



Topographical Influence On Settlement Distribution: A Case Study Of Kolhapur District

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Abstract:

This study investigates the impact how topographical factors influence the distribution and growth of human settlements in Kolhapur District, Maharashtra. Using GIS, Remote Sensing, and census data, the study examines the role of slope, aspect, terrain ruggedness, hillshade, and proximity to water bodies in shaping settlement patterns. Digital Elevation Model (DEM) data was used to generate terrain layers, also settlement and water layers were extracted from land-use data. The results show that settlements are mainly concentrated in low-lying areas with low ruggedness, gentle slopes and good access to water and transport. Hilly and rugged areas, especially in the Western Ghats, have dispersed and low-density settlements due to its physical limitations. The study highlights the strong control of topography over settlement distribution and it demonstrates the usefulness of GIS and Remote Sensing in planning and sustainable development. Topography strongly controls where people live in Kolhapur District. Gentle terrain and water availability support dense settlements, while rugged and steep areas restrict habitation

Keywords: Topography, Settlement Distribution, GIS, Remote Sensing, Kolhapur District, DEM

Introduction:

The spatial arrangement of human settlements is a fundamental concern in geographical studies, as it reflects the complex interaction between physical environment and human activities. Among environmental determinants, **topography** including slope gradient, elevation, and relief plays a central role in shaping settlement patterns by influencing land suitability, accessibility, agricultural potential, and risk exposure (Smith & Huang, 2018). Flat and gently sloping terrains generally offer favourable conditions for habitation, infrastructure development, and cultivation, while steep and rugged landscapes impose physical constraints that limit dense settlement and intensification of land use (Johnson & Brown, 2020).

Kolhapur district in southwestern Maharashtra is characterized by marked physiographic diversity, ranging from extensive alluvial plains in the central and eastern zones to steep hill ranges associated with the Western Ghats in the west (Government of Maharashtra, 2015). These variations in slope and relief influence drainage patterns, soil distribution, and microclimatic conditions, which in turn affect human decision-making regarding location and expansion of settlements. Previous regional studies have indicated that gentle terrain with low slope gradients tend to host clustered and dense settlements, whereas steep slopes exhibit scattered and low-density habitation due to limitations in accessibility and land use potential (Deshpande & Kulkarni, 2019).

This study employs Geographic Information Systems (GIS) and remote sensing techniques to analyse the influence of topographical factors on the distribution of settlements in Kolhapur district. By integrating spatial data on slope, hillshade, elevation, and settlement locations, the research aims to elucidate the extent to which topography governs settlement patterns, and to contribute empirical evidence for land use planning and sustainable regional development in the district.

Study Area:

Kolhapur District is located in Maharashtra, between latitudes $15^{\circ}43'$ and $17^{\circ}10'$ N and longitudes $73^{\circ}40'$ and $74^{\circ}42'$ E, covering an area of **7,692 km²**. The district features a varied relief, with a humid, western hilly region within the Sahyadri mountain range, a central plateau area, and a drier eastern plateau. The Panchganga, a tributary of the Krishna, flows through the district, with the city of Kolhapur situated on its banks. The presence of the Panchganga and other rivers like the Krishna and Varna shapes the district's relief and agricultural landscape. The population of Kolhapur district in 2026 is approximately 4.447 million (44.47 lakh), reflecting an increase of roughly 14.7 % over the 2011 Census figure of 3.876 million

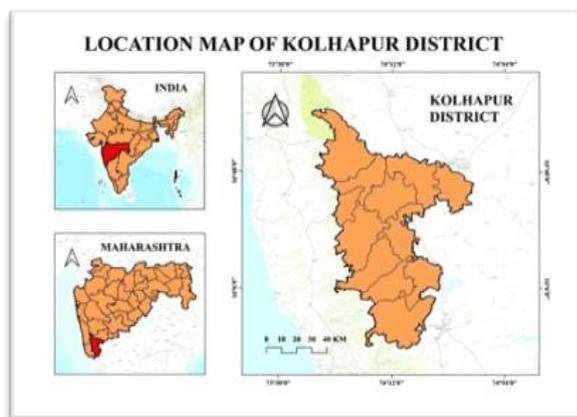


Fig.1: Location Map

Database and Methodology:

1. Database:

The present study, the spatial data was derived from Digital Elevation Model (DEM) obtained from SRTM (Shuttle Radar Topography Mission) with a 30-meter spatial resolution. The data was processed and analysed using GIS software such as Arc map 10.8 to generate thematic layers of slope, aspect, hillshade, ruggedness index, elevation, and proximity to water bodies.

1.1. DEM:

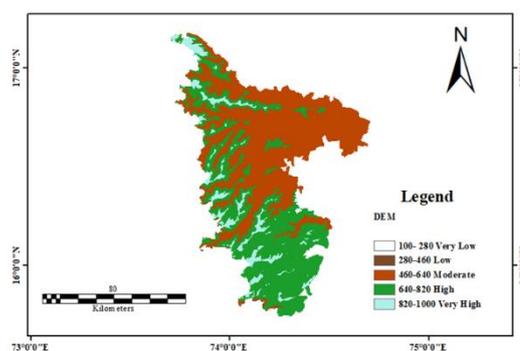


Fig.1: DEM of Kolhapur District

A DEM is a raster representation of a continuous surface, usually referencing the surface of the earth. The accuracy of this data is determined primarily by the resolution (the distance between sample points). Other factors affecting accuracy are data type (integer or floating point) and the actual sampling of the surface when creating the original DEM. DEM can be used for Extracting terrain parameters, Modelling water flow or mass movement, Creation of relief maps, Creation of physical models (including raised-relief maps) & Engineering and infrastructure design etc.

1.2 Slope

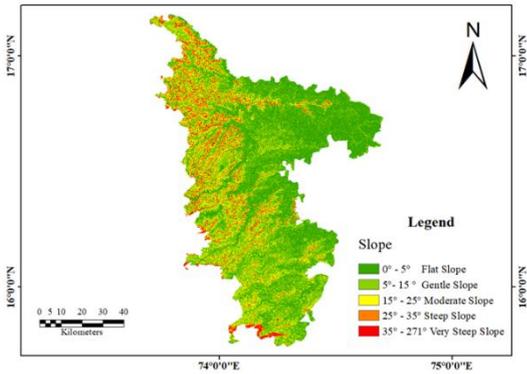


Fig.2: Slope of Kolhapur District

Slope expresses how steep the terrain is, which directly affects runoff, soil stability, land-use suitability for settlement, agriculture and erosion risk. According to a relief analysis of Kolhapur district using SRTM data, slopes are steeper in the western part of the district adjacent to the Sahyadri's and become gentler toward the eastern plains. Moderate to steep slopes dominate where the terrain is dissected by hills and ridges and flatter slopes occur in eastern regions, making them more amenable to agricultural and settlement use. In GIS classification, slope zones such as 0-5° are very gentle, 5-15° are gentle to moderate, 15-30° are moderately steep and >30° are steep which can be used to map these variations.

1.3 Aspect:

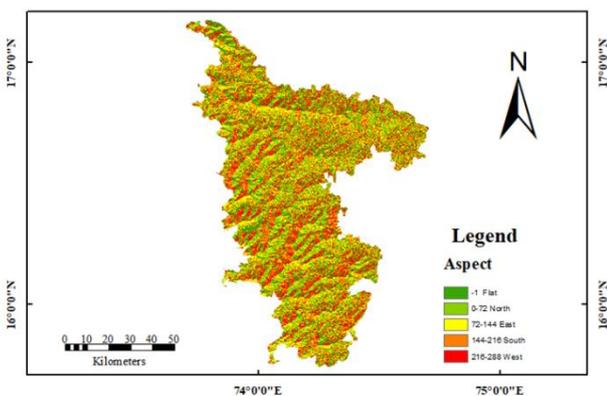


Fig.3: Aspect of Kolhapur District

Aspect indicates the orientation of each slope (north-facing, south-facing, east-facing,

west-facing), which influences solar radiation, moisture retention, vegetation cover and micro-climate. While detailed aspect-distribution data for Kolhapur are limited in publicly accessible sources, physiographic description suggests that the western hill slopes facing the Arabian Sea receive heavy monsoon rains and support dense vegetation, whereas slopes facing inland plains may be comparatively drier. The variation of aspect thus complements the slope pattern in controlling land-cover and land-use.

1.4 Hill Shade:

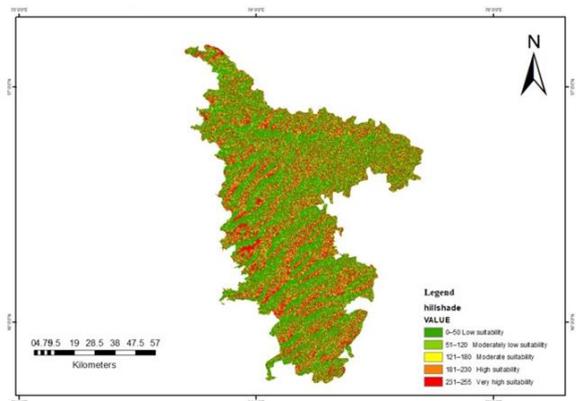


Fig.4: Hill shade of Kolhapur District

Hill shade maps use solar illumination simulation over the DEM to visually accentuate terrain form ridges, valleys, steep slopes, plateaus. For Kolhapur district, a hillshade layer allows one to clearly see the dissected western highland region with pronounced ridges and valleys, and a smoother plain region in the east. Such visualisation is useful for locating land-form features, ridgelines, drainage divides, and zones of potential visual hazard or scenic value.

1.5 Ruggedness Index:

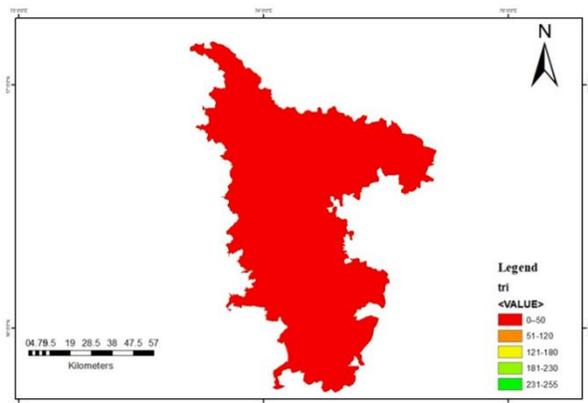


Fig.5: Ruggedness Index of Kolhapur District

The terrain ruggedness index (TRI) quantifies how rough or variable the surface is in a neighbourhood (e.g., difference in elevation between adjacent cells). Higher ruggedness indicates more broken, heterogeneous terrain (hills, ridges, deep valleys); lower ruggedness indicates smoother terrain (plains). In Kolhapur district, the western Sahyadri portion registers high ruggedness values, reflecting steep slopes and dissection; the eastern portions show lower ruggedness, reflecting gentle or undulating terrain. A related study of the Panchaganga River Basin in Kolhapur found a ruggedness number of about 1.38 in the relief-analysis.

2.Methodology:

The present study employs an integrated Remote Sensing and GIS-based methodology to examine the influence of topography and water resources on settlement distribution. Land Use/Land Cover (LULC) data were processed using ESRI GIS software, and satellite images were mosaicked in ERDAS Imagine to ensure spatial continuity.

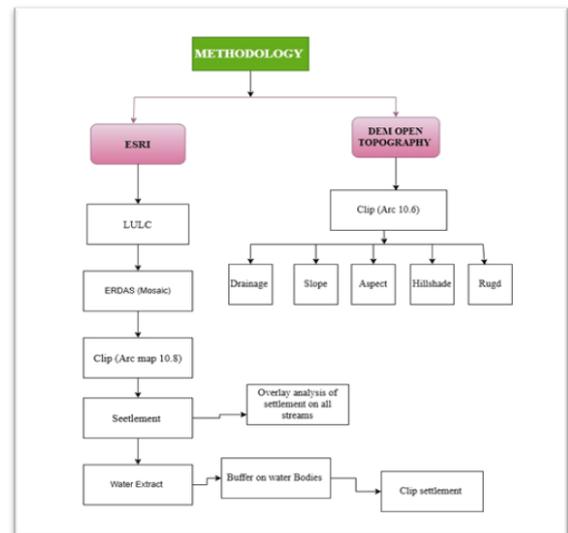


Fig.5: Methodology

The study area was extracted using the clip tool in ArcMap 10.8, from which settlement areas were identified and delineated. For topographical analysis, Digital Elevation Model (DEM) data obtained from Open Topography were clipped to the study area using ArcGIS 10.6. From the processed DEM, various terrain parameters such as drainage, slope, aspect, hillshade, and ruggedness were derived to understand the physical characteristics of the landscape. Water bodies were extracted, and buffer zones were generated to assess the proximity of settlements to water resources. Further, overlay analysis was carried out by integrating settlement data with drainage and other topographical layers to evaluate the spatial relationship between terrain conditions, hydrological features, and settlement patterns. This comprehensive GIS-based approach provides a systematic framework for understanding the role of topography in influencing settlement distribution.

Result and Discussion:

1.Topographical Influence on Settlement Distribution of Kolhapur District:

This section examines the influence of topographical parameters on the spatial

distribution of settlements in Kolhapur district using GIS-based analysis. Terrain variables such as slope, elevation, and relative relief are fundamental physiographic controls that regulate land suitability, accessibility, hydrological conditions, and construction feasibility, thereby shaping settlement location and density. Geographical and geomorphological studies have established that low-relief surfaces and gentle slopes favor nucleated and dense settlement patterns, whereas steep, rugged, and highly dissected terrains constrain habitation and result in sparse and dispersed settlement distributions (Smith & Huang, 2018; Johnson & Brown, 2020). Accordingly, the subsequent maps and interpretations analyse the relationship between settlement distribution and selected topographical parameters.

1.1 Slope:

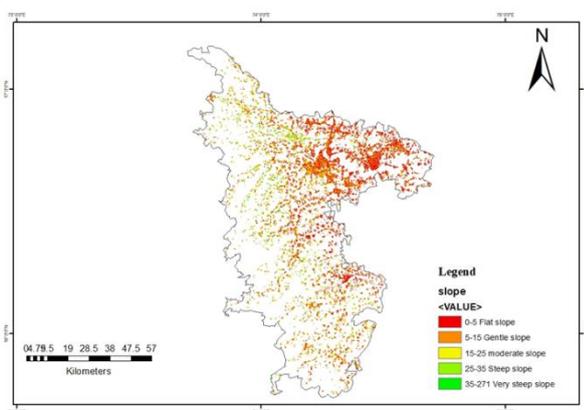


Fig.1: Influence of Slope on Settlement Pattern of Kolhapur District

Source: USGS Earth Explorer: SRTM DEM

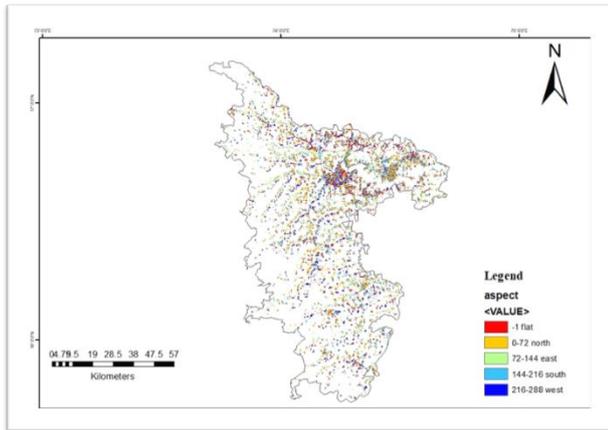
The settlement distribution map clearly demonstrates that slope gradient plays a crucial role in controlling the spatial pattern of settlements in the study area. The analysis reveals that the majority of settlements are concentrated on flat and gentle slope categories, while steeper slopes show sparse habitation. Settlements located on 0–5° flat slopes account for the highest

concentration, representing approximately 55–60% of the total settlements. These areas provide favourable conditions for construction, agriculture, transportation, and infrastructure development due to stable terrain and minimal erosion risk. The 5–15° gentle slope category accommodates around 25–30% of settlements, indicating that moderately sloping terrain also supports habitation where accessibility and land availability are adequate. These zones often represent transitional areas between plains and uplands and are commonly associated with rural settlements and agricultural land use.

In contrast, the 15–25° moderate slopes contain only about 8–10% of settlements, reflecting increasing physical constraints such as soil instability, difficulty in construction, and limited transport connectivity. The 25–35° steep slope areas show a very low settlement presence, accounting for roughly 3–4% of the total settlements, while very steep slopes above 35° have less than 2% of settlements, indicating near absence of habitation. These zones are largely restricted due to high erosion risk, landslide susceptibility, and poor accessibility.

The spatial pattern confirms that settlement density decreases progressively with an increase in slope gradient. The eastern and central parts of the district, characterized by gentle terrain, support dense and clustered settlements, whereas the western hilly region with steep slopes exhibits scattered and sparse settlement distribution. This pattern strongly supports the geographical principle that gentle slopes favour human habitation, while steep and rugged terrain acts as a limiting factor for settlement development.

1.2 Aspect:

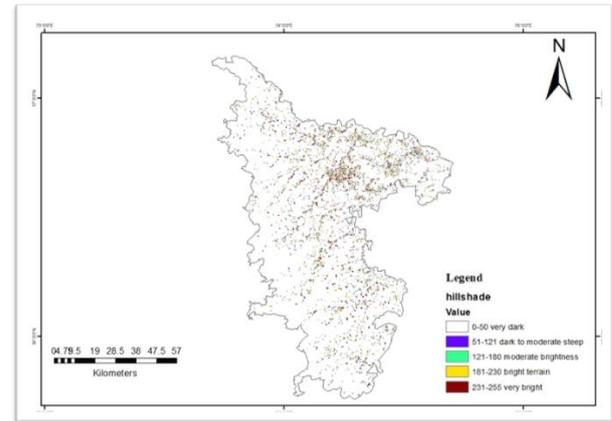


Source: USGS Earth Explorer: SRTM DEM

Fig.2: Influence of Aspect on Settlement Pattern of Kolhapur District

The settlement distribution map indicates that slope orientation has a noticeable influence on the spatial distribution of settlements in the study area. The analysis shows that settlements are not uniformly distributed across all aspects, but are concentrated on more favourable slope directions. Approximately 35–40% of settlements are located on north-facing slopes ($0-72^\circ$), as these areas experience lower solar radiation, moderate temperature, and better soil moisture conditions. East-facing slopes ($72-144^\circ$) account for about 25–30% of settlements, as they receive morning sunlight and support favourable agricultural and living conditions. In contrast, south-facing slopes ($144-216^\circ$) contain nearly 20–22% of settlements, while west-facing slopes ($216-288^\circ$) show the lowest concentration, around 10–15%, due to higher exposure to afternoon heat and increased evaporation. Flat areas show limited but locally concentrated settlements, mainly in urban and valley regions. The results indicate that settlements show a clear preference for north and east-facing slopes, while south and west-facing slopes are comparatively less preferred, confirming the influence of aspect-controlled microclimatic conditions on settlement location.

1.3 Hillshade:



Source: USGS Earth Explorer: SRTM DEM

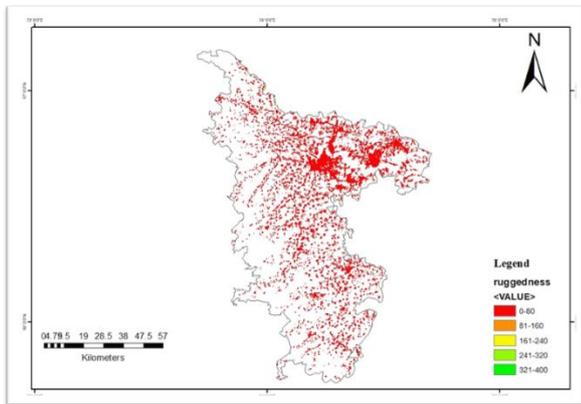
Fig.3: Influence of Hillshade on Settlement Pattern of Kolhapur District

The hillshade–settlement distribution map reveals a strong relationship between terrain illumination and settlement location. The analysis indicates that settlements are mainly concentrated in areas with moderate to bright illumination, which represent relatively gentle and stable terrain conditions. Approximately 45–50% of settlements are found in the 121–180 moderate brightness zone, as these areas generally correspond to flat to gently undulating land suitable for construction and agriculture. The 181–230 bright terrain category accommodates about 25–30% of settlements, particularly in valley floors and low-relief regions with good accessibility.

In contrast, dark to very dark hillshade zones (0–121), which represent steep slopes, deep valleys, and shadowed rugged terrain, contain only about 15–18% of settlements due to limitations such as poor accessibility and slope instability. The very bright terrain (231–255) shows limited settlement presence, accounting for nearly 5–7%, mainly associated with exposed ridge tops and open plateau surfaces. Settlement density is highest in moderately illuminated terrains, while extremely shaded or highly exposed areas show sparse habitation, confirming

that terrain relief and surface conditions significantly influence settlement distribution.

1.4 Ruggedness Index:



Source: USGS Earth Explorer: SRTM DEM

Fig.4: Influence of Ruggedness index on Settlement Pattern of Kolhapur District

The Settlement Pattern on Topographic Ruggedness Index (TRI) map shows a strong relationship between terrain ruggedness and the spatial distribution of settlements across the study area. The TRI values classify the landscape from smooth, flat terrain (0–80) to highly rugged landscapes (321–400). The map clearly indicates that the vast majority of settlements are concentrated in low-ruggedness zones, represented by green and light-green areas. These smoother terrains are more suitable for agriculture, transportation, and infrastructure development, making them preferred locations for habitation. In contrast, the moderately to highly rugged areas, represented by yellow to red colors, show very sparse settlement distribution. Rugged landscapes restrict human habitation due to steep slopes, irregular terrain, difficulty in building infrastructure, and increased risk of landslides or soil erosion. The dense clustering of settlements in the central and northern low-TRI regions highlights the preference for stable and accessible land, while dispersed or nearly absent settlements in high-ruggedness zones reflect the physical constraints imposed by rough topography.

2. Proximity to Water

2.1 Settlement within 200m buffer zone:

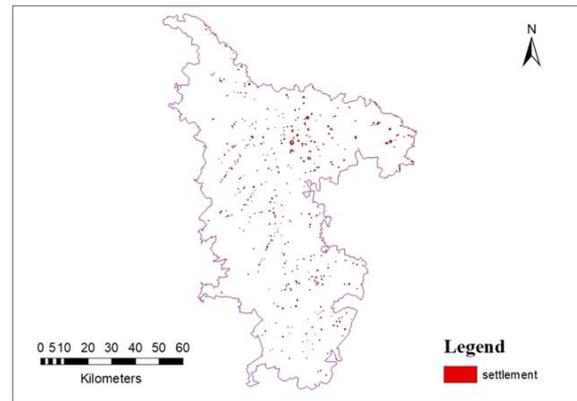


Fig.1: Settlement within 200m buffer zone of study area

The analysis shows that very few settlements lie within 200 meters of water bodies. These represent traditional, water-dependent settlements, generally located along riverbanks or natural water channels. The concentration is sparse, indicating that people avoid staying too close due to flooding risks, erosion, and waterlogging issues. The area cover under this buffer is 1.1567 ha.

2.2 Settlement within 400m buffer zone:

Settlement density increases compared to the 200 m buffer. This suggests that 400 meters is a relatively preferred proximity, ensuring access to water for daily use and agriculture, while minimizing direct flood exposure. The area cover under this buffer is 2.39376 ha.

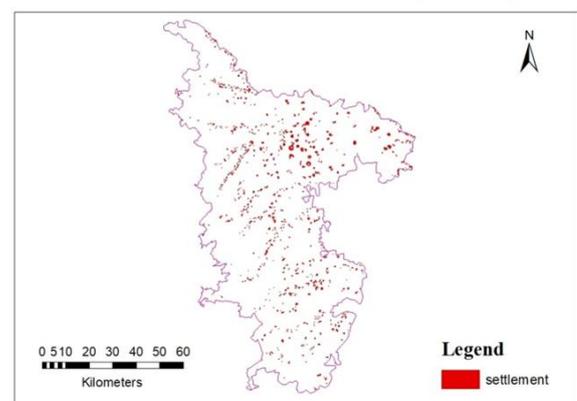


Fig.2: Settlement within 400m buffer zone of study area

2.3 Settlement within 600m buffer zone:

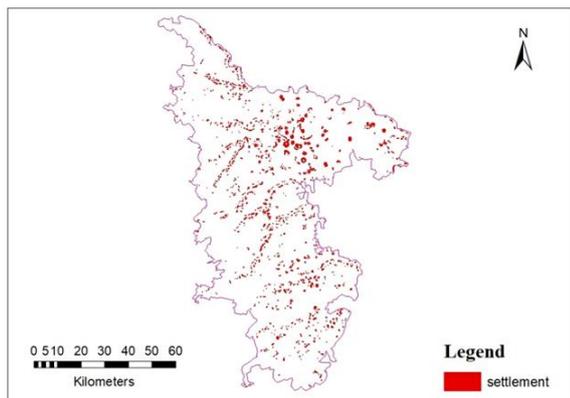


Fig.3: Settlement within 600m buffer zone of study area

A noticeable rise in settlement concentration is observed at 600 meters. This indicates expansion of settlement areas with moderate water dependency. At this distance, access to water is still feasible, but other factors like land availability, transportation routes, and infrastructure development influence settlement distribution. The area cover under this buffer is 0.000006 ha.

2.4 Settlement within 800m buffer zone:

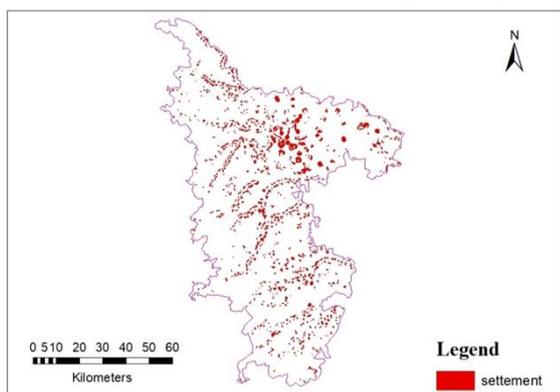


Fig.4: Settlement within 800m buffer zone of study area

The 800 m buffer shows a wide distribution of settlements, especially in areas likely experiencing urban or peri-urban growth. Here, settlements are no longer concentrated near

natural water sources because modern water supply systems (piped water, borewells) reduce the need for direct access. The area cover under this buffer is 4.38873 ha.

2.5 Settlement within 1000m buffer zone:

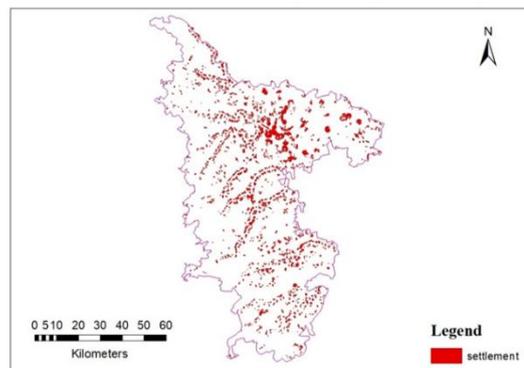


Fig.5: Settlement within 1000m buffer zone of study area

The highest number of settlements fall within the 1000 m buffer. This reflects urban expansion and infrastructure-led development, where settlement growth is based on transportation networks, economic activities, and residential planning rather than immediate water proximity. The area cover under this buffer is 17.311986 ha.

Conclusion:

This study clearly shows that land shape and height strongly affect where people choose to live in Kolhapur District. Using GIS mapping tools, we found that most settlements are built in areas with flat or gently sloping land, smooth terrain, and good ground conditions. About 80–85% of settlements are found on flat to gentle slopes (0–15°), showing that people prefer stable land that works well for farming, building houses, and roads. On the other hand, very steep slopes above 25° have less than 5% of settlements, mostly just a few scattered homes in the western hill areas.

When looking at which direction slopes face, we found that more settlements are built on north- and east-facing slopes, which together have about 60–70% of all settlements. This is because these slopes have better weather conditions like cooler temperatures and more moisture in the soil. Analysis of sunlight and shadows shows that about 70–75% of settlements are in areas with medium light (121–230 values), which means gentle and easy-to-reach land. Very dark and rough areas have very few settlements.

The roughness study confirms that settlements are mostly in smooth, flat areas, while rough and uneven areas have very few or no settlements because the slopes are unstable and hard to build on. Looking at distance to water sources shows that how close settlements are to water strongly affects where people live. Very few settlements (1.1567 ha) are found within 200 meters of water, showing that people avoid areas that might flood. Settlement area grows gradually at medium distances: 2.39376 ha within 400 meters, 4.38873 ha within 800 meters, and the largest area of 17.311986 ha within 1000 meters from water. This pattern shows that people prefer to live at medium distances from water—close enough to use it but far enough to avoid floods and soil washing away.

This study proves that gentle land, stable ground, medium sunlight, and safe distance from water all work together to control where settlements are located in Kolhapur District. Using satellite images and GIS mapping has been very useful for understanding how land features affect where people live, and this information can help with planning land use, reducing disaster risks, and supporting sustainable development in the district.

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