow different cultures, celebrate distinct festivals, perform unique rites and rituals and ultimately form the collective traditional lifestyles.

5.2.11 Education

Pokhara is not only a hub for tourism, but also for education.Pokhara has a long tradition of hosting good residential schools,and is seen by many families as a desirable alternative to Kathmandu for their children.With better road and air connectivity, Pokhara's importance as an educational centre is likely to grow in future.We have a university along with plenty of schools and specialised colleges in engineering, medical, hotel management, and nursing.The people of Gandaki Province do not need to go abroad for higher education any more.

5.2.12 Health

Good health facilities such as hospitals, clinics, medical camping timely,etc are available around the study area.Accessibility to the health facilities and administration is very good in comparison to other places of the country.The hospitals along the route are Paschimanchal Community Hospital,Gajuri Hospital,Galchhi Hospital,PHECT Hospital,Star Hospital Ltd.

5.2.13 Transport and Communication Network

It is one of the busiest roads in the central region.Thousands of passengers travel through it every day.One of the projects receiving Asian Development Bank(ADB) funding is the improvement programme for the Prithvi Highway, which connects capital Kathmandu with the Terai Region. This work will see the route being widened so that it features two lanes in either direction. An 81km stretch of the Prithvi Highway will be upgraded between Pokhara and Abukhaireni. The 8km stretch of the Prithvi Highway from Abukhaireni and Mugling may also be upgraded in the future.Pokhara airport serves as main gateway for the pilgrims and the tourists to travel the famous religious place, Muktinath,Jomsom and Annapurna Round Trek as well.Sometimes the vehicular movement gets disrupted due to landslide.Public as well as private vehicles both are popular along the route.

5.2.14 Administrative Condition

Most of the government offices are located in central Pokhara,which is just around a one hour road trip. The influence area is joining Pokhara City. Hence,the influence area has proper administrative access and facilities.

5.3 ENVIRONMENTAL IMPACT ANALYSIS AND SOCIAL IMPACT

5.3.1 Environment impact assessment

The baseline assessment includes key environmental attributes like physiography, drainage, geology, soil, hydrogeology, land use, flora, fauna, forest/vegetation cover, climate, ambient air quality, water quality, ambient noise levels, hazards and vulnerability; and social attributes such as private assets, cultural heritages, public utilities, Indigenous People, vulnerable groups, affected groups.

A. Physical environment

The physical environment passes through the hilly areas and sub-tropical region.The main problem with this alignment could be the vehicular emission,dust particles and noise pollution. Since the settlement along the route is not much, the noise pollution would not cause much problem and can be upto acceptable limit.The air quality should be monitored and should be within the National Ambient Air Quality Standard and the observed equivalent noise pressure levels not to exceed National Noise Quality Standard Limit.The vehicular emission should not destroy the scenic beauty and should not degrade the environment.The Abhukherini-Pokhara road section passes through numerous terraces consisting of recent alluvial materials and along the moderate to gentle hill slope with a few exceptions where the road passes through rocky terrain consisting vertical rocky cliff. Water quality is observed to be good and people use springs, pipe/tap water and small streams for drinking purposes.

B .Biological environment

There are no critically endangered and endangered species of flora and fauna found along the route.However the forestry should not be destroyed.There are also no sensitive wildlife habitats including protected areas,wildlife reserve or migratory corridors.The project road traverses seventeen (17) community managed forests from Mugling to Pokhara.The dominant forest types existing along the road corridor include Riverine forests,schima forests,Alnus nepalensis forests, and Shorea robusta forests. Three species namely, Shorea robusta, Bombax ceiba and Acacia catechu are protected plant species.Roadside plantations (avenue trees) are also noted almost throughout the road alignment in urban areas.The forest areas within the project area are the parts of Government Managed National Forests, some part of which are handed over to the Communities as Community Forests for the management purpose.The project area covers wide range of commonly found faunal diversity also.The influence area contains few perennial rivers and streams viz. Seti, Madi, Marsyangdi Rivers. Most of the other streams are perennial. Marsyangdi, Madi and Seti Rivers are the major sources of habitat for different types of fish species.

5.3.2 Socio-economic impact

The heavily congested highway passes through five districts: Kathmandu, Dhading, Chitwan, Tanahu and Kaski. This highway has a junction with Tribhuvan Highway at Naubise. The major settlement areas of the study area are Naubise, Dharke, Mahadevbesi, Galchi, Gajuri, Baireni, Majhimatar, Malekhu, Benighat, Charaudi, Kurintar, Ramailo Danda, Mugling, Majuwa, Bimalnagar, Dumre, Damauli, Khaireni, Pokhara. The caste and ethnic groups in the project area are Brahmin, Chhetri, Sanyashi, Kumai, Damai, Dalit, Muslims, Madhesi and Janajatis,Newar,Gurung, Magar, Tamang, Chepang, Thakuri.

Analysis of alternatives

Analysis of alternatives was based on safety considerations such as reduction in accidents, geometric improvements with current traffic and future projections, and social and environmental impacts such as no adverse effect on cultural/ethnic diversity and religious beliefs, etc as well as no degradation in the environment .Five alternatives are proposed for the project. The comparison between the alternatives was based on travel time, speed,cost of construction and cost of saving, delay, environmental impact during the travel and ranking was done. The alternative of fulfilling all the pre-defined properties of the project was selected.

Beneficial impacts of this project include economic development,saving time-delay, covering generation of employment and arising opportunities for businesses access to services and markets, improved road infrastructure contributing to safety issues and better transportation, etc. Beneficial impacts are related to improvement of roads and its technical efficiency, economic development and livelihoods of the local people. Also, the project after completion will bring carbon savings due to efficiency in road use.The improvement works of the route will be carried out with small land acquisition and minimal tree cutting and habitat disturbance are assessed to have moderate to substantial risks and impacts that are largely construction related.Vegetation clearing along ROW and bridge upgrading will impact on aquatic habitats, however the impact is expected to be moderate only.: There are no any impact and risk on tangible and intangible heritage by project intervention. The alignment of the road does not have any ancient monuments and tangible religious,cultural,historical and archaeological sites.Similarly, the cultural heritages, such as religious and cultural practices,languages,religions,values and norms of indigenous people community will not be affected.

CHAPTER 6: ECONOMICAL ASPECTS OF THE PROJECT AREA

6.1 INTRODUCTION

Highways and roads are the vital lifelines of the economy. They are the most preferred modes of transportation and considered the most cost effective mode of transportation. They are easily accessible to each individual and facilitate movements of both men and materials anywhere within a country and abroad providing linkages to other modes of transportation like railways, air ways, and shipping, etc. Roads help to bring national integration.

Lack of adequate road infrastructure, especially in rural areas, results in significant limitations for communities. These limitations occur in terms of access to socio-economic and cultural centres such as schools, clinics, markets and other business centres. Limited access to schools hamper educational access for learners, lack of access to clinics hamper health development and limited access and mobility to markets and other business centres places limits on trade opportunities, and subsequently also limits the potential opportunity for earning an income and a subsequent improvement in the day-to-day living standard. The result is a poor socio-economic development standard.

Road infrastructure provides accessibility and mobility, leading in turn to increased transport operations, economic activities, subsequent economic growth and ultimately a healthy and sound economy. An adequate road infrastructure network also provides an advantage to a country in terms of improved regional integration, which helps to promote regional and international trade and significantly enhances the economic growth and development of a country and consequently alleviates poverty.

Road transportation also affects the location of economic activities such as businesses, jobs and housing, and therefore the value of land and buildings. Improving access to areas with undeveloped resources (including land for housing or businesses, and tourism activities) tends to increase economic development.

Improvement of Kathmandu-Pokhara highway will provide easy access for different cities in Dhading, and Tanahun district to the capital city Kathmandu. People of Rural district Dhading which connects Kathmandu city through Kathmandu-Pokhara highway depends on different economic activities in Kathmandu city for which it is needed to have effective mobility and cost effective transport system for which improvement of Kathmandu-Pokhara highway is necessary.

The improvement of Kathmandu-Pokhara highway will provide the population of the affected area access to developed accessibility and mobility, leading in turn to increased transport services, economic activities, subsequent economic growth and ultimately a healthy and sound economy.

The improved freight movements and better connectivity will certainly reduce transportation costs and travel time leading to more competitive pricing of agricultural and construction materials produced in the affected area for exports to Pokhara, Kathmandu and other cities. With all these impacts of the road, opportunities for capital investments in different sectors will become more likely positively impacting the economic development of the influence area and that of the country.

6.2 IMPACTS OF KATHMANDU-POKHARA HIGHWAY

The sources of economic impacts attributable to the improvement of Kathmandu-Pokhara highway could generally be placed into three categories - direct impacts, user benefits and increased economic efficiency.

6.2.1 Direct Impacts

The direct impacts are most commonly associated with the improvements of existing road sections, whereby employment and income created by construction jobs contribute positively to the local economy. This type of impact is concentrated most heavily in the short-term and reduced significantly upon improvement of the highway.

The improvements of the existing Kathmandu-Pokhara highway require a lot of work force, local materials, different equipment and technologies for construction of tunnels, bridges etc. . Studies of previously completed highway projects in Nepal reveal that about 10% and 40% of total investment costs go for unskilled labour and local materials respectively. Most of them will be fulfilled through locally available labour force and resources. Currently, the cost of construction of a road on average is

NRs. 23.3 million/Km which means about NRs. 2.33 million in unskilled labour and NRs. 8 million in local materials need to be spent. This will funnel large amounts of cash into the local economy. Similarly, during the construction period concentration of a large number of work forces in different areas along the Kathmandu-Pokhara highway will demand large volumes of food grains, vegetables, livestock products such as milk, ghee, eggs and meat, consumption goods etc. These will give impetus to local people for opening of grocery shops, restaurants, tea stalls, and lodges and also growing of vegetables, livestock and poultry farming etc. All these will attract a lot of money in the local economy even if it will be for a shorter period of time.

After the improvement of the Kathmandu-Pokhara highway the above labour force concentration areas will be developed into permanent market centres.

6.2.2 User Benefits

The second category impact of road construction encompasses direct user benefits accruing to traders and travellers, including time savings and transport cost reductions. Currently, in the affected area of the project, modes of transport of people to travel to Pokhara and different cities of Dhading and Tanahun district takes a lot of time and cost due to bad condition of road and traffic congestion .. When the improvement of the highway will be completed, it will save time and money for people with safe travel. This results in frequent travelling of the vehicles which in turn saves the time saving of the users.

The improvements of the road also helps in daily life of people of Dhading district as they can sell their agricultural products in the capital city with low transportation cost which will result in saving of money.

6.2.3 Increased Economic Efficiency

The third category impact of Highway improvement covers local, regional and national economic developments through establishment of industries, expansion of trade and promotion of businesses.

Highway improvement promotes efficiency through adoption of new technologies, reduced costs and better access to markets. In addition to more traditional industrial and commercial firm location "roadside service industries" (e.g. gas stations, restaurants, hotels) and new tourism may emerge and boons to local economies. Business location/relocation that may follow highway construction is an additional potential source of economic impact. The improved freight movements and better connectivity and access to markets will deliver broad benefits by increasing farm gate prices and incomes for small and medium-sized farmers and traders, while reducing post-harvest losses due to good food rots in the field because the farmers lack the means to transport it to market on time. It will also provide direct jobs within value chains and other indirect employment opportunities for the landless poor and other vulnerable groups.

As access costs to markets decrease, agricultural households are seen to adjust their production activities as a reaction to the reduction in transport costs. Improved access also increases the availability of yield-increasing inputs in reduced prices. Commercial fertilisers, for example, can supplement natural compost. An effect of lower cost of access to markets encourages agricultural households to produce higher value-added marketable crops.

The area also has great potential for livestock farming. After the construction of the project, it is sure to encourage the people of the area to engage in livestock farming as this road provides easy access to the markets as well as technology needed for the farming. The improvement of roads can be expected to lure local people to exploit above-mentioned agricultural resources using modern technologies and increase their income level through the exports of the produce. The expansion of agricultural practices and cropping intensity will also create new employment opportunities for the local people and help raise their income level as well. All these developments in agriculture will help in alleviating poverty of the people and overall economic condition of the area.

6.2.4 Agricultural Development

Modernising agriculture is a central goal of Nepal's government, with 68% of the population relying on the sector for both their income and livelihood. However, output has not grown in line with past state-set targets, leaving persistently high levels of rural poverty.

6.2.5 Tourism Development

Several potential existing tourist attraction places are there in the influenced area of the Kathmandu-Pokhara highway like manakamana temple, Trisuli river. One of the biggest tourist destinations of Nepal, Pokhara connects capital city Kathmandu through Kathmandu-Pokhara highway.So it has high potential for tourism development. New places have also been identified as the tourist attraction centre included in the route. The economy of Dhading district can also be improved through tourism once it will have better access from different cities through Kathmandu-Pokhara highway.The construction of the project and few advertisements of the places can surely contribute to the development of the tourist industry in the area. It can boost employment opportunities, tourism and related industries, cultural conservation and exchange, and increase per capita income of the people.

6.2.6 Development of Trade and Business

An efficient and well-established network of highways/roads fulfils the needs of a sound transportation system and is desired for promoting trade and commerce in any country for sustained economic development.

Currently, the influence area of Kathmandu-Pokhara highway lags in good business and trading due to high transportation cost and longer travel time. Bad road conditions and longer routes increase transportation cost of the product produced by people of rural areas. This discourages people from being involved in agriculture. Once the highway is improved transportation cost will be decreased resulting in increase in trading and business.The increased trade and business will boost local economy thus providing impetus to the local economic development.

CONCLUSION

In technical evaluation, Alignment 3 has rank 1 but financially it has a payback period of 20.3 years. This alignment has a peak speed of 80kmph. Although Alignment 2 has a payback period of 10.2 years, technically it lags behind as it has lower peak speed i.e. 60kmph and higher grades. High grades result in an increase in fuel consumption and travel delay and reduction in speed which is uneconomic as well as unsustainable. As Alignment 3 is modification to current alignment, it requires very less cost for excavation unlike other alignments which results in faster and economic construction.

Considering these factors, we recommend Alignment 3 as the best one.

RECOMMENDATIONS

The following ideas are recommended:

1. Elevation data obtained from field surveys would give better results than that generated from GPS Visualizer.
2. A more systematic and scientific basis of scoring could be developed by detailed study of the governing parameters.
3. A more detailed benefit analysis could be done incorporating the following factors
    a. Reduction in vehicle maintenance expenses
    b. Reduction in fuel consumption from grade reduction.
    c. Reduction in greenhouse gases emission

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APPENDIX I: ESTIMATION OF DAILY PASSENGER VOLUME AND FUEL CONSUMPTION COST PER KM

The following data was used as a source for estimating daily passenger volume. This table was obtained from an Environment and Social Impact Assessment Report, mentioned in the references.

Vehicle	AADT 2018				
	Nagdhunga-Naubise Section	Naubise-Galchhi Section	Galcbhi-Malekhu Section	Malekbu-Mugling Section	Average
Motor Cycle	2384	1857	935	1807	1746
Car	1299	1 136	816	907	1007
Bus	1 086	1 340	1220	1214	1217
Micro Bus	434	414	242	1 79	363
Mini Bus	1071	858	670	710	827
4 Wheel Drive	552	609	332	487	495
Utility Vehicle	468	461	260	300	372
MAT	620	800	626	627	668
Heavy Truck	2996	2867	1841	1436	2285
Light Truck	319	467	375	277	360
Total	10143	8333	7317	7765	9341
Source: Consultants' surveys and estimates, 2018					

Table A1: Annual Average Daily Traffic Data of 2018

On the basis of this table, the following calculations are done. To project the traffic, 5% compounding is done for 4 years. Equivalency factors are taken from NRS 2070, and passenger per vehicle is fixed based on vehicle type.

Vehicle	AADT 2018	AADT 2022				
		Projected	Equivalency Factor	PCU	Passenger per Vehicle	Total Passengers
Motor Cycle	1746	2122	0.5	1061	1.5	3183
Car	1007	1224	1	1224	3	3672
Bus	1217	1479	3	4437	40	59160
Micro Bus	363	441	1.5	661	15	6615
Mini Bus	827	1005	2	2010	20	20100
4 Wheel Drive	495	601	1.5	901	4	2404
Utility Vehicle	372	452	3	1356	2	904
MAT	668	811	4	3244	2	1622
Heavy Truck	2285	2777	3	8331	2	5554
Light Truck	360	437	1.5	655	2	874
Total	9340	11349		23880		104088

Table A2: Annual Average Daily Traffic Data Projected for 2022

Based on the projected data, fuel consumption cost is calculated as follows. The data for mileage is obtained from the CO_2 emission paper mentioned in the references.

Vehicle	AADT 2018	AADT 2022				
		Projected	Mileage (KM / Litre)	Fuel Consumption Rate (Litre / KM)	Rate of Fuel (NRS / Litre)	Cost of Fuel per KM (NRS)
Motor Cycle	1746	2122	37.625	0.027	160	9023
Car	1007	1224	17.77	0.056	160	11020
Bus	1217	1479	2.8	0.357	130	68667
Micro Bus	363	441	10.2	0.098	130	5620
Mini Bus	827	1005	8	0.125	130	16331
4 Wheel Drive	495	601	15	0.067	130	5208
Utility Vehicle	372	452	2.5	0.400	130	23504
MAT	668	811	2	0.500	130	52715
Heavy Truck	2285	2777	2	0.500	130	180505
Light Truck	360	437	2.5	0.400	130	22724
Total	9340	11349				395317

Table A3: Fuel Consumption Cost Calculation

Thus, the total fuel consumption cost per KM of length travelled in a day is NRS 395317. Therefore, cost saved in one year per KM reduction in length is $395317 \times 365 = 144290705$, i.e, **0.144B**.

APPENDIX II: DETAILS OF SPEED ESTIMATION

Consider a curved section of a highway with deflection angle 'Δ', tangent length 'T' and grade of 'n'. Let superelevation be 'e' and the friction factor be 'f'. Maximum values of 'e' and 'f' are taken as 0.07 and 0.15 respectively as suggested by NRS 2070. Based on some standard results, the used formula is derived:

$$T = R\tan(\Delta/2)$$

$$R = T/\tan(\Delta/2)\ \ldots(1)$$
$$\Delta \to 0 \implies R \to \infty$$

$$e + f = \frac{v^2}{(1 \pm n)gR}\ \ldots(2)$$
$$e = 0.07$$
$$f = 0.15$$
$$v = \sqrt{0.22(1 \pm n)gR}$$

$$v = 1.47\sqrt{(1 \pm n)T/\tan(\Delta/2)}$$
$$V = 5.292\sqrt{(1 \pm n)T/\tan(\Delta/2)}$$

For very small deflection angle $(\Delta \to 0)$, velocity seems to be very large $(V \to \infty)$, but it is bounded by the velocity in straight reach, which is defined as earlier in 3.4.8.

APPENDIX III: 'ANALYSE.PY' SCRIPT

```
from math import sqrt, pi, sin, cos, tan, acos
import csv, sys

directory = sys.argv[1]
latLonAlt = directory + '\\CSVs\\data.csv'
output = directory + "\\CSVs\\analysed.csv"
projectCoords = True if 'p' in sys.argv else False
STRT_SPEED = float(input('Enter straight reach speed [default =
30kmph]'))
STRT_SPEED = STRT_SPEED if STRT_SPEED > 0 else 30

# ref:
https://en.wikipedia.org/wiki/Geographic_coordinate_conversion#Fr
om_geodetic_to_ECEF_coordinates
(Lichtenegger et al. 282)
def getXYZ(lat, lon, alt):
    a = 6378137 #semi-major axis
    b = 6356752.314245 #semi-minor axis
    e = 1 - (b/a)**2
    N = lambda lat: a/sqrt(1-e**2*sin(lat)**2)
    lat = lat*pi/180
    lon = lon*pi/180
    X = (N(lat) + alt)*cos(lat)*cos(lon)
    Y = (N(lat) + alt)*cos(lat)*sin(lon)
    Z = ((1-e)*N(lat) + alt)*sin(lat)
    return [X,Y,Z]

data = [['id', 'X','Y','Z',
'length','bridge','tunnel','grade','hz. angle','speed','time']]
with open(latLonAlt) as csvFile:
    cr = csv.DictReader(csvFile)
    rowIndex = 0
    for row in cr:
        Y = float(row['Y'])
        X = float(row['X'])
        alt = float(row['Z'])
        x,y,z = getXYZ(Y, X, alt) if projectCoords else [X,Y,alt]
```

```
        bridge = int(row['bridge']=='T')
        tunnel = int(row['tunnel']=='T')
        if rowIndex == 0:
            len = grade = 0
        else:
            x0,y0,z0 = data[-1][1:4]
            len = sqrt((x-x0)**2+(y-y0)**2+(z-z0)**2)
            grade = 100*(alt - alt0)/len
        if rowIndex < 2:
            hz = 0
            speed = STRT_SPEED
        else:
            x_1,y_1 = data[-2][1:3]
            l1 = sqrt((x-x0)**2+(y-y0)**2)
            l2 = sqrt((x0-x_1)**2+(y0-y_1)**2)
            gr = 0.005*(grade + data[-1][7])
            hz =
acos(min(1,((x-x0)*(x0-x_1)+(y-y0)*(y0-y_1))/(l1*l2)))
            speed = max(float(row['maxspeed']),
min(STRT_SPEED,5.292*sqrt((1-gr)*min(l1,l2)/tan(hz/2))))
        data.append([rowIndex+1, x, y, z, len, bridge, tunnel,
grade, hz*180/pi, speed, 3.6*len/speed])
        rowIndex += 1
        alt0 = alt

with open(output, 'w', newline='') as csvFile:
    writer = csv.writer(csvFile)
    writer.writerows(data)
```

APPENDIX IV: 'RATE.PY' SCRIPT

```
import csv, sys, json
from math import sqrt

def statAnal(data, cutHigh = False):
    if len(data)==0:
        return {
            'N': 0,
            'sum': 0,
            'avg': 0,
            'sum2': 0,
            'sigma2': 0,
            'sigma': 0,
            'sd2': 0,
            'sd': 0,
            'min': 0,
            'firstQ': 0,
            'med': 0,
            'thirdQ': 0,
            'max': 0,
            'freq': {
                '0-100': 100,
                '100-200' : 0,
                '200-300' : 0,
                '300-400' : 0
            }
    }
    data.sort()
    dataLen = len(data)

    if(dataLen>2):
        thirdQIndex = 3*(dataLen + 1)/4 - 1
        thirdQuartile = data[int(thirdQIndex)]+(thirdQIndex -
int(thirdQIndex))*(data[int(thirdQIndex)+1] -
data[int(thirdQIndex)])

        if cutHigh:
```

```
            data = list(filter(lambda x: x <= thirdQuartile,
data))
            dataLen = len(data)
            thirdQIndex = 3*(dataLen + 1)/4 - 1
            thirdQuartile = data[int(thirdQIndex)]+(thirdQIndex -
int(thirdQIndex))*(data[int(thirdQIndex)+1] -
data[int(thirdQIndex)])


        firstQIndex = (dataLen + 1)/4 - 1
        firstQuartile = data[int(firstQIndex)]+(firstQIndex -
int(firstQIndex))*(data[int(firstQIndex)+1] -
data[int(firstQIndex)])

        medQIndex = (dataLen + 1)/2 - 1
        median = data[int(medQIndex)]+(medQIndex -
int(medQIndex))*(data[int(medQIndex)+1] - data[int(medQIndex)])
    else:
        firstQuartile = data[0]
        median = 0.5*(data[0]+data[-1])
        thirdQuartile = data[-1]

    minimum = data[0]
    maximum = data[-1]
    quartile = (maximum - minimum)/4
    frequency = [0,0,0,0]
    sumData = 0
    sumData2 = 0

    for x in data:
        qIndex = int((x - minimum)/quartile)
        frequency[min([qIndex,3])] += 100/dataLen
        sumData += x
        sumData2 += x**2

    average = sumData/dataLen
    sumData2 = sumData2 - dataLen*average**2
    sigma2 = sumData2/dataLen
```

```
    sigma = sqrt(sigma2)
    sd2 = sumData2/(dataLen-1)
    sd = sqrt(sd2)

    frequency = {
        f'{round(minimum,3)} - {round(minimum + quartile,3)}' :
round(frequency[0],3),
        f'{round(minimum + quartile,3)} - {round(minimum + 2 *
quartile,3)}' : round(frequency[1],3),
        f'{round(maximum - 2 * quartile,3)} - {round(maximum -
quartile,3)}' : round(frequency[2],3),
        f'{round(maximum - quartile,3)} - {round(maximum,3)}' :
round(frequency[3],3),
    }

    return {
        'N': dataLen,
        'sum': round(sumData,3),
        'avg': round(average,3),
        'sum2': round(sumData2,3),
        'sigma2': round(sigma2,3),
        'sigma': round(sigma,3),
        'sd2': round(sd2,3),
        'sd': round(sd,3),
        'min': round(minimum,3),
        'firstQ': round(firstQuartile,3),
        'med': round(median,3),
        'thirdQ': round(thirdQuartile,3),
        'max': round(maximum,3),
        'freq': frequency
    }

directory = sys.argv[1]
analysed = directory + '\\CSVs\\analysed.csv'
output = directory + '\\Score\\score.json'


totalLength = 0;
```

```
bridges = [];
tunnels = [];
grades = [];
hzAngles = [];
speeds = [];
travelTime = 0;

with open(analysed) as pointFile:
    cr = csv.DictReader(pointFile)
    isBridge = 0;
    isTunnel = 0;
    for row in cr:
        grades.append(round(abs(float(row['grade'])),3))
        hzAngles.append(round(float(row['hz. angle']),3))
        speeds.append(round(float(row['speed']),3))
        isBridgeTemp = int(row['bridge'])
        if isBridgeTemp == 1:
            if isBridge == 0:
                bridges.append(float(row['length']))
            else:
                bridges[-1] += float(row['length'])
        isBridge = isBridgeTemp
        isTunnelTemp = int(row['tunnel'])
        if isTunnelTemp == 1:
            if isTunnel == 0:
                tunnels.append(float(row['length']))
            else:
                tunnels[-1] += float(row['length'])
        isTunnel = isTunnelTemp
        totalLength += float(row['length'])
        travelTime += float(row['time'])

bridgeAnal = statAnal(bridges)
tunnelAnal = statAnal(tunnels)
gradeAnal = statAnal(grades, True)
hzAnglesAnal = statAnal(hzAngles)
speedsAnal = statAnal(speeds)
```

```
outputJSON = {
    'Length': round(totalLength,3),
    'Bridges': bridgeAnal,
    'Tunnels': tunnelAnal,
    'Grades': gradeAnal,
    'Hz Angles': hzAnglesAnal,
    'Speeds': speedsAnal,
    'Travel Time': round(travelTime/3600,3)
}

with open(output, 'w') as outFile:
    outFile.write(json.dumps(outputJSON, indent=4))
    outFile.close()
```

APPENDIX V: MODIFIED DIJKSTRA'S ALGORITHM [PYTHON]

Raster.py

```
from math import floor

class RasterF:
'''


'''
    def __init__(self, raster_layer):
        self.ly = raster_layer
        self.xres = raster_layer.rasterUnitsPerPixelX()
        self.yres = raster_layer.rasterUnitsPerPixelY()
        self.provider=raster_layer.dataProvider()
        self.extent=self.provider.extent()

    def get_block(self,band):
            Return self.provider.block(
band,self.extent,self.ly.width(),self.ly.height())

    def block2matrix(self,block):
        contains_negative = False
        matrix = [[None if block.isNoData(i, j) else
block.value(i, j) for j in range(block.width())]
                  for i in range(block.height())]

    #    for l in matrix:
    #        for v in l:
    #            if v is not None:
    #                if v < 0:
    #                    contains_negative = True

        return matrix, contains_negative

    def ij_to_point(self,ij):
        x = (ij[1] + 0.5) * self.xres + self.extent.xMinimum()
        y = self.extent.yMaximum() - (ij[0] + 0.5) * self.yres
        return QgsPoint(x, y)
```

```
    def ijs_to_points(self, ijs):
        points = list(
            map(lambda ij: self.ij_to_point(ij), ijs))
        return points

    def ij_to_xy(self,ij):
        x = (ij[1] + 0.5) * self.xres + self.extent.xMinimum()
        y = self.extent.yMaximum() - (ij[0] + 0.5) * self.yres
        return [x,y]

    def ijs_to_xys(self, ijs):
        xys = list(
            map(lambda ij: self.ij_to_xy(ij), ijs))
        return xys

    def point_to_ij(self,point):
        j = floor((point.x() - self.extent.xMinimum()) /
self.xres)
        i = floor((self.extent.yMaximum() - point.y()) /
self.yres)
        return i, j



    def features_to_ij_and_info(self,point_features,block=None):
        ijs_and_info = []

        # if extent.isNull() or extent.isEmpty:
        #     return list(col_rows)

        for point_feature in point_features:
            if point_feature.hasGeometry():

                point_geom = point_feature.geometry()
                if point_geom.wkbType() == QgsWkbTypes.Point:
                    point = point_geom.asPoint()
                    if self.extent.contains(point):
```

```
                        ij = self.point_to_ij(point)
                        if block is not None:
                            value=block.value(ij[0],ij[1])
                            ijs_and_info.append((ij,value, point,
point_feature.id()))
                        else:
                            ijs_and_info.append((ij,None, point,
point_feature.id()))

                elif point_geom.wkbType() ==
QgsWkbTypes.MultiPoint:
                    multi_points = point_geom.asMultiPoint()
                    for point in multi_points:
                        if self.extent.contains(point):
                            ij = self.point_to_ij(point)
                            ijs_and_info.append((ij, point,
point_feature.id()))


        return ijs_and_info

    @staticmethod
    def create_path_feature_from_points(path_points,fid):
        polyline = QgsGeometry.fromPolyline(path_points)
        feature = QgsFeature()
        feature.setGeometry(polyline)
        feature.setId(fid)
        return feature
```

Grid.py

```
import numpy as np
import math as m

class Grid:
        def __init__(self, matrix):
            self.map = np.array(matrix)
```

```
            self.check=1
            self.h = len(matrix)
            self.w = len(matrix[0])
            self.manhattan_boundry = None
            self.curr_boundry = None

        def _in_bounds(self, ij):
            x, y = ij
            return 0 <= x < self.h and 0 <= y < self.w

        def _passable(self, ij):
            x, y = ij
            return self.map[x][y] is not None

        def is_valid(self, ij):
            return self._in_bounds(ij) and self._passable(ij)

        def neighbors(self, ij):
            x, y = ij
            results = [(x + 1, y), (x, y - 1), (x - 1, y), (x, y
+ 1),
                       (x + 1, y - 1), (x + 1, y + 1), (x - 1, y
- 1), (x - 1, y + 1)]
            results = list(filter(self.is_valid, results))
            return np.array(results)

        def neighbors_ext(self, ij):
            x, y = ij
            results = [(x + 1, y), (x, y - 1), (x - 1, y), (x, y
+ 1),
                       (x + 1, y - 1), (x + 1, y + 1), (x - 1, y
- 1), (x - 1, y + 1),

(x+2,y+1),(x+1,y+2),(x-1,y+2),(x-2,y+1),(x-2,y-1),(x-1,y-2),(x+1,
y-2),(x+2,y-1)]
            results = list(filter(self.is_valid, results))
            return np.array(results)
```

```
        def values(self, ij):
            return self.map[ij[:,0],ij[:,1]]

        def value(self, ij):
            return self.map[ij[0],ij[1]]

        def insert(self,value,ij):
            self.map[ij[0],ij[1]]=value

        def update_less_than(self,values,ijs):
            vals=self.values(ijs)
            ijs=ijs[np.where(values<vals)]
            list(map(lambda
n,m:self.insert(m,n),values[ijs],ijs))
```

Network.py

```
import pickle
from Raster import RasterF
from Grid import Grid
from pathlib import Path

path = str(Path.home()) + '\\Desktop\\Test'
Path(path).mkdir(parents=True, exist_ok=True)
ele=QgsProject.instance().mapLayersByName('DEM_A5')[0]
stp=QgsProject.instance().mapLayersByName('stp_tm')[0]
etp=QgsProject.instance().mapLayersByName('etp_tm')[0]
rfe=RasterF(ele)
blocke=rfe.get_block(1)
#mate,oute=rfe.block2matrix(blocke)
ss=rfe.features_to_ij_and_info(list(stp.getFeatures()),blocke)
es=rfe.features_to_ij_and_info(list(etp.getFeatures()),blocke)

gd=10 #limiting grade
ad=50 #slope scaling factor

#gr=Grid(mate);del(mate)
gr_ele = Grid(rfe.block2matrix(blocke)[0])
```

```
gr_n=Grid(np.full([gr_ele.h,gr_ele.w],None)) #stores neighbouring
points
gr_d=Grid(np.full([gr_ele.h,gr_ele.w],None)) #stores distances to
gr_n
gr_u=Grid(np.full([gr_ele.h,gr_ele.w],None)) #stores if useful
node
for i in range(gr_ele.h):
    for j in range(gr_ele.w):
        ij=np.array([i,j])
        if not gr_ele.is_valid(ij):
            continue

        nei=gr_ele.neighbors_ext(ij)
        if nei.size==0:
            continue

        xy0=np.array(rfe.ij_to_xy(ij))
        nei_xys=np.array(rfe.ijs_to_xys(nei))
        xy_diff=nei_xys-xy0
        xy_dist=np.linalg.norm(xy_diff,axis=1)


        e_xy0=gr_ele.value(ij)
        e_nei=gr_ele.values(nei)
        e_diff=e_nei-e_xy0

        slope=e_diff/xy_dist*100

        dslope_index=np.where(np.abs(slope)<gd)[0]
        if dslope_index.size==0:
            continue

modified_dist=xy_dist[dslope_index]*(1+ad*np.abs(slope[dslope_ind
ex])/100)
        oxsl=modified_dist.argsort()

        gr_n.insert(nei[dslope_index][oxsl],ij) #nei to dnei to
sorted dnei
```

```
        gr_d.insert(modified_dist[oxsl],ij)
        gr_u.insert(True,ij)

pickle.dump([gr_ele.map, ss[0][0], es[0][0], gr_d.map, gr_n.map,
gr_u.map], open(path+"\\dump.dat", "wb"))
```

Dijkstra.py

```
import pickle
from pathlib import Path
from Grid import Grid

path = str(Path.home()) + '\\Desktop\\Test'
gr_map,sp,ep,srd_map,srn_map,sru_map=pickle.load(open(path+'\\dum
p.dat','rb'))
sp=np.array(sp)
osp=sp.copy()
ep=np.array(ep)
gr=Grid(gr_map)
csrd=Grid(srd_map)
csrn=Grid(srn_map)
csru=Grid(sru_map)

del(srd_map,srn_map,sru_map,gr_map)
grd=Grid(np.full([gr.h,gr.w],np.inf)) #stores least distances
grp=Grid(np.full([gr.h,gr.w],None)) #save path in form of points
list

grd.insert(0,sp)
grp.insert(sp,sp)
sz=6000
get_nei=np.full([sz,2],-1)
get_nei[0]=sp
c_pp=np.full([sz,2],-1)
c_length=np.full([sz],np.inf)
locate=0
locatelist=[]
if csrn.value(sp).size!=0:
    c_pp[locate]=csrn.value(sp)[0]
```

```
        c_length[locate]=csrd.value(sp)[0]+grd.value(sp)
        locate=locate+1
else:
    print("Starting point has no neighbors")
    exit(0)

snei=csru.neighbors_ext(sp)
for point in snei:
    ppd=csrd.value(point)
    nein=csrn.value(point)
    pindex=np.where((nein== sp).all(1))[0]
    if pindex.size==0:
        continue
    ppd=np.delete(ppd,pindex)
    nein=np.delete(nein,pindex,axis=0)
    if nein.size==0:
        index0=np.where((get_nei==point).all(1))[0]
        if index0.size>0:
            get_nei[index0]=[-1,-1]
            c_pp[index0]=[-1,-1]
            c_length[index0]=np.inf
            locatelist.append(index0[0])
        csru.insert(None,point)
    csrd.insert(ppd,point)
    csrn.insert(nein,point)

i=1
psp=sp
while (sp!=ep).any():
    print(i)
    index=np.argmin(c_length[0:locate])
    pp=c_pp[index].copy()
    if (pp==np.array([-1,-1])).all():
        print("No further search possible; Reached sink or peak")
        break
    grd.insert(c_length[index],pp)
    grp.insert(get_nei[index].copy(),pp)
```

```
    if csrn.value(pp).size!=0:
        if locatelist:
            location=locatelist[0]
            locatelist.pop(0)
        else:
            location=locate
            locate=locate+1
        get_nei[location]=pp
        c_pp[location]=csrn.value(pp)[0]
        c_length[location]=csrd.value(pp)[0]+grd.value(pp)

    while True:
        c_pp_array=csrn.value(get_nei[index])
        c_length_array=csrd.value(get_nei[index])
        if len(c_pp_array)>1:
            c_pp[index]=c_pp_array[1]

c_length[index]=c_length_array[1]+grd.value(get_nei[index])
        else:
            csru.insert(None,get_nei[index])
            get_nei[index]=[-1,-1]
            c_pp[index]=[-1,-1]
            c_length[index]=np.inf
            locatelist.append(index)

        indexes=np.where((c_pp== pp).all(1))[0]
        if indexes.size==0:
            break
        else:
            index=indexes[0]

    snei=csru.neighbors_ext(pp)
    for point in snei:
        ppd=csrd.value(point)
        nein=csrn.value(point)
        pindex=np.where((nein== pp).all(1))[0]
        if pindex.size==0:
            continue
```

```
        ppd=np.delete(ppd,pindex)
        nein=np.delete(nein,pindex,axis=0)
        if nein.size==0:
            index1=np.where((get_nei==point).all(1))[0]
            if index1.size>0:
                get_nei[index]=[-1,-1]
                c_pp[index]=[-1,-1]
                c_length[index]=np.inf
                locatelist.append(index1[0])
            csru.insert(None,point)

        csrd.insert(ppd,point)
        csrn.insert(nein,point)

    psp=sp
    sp=pp

    i=i+1
    if i>545000:
        break

pickle.dump([osp,ep,grp.map,grd.map],open(path+'\\output.dat','wb
'))
```

Path.py

```
import pickle
from pathlib import Path
from Grid import Grid
from Raster import RasterF

path = str(Path.home()) + '\\Desktop\\Test'
sp,ep,grp_map,ts=pickle.load(open(path+'\\output.dat','rb'))

etp=QgsProject.instance().mapLayersByName('etp_temp')[0]
es=rfe.features_to_ij_and_info(list(etp.getFeatures()),blocke)
ep=es[0][0]
```

```
#ep=np.array([617,86])
print(ep)
grp=Grid(grp_map)
collect=np.array([ep])
while (ep!=sp).any():
    pp=grp.value(ep)
    collect=np.insert(collect,len(collect),pp,axis=0)
    ep=pp

points=rfe.ijs_to_points(collect)
geo=RasterF.create_path_feature_from_points(points,0)
geo.setAttributes([1])
loc=r'C:\Users\SANJEEV
BASHYAL\Documents\QGIS\Test\after_tunnel_1.shp'
fields=QgsFields()
fields.append(QgsField('id',QVariant.Int))
writer=QgsVectorFileWriter(loc,'UTF-8',fields,QgsWkbTypes.LineStr
ing,QgsCoordinateReferenceSystem('ESRI:102306'),'ESRI Shapefile')
writer.addFeature(geo)
del(writer)
iface.addVectorLayer(loc,'','ogr')
```