# Route alignment planning in hilly terrain using geospatial technology: A case study in parts of Arunachal Pradesh, India

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**Abstract**: Several studies show the use of geospatial technology in various aspects of planning and development activities as well as in the monitoring of implementation stages. This present paper highlights the advantages and effective utilization of geospatial technology for alignment of new route where the accessibility is the main cause of concerned. Since the study area is in rugged hilly terrain, the generation of landslide susceptibility map and the vertical alignment with defined criteria were adopted to find out the best possible route to connect two locations or points. Landslide susceptibility map that provides the information on spatial likelihood of occurrences of landslide was generated using heuristic or knowledge based approach. Using the contour map derived from Cartosat-1 Digital Elevation Model (DEM) and susceptibility map as a background with the incorporation of gradient criteria, the final route was prepared / generated connecting Dumro and Same Basti, Arunachal Pradesh, India.

**Keywords:** Geospatial technology, landslide susceptibility, vertical alignment, spatial likelihood, DEM

## 1. Introduction

Planning and construction of a new road or highway requires proper understanding of different aspects related to environment. It also requires a detail analysis of the site characteristics pertaining to the area such as existing dry and perennial streams, river configuration, surface soil conditions, geology, physiographic conditions, groundwater, land use/ land cover and particularly the slope condition. In absence of thorough investigation and proper scientific approaches, it may lead to more time consumption and expensive than expectations. Moreover, the degree of complexities may rise to double fold if the issues related to environment, social and or cultural are not properly addressed in public domain. However, in the last few decades with the advent of space technology and GIS, alignment/realignment planning of new route and/or old road in any area becomes easier and viable in resolving these issues extensively.

Since the study area is falling in hilly terrain, it was realized the need and the importance of landslide susceptibility map as an essential component for alignment of new route to avoid landslide prone areas. Landslide or slope failure is one of the major recurring natural hazards which cause loss of lives, property in hilly terrain (Champati et al., 2004). North Eastern Region (NER) falls in the high and medium to high category of the Global Landslide Susceptibility Map with few hotspot areas along Arunachal Himalaya (Hong and Adler, 2008). In global view of landslide susceptibility, the study area is falling in severe category (Dalia and Stanley, 2017).

The present study has been carried at the request of Boarder Road Organization (BRO) under the Project Brahmank, Arunachal Pradesh. The study aims to find out a best suitable route to connect two villages - Dumro and Same Basti of Upper Siang and Lower Dibang Districts, Arunachal Pradesh.

### 1.1 Objectives

- To generate landslide susceptibility map on 1:50,000 scale using various geo-environmental parameters with the help of remote sensing and GIS techniques in conjunction with existing data such as Survey of India Topographical Maps, published maps and literatures with limited field check.
- To generate and suggest a new route alignment using Cartosat-1 DEM and the landslide susceptibility map to avoid landslide prone areas with maximum possibility

## 2. Materials and methods

### 2.1 Study area

The study area covers part of Upper Siang and Lower Dibang Districts and a very small northern portion of East Siang district of Arunachal Pradesh and falling under the Yamme and Sessari River Catchment of Lesser Himalaya (Figure 1). It is located between 95˚11'E to 95˚13' longitudes and 28˚13' N to 28˚29' N latitudes with an area of 537 sq. km. The highest and lowest elevation is 3251.54 m and 234.21 m with reference to ellipsoidal datum (WGS 84) respectively. Apart from the various means of communication facilities, the study area is connected only with one road which is in a very poor condition with frequent landslides and subsidence. It has a relatively long rainy and winter season but a short and pleasant summer. During winter the mercury drops below 0˚C and during summer the maximum temperature is about 25˚C. Dumro village, located at the height of 1126 m, is relatively a larger settlement area compared to Muri Basti, Lema Basti etc. The nearest town is Yinkiong and Pashigahat.

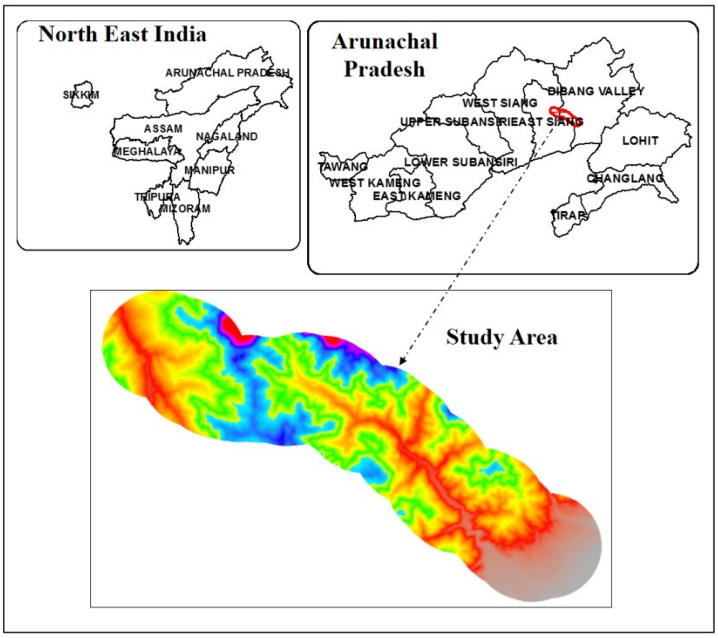


**Figure 1: Location map of the study area**

**2.2 Data used**

Cartosat-1 (2.5 m resolution) of year 2007&2008, Cartosat-1 Digital Elevation Model (DEM-30m resolution), Multispectral LISS-IV-MX (5.8m resolution) of year 2013 & 2014 of Indian Remote Sensing Satellite were used. Survey of India topographical map (1:50,000 scale) was also used as a reference to identify the location information for preparation of base map as well as other details. Details of satellite imagery and other collateral data used in the study are as follows:

- Cartosat-1 data of year 2007 and 2008 (2.5 m spatial resolution)
- IRS (Indian Remote Sensing Satellite) Resourcesat 2, LISS-IV MX, 113-051c data acquired on 15 Nov, 2013
- IRS (Indian Remote Sensing Satellite) Resourcesat 2, LISS-IV MX, 113-051d data acquired on 26 Jan, 2014 (3 Band, 6 m spatial resolution)
- Cartosat-1 stereo pair derived Digital Elevation Model (DEM-30m spatial resolution) prepared by NESAC
- Survey of India (SOI) Topographical Map No.82P/3, 82P/7, 82P/11and 82P/12 (1: 50, 000 scale)
- Collateral data with limited field survey

**2.3 Methodology**

In order to meet the objectives, the methodology has been divided broadly into two parts. Preparation of various thematic layers and generation of landslide susceptibility map. Flow chart of the methodology implemented is shown in figure 2.

**Base Map:** Base map was prepared from IRS LISS-IV data aided by information from the topographical maps (1: 50,000 scale). These include major road, other road, village or settlement locations etc. The locations of villages were interpreted from IRS Resourcesat-2 LISS-IV MX satellite image and names were taken from topographical maps.

**Lithology**: Lithology map was prepared by compiling all existing information from literature and published maps and maps prepared for groundwater prospect mapping under Rajiv Gandhi National Drinking Water Mission (ARSAC, 2010).

Necessary modification in delineating the boundaries of the litho units and further details were carried out based on the interpretation of satellite data and finalized with selective field verifications (Figure 3). The major portion of the study area falls in Tenga formation composed of green phyllite, meta-volcanics, sericite, quartzite and phyllite and Ziro biotite granite gneiss of Bomdila Group. Miri formation which is mainly composed of feldspathic quartzite, purple shale, and conglomerate of Gondwana Group is exposed in the south eastern part of the study area. Abor volcanic composed of mainly basalt of the same Group was exposed in North western part of the study area. Older Alluvium of Quaternary sediments composed of boulders, cobbles, pebble, sand and sandy clay beds are found deposited in the south eastern corner of the study area where the rivers inters in the piedmont zone (GSI, 2010).

**Geomorphology**: It was prepared from remotely sensed data and accordingly various units were delineated using the manual/ guidelines framed under National Geomorphology and Lineament Mapping (NRSC, ISRO, GSI, 2012) with minor modification as per the requirement (Figure 4). It is the study of classification, description, nature, origin, and development of present landform and their relationship to underlying structures and geologic changes as recorded by these surface features (Bates & Jackson, 1980). The major portion of the study area falls under Lesser Himalaya and portion of extreme south eastern part under Brahmaputra Plain (GSI, 2010).

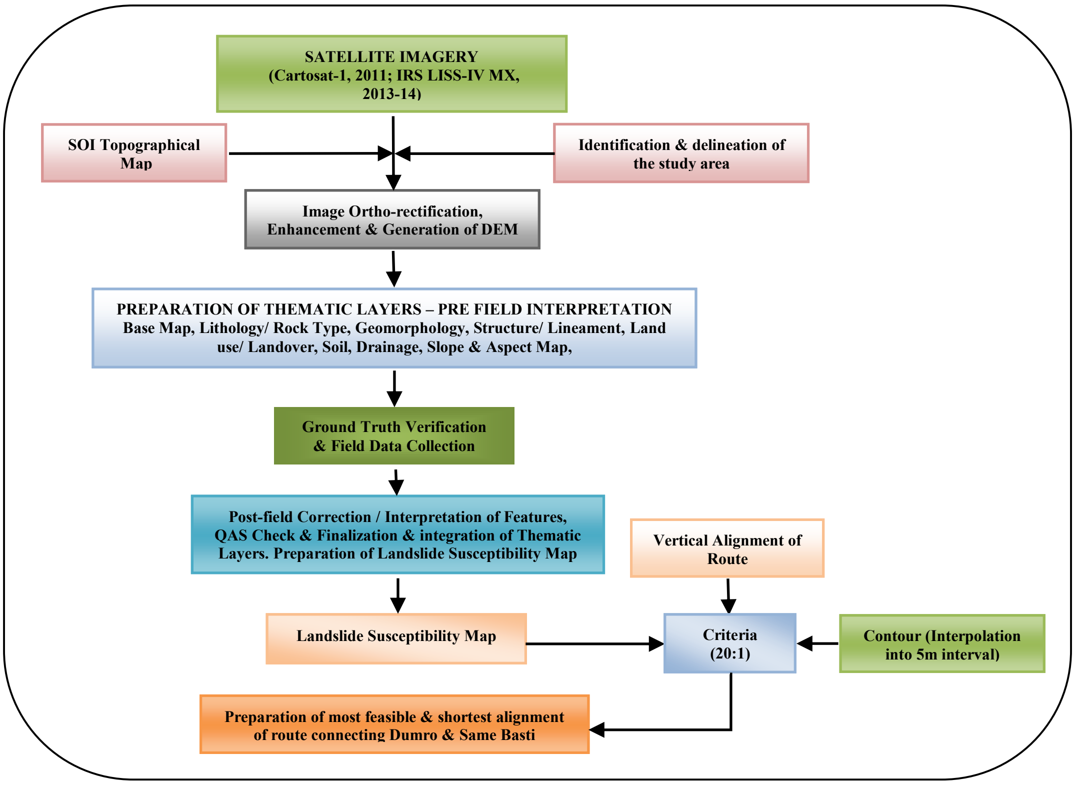


**Figure 2: Methodology flow chart**

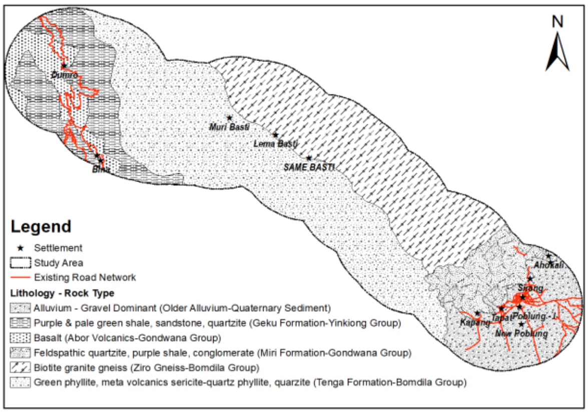


**Figure 3: Lithology of the study area**

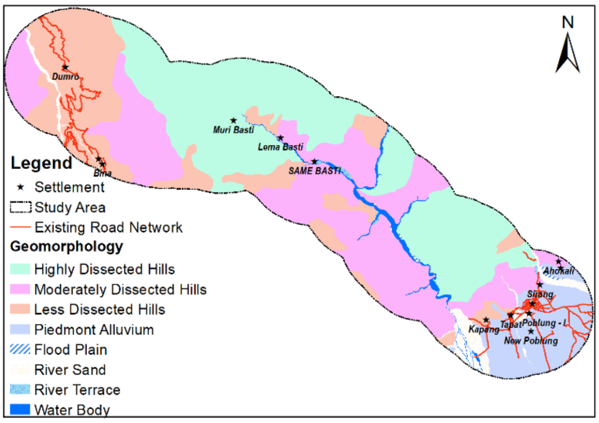


**Figure 4: Geomorphology of the study area**

Dissected hills of structural and older alluvium of fluvial origin are major geomorphic units found in the area with larger area coverage and other features like flood plain, river terrace, and river sand occupy small portion. Dissected hills of structural origin are further divided into- highly dissected, moderately dissected and low dissected hills according to their degree of dissection pattern on land surface.

**Structure/ lineament:** The lineament map was prepared from satellite data in conjunction with other diagnostic criteria such as channel offset, bank erosion and down-cutting of channel along lineament, branching of river course, abrupt change of river course, presence of dry channel in an active river course, linear ridges, scarp surface, linear alignment of water bodies, straight channel segments etc.

It may be defined as ‘A linear topographic feature of regional extent that is believed to reflect crustal structure’ (Bates & Jackson, 1980) or in simplest term ‘A linear feature of geologic interest’ that reflects the discontinuity of the underlying bedrock. Lineaments occur as straight, curvilinear, and parallel or en-echelon features which are generally related to fracture systems, discontinuity planes, fault planes, shear zones in rocks (Gupta, 2003). They are also considered very important parameter as they influence slope stability of a region. The lineament map thus prepared from satellite data was used in calculation of lineament density (Figure 5). The density map was slices into three classes of intervals using natural breaks - low (11.13% of total area), moderate (44% of total area) and high (44.6% of total area) to understand a particular area falls into which area of bedrock conditions having highest discontinuity as well as to establish the relationship with the occurrences or likelihood of occurrences of landslides. Major portion of the study area falls under moderate and high category.

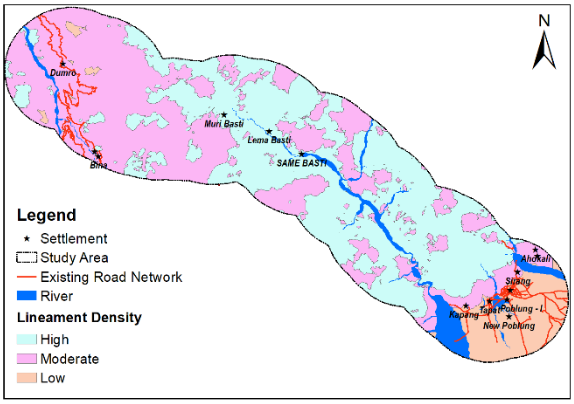


**Figure 5: Lineament density of the study area**

**Drainage:** Drainage in an area is governed by bedrocks, soils and rock structures and one of the important geotechnical or terrain element used as a clue to identify the same in an area (Pandey, 1984). Drainage map was prepared mainly from the remotely senses data aided by information from topographical maps (Figure 6).

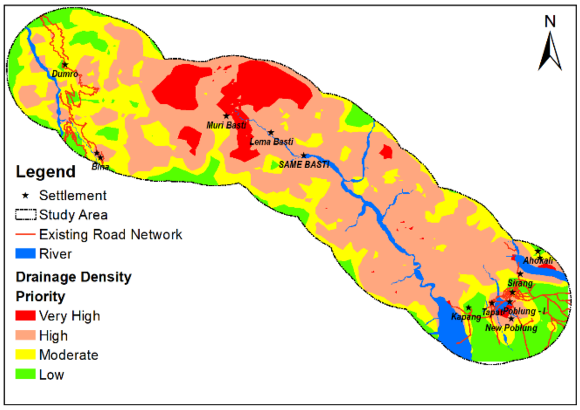


**Figure 6: Drainage map of the study area**

Major rivers having sufficient width are represented as polygon features and the remaining are represented as line features. The study area falls under the catchment of Yamme and Sesseri or Sissar River which shows overall dendritic drainage pattern. However, in the upper reaches of Sissar River, minor anomalies in pattern are observed which generally inferred that the major controlling factors may be fractures/ joints. Using the drainage, drainage density was generated. The density map was further slices into four classes of intervals using natural breaks low (12.32% of total area) moderate (26.18% of total area), high (52.38% of total area) and very high (9.13% of area). This map helps in understanding the landscape dissection and runoff potential in the area. From this map, it is well observed that the major portion of the study area falls under moderate and high drainage density where the actual alignment of route is being carried out.

**Land use/ land cover:** Land use/land cover map was prepared from remotely sensed dada with existing information and limited field investigation (Figure 7). Different classes of land use/ land cover were interpreted using NRC-LULC50K Mapping Project (NRSA, 2006) manual with minor modification as per the requirement.

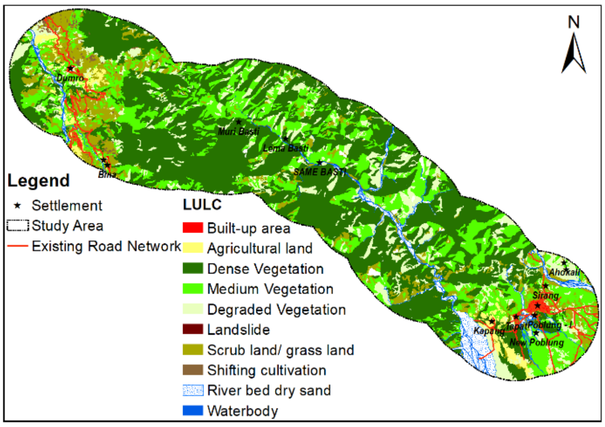


**Figure 7: Land use/land cover map of the study area**

In the study area, major portion was occupied by dense vegetation (more than 40% canopy cover/density), medium vegetation (10 to 40% canopy cover/density) and degraded vegetation (less than 10% canopy cover/ density) and the built-up area occupied the least. Area-wise percentage is given in table 1.

**Table 1: Land use/ Land cover Class (area %)**

| Sl. No | Land Use /Land Cover Type | Area % |
|---|---|---|
| 1 | Built-up area | 0.41 |
| 2 | Agricultural land | 1.90 |
| 3 | Dense Vegetation | 46.54 |
| 4 | Medium Vegetation | 23.53 |
| 5 | Degraded Vegetation | 12.05 |
| 6 | Scrub land/ grass land | 10.39 |
| 7 | Barren/ Rocky area | 0.53 |
| 8 | Shifting cultivation | 0.44 |
| 9 | River bed dry sand | 3.61 |
| 10 | Water body | 0.58 |

**Soil texture**: The soil texture map was prepared with the help of available small scale map (NBSS & LUP, 1997) since 1: 50,000 scale map or larger is not available of the study area. Three broad textural classes such as clayey, loamy and loamy skeleton were considered (Figure 8). It may be noted that, at the time of data integration it has been given lower rank since it is highly generalized and arbitrary in nature.

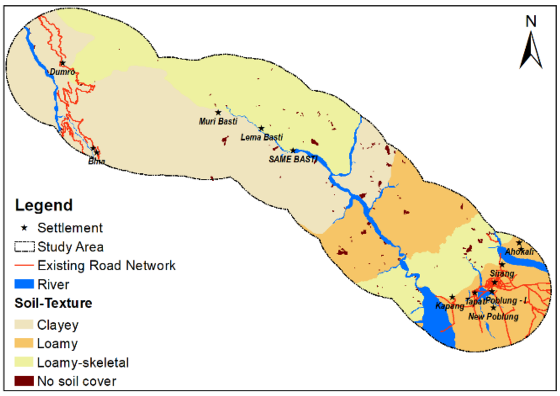


**Figure 8: Soil texture map of the study area**

**Slope & aspect map:** The various slope components are considered as important inputs for evaluation of slope stability of the area. Slope steepness or amount of slope is a factor which associates the effectiveness of gravity acting on a slope to landslide susceptibility (NESAC, 2014). The topographic slope / slope gradient map and slope aspect or orientation maps was prepared from Cartosat-I DEM with 30m spatial resolution and 8m height accuracy. The slope map was classified into eight classes (Figure 9). Slope aspect is the compass direction that a slope faces and it can have a strong influence on temperature. Direction/ orientation of maximum slope aspect was calculated for each pixel in 3×3 pixels' window and classified into nine classes (Figure 10).

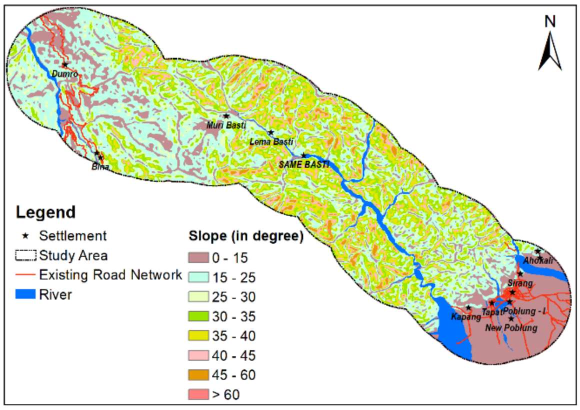


**Figure 9: Slope map of the study area**

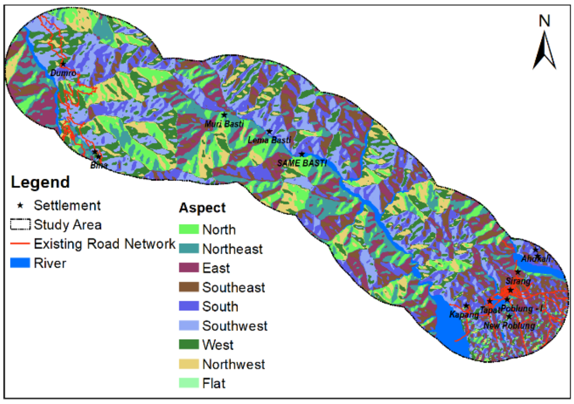


**Figure 10: Slope aspect map of the study area**

**Data integration & susceptibility zonation**: There are various approaches for the preparation of landslide susceptibility zonation adopted by many experts. Susceptibility is defined as 'a quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslide which exist or potentially may occur in an area (Australian Geomechanics Society, 2007). It may also include a description of the velocity and intensity of the existing or potential land sliding. Zonation refers to the division of a land surface into homogeneous areas or domains and their ranking according to the different degrees of actual/ potential hazard caused by mass movement (Varnes, 1984). Landslide Susceptibility map can be prepared using pure statistical techniques as well as pure knowledge-based approach (Westen, 1993; Carrara et al., 1995; NRSA, 2001). In the present study, knowledge-driven heuristic approach (Guzzetti et al., 1999) was adopted. Each geo-environmental factors/ parameters class influencing landslides, such as lithology / rock type, geomorphology / landform, structure/ lineament (density), drainage (density), land use/ land cover, soil texture, slope and aspect were assigned weights for each class and integrated in GIS with knowledge based rank and thus generated the cumulative susceptibility map. These weights and ranks are based on their assumed or expected importance in causing mass movements/ landslide and 'a-priori' knowledge available to the experts in the particular area of study (IIRS, 2008). Finally, the susceptibility pixels are classified into one of the following five classes – very low, low, moderate, high and very high using natural cut-off ranges (Figure 11).

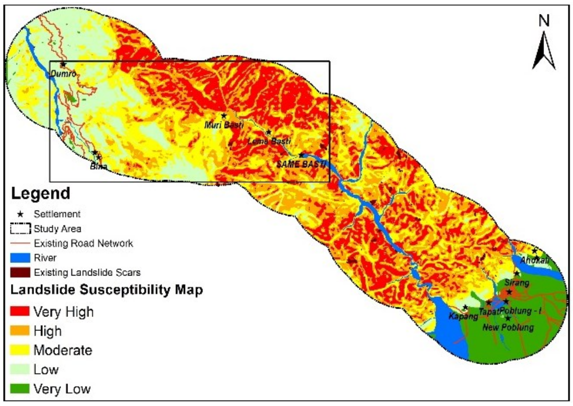


**Figure 11: Landslide susceptibility map**

The validation of the susceptibility map thus generated was carried out based on the distribution existing landslide in the area. It was observed that 80% of the slides are falling in high and very high category which occupies 53.25% and 31.01 % of the total area respectively and 20% are falling in moderate and low category which occupies 11.01% and 4.45% of the total area. Very low category occupies 0.28% of the total area where no slide has been detected.

**Route alignment (vertical alignment)**

Route alignment / location aims at evaluating the ground condition of a very large area between two end points. Planning for development of a new route to connect between two end points or places is based on the various factors such as the socio-economic, administrative as well as strategic importance of the area, region or the country. 'The position or the layout of the centre line of the highway on the ground is called alignment'. In general, alignment is of two type – horizontal alignment and vertical alignment (Subramani and Kumar, 2012). Route alignments in hilly areas are more winding/ curving in nature up to certain extent in comparison to horizontal alignment and it is mostly controlled by the topography. During the analysis the identified criteria i.e. for every 20 m horizontal length, the permissible vertical raise or fall of 1 m (20:1) was incorporated wherever applicable. The aligned route superimposed on susceptible map is shown in figure 12.

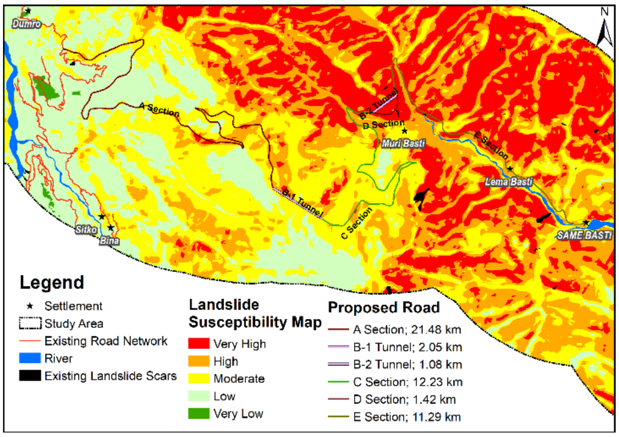


**Figure 12: Aligned route superimposed on susceptibility map**

## 3. Results and discussion

The proposed aligned route has been carried out to connect between Dumro Village of Upper Siang and Same Basti Village of Lower Debang Valley Districts of Arunachal Pradesh. It may be highlighted that the aligned road is about 48.47 km in length. The starting point of the aligned route is from the existing road at the height of 850 m, on the right bank of Sipung Korong stream and about 1.5 km before reaching Dumro Village. For easy understanding and clear viewing, the entire length of the route is divided into A, B1 & B2 tunnels, C, D and E sections respectively.

The first section denoted as ‘A Section’ is 21.48 km in length. In this section it is observed that 31% falls in low, 39% in moderate, 25% in high and 5% in very high category in the susceptibility map. Figure 13a &13b shows the 3D-view and longitudinal profile of ‘A-Section’. The second section denoted as ‘B-1 Tunnel’ is the suggested tunnel site having 2.05 km in length. It started at an elevation 1870 m and ends at 1850 m with 0.0098 percent raise or 0.5615° gradients. The thickness of the overburden is 230m at the highest point. Figure 14a &14b shows the 3D-view, longitudinal and overburden profile of ‘B-1 Tunnel’ Section. The third section denoted as ‘C Section’ is 12.66 km in length. Out of which 65% falling in moderate, 22% and 13% are falling in high and very high category in the susceptibility map. 3D-view and longitudinal profile of ‘C Section’ is shown in figures 15a & b.

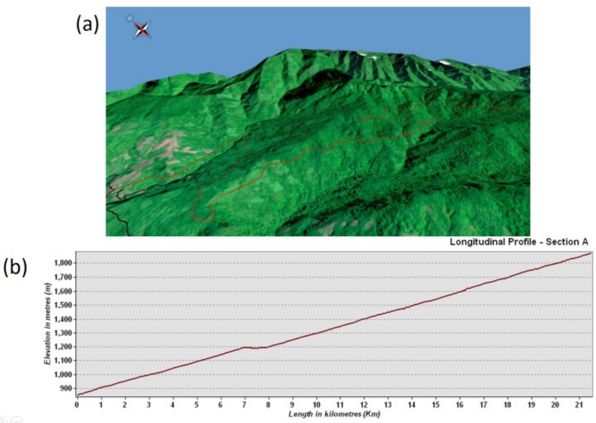


**Figure 13: (a) 3D-view and (b) longitudinal profile of A-section**

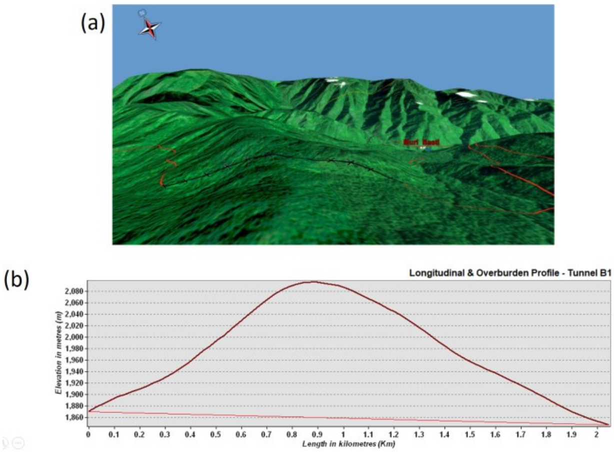


**Figure 14: (a) 3D-view and (b) longitudinal profile of B-1 tunnel section**

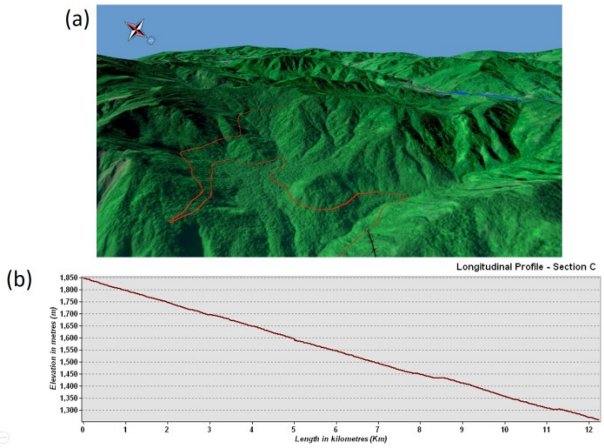


**Figure 15: (a) 3D-view and (b) longitudinal profile of C section**

The fourth section denoted as ‘D Section’ is having a length of 12.42 km. It may be noted that 95% of the length of the section is falling under very high and 5% in high category in the susceptibility map.

Figure 16 a & b shows the 3D-view and the longitudinal profile of the ‘D Section’. It is observed that this section is passing just above the crown of an active landslide area that may reactivate at any time. With this observation, a tunnel denoted as ‘B-2 Tunnel’ is suggested in the same section having a length of 1.08 km that reduces the 0.34 km of the total length. The suggested tunnel is having 2.3 percent raise or 1.33° gradient. The thickness of the overburden is 90 m at the highest point. The last section denoted as ‘E Section’ is 11.29 km in length and follows a small section on the right bank and major section on the left bank of Sessari River. In this section, maximum length of the suggested route is falling under very high category (44%) in the susceptible map in comparison to high (38%) and moderate (18%) category.

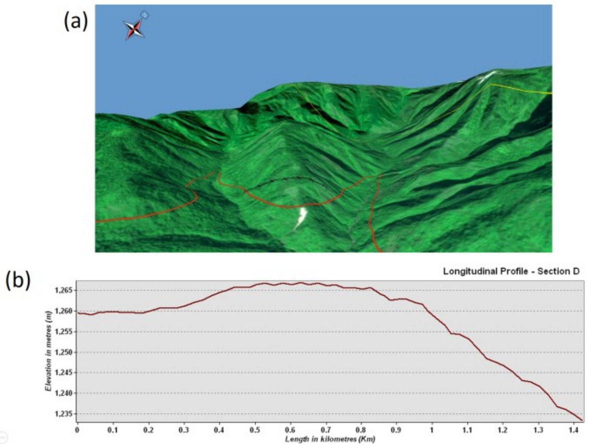

**Figure 16: (a) 3D-view and (b) longitudinal profile of D tunnel section**

Figure 17 a &17 b shows the 3D-view and longitudinal profile of 'E Section'.

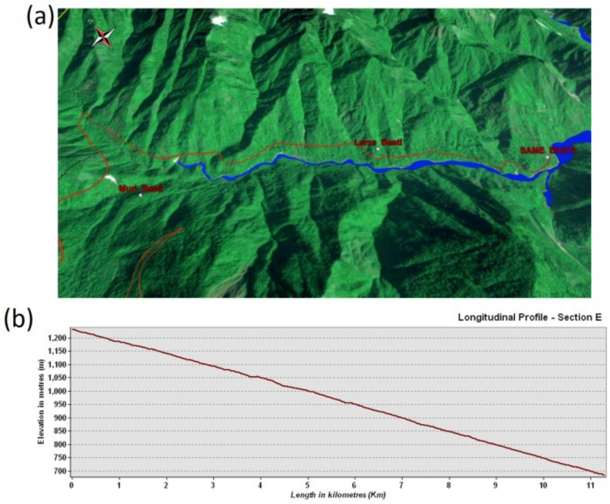

**Figure 17: (a) 3D-view and (b) longitudinal profile of E section**

In the suggested 'A section' of the route, it is well observed that there are two hairpin bend curves (Hairpin Bend Curve 1 & 2) and one major curve over the Sipung Korong stream is indicated as Major Bridge Location–1 in satellite data with suggested length of 100 m approximately. Three major curves are observed in the suggested 'C Section' out of which one is hairpin bend (Hairpin Bend Curve–3) one is major curve (Major Curve – 2) which is indicated as major bridge location-2 with approximate length of 45 m over the Sipinala. In the 'E Section' of the route, three major bridges are suggested over the Sikhu Nala (Major Bridge Location-3), Namsi Nala (Major Bridge Location-4), Same Nala (Major Bridge Location-5) with approximate length of 122 m, 99 m and 100 m respectively. Locations of major bridges and curves on Satellite data are shown in figure 18.

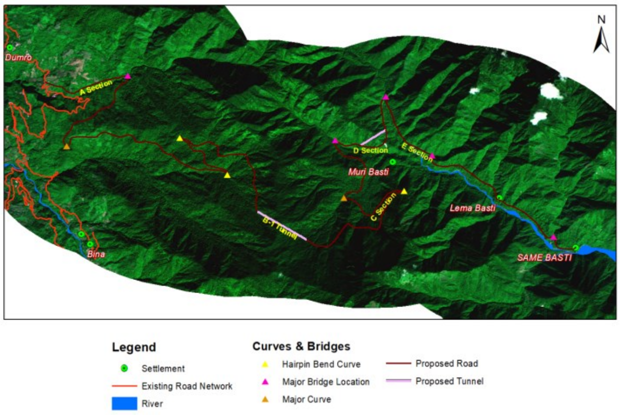

**Figure 18: Locations of major bridges and curves on satellite data**

## 4. Conclusion and recommendations

From the results and discussion, it is clearly indicated that remote sensing techniques aided with limited field investigation are very useful in various stages of preliminary study of the area especially where the accessibility is very poor. On the other hand, GIS played a significant role in providing the most feasible and shortest alignment of new route/road since it has the capability of handling large spatial data and integration. In the entire process of alignment, an attempt has been made to follow the criteria strictly and maximum effort has been given to avoid the existing active landslide areas as well as high and very high categories as indicated in the susceptibility map. However, it may be noted that during and/ or after the construction of the road, different category of different category of susceptibility zone may change into another due to the disturbance on the stability of slope. The environment of the area may be affected in micro or meso scale due to felling of trees as well as wildlife habitats.

The following points are put forward as recommendations

- Proper channelization of seepage zones.
- Adoption of slope and landslide protection measures wherever possible such as afforestation and other conservation measures (engineering & bio-engineering), terrace cultivation on steep slopes, etc.
- Protection of river bank erosion or toe cutting.

**Limitations**

More than 90% of the study area is inaccessible so that limited field investigation was concentrated along the road for some of the parameter used in the study. It may also be noted that, soil texture map was derived from available small scale soil map so that it is highly generalized and arbitrary in nature. Geo-technical properties of rocks such as dip-slope relationship, fracture/ joint patterns, their orientation and tectonic relationship are not included in the study. Hence, the landslide susceptibility map generated is qualitative in nature and provide only broad idea about the spatial likelihood of occurrence of landslide in future. Moreover, since the alignment of the route is mandatory with strict gradient criteria and predefined approximate length, complete avoidance of very high and high landslide susceptible zone is hardly possible. In addition, due to resolution of the satellite data used and working scale factor, detection/ identification of number of culverts, minor bridges etc. which require extensive ground information are not included in this scope of the work.

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