# GIS in analyzing Topography to locate Infrastructure facilities in Hilly regions

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## Abstract:

Topography plays important role in identifying adverse locations that may delay construction, increase development and construction cost besides creating the safety and security related issues. It helps in pinpointing areas that can be developed with minimum resources or to be restricted. In current practice architects or engineers use 2D contour maps for analyzing hill sites and locate infrastructure facilities on the basis of their knowledge and experience. The geographic information systems (GIS) help in evaluating topographical aspects by modeling topography. It portrays the complete picture of the topographical information of the hill region where infrastructural facilities were proposed and likely to be located. This paper highlights various topographical aspects that play a significant role in locating infrastructure facilities. The developed GIS-based methodology was demonstrated in evaluating the infrastructure facilities of the campus of Jawaharlal Nehru Government Engineering College (JNGEC) Sundernagar, India, as a case study.

Keywords: GIS, topography, site selection, geospatial analysis.

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## Introduction

The infrastructure facilities in any hilly region are located after comprehensive understanding of topography of area. Usually, architects or engineers accomplish the task of locating various infrastructure facilities. In current practice architects or engineers consider the topographical aspects manually in locating infrastructure facilities, result vary from person to person.

In hilly regions, understanding of topographical aspects is essential for pinpointing the infrastructure facilities that are placed in disadvantageous locations. The issue is most significant for architects or engineers. The evaluation of locations of facilities along with topography and surrounding conditions clearly indicates whether an infrastructure facility is correctly located or not, especially when these facilities are to be on undulating land where topography surroundings and other aspects have a considerable role to play. Considering the topographical aspects in locating infrastructure facilities in hilly regions shall help in achieving sustainability concepts [1].

In developing countries, project fails because of poor understanding of topographical aspects thereby locating infrastructure facilities at disadvantageous locations [2]. The process of locating the infrastructure facilities after proper understanding at suitable locations shall reduce development and construction costs [3]. Therefore, prior to locating infrastructure facilities, architects or engineers should understand topography, surrounding and their impact on the development of the hilly region.

The ascertaining a proper location for an infrastructure facility is always a significant issue [4]. It necessitates a complete understanding of topography of a region [5]. Studies [6]; [7] recommended that facility designers can affect location of facility by isolating disadvantageous locations. The appropriateness of location for any particular facility is based on physical parameters and economic factors. The physical parameters of the land are evaluated through analyzing the topographical aspects like slope, elevation, and runoff patterns.

The evaluation of physical parameters indicates the constraints of the land for locating a particular infrastructure facility. The constraints need to be considered with respect to the topography and surrounding for ensuring sustainability of a region.

Rajendran and Gambatese [8] suggested that the sustainable development of hilly regions can be ensured if topography is considered while locating various infrastructure facilities. The sustainable growth of a hilly region necessitates visualization of topography, surrounding environment and spatial relationships among existing and proposed infrastructure facilities [9]. The traditional way of facilities location includes efforts of various experts to select the most appropriate location by considering the available information. The process depends on experience, knowledge and individual's perspective in understanding of topography and thereby facility location, which leads to variations in interpretation.

2D maps, and sketches are used in deciding locations of infrastructure facilities. Architects or engineers' ideas are represented through solid three-dimensional (3D) models and CAD-based 3D models [10]. CAD-based 3D modeling focuses on the visualization, whereas evaluation of topography and surrounding requires database management, graphical and non-graphical analyses, and geo-spatial analysis where CAD-based systems are lacking. Hence, architects or engineers have to repetitively organize, interpret, and link graphical and non-graphical information manually to evaluate the locations of infrastructure facilities.

The locations of facilities in a hilly region where topography plays major role cannot be decided without modeling topography, surrounding and geo-spatial analysis capabilities [11]; [12]. Such inter-dependence cannot be easily modeled in absence of GIS. It facilitate in perceiving and exploring the effects of locating a new facility in the neighborhood of existing facilities/utilities [13]. Cheng et al. [14] developed a GIS-based decision support system (DSS) to help the construction engineers. It improves the effectiveness of instrumentation programs; integrate location-based and thematic information, graphical displays, and database queries. Bansal [15] suggested that the use of GIS for retrieving the information from database can help architects or engineers in decision making. Manase et al. [16] developed GIS-based accident prevention (GISAP) system with GIS capabilities that can enhance the analysis of fragmented information. Cheng and Ko [5] developed a decision support system (DSS) for monitoring of hillsides safety.

## Need for study

Although there is a lot of information available nowadays but due to the lack of an integrated framework to manage, manipulate, analyze, and present information, majority of the available information is poorly utilized, resulting poor location the infrastructure facilities. CAD-based techniques do not include provision to consider the topographical aspects of a region. Also, visualization provided by them is not easily customizable and moreover their use is somewhat difficult [17].

Computer-aided DSS developed by Cheng and Ko [5] and GIS-based DSS developed by Cheng et al. [15] did not utilize the full potential of GIS, however they were used for preliminary investigation of site conditions. Cheng and Ko [5] recommended that the use of GIS only to improve the graphical visualization and monitoring of hillsides conditions, whereas Cheng et al. [14] used GIS for integration of location-based and thematic information. Both the studies were based on fuzzy set theory, involving lengthy and time consuming process. Further, GISAP developed by Manase et al. [16] used many software packages which result lengthy and time consuming analysis, interpretation, and prediction of fragmented information.

With change in topography, site conditions vary from place to place and there is no integrated framework to analyze topography so as to locate infrastructure facilities appropriately in hilly regions. Literature indicates that there is a lack of responsive tools for evaluating locations of proposed facilities in hilly regions. A well-defined framework for pinpointing locations of adverse conditions and potential locations for infrastructure facilities has not been explored much. Therefore, the best way to enhance the sustainability of a hilly region is to consider the topography and surrounding.

Keeping in view the significance of GIS, experts create, store, and share information about 3D models of existing facilities along with surrounding topography [15]. Visualization of existing facilities along with surroundings, database management, and geospatial analysis capabilities on a single platform help in determining the locations the proposed facilities by using GIS. Kumar and Biswas [18] also suggested that GIS-based evaluation being simple and flexible can analyze the potential locations for the facility location in a hilly region.

GIS-based modeling of existing facilities along with topography facilitates architects or engineers in examining what adverse conditions exist, where? The work envisaged in the present study is an attempt to explore the potential of GIS. A location identified in accordance with topography strengthens decision making process and help in locating a facility more appropriately. To ensure that the topographical aspects influencing the location of infrastructure facilities in a hilly region are not overlooked; a framework has been evolved in the present study. It identifies those proposed facilities which are found in areas of adverse site conditions. This facilitates in taking corrective measures and locates the proposed facilities at more appropriate locations. The key objective of the present study to develop the GIS-based framework for locating infrastructure facilities in the hilly region was accomplished through:

- Identifying topographical aspects,
- Modelling of topography along with surrounding and

The developed framework was used for studying the infrastructure facilities' in the campus layout of Jawaharlal Nehru Government Engineering College (JNGEC) Sundernagar, India.

## Objectives

In order to ensure that the critical aspects influencing the location of infrastructure facilities in a hilly region are not overlooked, a framework has to be evolved. The present study explores the application of GIS taking into account the topographical aspects. It identifies those proposed facilities which are located in areas of adverse site conditions. This facilitates in taking corrective measures and locates the proposed facilities at more appropriate locations. Therefore, the main objective of the present study was to develop the GIS-based framework for locating infrastructure facilities in hilly region accomplished through:

Identification of aspects affecting site selection decisions, modeling of topographical and Geo-spatial analysis to identify infrastructure facilities located in areas of adverse locations.

The developed framework was used for assessing the infrastructure facilities' in the campus layout of Jawaharlal Nehru Government Engineering College (JNGEC) Sundernagar, India. The various topographical aspects and existing facilities/ utilities considered for evaluating the infrastructure facilities' in the campus layout of JNGEC, Sundernagar, have been discussed below:

## Aspects required to be considered

Topography symbolizes slope, and elevation of the hilly region. Topography can be preserved by locating a facility with respect to natural contours of a region. Selection of a location having minimum disturbance to the natural topography reduces retaining works, cut/fill, construction cost, and ultimately enhances location-based safety [15]. The elevation of a location is another factor that is important for deciding the facility location in a hilly region. A location on higher elevation is considered suitable for overhead tank whereas a location on lower elevation is suitable for rain harvesting water tank. In a hilly region, understanding of how water flows naturally and after a change in topography is also very important important in locating infrastructure in the hilly regions. Beside topographical aspects, other aspects that are crucial for locating infrastructure facilities include: Open space, existing facilities location of septic tank, utility services etc. Open space around a facility improves inside-out climate of facilities and abates heat-island effect by their ecological-balancer function [20]. It has also ecological and environmental importance. Open space left around and in between two facilities provide light, ventilation, and ensures safety to the existing facility and its users during construction [21]. Utility services furnish an everyday necessity to the public at large. Public utilities provide water, electricity, natural gas, telephone service, and other essentials. Water supply line laid with respect to the topography ensures proper water supply besides ensuring its safety during catastrophes. A sub-soil dispersion system should be located away from the nearest habitable building as economically feasible [19].

## GIS-based framework

The detailed criteria involved in developing the GIS-based framework for locating facilities in the hilly region has been discussed below:

## Modelling of Topographical aspects

To evaluate the impact of topography in JNGEC campus of an area of more than ten acres, a surface model (digital representation of a surface in 3D), triangulated irregular network (TIN) as shown in Fig. 1 was developed. The .pdf file of architectural drawing showing contours, existing facilities/utilities, and proposed facilities was converted into an image file and used for digitisation in ArcGIS. The contours were digitized from image file, assigned elevation values in the corresponding rows of the attribute table. The resulting feature class was converted to TIN in ArcGIS. The 2D aerial photograph of campus as shown in Fig. 2 was draped over the developed TIN to facilitate visualisation of the open space and topography of the campus.

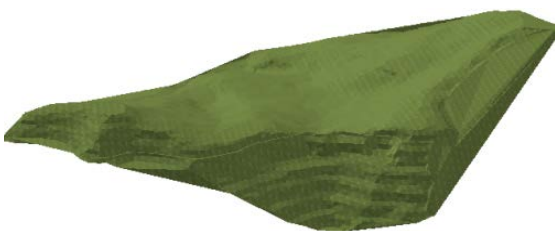

Fig: 1- Surface model (TIN) of JNGEC campus

Fig: 2- 2D aerial photograph of campus.

## Modelling of Existing facilities/utilities

The existing facilities/utilities in present case include: buildings, roads, sub-soil dispersion system, and overhead electrical supply lines, along with proposed facilities were digitized from image file, assigned elevation values in ArcGIS. The existing facilities/utilities were modelled to visualize their impacts in locating the proposed infrastructure facilities. Later on, the footprints of existing facilities were exported for 3D modeling. All existing facilities were modelled on their respective footprints (Fig. 3), and imported back to ArcGIS as 3D *multipatch* in the *geodatbase* [22].

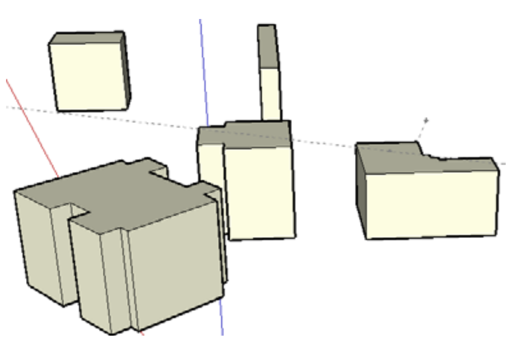

Fig: 3- 3D modeling of existing and proposed infrastructure facilities/utilities

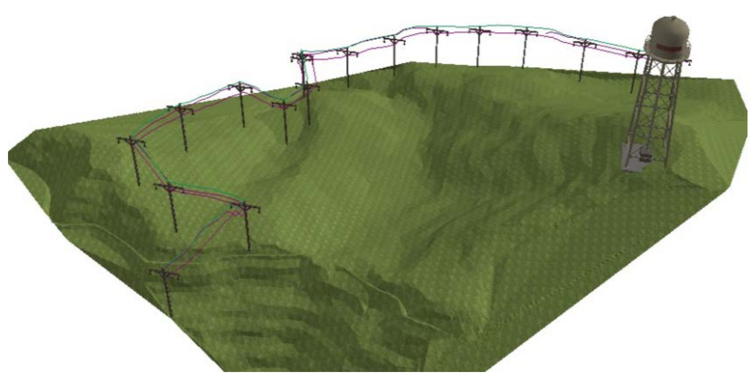

Fig: 4- 3D view of topography and infrastructure

## Integrating Topographical aspects with Existing facilities/utilities

Existing facilities/utilities were placed on their respective locations on the topographical model developed earlier. The integrated model of surface and facilities helps in measuring horizontal distances, elevation, and slope on a surface (Fig. 4). Fig. 5 gives 3D view of existing and proposed facilities/utilities along with topography. It helps in the visualisation of spatial relationships among existing facilities/utilities required in locational evaluation of proposed facilities.

## Development of Input Datasets

Input datasets are information pertaining to topography and facilities. In order to develop GIS-based framework to pinpoint adverse locations of proposed facilities, input datasets like elevation, land use as raster datasets whereas electric line sub-soil dispersion system, existing buildings and road as feature class were created in ArcGIS. For the present case study, five topographical aspects are used as input datasets in ArcGIS (as shown in Tab.1), however, numbers of input datasets vary depending upon type of project under consideration.

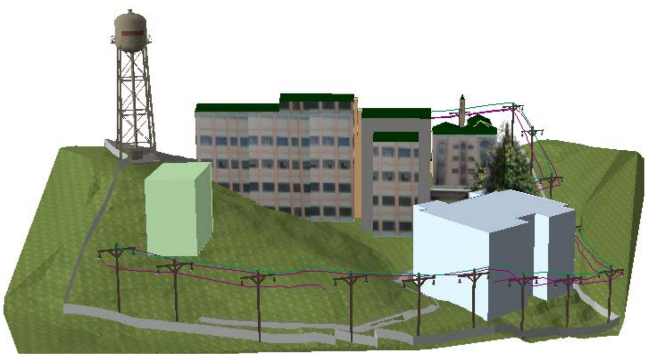

Fig: 5- 3D view of existing and proposed infrastructure facilities with topography.

**Table 1 GIS input dataset**

| Sr. No. | Input dataset | Type of dataset |
|---|---|---|
| 1 | Elevation | Raster dataset |
| 2 | Land use | Raster dataset |
| 3 | Electric line | Feature class |
| 4 | Sub-soil dispersion system | Feature class |
| 5 | Existing building | Feature class |
| 6 | Road | Feature class |

## Analysis

Elevation raster of the region derived from TIN gives overall idea of the elevations of various locations on a hilly region, similarly runoff pattern dataset facilitates in visualizing how water naturally flows in the region. Slope dataset derived from TIN help to identify steep or flat portion of the region. The derived datasets are presented as floating points, continuous, and in different ranges and are not comparable due to non-uniformity of datasets. Hence, to compare these datasets, derived datasets were re-classified to a common scale of 1 to 10. Higher scale values (SV) indicate more suitable attributes whereas lower values give an idea of less important attributes. For example, slope dataset was reclassified into 10 equal intervals. A higher SV was assigned to the almost flat terrain having lower slope range of 0-2° and lower SV to the steep portion having range of slope range 29-35° in the present case. Similarly, for re-classified elevation raster, higher SV was given to lowest elevation range of 208m to 223m lower SV to the highest elevation range of 313m -328m in present case. To know the natural flow of water of the study area, in case of re-classed stream order dataset the highest SV was given to the horizontal surface and lowest SV to the steep sloped area.

## Conclusion

The understanding of Topographical aspects along with existing facilities, open space etc. plays an important role for locating infrastructure facilities in a hilly region. It affects the development of the region and ensures construction safety. The various aspects considered provide a specific solution for evaluating locations of various infrastructure facilities/utilities. The inclusion of topography in analysis reduces the site development cost, construction cost, ensures construction safety, and the sustainability of a hilly region. The GIS used in present case study encourages architects/engineers to consider the topography in developing the GIS-based framework for assessing the locations of various infrastructure facilities. Geo-spatial analysis help in pinpointing infrastructure facilities/utilities which were located in adverse locations, and in turn help in developing the region more naturally.

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