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Comprehensive Analysis of Landform and Land Use/ Land Cover Mapping of Waghora Watershed Using Sentinal-2B and SRTM-DEM Data

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Authors' contributions

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

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ABSTRACT

This paper aims to integrate the use of high spectral resolution a remote sensing data of Sentinel-2B imagery along with the Digital Elevation Model (DEM) derived from the SRTM stereo data to delineate the landforms and analyze the land use and land cover in Waghora watershed, Sausar tehsil, Chhindwara district, situated on basaltic terrain in northern Deccan plateau. A 30 m resolution DEM of the study area was generated, capturing terrain parameters like elevation, slope, aspect, hillshade, and drainage. Sentinel-2B (10 m) images from two seasons were collected FCC (false colour composite) and were prepared by ARCGIS software. combination of Sentinel-2B imagery, SRTM-DEM data, and ground truth verifications to delineate eight major landforms in the

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studied area. Slope information, extracted from high-resolution DEMs, reveals 4 distinct slope classes. The landforms, including Plateau, Escarpment, Foot Slope, Upper Pediment, Lower Pediment, Valley, Interfluve, and Mound, are characterized based on visual interpretation and geological context. Each landform exhibits unique features, elevation ranges, and dominant land use/cover types, such as single crop cultivation, forest, or degraded land. This detailed terrain analysis aids in land-use planning and environmental management initiatives. The land use/land cover analysis utilizes Sentinel-2B data to identify five classes: degraded forest, double crop, single crop, orchard, and land with and without scrubs. Dense forest dominates 24.2% of the watershed, while double crop and single crop lands cover 36.7% and 24.2% respectively. Orchards occupy a minimal 0.8% of the area, and wastelands account for 5.7%. The relationship between landforms, slope, and land use/cover reveals dominant forestation on steep escarpments, while valleys and interfluves support double cropping due to gentle slopes and depositional processesThe study elucidated connections to examine diverse biophysical phenomena. It highlights the effectiveness of employing SRTM-DEM and Sentinel-2B imagery for analyzing geomorphic characteristics and mapping land use/land cover, offering significant perspectives for land management and planning approaches.

Keywords: Landform; landuse/land cover; slope; ArcGIS; Sentinel-2B; SRTM-DEM.

1. INTRODUCTION

Land use, land cover, and land form are important components of the Earth's surface that play a crucial role in various environmental processes and human activities [1]. These patterns provide valuable information about how land is being utilized, the types of vegetation and structures present, and the physical characteristics of the terrain. Accurate characterization of these factors is essential for making informed decisions regarding land management, conservation efforts, and land-use planning. In India, a watershed is a commonly used spatial unit of analysis for land resource management and planning. The country's watershed approach to land resource management recognizes the interconnectedness of land, water, biodiversity, and human activities within a specific geographic area [2]. Remote sensing is an advanced tool that aids in gathering and updating information for better management of existing crops and to bring more areas under agriculture crops. This can be achieved through the use of various types of sensors, such as microwave radiometers, laser meters, magnetic sensors, and cameras, which collect electromagnetic information to derive accurate, large-scale information about the Earth's surface and atmosphere. The use of Digital Elevation Models has become increasingly important in land form mapping. DEM data provides valuable information about the elevation and topography of an area, allowing for a more accurate representation of landforms. It enables researchers to analyze and understand various landforms and their characteristics, such as mountains, valleys, ridges, and slopes [1]. Additionally, the integration of DEM data with other geospatial datasets, such as satellite imagery and land cover data, enhances the accuracy and precision of landform mapping also offers a multifaceted approach to soil surveying, resulting in cost reduction, time efficiency, and enhanced data acquisition [3]. Using SRTM data for landform mapping allows accurate determination of elevation and slope, providing valuable information for understanding landforms [4,5] also Sentinel-2 data for land cover monitoring, finding its global potential widely used for land form and land use cover mapping [6,7]. It outperforms Landsat-8, integrating with LiDAR and UAVs in developing countries [8]. And integration of the Sentinel-2B and SRTM Digital Elevation Models, have greatly facilitated the characterization of land use, land cover, and land form [9,10]. One of the key benefits of using Sentinel and SRTM data for land characterization is their ability to provide a comprehensive and up-to-date view of the landscape. These satellite and elevation data sources offer near-real-time information, capturing changes in land use and cover rapidly. This allows for timely monitoring and assessment of land use changes, enabling stakeholders to take proactive measures to mitigate negative impacts on the watershed. Utilizing Remote Sensing alongside a GIS database offers a multifaceted approach to soil surveying, resulting in cost reduction, time efficiency, and enhanced data acquisition. The scientific community extensively employs Satellite Photogrammetry techniques to produce high-resolution DEMs, ortho images, and terrain parameters like slope, contours, and drainage patterns. Building upon these applications, this research paper main objective is delineation of land form and land use cover with the help of SRTM-DEM derived derivatives with integration of Sentinel data.

2. MATERIALS AND METHODS

2.1 Study Area

The Waghora watershed is a part of the Northen Deccan Plateau, located in the Sausar tehsil of Chhindwara district of Madhya Pradesh. The Waghora watershed is located between 21º 33' 36" to 21 º 36' N latitude and 78 º 45' 36" to 79 º 48' 36" E longitude. The watershed covers an area of about 1303 ha, which is delineated and coded 4E8E5a3 (Soil and Land Use Survey of India, 2017). There are two settlements viz. Waghora and Dhotki in the watershed. The Waghora watershed is named after one of these settlements. The location map of the watershed is given in Fig. 1. The climate of the area is subtropical, dry, and subhumid, with a well-expressed summer (March to May), monsoon season (June to September), post-monsoon season (October to November), and winter season (December to February). The mean annual temperature is 25.4 °C, with a mean maximum of 41.7 °C in the summer and a mean minimum of 11.7 °C in the winter. The relative humidity ranges from 47.66 to 51.93 percent. The mean monthly rainfall shows wide variability and ranges from 1.2 to 392.3 mm and the mean annual total rainfall in the region is 1211.7 mm. The area falls under the 10.4 agro-ecological sub region (hot, sub-humid, dry) with 'ustic' soil moisture and a 'hyperthermic'.The natural vegetation comprises grasses, shrubs, and trees. The dominant tree species of the area of Babul (*Acacia arabica*), Ber (*Zizyphus jujuba*), Babul (*Acacia species*), Bamboo (*Bambusodeae Luerss*), Hiver (*Acacia leucophloea*), Mahua (*Maduca longifolia*), Neem (*Azadirachta indica*), Palas (*Butea frondosa*), Pipal (*Ficus religiosa*), Subabul (*Leucaena Leucocephala*), Teak (*Tectona grandis*), *etc*. Majority of cultivated land is covered under kharif crops such as cotton (*Gossypium hirsutum*) and pigeon pea (*Cajanus cajan*), and some parts of the area are cultivated with groundnut (*Arachis hypogaea*) during rabi under irrigation or stored moisture. Orange *(Citrus sinensis)* is an important horticultural crop in the study area.

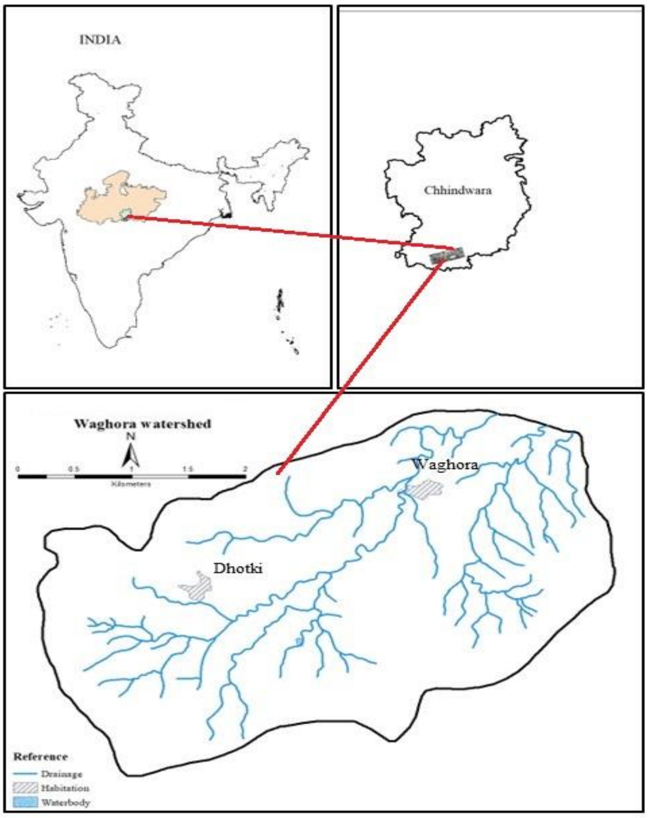

Fig. 1. Location map of Waghora watershed, Sausar tehsil, Chhindwara district

2.2 Data Used

The satellite data SRTM, and Sentinel-2B were used in the present study. The satellite data were acquired from different sources and preprocessed for identification of land use land cover and land form map. The detailed description of remote sensing data is given in Table 1.

2.2.1 SRTM- DEM

SRTM (Shuttle Radar Topography Mission) data is a digital elevation model (DEM) dataset created by the NASA Shuttle Radar Topography Mission during a space shuttle mission in February 2000. The mission employed synthetic aperture radar (SAR) technology to collect elevation data of the Earth's surface with a 30-meter spatial resolution and provide elevation values for each pixel in the dataset The SRTM-DEM data was accessed openly on the US Geological Survey (USGS) Earth Explorer website (https://earthexplorer.usgs.gov/).

2.2.2 SENTINEL-2B

Sentinel-2B is an Earth observation satellite launched as part of the European Space Agency's (ESA) Copernicus program. The imagery data is accessed through a freely available site, the US Geological Survey's (USGS) Earth Explorer website (https://earthexplorer.usgs.gov/), for the study. These products were geometrically and radiometrically corrected. The imagery data was taken of both kharif and rabi seasons on September 24, 2017 and January 27, 2018 to study the variation of vegetation. The bands 3(B3- green, 559.8 nm), 4 (B4- red, 664.6 nm), and 8 (B8- narrow NIR, 842 nm) were selected from Sentinel -2B for generation of standard false colour composite FCC by using the ARCGIS software, which has been used for land use land cover mapping.

2.3 Remote Sensing Data Interpretation

2.3.1 Georeferencing of base maps

SENTINEL-2B data (10 m) data (24.09.2017 and 27.01.2018) and SRTM data were georeferenced using WGS 84 datum, Universal Transverse Mercator (UTM) zone 44N projection in ArcGIS desktop10.1. The rasterized cadastral map and sentinel-2B data were co-registered using orthorectified SRTM data as a reference. The methodology adopted in study area showed in Fig. 2.

2.3.2 DEM extraction from SRTM

In this study, DEM and ortho-images were generated from SRTM stereo pairs using LPS. The block project was assigned horizontal and vertical coordinates with UTM projection and WGS 84 datum, and stereo images were integrated into the frame. Interior and exterior orientations, corresponding to Rational Polynomial Coefficients (RPC) files, were established. LPS automatically generated tie points, supplemented by manual addition for even distribution. Triangulation verified tie point accuracies, with additional manual GCPs added and triangulation repeated. The overall image root mean square error (RMSE) achieved was 0.58 pixels. DEM creation employed a cell size of 30 m and was subsequently used for orthorectification using ERDAS Imagine software.

2.3.3 Landform delineation and land use/land cover analysis

The process of delineating landforms involved on-screen image visual interpretation techniques. Geomorphic features were interpreted based on key image elements such as shape, tone or colour, pattern, shadow, association, and texture. A false color composite (FCC) was generated from different band combinations of satellite data for image interpretation and on-screen mapping. Landform analysis utilized elevation information from the SRTM DEM and hillshade generated using ArcGIS software. Orthorectified SRTM data, along with hillshade, were superimposed on the SRTM DEM to create a stereo view, aiding systematic visual interpretation of the study area's various landforms. Furthermore, the study utilized visual image interpretation of SRTM sharpened with Sentinel-2B data from two seasons (September 2017 and January 2018). Forest boundaries were digitized from Survey of India toposheets and overlaid onto the satellite data, facilitating interpretation of various land use/land cover classes. Field traverses and GPS correlation were conducted to identify different landform units, slopes, and land use/land cover classes, with boundaries verified and corrected as necessary. This methodology aligns with previous work, notably a study by Sahu et al. [11] albeit with different satellite data [12].

Table 1. Details of the remote sensing data used for the study

Satellite	Spatial Resolution	Date of acquisition	Source
SRTM	30 m	-	https://earthexplorer.usgs.gov/
Sentinel-2B	10 m	24, Sep 2017 and 27, Jan 2018	https://earthexplorer.usgs.gov/

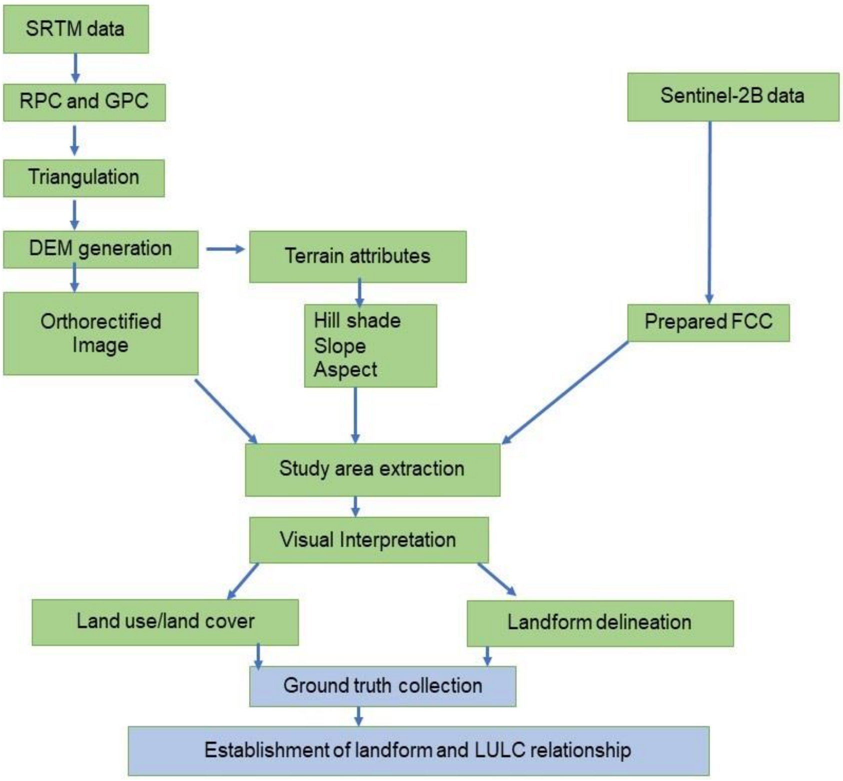

Fig. 2. Flowchart of the methodology adopted in the study

3. RESULTS AND DISCUSSION

3.1 Terrian Analysis

The delineation of landforms is crucial for various purposes such as land-use planning, environmental management, and geological studies [11]. Based on visual interpretation of Sentinel-2B, terrain parameters *viz*. Aspect, Slope, hill-shade derived from SRTM-DEM data in conjunction with SOI toposheet and subsequent ground truth verifications, eight major landforms were delineated. Slope information was derived from the high-resolution SRTM- DEM and reclassified into different slope classes similar to the work done by Reddy and Maji [13]. Furthermore, the SRTM sharpened with Sentinel-2B data were used to segment the area into precisely defined different land-use/ land-cover classes.

3.2 Slope

The information of the slopes was derived from SRTM data [14]. Eliminating the speckle effects of high-resolution DEM, we observe that the raster slope map was reclassified. We see that there are seven slope classes, viz. very gently sloping (1– 3%), gently sloping (3–5%), moderately sloping (5– 10%), strongly sloping (10–15%) and steeply sloping (15– 30%).

3.3 Landforms Delineation and Characterization

The Landform of the area have been evolved from the basaltic flows of paleo-climatic succession. Based on visual interpretation landform were characterized and interpreted on 8 major land form Plateau top (Pt), Escarpment (Er), Foot Slope (Fs), Upper pediment (Ud), Lower pediment (Ld), Valley (Va), Interfluve (If) and Mound (Md) Fig. 2.

Plateaus is a flat area bounded by steep slope. These abrupt change in elevation create a distinctive visual contrast between the plateau top and the surrounding terrain. The plateaus range from 448 to 479 m above MSL elevations. It occurs on moderately sloping (5-10 %) land and occupies 4.7 per cent total geographic area of the watershed area. The moderate sloping land and low fertile soil are favorable for single crop and forest. Escarpment are steeply slopy land occupy 21.4 per cent total geographic area of the watershed having elevation 355-460. They formed by vertical movement of earth crust or erosion of sedimentary crop. Degraded forest is dominant land use land cover of the landform unit. These are lower portion of steeper slope, transition zone of the upslope and flatter downslope area. The elevation of the foot slope ranges 360 to 412 m above MSL. It occurs on gently sloping (3-5 %) to steep sloping (10-15 %) and occupies 11.7 percent of the total geographic area. Due to the continuous erosion and deposition of rocks, only single crop is practiced in land form. Pediment refers to the erosional landscape adjacent to escarpment and the Upper pediment is the upper portion of erosion surface having moderately sloping (5-10 %) land. It occupies 246.1 ha (24.0 per cent of TGA) of the total area of watershed. The elevation varies from 348- 401 m above MSL. Pediment refers to the erosional landscape adjacent to escarpment and the Upper pediment is the lower portion of erosion surface having moderate sloping (5-10 %) land with well drained soil. It occupies 246.1 ha (24.0 per cent of TGA) of the total area of watershed. The elevation varies from 348- 401 m above MSL. Lower pediment is Gentle Sloping (3-5 %) to moderate sloping (5-10%) land located at below the upper pediment. The transported material in downslope deposited in lower pediment. It occupies a maximum area of watershed which is a 29.3 percent of total geographical area having an elevation range from 347 to 380 above MSL. Due to the different slopy land and availability of water with both upper and lower pediment land use and land cover with single, double and orchard and some parts of the land which is degraded and highly eroded were cover wasteland with or without scrub. Valley is the low laying area of the land formed by the erosive action of drainage channel. It has gentle Sloping land which occurs at an elevation range between 328 to 377 m above MSL and occupies 15.3 per cent of total geographic area with double crop. Interfluve is higher elevated area between two valleys which is separated by drainage basin or stream having flat compared to the valley formed due to the erosion by water in sideways as it moves downstream. It occupies an area of 13.8 percent of total geographic area with elevation ranges between 332 to 363 m Above MSL and dominant land are the double crops**.** The Mound ranges between 375 to 474 m elevations above MSL and occupies an area of 0.5 % of the total area of watershed. These are small hillocks in the area Moderate sloping (5-10 %). It is the highly eroded land in area which is a continue process with wasteland without scrub.

3.4 Land Use/ Land Cover Analysis

The Sentinel-2B data of two seasons on September 24, 2017 and January 27, 2018 were visually interpreted and identified into five land use/ land cover classes namely degraded forest, double crop, single crop, orchard and land with and without scrubs. The present land use map of the watershed has been shown in Fig. 3.

In the notified forest category dense forest exhibits red and brown tone with medium texture. It occupies 24.2 per cent of total watershed. Double crop land exhibits dark red tone with bold checkerboard pattern, while the bluish-green and pink tone work with diffuse checkerboard pattern and occupies 36.7 per cent total geographic area of the area of watershed, whereas single crop land exhibits dark red tone with bold checkerboard pattern and covered 24.2 per cent total geographic area of the watershed. Cotton and pigeon pea intercropping spread maximum area of cultivation. Orange orchard covered very less 0.8 percent. The wasteland exhibits bluish green tone and pink patches with medium texture on the imagery. It occurs on very gently sloping plateau, moderately steep sloping escarpment and isolated hillock and very gentle sloping pediments which occupies 5.7 per cent total geographic area of watershed.

3.5 Landforms and Land Use/Land Cover Relationship

We evaluated the different land use/land cover and slope spread on different landforms and to studied the relationship (Table.2) presented in Fig. 4. In this fig landform, slope and land use/ land cover coded as Plateau top (Pt), Escarpment (Er), Foot Slope (Fs), Upper pediment (Ud), Lower pediment(Ld), Valley (Va), Interfluve (If) and Mound (Md) very gently sloping (3), gently sloping (4), moderately sloping (5), strongly sloping (6) and steeply sloping (7), Forest (F), Double crop (D) Single crop (S), Orchard (O) and Wasteland with and without scrub (W). for easy identification in map.

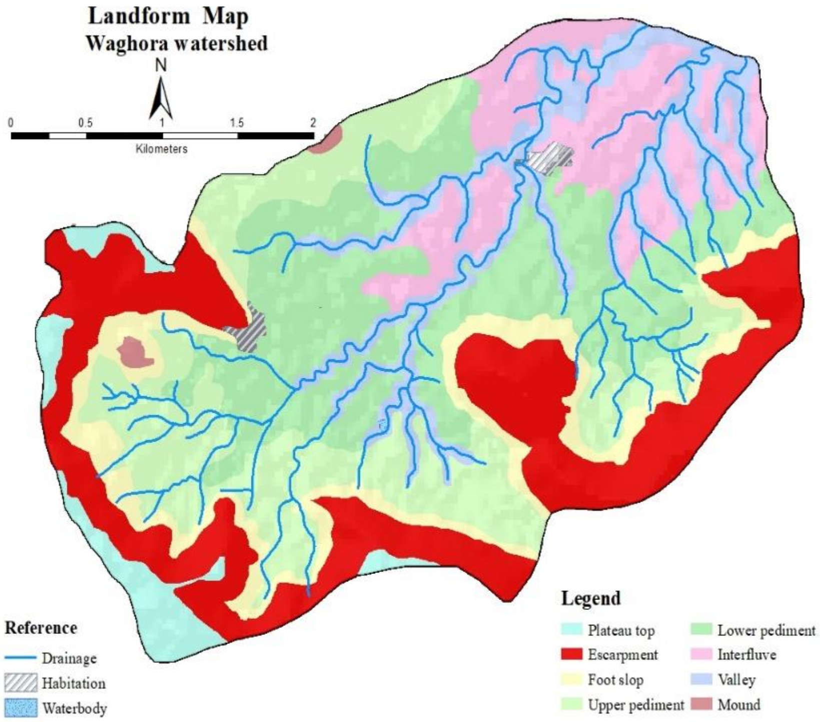

Fig. 3. landform of Waghora watershed derived from SRTM-DEM data

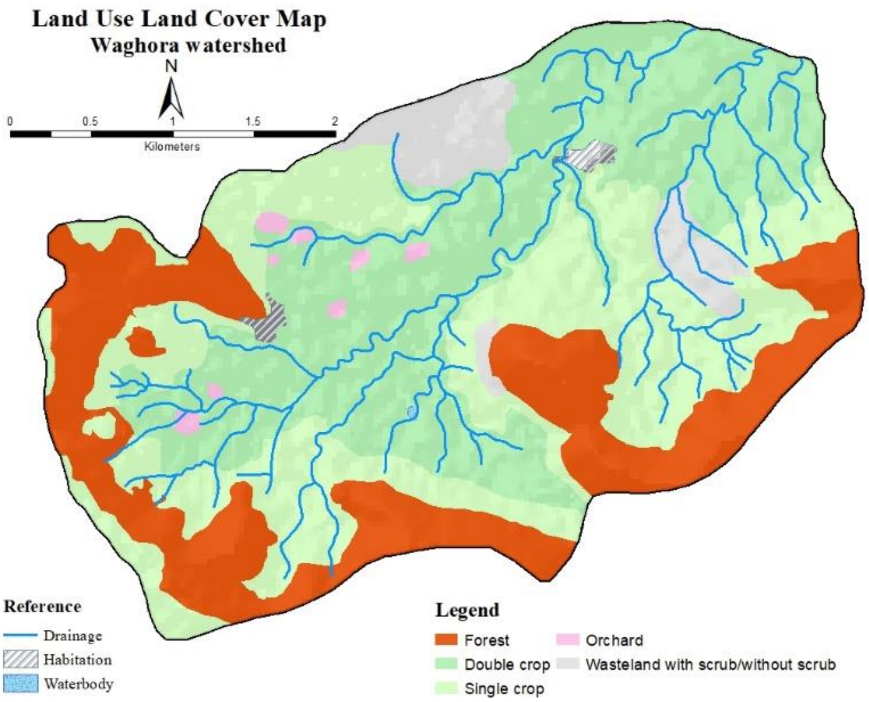

Fig. 4. Land use/land cover map of Waghora watershed derived from Sentinel-2B (September 24, 2017 and January 27, 2018) data

Table 2. land form, slope and land use/land cover relationship and their description

S no.	symbol	Image description	Area (ha)	% of TGA
1	Pt4S	Moderately sloping plateau top having bluish green and pink tone with diffuse checkerboard pattern (single crop).	30.2	2.3
2	Pt4F	Moderately sloping plateau top having red and brown tone with medium texture (moderately dense forest).	17.6	1.4
3	Er7F	Moderately steeply sloping escarpment having red and brown tone with medium texture (moderately dense forest).	278.7	21.4
4	Fs3S	Gently sloping foot slope having bluish green and pink tone with diffuse checkerboard pattern (single crop).	68.5	6.7
5	Fs4S	Moderately sloping foot slope having bluish green and pink tone with diffuse checkerboard pattern (single crop).	17.3	1.7
6	Fs5S	Strongly sloping foot slope having bluish green and pink tone with diffuse checkerboard pattern (single crop).	13.2	1.3
7	Fs3F	Gently sloping foot slope having red and brown tone with medium texture (moderately dense forest).	4.2	0.4
8	Fs5F	Strongly sloping foot slope having red and brown tone with medium texture (moderately dense forest).	11.7	1.1
9	Fs6W	Very strongly sloping foot slope having bluish green tone and pink patches with medium texture (wasteland).	4.9	0.5
10	Ud3D	Gently sloping upper pediment having dark red tone with bold checkerboard pattern (double crop).	39.6	3.9
11	Ud4D	Moderately sloping upper pediment having dark red tone with bold checkerboard pattern (double crop).	36.8	3.6
12	Ud4S	Moderately sloping upper pediment having bluish green and pink tone with diffuse checkerboard pattern (single crop).	150.2	14.7
13	Ud4O	Moderately sloping upper pediment having red and brown tone with bold checkerboard pattern (orange plantation).	3.2	0.3
14	Ud4W	Moderately sloping upper pediment having bluish green tone and pink patches with medium texture (wasteland).	19.4	1.9
15	Ld3D	Gently sloping lower pediment having dark red tone with bold checkerboard pattern (double crop).	126.3	12.3
16	Ld3S	Gently sloping lower pediment having bluish green and pink tone with diffuse checkerboard pattern (single crop).	91.8	9.0
17	Ld4S	Moderately sloping lower pediment having bluish green and pink tone with diffuse checkerboard pattern (single crop).	44.4	4.3
18	Ld4O	Moderately sloping lower pediment having red and brown tone with bold checkerboard pattern (orange plantation).	6.9	0.5
19	Ld4W	Moderately sloping lower pediment having bluish green tone and pink patches with medium texture (wasteland).	37.3	3.6
20	Va3D	Gently sloping valley having dark red tone with bold checkerboard pattern (double crop).	150.0	14.6
21	Va3W	Gently sloping valley having bluish green tone and pink patches with medium texture (wasteland).	6.7	0.7
22	If3D	Gently sloping interfluve having dark red tone with bold checkerboard pattern (double crop).	136.3	13.3
23	If4W	Moderately sloping interfluve having bluish green tone and pink patches with medium texture (wasteland).	4.6	0.5
24	Md4F	Moderately sloping mound red and brown tone with medium texture (moderately dense forest).	3.0	0.3
25	Md4W	Moderately sloping mound having bluish green tone and pink patches with medium texture (wasteland).	1.8	0.2

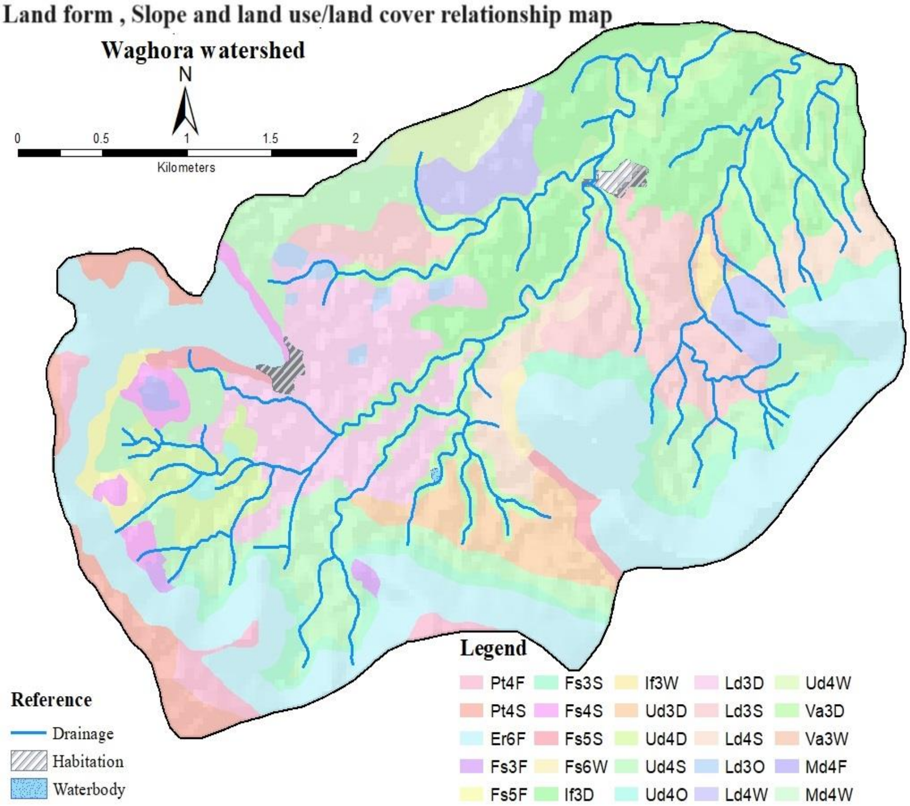

Fig. 5. Landform, Slope and Land use/land cover realtionship in Waghora watershed

Major part of the study area is covered with forest (21.4%) in escarpment with steep sloping. The erosional process and steep slopes are not suitable for cultivation. The dominant trees are teak, mahua, subabul and bamboo etc. Mainly cotton, pigeon pea, sorghum etc. Evaluating the satellite data of the two seasons Rabi and Kharif - the agriculture area could be clearly delineated as single crop and double crop. Very low area covered with orchard in pediment due to well-drained soil. Valleys and interfluve are formed by the processes of depositional, thus this unit is rich in mineral deposits with very gentle slope to gentle slopes suitable for double cropping mainly wheat, gram, vegetables, etc.

4. CONCLUSION

The research underscores the practicality of utilizing SRTM-DEM to delineate various landforms by employing several key interpretations features like image tone, hill shade, and terrain shadow. Moreover, the primary landforms identified include plateau tops, escarpment, pediments, valleys, interfluve and Mounds. These landforms have predominantly formed by the factors like slope position control and moisture availability.

A comprehensive land use/land cover map was produced, comprising five categories: degraded forest, double crop, single crop, orchard and waste land with and without scrubs. Single crop covers approximately 37.5 % of the study area across all landforms except plateau and escarpment. Double crop cultivation is prevalent in undulating lower plains and valleys, attributed to increased moisture availability and mineral richness.

The study highlights the effectiveness of utilizing 20m DEM from SRTM and Sentinel-2B (5.8m) for mapping geomorphic features and land use/land cover at a large scale (1:20,000) for their high-resolution imaging capabilities. The delineated landforms in the study area which can serve various purposes such as soil resource-inventory, identification of various groundwater opportunity zones, and agricultural land use planning at the village level.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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