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Impact of soil and water conservation measures on soil organic carbon and soil aggregate stability in the watershed

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Abstract

Soil aggregate stability and soil organic carbon is a critical indicator of soil health and useful for climate change mitigation. Therefore, the purpose of this study was to investigate the impact of soil and water conservation (SWC) measures on soil aggregate stability. This research was conducted at the “Central MPKV Campus Watershed” located in the Rahuri tahsil of Ahmednagar district, Maharashtra, India. The watershed was categorized into seven primary land use land cover (LULC) classes: Natural Vegetation, Horticulture, Agriculture, Current Fallow, Barren, Settlement, and Waterbody. The study analyzed the impact of SWC measures on soil organic carbon, bulk density and soil aggregate stability under different land use land cover. The soil aggregate stability was found higher in treated areas than untreated areas. The average Mean Weight Diameter (MWD) in the untreated area of the watershed was 0.58 mm at a depth of 0-15 cm, and 0.41 mm at a depth of 15-30 cm. Similarly, the average MWD in the treated area of the watershed was 0.69 mm at a depth of 0-15 cm, and 0.53 mm at a depth of 15-30 cm. In untreated areas, MWD were 0.26 mm at the 0-15 cm depth and 0.23 mm at the 15-30 cm depth and in treated areas, MWD were 0.42 mm at the 0-15 cm depth and 0.27 mm at the 15-30 cm depth.

Keywords: Soil aggregate stability, land use land cover, mean weight diameter, treated, untreated

1. Introduction

Soil is the earth's surface mixture of organic matter, minerals, gases, liquids, and living organisms. Soil organic carbon (SOC) acts as a binding agent, helping to bind soil particles together to form stable aggregates (Freitas *et al.*, 2021) ^[1]. Soil aggregates are clusters or groupings of soil particles that bind together more strongly than to adjacent particles (Hermine Dameni, Jingguo Wang, 2010) ^[4]. Soil aggregate stability refers to the ability of soil aggregates to resist disintegration when exposed to external forces like water, wind, or mechanical disturbance (Guo *et al.*, 2019) ^[2]. Soil aggregate stability is essential for sustaining soil health and long-term productivity because it supports key physical, biological, and environmental processes (Han *et al.*, 2010) ^[3]. Well-formed and stable aggregates improve water infiltration and storage by allowing water to move into the soil rather than running off the surface, which helps reduce erosion and ensures moisture availability for crops. They also create a favorable structure for root development, enabling roots to grow deeper, access nutrients efficiently, and enhance overall plant growth. Furthermore, stable soil aggregates protect organic matter from rapid breakdown, promoting carbon storage in the soil and helping to reduce greenhouse gas emissions (Liu and Han, 2019) ^[5]. Through these combined functions, soil aggregate stability plays a crucial role in maintaining soil quality, supporting agricultural sustainability, and contributing to climate resilience.

Studying the impact of soil and water conservation measures on soil aggregate stability within a watershed is important for understanding how these practices improve soil condition and support sustainable land management. Conservation measures such as contour bunds, terraces, and small water-harvesting structures help slow surface runoff and minimize soil loss, which contributes to the preservation of soil structure. Improved soil aggregate stability enhances the soil's resistance

to erosion, increases water infiltration, and improves moisture availability for plants. Assessing these effects at the watershed level provides practical insight into the effectiveness of conservation interventions and supports better planning and management strategies aimed at improving soil health, agricultural productivity, and long-term environmental sustainability.

2. Materials and Methodology

2.1 Study Area

The study was conducted at the “Central MPKV Campus Watershed” in Rahuri Taluka in Ahmednagar District of

Maharashtra State, India. The study area is between latitudes 19° 21.77' N and 19° 18.73' N and longitudes 74° 37.79' E and 74° 36.49' E. The location map of the study area is shown in Fig. 1. It has a north-south length of about 6 km and an average east-west extension of about 3 km, suggesting that the watershed has an elongated shape with a longer axis oriented in the north-south direction. The study area covers 1260 ha, with elevation ranging from 441 to 542 m above mean sea level, suggesting that the watershed has some variability in elevation, with a difference of approximately 101 m between the highest and lowest points.

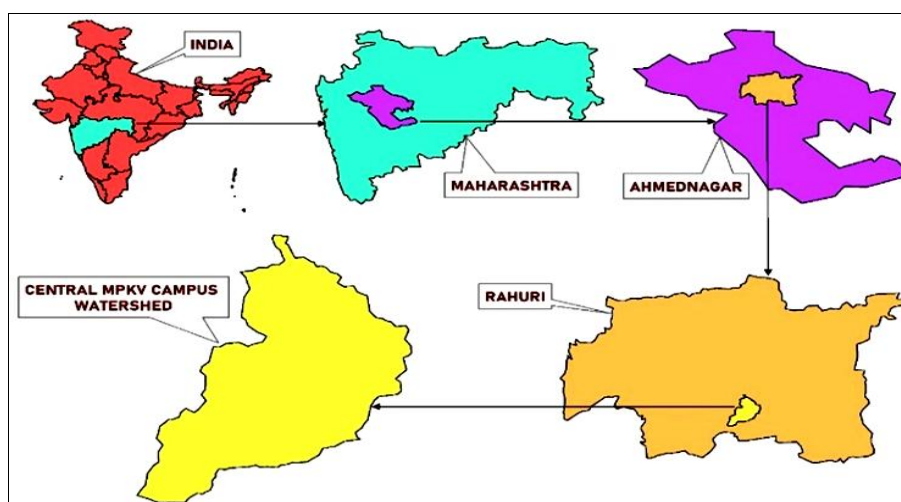


Fig 1: Location map of the study area (Central MPKV Campus Watershed)

2.2 Adopted Soil and Water Conservation Measures in the Study Area

The Central MPKV Campus Watershed covered a 1260 ha. The watershed was treated with various scientifically planned soil and water (SWC) conservation measures under the watershed development program of Adarsh Gaon Yojana, Govt. of Maharashtra. A total of 545 ha of the total watershed area has

been treated with various soil and water conservation measures, as shown in Figure 2. The land area treatments in the watershed include deep continuous contour trenches (DCCT) and compartment bunding, while drainage line treatments include earthen nala bunds, loose boulder structures, and percolation tanks. Table 1 provides detailed information on the SWC measures implemented in the watershed.

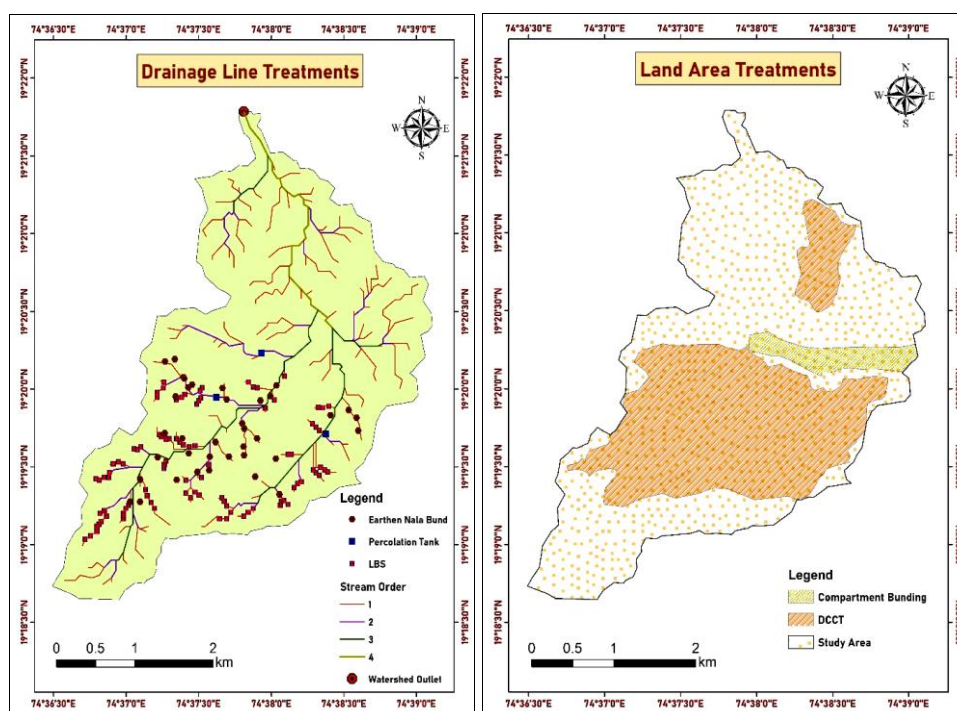


Fig 2: SWC measures of study area a) Drainage area b) Treated area of study area

Table 1: Soil and water conservation measures in the watershed

SWC Treatments in the Watershed	
Total Study Area	1260 ha
Total Treated Area	545 ha
Perimeter of Treated Area	12.77 km
Area Under DCCT	495 ha
Length of DCCT	99,600 running m
Area Under Compartment Bunding	50 ha
Earthen Nala Bunds	38
Percolation Tanks	2

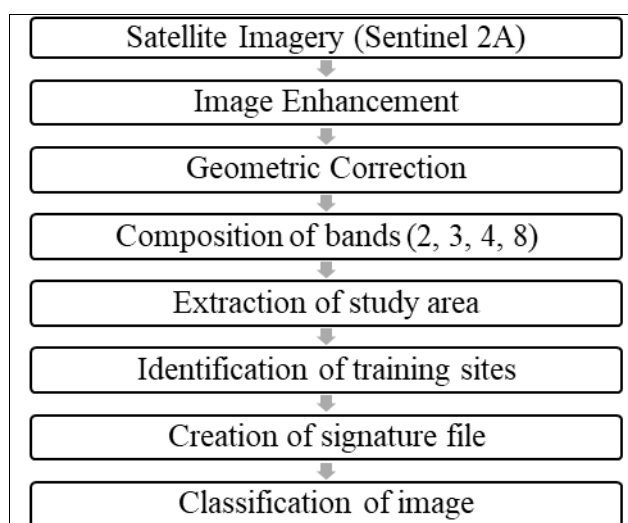
Data Collection and Pre-processing

1. Soil samples were collected from 122 different locations in the watershed using a grid sampling method that covered a variety of land use patterns.
2. Soil samples were collected at 0-15 cm and 15-30 cm soil depths from each selected sampling site in the watershed to estimate soil physical and chemical properties.
3. The different physical and chemical properties of the soil such as soil organic carbon, mean weight diameter were determined in the soil mechanics laboratory MPKV, Rahuri.
4. Land use / land cover data for the watershed was derived

from Sentinel 2A satellite imagery.

2.3 Land Use/Land Cover Mapping of the Watershed

The terms land use and land cover of the watershed are frequently used interchangeably, but each has its distinct meaning. Land use refers to how people use the land, whereas land cover refers to the physical land type. Advanced geospatial techniques such as remote sensing (RS) and geographic information systems (GIS) can facilitate better extraction and analysis of land use/land cover (LU/LC) information (Shinde *et al.*, 2024) ^[7]. Geographic Information System technology has the potential to generate a thematic layer of land use/land cover. For the present study, the land use/land cover map was generated from satellite imagery. Sentinel-2 satellite imagery for the study area was downloaded directly from the Copernicus portal at processing level 2A (Mahendra *et al.*, 2025) ^[6]. Cloud-free satellite images were visually identified on the platform and selected for download. A supervised image classification method achieved thematic mapping of the different land use/land cover classes (Singh *et al.*, 2019) ^[8]. The maximum likelihood classifier technique was used to classify the image into seven land cover classes. Image processing was performed using Q-GIS software, as shown in Fig 3.

**Fig 3:** Flowchart showing methodology adopted for LULC mapping

2.4 Determination of Soil Organic carbon (SOC)

Determining soil organic carbon (SOC) is essential for understanding soil health, fertility, and its role in the global carbon cycle. Various methods exist to quantify SOC; therefore, in the present study, the Walkley-Black method was used to determination of SOC, which is suggested by (Nelson and Sommers, 1982).

2.4.1 Walkley- Black method

The Walkley-Black method is widely used for determining soil organic carbon (SOC) content. In this method, a soil sample is first treated with a known amount of 1 N potassium dichromate ($K_2Cr_2O_7$) solution, followed by carefully adding concentrated sulfuric acid (H_2SO_4). The acid provides the necessary heat to facilitate the oxidation of organic carbon in the soil by the dichromate. The mixture is then allowed to stand for about 30 minutes to ensure complete oxidation. After the reaction, the mixture is diluted with distilled water, and phosphoric acid is added to enhance the endpoint detection during titration. An

indicator, such as diphenylamine or ortho-phenanthroline, is added, and the solution is titrated with 0.5 N ferrous sulfate ($FeSO_4$) solution until a color change occurs, signifying the end of the reaction. A blank titration, performed without soil, accounts for any dichromate that did not react with the soil organic carbon. The difference between the titration volumes of the blank and the sample is used to calculate the SOC content, with a correction factor often applied to account for the incomplete oxidation of organic carbon.

Soil Organic carbon (%) =

$$(B - T) \times N \times 0.003 \times \frac{100}{\text{Weight of soil sample}}$$

Where,

B= mL of standard $FeSO_4$ required for blank

T= mL of standard $FeSO_4$ required for soil sample

N= Normality of standard $FeSO_4$ solution

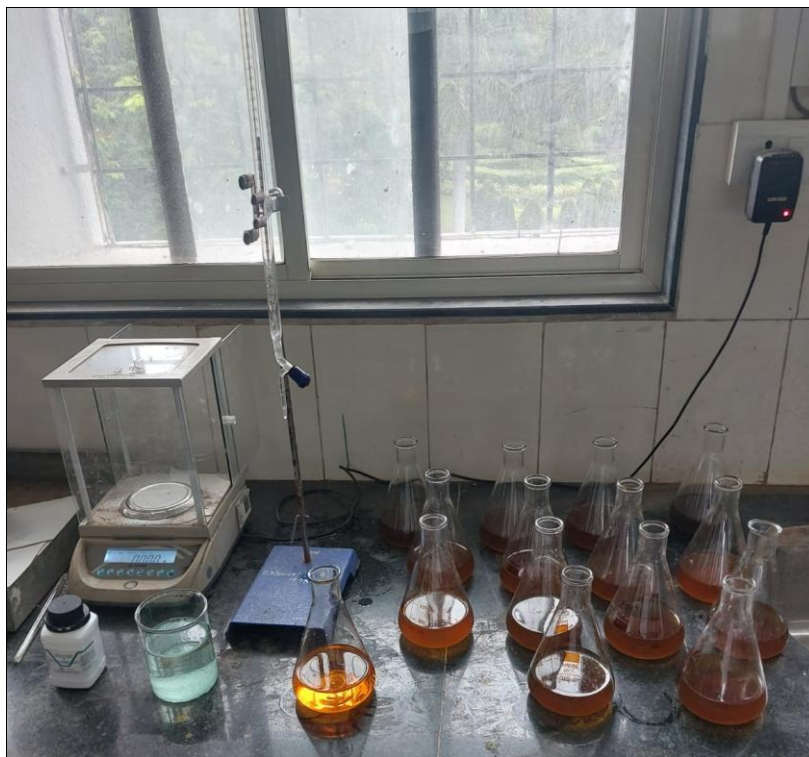


Fig 4: Soil organic carbon analysis

2.5 Determination of soil aggregate stability

Several techniques were used to measure the stability of soil aggregate, such as dry sieving and wet sieving methods. Regarding reproducibility and ability to distinguish between soils, Yoder's wet sieving method was the most suitable technique (YODER, 1936) ^[9]. The results are expressed as a mean weight diameter (MWD) value, which is the sum of the percentage of soil on each sieve multiplied by the mean diameter of adjacent sieves.

2.5.1 Wet sieving method for measuring soil aggregate stability

The procedure to find soil aggregates' mean weight diameter (MWD) using the wet sieving method with a Yoder apparatus involves several detailed steps designed to assess soil structure and aggregate stability. First, a representative soil sample is collected and prepared by air-drying and sieving to remove large debris and obtain a uniform sample. The sample is then weighed and placed into the Yoder apparatus's top sieve, consisting of a series of nested sieves with progressively smaller mesh sizes (i.e., 5 mm, 3 mm, 1 mm, 0.5 mm, 0.25 mm, 0.05 mm, and 0.01 mm). The set of sieves is immersed in a container filled with water. The soil is subjected to mechanical agitation to dislodge and break apart the aggregates. As the soil passes through each sieve, the aggregates are retained on different sieves based on their size. After the sieving process, the soil remaining on each sieve is carefully collected, dried, and weighed. Next morning, remove sand particles from soil aggregates retained on each sieve. The weights of the soil aggregates retained on each sieve are recorded. To calculate the MWD, each sieve's aggregate weight is multiplied by the mean diameter of the aggregates retained on that sieve. The results from all sieves are then summed and divided by the total weight of the soil sample. This provides the mean weight diameter, which measures the average size of the soil aggregates and reflects the soil's structural stability and quality. This method helps understand soil aggregation and its response to various management practices,

influencing soil health and erosion control strategies.

Mean weight diameter (MWD) from the observation can be calculated using expression as under

$$\text{MWD} = 4 \times Y_1 + 2 \times Y_2 + 0.75 \times Y_3 + 0.375 \times Y_4 + 0.175 \times Y_5 + 0.05 \times Y_6$$

Where,

$Y_1, Y_2, Y_3, Y_4, Y_5, Y_6$ = Weight of aggregate of respective sieves.

Table 2: Observation Table

Sr. No	Aggregate size range	Mean aggregate size (mm) D_i	Weight of aggregate (dry weight) W_i
1.	5.0 to 3.0	4.0	$W_1-S_1=Y_1$
2.	3.0 to 1.0	2.0	$W_2-S_2=Y_2$
3.	1.0 to 0.5	0.75	$W_3-S_3=Y_3$
4.	0.05 to 0.25	0.375	$W_4-S_4=Y_4$
5.	0.25 to 0.10	0.175	$W_5-S_5=Y_5$
6.	0.10 to 0.00	0.050	$W_6-S_6=Y_6$

Where,

$W_1, W_2, W_3, W_4, W_5, W_6$ - Dry weight of aggregates collected from different sieves 5, 3, 1, 0.5, 0.25, 0.1 and 0.05.

$S_1, S_2, S_3, S_4, S_5, S_6$ - Weight of sand collected from different sieves 5, 3, 1, 0.5, 0.25, 0.1 and 0.05.

4. Results and Discussion

4.1 Land use/ Land cover (LULC) Mapping of the Watershed

The watershed was categorized into seven primary land use land cover (LULC) classes: Natural Vegetation, Horticulture, Agriculture, Current Fallow, Barren, Settlement, and Waterbody. The results of the land use land cover classification, obtained from satellite imagery, are illustrated in Figure 5, with the areas of each land cover class detailed in Table 3.

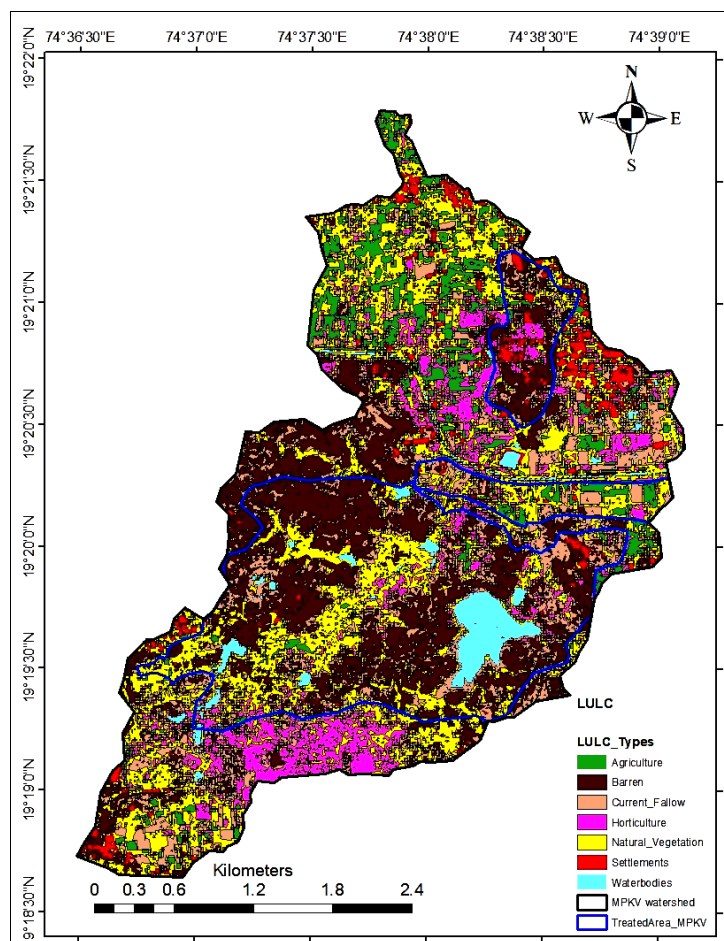


Fig 5: Land Use Land Cover Map

Table 3: Area covered by different Land use Land Cover classes

Land cover class	Area (ha)	Area (%)
Natural Vegetation	368.085	29.14
Horticulture	152.833	12.10
Agriculture	103.344	8.18
Current Fallow	229.071	18.14
Barren	313.446	24.82
Settlement	59.985	4.75
Waterbodies	36.445	2.89

The land use and land cover analysis shows that natural vegetation occupies the largest share of the total area (29.14%), indicating the presence of substantial vegetative cover that supports ecological stability and soil protection within the watershed. Barren land accounts for a significant portion (24.82%), highlighting areas with sparse or no vegetation that may be more prone to soil erosion and degradation if not properly managed. Current fallow land covers 18.14% of the area, reflecting seasonal or temporary non-cultivation practices that can influence soil condition depending on land management. Horticulture and agriculture together constitute about 20.28% of the total area, suggesting moderate agricultural activity dominated by perennial and annual cropping systems. Settlement areas occupy a relatively small proportion (4.75%), indicating limited urban or built-up expansion, while waterbodies cover only 2.89% of the area but play an important role in supporting irrigation, water availability, and ecological balance. Overall, the land use pattern reflects a mixed landscape with a strong presence of natural vegetation and considerable barren land, underscoring the need for targeted soil and water conservation measures to enhance land productivity and

environmental sustainability.

4.2 Soil organic carbon content between treated and untreated areas across different land use and land cover types in the watershed.

The soil organic carbon content varies noticeably among land use and land cover classes, soil depths, and management conditions, as shown by the measured values. In both untreated and treated areas, higher soil organic carbon is observed in the surface layer (0-15 cm) compared to the subsurface layer (15-30 cm). Under natural vegetation, soil organic carbon in the untreated area is 0.69% at 0-15 cm and 0.64% at 15-30 cm, which increases to 0.87% and 0.79%, respectively, in the treated area. Similar trends are observed in horticulture, where values increase from 0.67% and 0.60% in the untreated area to 0.83% and 0.76% in the treated area, and in agriculture, where soil organic carbon rises from 0.65% and 0.56% to 0.80% and 0.72% after treatment. Current fallow land shows relatively lower values, with untreated soil organic carbon of 0.47% and 0.44% increasing to 0.63% and 0.57% in the treated area. The lowest values are recorded in barren land, where soil organic carbon

increases from 0.42% and 0.39% in the untreated area to 0.59% and 0.50% in the treated area. Overall, the results clearly indicate that soil and water conservation treatments lead to a substantial improvement in soil organic carbon across all land

use classes and soil depths, with more pronounced benefits in degraded land uses. The table 4 shows the soil organic carbon in treated and untreated watershed. Fig 6 and 7 shows the SOC from 01-5cm and 15-30 cm.

LULC	Soil organic carbon (%) Untreated Area		Soil organic carbon (%) Treated Area	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Natural Vegetation	0.69	0.64	0.87	0.79
Horticulture	0.67	0.60	0.83	0.76
Agriculture	0.65	0.56	0.80	0.72
Current Fallow Land	0.47	0.44	0.63	0.57
Barren	0.42	0.39	0.59	0.50

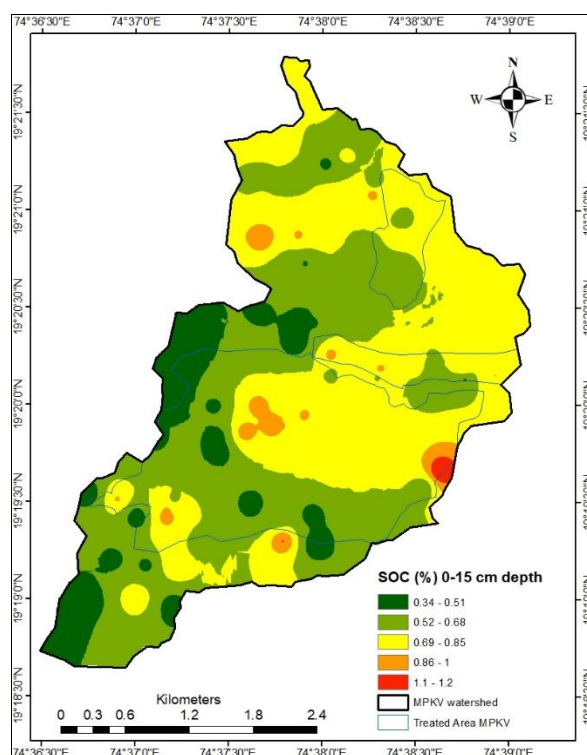


Fig 6: Soil organic carbon (%) (0-15 cm depth) map of study area

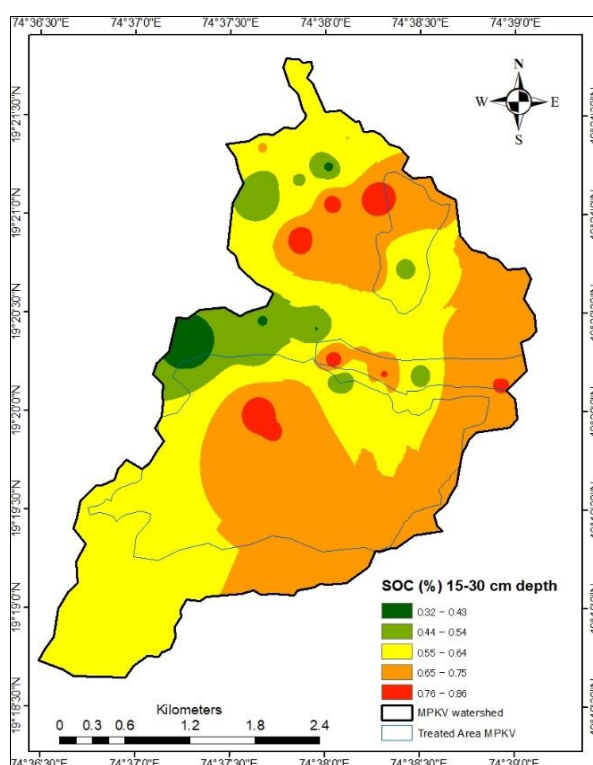


Fig 7: Soil organic carbon (%) (15-30 cm depth) map of study area

4.3 Soil aggregate stability across different land use and land cover in treated and untreated areas

The mean weight diameter (MWD) of soil aggregates shows clear differences among land use and land cover classes, soil depths, and management conditions, indicating the effect of conservation treatments on soil aggregate stability. In all land uses, higher MWD values are observed in the surface layer (0-15 cm) compared to the subsurface layer (15-30 cm), reflecting better aggregation near the soil surface. Under natural vegetation, MWD in the untreated area is 0.81 mm at 0-15 cm and 0.68 mm at 15-30 cm, which increases to 0.88 mm and 0.83 mm, respectively, in the treated area. In horticulture, MWD improves from 0.74 mm and 0.46 mm in the untreated condition to 0.83 mm and 0.60 mm after treatment, while agricultural land shows an increase from 0.73 mm and 0.41 mm to 0.78 mm and 0.56 mm in the treated area.

Current fallow land and barren areas exhibit the lowest MWD values, indicating weaker aggregate stability; however, both show noticeable improvement following treatment. In current fallow land, MWD increases from 0.32 mm and 0.28 mm in the untreated area to 0.52 mm and 0.38 mm in the treated area, while barren land shows an increase from 0.26 mm and 0.22 mm to 0.42 mm and 0.26 mm, respectively. Overall, the results demonstrate that soil and water conservation measures significantly enhance soil aggregate stability across all land use classes, with more pronounced improvements in degraded lands, particularly in the surface soil layer.

5. Conclusion

The results from the MPKV Rahuri watershed show a diverse land use-land cover pattern, where natural vegetation occupies the largest area (29.14%), followed by barren land (24.82%) and current fallow land (18.14%). This indicates that while a good portion of the watershed supports ecological stability. Soil and water conservation practices led to clear improvements in soil organic carbon (SOC) across all land use types and soil depths. SOC under natural vegetation increased from 0.69% to 0.87% in the surface soil, whereas barren land showed an increase from 0.42% to 0.59%, suggesting that degraded lands responded strongly to the treatments. Soil physical condition (aggregate stability) also improved, as reflected by higher mean weight diameter (MWD) values, which increased from 0.26-0.81 mm in untreated soils to 0.42-0.88 mm in treated soils, with greater improvement in the surface layer. Notably, current fallow and barren lands exhibited substantial gains in aggregate stability following SWC measures, reflecting reduced erosion susceptibility and improved soil physical condition. These quantitative findings confirm the effectiveness of conservation measures in enhancing soil carbon sequestration, aggregate stability, and overall soil health, thereby supporting sustainable land management and long-term watershed resilience.

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