Scientific Research Publishing

Journal of Geoscience and Environment Protection, 2025, 13(4), 455-492
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Investigation of Soil Geomorphological Character of the Ajodhya Hill Area and Its Influence on Land Use and Land Cover

Arindam Sarkar

Department of Geography, Purash Kanpur Haridas Nandi College, University of Calcutta, Kolkata, India
Email: arindam.srkr1@gmail.com

How to cite this paper: Sarkar, A. (2025) Investigation of Soil Geomorphological Character of the Ajodhya Hill Area and Its Influence on Land Use and Land Cover. *Journal*, *13*, 455-492.
https://doi.org/10.4236/gep.2025.134023

Received: March 27, 2025
Accepted: April 25, 2025
Published: April 28, 2025

Abstract

Soil geomorphology deals with scientific experiments on different interdependent parameters of soil and landforms. The objectives are to discover the various attributes of soil and geomorphology and their interrelationship. Another objective is to determine the relationship between the character of soil geomorphology and the attributes of land use and land cover. SRTM and ALOS data are used to prepare an accurate DEM for analysis of the morphology and topography of this region. The LULC map is prepared from Landsat 8 satellite imagery through remote sensing software. Ajodhya Hill is situated in the Purulia district of West Bengal. The maximum elevation of the hill is about 698 m above the MSL. Ajodhya Hill is composed of older Archaean rock (granite). The foothill area of Ajodhya Hill has a gentle slope varying between 0˚ - 5˚ with a moderately thick soil layer. Much of the hill area is covered by healthy forests. Scattered vegetation, fallow land, and agricultural activity are found in the foothill pediment area. Sandy loam is the principal soil texture. Soil pH is primarily neutral. Most soil samples have a 32 - 95 µS/cm salinity level. Surface soils are dry, having about 0.1 - 3 percent soil moisture. This area is dry and only fed by rainfall during the monsoon season. Local people store water by creating an artificial reservoir for agriculture and household purposes. Sustainable management of resources is beneficial for that region.

Keywords

Oxisol, Agriculture, Soil, Geomorphology, Scattered, Forest

1. Introduction

Soil geomorphology is concerned with the relationship between geomorphology and pedology. Both are considered scientific disciplines of earth science. It is inseparable from each other. "Tricart suggests that pedology ought to be a branch of geomorphology, for the reason pedology studies specific features of the phenomena taking place at the contact between lithosphere and atmosphere" (Zinck et al., 2016). Tricart (Tricart, 1965a) pioneered the discovery of the relationship between geomorphology and pedology. After that, Hall conceptualized it (Hall, 1983). Significant work was carry forwarded in context to Morphopedology (Tricart & Kalian, 1979; Tricart, 1965c, 1994; Legros, 1996), Geopedology (Principi, 1953; Pouquet, 1966; Brikeland, 1974, 1990, 1999), Pedogeomorphology (Conacher & Dalrymple, 1977; Elizalde & Jaimes, 1989) and Soil geomorphology (Daniels et al., 1971; Conacher & Dalrymple, 1977; McFadden & Knuepfer, 1990; Daniels & Hammer, 1971; Gerrard, 1993, 1995; Schaetzl & Anderson, 2005; Zinck, 2013; Schaetzl & Thompson, 2015). The analysis of the balance between geomorphogenesis and pedogenesis and the terms of control of the former on the latter in soil formation (Tricart, 1965a, 1965b, 1994). The study of soil geomorphology is concerned with explaining the landscape and the influence of the processes acting in the landscape on the formation of the soil. The scientific study of soil and geomorphology can explain the genetic relationship of a landscape. The principal objective of soil geomorphological study is to assess the genetic relationship between soils and landforms (Coacher & Dalrymple, 1977; McFadden & Knuepfer, 1990; Gerrard, 1993). Soil geomorphology is the scientific study of the processes of evolution of the landscape and the influence of these processes on the formation and distribution of the soils on the landscape (Goudie, 2003). In the present study, pedology is considered a supporting discipline of geomorphology. This is known as the geomorphological approach of soil geomorphological research. Several research works have been carried out to determine the relationship between the parameters of soil and landforms and vice versa (De, 1972; Pofali et al., 1979; Chaudhuri, 1982; Pofali & Hirekerur, 1983; Goswami & Das, 1984; De, 1984a, 1984b; Dhankar & Jain, 1985; De & Ghosh, 1986; Sarkar, 1987, 1988; Dey & De, 1988; Pal, 1989; Chatterjee, 2005; Chatterjee & De, 2009; Sarkar & Das, 2018; Sarkar, 2019b). A study of Inclusive Tourism Adopted to Geosites in the Ajodhya Hills was conducted by Ghosh et al. (2023). Ghosh and Mukhopadhyay (2022) researched the Evaluation of springs and waterfalls as Geomorphosites and the proposition of strategies to develop Geotourism at Ajodhya Hill. However, there is a continuous lack of literature on determining soil geomorphological character and its relation to land use and cover.

The objectives of this study are to find out the geomorphological, pedological, and land use and land cover characteristics of Ajodhya Hill and establish a relationship between soil geomorphological attributes and land use and land cover. The present study has considered two geomorphological (elevation, slope) and seven pedological attributes (soil texture, hygroscopic moisture, organic matter, pH, salinity, and NPK). Ajodhya Hill is considered for the present study's location (**Figure 1**). It is located in the southwestern part of the Purulia district of West Bengal. The highest elevation of the hill is about 698 meters. A 300-meter contour was taken for the base contour; it is limited to the foothill of the Ajodhya Hill area. This area's geological, geomorphological, and pedological significance are important reasons for selecting this area for study. In the present study, elevation and slope were selected only because they play a significant role in forming and developing soil profile and character.

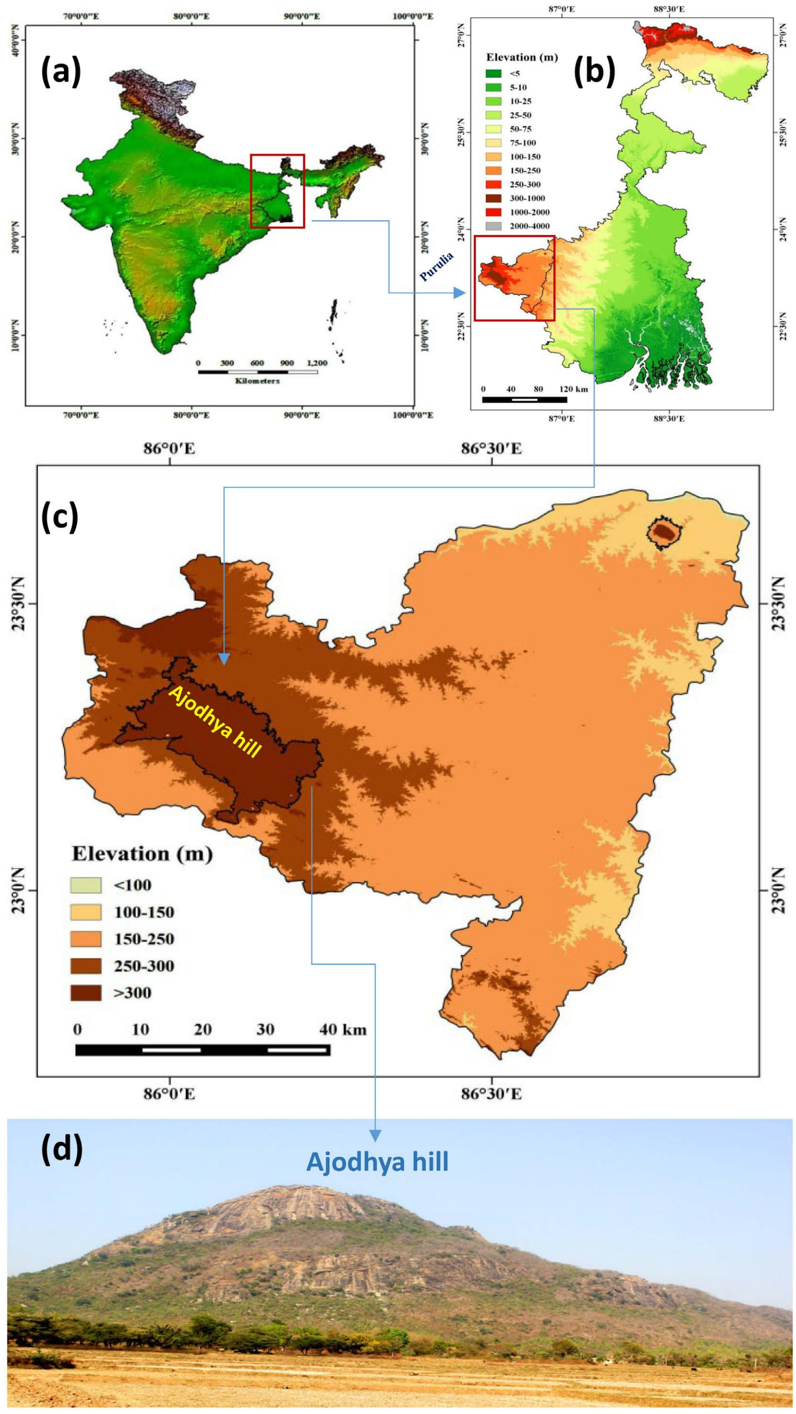


Figure 1. Location of the study; (a) Map of India, (b) Elevation map of West Bengal, (c) Elevation map of Purulia district, (d) Photograph of Ajodhya hill (Northeast part).

2. Data and Methodology

The present study can be broadly divided into three phases: 1) pre-filed (preparation of research), 2) during field (collection of samples), and 3) post-field work activity (laboratory analysis, data evaluation, and preparation of report). Laboratory analysis of the sample was done to find out the pedological character. Geomorphological parameters (elevation, slope) have been analyzed using geo-informatics techniques (**Table 1**)**.** SRTM data (**Table 1**) are analyzed by remote sensing software to find out the geomorphological character of the area. Statistical techniques have been used to establish soil geomorphological character. Twenty soil samples were taken from the top of the hill to the foothill pediment area, with elevation changes and slopes for laboratory analysis. Samples were collected using a random sampling method according to the change of elevation measured by an altimeter and a global positioning system (GPS) receiver.

Table 1. Details of satellite data, date of acquisition, and resolution.

Satellite and Sensor	Date of acquisition	Path/Row	The band used Spatial resolution
Landsat 8 "OLI_TIRS"	04/04/2014	140/44	30 m
	29/04/2014	139/44	
	22/01/2017	140/44	
	31/01/2017	139/44	
SRTM	23/05/2010		30 m

Soil samples are taken from different elevation and slope zones. Some field instruments (altimeter, GPS handset, and clinometer) have been used to measure the elevation and slope of the soil sampling location. Satellite data (SRTM) is used to recheck the elevation and slope values of the sampling point, which were taken during the field. Each sample contains 200 grams of soil and is kept in an air-locked sampling caliper plastic bag for laboratory analysis. The distance between the two sampling points varies with the change in elevation and slope. The statistical sampling method is recognized as unequal probabilistic sampling (stratified random sampling). The sample number depends on the length and extent of elevation and slope zone. For the present study, 23 sample points (**Figure 2**) have been collected from the Northern foothill to the southern foothill (across the hill). Samples have been kept in the laboratory in the open air (at laboratory temperature) for a week of analysis (texture, organic matter, pH, and salinity analysis). Samples get dried at 105˚C - 110˚C for several hours in a hot air oven (Das et al., 2014) to determine the soil moisture percentage. The percentage of hygroscopic moisture has been measured by heating the air-dry samples for three hours at a temperature of 105˚C in a hot air oven (Piper, 1950). The application of the air-dry method is required for texture analysis

(Das et al., 2014). Robinson pipette and Hydrometer methods have been used to determine the percentage of sand, silt, and clay (texture). Analysis of organic matter, pH, and salinity does not require oven-drying of samples. Air drying is sufficient (Piper, 1950). Because organic matter and the soil reaction ability of soil can be destroyed by oven temperature (Das et al., 2014). Walkley and Black's wet combustion method determined the percentage of soil organic matter in 1934. The Walkley-Black (WB) titration method is one of the classical methods

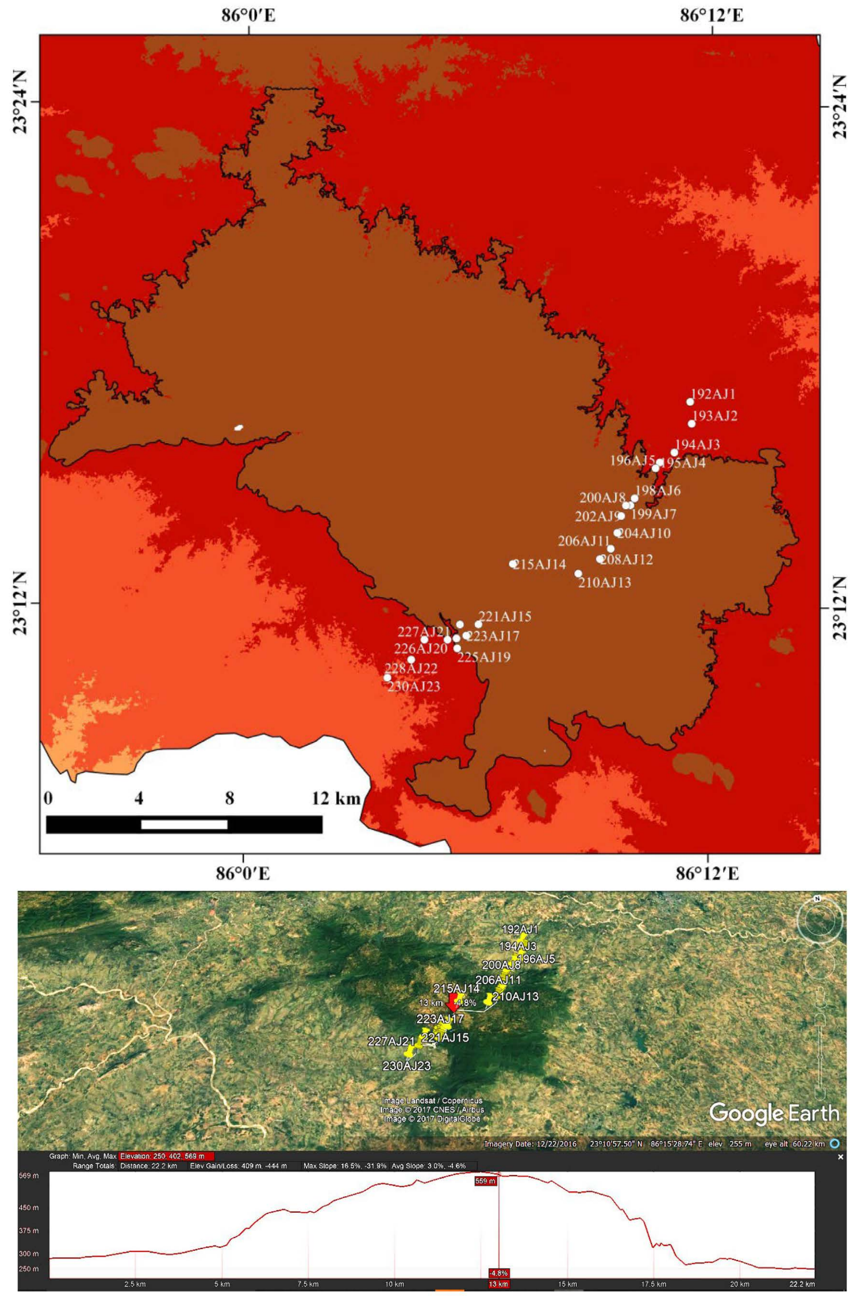


Figure 2. (a) Sample locations in Ajodhya hill (North to South; across the hill), (b) Cross profile of sample points. The elevation profile has been created on the Google Earth platform by exporting GCP from the GPS receiver.

for the rapid organic carbon (OC) analysis in soils and sediments (Gelman et al., 2011; Sato et al., 2014; Andrews et al., 2002). A global digital pH meter and digital conductivity meter have been used to determine soil pH and salinity. The testing kit has determined the status of NPK. In 1993, the Ontario Centre for Soil Resource Evaluation made a soil structure code based on soil textural classification. This system has four structural codes; each contains different soil types according to their texture—Global Chemical Industry Digital pH Meters, Model No.: DPH-500 has been taken to determine soil pH. Digital Conductivity TDS Meter DCM 900 was used to determine the soil sample's salinity status.

Soil geomorphological relationship is associated with statistical analysis (regression and principal component analysis) of geomorphological and pedological data through statistical software. Different cartographic techniques did data presentation. The normalized difference vegetation index (NDVI) is a popular band ratioing technique in remote sensing measurement. Rouse et al. (1973) did the Pioneer vegetation indices work. The calculation of vegetation indices requires good-quality multispectral imagery. Multispectral satellite data are beneficial for considering the earth's environment. Band rationing is a technique that can gather knowledge by extracting facial characteristics of spectral signatures stored in satellite images. The mathematical computation of NDVI is expressed as (NIR-R/NIR + R). NDWI is a critical band rationing technique. Spectral rationing is an image enhancement performance in which the pixel of a raster image of one spectral band can be divided by its immediate corresponding pixel in the same manner (Lillisand et al., 2010). The effect of soil background is essential in the case of partial vegetation cover because NDWI acts very sensitive to changes in the liquid water content of Vegetation Cover (Gao, 1996). The land surface temperature is estimated from the upper atmosphere based on the brightness temperature of the EMR (Infrared Spear Channel). Geo-informatics have become powerful tools for acquiring perfect and timely information on the spatial distribution of pedo-geomorphic character about the LULC pattern of that area (Ulbricht & Heckendorf, 1998; Carlson & Sanchez-Azofeifa, 1999; Rogan & Chen, 2004). GIS can furnish a ductile environment for the analysis of satellite imageries for recognition of surface morphology and LULC of the area (Prenzel, 2004; Demers, 2005; Wu et al., 2006; Xu, 2006).

3. Result and Discussion

3.1. Geology and Geomorphology of the Ajodhya Hill Area

This area comprises the Archaean and the Gondwana geological formations (Bhattacharya et al., 1985; Bandyopadhyay et al., 2014). The Archean is the oldest age of rock formation in the study area and is composed of granite and gneiss (Das et al., 2010; Bandyopadhyay et al., 2014; Dasgupta, 2015) (**Figures 3-5**). The Gondwana basin, composed of oceanic sediments (laterite) and woody materials (echno-fossils), was formed during the upper Carboniferous-Triassic periods (Bhattacharya et al., 1985; Das et al., 2010; Bandyopadhyay et al., 2014). The topography of this area is formed on the basement of the peninsula shield on which Gondwana deposition took place (Kumar, 1979; GSI, 1999). The Archean formation is associated with granitic (grey-bedded biotite, granite, genesis, etc.), as well as sedimentary (conglomerate) and schistose rocks (phyllite, quartzite, schist, etc.) (Kumar, 1979; Singh, 1969). Rocks composed of glacial materials, fluviatile sandstone, and shales were formed during the Gondwana system, and the laterite formation of this area is also the product of the Gondwana age (Singh, 1969; Kumar, 1979; GSI, 1999). Ajodhya Hill is a separate residue of the Chhota Nagpur Gneissic Complex (CGC), which was tectonically active for more than 1.6 billion years (Bhattacharya, 1990; Bhattacharya & Ghoshal, 1992; Dasgupta, 2015). This is considered the oldest wide-open landscape of the Bengal Delta (Baidya, 1984). Weathering and overland flow are dominant geomorphic processes operating here throughout the year. Local geological character and variation in rainfall and temperature throughout the year are responsible for the intense operation of weathering and overland flow. Banded varieties of gneiss and schist are highly prone to weathering (Bose, 1957; Bose, 1992; Dasgupta, 2015). According to a geological map prepared by the photo geology and remote sensing division of the Geological Survey of India (Eastern region, Kolkata), the Northern and central part of Ajodhya Hill is composed of composite

Figure 3. This image shows an exposed rock section at Ajodhya Hill (known as Marble Rock), illustrating several geological features. The light-coloured rock in the lower part of the section is high-grade metamorphic granite-gneiss. The darker part of the upper section represents deeply weathered granite-schist resulting from prolonged exposure and erosion. This crystalline rock formed through deep crustal processes. Visible vertical and sub-vertical joints are cooling fractures. The boundaries within the rock strata indicate a lithological contact or an unconformity. Angular boulders and broken fragments in this section provide significant evidence of mechanical weathering across this landscape. Vegetation growing in the cracks suggests that chemical weathering processes, such as hydration and oxidation, occur.

Figure 4. An outcrop of metamorphic rock (gneiss) showcases visible structural features. Prominent foliation and mineral banding are distinctly apparent. Alternating light and dark bands indicate high-grade metamorphism. The clear foliation displays the alignment of minerals under immense pressure. A visible fracture cutting through the rock signifies brittle deformation. The bending and displacement of foliation near the fractures may result from shear movement. A GPS device is positioned on the outcrop for scale reference, indicating geological fieldwork and geolocation mapping.

Figure 5. The outcrop consists of two visually contrasting rock units: the upper section is weathered and fractured, likely composed of granitic or metamorphic rock, with a beige to light brown colour suggesting feldspar-rich material. The lower section appears more massive, less weathered, and lighter in tone—possibly quartzite or gneiss. Some localized bending and displacement of layers may indicate the activation of shearing forces in the geological history of this region. This geological exposure represents an intrusive body of granitic rock overlying a metamorphic basement.

gneiss and migmatite, and the Southern part is composed of biotite gneiss (**Figures 3-5**). Scattered patches of mica-schist (**Figure 6**) and quartzite (**Figure 7**) are also located in different parts of Ajodhya Hill. Physical and chemical weathering is very active on this hill. Signatures of the weathering process, like mechanical disintegration (**Figure 6**), joint block separation, and exfoliation in dome-shaped hillocks, are identified in Matha, Boro, and Jhalda (**Figure 8**, **Figure 9**). Chemical weathering is well-active in gentle to moderate slope areas.

Figure 6. Patches of Mica schist. The photograph of patches of Mica schist reveals a striking example of a metamorphic rock, characterized by its distinctive layered or flaky texture, which is a result of the compression and alteration of shale or phyllite under high pressure and temperature conditions, resulting in a rock that is rich in mica minerals, such as biotite or muscovite, and often exhibits a shimmering or glittering appearance due to the reflection of light off the flat surfaces of the mica crystals.

Figure 7. Soil profile with alteration of bedrock Mica schist and Quartzite. The green line indicates patches of Quartzite, and the green line indicates patches of Mica schist.

Figure 8. Weathering residuals look like balancing rock. Weathering residuals that resemble balancing rocks are fascinating geological formations that have been shaped by the forces of weathering and erosion over thousands or millions of years. These formations are characterized by their unique appearance. They feature a large rock or boulder perched precariously on a smaller base, giving the impression of being balanced or teetering on the edge of collapse.

Figure 9. Signature of mechanical weathering (exfoliation dome). Exfoliation domes are fascinating geological formations that are formed through the combination of weathering, erosion, and exfoliation processes. These formations are characterized by their distinctive dome-shaped structure, layered or sheeted appearance, and smooth surface, and are often composed of a more resistant type of rock at their core. Examples of exfoliation domes can be found worldwide, providing valuable insights into the geological history and processes that have shaped our planet.

Purulia district is situated in the eastern portion of the Chhota Nagpur plateau (Ghosh et al., 2023). Paleogeographically, this area is most significant. This is an intrinsic part of the peninsular shield of India. The geological formation of the Purulia district broadly can be divided into two geological formations: 1) a Peninsular shield formed in the Archean age entirely dominated by granite and Gneiss rocks, 2) a Gondwana basin that was raised by oceanic sediment and woody materials during upper Carboniferous—Triassic periods. Archean is the oldest comprehensive rock formation in this area. Ajodhya Hill is challenging and well erosion-protected. The Ajodhya Hill creates a water shade boundary between Kangashabati in the North and Subarnarekha in the South (Figure 10). Various residual hills are isolated and detached from Ajodhya Hill in the West and Southeast. Ajodhya Hill

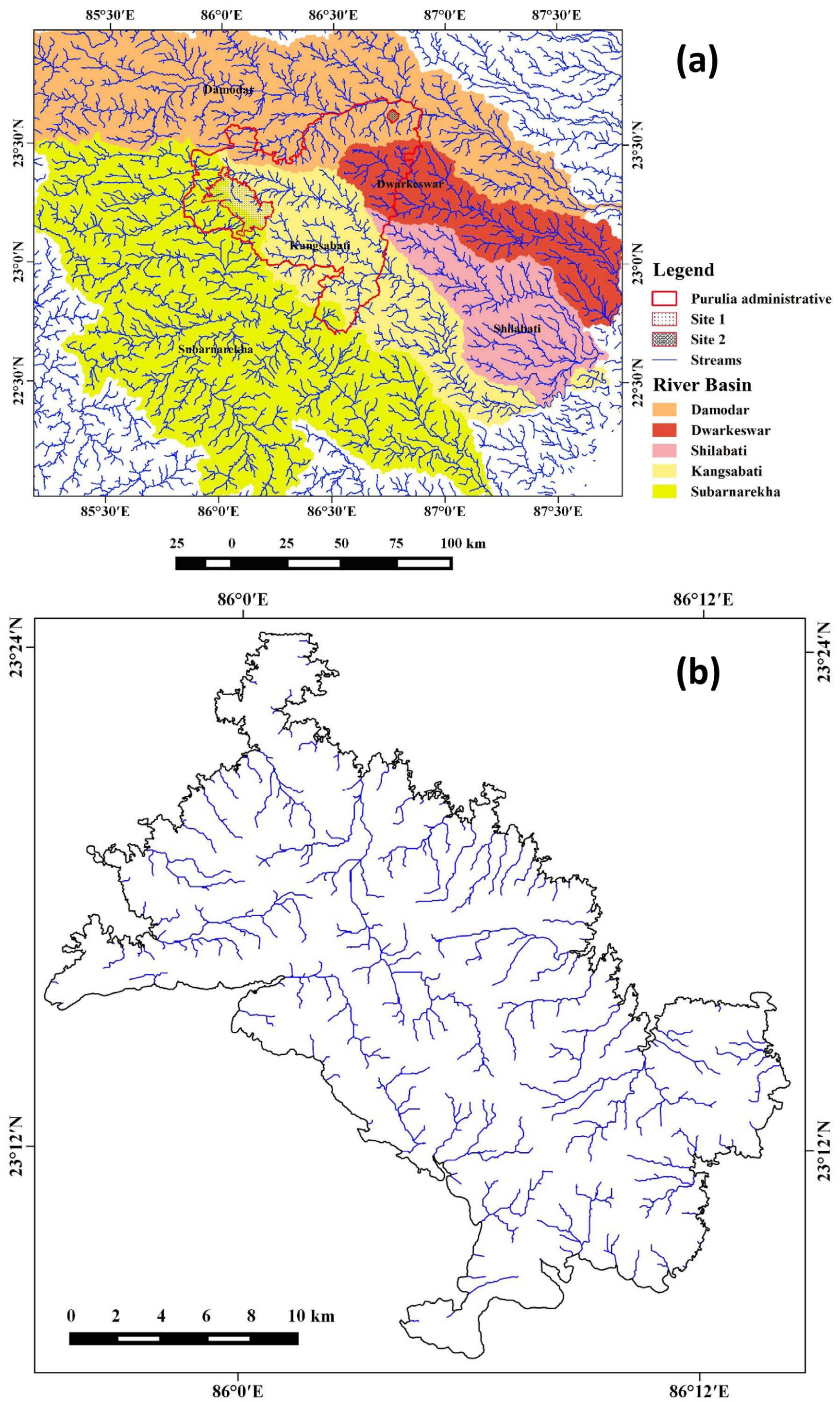


Figure 10. (a) River basin map of Purulia district and its surrounding area, (b) Drainage system of Ajodhya hill.

(flat top with isolated peaks) is a plateau (300 - 665 m) of 401.4 km^2 area (Dasgupta, 2015). A dome-shaped hill is located in Jhalda. Ajodhya Hill is associated with some peaks like Boro Hill, Chemtu Hill, Kukuburu Hill, Pakhi Hill, and Gorgaburu Hill (Figure 11(a), Figure 11(b), Figure 12), which are composed of porphyritic granite–gneiss. A break of slope zone associated with escarpment has been identified in the hill's eastern, southeastern, northwest, and western parts. Various falls have been located in different parts of the hill (Figure 11(a); Figure 11(b)).

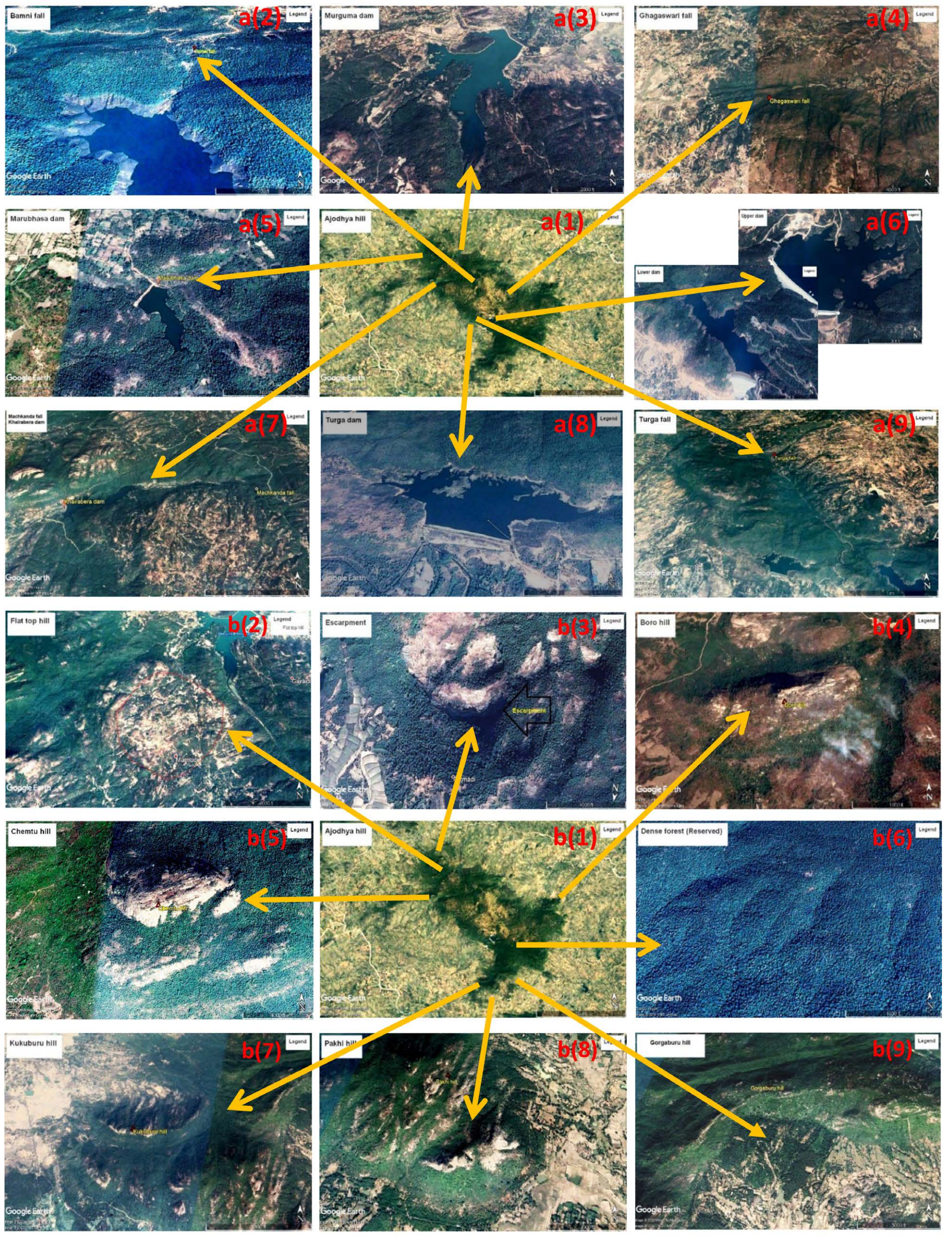


Figure 11. (a) (1) Ajodhya hill, (2) Bamni fall, (3) Murguma dam, (4) Ghagaswari dam, (5) Marubhasa dam, (6) Upper and Lower dam, (7) Machkanda fall and Khairabera dam, (8) Turga dam, (9) Turga fall. Snapshots are generated from Google Earth. (b) (1) Ajodhya Hill, (2) Flat top Hill, (3) Escarpment, (4) Boro Hill, (5) Chemtu Hill, (6) Dense forest, (7) Kuku Buru Hill, (8) Pakhi hill, (9) Gorgaburu hill. Snapshots are generated from Google Earth.

Figure 12. The image depicts Gorgaburu Hill and Pardi Dam in the Ajodhya Hills range. It stands as the second-highest peak in the Ajodhya Range, reaching a height of 677 meters (2221 feet). Pardi Dam is a small reservoir managed by the Water and Irrigation Department of the Government of West Bengal. It is located at the base of the hill and is likely used for local irrigation, drinking water, and seasonal water storage. The calm surface indicates limited water flow and a controlled environment. The hill is covered with sparse vegetation, including patches of shrubs and small trees, suggesting a semi-arid or dry deciduous forest ecosystem.

The hill area is surrounded by the signature of the erosional plateau, scarps, foothill erosional plain, natural terrace duricrust, etc. The Foothill area of Ajodhya Hill can be demarcated by a 300 m contour (**Figure 13**). A thick soil layer covers the Surface of the foothill pediment area. The steep escarpment continues up to the northeast and southwest of Ajodhya Hill. The hill area is almost flat-topped and covered with dense vegetation. The Foothill area of the Ajodhya fill is well extended from the northeast to the southwest. Three waterfalls are near the upper dam in the south, west, and middle hill areas. According to surface analysis, the maximum portion of the area is dominated by a 0˚ - 40˚ slope (**Figure 14**), but the slope varies from 4˚ to 43˚ around the isolated residual hill. The foothill pediment area experiences a 4˚ - 10˚ slope, and the slope of the hill area fluctuates from 10˚ - 43˚. Most of the hill area experiences steep slopes of about 19˚ - 43˚. The foothill of the isolated residual hills and flat areas of Ajodhya has a meager value on the ground slope. The hillside escarpment area also experiences steep slopes ranging between 34˚ - 67˚.

3.2. Characterization of Soil

Complex geomorphic processes have produced the soil of this area. Geology and geomorphology are essential in determining the soil's nature and properties in this area. Soils of the Ajodhya hill and its surrounding area are residual types. Residual soil is produced by deep weathering on Archean granite, gneisses, and schists (Figure 7). Moderately drained sandy loam soil has been located over the Gondwana group of sedimentary rocks (sandstone, red sandstone, red clay, shales). Generally, coarser loamy laterite soil is found over the Singhbhum (granite, gneiss, migmatite, quartz, quartz-schist, mica-schist, crystalline limestone, hornblende, schist, etc.) and Dalma (metamorphosed bare volcanic rock) group of rocks. The Chhotanagpur gneissic rock group is associated with a loamy soil and gravel mix. The older alluvium of the Pleistocene age and sandy loam is located on the southern foothill (Bagmundi village area) of Ajodhya Hill. Sandy Loam is also in the Northern foothills (Arsa village area). Other essential soil textures of this area are sandy clay loam and loamy sand. Those are located at Arsa village (Northern foothill), Bagmundi village (Southern foothill), and Jhalda (Western foothill). Sandy loam is also identified on the gently sloped area to undulating plateaus.

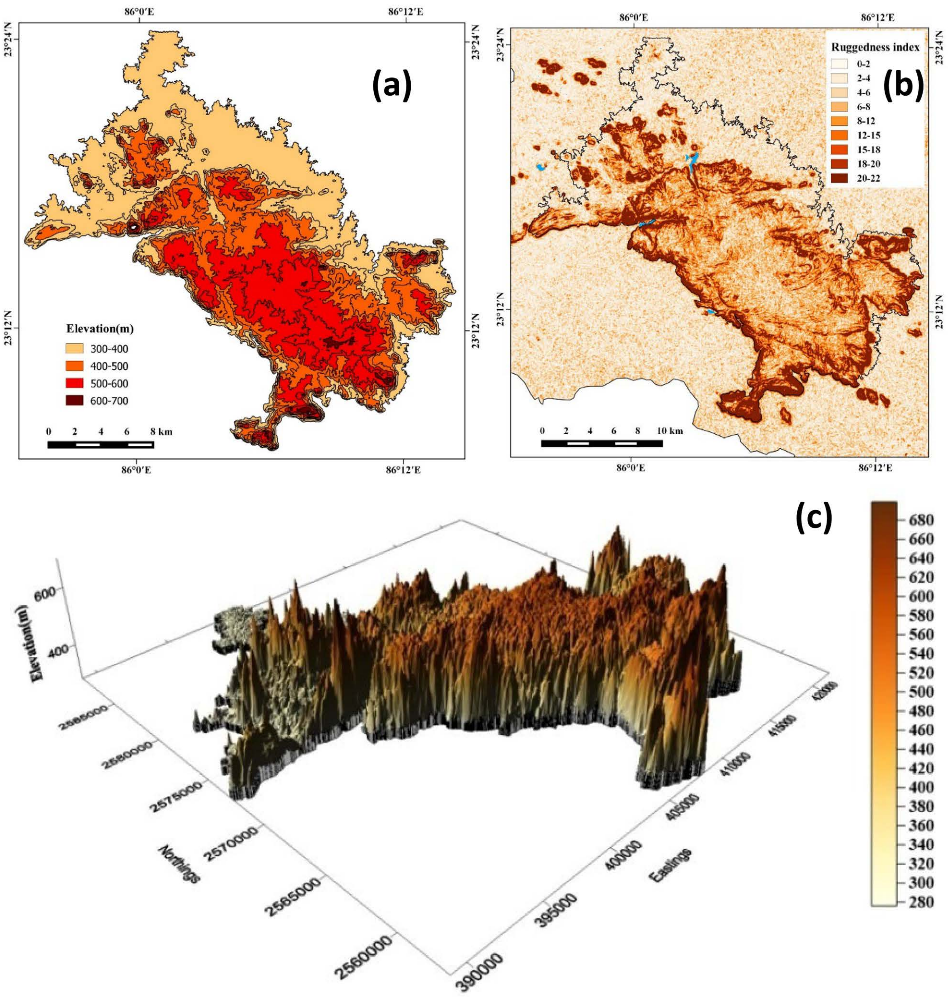


Figure 13. (a) Elevation map (DEM) of Ajodhya Hill, (b) Ruggedness map of Ajodhya Hill, (c) 3D view of Ajodhya Hill. The third dimension view is derived from SRTM elevation data by surface analysis tool.

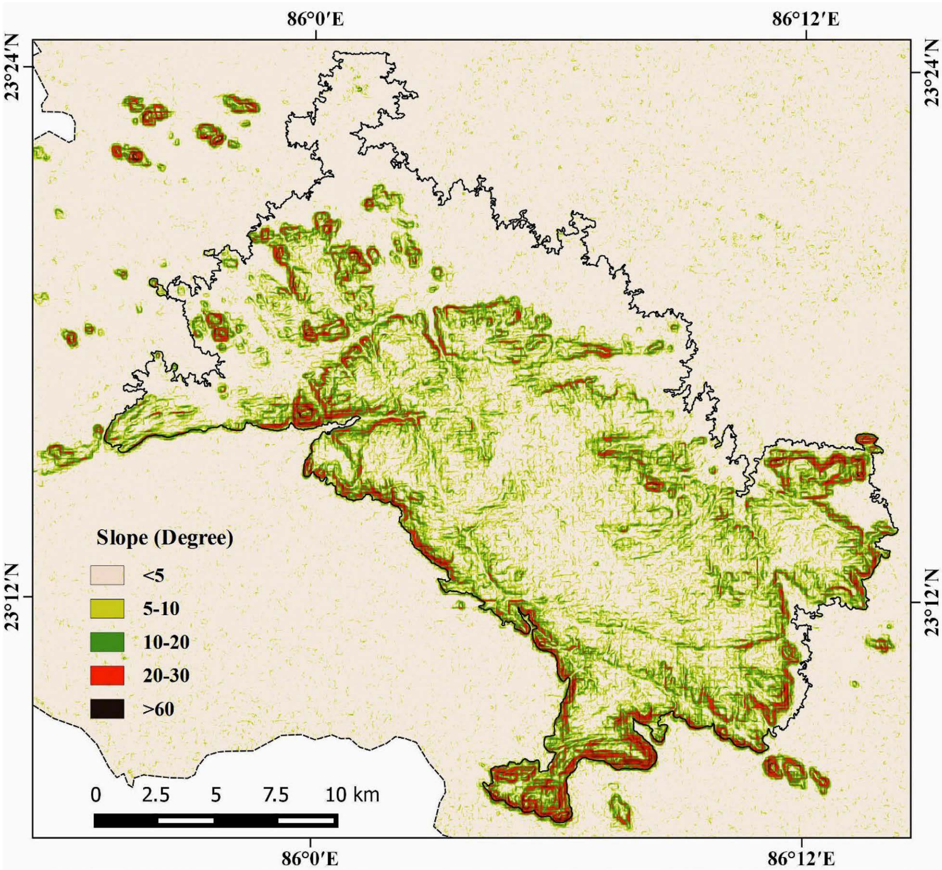
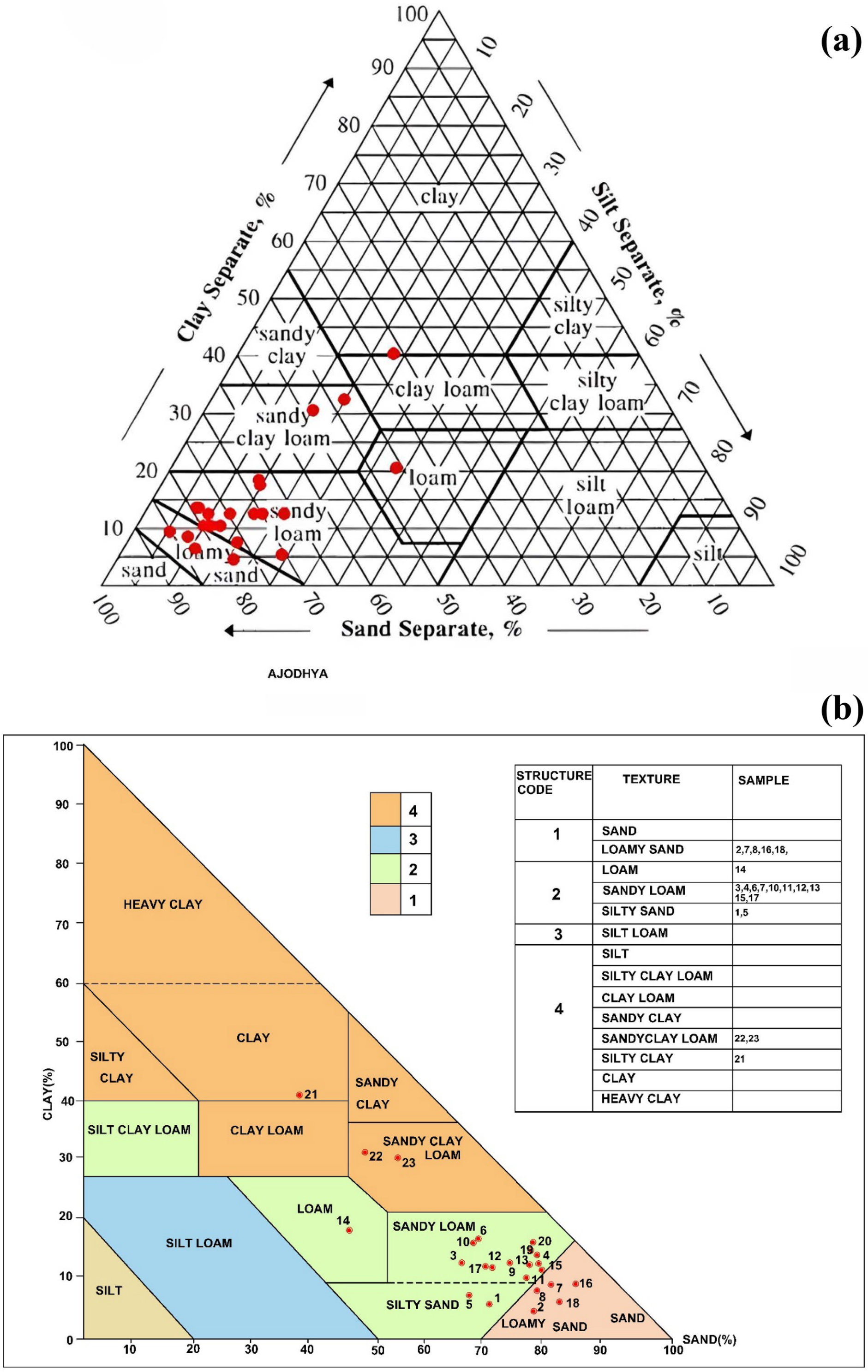


Figure 14. Slope map of Ajodhya hill.

A soil profile description describes secondary weathering features related to soil development (e.g., horizons, colors, and soil structure) and any primary features inherent to the parent material, such as sedimentary stratigraphy, grain size, or mineralogy (Eppes, 2009). Weathering, humification, and mineralization are essential components of the pedological system. Soils of this area are formed in situ. A soil layer has been developed on the complex, massive crystalline rock. The depth of the soil in the hill area is less. Regolith is produced from detrital sediment. Sand and clay result from the breakdown and disintegration of schistose rock through weathering and denudation processes. Quartz-biotite schist is most susceptible to weathering on Ajodhya Hill (Dasgupta, 2015). The alteration of feldspar and mica produces sandy clay particles in the soil texture. Sand and silt also derive from quartz and other resistant minerals (**Figure 7**). This is the only reason for this region's porous, loose, and granular soil character. Here, the soil is formed from the residual parent material. Feldspar becomes a clay mineral in contact with water with cations and anions in the solutions. The soil-forming process in this area is also dominated by biological weathering. Organic acid is produced from the decomposition of organic debris, which plays a vital role in the decomposition of rocks and minerals. Rainfall intensity and variation in the rain and high temperature lead to decomposition and horizontal variation in the distribution of organic matter. Granite, genesis, sandstone, and conglomerate play roles in the parent material development of the soil profile of this area. This patent material forms soil texture like sandy loam, predominantly over the whole area (Figure 15(a)-(c)). Study areas are associated with sandy loam and loamy fine soil texture. Another predominant soil texture is sandy clay loam. The surface soil is dry



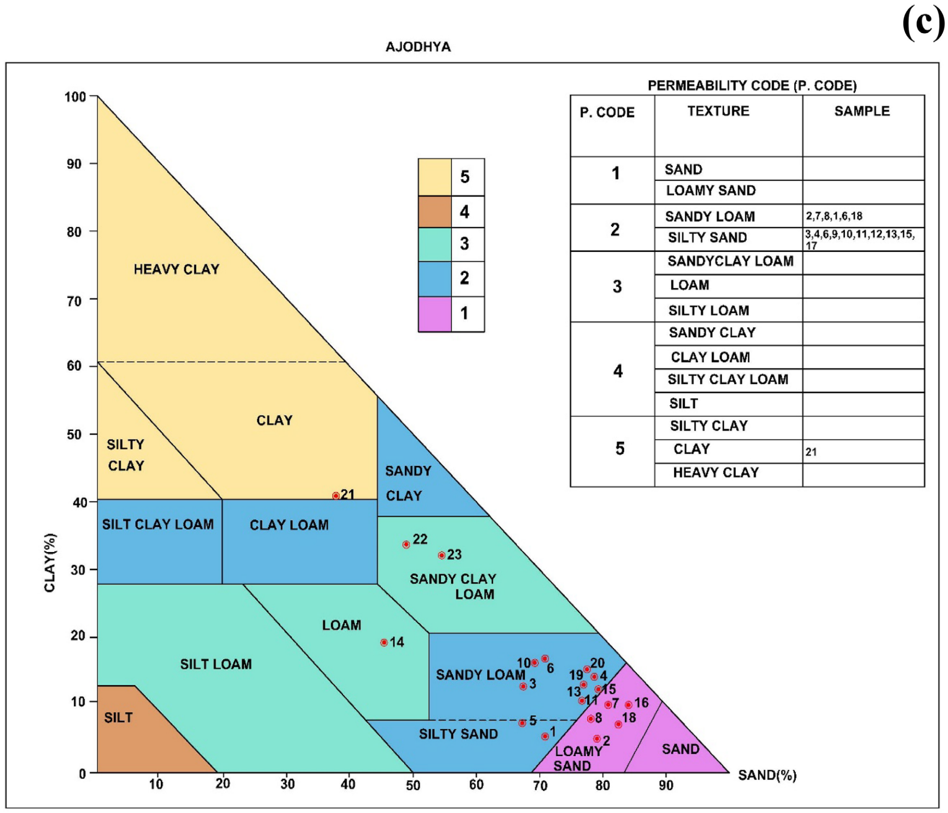


Figure 15. (a) Ternary diagram. The percentages of sand, silt, and clay in each sample have been plotted on a soil texture calculator. According to the textural plot, sandy loam and loamy sand dominate soil texture (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054167). (b) Textural classification for determination of soil type by plotting of percentage of sand and clay matter in the sample. Soil Structure Code based on textural classification after Ontario Centre for Soil Resource Evaluation, 1993 and Wall et al, 1997. (c) Textural classification for determination of soil type by plotting the percentage of sand and clay matter in the sample. Soil Permeability code based on textural classification After Ontario Centre for Soil Resource Evaluation, 1993. (Code-1-Very high permeability; Code-2-High permeability; Code-3-Permeability; Code-4-Low permeability; Code-5-Very low permeability).

(Figure 16(a)). The concentration of hygroscopic moisture in this area ranges up to 2 percent. Sometimes, it varies up to four percent. Soil organic matter also ranges up to 3 percent (Figure 16(b)). Soil pH is neutral (Table 2). The Maximum number of samples having conductivity level of 30 - 45 μS/cm and 30 - 90 μS/cm (Figure 16(c)). Status of nitrate nitrogen (NN) in soil is very high ammonical nitrogen (AN) is medium, phosphorus (P) and potassium (K) are low in status (Figure 17).

3.3. Soil Geomorphology

The elevated area of Ajodhya Hill is less graveled. Gravels accumulated on the depression over a moderate to gentle slope area because the higher elevated area of the Ajodhya hill is fully covered by forest; Grassland is dominant in the escarpment area. Forest cover and grassland can protect the disintegration and breakdown of rock by weathering in this area. On the other hand, the percentage of sand increases

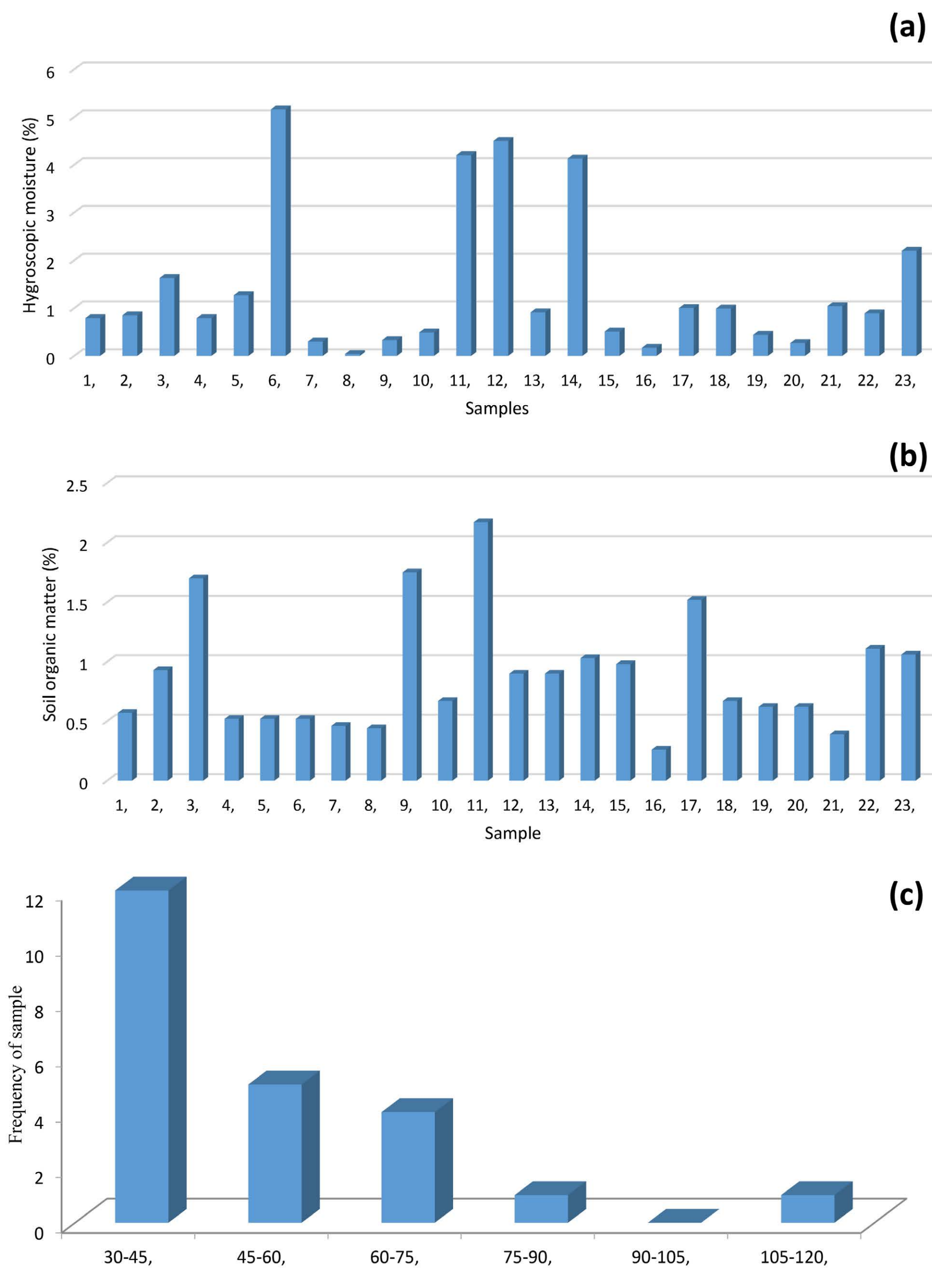


Figure 16. (a) Percentage of Hygroscopic moisture of the samples. That has been determined by oven-drying samples for 3 hours at a temperature of 105˚C. (b) Percentage of organic matter of the samples. That was determined after Walkley and Black's wet combustion method in 1934. (c) Amount of Salinity of the samples. That has been defined by using a Digital Conductivity TDS Meter (Model-DCM 900).

Table 2. Range of pH of samples of the study areas.

Denomination	pH range	Sample	
		No.	Percentage (%)
Extremely acid	3.5 - 4.4	-	-
Very strongly acid	4.5 - 5.0	-	-

Continued

Strongly acid	5.1 - 5.5	-	-
Moderately acid	5.6 - 6.0	1	4.34
Slightly acid	6.1 - 6.5	3	13.04
Neutral	6.6 - 7.3	19	82.60
Slightly alkaline	7.4 - 7.8	-	-
Moderately alkaline	7.9 - 8.4	-	-
Strongly alkaline	8.5 - 9.0	-	-
Very strongly alkaline	>9.0	-	-

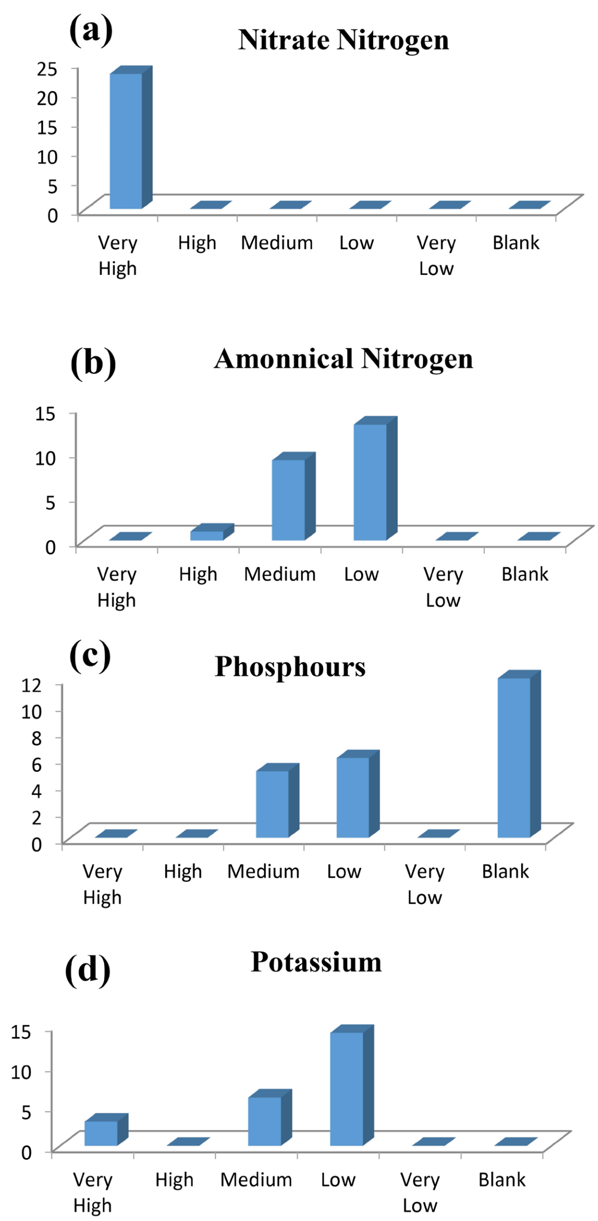


Figure 17. Status of NPK. Determine the status of NPK has been done by using a soil testing Kit (no: A0).

with an increase in elevation. The percentage of silt and clay decreases with the elevation increase (Figure 18, Table 3). Because surface runoff carries silt and clay from a high elevation to a low-elevated area. The percentage of HM in the surface soil of the hill area is more significant than in the foothill pediment area. The percentage of HM and SOM increases with the elevation increase because this area is associated with forest cover and grassland. Forests and grasslands can produce an immense amount of SOM. The decomposition of soil organic matter needs water availability in the soil. The range of pH increases with elevation. The top of the hill area is associated with a higher pH than the pediment area (Table 3, Table 4). Here, the decomposition of organic matter is the source of the soil's high acidic tendency. When the elevation is high, the salinity of the surface soil is low.

Table 3. Summary of PCA analysis.

Summary of PCA analysis					
Component	**Percentage of variability**	**Cumulative percentage of variability**	**Total variability (>75% explanation)**	**Total number of components up to (75% explanation)**	**Remarks**
Elevation	34.43	34.43	80.31	4	Very well explained
Slope	22.03	56.47			
Sand	15.18	71.65			
Silt	8.65	80.31			

Table 4. Relationship among elevation vs soil structure and permeability.

Elevation (m)	Soil Texture	Permeability
>500	Sandy loam	Very high permeability
	Loam	High permeability
	Lomay fine sand	Permeability
400 - 500	Sandy loam	Very high permeability
	Lomay fine sand	Permeability
300 - 400	Sandy loam	Very high permeability
	Lomay fine sand	Permeability
<300	Sandy loam	Very high permeability
	Lomay fine sand	Permeability
	Sandy clay loam	Permeability
	Clay	Low permeability

The data of soil geomorphological parameters of 23 sample locations across Ajodhya Hill have statistically examined. The correlation matrix, regression trend line (yc), and coefficient of determination have been calculated (Table 3, Table 5).

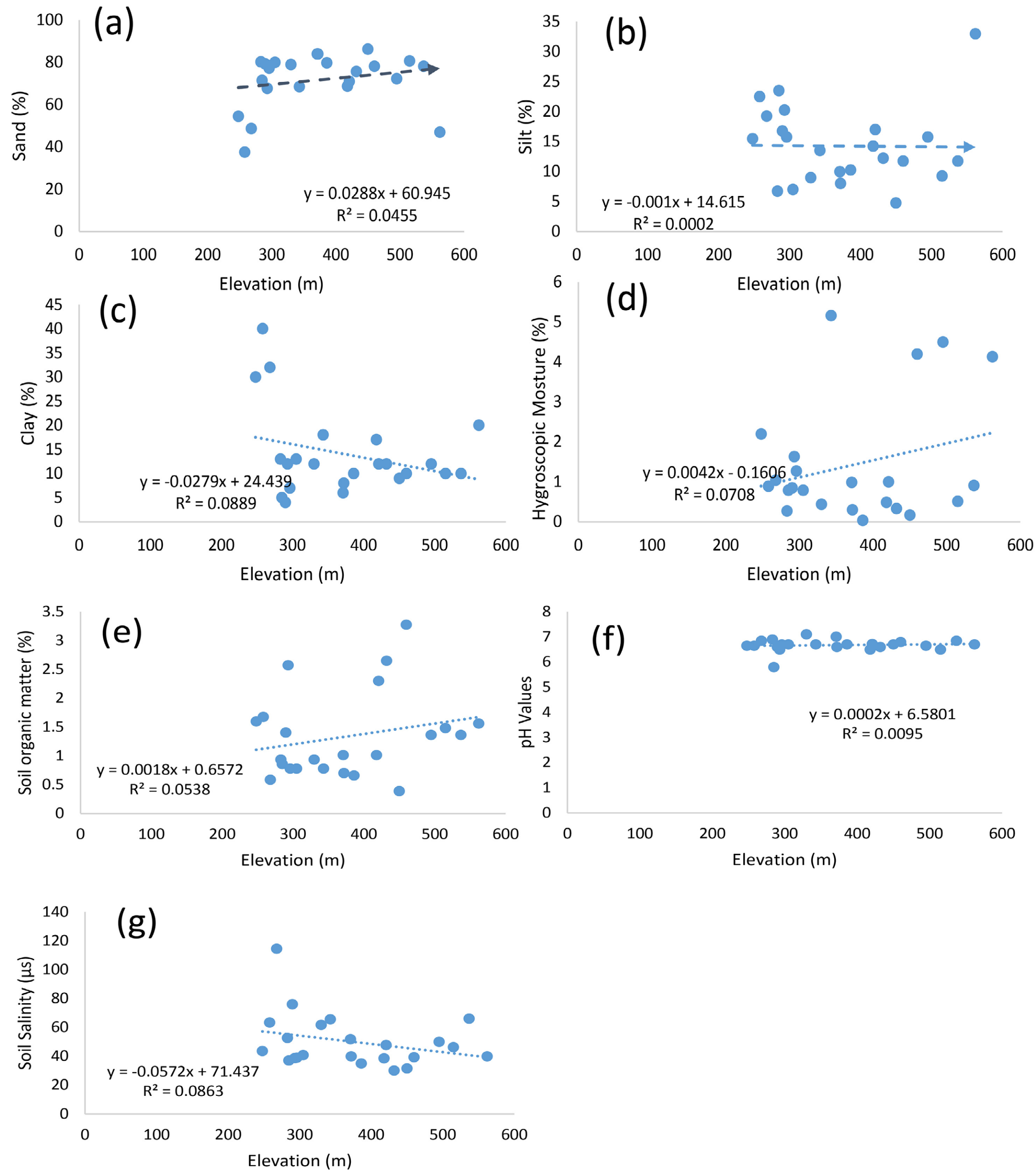


Figure 18. Correlation between (a) elevation and percentage of sand, (b) elevation and percentage of silt, (c) elevation and percentage of clay, (d) elevation and hygroscopic moisture in percent, (e) elevation and soil organic matter in percent, (f) elevation and pH, (g) elevation and soil salinity in µS/cm. R^2 (R-squared) is considered a statistical measure of the closeness of data to the regression line. R^2 is also called the coefficient of determination. R^2 ranges between 0 and 100; low R^2 values indicate less explanation of the variability of the response data around its mean. R^2 value can indicate how many points fall on the regression line. For example, in the case of elevation versus clay, the R^2 value is 0.08 (8%), which means that 8% of the variation of y-values around the mean is explained by x-values, and the model fits 8% of the value.

Table 5. Relationship between slope and soil NPK.

Slope (degrees)	AN	NN	P	K
>20	Low	High	Low-Medium	Low-Medium

Continued

15 - 20	Low-Medium	High	Medium	Low
10 - 15	Low-Medium	High	Low	Low
5 - 10	Low	High	Very Low	Low
<5	Low-Medium	High	Very Low	Low-High

AN—Ammonical Nitrogen, NN—Nitrate Nitrogen, P—Phosphorus, K—Potassium.

A Significant relationship is shown between the slope and the different characteristics of the soil. The percentage of sand increases with the increase of slope. The percentage of slit and clay is less in the steep sloping and escarpment area (Table 6). Silt and clay have been taken out by the surface runoff and moved into a downward, less sloping area. The grass arrests particles of sand. The percentage of HM is less in the steep sloping area; it increases with the slope decrease because the slope gradient and gravitational pull of sand-dominated textured soil cannot hold a significant amount of HM in the soil. The percentage of SOM increases with the increase in slope (Figure 19). Because the steeply sloped escarpment area is entirely dominated by annual grassland. Grassland has greater root density than forest. That can produce much SOM than forest. An increase in soil pH is associated with an increase in slope. According to principal component analysis, the total variability of the components of the study area is well explained. The components' total variability (greater than 75 percent explanation) is done by the first four components (elevation, slope, sand, and silt). Those are statistically significant in soil geomorphology. These four factors can explain 80% of the regression in combination (Table 7). Elevation, slope, and sand are the principal components of the study area.

Table 6. Relationship among slope vs. soil structure and permeability.

Slope (degrees)	Soil Texture	Permeability
>20	Sandy loam	Very high permeability
	Lomay fine sand	Permeability
15 - 20	Sandy loam	Very high permeability
	Lomay fine sand	Permeability
10 - 15	Sandy loam	Very high permeability
	Lomay fine sand	Permeability
5 - 10	Sandy loam	Very high permeability
	Sandy clay loam	Permeability
<5	Sandy loam	Very high permeability
	Lomay fine sand	Permeability
	Sandy clay loam	Permeability
	Clay	Low permeability

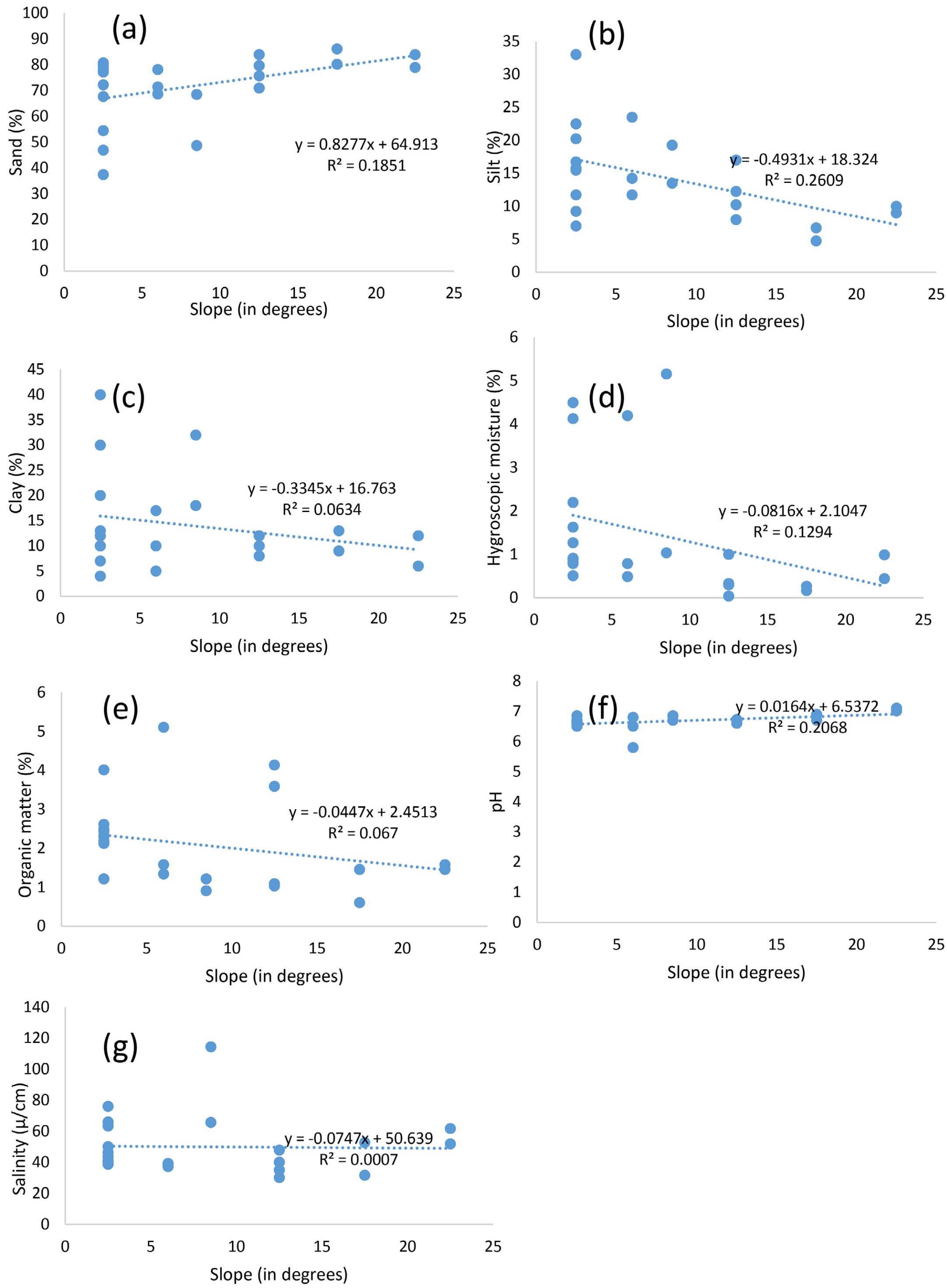


Figure 19. 11 Correlation between (a) slope and percentage of sand, (b) slope and percentage of silt, (c) slope and percentage of clay, (d) slope and hygroscopic moisture in percent, (e) slope and soil organic matter in percent, (f) slope and pH, (g) slope and soil salinity in µS/cm. R^2 (R-squared) is considered a statistical measure of the closeness of data to the fitted regression line. R^2 is also called the coefficient of determination. R^2 ranges between 0 - 100; low R^2 values indicate less explanation of the variability of the response data around its mean. R^2 value can indicate how many points fall in the regression line. For example, in the case of slope versus silt, the R^2 value is 0.26 (26%), which means that 26% of the variation of y-values around the mean is explained by x-values and 26% of the value is fit by the model.

Table 7. Correlation result matrix and R^2 (coefficient of determination) values.

Correlation result matrix			R^2 values	
Components	**Elevation**	**Slope**	**Elevation**	**Slope**
Sand	Positive	Positive	4	19
Silt	Negative	Negative	0	26
Clay	Negative	Negative	8	6
HM	Positive	Negative	7	13
SOM	Positive	Negative	5	7
pH	Positive	Positive	1	21
Salinity	Negative	Negative	8	0

SOM—Soil Organic Matter, HM—Hygroscopic moisture. R^2 values are in percentage.

The highly elevated area (>500 m) of the Ajodhya hill is dominated by very high permeable sandy loam, high permeable loam, and permeable loamy fine sand (Table 4) soil texture. Between 300 - 500 m elevated area is associated with very high permeable sandy loam and permeable loamy fine sand. Elevations below 300 m and slopes less than 5˚ are characterized by sandy loam, loamy fine sand, permeable sandy clay loam, and low-permeable clay soil texture (Table 4, Table 6). An area with greater than 10˚ slope is associated with sandy loam and loamy fine sand soil texture (Table 6). Status of AN, P, and K is low in the high-elevation (>500 m) (Table 8). Status of AN, P, and K between the elevation of 300 - 500 m remains low-medium, very low and low to medium. Status of NPK in the foothill area (elevation <300 m and slope <5˚) Fluctuates rapidly. The status of NN always remains high in Ajodhya Hill (Table 5, Table 8). Moderate slope area (10˚ - 20˚) is associated with low-medium AN, P, and K. Slope area between 5˚ - 10˚ is characterized by low AN, K, and deficient P (Table 5).

Table 8. Relationship between elevation and soil NPK.

Elevation (m)	AN	NN	P	K
>500	Low	High	Very Low	Low
400 - 500	Medium	High	Very Low	Low
300 - 400	Low	High	Very Low	Low-Medium
<300	Low-Medium	High	Low-High	Low-High

AN—Ammonical Nitrogen, NN—Nitrate Nitrogen, P—Phosphorus, K—Potassium.

3.4. Soil Geomorphology and LULC

Six broad land use (LU) and land cover (LC) categories have been selected for LULC mapping. Categories of LC are forest, moderate forest, dense forest, and scattered vegetation. Land use and agricultural land are currently falling. Land use and land cover categories have been developed based on soil geomorphological character. A dense forest (Figure 20(a)) is located on the highly elevated and less sloped areas (Figure 11(b)). Moderate vegetation is located on the medium elevated and relatively greater sloped areas. Steep-sloped and escarpment areas are dominated by scattered vegetation (Table 9) (Figure 20(b)) and grassland. Agriculture is developed on the foothill pediment (Figure 20(c)) areas where elevation and slope are shallow and a thick layer of relatively fertile soil is present. The depth of the soil at the escarpment area is less. High-elevation Forest areas are less sloped where soil thickness exceeds the escarpment area.

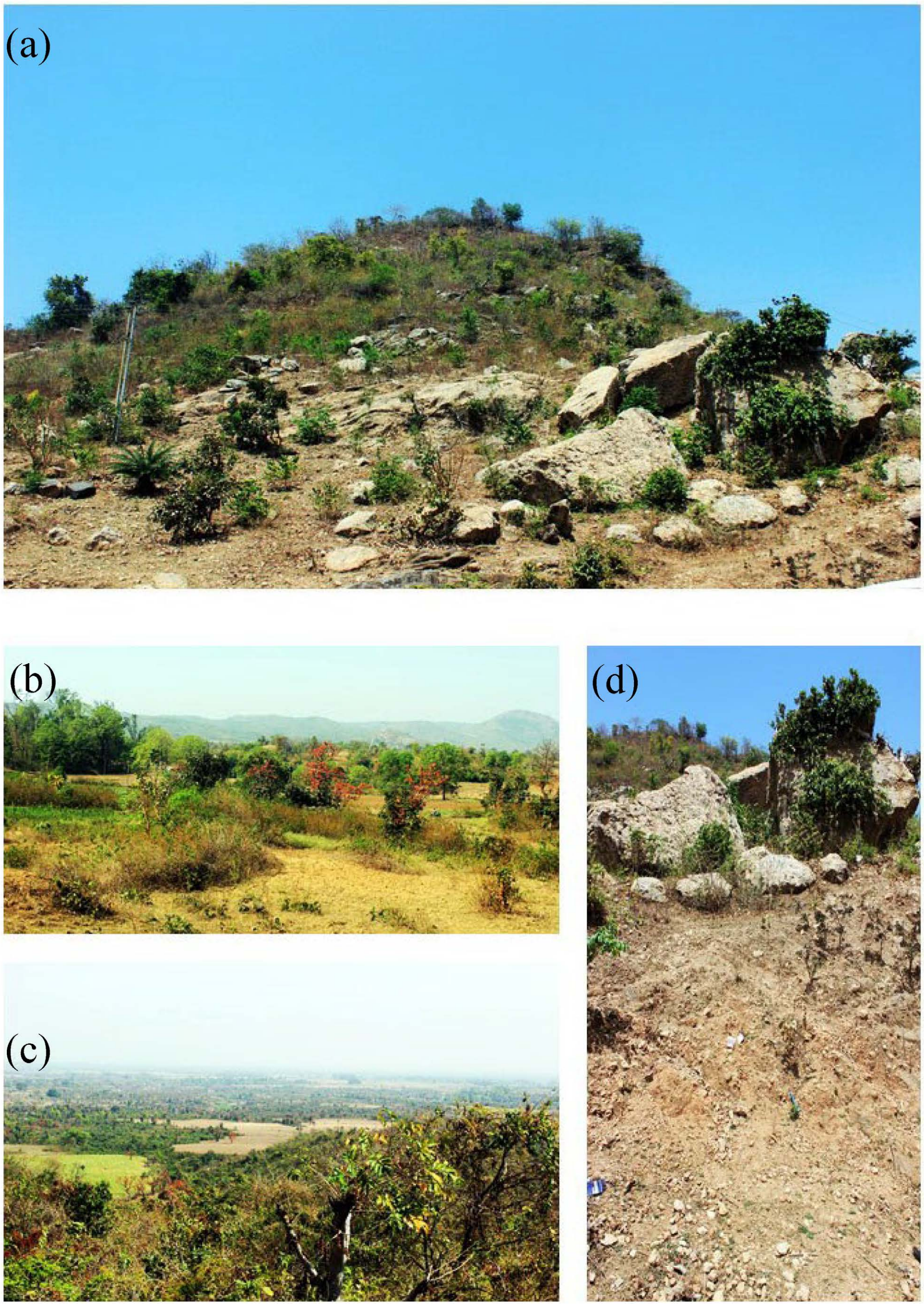


Figure 20. Forest area (a), scattered vegetation (b), foothill agriculture land and current fallow (c), bare ground (d).

Some band-ratioing techniques are also used to support LULC categories. The authentication of LU and LC categories can be checked by analysis of vegetation (NDVI) and water (NDWI). Land surface temperature (LST) is essential for identifying LU and LC attributes. Different LU and LC categories can be easily identified by the reflectance of heat from their bodies. The LST of the dense forest area (Figure 21(d)) is less than that of the bare or exposed soil ground (Figure 21(c)). The LULC categories of the foothill pediment area of the hills are classified by analysis of the band information of satellite data. Forest areas are associated with high NDVI values (Figure 21(a)), which indicates good vegetation health. A high NDWI value is associated with a high moisture content area and lower temperature in the surrounding area (Figure 21(b)). Bare soil ground is associated with lower NDVI values, indicating less vegetation in this area. Lower NDWI values denote less available water content and high temperature (Table 10).

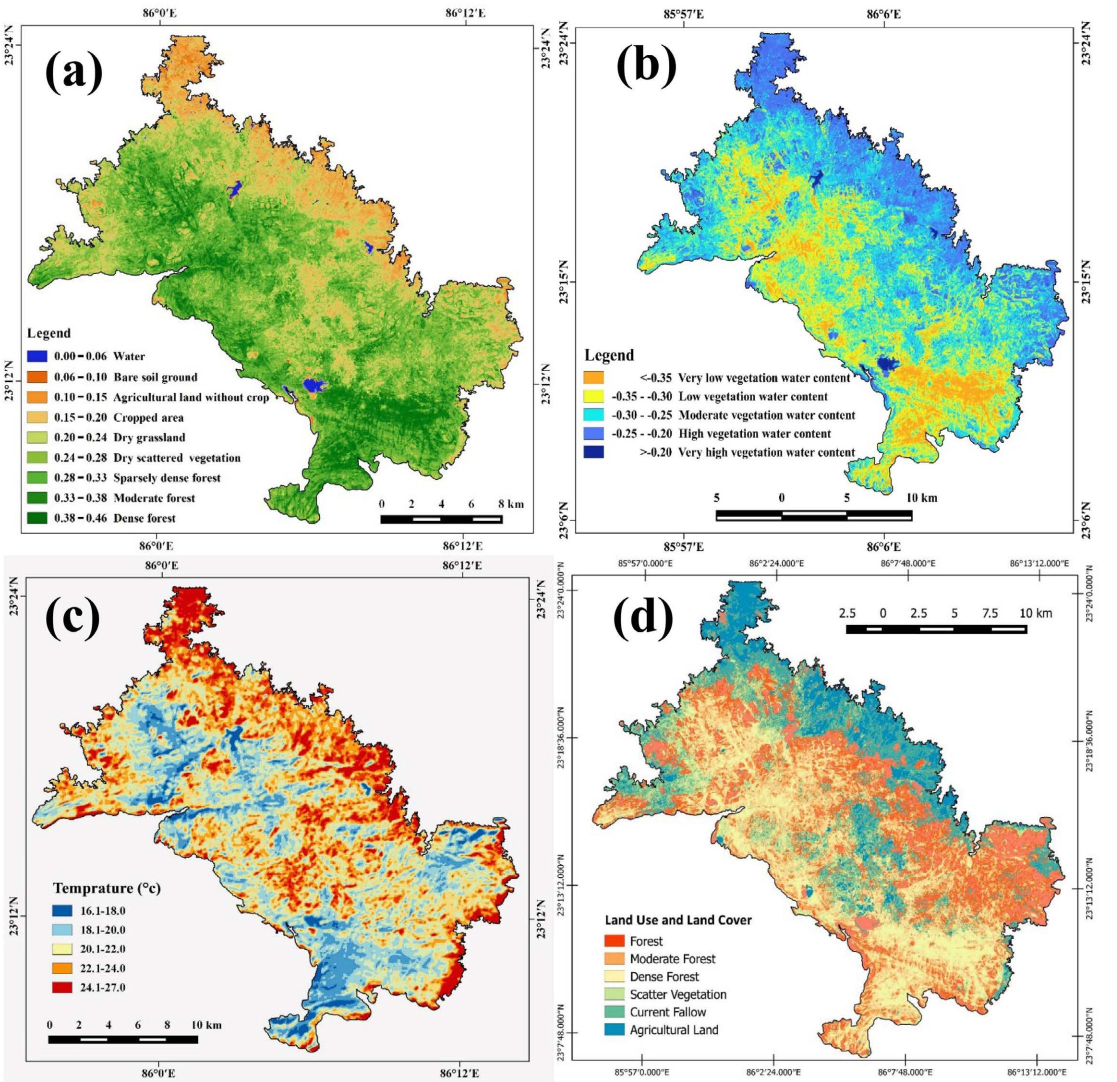


Figure 21. (a) NDVI map of Ajodhya Hill, (b) NDWI map of Ajodhya Hill, (c) LST map of Ajodhya Hill, (d) LULC map of Ajodhya Hill.

Table 9. Soil geomorphology and land use land cover.

Category	Geomorphology		Soil Character				
	Elevation (m)	Slope (degrees)	Texture	S O M (%)	HM (%)	pH	Salinity (µS/cm)
Dense forest	350 - 560	5 - 10 10 - 15	SL	0.90 - 1.30	4 - 5	6.5 - 6.85	30 - 50
Moderate forest	450 - 550	5 - 10 10 - 15	SL	0.90 - 1.30	4 - 5	6.4 - 6.75	30 - 50
Scattered vegetation	250 - 450	10 - 15 15 - 25	SL, LFS	0.26 - 1.52 (S), 0.9 - 2.17 (N)	2 - 4	6.7 - 6.8	50 - 60
Follow	<350 390 - 562	<5 5 - 10	LFS	0.39 (S), 0.67 - 1.75 (N)	<1	6.7 - 6.8	40 - 77
Current fallow	<350	<5	SL	1.1 - 1.06 (S), 0.57 - 1.70 (N)	<1	5.8 - 6.8	37 - 76
Agriculture	<350	<5	SL, C, SCL	1.1 - 1.06 (S), 0.57 - 1.70 (N)	<1	5.8 - 6.8	37 - 76

SOM = Soil Organic Matter, HM = Hygroscopic moisture. SL = Sandy Loam, LFS = Loamy fine sand, C = Clay, SCL = Sandy clay loam, S = South facing slope, N = North facing slope.

Table 10. Comparison between LULC categories and NDVI, NDWI, LST.

LULC Categories	NDVI values	NDWI values	LST values (˚C)
Dense forest	0.38 - 0.46	<(−)0.35	16 - 18
Moderate forest	0.33 - 0.38	(−)0.35 - (−)0.30	18 - 20
Forest	0.28 - 0.33	(−)0.35 - (−)0.30	18 - 20
Scattered vegetation	0.24 - 0.28	(−)0.25 - (−)0.20	20 - 22
Current fallow	0.10 - 0.15	(−)0.35 - (−)0.30	24 - 27
Agricultural land	0.15 - 0.20	(−)0.25 - (−)0.20	21 - 24
Water	0.00 - 0.06	>(−)0.20	16 - 18

The hilly area is associated with flat tops and dense forests (Figure 22). Sandy loam is a typical soil texture in this area where SOM is about 0.90 to 1.30 percent with 3 to 5 percent HM. The acidity (pH) and salinity of dense forest areas range between 6.5 and 6.85 and 30 and 50 µS/cm. Moderate Forest and scattered vegetation have been observed at 250 to 550 m elevation. Where the slope ranges between 10˚ and 15˚, the SOM of this area increases by 0.90 to 1.30 percent when HM is greater than 2 percent. The soil is slightly acidic, and salinity ranges between 30 and 50 µS/cm. Fallow, current fallow, agricultural land, and scattered vegetation are very common in the foothill area of the hill. Less than 300 m elevation and 5˚ slope were the criteria for delineating the foothill area. Foothill comprises clay and sandy loam soil texture with 0.57 to 1.70 percent SOM. HM of the foothill is less than 0.79 to 1.63 percent with slightly acidic soil. The Foothill area is associated with agricultural land, current fallow, stone waste, etc. Farmers produce rice, wheat, and vegetables by plowing and using terrace cultivation methods. The methods and techniques of cultivation of different crops in the

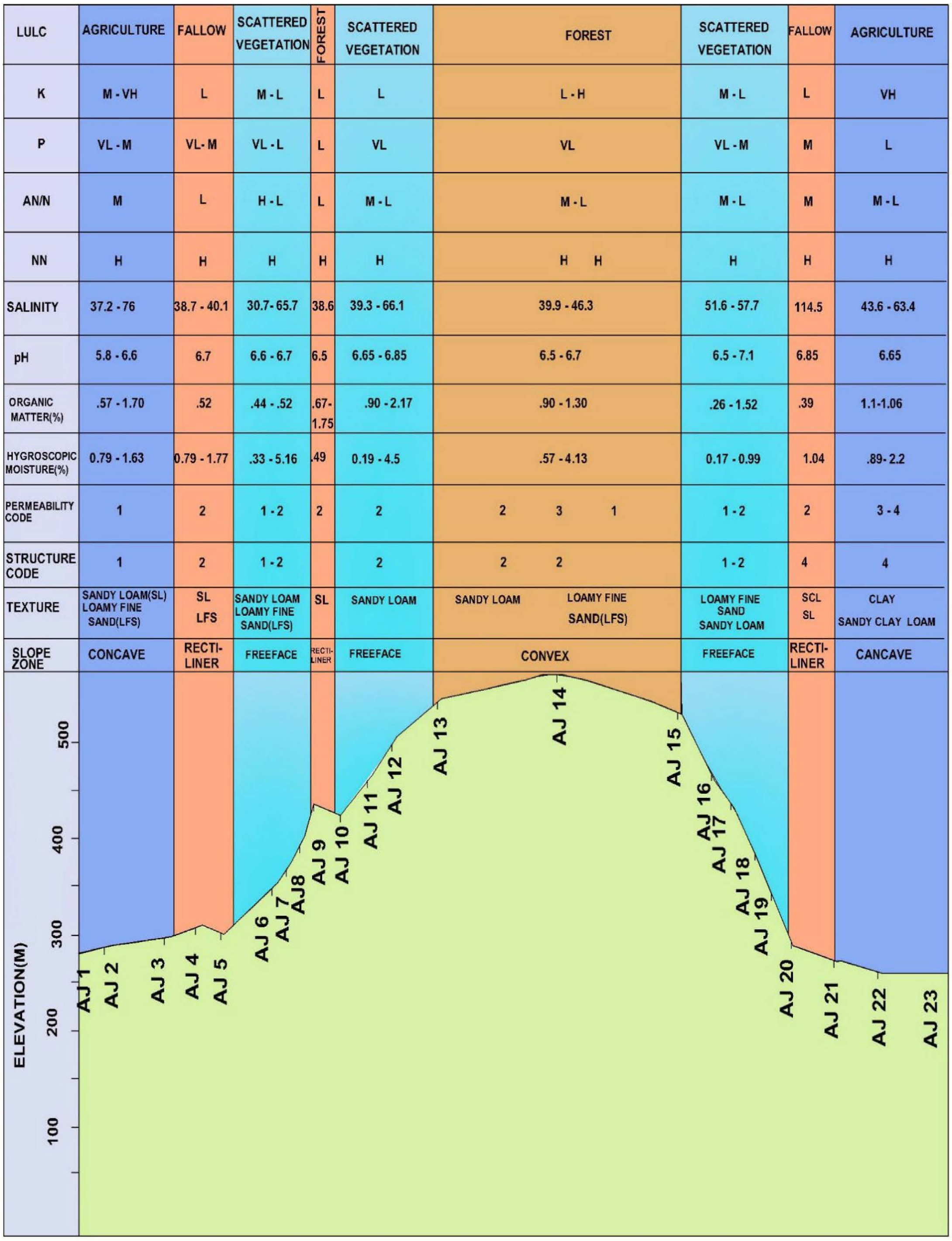


Figure 22. Two-dimensional model of four units of soil geomorphology. Transect showing elevation and slope-wise distribution of soil character (percentage of sand, percentage of silt, percentage of clay, percentage of soil organic matter, salinity, pH, and NPK) and attributes of land use and land cover.

foothill area of the hills vary to some extent (area to area). Irrigation is done using water from the dam. Productivity and yield have been rapidly increased by irrigation from the Murguma dam for the northern foothill area and the PSPL upper dam and lower dam for the southern foothill area during the dry season.

3.5. Soil Geomorphic Unit

The interaction between landscape evolution and soil-forming processes produces soil geomorphic units. Other important factors in forming soil geomorphic units are soil moisture, overland flow, slope segments, vegetation, etc. The character of soil geomorphic units varies with slope segment and elevation changes. Soil geomorphic unit is deeply related to soil catena, pedon, poly-pedon, state and intensity of pedogenesis, climate, land surface system, etc. (Sarkar, 2019a). A two-dimensional, four-unit soil geomorphological model is the critical concern. Different research has been done on landscape segment-wise description of soil character in different topo sequences as a contemporary approach (Ruhe & Scholyes, 1959; Ruhe, 1960, 1965; Ruhe et al., 1967; Ruhe & Walker, 1968; Ruhe, 1969, 1975; Monger & Bastelmeyer, 2006; Li et al., 2000; Wysocki et al., 2011; Lisi et al., 2013). Land surface and soil formation processes operate together. Pedogenesis and geomorphology are integrated with the formation of soil geomorphic units. The concept of slope segment is a principal concern for investigating and explaining soil geomorphic units. An individual segment of the slope is contemplated as a soil geomorphic unit. In the present study, the slope can be divided into four units, and each unit represents an ordinary soil geomorphic character. Each slope unit represents a land unit (Chatterjee & De, 2009). In the present study, four soil geomorphic units have been identified (**Table 11**).

Table 11. Description of soil geomorphic units.

Character	Soil geomorphic Unit-I	Soil geomorphic Unit-II	Soil geomorphic Unit-III	Soil geomorphic Unit-IV
Topography	Hilltop	Escarpment	Undulating	Foothill pediment
Slope segment	Convex	Free face	Rectilinear	Concave
Texture	SL, LFS	SL, LFS	SL, LFS, SCL	SL, LFS, SCL, C
Permeability	VH Per-Per	VH Per-H Per	H Per	VL Per
HM (%)	0.57 - 4.13	0.17 - 4.5	0.79 - 1.77	0.79 - 2.2
SOM (%)	0.9 - 1.3	0.26 - 2.17	0.39 - 0.52	0.57 - 1.70
pH	Natural	Natural	Natural	Natural-Slightly acidic
Salinity (µS/cm)	39 - 46	39 - 66	38 - 114	37 - 76
NN	H	H	H	H

Continued

AN	M-L	H-L	L	M-L
P	VL	VL-M	VL-M	L
K	H-L	M-L	L	V H
LULC	Forest	Scattered Vegetation	Follow	Agriculture

SOM—Soil Organic Matter, HM—Hygroscopic moisture, NN—Nitrate Nitrogen, AN—Ammonical Nitrogen, P—Phosphorous, K—Potassium, SL = Sandy Loam, LFS = Loamy fine sand, C = Clay, SCL = Sandy clay loam, Per—Permeable, V—Very, H—High, M-Medium, L—Low.

4. Findings

The elevation and slope of this area decrease from the west of the Purulia district to the east, towards the Bankura district. Ajodhya is the most elevated area of the Purulia district. Weathering and overland flow are the main geomorphic processes operating here throughout the past. Ajodhya Hill has several isolated residual hilltops that cover the maximum area. The mid-hill portion of Ajodhya Hill is almost flat (west) and covered by dense forest (east). The maximum slope occurs at the hill margin escarpment area. Sandy loam is the principal soil texture of this area. The siliceous types of the parent material form this. The soil-forming process moves faster in the foothill area than in the escarpment area. The rate of soil development in this area is higher. Sand allows a suitable situation for water percolation in the soil profile. The surface soil of this area has been developed on the basis of complex, massive crystalline rock. The soil depth atop the hill and escarpment area is thin due to the downward movement of soil-forming materials. Due to the minimum slope and elevation, it goes toward the downslope and accumulates in the foothill pediment area. The soil profile development has been influenced mainly by granite, genesis, sandstone, and conglomerate, producing a sandy-loam type of soil texture. The mid and foothill areas of Ajodhya Hill bear the signature of bare soil, cultivated areas, fallow land, and unhealthy vegetation. A Foothill pediment area is associated with a thick and relatively developed soil profile with good fertility conditions. The percentage of SOM is maximum in forest areas and escarpment grassland. Nitrate nitrogen (NN) status in the soil is very high when ammoniacal nitrogen (AN) is medium. The high status of nitrogen (N) in the soil leads to a high rate of photosynthesis as well as the growth of plants. The status of phosphorus (P) and potassium (K) is deficient in the soil. The presence of nitrogen is high in the soil of this area because of the sufficient supply of organic matter in the soil. Organic matter accumulates in highly elevated dense forest areas, the escarpment area of surface grass cover, and the foothill area of crop residues and manure. Organic matter is converted into inorganic nitrogen by the mineralization process.

A high range of seasonal and diurnal temperatures and variation in rainfall due to monsoon currents dominate soil character. Elevation and slope are essential in maintaining the temperature-moisture ratio in surface soil. The infiltration rate in the escarpment area is minimal when the overland flow is maximum. This phenomenon does not provide suitable conditions for the growth and development of soil profiles. That is why the thickness of the soil profile of the escarpment area of the hill is shallow. The surface soil of the escarpment area is dry because it cannot hold moisture due to the soil characteristics and slope phenomena. So, the rate of organic matter decomposition is slow in this area. The surface soil of dense forest and grassland areas has been observed to be rich in soil organic matter. Sand has been arrested by surface vegetation and grassland. When vegetation and grass cover are less in the sloped area, the percentage of sand decreases with the slope increase. Silt, clay, and hygroscopic moisture percentage are lower in the step-slopped and escarpment areas. The soil organic matter, pH, and salinity concentration are high in steep-sloped escarpment areas. So, it can be concluded that elevation and slope (geomorphic factor) are independent variables, and the rest of the components, i.e., sand, silt, clay, HM, SOM, pH, and salinity, are dependent variables. Components of soil depend on the elevation and slope of this area. Elevation and slope mainly explain the variability. The elevation of this area is the principal independent factor. Among the components of soil, sand is the principal component. Sand is the predominant component of the texture. The effect of other factors like silt, clay, HM, SOM, pH, and salinity is negligible. That is why the soil of this area is influenced by sand-dominated soil texture (i.e., sandy loam).

Categories of land use and land cover are dependent on soil geomorphological characteristics. The dense forest is located in a highly elevated area. The escarpment area is associated with scattered vegetation and dry grassland. The maximum salinity of soil occurs in the dense forest area. This area gets toxic organic compounds from decomposing organic compounds in contact with rainwater. A moderate forest is between 350 and 500 m, with a slope of 10˚ to 20˚. The slope condition of dense and moderate forests remains the same in association with an identical pedological character. This area produces high organic matter, so soil pH ranges between neutral and slightly alkaline, and the salinity level remains high. The causes of the high concentration of organic soil in the surface soil of escarpment grassland areas are their seasonal growth characteristics and intensive root density. So it can produce the maximum amount of organic debris in the soil. Sometimes, scattered vegetation is found in the fallow land of the foothill area. This area is associated with sandy clay loam and clay loam soil textures. Clay minerals have been added to the soil of this area from the elevated area through overland flow. Agricultural waste and scattered vegetation are the primary sources of organic debris in this area's soil. The concentration of hygroscopic moisture in the soil of this area remains high (0.30 - 1.94 percent). Because clay can hold water and store it in the soil as moisture. The soil pH of the foothill area is neutral. The concentration of soil salinity in the foothill area remains normal.

5. Broader Significance of the Findings

The present study has the potential to hold broader significance across multiple sub-disciplines, particularly in environmental management, sustainability, development, and social planning, which foster economic stability. The results and discussion of this study have broader implications, including theoretical implications for geomorphological concerns in the Ajodhya Hill area and practical implications for land management and policy.

5.1. Field of Ecology and Environment

The interconnected study of soil and geomorphology provides a better understanding of soil type and composition following the landscape's geomorphological features (elevation, slope). Soil geomorphological factors (Soil and landform characteristics) are the principal influencing factors of drainage systems, vegetation cover, biological diversity, dynamic ecological systems, and the utilization of landforms. The findings of the present study can evaluate the landscape's vulnerability. The study has the potential to identify and reveal management procedures for soil erosion and soil degradation. These are crucial factors for preserving ecology, reducing environmental degradation, and decreasing the deadly effects of hazards. This region's forest and biological diversity conservation is associated with eco-sensitive zonation mapping and procurement. The components of eco-sensitive zonation mapping are the different physical-chemical-biological characteristics of soil, landforms, and land-use patterns of the landscape. The outcome of this study gives insights into conservation strategies for the indigenous floral community.

5.2. Sustainability and Scientific Land Use Practices

This research can delineate scientific and sustainable areas of land use. Soil character and state of soil fertility are used to determine suitable areas for agriculture and cropping patterns. The study output is associated with geomorphological stability and soil characterization, two primary components of sustainable agricultural practices in the Ajodhya Hill area. The research findings provide valuable insights for local authorities in formulating land use policies that balance developmental needs with ecological preservation and environmental sustainability. Water shade management is crucial for sustainable agricultural practice and livelihood patterns. Soil permeability and regional slope are key for water shade and sustainable land use planning.

5.3. Socio and Economical Perspectives

A unique technique characterizes landscapes through analysis and correlation among different parameters of soil and geomorphology. Soil geomorphology reveals the relationship between soil character and land cover, which is crucial for local livelihood and sustainability. The research results give meaningful insights to guide scientific agricultural practices, the collection of forest products, the promotion of tourism, the proper allocation of resources, and community-based development. Identifying geomorphologically and pedologically vulnerable areas can help local governments mitigate risks from soil erosion, landslides, or flash floods, protecting lives and property.

Policy Framework and Implementation

The present study's results are helpful for decision-making about resource potentiality, scientific use of resources, allocation of land for future use, scientific land use planning for sustainable development, ecological carrying capacity, implementation of existing plans, infrastructure planning and management, and local governance. The study gives some initial insights into climate resilience strategies by analyzing how soil and geomorphological changes affect land cover, particularly in areas prone to drought or erratic rainfall.

6. Conclusion

The Foothills area is associated with relatively intensive agricultural activities by the local people. Rice, wheat, maize, sugarcane, pulses, chili, and vegetables are the main crops of this area, produced by plowing and terrace cultivation methods. The wooden plow is used for cultivation. This area also has three types of rice crops (aus, amon, and boro) and robi crops (wheat, maize, sugarcane, pulses, chili, and vegetables). Amon and boro are the most important crops in this foothill area. Boro is a summer crop, so it requires proper irrigation. Farmers in this area stored rainwater in artificial reservoirs. Some natural water bodies are also present in the foothill area. Irrigation for robi and boro crops is done from natural and artificial water bodies. The yield of boro crops mainly depends on the rainfall produced by western disturbances and local depressions. Traditional rainwater harvesting is expected in this area throughout the year. This is the only water source for irrigation in agricultural fields during dry spells. It is essential to introduce sustainable utilization of resources and scientifically managed agrarian activities.

The current study focuses on the interaction of soil, geology, and terrain complexity. In conclusion, it is essential to highlight that the Ajodhya Hill area is characterized by diverse soil geomorphological features resulting from complex geological processes, including the weathering of Precambrian rock basins. Land use practices across the landscape have been influenced by soil texture, composition, and depth in various geomorphic units. The elevated terrains of the hill are linked to limited agricultural productivity due to the shallow soil depth and the rocky soil profile. The undulating terrain and poor soil fertility on the slopes encourage extensive forest cover of deciduous vegetation and shrublands. The foothills are undergoing agricultural practices through various rainwater harvesting projects. Human activities in the natural system of this hill, such as step cultivation and removal of earth materials, accelerate soil loss and hinder sustainable land management. Limited arable land leads to mixed land-use patterns, which combine subsistence agriculture, grazing, and forest resource collection. The people in this area depend economically on the forests within this landscape. Forest-based livelihoods present challenges for sustainable development and resource conservation. Effective land use planning must incorporate soil geomorphological assessments to mitigate erosion risks and support sustainable agriculture. Long-term monitoring of soil quality and geomorphological dynamics is critical for maintaining the ecological integrity of the Ajodhya Hill area. These findings demonstrate the interconnectedness of soil geomorphological features and land use dynamics, emphasizing the necessity for sustainable practices to balance environmental conservation with local socio-economic needs.

Acknowledgments

I sincerely thank Dr. Sunando Bandyopadhyay, Professor & Head, Department of Geography, University of Calcutta, for his guidance during field studies. I also sincerely thank Dr. Srikumar Chattopadhyay, a scientist at the Centre for Earth Science Studies in Trivandrum. I am grateful to Prof. V.S. Kale, former Professor of Geography at the University of Pune, and Dr. Lakshmi Sivaramakrishnan, Professor and head of the Department of Geography, Jadavpur University, for their suggestions. I thank my research guide, former Prof. Pannalal Das, Department of Geography, University of Calcutta, for his motivation and tips.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

Andrews, S. S., Karlen, D. L., & Mitchell, J. P. (2002). A Comparison of Soil Quality Indexing Methods for Vegetable Production Systems in Northern California. *Agriculture, Ecosystems & Environment, 90,* 25-45. https://doi.org/10.1016/s0167-8809(01)00174-8

Baidya, T. K. (1984). A New Approach to Pre-Cambrian Geology and Mineral Prospecting in Puruliya District, West Bengal. *Journal Mines, Metals and Fuels, 32,* 570-574.

Bandyopadhyay, S., Sekhar Kar, N., Das, S., & Sen, J. (2014). River Systems and Water Resources of West Bengal: A Review. In R. Vaidyanadhan (Ed.), *Water Resources* (pp. 63-84). Geological Society of India. https://doi.org/10.17491/cgsi/2014/62893

Bhattacharya, B. K., Chakraborty, B. R., Sen, N. N., Mukherji, S., Ray, P., Sengupta, S., Sengupta, K. S., Sen, N. N., & Maity, T. (1985). *West Bengal District Gazetteers: Puruliya*. Government of West Bengal.

Bhattacharya, B. P. (1990). Mantle Petrogeny Related to Tectonic Evolution of the Chhotanagpur Region, E. India. *Bulletin Geological, Mining and Metallurgical Society of India, 56,* 13-14.

Bhattacharya, D. S. & Ghoshal, A. (1992). Petrofabric Patterns of the Chhotanagpur Gneiss and the Adjoining Schists of the Singhbhum Group. *Indian Journal of Geology, 64,* 196-209.

Birkeland, P. W. (1974). *Pedology, Weathering, and Geomorphological Research*. Oxford University Press.

Birkeland, P. W. (1990). Soil-Geomorphic Research—A Selective Overview. *Geomorphol-*

ogy, 3, 207-224. https://doi.org/10.1016/0169-555x(90)90004-a

Birkeland, P. W. (1999) *Soil and Geomorphology* (3rd ed.). Oxford University Press.

Bose, M. K. (1992). Chhotanagpur Granite Gneissic Complex of Eastern Indian Shield: Problems and Prospects. *Indian Journal of Geology, 64,* 151-159.

Bose, R. N. (1957). The Metamorphic Rocks around Barabhum and Bundnan, South Manbhum. *Quarterly Journal of Geological, Mining and Metallurgical Society of India, 29,* 19-36.

Carlson, T. N., & Sanchez-Azofeifa, G. A. (1999). Satellite Remote Sensing of Land Use Changes in and around San José, Costa Rica. *Remote Sensing of Environment, 70,* 247-256. https://doi.org/10.1016/s0034-4257(99)00018-8

Chatterjee, S. (2005). *Pedogeomorphology of Some Districts of West Bengal with Application of Models*. PhD Thesis, The University of Burdwan.

Chatterjee, S., De, N. K (2009) Pedogeomorphological Model and Land Evolution. In V. S. Kale, & H. S. Sharma (Ed.), *Geomorphology of India* (Prof. Savindra Singh Felicitation Volume, pp. 547-563). Prayag Pustak Bhaban.

Chaudhuri, R. N. (1982). Morpho-Edaphic Analysis of the Bhagirathi-Alakananda Basin of the Garhwal Himalaya. *Geographical Review of India, 44,* 44-51.

Coacher, A. J., & Dalrymple, J. B. (1977). The Nine-Unit Land Surface Model: An Approach to Pedogeomorphic Reaches. *An International Journal of Soil Science, Geoderma, 18,* 127-144.

Conacher, A. J., & Dalrymple, J. B. (1977). The Nine-Unit Land Surface Model: An Approach to Pe-Dogeomorphic Research. *Geoderma, 18,* 1-154.

Daniels, R. B., & Hammer, R. D. (1971). *Soil Geomorphology*, Wiley.

Daniels, R. B., Gamble, E. E., & Cady, J. G. (1971). The Relation between Geomorphology and Soil Morphology and Genesis. *Advances in Agronomy, 23,* 51-88. https://doi.org/10.1016/s0065-2113(08)60150-9

Das, P., & Basu, S. (2014). *Soils and Soils of India*, Grantha Tirtha Publisher and Booksellers, 78-93.

Das, T., Sarkar, D., Chattopadhyay, T., Dutta, D., Singh, D. S., Mukhopadhyay, S. et al. (2010). *Soils of Puriliya District, West Bengal for Optimizing Land Use*. NBSS & LUP.

Dasgupta, P. (2015). Rock Characteristics and Susceptibility to Weathering: A Study in the Metamorphic Terrain of Ajodhya Hill, West Bengal. *Journal of Indian Geomorphology, 3,* 27-47.

De, N. K. (1972). Measuring Soil and Landform Characteristics of Parts of Banka Basin, Burdwan. In *Proceedings Symposium on Geomorphology, Geohydrology* (pp. 46-58). Geotectonic of the Lower Gang Basin IIT.

De, N. K. (1984a). Pedogeomorphology. A Concept in Earth Science. *Burdwan University Journal of Science, 1,* 18-25.

De, N. K. (1984b). *Measuring Land Potentials in Developing Countries*. The University of Burdwan.

De, N. K., & Ghosh, P. (1986). *India, a Study of Soil Geography*. Sribhumi Publishing company.

Demers, M. N. (2005). *Fundamentals of Geographic Information Systems*. John Wiley Sons, Inc.

Dey, B., & De, N. K. (1988). Pedogeomorphological Study in Lower Bengal Basin, India with Land MSS Data. *Land Scape System and Ecological Studies, 11,* 110-120.

Dhankar, R. P., & Jain, S. P. (1985). Landscape Soil Relationship in Gazipur District. *Geo-*

Graphical Review of India, 47, 42-46.

Elizald, G., & Jaimes, E. (1989) Proposal for a Pedogeomorphological Model. *Revista Geografica, Venezolana, 30,* 5-36.

Eppes, M. C. (2009). Introducing Field-Based Geologic Research Using Soil Geomorphology. *Journal of Geoscience Education, 57,* 11-22. https://doi.org/10.5408/1.3544222

Gao, B. (1996). NDWI—A Normalized Difference Water Index for Remote Sensing of Vegetation Liquid Water from Space. *Remote Sensing of Environment, 58,* 257-266. https://doi.org/10.1016/s0034-4257(96)00067-3

Gelman, F., Binstock, P., & Halicz, L. (2011). *Application of the Walkley-Black Titration for Organic Carbon Quantification in Organic-Rich Sedimentary Rocks*. Report GSI/13/2011, Geological Survey of Israel. http://www.gsi.gov.il/_Uploads/ftp/GsiReport/2011/Gelman-Faina-GSI-13-2011.pdf

Gerrard, J. (1993). Soil Geomorphology—Present Dilemmas and Future Challenges. *Geomorphology, 7,* 61-84. https://doi.org/10.1016/0169-555x(93)90012-q

Gerrard, J. (1995). *Soil Geomorphology, an Integration of Pedology and Geomorphology* (pp. 29-50). Chapman & Hall.

Ghosh, A., & Mukhopadhyay, S. (2022). Evaluation of Springs and Waterfalls as Geomorphosites and Proposition of Strategies to Develop Geotourism at Ajodhya Hill, Puruliya District, Eastern India. *GeoJournal, 87,* 1047-1067. https://doi.org/10.1007/s10708-020-10298-x

Ghosh, A., Mandal, R., & Chakrabarty, P. (2023). Inclusive Tourism Adopted to Geosites: A Study in the Ajodhya Hills of West Bengal in India. *Tourism and Hospitality, 4,* 321-335. https://doi.org/10.3390/tourhosp4020020

Goswami, A., & Das, A. L. (1984). Impact of Landscape on Soils—A Case Study of Bankura District (West Bengal). *Geographical Review of India, 46,* 51-57.

Goudie, A. S. (2003). *Encyclopedia of Geomorphology*. Routledge Publication.

GSI: Geological Survey of India (1999). Geology and Mineral Resources of the States of India, Pt. 1: West Bengal.

Hall, G. F. (1983). Pedology and Geomorphology. *Developments in Soil Science, 11,* 117-140. https://doi.org/10.1016/s0166-2481(08)70600-7

Hall, G. F., & Olson, C. G. (2015). Predicting Variability of Soils from Landscape Models. In M. J. Mausbach, & L. P. Wilding (Eds.), *SSSA Special Publications* (pp. 9-24). Soil Science Society of America. https://doi.org/10.2136/sssaspecpub28.c2

Kumar, A. (1979). *Geomorphology of Simdega and Its Adjoining Area, Bihar*. (pp. 18-22). The National Geographic Society of India.

Legros, J. P. (1996). *Soil Maps, from Spatial Analysis to Land Management*. Presses techniques.

Li, W., Liu, X.-J., Khan, M. A., & Gul, B. (2000). Relationship between Soil Characteristics and Halophytic Vegetation in the Coastal Region of North China. *Pakistan Journal of Botany (Pakistan), 40,* 1081-1090.

Lillisand, T. M., Kiffer, R. W., & Chapman, J. W. (2010). *Remote Sensing and Image Interpretation* (5th ed.). Wiley.

Lisi, P. J., Schindler, D. E., Bentley, K. T., & Pess, G. R. (2013). Association between Geomorphic Attributes of Watersheds, Water Temperature, and Salmon Spawn Timing in Alaskan Streams. *Geomorphology, 185,* 78-86. https://doi.org/10.1016/j.geomorph.2012.12.013

McFadden, L. D., & Knuepfer, P. L. K. (1990). Soil Geomorphology: The Linkage of Pedology and Surficial Processes. *Geomorphology, 3,* 197-205. https://doi.org/10.1016/0169-555x(90)90003-9

Monger, H. C., & Bestelmeyer, B. T. (2006). The Soil-Geomorphic Template and Biotic Change in Arid and Semi-Arid Ecosystems. *Journal of Arid Environments, 65,* 207-218. https://doi.org/10.1016/j.jaridenv.2005.08.012

Pal, S. S. (1989). *A Study in Landform and Soil Relationship in Damodar-Ajoy interfluve, West Bengal*. National Seminar, National Atlas and Thematic Mapping Organisation.

Piper, C. S. (1950). *Soil and Plant Analysis*. The University of Adelaide.

Pofali, R. M., & Hirekerur, L. R. (1983). Significance of Geomorphological Analysis for Soil Mapping. *Geographical Review of India, 45*.

Pofali, R. M., Bhattacharya, J. C., & Landey, R. J. (1979). Landscape Analysis from Soil Mapping in Basaltic Terrain. *Geographical Review of India, 41,* 267-276.

Pouquet, J. (1966). *Initiation Geopedology*. Les Sol set la geographie, SEDES.

Prenzel, B. (2004). Remote Sensing-Based Quantification of Land-Cover and Land-Use Change for Planning. *Progress in Planning, 61,* 281-299. https://doi.org/10.1016/s0305-9006(03)00065-5

Principi, P. (1953). *Geopedologia (Geologia Pedologia)*. Studio dei terreni naturali er agrari Ramo Editoriale degli Agricoltori.

Rogan, J., & Chen, D. (2004). Remote Sensing Technology for Mapping and Monitoring Land-Cover and Land-Use Change. *Progress in Planning, 61,* 301-325. https://doi.org/10.1016/s0305-9006(03)00066-7

Rouse, J. W., Haas, R. H., Schell, J. A., & Deering, D. W. (1973). Monitoring Vegetation Systems in the Great Plains with ERTS (Earth Resources Technology Satellite). In *Proceedings of 3rd Earth Resources Technology Satellite Symposium* (pp. 309-317).

Ruhe, R. V. (1960). Elements of the Soil Landscape. *Transactions of 7th International Congress of Soil Science, 23,* 165-169.

Ruhe, R. V. (1965). Quaternary Paleopedology. In H. E. Wright, & D. G. Frey (Eds.), *The Quaternary of the U.S.* (pp. 755-764). Princeton University Press. https://doi.org/10.1515/9781400876525-048

Ruhe, R. V. (1969). *Quaternary Landscapes in Iowa*. Iowa State University Press.

Ruhe, R. V. (1975). *Geomorphology*. Houghton Mifflin.

Ruhe, R. V., & Scholtes, W. H. (1959). Important Elements in the Classification of the Wisconsin Glacial Stage: A Discussion. *The Journal of Geology, 67,* 585-593. https://doi.org/10.1086/626616

Ruhe, R. V., & Walker, P. H. (1968) Hillslope Models and Soil Formation. I. Open Systems. *Transactions of 9th International Congress of Soil Science, 4,* 551-560.

Ruhe, R. V., Daniels, R. B., & Cady, J. G. (1967). *Landscape Evolution and Soil Formation in Southwestern Iowa*. USDA Technical Bulletin No. 1349.

Sarkar, A. (2019a). Soil Geomorphology of Garpanchkot Hill Area and Its Influence on Land Use and Land Cover. *Journal of Geoscience and Environment Protection, 7,* 108-135. https://doi.org/10.4236/gep.2019.77009

Sarkar, A. (2019b). Soil Geomorphological Model and Its Relation to Land Use Planning: A Case Study of Biharinath Hill, Bankura District, West Bengal. *Indian Journal of Landscape Systems and Ecological Studies, 42*.

Sarkar, A., & Das, P. (2018). Pedogeomorphology of the Plateau Fringe Region of Biharinath Hill, Bankura Districts of West Bengal and Its Influence on Land Use and Land

Cover. *International Journal of Research and Analytical Reviews, 5,* 488-501. http://www.ijrar.org/IJRAR1903707.pdf

Sarkar, H. K. (1987). Relationship between Geomorphology and Soil in the Mand River Basin, Madhya Pradesh. *Geographical Review of India, 49*.

Sarkar, H. K. (1988). *Pedogeomorphology of Part of the Mand Basin, Madhya Pradesh, India*. Ph.D. Thesis, The University of Burdwan.

Sato, J. H., de Figueiredo, C. C., Marchão, R. L., Madari, B. E., Benedito, L. E. C., Busato, J. G. et al. (2014). Methods of Soil Organic Carbon Determination in Brazilian Savannah Soils. *Scientia Agricola, 71,* 302-308. https://doi.org/10.1590/0103-9016-2013-0306

Schaetzl, R. J., & Anderson, S. (2005). *Soils: Genesis and Geomorphology*. Cambridge University Press. https://doi.org/10.1017/cbo9780511815560

Schaetzl, R. J., & Thompson, M. L. (2015). *Soils: Genesis and Geomorphology* (2nd ed.). Cambridge University Press. https://doi.org/10.1017/cbo9781139061803

Singh, R. P. (1969). *Geomorphological Evolution of Chhotanagpur High Lands, India*. National Geographical Society of India.

Tricart, J. (1965a). Principes et Méthodes de la Géomorphologie. *Soil Science, 100,* 300. https://doi.org/10.1097/00010694-196510000-00015

Tricart, J. (1965b). Morphogenèse et pédogenèse. I. Approche méthodologique: Géomorphologie et pédologie. *Science du Sol A, 1,* 69-85.

Tricart, J. (1965c). *Principal Methods of Geomorphology*. Masson.

Tricart, J. (1994). *Ecogeographie des espaces ruraux*. Nathan.

Tricart, J., & Kilian, J. (1979). *L'eco-geographie et l'amanagement du milieu naturel*. Editions Maspero.

Ulbricht, K. A., & Heckendorff, W. D. (1998). Satellite Images for Recognition of Landscape and Landuse Changes. *ISPRS Journal of Photogrammetry and Remote Sensing, 53,* 235-243. https://doi.org/10.1016/s0924-2716(98)00006-9

Wu, Q., Li, H., Wang, R., Paulussen, J., He, Y., Wang, M. et al. (2006). Monitoring and Predicting Land Use Change in Beijing Using Remote Sensing and GIS. *Landscape and Urban Planning, 78,* 322-333. https://doi.org/10.1016/j.landurbplan.2005.10.002

Wysocki, D. A., Schoeneberger, P. J. Hirmas, D. R., & LaGarry. H. E. (2011). Geomorphology of Soil Landscapes, In P. M. Huang, Y. Li, & M. E. Sumner (Eds.), *Handbook of Soil Science: Properties and Processes* (2nd ed., pp. 29.1-29.26). Chemical Rubber Company Press.

Xu, H. (2006). Modification of Normalised Difference Water Index (NDWI) to Enhance Open Water Features in Remotely Sensed Imagery. *International Journal of Remote Sensing, 27,* 3025-3033. https://doi.org/10.1080/01431160600589179

Zinck, J. A. (2013). *Geopedology*. ITC Special Lecture Notes Series.

Zinck, J. A., Metternicht, G., Bocco Verdinelli, G. H. R., & Del Valle, H. F (2016). *Geopedology: An Integration of Geomorphology and Pedology for Soil and Landscape Studies*. Springer.