

Kapoor, N.; Bansal, Vijay Kr.

Article

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Research Article

Spatial suitability assessment for planning infrastructure facilities at site level in hill areas

N. Kapoor^{a,*}, V.K. Bansal^b^aArchitecture Department, National Institute of Technology (NIT), Hamirpur, Himachal Pradesh, 177 005, India^bDepartment of Civil Engineering, National Institute of Technology (NIT), Hamirpur, Himachal Pradesh, 177 005, India

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ABSTRACT

Hill areas have gained considerable attention in recent years because of continuously increasing demand for infrastructure facilities. Spatial planning of infrastructure facilities is a challenging task in hill areas because of topographical variations, ecological sensitivity, and extreme climatic conditions. This becomes more critical because of the lack of an integrated quantitative approach for the assessment of land for its suitability. The paper aims at the spatial suitability assessment for planning infrastructure facilities at site level in hill areas. This has been accomplished in four stages; identification of the criteria, determination of weights of the criteria, spatial suitability assessment of the site, and scenario generation. In the first stage, a structured literature survey was done for the identification of the criteria influencing spatial planning of infrastructure facilities in the hill areas. In the second stage, an expert questionnaire survey was conducted for determining the percentage influence of the criteria and the responses were analysed through the analytical hierarchy process. In the third stage, spatial suitability map was generated in geographic information system for locating the infrastructure facilities. The vulnerability map was created for identifying the hazard prone areas. In the fourth stage, the developed suitability map and vulnerability map were aggregated to generate the scenario. A case study was taken for the implementation of the developed methodology which is useful for decision making for practitioners involved in the planning of infrastructure facilities in hill areas.

1. Introduction

Hill areas are increasingly becoming the focus of research to promote sustainable development (Tan & Mokhtar, 2011). Kapos et al. (2000) defined hill areas based on a combination of elevation and slope at a very fine resolution with operational definition of 6 categories ranging from 300 to 1000 m to more than 4500 m above mean sea level. The global hill area thus defined is almost 27% of Earth's surface. Meybeck et al. (2001) defined hill areas by preparing a catalogue of 15 relief classes based on a relief roughness indicator and altitude zones. Gasim et al. (2009) categorised the areas that have elevation more than 1000 m as mountains, 100–1000 m as hills, and 30–100 m as developable land. The spatial planning of infrastructure facilities in hill areas is a challenging task because of the sloping terrain, sharp gradients, complex geological structure, scarcity of developable land, proneness to natural disasters, and their ecological sensitivity (Rahman et al., 2017; Rimal et al., 2018; Saadati et al., 2012). Moreover, the topographical variation at micro-level poses enormous problems in the adoption of generalised norms and standards of planning. Hill areas are facing various issues which

* Corresponding author.

E-mail addresses: neetu@nith.ac.in, nitishakapoor@gmail.com (N. Kapoor), vkb@nith.ac.in, vijaybansal18@yahoo.com (V.K. Bansal).<https://doi.org/10.1016/j.jum.2021.02.003>

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include high-density development (Shekhar, 2011), congestion on desirable slopes (Hassan, 2008), development on steep slopes (Sekar & Thirumeni, 2009), unauthorised development (Government of India, 2014), and urban sprawl (Jutla, 2000; Shekhar, 2011; Sudhira & Ramachandra, 2007).

The issues of hill areas are because of poor spatial planning decisions; therefore, planners need new tools to equip themselves for meeting the growing technical requirements in planning practices. As a result, researchers came up with Planning Support System (PSS) which provides a set of such new tools that can assist planners to foresee the potential scenarios of land utilisation in the future and make better spatial planning decisions (Vonk et al., 2007). PSS generally functions at three levels: data structuring related to planning problem, optimising the planning processes, and virtual scenario generation. Few of the existing PSS are Community Viz (Kwartler & Bernard, 2001; Placeways, 2010), What If? (Klosterman, 2001; Pettit et al., 2013), and SPARC (Criterion Planners, 2014; SPARC, 2020). The acceptance of PSS has been low despite their widespread availability, the maturation of PSS tools, and their demonstrated abilities to improve planning outcomes (Geertman, 2016; Geertman & Stillwell, 2004; Wang et al., 2014).

Avin (2016) conducted a survey of users of existing PSS tools and identified limitations of the various tools individually. The key issue that hampers broad acceptance of PSS is that they do not fit the workflow of planner because they operate on the black box model (Vonk et al., 2005). A recently conducted international interview confirmed that PSS are not often used because they do not properly fit in the needs of users, considered difficult to use, and lack transparency (Russo et al., 2017). Waddell (2011) adds to this by listing various conflicts of using PSS for integrated land-use planning like non-compliance with land-use and environmental policy. Also, most of PSS tools are commercially available having high initial cost, which restricts their use at the local and site level. All tools run on complicated algorithms which hamper the transparency of the planning process, this in turn require experts for their use, making them less user-friendly (Vonk et al., 2005). Further, PSS tools lack uniform acceptance in various planning organisations in the developing countries (Wang et al., 2014). The common language between various tools for supporting interoperability is also missing. Hence, there is a need of a more transparent and user-friendly computer-based methodology that can be applied in the planning context to support the spatial planning process at site level.

Spatial planning, right from the site level to the state level and ultimately to the national level takes care of genuine felt needs of the masses by way of their spatial manifestation, planning, and development (Haughton et al., 2009). Existing studies on the spatial planning decisions are mostly limited to large-scale (regional and national) where the main purpose is the identification of suitable land for different land use through land suitability analysis (Phua & Minowa, 2005; Wang et al., 2013; Chakma, 2014; Liu et al., 2014; Parry et al., 2018), which is often neglected at small-scale (site level) spatial planning of the infrastructure facilities (Kumar & Biswas, 2013; Liu et al., 2007; Youssef et al., 2011). Land suitability analysis is an effective technique for identifying the best location for an infrastructure facility by considering different criteria and their weights (Collins et al., 2001; Javadian et al., 2011; Shen et al., 2009). There are limited studies on the land suitability analysis for small-scale, which result in a highly immeasurable and opaque spatial planning process at small-scale (Bansal, 2014; Flaxman, 2010; Hui et al., 2011). Lack of suitable methods to deal with the spatial planning problems and lack of empirical inquiry of the criteria affecting planning of infrastructure facilities at site level make it difficult for planners to check their decision for sustainability (Choguill, 2008). This leads to non-contextual, unplanned, and haphazard development in hill areas.

The literature suggests that the criteria influencing the spatial planning decisions through land suitability analysis are taken unsystematically (Carsjens & Ligtenberg, 2007; Jain & Subbaiah, 2007; Kumar & Biswas, 2013; Yang et al., 2008; Youssef et al., 2011). Land, in general, is allocated for different infrastructure facilities without attention to certain criteria like topography, solar exposure of the site, direction of slope inclination, green cover, and type of soil. There has been little systematic empirical work for identifications of criteria affecting the spatial planning decisions and evaluating their weights in areas like coastal and peri-urban plain areas (Latinopoulos et al., 2012; Pourebrahim et al., 2011), but limited work has been reported on site level spatial planning in hill areas, which are under the pressure of increasing demand of infrastructure facilities. Moreover, the existing studies for different contexts and levels of spatial planning have taken up the weights of the unsystematically selected criteria without using any scientific base (Carsjens & Ligtenberg, 2007; Jain & Subbaiah, 2007; Kumar & Biswas, 2013; Yang et al., 2008; Youssef et al., 2011). There are several methods to find weights of criteria using expert opinion. Malczewski (1999) compared different methods of criteria weighting: ranking, rating, pairwise comparison, and trade-off analysis and concluded that the pairwise comparison methods offer much more precision in terms of calculating weights as compare to other methods and has underlying theoretical bases. The method that introduced the use of pairwise comparison for determining criteria weights is Analytical Hierarchy Process (AHP).

Hence, there is a need for the development of a more transparent, rational, and understandable methodology for spatial suitability assessment of the site under consideration, which defines the logical steps for spatial planning of the infrastructure facilities for sustainable development of hill areas (Zheng et al., 2014).

2. Study objectives

The main aim of the present study was to develop the methodology for spatial suitability assessment for planning the infrastructure facilities at the site level in hill areas. This was accomplished through identification of all suitability and vulnerability criteria influencing spatial planning at the site level in hill areas. The percentage influence of the each identified criterion was determined for the spatial suitability and vulnerability assessment of land for each desired zone of the proposed development. This assessment helps in scenario generation through the aggregation of suitability and vulnerability maps of the site under consideration. The developed methodology was implemented by taking the case study of a university campus proposed at Hamirpur District of Himachal Pradesh, India.

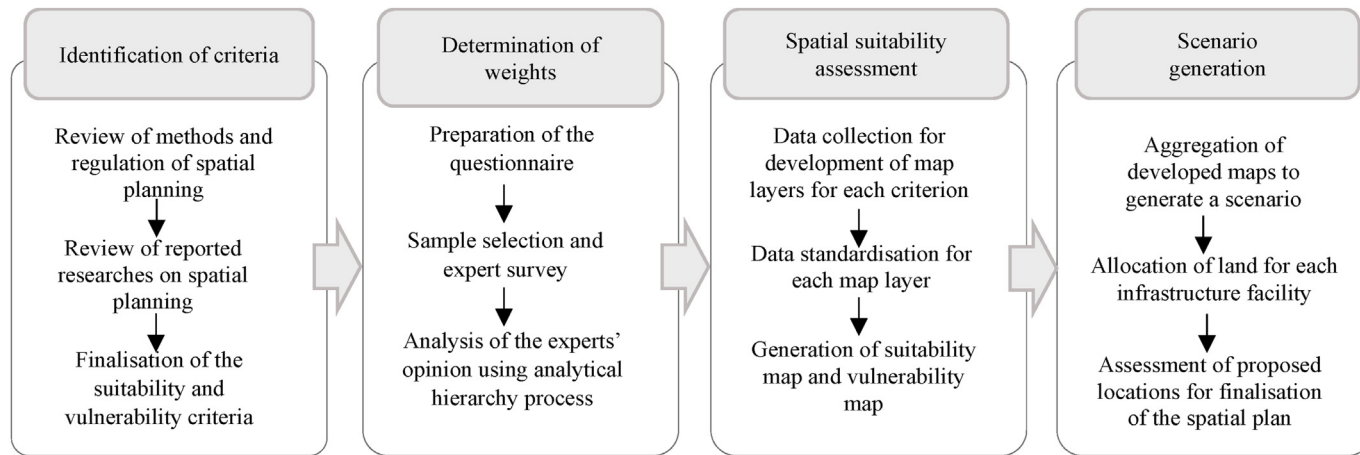


Fig. 1. Methodology for the spatial suitability assessment for planning of infrastructure facilities in hill areas.

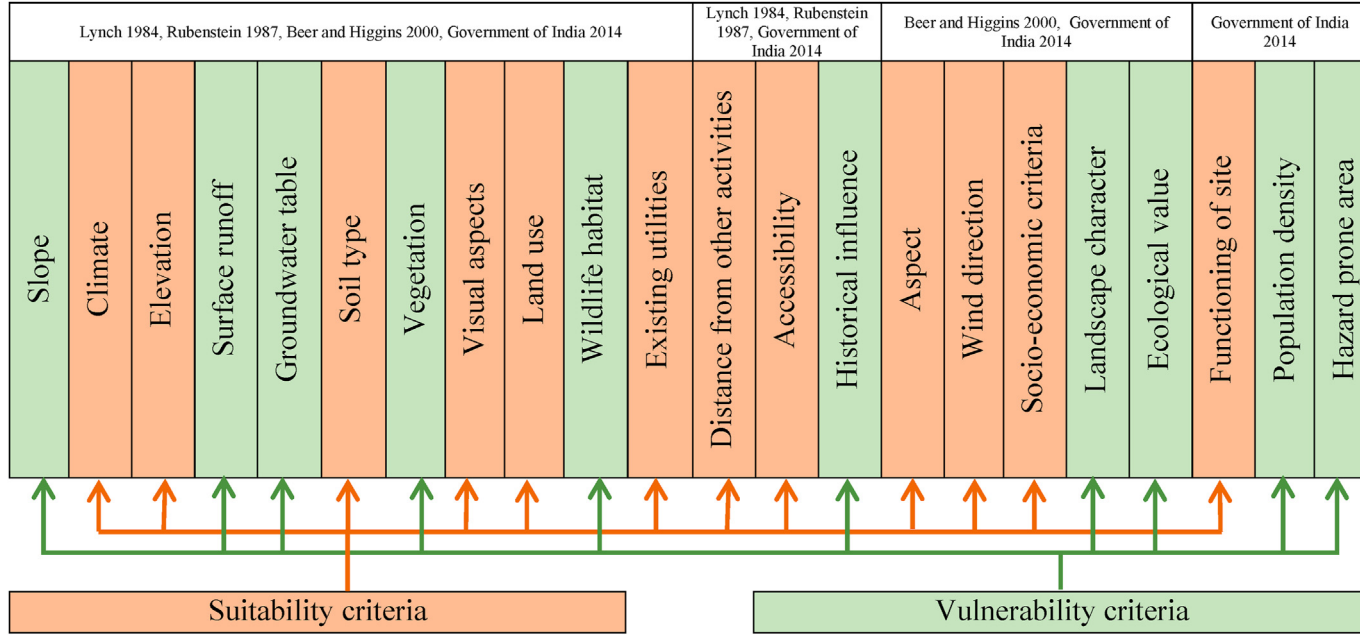


Fig. 2. Comprehensive list of criteria affecting spatial planning in hill areas.

3. Study area

The proposed new campus of Himachal Pradesh Technical University (HPTU) was selected as the case study for the implementation of the developed methodology at the site level. HPTU was established by the Government of Himachal Pradesh, India to impart the technical education across the state. The campus lies between the latitude of 31°40'30"N to 31°41'30"N and longitudes of 76°28'40"E to 76°29'40"E in a hilly terrain which makes it vulnerable to many natural hazards. The site has not been mapped in the hazard prone map developed by Survey of India (Survey of India, 2020). Further, the area of the site is approximately 130 acres (526091 square meters), which is larger than many villages in Himachal Pradesh, India. The site is situated at an altitude of about 785 m with a warm and temperate climate. The meteorological data for the site was obtained from the data acquisition system installed at National Institute of Technology (NIT) Hamirpur, Himachal Pradesh. The average annual temperature of the site is 21.6 °C and it receives about 280 days of sunshine over a year. It gets approximately 1572 kWh/m² radiation in a whole year. The highest amount of solar radiation approximately 195.8 kWh/m² is received in the month of May and the lowest approximately 80.9 kWh/m² is in the month of January.

The site has to accommodate various academic, administrative, and residential facilities. The site has constraints of existing water channels, overhead electric power line, electric poles, and some private properties inside it. Moreover, the site is in four parts, which were to be connected with the efficient road network. All these constraints make the spatial planning of the infrastructure facilities in the campus a tedious task. The campus requires integrated spatial planning for allocation of land for different facilities in the three different zones, which are *built-up area*, *open area*, and *green area*. In addition to this, the hazard prone locations were also required to be identified. This made it the most suitable site to be taken as case study for the implementation of the methodology to be developed.

4. Development of methodology and its implementation

The methodology for the spatial suitability assessment for the planning of infrastructure facilities in hill areas has four stages. All stages have different functions and are linked to each other in terms of data flow for providing solution as shown in Fig. 1. The first stage is the identification of the criteria, which was done through an extensive literature review. The identified criteria were categorised into suitability and vulnerability criteria. The second stage is the determination of the weights of the criteria required for spatial suitability assessment. The expert questionnaire survey was conducted and analysed with the help of AHP for finding out the weights of the criteria. The third stage is spatial suitability assessment, for which the process was developed in Geographic Information System (GIS). This includes the generation of suitability map and vulnerability map of the site under consideration by using the weighted overlay of the respective criteria maps. The fourth stage is scenario generation through the aggregation of the suitability map and the vulnerability map created in the third stage.

GIS has advanced spatial analysis capabilities, which may help in the spatial suitability assessment for the allocation of suitable land for a particular infrastructure facility (Dhiman et al., 2018; Ervin, 2011). This leads to the development of spatial suitability map for allocating land for the infrastructure facilities and development of vulnerability map for the identification of hazard prone locations. The suitability map and vulnerability map are aggregated for the visualisation of the future development of a site under consideration known as a scenario. The scenario is a composed image of the development patterns of an area that would result from a particular spatial plan implemented at a certain point in time. GIS assists planners to generate different scenarios efficiently and logically (Abdoli et al., 2018; Government of India, 2014).

4.1. Stage 1: identification of criteria

Identification of the criteria influencing planning decisions at the site level for hill areas was done in the following three steps.

4.1.1. Review of methods and regulations of spatial planning

In the first step, the methods of spatial planning at the local level and site level proposed by eminent planners and the planning regulations for the development of hill areas in India have been reviewed. The criteria suggested after removing all repetition have been enlisted as shown in Fig. 2. The methods include the technical method by Lynch (1984) and the experimental method by Rubenstein (1987) and Beer and Higgins (2000). In addition to this the guidelines provided by Ministry of Urban Development, Government of India for Urban and Regional Development Plans Formulation and Implementation (URDPFI) (Government of India, 2014) have also been reviewed. The criteria considered by Lynch (1984), Rubenstein (1987), Beer and Higgins (2000), and Government of India (2014) are *slope*, *climate*, *elevation*, *surface runoff*, *groundwater table*, *soil type*, *vegetation*, *visual aspects*, *land use*, *wildlife habitat*, and *existing utilities*. The list was further expanded by adding criteria which are common in the three studies by Lynch (1984), Rubenstein (1987), Government of India (2014) which include the *distance from other activities*, *accessibility*, and *historical influence*. The list was further expanded by adding criteria common in Beer and Higgins (2000) and guidelines provided by Government of India (2014) which include *aspect*, *wind direction*, *socio-economic criteria*, *landscape character*, and *ecological value*. At last the criteria suggested by only Government of India (2014) were added which include consideration of *functioning of the site*, *population density*, and *hazard prone area* as additional criteria influencing spatial planning. The first step of the literature review led to the identification of a total of 22 criteria after the elimination of all the repetitions.

4.1.2. Review of reported studies

In the second step, reported studies on spatial planning after the year 2000 were reviewed in order to supplement the criteria enlisted in the first step. The criteria considered by identified 30 researchers have been enlisted (Supplementary Table 1). It was found that all

the criteria considered by various researchers were already present in the list made in the first step. Hence, there was no additional criterion to be included in the list. The identified 22 criteria were categorised into suitability criteria and vulnerability criteria. *Climate, elevation, soil type, visual aspects, land use, existing utilities, distance from other activities, accessibility, aspect, wind direction, socio-economic criteria, and functioning of the site* were considered as suitability criteria, which will help in identification of the suitable land for locating the infrastructure facilities in hill areas. However, hill areas are vulnerable to many natural and man-made hazards, which are assessed using the vulnerability criteria (Zhou & Liu, 2012). The vulnerability criteria include *slope, surface runoff, groundwater table, vegetation, wildlife habitat, landscape character, ecological value, population density, and hazard prone area*. The comprehensive list of criteria with different categorisation is shown in Fig. 2.

4.1.3. Finalisation of the criteria

In the third step, the matrix was developed between the 22 criteria identified and their sources as shown in Supplementary Table 2. The matrix helped in determining the frequency of occurrence of the criteria as shown in Fig. 3. The context of the site for the proposed infrastructure does not need consideration of *wildlife habitat, distance from other activities, historic influence, socio-economic criteria, functioning of site, and population density*. Hence, the list of 22 criteria identified was condensed to 16, based on the relevance of the criteria to the context of the case study site. Moreover, the site has not been mapped in the *hazard prone* map developed by Survey of India (Survey of India, 2020). The vulnerability of the site for multi hazard was planned to be evaluated by using the vulnerability criteria. Further, *landscape character* as a criterion was planned to be assessed through the vegetation analysis. The consideration of *ecological value* was done through the analysis of *slope* and *surface runoff* of the site. Hence, *hazard prone area, landscape character, and ecological value* were not considered, making the total of 13 suitability and vulnerability criteria as discussed below:

4.1.3.1. Suitability criteria. **Climate:** Climatic conditions that influence spatial planning decisions include precipitation, air temperature, and solar incidence. Microclimate varies greatly over short distances and over short time spans. Brown and Gillespie (1995) recommend a process for mapping site microclimate that identifies the site’s exposure to both solar radiation and wind (Beer and Higgins 2000). The microclimate of the area has a great influence on the spatial planning decisions. The microclimate is modified by *vegetation, slope, and aspect*. For example, shade trees interrupt the solar radiation that would otherwise reach the pavement, rooftops,

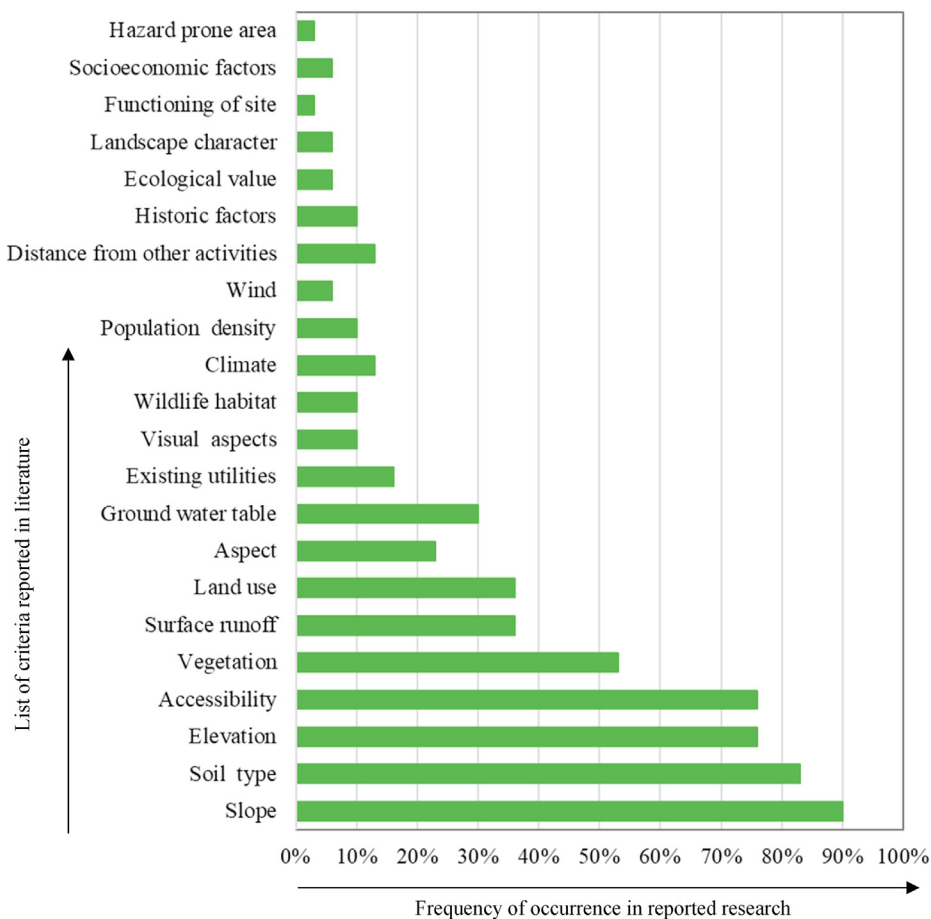


Fig. 3. Frequency of occurrence of criteria in reported research.

and other inorganic surfaces. *Slope* and *aspect* affect the amount of solar radiation touching the site's surface. Consideration of microclimate of the site is important for locating different facilities because it affects the energy consumption for heating and cooling of buildings and the comfort of people in outdoor settings.

Elevation: Elevation of a location is its height above a fixed reference point, most commonly the Earth's mean sea level. It has a significant influence on planning decisions in hill areas because of their effects on various other criteria like drainage pattern, visibility, and wind pressure (Kraus & Charvátová, 2016). The locations at different elevation levels of a site are suitable for different type of infrastructure facilities. For example, a location on higher *elevation* is considered suitable for overhead tank whereas a location on the lower *elevation* is suitable for rain water harvesting tank.

Soil type: It is described as a systematic categorisation of soil in terms of its texture like sand, silt, and clay. Consideration of *soil type* is important because of its attributes like bearing capacity, fertility, permeability, etc. The suitability classes of different *soil types* for the particular use is represented with choropleth maps (Ditzler, 2017; Ferguson, 1999). Areas with highly erodible soils should be avoided for the construction of *built-up* facilities to safeguard potential structural problems, whereas areas with fertile soil should be used for *green areas* like agricultural fields, gardens, or forests.

Visual aspects: *Visual aspects* of a site affects its usability. Visual resources create memorable images of a site. The visual quality of a site itself, as well as visible off-site features are important to be considered before allocating land for a particular facility. The *visual aspects* of a site are mapped through viewshed analysis. A viewshed map graphically shows the locations that can be seen from an individual viewing point or line (Computer Terrain Mapping, 1997).

Land use: It refers to the use of land such as fields, water bodies, forests, and built-up spaces. For the contextual development, existing *land use* of the site should be considered before taking planning decisions (Richard, 2000). Spatial planning should protect natural areas, including wetlands, wildlife habitats, lakes, woodlands, open spaces, groundwater resources, and other economically productive areas including farmland and forests (Persson, 2013).

Existing utilities: Public utilities such as water supply networks, overhead electric supply lines, telephone lines, existing roads, and pathways provide everyday necessities to users of various facilities developed, thus affect the planning decisions in hill areas. It is important to understand where the *existing utilities* are located, before taking planning decisions, in order to determine the locations, where the new development will connect to the existing one (NBC 2016).

Accessibility: It is the degree to which a site is accessed by roads and other kinds of transportation modes. *Accessibility* of a site is required for the transportation of raw materials for construction as well as for providing other services (Curtis, 2008). Infrastructure facilities are located nearer to the existing road as far as possible because the construction of a new approach road is costly in hill areas and moreover it also disturbs the natural geological structure of hills (NBC 2016).

Aspect: It is the compass direction that a slope faces. It can have a strong influence on spatial planning in hill areas because it affects the microclimate of an area (Begum et al., 2010). In the northern hemisphere, the north side of slopes is often shaded, while the southern side receives more solar radiation in winters. In the northern hemisphere, a south-facing slope (more open to sunlight and warm winds) is warmer and drier due to higher level of evapotranspiration than a north-facing slope. At the hottest time of a day in the afternoon, the sun's rays are in the west that is why a west-facing slope will be warmer than a sheltered east-facing slope. The *aspect* of a location also affects its proneness towards landslide (Bai et al., 2008; Tian et al., 2010).

Wind direction: It is the current of air that is moving across the earth's surface. Seasonal and monthly data pertaining to *wind direction* is available from national weather services. Greater energy efficiency can be achieved by moderating winds and breezes near buildings. Wind speed and *wind direction* at a particular location over a period of time are graphically displayed with the wind rose diagram. When winds are of low velocity, they may be pleasant, but when velocity increases, they may cause discomfort or damage (Hsieh & Huang, 2016).

4.1.3.2. **Vulnerability criteria. Slope:** *Slope* is the gradient or incline/decline of the land. The value of *slope* may be expressed as a ratio, as a percentage or as an angle (Steven et al., 2013). *Slope* analysis is an important process that helps a planner in determining the developable portions of a site to ensure safe, cost-effective, and efficient planning solution (Rao, 2005). This process involves dividing the topography into various grades which create the desired patterns for given *land use*. NBC (2016) suggests that no construction should be done in areas with *slopes* above 30° or in landslide hazard zones.

Surface runoff: *Surface runoff* is the flow of water that occurs over the earth's surface due to rain, storm water, or other sources (Liang & Xie, 2001). *Surface runoff* often occurs because of impervious surfaces and topographic variation which create drainage patterns on the surface. When infrastructure facilities encroach existing drainage channels, their capacity to carry water decreases and the probability of structural harm to the infrastructure increases (Bindu & Mohamed, 2016). Hence, water should be channelised in order to avoid these risks.

Groundwater table: It is the upper level of an underground surface below which the *soil* or rocks are saturated with water. The depth of *groundwater table* is obtained through surface geophysical method or by measuring the water level in a shallow well (Komatina, 1994). The possible groundwater rise and its corrosive potential causes problems to the *built-up* facilities, which makes it an important criteria to be considered while taking planning decisions in hill areas.

Vegetation: Existing *vegetation* on a site is an asset that has many ecological, economic, and social benefits. The major part of existing *vegetation* on a site located in hill areas is trees. Planning decisions should protect existing *vegetation* and incorporate more *vegetation* into the proposed plan to make it more efficient and sustainable (Petit et al., 2004). Normalised Difference Vegetation Index (NDVI) is a standardised index used to monitor the density of green *vegetation* growth using the spectral reflectivity of solar radiation with values between -1.0 and +1.0 (Kaufman, 1989; Viña et al., 2004). Hillside with thick *vegetation* should be avoided as far as possible for

Table 1

A component of the developed questionnaire for the expert survey.

With respect to goal: Spatial planning in hill areas,

Using the scale from 1 to 9 (where 9 is extremely and 1 is equally important), please indicate (X) the relative importance of Climate (left column) to the suitability criteria enlisted in options B (right column) for locating *built-up* facilities.

A Option	Extremely	Very strongly	Strongly	Moderately	Equal	Moderately	Strongly	Very strongly	Extremely	B Option
Climate	9	8 7	6 5	4 3	2 1	2 3	4 5	6 7	8 9	Option
	9	8 7	6 5	4 3	2 1	2 3	4 5	6 7	8 9	Elevation
	9	8 7	6 5	4 3	2 1	2 3	4 5	6 7	8 9	Soil type
	9	8 7	6 5	4 3	2 1	2 3	4 5	6 7	8 9	Visual aspects
	9	8 7	6 5	4 3	2 1	2 3	4 5	6 7	8 9	Land use
	9	8 7	6 5	4 3	2 1	2 3	4 5	6 7	8 9	Existing utilities
	9	8 7	6 5	4 3	2 1	2 3	4 5	6 7	8 9	Accessibility
	9	8 7	6 5	4 3	2 1	2 3	4 5	6 7	8 9	Aspect
	9	8 7	6 5	4 3	2 1	2 3	4 5	6 7	8 9	Wind direction

locating new *built-up* infrastructure facilities.

4.2. Stage 2: determination of weights of the identified criteria

Determination of the weights of the identified criteria has been done in the following three steps:

4.2.1. Preparation of questionnaire

Two sets of questionnaire were developed for the expert survey. The questionnaire was designed as per the requirement of AHP and its software tools available (Goepal 2018; Goepel, 2014; Saaty, 1980). The first set has 8 sections in which each of the 9 suitability criterion was ranked against every other suitability criterion on the scale of 1–9, where 1 represents equal importance and 9 represents extremely important. In the first section of the questionnaire, *climate* was compared to *elevation*, *soil type*, *visual aspects*, *land use*, *existing utilities*, *accessibility*, *aspect*, and *wind direction* for the three categories of the infrastructure facilities which are *built-up areas*, *open areas*, and *green areas* as shown in Table 1. Similarly, the second set has 3 sections for ranking 4 vulnerability criteria with each other. The complete first set of the questionnaire, containing the comparison of suitability criteria, is shown in Supplementary Table 3. The developed questionnaire was pretested through the pilot survey and the respondents were from the same experts who were selected for the main survey. The pilot survey was done to check the probable response rate, appropriateness of the questions, and the clarity of the questionnaire. Based on their feedback, unclear terms were reformulated and necessary modifications were made in the developed questionnaire, which was mailed to the experts for the main survey.

4.2.2. Sample selection and expert survey

The selection of planning experts, as the sample used in the present study was made through purposive expert sampling technique. Literature of purposive expert sampling suggests that the domain knowledge and experience of the experts comprising the sample is more important than the number of experts (Nikolaos & Panagiotis, 2016; Oliver, 2006). The experts were selected from two groups. The first group consisted of government officials which include members of the Town and Country Planning Organisation (TCPO) and Public Works Department (PWD) situated in hill areas of various parts of India. The second group consisted of planning professionals from private planning and designing organisations and academicians. In total, 50 experts were selected, and the developed questionnaire was mailed to them. 26 (52%) responses out of 50 distributed questionnaires were received back. Out of 26, 19 (73%) responses were from the first group, and 7 (27%) responses were from the second group of the experts. 6 (23%) respondents were having less than 10 years of experience, 11 (42%) respondents were having about 20 years of experience, 5 (19%) respondents were having 25–30 years of experience, and 4 (16%) respondents were having more than 30 years of experience. The distribution and experience of the experts are shown in Fig. 4.

4.2.3. Analysis of questionnaire to determine weights of criteria

The expert survey results were analysed through AHP to determine weights of the criteria. The pairwise comparison matrix for the criteria was constructed for each expert survey. After that, each identified criteria value was normalised for generating the normalised matrix. For normalising the criteria value, each value in the pairwise comparison matrix was divided by its column total. The relative weights of the criteria for locating the *built-up* facilities were calculated for each criterion from the normalised pairwise comparison matrix.

AHP deals with consistency explicitly, because in making paired comparisons, people do not have the intrinsic logical ability to always be consistent (Saaty, 2000). To ensure the consistency of the responses, Saaty (1980) provided a single numerical index called

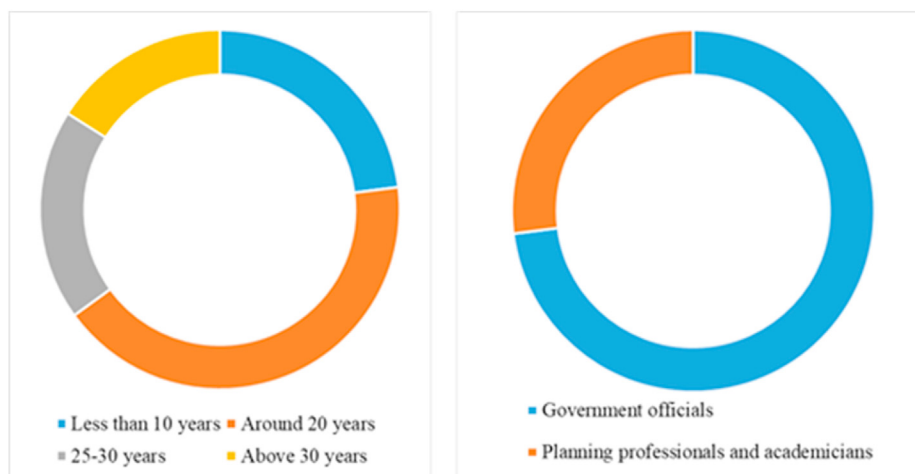


Fig. 4. Distribution and experience of experts.

consistency ratio (CR). In this study, CR was calculated to assess individual experts' consistency across all judgments. If $CR < 10\%$, the ratio indicates a realistic level of consistency in the pairwise comparisons; in case $CR > 10\%$, then the values of the ratio are indicative of inconsistent judgments. In such cases, the values should be reconsidered and revised in the pairwise comparison matrix. In the present expert survey, CR was calculated to check the consistency across the survey. The cumulative CR value for suitability criteria was 7.4% and for vulnerability criteria, it was 7.2%. The consolidated matrix of the weighted geometric mean of all the experts for suitability criteria are tabulated in [Supplementary Table 4](#). The consolidated matrix of the weighted geometric mean of all the experts for vulnerability criteria are represented in [Supplementary Table 5](#). The relative weights of the suitability and vulnerability criteria for locating *built-up* facilities are tabulated in [Table 2](#).

The analysis of experts' opinion through AHP has successfully identified *aspect* as the suitability criterion with highest weight of 31.5% for locating *built-up* facilities followed by *land use* and *existing utilities*, with respective weights of 16.5% and 15.1%. Whereas *slope* as the vulnerability criterion has the highest weight of 35% followed by *vegetation*, *surface runoff*, and *groundwater table* with respective weights of 23.8%, 21.8%, and 19.4% respectively. The other important suitability criteria with high percentage influence for locating *built-up* facilities are *accessibility*, *climate*, and *visual aspects* with the respective weights of 12.1%, 8.4%, and 5.1%. These are followed by the *wind direction*, *soil type*, and *elevation* which had the respective weight of 4.9%, 4.1%, and 2.4%. The evaluated weights of the suitability criteria were used in the spatial suitability assessment of the proposed site under consideration. The weights of the vulnerability criteria were used for identifying the multi hazard zone. Higher the weights for a particular criterion, more influence it will have in defining the *most suitable* locations for a particular facility in the proposed campus.

4.3. Stage 3: spatial suitability assessment

The process of spatial suitability assessment is divided into following three steps as shown in [Fig. 5](#).

4.3.1. Data sources for the development of map layers

The first step was to acquire geographical information from the data sources for creating map layers for the representation of the identified suitability and vulnerability criteria. The geographical information required for developing map layers was obtained from the field survey and the existing data sources provided by the Government of India. The field survey helped in the development of elevation raster of the study area. The four map layers derived from the elevation raster were *elevation*, *slope*, *aspect*, and *surface runoff*. For generating map layers corresponding to the *existing utilities* and *accessibility*, data related to existing road, water channel, and campus boundary was acquired from the field survey. NDVI was used to develop *vegetation* map layer by taking the satellite image of the study area as an input. Survey of India toposheets were used to prepare map layers corresponding to the *groundwater table*, *soil type*, and *land use*. The data related to *visual aspects* was generated by the veiwshed analysis performed on the elevation raster of the site. The data pertaining to the *wind direction* was acquired from the global wind atlas.

4.3.2. Data standardisation

All these map layers were developed in raster data format with similar cell size, for the determination of a score for each pixel. The score values were derived and standardised for the suitability and vulnerability criteria before combining these criteria. Unlike conventional standardisation methods, such as linear transformation, a scoring and ranking system was used to quantify the suitability and vulnerability levels which are from 1 to 4 where 1, 2, 3, and 4 represents *most suitable*, *moderately suitable*, *less suitable*, and *least suitable* conditions respectively as shown in [Table 3](#). The ranges for the criteria were decided on the basis of review of relevant codes ([NBC 2016](#)), planning regulations ([Government of India, 2014](#)), and relevant literature ([Dai et al., 2001](#); [Jain & Subbaiah, 2007](#); [Kumar & Bansal, 2016](#); [Kumar & Biswas, 2013](#); [Youssef et al., 2011](#)). Here, a higher score indicated higher degree of vulnerability or lower degree of suitability.

Table 2

Weights of the suitability and vulnerability criteria.

Suitability Criteria		Weights	Rank	CR
1	Climate	8.4%	5	7.4%
2	Elevation	2.4%	9	
3	Soil type	4.1%	8	
4	Visual aspects	5.1%	6	
5	Land use	16.5%	2	
6	Existing utilities	15.1%	3	
7	Accessibility	12.1%	4	
8	Aspect	31.5%	1	
9	Wind direction	4.9%	7	
Vulnerability Criteria		Weights	Rank	7.2%
1	Slope	35.0%	1	
2	Surface runoff	21.8%	3	
3	Groundwater table	19.4%	4	
4	Vegetation	23.8%	2	

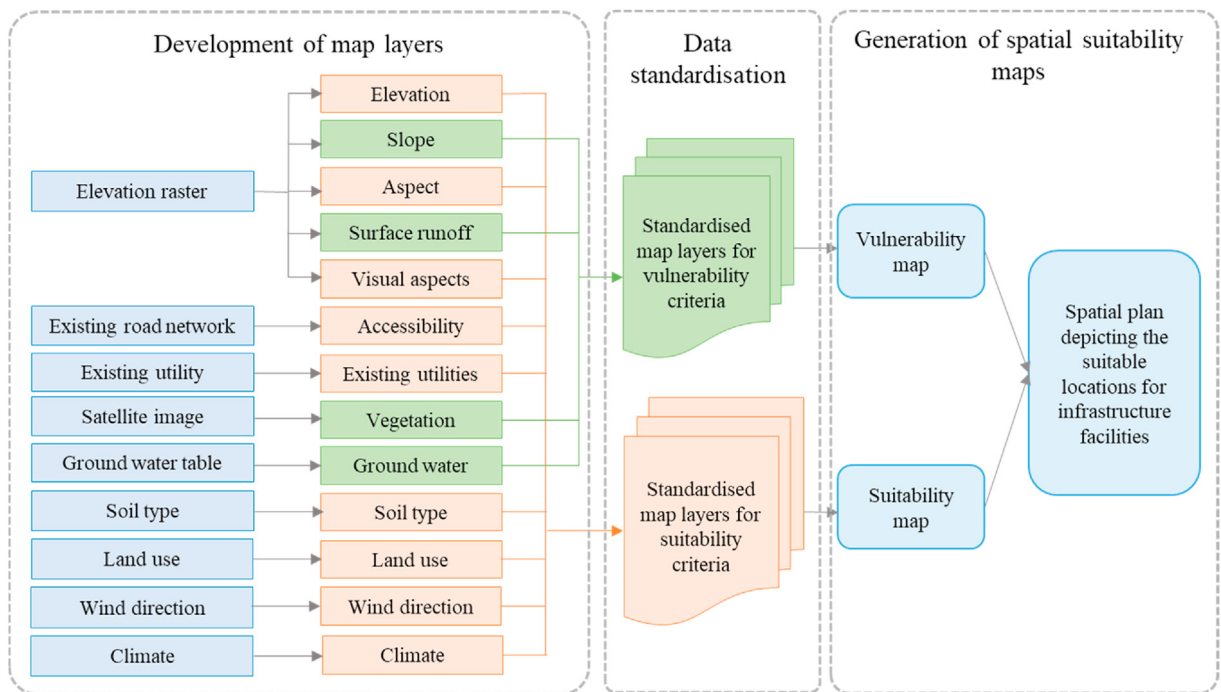


Fig. 5. Steps of the process for spatial suitability assessment.

4.3.3. Generation of spatial suitability maps

The third step is to generate suitability and vulnerability maps of the site. The map layers corresponding to the suitability criteria were overlaid in GIS using weighted overlay for generating suitability map of the site. The map layers corresponding to the vulnerability criteria were overlaid in GIS using weighted overlay for generating vulnerability map of the site. The weights derived from the analysis of expert opinion through AHP were assigned to each criterion for generating suitability and vulnerability maps by using the following formula:

$$\text{Vulnerability or Suitability map} = \sum [(\text{map layer}) \times (\text{weight})]$$

This categorised the proposed site into four classes of *most suitable*, *moderately suitable*, *less suitable*, and *least suitable* land for locating infrastructure facilities in the suitability map as shown in Fig. 6 and *least vulnerable*, *less vulnerable*, *moderately vulnerable* and *most vulnerable* locations prone to hazards in the vulnerability map as shown in Fig. 7.

4.4. Stage 4: scenario generation

In the fourth stage, the infrastructure facilities were located and the spatial plan of the campus was developed through scenario generation. The process of generation of scenario in the present study is divided into the following three steps:

4.4.1. Aggregation of developed maps

The first step for the generation of scenario representing spatial plan for the site under consideration was to aggregate the developed suitability and vulnerability map for the identification of the *most suitable* locations for the infrastructure facilities which are *least vulnerable* to any hazard. The developed aggregated suitability map is shown in Fig. 8.

4.4.2. Allocation of land for each infrastructure facility

The four classes in the aggregated suitability map are *most suitable*, *moderately suitable*, *less suitable*, and *least suitable*. The first step for allocating land for a particular facility was to remove the area under *less suitable* and *least suitable* classes. The land was allocated for each facility based on the minimum area required for the proposed facility and the land patch available under the *most suitable* and *moderately suitable* classes. For example, the cell size of the suitability maps in the present study was 6 m. So, the area of one cell count is equal to 36 square meters. The area required for the administrative building is 2000 square meters, which require minimum cell count of 55 or more. Moreover, the administrative building is required at the most accessible location. So, the potential land identified in the suitability map for *built-up*, having minimum cell count of 55, and easily accessible was allocated to the administrative building. Similarly, the other facilities were located depending upon the area required and cell count available under the *most suitable* and *moderately suitable* categories.

The same process was followed for allocating land for *open areas* and conserving the existing *green forest*. The areas which are

Table 3
Reclassified values of different criteria for locating built-up, open, and green areas.

Criteria	Reclassified value	Zones Built-up	Open	Green
Suitability Criteria				
<i>Climate</i>	Same for the whole site			
<i>Elevation (Meters)</i>	1 (Most Suitable)	801–870	701–750	630–700
	2 (Moderately Suitable)	751–800	751–800	701–750
	3 (Less suitable)	701–750	630–700	751–870
	4 (Least Suitable)	630–700	801–870	–
<i>Soil type</i>	1 (Most Suitable)	Calcareous fine loamy soils with moderate erosion	Calcareous fine loamy soils with moderate erosion	Fine loamy soil with severe erosion
	2 (Moderately Suitable)	Fine loamy soil with slight erosion	Fine loamy soil with slight erosion	Fine loamy soil with slight erosion
	3 (Less suitable)	Fine loamy soil with severe erosion	–	Calcareous fine loamy soils with moderate erosion
	4 (Least Suitable)	–	Fine loamy soil with severe erosion	–
<i>Visual aspects</i>	1 (Most Suitable)	Visible	Visible	Visible
	2 (Moderately Suitable)	Visible	Visible	Not visible
	3 (Less suitable)	Not visible	Visible	Not visible
	4 (Least Suitable)	Not visible	Not visible	Not visible
<i>Land use</i>	1 (Most Suitable)	Scrub land	Scrub land	Evergreen trees
	2 (Moderately Suitable)	–	Forest plantation	Forest plantation
	3 (Less suitable)	Agricultural plantation	Agricultural plantation	Agricultural plantation
	4 (Least Suitable)	Evergreen trees	Evergreen trees	–
<i>Existing utilities</i>	1 (Most Suitable)	More than 6 m from existing utilities	–	More than 6 m from existing utilities
	2 (Moderately Suitable)	–	–	–
	3 (Less suitable)	–	–	–
	4 (Least Suitable)	Within 6 m from existing utilities	–	Within 6 m from existing utilities
<i>Accessibility (Meters)</i>	1 (Most Suitable)	Within the reach of 100 m from a road	More than 100 m distance from main road	–
	2 (Moderately Suitable)	More than 100 m distance from main road	Within the reach of 100 m from a road	–
	3 (Less suitable)	–	–	–
	4 (Least Suitable)	–	No vehicular Access	No vehicular Access
<i>Aspect</i>	1 (Most Suitable)	South, South East, South West	South, South East, South West	North
	2 (Moderately Suitable)	West, East	West, East	North East, North West
	3 (Less suitable)	North East, North West	North East, North West	West, East
	4 (Least Suitable)	North	North	–
<i>Wind (Meters per second)</i>	1 (Most Suitable)	2.42–2.60	2.72–2.85	2.85–2.95
	2 (Moderately Suitable)	2.61–2.72	2.61–2.72	2.72–2.85
	3 (Less suitable)	2.73–2.85	2.42–2.60	2.61–2.72
	4 (Least Suitable)	2.86–2.95	2.85–2.95	2.42–2.60
Vulnerability Criteria				
<i>Slope (Degree)</i>	1 (Most Suitable)	0°–15°	0°–10°	Greater than 45°
	2 (Moderately Suitable)	15.1°–25°	10.1°–20°	30.1°–45°
	3 (Less suitable)	25.1°–35°	–	10°–30°
	4 (Least Suitable)	35.1°–45°	20.1° and above	–
<i>Surface runoff</i>	1 (Most Suitable)	4 m away from flow accumulation	4 m away from flow accumulation	Less than 2 m away accumulation
	2 (Moderately Suitable)	3 m away from flow accumulation	3 m away from flow accumulation	2 m away from flow accumulation
	3 (Less suitable)	2 m away from flow accumulation	2 m away from flow accumulation	3 m away from flow accumulation
	4 (Least Suitable)	Less than 2 m away from flow accumulation	Less than 2 m away accumulation	–
<i>Groundwater table (Meters)</i>	1 (Most Suitable)	40 to 50	40 to 50	32 to 40
	2 (Moderately Suitable)	32 to 40	32 to 40	40 to 50
	3 (Less suitable)	–	–	–
	4 (Least Suitable)	–	–	–
<i>Vegetation</i>	1 (Most Suitable)	NDVI -1 to 0	NDVI 0 to 0.5	NDVI 0.8 to 1
	2 (Moderately Suitable)	NDVI 0 to 0.5	NDVI -1 to 0	NDVI 0.5 to 0.8
	3 (Less suitable)	NDVI 0.5 to 0.8	NDVI 0.5 to 0.8	NDVI 0 to 0.5
	4 (Least Suitable)	NDVI 0.8 to 1	NDVI 0.8 to 1	–

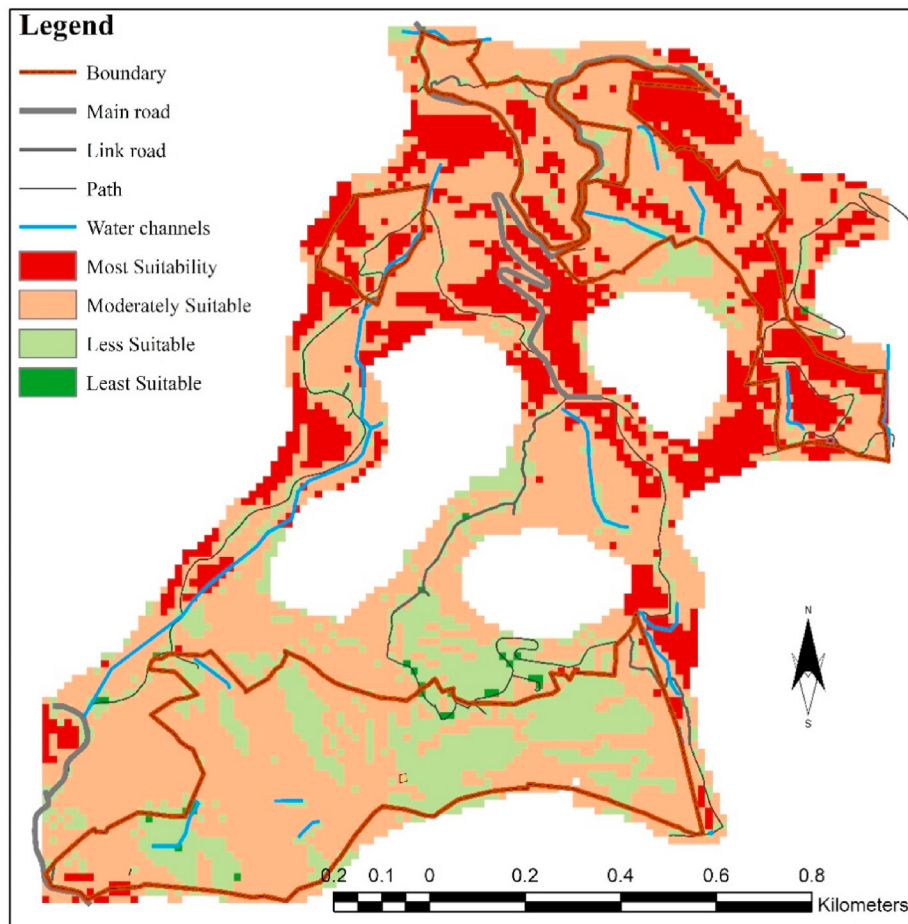


Fig. 6. Suitability map of Himachal Pradesh Technical University Hamirpur.

surrounding the land patches identified for *built-up* infrastructure were allocated for *open areas*, so as to provide the foreground to the proposed buildings as well as to enhance the light and ventilation in the buildings. The site under development for the proposed university campus has a forest in it, which need to be conserved. At the end of this step, the spatial plan of the proposed campus was developed as shown in Fig. 9.

4.4.3. Assessment of the proposed locations of different facilities for road connections

The land allocated for a particular infrastructural facility was assessed for the existing road connections. It was found that the four parts of the proposed site were already connected through existing roads. Only a few facilities were not connected through the existing road network, hence, new roads were proposed to connect these facilities.

5. Results and discussion

The present research addresses two major pitfalls of sustainable spatial planning in hill areas: environmental consideration while planning and governing the development process in a rational, logical, and transparent manner. Existing methods of spatial planning face a major challenge of achieving a balance between complexity in terms of handling a large number of input criteria and simplicity in terms of providing output in a user-friendly manner (Geertman, 2016). The methodology developed in the present study helps in achieving this balance by identification and evaluation of the various criteria and generating scenarios before taking spatial planning decisions. The involvement of experts in the evaluation of criteria in the methodology ensures the efficient planning decisions. Also the transparency of the methodology in terms of various analysis performed while taking spatial planning decisions ensures the active role of planners in taking the planning decisions. Whereas the black box modelling approach used in various existing spatial planning methods, disempowered planners and experts in the planning process (Pettit et al., 2013; Townsend, 2013). The methodology is systematic for geographic planning and decision making. It starts by collecting all the geographic knowledge pertaining to the site, maintaining it in the form of information layers, and plugging it into a new interactive process which helps in taking the planning decisions.

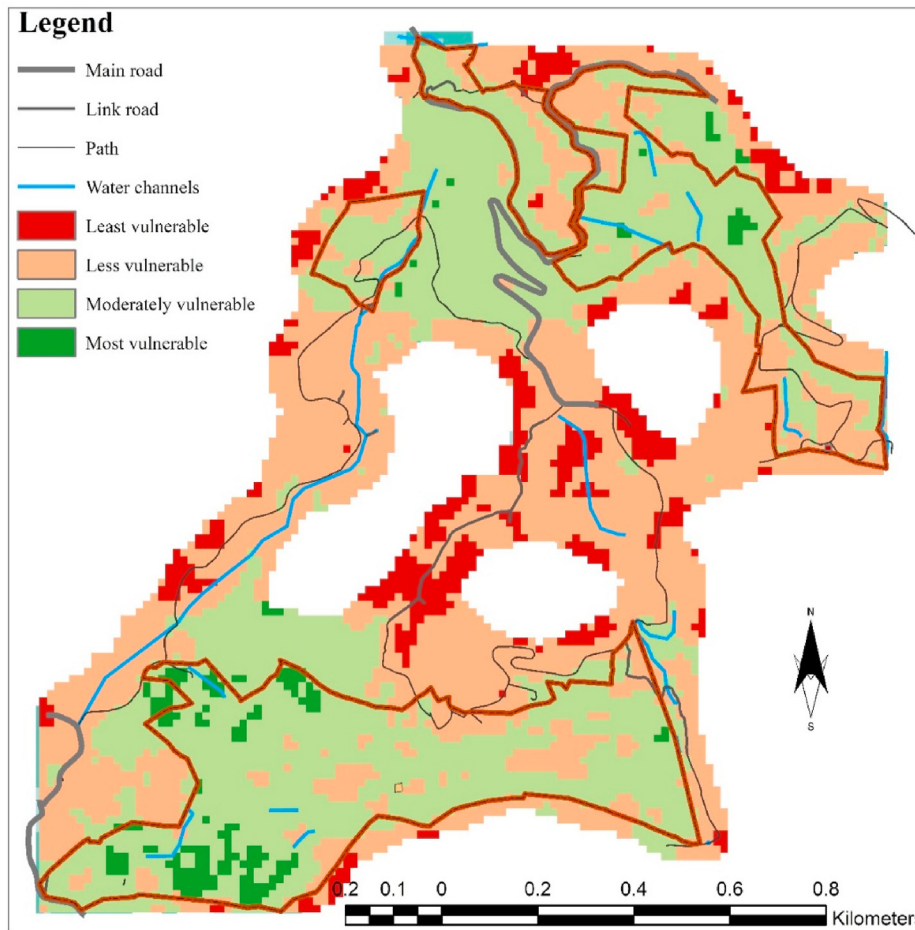


Fig. 7. Vulnerability map of Himachal Pradesh Technical University Hamirpur.

The expert survey conducted in the present research identified *aspect* as the suitability criterion with the highest weight of 31.5%. It indicates that the most important consideration while locating *built-up* facilities in hill areas is the *aspect* of the site to ensure maximum sunlight. Whereas, some of the researchers have not considered *aspect* while taking spatial planning decisions (Chandio et al., 2014; Dai et al., 2001; Nguyen et al., 2015). Similarly, *slope* was identified as the vulnerability criteria with highest weight of 35%. The most important challenge for locating *built-up* facilities in hill areas is its topographical variation. Most of the researchers have also identified *slope* as the most important criterion to be considered while taking spatial planning decisions (Dai et al., 2001; Marinoni, 2004; Xi et al., 2018; Xiao et al., 2018; Yang et al., 2008).

The implementation of the developed methodology in the present research resulted in the generation of the suitability map for the *built-up* infrastructure of an educational institution situated in hill areas. It also resulted in the generation of vulnerability map to identify the most vulnerable locations for hazards. The percentage of the land in the different classes of suitability and vulnerability are depicted in Fig. 10.

The results of suitability analysis show that 19.6% of the total land falls under *most suitable* class and 20% of the total land falls under *less suitable* class for locating *built-up* infrastructure. Whereas major part of the land which is 60.4% falls under *moderately suitable* class for locating *built-up* infrastructure. The results show that the major part of the site is *less suitable* for locating *built-up* infrastructure and the areas with the highest suitability values for the *built-up* areas are concentrated mainly in one part of the site under examination, which is having the highest elevation and is well connected with the road.

The vulnerability analysis of the site resulted in almost equal percentage of land under the *most vulnerable* and *least vulnerable* classes which are 6.5% and 7.5% respectively. Whereas the percentage of land under *moderately vulnerable* and *less vulnerable* are 44.5% and 41.5% respectively. This clearly shows that almost half of the land is under *most* and *moderately vulnerable* condition, which makes it more prone to any forthcoming natural hazard and less available for construction of *built-up* facilities. After aggregating both the results, the final map which depicted the 4 classes of land for locating the *built-up* infrastructure of the institutional campus has 9.8% land under *most suitable*, 67.5% land under *moderately suitable*, 22.4% land under *less suitable*, and 0.3% land under *least suitable* class. It was found that the spatial plan developed through the execution of the methodology has retained most of the dense vegetation present on the site, natural water drains, and the natural topography of the site. Thus, making the spatial plan contextually more responsive and

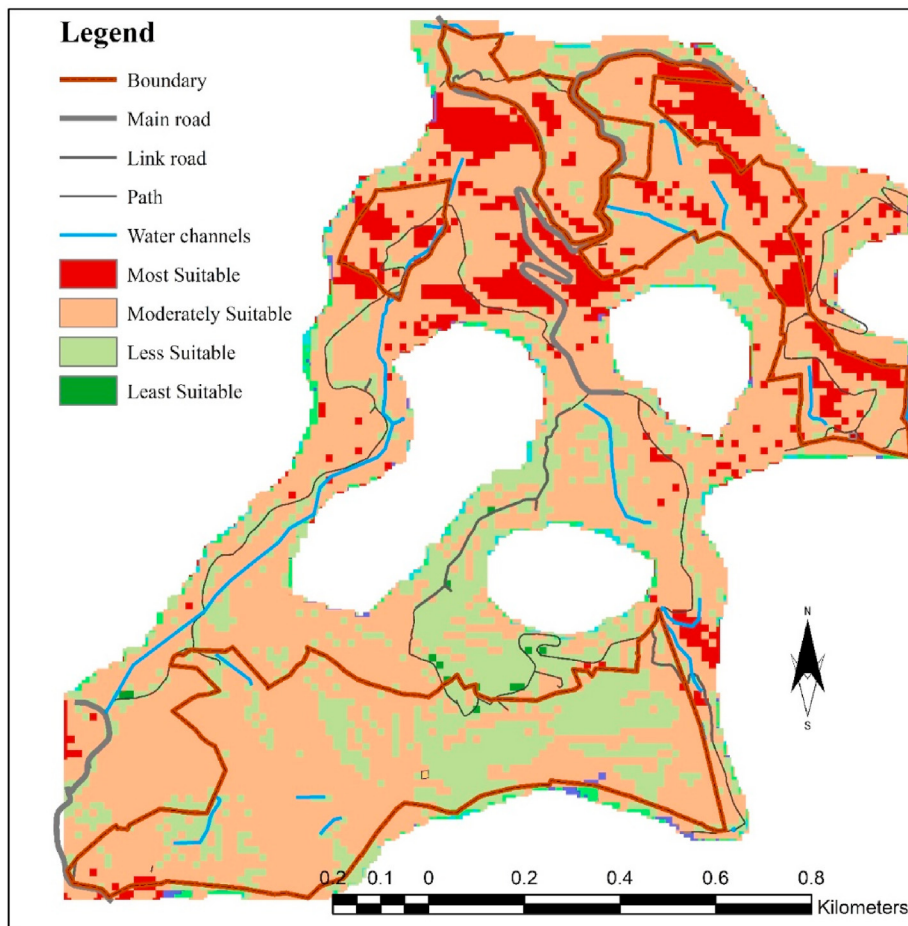


Fig. 8. Aggregated suitability map of Himachal Pradesh Technical University Hamirpur.

efficient by conserving the natural ecology of the site.

6. Limitations

The present study is a step towards allocating land for built-up facilities in hill areas through a quantifiable and rational approach, still, it has few limitations. The methodology developed was executed only on one institutional campus located on a hilly terrain. For further improvements, this needs to be tested on more institutional campuses located in different locations. The lack of collaborative platform is also one of the limitation of the present study. Further, research is required to provide the provision of collaboration by making the input, output, and processing of all the steps involved in the four stages of the developed methodology web-based. The web-based version of the methodology may help in bridging the knowledge and experience of experts, planners, and stakeholders involved in the spatial planning process. Further, efficient scenario management is required to facilitate various aspects including the creation of scenarios and how they are referenced, stored, retrieved, compared, revised, and how portions of one scenario can be combined with portions of another scenario to create an aggregated scenario. However, these limitations do not undermine the contribution of the present study.

7. Conclusion

The methodology developed was applied for performing spatial suitability assessment for the allocation of land for *built-up* facilities on a case study site located in hill areas to ensure its sustainable development. The developed methodology consists of four stages. In the first stage, suitability and vulnerability criteria were identified. In the second stage, experts' participation was ensured through a questionnaire survey, which was analysed through AHP for the determination of weights of the criteria for locating infrastructure facilities. In the third stage, determined weights were assigned to the map layers corresponding to the criteria for the site under consideration. The integration of GIS and AHP makes the decision making process transparent and rational, and also facilitates in controlling the process of land allocation. In the present case study, *aspect* was identified as the most important suitability criterion for

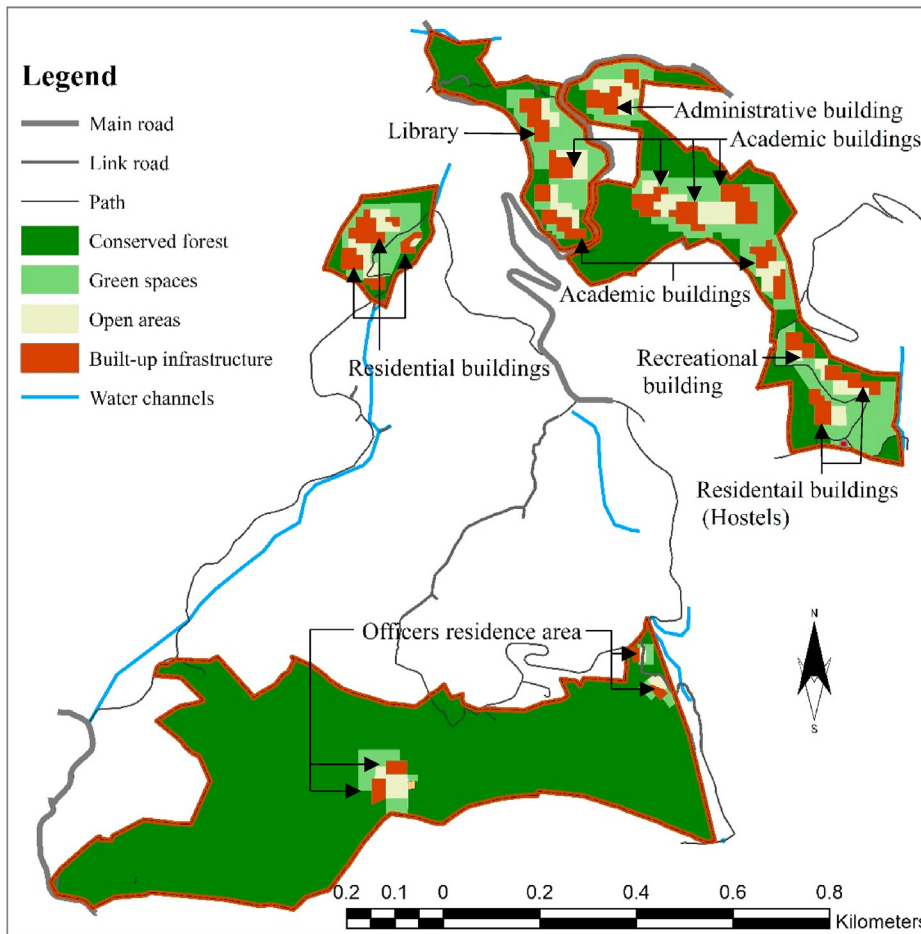


Fig. 9. Finalised spatial plan of Himachal Pradesh Technical University Hamirpur.

the identification of land for allocating land for *built-up* infrastructure with the respective weight of 31.5%. Whereas *slope* was identified and the most important vulnerability criterion for locating multi hazard zones with the respective weight of 35%. The aggregation of suitability and vulnerability maps categorised the study area into four classes of *most suitable*, *moderately suitable*, *less suitable*, and *least suitable* land for locating *built-up* infrastructure facilities. In the fourth stage, the required facilities were located depending upon the minimum area required and cell count available under four derived classes. The first priority was given to the land under the *most suitable* class followed by *moderately suitable*, *less suitable*, and *least suitable* class. Finally, all developed suitability maps were aggregated and the existing and proposed road network was laid to the map to generate the final scenario representing the spatial plan of the campus.

The major contribution of the developed methodology is for both academicians and practitioners. In academics, it fills the gap by providing a rational quantitative approach for integrated spatial planning in hill areas. For practitioners, the methodology assists in solving the practical problems faced while taking planning decisions in hill areas. The political interference is one of the major problem faced by the planners while taking spatial planning decisions at site level in hill areas specifically in developing countries. The developed methodology supplemented with quantitative evaluation of land provides the rational for supporting the decisions of the practitioners. The methodology for the evaluation of land using GIS and AHP as well as workflow designed in this study could be useful in numerous spatial planning problems related to different facilities (e.g. built-up, roads, parks, open areas). It can be applied for land allocation for different infrastructure in hill areas with similar geological composition and hydrogeological conditions. Although, additional criteria could be added or removed from the spatial suitability assessment as required.

Declaration of competing interest

The authors declare that they have no conflict of interest.

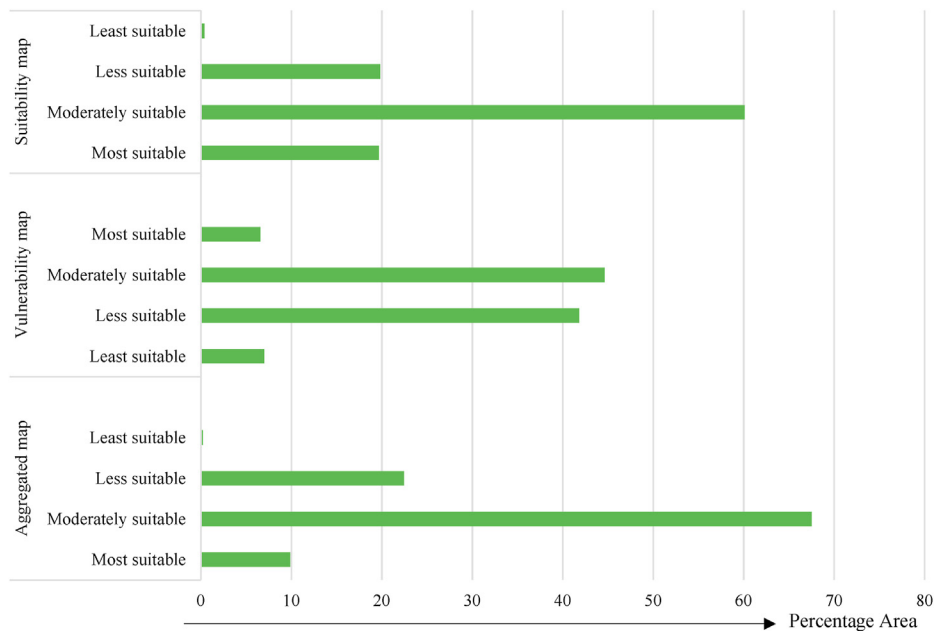


Fig. 10. Percentage of land under various classes of suitability and vulnerability.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jum.2021.02.003>.

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