Terrain Analysis of Elements using LISS-IV Satellite image in Bhainsa region, northwestern part of Nirmal district, Telangana State, India

Abstract

Terrain is considered one of the most important natural geoic features and is a vital factor in physical processes. This study focuses attention on terrain analysis of the study area. The effect of this terrain analysis on the surface characteristics were analyzed, this was achieved by generating and extracting data and a high-resolution 5.8m satellite image (IRS P6-LISS IV) of the area respectively. The Remote sensing satellite data and geoic information system (GIS) are used in terrain analysis is defined as the study of the nature, like drainage, digital elevation model (DEM), land use/ land cover, lithology, geomorphology features, and soil characteristics around Bhainsa region, northwestern part of Nirmal district. The drainage pattern is dendritic to sub-dendritic and the topoy of the study region is undulating with a gentle slope towards southeast. The morphological features composition of land forms, the result of which is a land form or land component of the region. The diverse land use categories such as forest, agriculture, water bodies, drainage, and the land cover pattern are divided into agriculture land, barren land, forest, built up, mining and industrial, scrub land and water bodies. The major litho-units in the study area are occupied by granitic terrain and deccan traps basalt. The soils are covered in region black clayey, reddish brown, and gravelly clay red soils. IRS P6-LISS IV, 2016 satellite image made optimum utilization for the interpretation of terrain analysis. The terrain parameters were further used as input to analyze the surface characteristics in the locality.

Key words: Terrain analysis, Land use and land cover, Drainage and digital elevation model (DEM), lithology, geomorphological features.

INTRODUCTION

Data acquisition for most geological and geophysical surveys is commonly referred to and carried out on the surface of the earth. These surveys however suffer from serious disadvantages where the area concerned is unapproachable or dangerous. Also ground surveys are generally limited in extent because covering very large areas by these methods is expensive in terms of time and money. Thus, of late a number of alternative techniques have been developed for obtaining information regarding significant parts of the globe from observation platforms situated or moving at a height above the earth's surface and employing appropriate sensing devices. Such techniques have come to be known as Remote Sensing (RS) techniques.

Using aircraft or satellites to capture the interaction between electromagnetic radiation and matter without making physical contact with the item, remote sensing is the technique of gathering information from photos and related data (Sabins, 1997). Because they allow for the quick and accurate identification of vast regions, remote sensing techniques are thought to be cost-effective (Ezzati et al., 2014). Since the turn of the century, investigations on land use and cover have made use of remote sensing technology in earth science (El Khidir and Babikir, 2013,40,41,42,43).

Terrain is a crucial component of physical processes and is regarded as one of the most significant natural geoic features. The geomorphology is usually indicative of the nature of geological formations. Hills, ridges and steep slopes are indicative of hard formations such as igneous rocks, quartzites or limestones, while valleys and depressions and flat lying portions indicate softer formations like shales, sandstones etc. The soil cover can change with the lithology and its colour and grain size being dependent on the underlying formations. The vegetation in a similar fashion is characteristic of the rock formations.

It is amazing that researchers may use their understanding of terrain analysis and geomorphology to not only address conventional problems like landform-related research but also to seek to finish numerous studies that span multiple domains and specialties. We have seen that other geoscientific subfields like the landscape, hydrology, ecology, and geology are frequently closely related to geomorphology and terrain analyses (Florinsky, 1998b; Macklin et al., 2006; Florinsky, 2016; Ironside et al., 2018; Liu et al., 2020a; Jancewicz et al., 2022; Ma and Zhao, 2022; Xiong et al., 2022).

“Understanding the changes in land use and land cover is crucial for managing, conserving, and using natural resources” (Nagamani and Ramachandram, 2003; Alekya et al, 2017; Linga Swamy et al., 2022). Environmental elements include soil properties, climate, topoy, and vegetation limit how land can be used. According to Uma Maheshwari et al. (2015), Udaya Laxmi et al. (2016), Linga Swamy et al. (2022), “it also illustrates how important and limited land is for the majority of human developmental activities, including agriculture, industry, forestry, energy, production, and settlement, as well as for recreation, water catchments, and storage”. Even though the terms "land use (LU)" and "land cover (LC)" are occasionally used synonymously, they are not the same. To put it simply, land usage refers to how the land is used, and land cover is what covers the earth's surface. Water, snow, grassland, deciduous forest, and bare soil are a few types of land cover. Examples of land uses are urban areas, agricultural areas, wildlife management areas, and recreational areas, among others. While the land uses of two land parcels may differ, they may have similar land covers.

To provide continued remote sensing data services on an operational basis for integrated land and water resources management at micro level with enhanced multi-spectral and spatial coverage with stereo imaging capability.

This study focuses on the IRS P6-LISS IV analyses and interpretation of satellite imagery in the Bhainsa region of Nirmal district, Telangana state, to evaluate several terrain features, including elevation, drainage, soil, land use/cover, and mapping of inferred lithology/geology. The geoic location map of the study area shown in Figure 1.

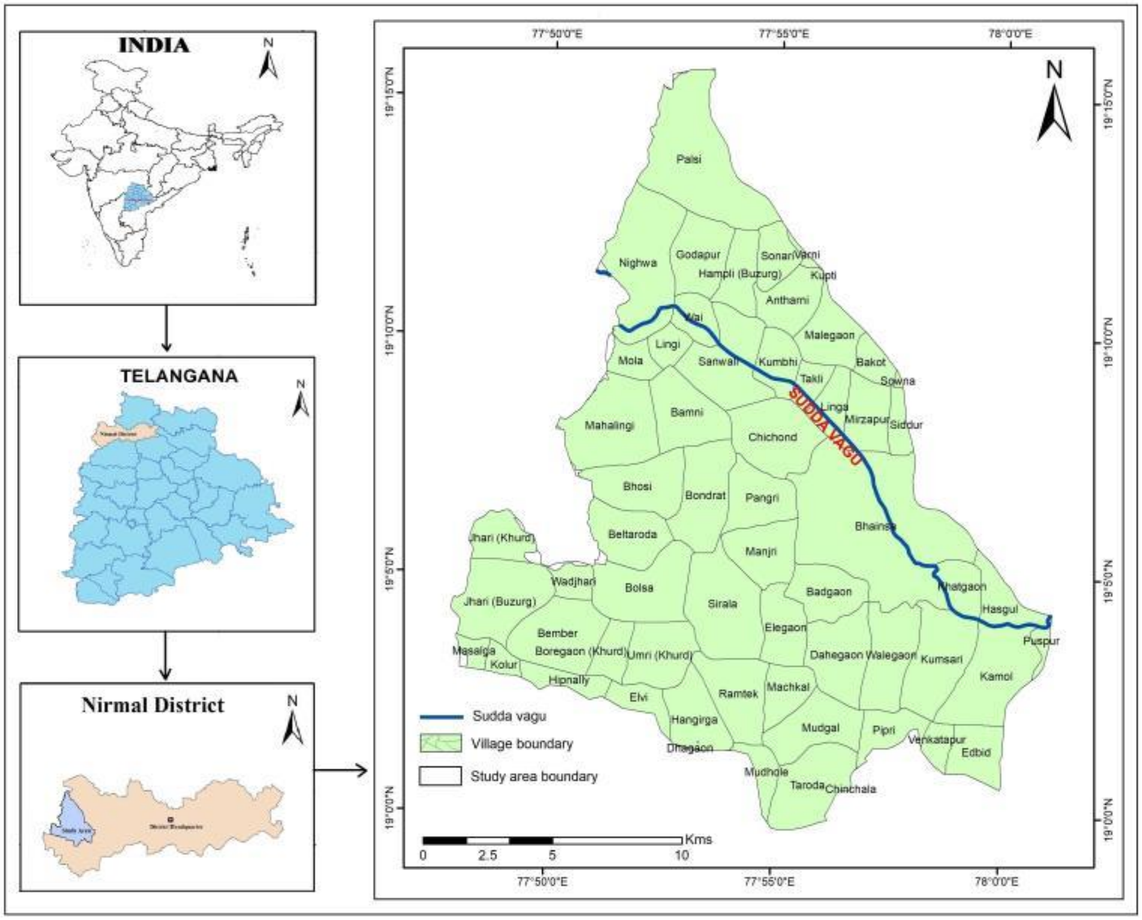

Figure 1. Location map of the study area.

MATERIALS AND METHODS

The present study area around Bhainsa region lie between 77° 47' 00" to 78° 02' 00" E longitude and 18° 59' 00" to 19° 17' 00" N latitude of Nirmal district, Telangana state covers to area of 323.8 sq.km (Figure 1).

It is intended for IRS-P6 (RESOURCESAT-1) to be an improved version of IRS-1C/1D. The satellite's purpose is to deliver panchromatic and multispectral images of the surface of the Earth. It is equipped with three sensors: An On-Board Solid-State Recorder (OBSSR), a high resolution multi-spectral camera called LISS-IV, an Advanced Wide Field Sensor (AWiFS), and a Linear Imaging and Self Scanning sensor called LISS-III. The three cameras will be utilizing linear arrays of Charge Coupled Devices (CCDs) to experiment with the "push broom scanning" concept. In this method of operation, the satellite moves forward to picture consecutive lines while electronically scanning each line of image. The IRS P6-LISS IV Satellite image (NRSC- National Remote Sensing Centre, Hyderabad) (Source: http:// bhuvan.nrsc.gov.in) whose resolution is 5.8 m, along with three spectral bands (B2: 0.52-0.59 µm; B3: 0.62-0.68 µm; B4:0.77-0.86 µm) accessed for the study area (Figure 2) and is utilized to examine the regional/ geological and geomorphological features to understand the groundwater potentiality in the region. The LISS-IV sensor produces data in multispectral mode that correspond to 4096 contiguous pixels that have been pre-selected, covering a 23.5 km swath. By using an electronic scanning system to command the start pixel number, the 4K strip can be selected anywhere within the 12K pixels. A 70 km wide swath of data, or all 12K pixels of any one chosen band, can be sent in mono mode. In this mode, Band-3 data will be transmitted nominally. By tilting the camera by +/- 26 degrees, the LISS-IV camera can be used to see objects off-nadir. In this manner, it can deliver a five-day revisit for any given ground area. The database is made possible by several publicly available sources and is also accessible for free online. The fundamental information gathered consists of 1:50,000 scale Survey of India (SOI) toposheets (toposheet Nos. 56 E/15, 56 E/16, 56 F/13, and 56 I/04). Standard image enhancement techniques (such as spectral and spatial filtering, image translation, image enhancement, and contrast) have been discussed by a number of authors, including Miller and Pearson (1971), Goetz (1975), Castleman (1978), Singer (1980), Hammond and McCullough (1980), Chavez et al. (1982), Short (1982), and Price (1995).

The 2003 IRS-P6 data user's manual was used to obtain image data of the earth's surface. When necessary, methods such as stratification, directed filtering, layered approach, composition, aggregation, and refinements were also applied to enhance the mapping quality.

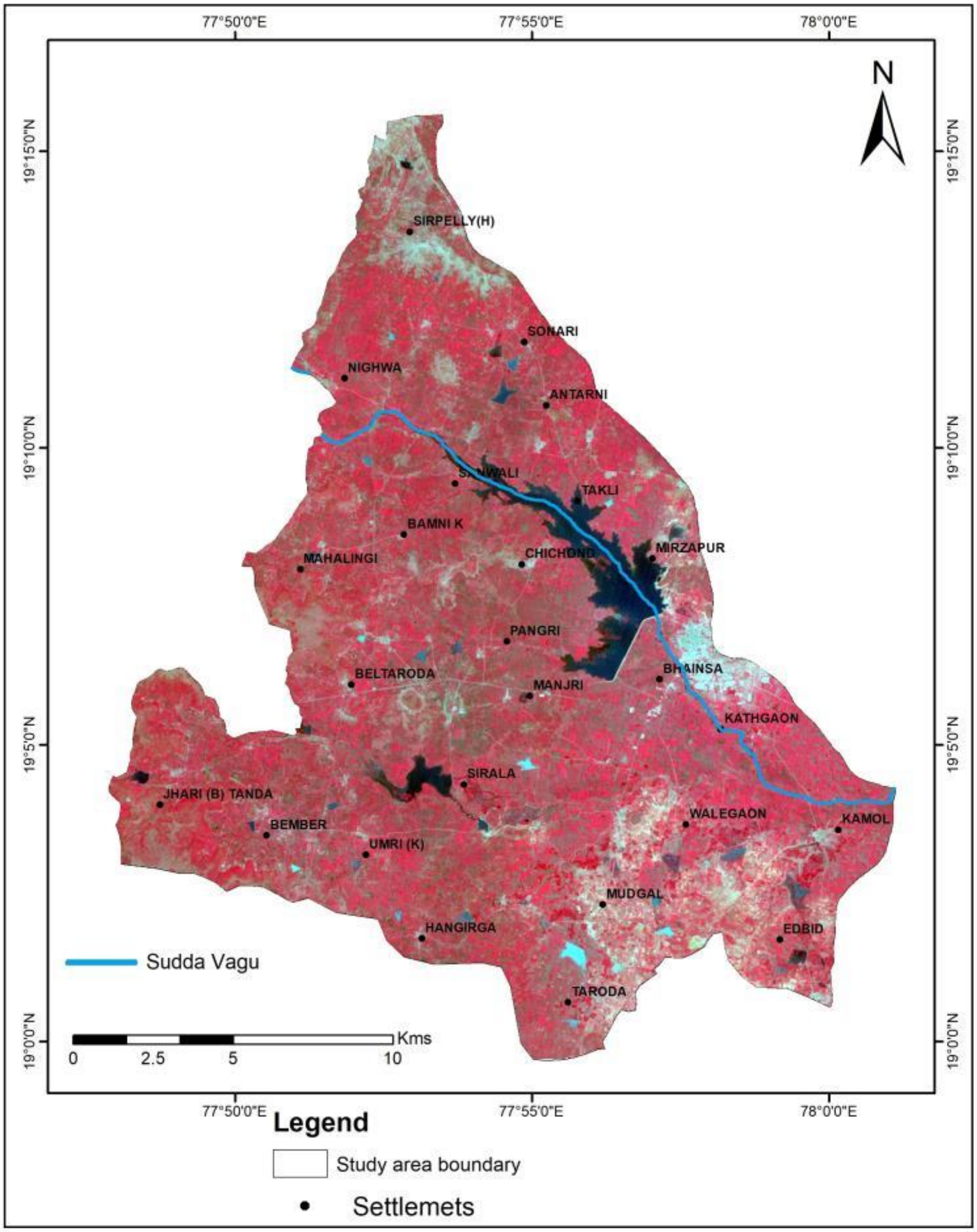

Figure 2. IRS-P6 LISS-IV Satellite map of the study area.

RESULT AND DISCUSSION

Terrain Elements Analysis

The study region was geo-referenced, digitally processed, and visually interpreted for terrain elements analysis of topoy/ landform, drainage patterns, lithology, stream order and Land use/Land cover (Rao, 1995).

Topoy: The topoy of the study area is undulating with a gentle slope towards southeast. The maximum elevation is 471 m and the minimum elevation is 340 m above mean sea level shown in (Figure 3) The geology and geomorphological of a region comprise the preliminary database requisite for any geophysical/geochemical survey program. Based upon the parameters, exploration or investigation strategies are evolved. Similarly, another set of parameters that give a valuable input for designing survey methodologies. The various types of roads in the study area are metalled and non-metalled roads, cart tracks and foot tracks. All the settlements in the study area are connected by metalled and non-metalled roads.

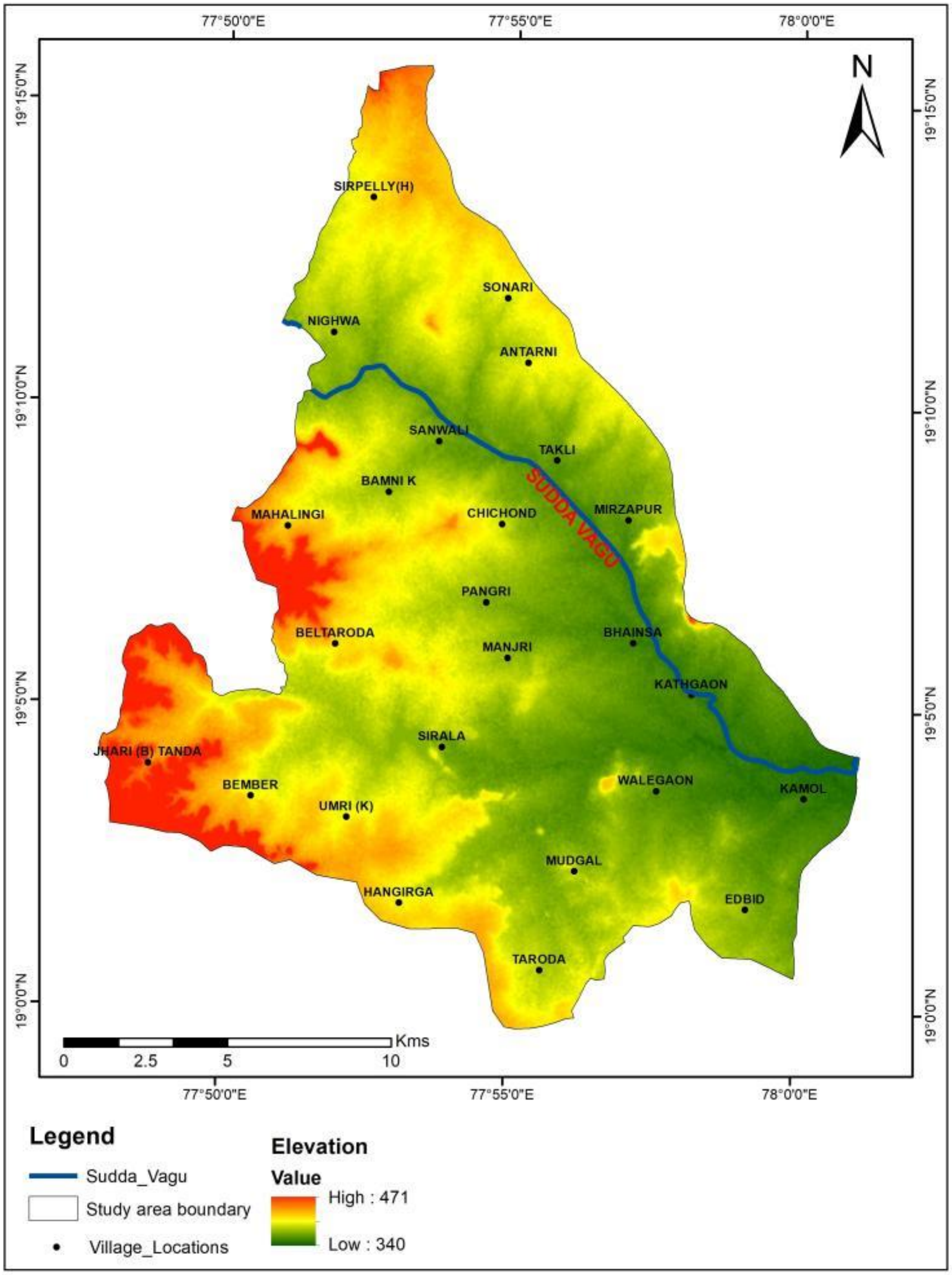

Figure 3. Digital elevation map of the study area

Lithology: **"**The identification of topoy/ landforms in an area will help to decipher the underlying lithology. Often many of the rock types have distinct topoic expressions. Type and composition of minerals determine the spectral response of the rock type" (Miller and Pearson, 1971 and Singer, 1980, Price, 1995). IRS P6-LISS IV satellite imagery is used to analyze the various geological formations based on different FCC signatures. These signatures depend on several band combinations (B2: 0.52 -0.59; B3: 0.62-0.68; B4:0.77-0.86 in μm) and many band rationing/ indexing techniques adopted by several authors Miller and Pearson, (1971); Goetz, (1975); Singer, (1980); Chavez et al., (1982); Price, (1995); Subhash Babu et al., (2014) and made possible to correlate with the available lithology (Figure 4). This lithology map of the region is inferred from the satellite image. The major litho-units in study region are a part of the Upper Cretaceous to Paleocene age of Sahyadri Group of Deccan trap represented by basalt covers major Central, NW and SW part and, Peninsular Gneissic Complex, comprising of Archaean to Paleoproterozoic granites and gneisses and covers southeast part of study area (Figure 4). The geological formations encountered in the study area are granites, granodiorites and banded gneisses. The Archaean rock consists of mainly of pink granite, grey biotite granite, and grey hornblende biotite granite. The pink granites and grey granites are closely associated with each other. The pink granite is generally porphyritic with large phenocrysts of pink orthoclase feldspar. Biotite, Chlorite, hornblende, epidote and tourmaline occur as accessories. The pink granites are more susceptible to weathering than the grey granites.

Deccan basalts comprise in the major part of the study area. Nearly horizontal lava flows are considered as a result of fissure type of lava eruption during late Cretaceous to early Eocene period. The Deccan trap basalts in Peninsular India are the result of fissure eruptions of molten lavas which flowed to long distances covering hundreds of kilometers of the country to form extensive flows. These rocks are generally horizontal and layered and each layer ranges from a few meters to 40.0 meters in thickness. The Basalts, though generally uniform in composition, show variation in colour, texture and mode of weathering and the deccan traps unconformable overlying the PGC-II rocks. In the study area of limestone Penganga group of Neo Proterozoic age continue isolated patches are presented in western part of Mahalingi to Meltaroda areas and south part of

Umri area. The limestones are seen with typical elephant skin weathering. Special features of limestone like elephant skin weathering, bedding joints, caverns. Upper Cretaceous age Infratrappean bed N-S direction contact line of Takli to Taroda in continuous isolated patches exposed between the granite and overlying deccan trap basalt. A wide-ranging geological stratiic succession of the study area is presented in Table 1.

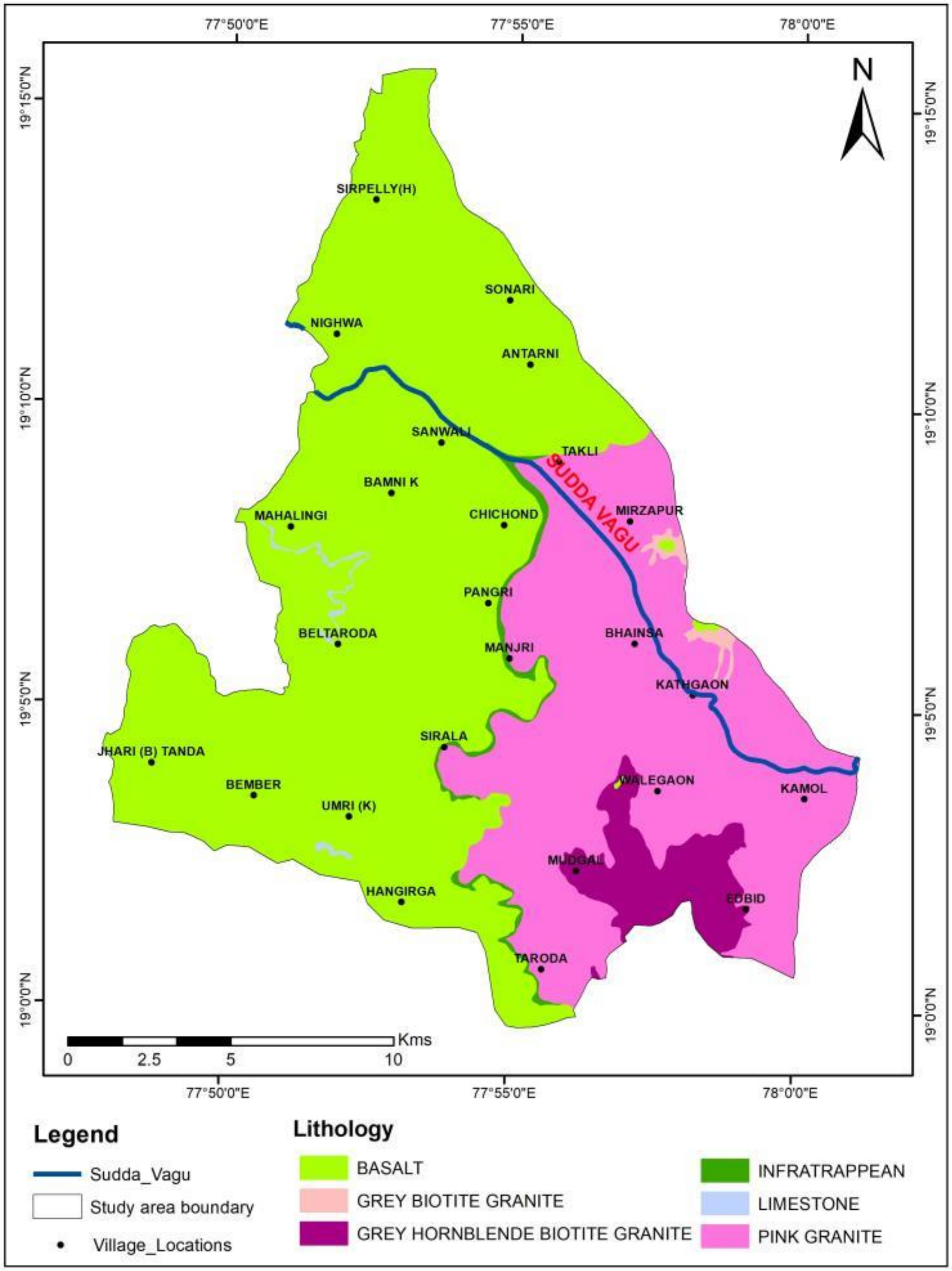

Figure 4. Lithology map of the study area.

Table 1. Stratiic succession of the study area.

Litho-units	Group	Super Group	Age
Basalt	Sahyadri	Deccan Trap	Upper Cretaceous to Paleocene
Infratrappean	_		Upper Cretaceous
Limestone	Penganga		Neo Proterozoic
Pink granite, grey biotite granite, and grey hornblende biotite granite	Peninsular Gneissic Complex		Archaean to Paleoproterozoic

Drainage: The drainage pattern and texture seen on images are good indicators of landform and bedrock type (Thornbury, 1986) and also suggest the soil characteristics and drainage conditions. The drainage pattern of an area refers to the design of the stream courses and their tributaries. It is influenced by the slope of the land, lithology and structures. The distribution and attitude of the rock systems and their arrangements also control the drainage pattern. The Sudda vagu/river flow direction from NNW-SSE in the study area. The area is occupied by numerous small and medium size streams and streamlets. General slope of the area is towards southeast part and the drainage pattern in the study area is dendritic to sub dendritic (Figure 5).

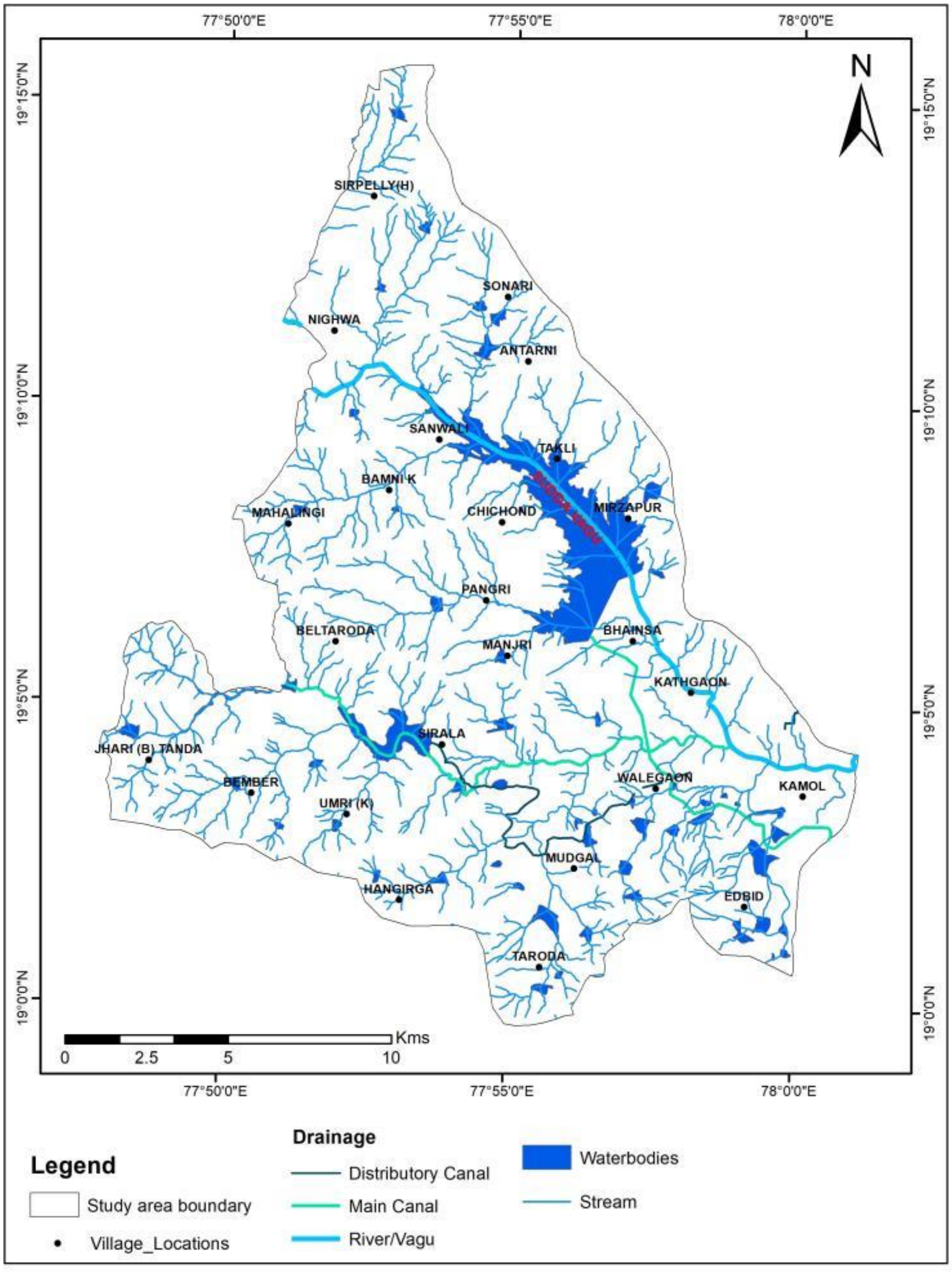

Figure 5. Drainage map of the study area.

Geomorphological features: The geomorphological features of an area provide strong basis to determine the water resource occurrence, distribution, and management. The geomorphological map of Bhainsa region (Figure 6) has been prepared using Indian Remote Sensing (IRS) satellite imagery data. Geomorphology comprises studying landforms, simulating the process that gave rise to them, and examining how tectonics have affected. The properties of the landform are crucial in the potential for groundwater and surface water in drainage basins. Additionally, the characteristic geomorphic units that characterize the drainage and weathering processes of the landform plays key role in the groundwater potential & recharge capability of particular regions. Long-term processes design a shallow layer with varying levels of porosity and porousness in tropical and central areas (Aboyeji et al., 2012). Research that combines data on lineaments hydro-morphology and hydrogeology have proven to be effective for identifying groundwater potential zones. The key landscape physical characteristics can be utilised to assess the spatial distribution of groundwater in various geological contexts and the distribution of different geomorphology units, which were categorized into i) Pediplain moderate, ii) Pediplain shallow, iii) Plateau high dissected, iv) Plateau moderate dissected, v) Plateau slightly dissected, vi) Plateau weathered, vii) Pediment, viii) Valley fill shallow, ix) Denudational hill, x) Inselberg, xi) Mesa, and xii) Butte. The geomorphology features cover is made conventional divisions in the present study and is shown in Table 2.

i) Pediplain moderately (PPM): Pediplains moderately is area characterized by flatter or gentle sloping surface of the south part, which is the end product of coalescence of several pediments at the foot of hill slopes. These pediplains regions are covered by reddish brown and black clayey soils. Groundwater potential in the weathered zones is reduced by deep weathering. Fractures with moderate potential that are appropriate for bore wells (Ram Krishan Desai, 2006).

ii) Pediplain shallow weathered (PPS): This sloping surface of pediplain shallow is notices in southwest, central, north covered large area, these plains are well characterized both sides of the Sudda vagu/river. The groundwater prospects for wells are good to moderate. The good yields are anticipated along the intersections of the lineaments and fractures.

iii) Plateau weathered (PW): The gradually sloping of plateau weathered is observed major part NNW-SSE trend, this plateau weathered is fit categorized along the Sudda vagu, and also small part of the covered in west side of Umri and Bember areas. The groundwater predictions for wells are very good to good, the harvests are predicted along the intersections of the lineaments and fractures. In addition to that, plateau slightly dissected is covered in central part of Pangri and Manjri, north part of Sirpelly areas, Similary, the plateau moderate dissected and plateau high dissected features are covered in western part and north part of the corner.

iv) Pediments, inselbergs and denudational hills: The small part of the area is consisting of pediments and especially on the southeastern side. The general slope of the region is towards east and the impact of erosion is more intense leading to washout of soil and weathered material. Therefore, the bed rock is exposed to the surface. The undulating topoy abounded with small moulds, hills or tors etc. The inselberg complex is permanently seen on the southeastern side around Walegaon, near Kamol and Edbid villages. Similarly, this unit of denudational hills is prominently seen on the southern region in west part of Edbid village.

v) Valley fill shallow (VFS): The valleys are most commonly drained by rivers and may occur in a relatively flat plains or between ranges of hills or mountains and the valley dimensions are varying and is wide at the river meandering and its covered southeast part. Further, the valley became a junction for merging with another channels. A flood plain is generally flat area of land next to river or stream it stretches from the banks of the river to outer edges of the valley and which experiences flooding during periods of high discharge. The soils in the area are derived from the disintegration and decomposition of parental rock granite. The soils are reddish brown and black clayey in colour. On the flood plain regions, the soils are mainly loamy and clayey while in the valley portions due to intense erosion and transportation only sand with little silt noticed.

Table 2. Spatial distribution of the geomorphology features

Geomorphology features	**Area in Sq Km**	**Area in %**
Butte (B)	0.53	0.16
Denudational Hill (DH)	3.34	1.03
Inselberg (I)	0.53	0.16
Mesa (M)	3.21	0.99
Pediment (PD)	17.62	5.45
Pediplain Moderate (PPM)	29.90	9.23
Pediplain Shallow (PPS)	11.45	3.54
Plateau Highly Dissected (PLH)	1.38	0.43
Plateau Moderately Dissected (PLM)	33.78	10.44
Plateau Slightly Dissected (PLS)	18.92	5.82
Plateau Undissected (PLU)	126.95	39.24
Plateau Weathered (PLW)	52.83	16.30
Valley Fill Shallow (VFS)	6.31	1.94
Water Body	17.06	5.27
Grand Total	**323.81**	**100**

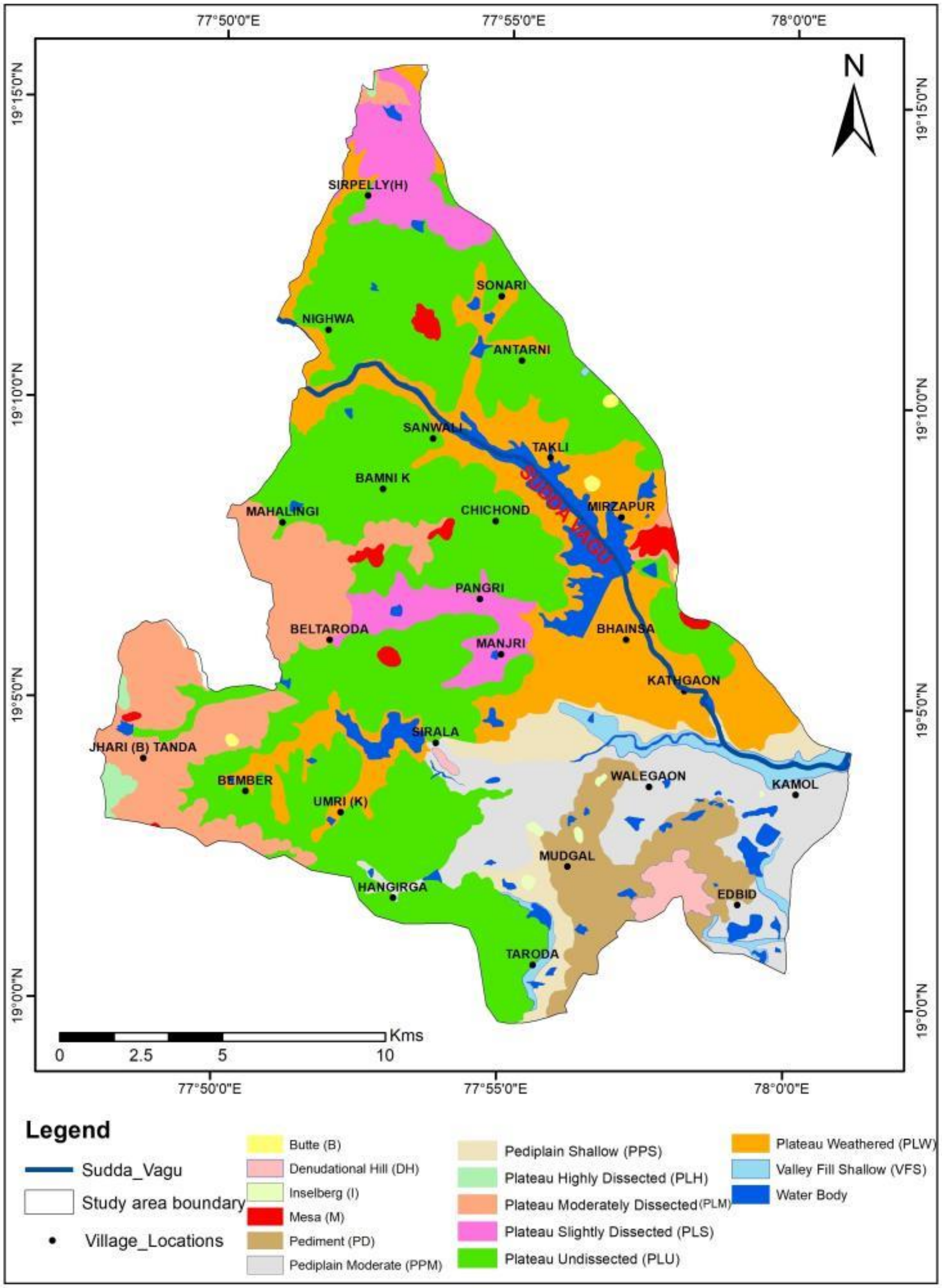

Figure 6. Geomorphology map of the study area

Land use land cover: Land use/ land cover refers to anthropogenic activities and uses that are carried out on land surface; however, this has good correlation with lithological and morphological units (Varde et al., 2011). The land use and land cover play a significant role in the development of groundwater resources. The nature of land surface and its pattern control infiltration and runoff (Kumar et al., 2007). Land use land cover (LULC) is an important attribute of the runoff process that affects water infiltration capacity, erosion, and evapo-transpiration. Land use land cover map was derived using LISS-IV IRS-P6 satellite image and generated by layer stacking, signature editing on images for LULC. The land use land cover map (Figure 7) of study region is categorized into different classes such as agriculture land, barren land, forest, built up, mining and industrial, scrub land and water bodies. The majority part of Bhainsa region is covered by crop land and scrub land followed by barren rocky and built-up land. However, at few places mining and industrial covers are also identified. The land use Land cover is made conformist divisions in the present study and is shown in Table 3.

Table 3. Spatial distribution of land use-land cover

Land use land cover type	**Area in Sq. Km**	**Area in %**
Barren rocky	0.43	0.12
Built up	7.39	2.28
Crop land	248.47	76.80
Forest	9.27	2.86
Mining/Industrial	1.17	0.35
Reservoir/Tanks	21.78	6.73
River/Stream/Drain	4.14	1.28
Scrub land	31.16	9.58
Grand Total	**323.81**	**100**

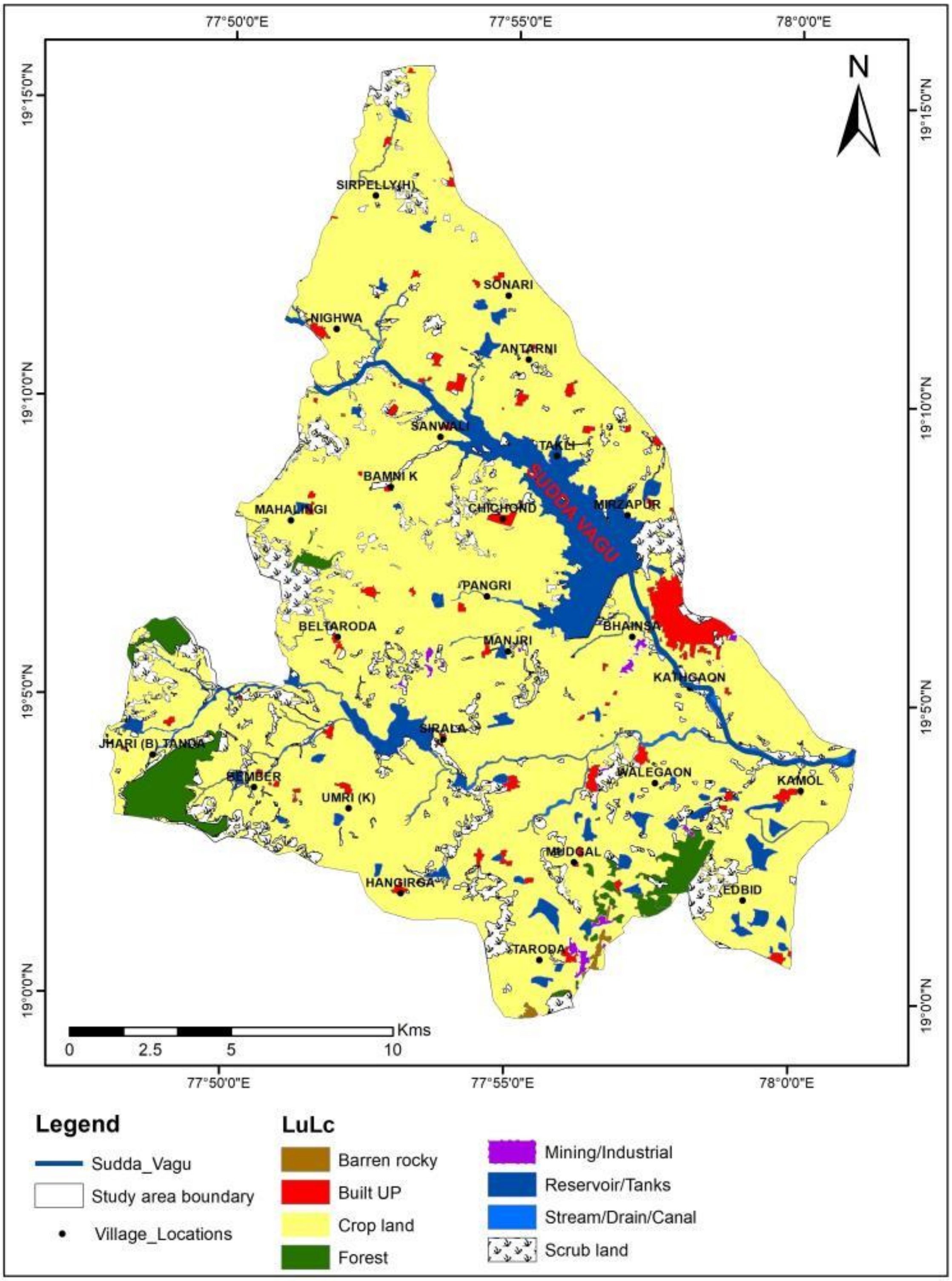

Figure 7. Land use land cover map of the study area

Soil: The soil is composed of mineral particles, organic matter, water, and air. Soil texture is commonly classified as sand, silt, or clay (Le Bas and Streckeisen, 1991). Soil properties such as depth to water table, depth to bedrock, flood potential, and permeability are important considerations in assessments. The major part of the area black clayey soils covering most parts of the hilly terrain to downstream, and forest areas, where the soil is thin may be the result of erosion and denudation mass wasting (Figure 8). The forest cover in plateau regions promotes the infiltration of rainwater to enhance the groundwater resource in the downstream region. Reddish brown soil is seen along the southeastern boundary of the study region. The remaining areas in the SW margin and north corner parts covered gravelly clay red soils. The soil cover is made obedient divisions in the present study and is shown in Table 4.

Table 4. Spatial distribution of the soil types

Soil Type	**Area in Sq. Km**	**Area in %**
Deep black clayey soils	266.79	82.43
Loamy to clayey skeletal deep reddish brown soils	24.54	7.56
Shallow loamy to gravelly clay red soils	32.48	10.01
Grand Total	**323.81**	**100**

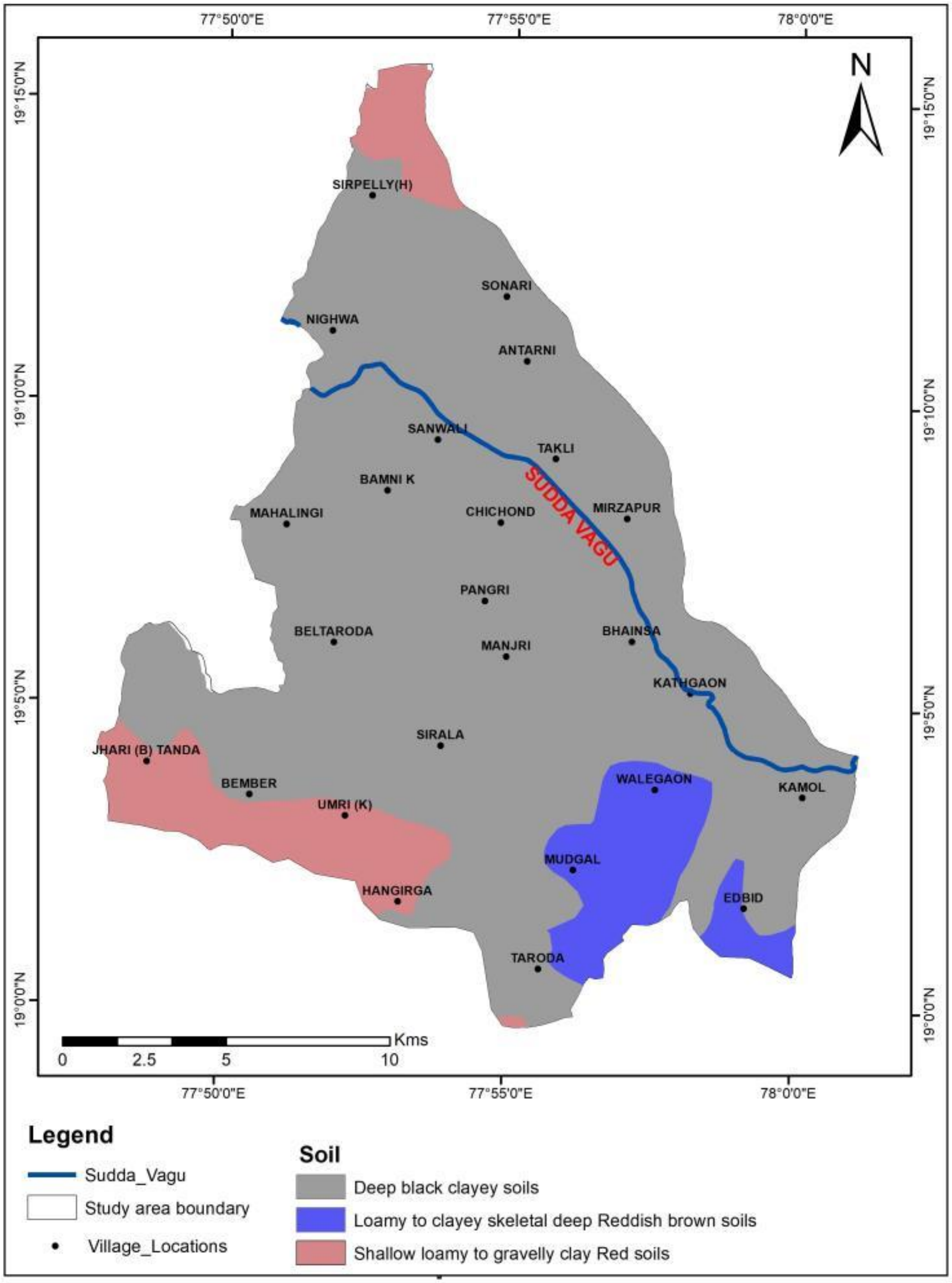

Figure 8. Soil map of the study area.

CONCLUSIONS

Elucidation of lithological, drainage, geomorphology, land use land cover and soil units and demarcation of their boundaries are made possible by utilizing satellite imaginary IRS-P6 LISS-IV with a spatial resolution of 5.8m. Satellite image digitally processed and interpreted using Arc GIS to achieve structural fabric. After the amalgamation of all the units, a detailed land use-land cover map is attained. Agricultural cropland area is around 76.80% and forest area is 2.86% which needs further forestation in the area of investigations. Undeveloped open scrubland area 9.58% required more attention to bring the land into utility. Satellite images in combination with topo sheet of the similar scale of Survey of India used for analyzing the land use and land cover studies. The Sudda vagu/river flow direction from NNW-SSE and slope of the study area is towards southeast part. The drainage pattern in the study area is dendritic to sub dendritic. The geomorphological units such a pediplain moderate to shallow, plateau weathered, valley fills are most prospective zones for the groundwater development in the locality.

Competing interests: Authors have declared that no competing interests exist.

Authors contribution: This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of manuscripts.

List of Abbreviations:

IRS - Indian Remote Sensing

GIS- Geoic information system

DEM- Digital Elevation Model

RS- Remote Sensing

LU/LC- Land Use/ Land Cover

LISS- Linear Imaging and Self Scanning Sensor

CCDs- Charge Coupled Devices

OBSSR- On-Board Solid-State Recorder

AWiFS- Advanced Wide Field Sensor

NRSC- National Remote Sensing Centre

NNW- North North West

SSE- South South East

PPM- Pediplain moderately

PPS- Pediplain shallow weathered

PW- Plateau weathered

VFS- Valley fill shallow

PLU- Plateau Undissected

References

1. Alekhya, K., Ramadass, G. and Udaya Laxmi, G., 2017. Application of remote sensing and GIS mapping for Hydrogeomorphological and land use studies in Southern parts of Godavari River basin, Jagtial District.T.S. India. International Research Journal of Natural and Applied Sciences, Vol.4, Issue, 8, pp.62-77.

2. Aboyeji, O. S., Mogaji, K. A., & Oyinloye, R. O. (2012). Structural Interpretation of Remotely Sensed Sets, It Hydrogeological Implication over Ile-Life and Environs. Ozen Journal of Applied Sciences, Vol. 5, pp.43-54.

3. Ramkishan Desai, (2006). Ground water Investigations, Development and Management in tribal tracts of Utnoor Area, Adilabad District, Andhra Pradesh, India – Ph.D Thesis submitted to Dept. of Geology, Osmania University.

4. Castleman, K.E. 1978. The gray level histogram, Digital Image Processing. Printice- Hall, Englewood Cliffs, New Jersey, Inc., pp. 68-84.

5. Chavez, P.S. Jr., Berlin, G.L. and Sowers, L.B. 1982. Statistical method for selecting Landsat MSS ratios, Journal of Applied Photoic Engineering, Vol. 8(1), pp. 23-30.

6. El Khidir, S.O. and Babikir, I.A., 2013. Digital image processing and geospatial analysis of landsat 7 ETM+ for mineral exploration, Abidiya area, North Sudan. International Journal of Geomatics and Geosciences, 3(3), pp.645-658.

7. Ezzati, S.A., S.R. Mehrnia and K.S. Ajayebi (2014). Detection of hydrothermal potential zones using remote sensing satellite data in Ramand region, Qazvin Province, *Iran* j*ournal of Tethys*, Vol. 2 (2), pp. 93–100.

8. Hengl, T., Reuter, H.I., 2008. Geomorphometry: concepts, software, applications. Newness'.

9. Evans, I.S., 2019. General geomorphometry, derivatives of altitude, and descriptive statistics. In: Spatial Analysis in Geomorphology. Routledge, pp. 17–90.

10. Florinsky, I.V., 2017. An illustrated introduction to general geomorphometry. Prog. Phys. Geogr. 41 (6), 723–752.

11. Sofia, G., 2020. Combining geomorphometry, feature extraction techniques and Earth-surface processes research: The way forward. Geomorphology 355, 107055.

12. Wilson, J.P., 2022. Recent advances and challenges in geomorphometry. J. Treat. Geomorphol. 141–168.

13. Wilson, J.P., Gallant, J.C., 2000b. Terrain Analysis: Principles and Applications. John Wiley & Sons.

14. Florinsky, I., 2016. Digital Terrain Analysis in Soil Science and Geology. Academic Press.

15. Florinsky, I.V., 1998b. Combined analysis of digital terrain models and remotely sensed data in landscape investigations. Prog. Phys. Geogr. 22 (1), 33–60.

16. Ironside, K.E., Mattson, D.J., Arundel, T., Theimer, T., Holton, B., Peters, M., Edwards Jr., T.C., Hansen Jr., J., 2018. Geomorphometry in landscape ecology: issues of scale, physioy, and application. Environ. Ecol. Res. 6 (5), 397–412.

17. Jancewicz, K., R´o˙ zycka, M., Szymanowski, M., Kryza, M., Migo´n, P., 2022. Topoic Characteristics of Drainage Divides at the Mountain-Range Scale—A Review of DTM-Based Analytical Tools. ISPRS Int. J. Geo Inf. 11 (2), 116.

18. Kumar, P.K.D., Gopinath G. and Seralathan P. (2007) Application of remote sensing and GIS for the demarcation of groundwater potetential zones in a river basin of Kerala, southwest coast of India. International Journal of Remote Sensing, 28 (24) pp. 5583-5601.

19. Le Bas, M.J. and Streckeisen, A.L., 1991. The IUGS systematics of igneous rocks. Journal of the Geological Society, 148(5), pp.825-833.

20. Liu, K., Song, C., Ke, L., Jiang, L., Ma, R., 2020a. Automatic watershed delineation in the Tibetan endorheic basin: A lake-oriented approach based on digital elevation models. Geomorphology 358, 107127.

21. Ma, D., Zhao, S., 2022. Quantitative Analysis of Land Subsidence and Its Effect on Vegetation in Xishan Coalfield of Shanxi Province. ISPRS Int. J. Geo Inf. 11 (3), 154.

22. Macklin, M.G., Brewer, P.A., Hudson-Edwards, K.A., Bird, G., Coulthard, T.J., Dennis, I. A., Lechler, P.J., Miller, J.R., Turner, J.N., 2006. A geomorphological approach to the management of rivers contaminated by metal mining. Geomorphology 79 (3–4), 423–447.

23. Linga Swamy Jogu, Udaya Laxmi G, Naveen Kumar Gradas, and Vidyasagar Chary (2022) “Analysis of Terrain elements using IRS P6-LISS-IV image in parts of Nagarkurnool and Wanaparthy districts in Telangana State, India.” Indian Society of Applied Geochemists (ISAG)-Journal of Applied Geochemistry, ISSN (Print): 0972-1967 ISSN (Online): 2319-4316, Volume: 24, Issue: 4, PP.197-202.

24. Goetz, A.F.H. 1975. Application of ERTS images and image processing to regional geologic problems and geologic mapping in northern Arizona, JPL Technical Report 32-1597, Jet Propulsion Laboratory, Pasadena, CA.

25. Hammond, R. and McCullagh, P.S. 1980. Quantitative techniques in geoy. Oxford, England: Clarendon Press.

26. IRS P6 data user’s manual, IRS-P6/ NRSA/NDC/HB-10/03, 1/October-2003.

27. Miller, L.D. and Pearson, R.L. 1971. Areal mapping program of the IBP grassland biome: Remote Sensing of the productivity of the shortgrass prairie as input into biosystem models, 7th Proceedings of International Symposium. Remote Sensnsing of Environment. Vol. 1, pp. 175–205.

28. Nagamani, K. and Ramachandran, S., 2003, December. Land use/land cover in Pondicherry using remote sensing and GIS. In Proceedings of the Third International Conference on Environment and Health, Chennai, India (pp. 15-17).

29. Price, J.C. 1995. Examples of high resolution visible to near infrared reflectance spectra and a standardized collection for remote sensing studies: International Journal of Remote Sensing, Vol. 16, pp. 993–1000.

30. Rao, D.P. 1995. Remote Sensing for Earth Resources, AEG Publication.

31. Sabins, F.F. (1997). Remote Sensing: Principles and Interpretation, 3rd Edn. WH Freeman and Company, New York, 494p.

32. Short, N.M. 1982. The Landsat Tutorial Workbook, Basics of Satellite Remote Sensing, Washington, D.C.: NASA Scientific and Technical information Branch, NASA, pp. 174-175.

33. Singer, R.B. 1980. Near–infrared spectral reflectance of mineral mixtures, systematic combinations of pyroxenes, olivine and iron oxides, PSD Publications. No. 258, MIT, Cambridge, MA.

34. Subhash Babu, A., Udayalaxmi, G. and Ramadass, G., 2014. Integration of Litho-Units derived from Satellite data. International journal of Research in Science & Technology (IJRST) Vol.1, Issue 11, December 2014, pp.26-30.

35. Thornbury, W.D. 1986. Principles of Geomorphology, 2nd Edition. Wiley Eastern Ltd.

36. Udaya Laxmi G., Narsimha,K., Linga Swamy Jogu, Telu Raju, Ramadass,G., 2016. IRS R2-LISS IV Satellite Image Analysis for Mapping Lithological, Geomorphological, Drainage and Structural Features Along the Kalwakurthy-Nalgonda-Huzurnagar Profile, Telangana State, India. Int. Journal of Research in Engineering and Technology (IJRET) Vol. 5 Issue-07, pp.129-137**.**

37. UmaMaheshwari R., Rajkumar R., Surendran A. and Krishnamoorthy B.S., 2015). Monitoring changes in land use/land cover using multi temporal/sensor satellite data: a case study in Palani. (IJRSR), 6(2), 2867- 2870.

38. Xiong, L., Li, S., Tang, G. and Strobl, J., 2022. Geomorphometry and terrain analysis: Data, methods, platforms and applications. Earth-Science Reviews, 233, p.104191.

39. Varde, A.M., Wath, P., Dongre, K.P., Khare, Y.D. and Khandare, H. (2011). Integrated approach using remote sensing and GIS for assessment of groundwater situation in parts of Chandrapur and Gadchiroli Districts of Maharastra, Journal of Indian Geophysics Union, v.15 (4), pp.195-206.

40. Sangeetha , C., Vishnu Moond, Rajesh G. M., Jamu Singh Damor, Shivam Kumar Pandey, Pradeep Kumar, and Barinderjit Singh. 2024. “Remote Sensing and Geoic Information Systems for Precision Agriculture: A Review”. International Journal of Environment and Climate Change 14 (2):287-309. https://doi.org/10.9734/ijecc/2024/v14i23945.

41. Virugu, Karunakar, Ashok Kumar Lonavath, V. Sathish Kumar, and K. Jhansi. 2018. “Digital Earth in Enhanced Teaching Methods of Geoy”. Journal of Geoy, Environment

and Earth Science International 13 (2):1-13. https://doi.org/10.9734/JGEESI/2017/37716.

42. Sahu N, Singh SK, Reddy GO, Kumar N, Nagaraju MS, Srivastava R. Large-scale soil resource mapping using IRS-P6 LISS-IV and Cartosat-1 DEM in Basaltic Terrain of Central India. Journal of the Indian Society of Remote Sensing. 2016 Oct;44:811-9.

43. Vibhute AD, Kale KV, Gaikwad SV, Dhumal RK, Nagne AD, Varpe AB, Nalawade DB, Mehrotra SC. Classification of complex environments using pixel level fusion of satellite data. Multimedia Tools and Applications. 2020 Dec;79:34737-69.