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Topographical Position Index Based Terrain Classification and Its Impact on Land Use and Land Cover on Ajodhya Hills Region, (Chotanagpur Plateau) India.

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Abstract

Nowadays of geospatial semi-automatic computer-based algorithms have been widely used for the analysis of geomorphic landforms. The present study is carried out to classify geomorphic landforms in the Ajodhya hills region of the Chotanagpur plateau using Topographical Position Index (TPI) and to find out its relationship (landforms) with Land Use and Land Cover (LULC) of this region. The study used 11 different TPI values from 10 to 210 with 20 neighborhood cell intervals by using TPI, for the classification of landforms. The Latest Landsat 8 Operational Land Imager (OLI) satellite imagery data have been used to classify LU and LC of the Ajodhya hills region. The results of the study revealed that landforms of the Ajodhya Hill region influenced out of all landforms, the wide valley zone is the dominant landform where maximum LULC classes are observed in the Ajodhya Hills region, which has a significant influence on the LULC over the entire vicinity.

Keywords: Landform Classification, Topographical Position Index (TPI), Land Use and Land Cover (LULC), Ajodhya Hills

1. Introduction:

Geomorphology is the study of landforms and in particular their nature, origin, processes, development, material composition, etc. Most of the geomorphic research is potentially applicable to some problems of environmental management. The use of geomorphologic knowledge can be used effectively in environmental management.

The recognition of morphological or terrain units is an exercise of regional classification of terrain with similar properties on varying scales. The variation of scale creates a hierarchical pattern of morphological units. The highest order of morphological units could be a very simple exercise of identifying broad sections; such as mountains, plains, plateaus, etc. These broad units of landforms can be further classified into sub-units by considering parameters like climate, vegetation, and broad lithological units and their alignment. The next order of morphological unit involves a detailed exercise

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of identifying landform patterns at the micro level and their similarities. Such patterns have been recognized by studying a landform by splitting it into its elements like altitude, slope, intensity of drainage, etc.

Several efforts have been made to categorize the micro terrain and to identify the morphological units of different hierarchical order on a different basis. Jorge (1914) adopted both inductive and deductive methods to divide North America into morphological regions; which he called 'natural regions' based on the uniformity of geochronology. Bourne (1931) used the term 'morpho units' for morphological regions, which were based on the concept of 'characteristics site assemblage; wherein the demarcation of the first order morpho-units were based on topographic features as shaped by the denudational processes; whereas second order morpho units were based on uniform environmental conditions. Horton (1945), Miller (1953), and Hammond (1964) made 'terrain characteristics of landscape components' on the basis of mapping, identification, and demarcation of morpho units. Hammounds (1964) method was used by several researchers i.e. Linton (1970), Crozier, and Owen (1983) for terrain classification. Savigear (1965) demarcated morpho units by superimposing morphological maps of selected geomorphic variables and named them on the basis of natural regions. Gellert (1972) propounded the concept of morphological regionalization and identified 'morpho-tops' or 'morphofacies' as basis units which, according to him, never occur as isolated forms but form together a joint regional unit as complexes and form-groups with similar but heterogeneous geomorphological marks in the form of orographical, morphological, morphometric, lithological, sedimentological, morphogenetic and morpho-structural kind. In the past, landform properties were calculated manually, which was time-consuming. Thereafter, geomorphologists used a variety of approaches, including the classification of morphometric parameters, filter techniques, cluster analysis, and multivariate statistics for the derivation of landforms' classification.

In recent times, the advancement of digital computer technology, the new generation of modern software, and geospatial analysis methods have further advanced geomorphological studies (Pike, 1999). Semi-automatic algorithms of many computers have been developed for calculating the geomorphological dimensions of the earth's surface. Now in the era of modern geospatial technology, Geographical Information System (GIS) and Digital Elevation Model (DEM) have been extensively used for the classification and representation of terrain units by geomorphologists and geomorphometrical investigators (Franklin, 1987 and Ventura, S.J et. al, 2000). Dikau et al. (1991) developed automated processes for morphological landforms and tested them in the New Mexico region using a 200m cell size DEM. This semi-automated method was significantly more appropriate for providing watershed information (Band, 1986), mapping land components (Dymond et al., 1995), and erosion modeling (Dikau et al., 1991). The GIS analysis was also used for micro landforms by Brabyn (1998) in the South Island of New Zealand.

Guisan, et al. (1999) and Weiss (2001) introduced customized GIS applications for semi-automatic landform classification and Jenness,J. (2004, 2006) applied a method called Topographic Position Index(TPI), for calculating geomorphic landforms surface area and its grid directly from remotely sensed DEM. TPI was defined by Gallant and Wilson (2000). The main aim of the present study is to classify the mountain landforms into different terrain units in the Ajodhya hills region of the Chotanagpur plateau based on the TPI method employing Weiss's (2001) algorithm.

2. Objective of the Study

The main objectives of the present study are to classify the geomorphic landforms of the Ajodhya Hills region using TPI, and investigate the relationship among different geomorphic landforms using the Weiss algorithm (2001) with Land Use and Land Cover (LULC) of the study region.

3. Study Area

The Ajodhya Hills region, also known as Baghmundi-Ajodhya upland, constitutes the South-Eastern part of Chotanagpur plateau, which is geologically an integral part of peninsular India. The whole study region is demarcated based on natural features (i.e. various geomorphic characteristics like slope, relief, drainage condition, and surface configuration). The cultural aspect was also considered for the demarcation of the boundary. The parts of the Chotanagpur Plateau of the Purulia District in West Bengal are located between 23°2'56.98"N to 23°26'5.59"N latitude and 85°49'8.69"E to 86°15'26.63"E longitude within the boundaries of five Community development blocks i.e., Jhalda-I, Jhalda- II, Bagmundi, Arsha and Balarampur (Figure 1). The study area is the source region of the Salda Nadi, Karru Nadi, Kistobazar Nala, Rupai, Kulbera, Turga, Ghosra Nala, Sanka River, Goura Nadi (Subarnarekha River System) Bandu Nadi, Shaharjhor River, Chunmatia, Kumari Nadi (Kangsabati River System). The hilltops, mountain ranges, and drainage lines covered the entire study area. The whole landscape is undulating and the elevation ranges vary from 270 m to 644 m from Mean Sea Level (MSL). The total geographical area of the region is approximately 1032 km^2. The top hill ranges are covered by the Reserved Forest (RF). There are approximately 417 revenue villages located in and around the Ajodhya Hills region.

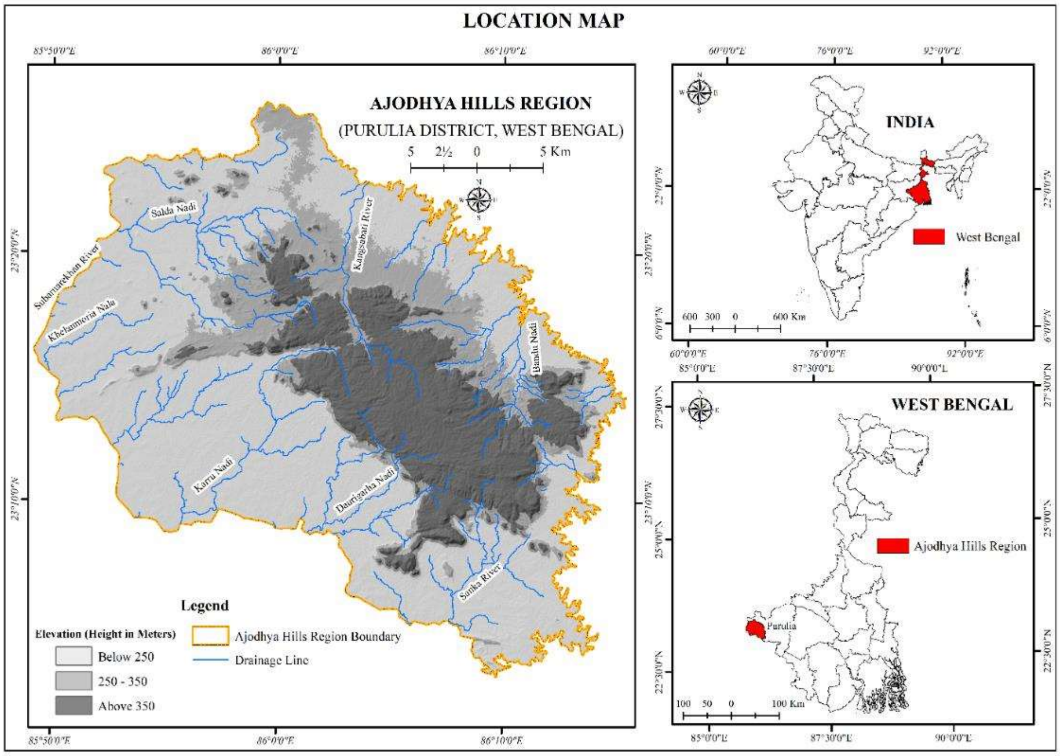

Figure 1: Study Area Map

4. Research Methods

The main data sources of present study are 1:50,000 Survey of India (SOI) Toposheets (73 I/3, 73 I/4, 73 E/15, 73 E/16, 73 I/7, and 73 I/8.). Landsat 8 OLI satellite imagery data, dated April 2021, which was collected from the USGS Earth Explorer (https://earthexplorer.usgs.gov/) of path 140 row 44 has also been used. The ground verification was carried out by Etrex 30x GPS. Similarly, high-resolution (12.5m) Alos Palsar Digital Elevation Model (DEM) data was downloaded from the Alaska Satellite Facility (https://search.asf.alaska.edu/#/).The whole Geospatial data such as landforms data, and LULC data were driven in Arc GIS 10.4 and ERDAS 14.0 software. The overall methodology is shown in Figure 2.

The landforms of the Ajodhya Hills region were identified and classified by TPI using Weiss's (2001) algorithm. According to Jennens Jeff (2006) Topographical Position Index (TPI) is the basis of the geomorphic terrain classification system and is simply a difference between a cell elevation value and the mean elevation of the neighborhood around that cell (Chauniyal et.al, 2018). According to Jennens Jeff (2006), High TPI values are found in top or ridge regions whereas low TPI values are found in the valley regions, and near 0 TPI values are found in the flat regions.

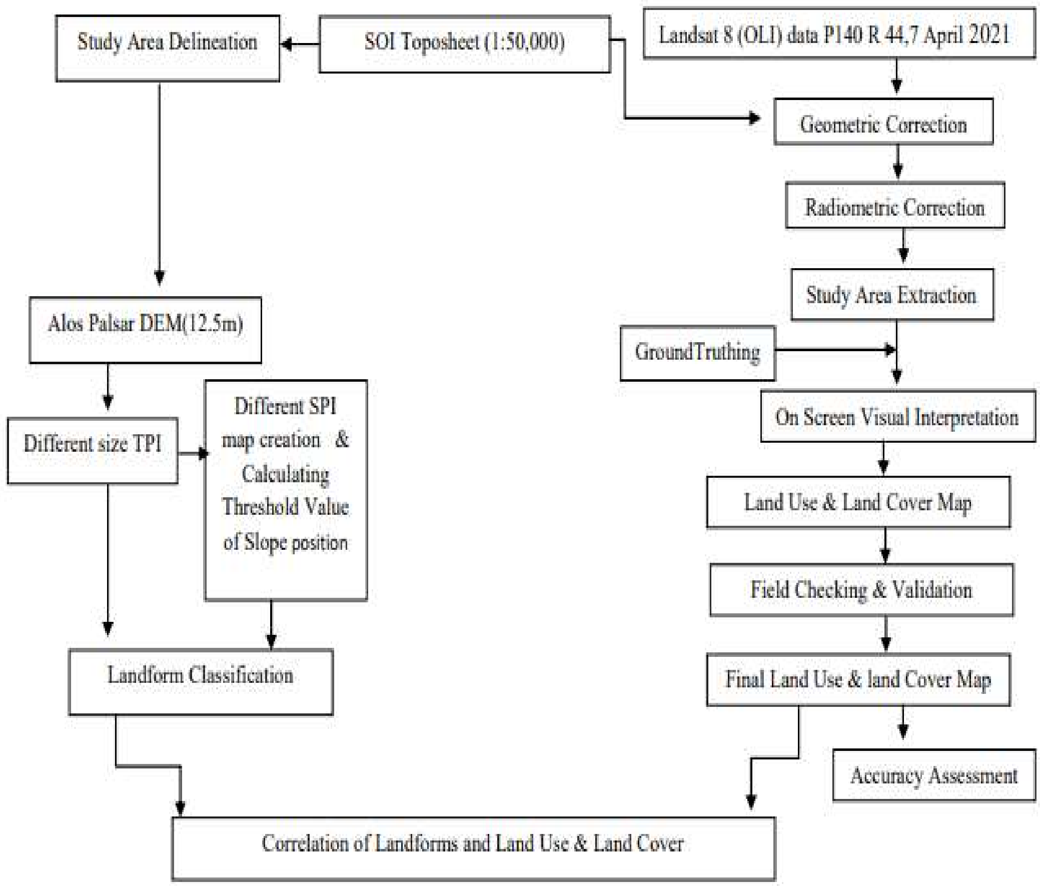

Figure 2: Overall Methodology Framework

The following formula has been used for TPI –

$TPI\ i = Z_0 - \Sigma_{n-1} Z_n / n$

Where;

Z_0 = elevation of the model point under evaluation (particular cell).
Z_n = elevation of the grid within the local window.
n = the total number of neighboring points employed in the evaluation.

These TPI values help to classify slope position classes. TPI values can simply be categorized into slope position classes based on how extreme they are and by the slope of each and individual point. The slope position classes generally differ from +1 to – 1 TPI threshold value.

For the analysis of landform classification, it is very difficult to identify the different types of land features. TPI is naturally very scale-dependent.

Different-scale circular windows of the neighborhood are used to delineate TPI. The question is, what is the extreme TPI value which the authors will apply in their study area? In the present study, authors have applied 11 different TPI values from 10 to 210 with 20* 20 intervals (Figure 3). TPI, slope position, and landform classification were derived using Arc GIS Topography tools, which are based upon Arc View 3.3 Tools by Jeff Jennens (2006). For the identification of the landform, the next phase is to take the slope position. Weiss (2001) first calculated the slope position for the identification and classification of the geomorphic landforms.

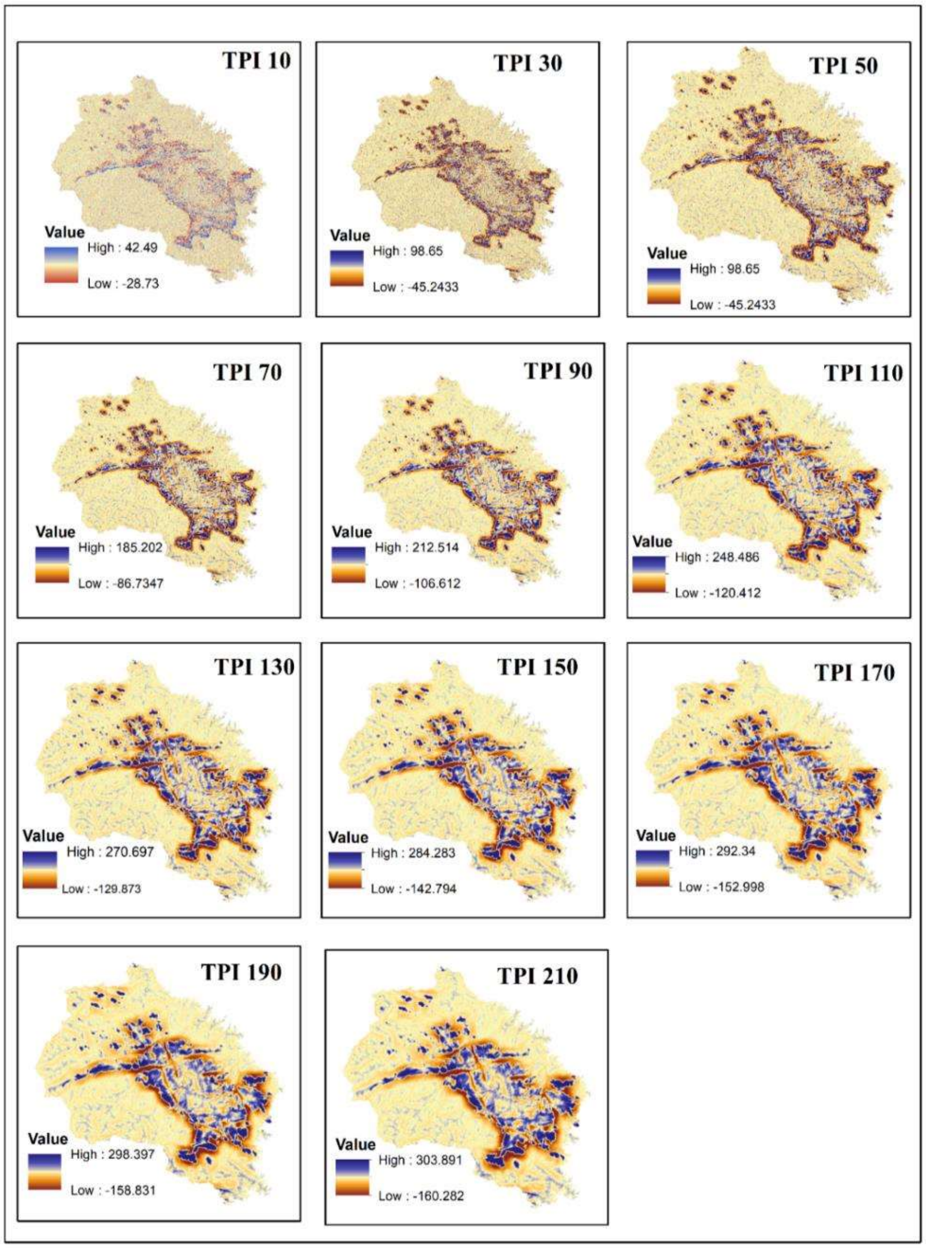

Figure 3: TPI values of Ajodhya Hills Region using different windows

4.1 Slope Position

Slope position was first calculated for the identification and classification of landforms. In the present study, many individual micro landform units like valleys, toe slopes, flat, mid-slopes, upper slopes, and ridges have been delineated at the fine scale using 10 TPI values (Figure 4 and Figure 5). Besides this, with TPI 210 values in large scale classification, only generalized macro landform units i.e., ridges and valleys were identified (Figure 4). It shows that as the scale increases (between 10 to 210 TPI), slope position classes decrease and small landforms disappear (1% or below 3%). In the present case, the TPI value disappears after 210 TPI (Table 1 & Figure 4). The low TPI value (10 TPI) is very useful for the identification of micro landforms, while 210 TPI or more shows only generalized landform in the study area.

Table 1: Area of the Slope Classes (%) using Different TPI grid (Weiss 2001)

Slope Class	SPI 10	SPI 30	SPI 50	SPI 70	SPI 90	SPI 110	SPI 130	SPI 150	SPI 170	SPI 190	SPI 210	SPI 230
Valleys	24.1	39.1	43.6	46.3	48.0	49.4	50.4	51.1	51.9	52.6	53.2	53.9
Toe Slopes	12.2	6.7	5.2	4.3	3.7	3.3	3.0	2.8	2.6	2.4	2.3	2.1
Flat	21.0	10.3	7.7	6.3	5.5	4.9	4.4	4.1	3.8	3.5	3.3	3.1
Mid slopes	8.0	3.4	2.5	2.1	1.8	1.6	1.4	1.3	1.2	1.1	1.1	1.0
Upper Slopes	11.7	6.3	4.8	3.9	3.4	3.0	2.8	2.5	2.4	2.2	2.1	2.0
Ridges	23.1	34.1	36.3	37.2	37.6	37.8	38.0	38.2	38.3	38.2	38.1	38.0

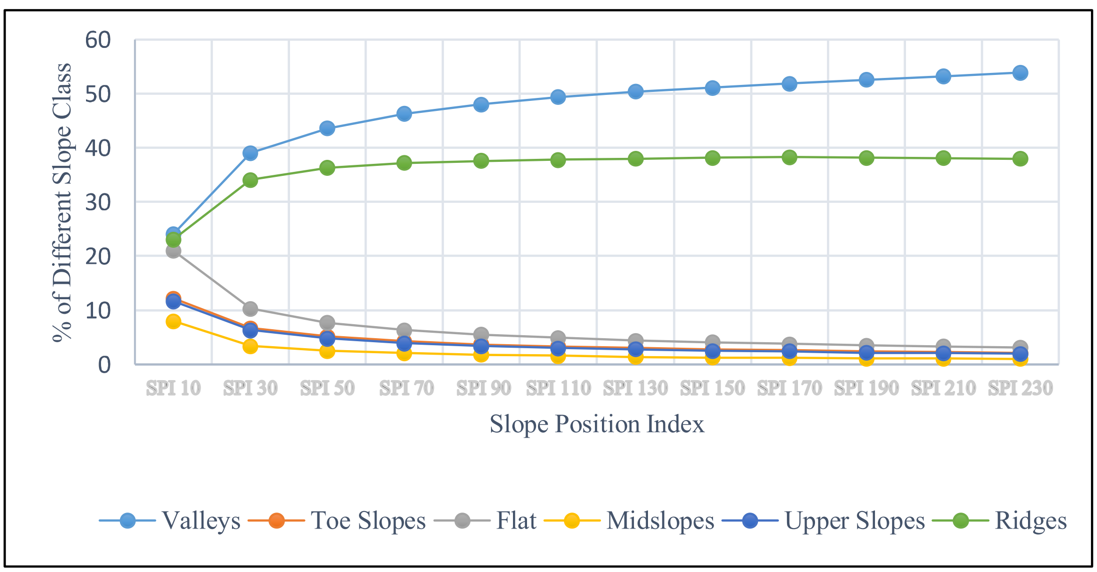

Figure 4: Graphical representations of Slope Classes and Area (Weiss 2001)

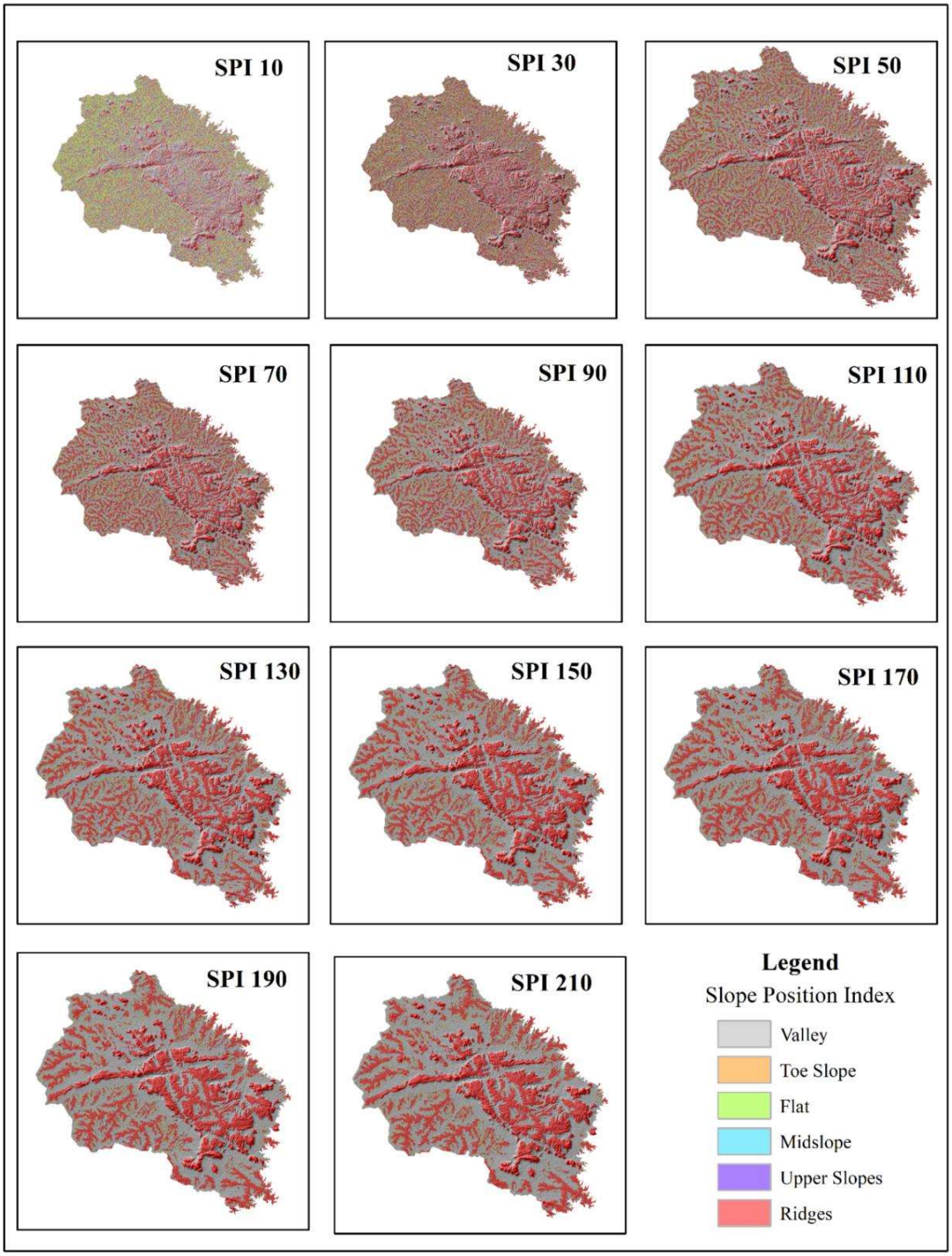

Figure 5: SPI values of Ajodhya hills Region using different windows

4.2 Topographic Position Index and Landform Classification

Following the landform classification methodology of Weiss and Jeness (2001, 2006), the present study area is classified into micro landform units based on extreme TPI scale values i.e., lowest 10 and highest 210. The TPI algorithm was performed using circular neighboring of 10 to 210 TPI in 11 classes (Figure 4). After the test of 11 different sizes of circular windows, it was found that 10 windows circular TPI gave the best results of micro landforms. Most of the minor details are clearly expressed in it (Figure 5). Besides this, 210 or 230 circular window TPI sizes or above yielded the generalized shape of landforms. Therefore, according to Weiss and Jeness (2001, 2006), the 10 small TPI and 210 large TPI scale values were combined and the final results of landforms were calculated which distinguished the variety of nested landforms. In this way the smallest to the broadest landform units can be identified successfully.

Thus, the whole Ajodhya Hills region is automatically classified into 10 landform classes based on small neighboring and large neighboring slope position classes (employing Weiss's 2001 algorithm). Table 2 illustrates that some of the landforms classes occupy less than 1% to 3% areal coverage, and their existence is in the study area. So, some of these classes were combined into 6 new classes and consequently assigned new names considering with the field confirmation.

Table 2: Landform Classification Based on Weiss (2001) on 10 and 210 TPI Values.

SL.No	Landform	Area In %	New Class	Area In %
1	Canyons, deeply incised streams	15.62	Valley Bottoms	15.62
2	Midslope drainages, shallow valleys	1.15	Mid Slope Zone	8.28
3	Upland drainages, headwaters	7.13		
4	U-shaped valleys	33.16	Wide Valley Zone	36.09
5	Plains	2.93		
6	Open slopes	0.99	Upper Slope Zone	17.44
7	Upper slopes, mesas	16.45		
8	Local ridges, hills in vallyes	7.61	Local Lower Hills	9.61
9	Midslope ridges, small hills in plains	1.71		
10	Mountain tops,high ridges.	12.96	High Ridges	12.96
	Total	100		100

4.3 LULC classification:

For the analysis of LULC, Landsat 8 OLI data was used. The image was geo-referenced using Toposheet (UTM coordinate System, Zone 45, WGS 84 datum) and the nearest neighborhood re-sampling method. After geo -

referencing, the satellite image was radiometrically corrected and a subset (study area) was generated. The whole image classification was done with the help of on-screen visual interpretation with interpretation keys and knowledge from field surveys. The accuracy of classification was done with field verification using 81 randomly distributed points. The whole LULC area was categorized into 8 classes based on their uses and dominant species presented in that area (Table 3).

Table 3: LULC of the Ajodhya Hills Region

SL.No	Class	Area in Km^2	Area in %
1	Water	12.53	1.21
2	Deciduous Broadleaf Forest	327.11	31.69
3	Grassland	0.60	0.06
4	Plantation	0.01	0.00
5	Agriculture Land	501.09	48.54
6	Mixed Broadleaf Forest	123.18	11.93
7	Built Area	67.17	6.51
8	Open Rock	0.57	0.06
	Total	1032.26	100.00

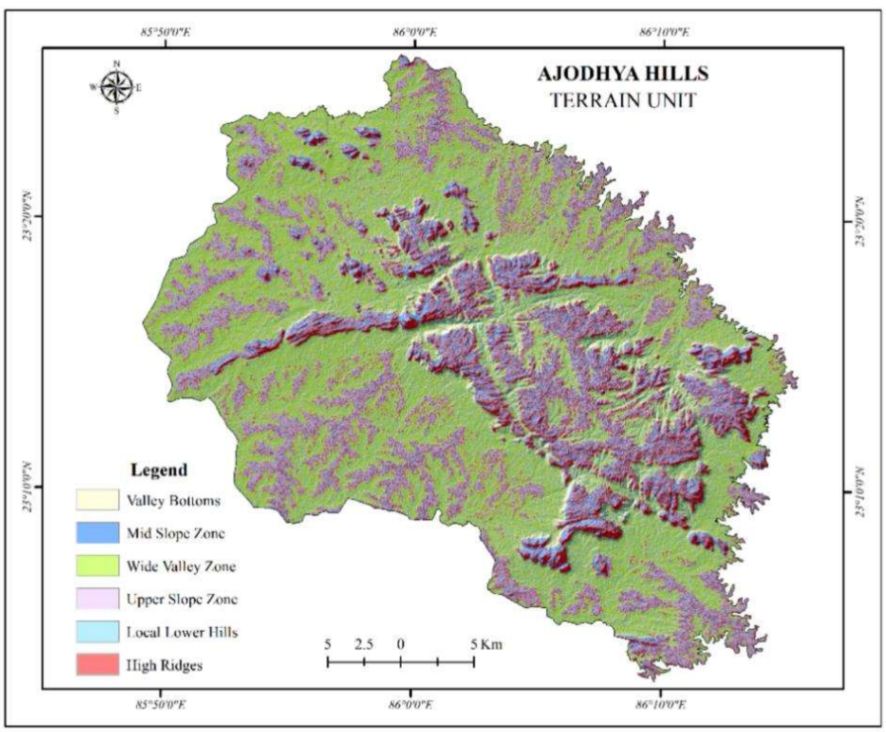

Figure 6: Terrain Units of Ajodhya Hills Region

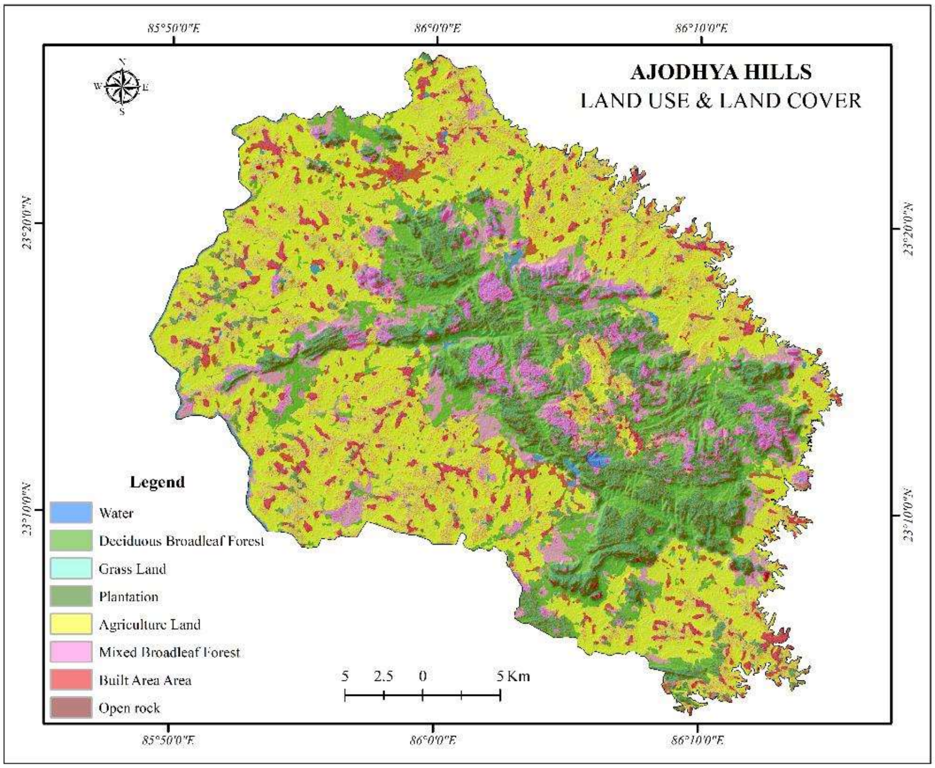

Figure 7: Land Use & Land Cover of Ajodhya Hills Region

5. Results

5.1 Topographic Position Index and Landform Classification of Ajodhya Hills region

The TPI algorithm was performed using circular neighboring of 10 and 210 TPI in 11 classes (Figure 6). After the test of 11 sizes of the circular windows it was found that 10 TPI gave the best results of micro landforms. Besides this 210 TPI gave the generalized shape of landform. Therefore, according to Weiss and Jeness (2001, 2006), the 10 small TPI and 210 large TPI scale values were combined and the final results of landforms were found which has a distinguished variety of nested landforms.

Thus, the whole Ajodhya Hills region is classified into 10 landform classes based on small neighboring and large neighboring slope position classes (Weiss, 2001). Table 2 reveals that several landform classes occupy less than 1% to 3% of areal coverage and their existence is negligible in the study area. Therefore, these classes are combined into 6 classes and given specified new names according to local knowledge.

Table 2 shows that the maximum area coverage of 36.09% is found in the Wide Valley Zone following the Upper Slope Zone i.e. 17.44%. The minimum area coverage (8.28%) is found in the slope class of Mid Slope Zone followed by Local Lower Hills, High Ridges, and Valley Bottoms which are occupied by 9.61%, 12.96%, and 15.62% respectively. The results are verified in the field and found almost correct according to topographic formation.

5.2 LULC of Ajodhya Hills Region

As far as the vegetation cover is concerned Sal (*Shorea robusta*) is the dominant forest species in the Ajodhya Hills region. Around 31.69% of the area is occupied by this forest. Further, in the Ajodhya Hills region, some of the vegetation patches are found (11.93%) in mixed forest species which can be discriminated by other attributes such as Mahua (*Madhuca latifolia*), Kusum (*Schleicheraoleosa*), sonajhuri (*Acacia auriculiformis*), Jamun (*Syzygiumcumini L.*), Palash (*Butea monosperma*) etc.

Among the non-tree areas, agricultural land covers the largest area of 501.09 km^2 that is 48.54%, where built-up areas cover 6.51% and open rock is found at 0.06% of the total geographical area in the Ajodhya Hills region (Table 3).

5.3 Relationship between Terrain Units and LULC in Ajodhya Hills region

Six geomorphic terrain units which are TPI-based, such as valley bottom, mid-slope zone, wide valley zone, upper slope zone, local lower hills, and high ridges are taken into consideration for the analysis of landforms in the Ajodhya Hills region. The study area is divided into 8 LULC classes that are calculated on the GIS platforms and the values of each Land form class are correlated with LULC.

Table 4 depicts that in the Ajodhya Hills region, water bodies, deciduous broadleaf forest, agricultural land, mixed forest, and plantation are mostly found in the wide valley region whereas built up are mostly found in the valley bottom region. Wide valley zone is very much suitable for human settlement in the Ajodhya Hills Region. Similarly, grasslands are mostly found in the upper slope region.

6. Discussion

After the investigation and classification of landforms based on TPI which is the method of determining landforms and the test, 11 sizes of the circular window TPI scale values were combined for analyzing the proper terrain to understand the correlation of landforms with LULC. It is also found that TPI is the single inherent environmental aspect of landform which directly affects the land use and land cover of the study area. (Xian et al., 2007). In the Ajodhya Hills region water bodies are found mostly in the wide valley zone which covers almost 0.49% of the total water bodies in the study area followed by valley bottoms

(0.32%) and Upper Slope Zone (0.13%). This is because this region is located in a hot and humid climatic zone where rainfall is only occurring in the rainy season and after rain falls the rainwater from all directions of Ajodhya Hills come into the wide valley zone as well as valley bottoms. Thus water and wetlands were usually affected by relief and were concentrated in the lower part like the valley bottom. Related findings are also initiated by Bian., K et.al (2023) during the Study in Quinhai Tibet Plateau, China. The concentration of deciduous broadleaf forest (6.75%) is found mainly in the wide valley zone followed by 6.30% in the High Ridges, 5.47% in the Upper Slope, 5.46% in the Valley Bottoms. Whereas the total area of the wide valley zone in the Ayodhya Hills is 36.09%, High Ridges are found at 12.96%, the Upper slope zone is found at 17.44% and valley bottoms are found at 15.62% (Table no 03). So, by this, it is very clear that the distribution of deciduous forest remains very high in the valley bottoms whereas the distribution of the same forest is comparatively low in the wide valley zones. The researchers observed that due to the popularity of the tourism industry and the increase in cultural landscape as well as agricultural practices, the distribution of deciduous forests is comparatively lower than that of valley bottom where the effect of the above-mentioned factors is negligible. In the study area, 48.54% of the total area is covered by agricultural land. Out of this total agricultural land, almost 23.54% of agricultural land is found in the wide valley zones as it is comparatively the flat zone of the study area, and most water bodies are concentrated here. The built-up areas are mostly found in the wide valley zone (3.68%) as the flat wide valley is very much suitable for human settlement and agriculture followed by the valley bottom region (2.01%) as these built-up areas are newly developed for small hotels and lodges for the benefit of tourists in that particular landform. During their field observations the researchers found that agriculture and tourism harmed natural forests. Similar results are established by Pongpottananurak., N (2018) in Thap Lan National Park, Thailand.

Therefore, all results depend on the TPI method which was used to generate morphological types for semi-automated methodological landform elements. With the existing methodology, landform elements have been produced and consequences reflected according to Weiss's (2001) algorithm. DEM is very helpful in identifying a wide variety of landscape morphological characteristics. This study describes the topographic concepts which are very useful to explain geomorphologic processes and micro landform feature extraction.

Table 4: Relationship between Terrain Units and LULC in Ajodhya Hills Region (Area in %)

Landform	Land Use & Land Cover Class							
	Water	Deciduous Broadleaf Forest	Grassland	Plantation	Agriculture Land	Mixed Broad leave Forest	Built Up Area	Open rock
High Ridges	0.10	6.30	0.01	0.00	3.56	1.88	1.11	0.00
Local Lower Hills	0.14	3.28	0.00	0.00	4.55	1.23	0.39	0.01
Mid Slope Zone	0.04	4.42	0.01	0.01	2.12	1.23	0.45	0.00
Upper Slope Zone	0.13	5.47	0.02	0.00	7.34	1.90	2.58	0.00
Valley Bottoms	0.32	5.46	0.00	0.00	7.43	2.01	0.38	0.02
Wide Valley Zone	0.49	6.75	0.02	0.00	23.54	3.68	1.59	0.02

7. Conclusion

The results related to the relationship between terrain units and land LULC in the Ajodhya Hills Region also depend on the nature and scale of the study area. The effects of scale and generalization need special attention to find a proper inference. In the present study, the generalized results are satisfactory to some extent because the study area is a homogeneous mountainous terrain. There is no large dissimilarity in the topography. Generalized features i.e. hill ranges, valleys, mid-slopes, river channels, and slope features are noticeably visible on the map. In the large-scale mapping micro landform features can be clearly seen. Thus, TPI provides a powerful tool to describe the topographic attributes of any study area.

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