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Comparative assessment of soil aggregate stability in treated and untreated watersheds

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Abstract

Soil aggregate stability is an important indicator of soil quality, especially in areas affected by land degradation due to water erosion. Increasing human activities over time have accelerated soil erosion, making it necessary to assess soil aggregate stability under different land use and land cover types within a watershed. This study examined the stability of surface soil aggregates in various land use/land cover classes in two watersheds: Hiware Bazar (1287.6 ha) and Daithane Gunjal (116.63 ha), located in drought-prone Ahilyanagar, Maharashtra. The area has slopes ranging from 3–25% and receives less than 400 mm of annual rainfall. Hiware Bazar is a treated watershed with soil and water conservation measures, while Daithane Gunjal is untreated. The results show the positive impact of watershed management on land use and soil stability. In Hiware Bazar, land use includes 65.5% cropland and fallow land, 19.75% forest, and 11.18% barren land. This watershed showed higher mean weight diameter (MWD) values, indicating better soil aggregate stability (forest: 1.13–0.99 mm, cropland: 0.84–0.70 mm, fallow: 0.50–0.42 mm, barren: 0.30–0.24 mm) compared to Daithane Gunjal (forest: 0.75–0.65 mm, cropland: 0.55–0.39 mm, fallow: 0.35–0.30 mm, barren: 0.26–0.21 mm). These findings confirm that long-term conservation measures and improved land management practices in Hiware Bazar have enhanced soil structure, aggregate formation and resistance to erosion.

Keywords: Land use land use cover, soil aggregate stability, mean weight diameter (MWD)

Introduction

Soil aggregate stability measures the resistance of soil structure to mechanical or physico-chemical forces and strongly influences soil erodibility, water retention, nutrient availability, and root growth (Hashimi *et al.*, 2019) ^[6]. Higher aggregate stability reduces soil loss, improves macro-aggregate formation, enhances porosity, and limits the loss of carbon, nitrogen, and phosphorus, thereby supporting overall soil fertility and plant growth (Dorji *et al.*, 2020) ^[3]. Bless (2022) ^[1] reported that forage cropping increased macro-aggregates (>1 mm) and organic carbon, enhancing aggregate stability compared to fallow land. Soil erosion disrupts aggregate formation by removing fine particles and cementing agents.

Soil aggregate stability is a key determinant of soil erodibility, influencing dispersion, surface sealing, and degradation (Fulpagare *et al.*, 2023) ^[4]. Measuring aggregate stability offers a cost-effective alternative to field erosion studies for assessing soil vulnerability. Aggregate stability also plays a crucial role in protecting soil organic carbon and linking it to erosion processes across landscapes (Kalhor *et al.*, 2017) ^[7]. Soil aggregation and carbon storage are difficult to measure due to spatial and temporal heterogeneity (Han *et al.*, 2010) ^[5]. Water-stable aggregate tests provide a simple, rapid way to assess the effects of land management on aggregation and carbon (Mbanjwa *et al.*, 2022) ^[14]. Aggregate stability improves with higher organic carbon, especially in clay-rich soils, enhancing structure and resistance to water erosion (Mohanty *et al.*, 2012) ^[16]. Several studies have used ASTER, SRTM and Cartosat DEM with 30 to 90 m resolution in predicting soil parameters for small and large area (Liu *et al.*, 2019) ^[12].

Soil aggregates are formed by physical, chemical, and biological processes and are held together by different binding materials (Panet *et al.*, 2015) ^[18]. However, they can break down due to natural forces like rainfall and erosion, and human activities such as tillage and machine traffic

(Lawal *et al.*, 2019) ^[9]. When aggregates break, the organic matter stored inside them is exposed and decomposes. Macroaggregates go through cycles of formation and breakdown depending on biological activity and the addition of fresh plant residues (Kumar *et al.*, 2023) ^[8]. In monsoon regions, water stability of aggregates is very important because heavy rainfall can cause slaking and rapid breakdown (Han *et al.*, 2010) ^[5]. Water-stable aggregates are considered an important indicator of soil quality, as they are closely related to erosion control, carbon storage, and nutrient movement (Mandal *et al.*, 2017) ^[13].

Soil and water conservation measures help improve soil aggregate stability (Lee *et al.*, 2012) ^[10]. Practices such as contour farming, terracing, mulching, cover crops, reduced tillage, and vegetative barriers reduce soil disturbance and protect the soil surface from heavy rainfall. These practices increase organic matter and root growth, which help bind soil particles together (Mesfin *et al.*, 2018) ^[15]. Less disturbance also allows aggregates to remain stable for longer periods. Improved aggregate stability leads to better soil structure, increased water infiltration, reduced erosion, and improved soil fertility (Singh *et al.*, 2019) ^[19].

A comparative assessment of soil aggregate stability in treated and untreated watersheds is necessary to understand the impact of conservation measures. Treated watersheds are expected to

have better soil structure and more water-stable aggregates than untreated areas (Nandgude *et al.*, 2015) ^[17]. Such a study helps measure the benefits of conservation practices and provides useful information for improving watershed management. This is especially important in monsoon regions where soils are highly vulnerable to erosion.

The present study was aimed to investigate the soil aggregate stability in different land use/ land cover as well as to assess the soil aggregate stability in relation to soil properties and terrain attributes of the watershed.

Materials and Methods

Study area

The study area includes the Hiware Bazar and nearby Daithane Gunjal watersheds located in Ahilyanagar taluka, Maharashtra, India. The Hiware Bazar watershed covers an area of 1287.60 ha and is situated in a drought-prone rain-shadow region of the Western Ghats. It has undulating terrain with elevations ranging from 600 to 720 m above mean sea level (MSL), slopes between 3 and 25 percent, and receives less than 400 mm of annual rainfall. The Daithane Gunjal watershed covers 116.63 ha and has similar climatic and topographical conditions but remains untreated, with no soil and water conservation measures implemented.

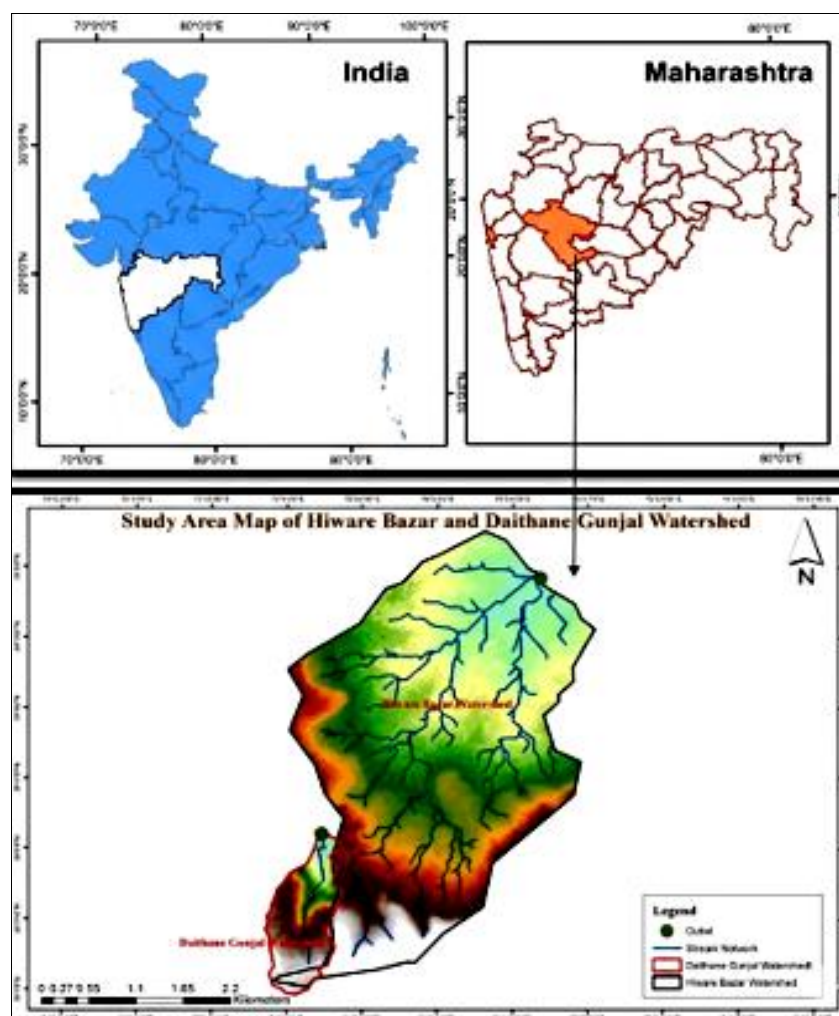


Fig 1: Location map of the study area (Hiware Bazar and Daithane Gunjal Watershed)

Soil sampling

Soil samples from the watershed were collected from different land cover patterns. A total 122 soil samples were collected in the treated and untreated areas from the watershed, and their

location was recorded using a GPS device. Soil samples were collected using soil auger at two different depths, one at 0-15 cm depth and another at 15-30 cm depth.

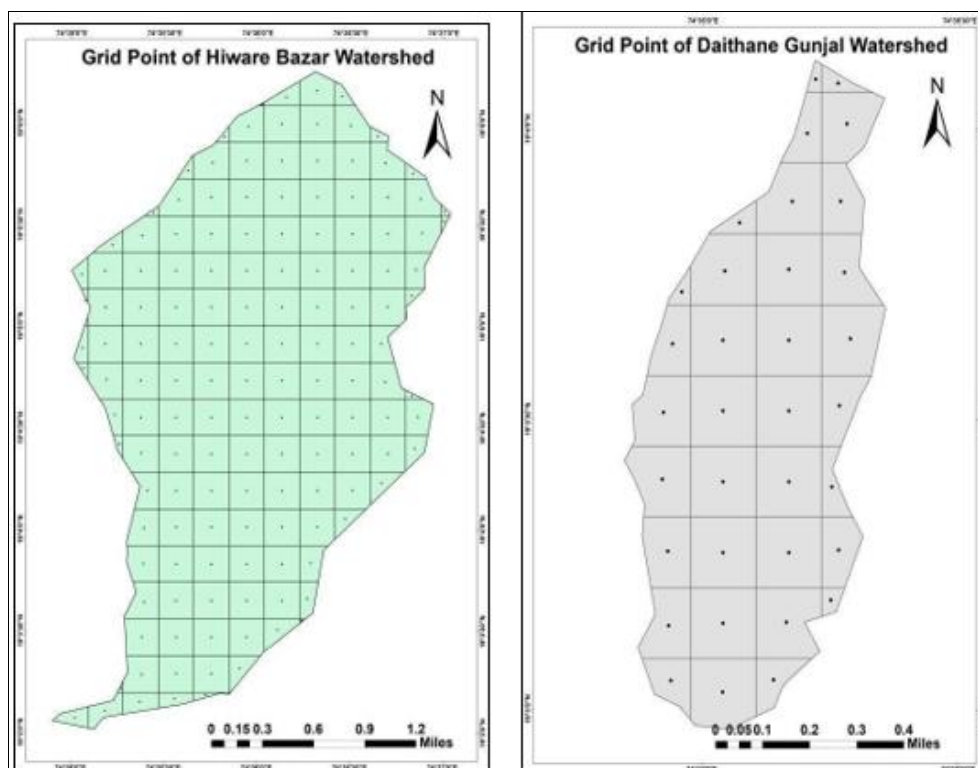


Fig 2: Representation of grid of both watersheds

Land use and Land cover mapping of the Watershed

In this study, a land use land cover (LULC) map was created using cloud-free Sentinel-2A satellite imagery downloaded from the Copernicus portal. A supervised image classification method, employing the maximum likelihood classifier, was used to categorize the imagery into seven land cover classes. The image processing was performed using ArcGIS 10.8.2 software.

Soil Aggregate Stability analysis

In the present study, soil aggregate stability was assessed using the wet sieving method with Yoder's (1936) [20] apparatus, and results were expressed as Mean Weight Diameter (MWD), calculated from the proportion of soil retained on successive sieves. MWD was determined for all soil samples collected from the Hiware Bazar and Daithane Gunjal watersheds.

Soil aggregate stability was determined using the wet sieving method with a Yoder apparatus (Yoder, 1936) [20]. Air-dried and sieved soil samples were placed on nested sieves with mesh sizes of 5 mm, 3 mm, 1 mm, 0.5 mm, 0.25 mm, 0.05 mm, and 0.01 mm, and immersed in water. The soil was mechanically agitated to separate aggregates by size, after which aggregates retained on each sieve were collected, dried, weighed, and sand particles removed. The mean weight diameter (MWD) was calculated by multiplying the weight of aggregates on each sieve by their mean diameter, summing across all sieves, and dividing by the total soil weight. MWD represents the average size of soil aggregates and serves as an indicator of soil structural stability, influencing water infiltration, erosion resistance, and response to management practices (Zhou *et al.*, 2020; Li, 2023; Chaudhari *et al.*, 2013) [21, 11, 2].

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

Where,

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

Table 1: Observation table of mean weight diameter

Sr. No	Aggregate size range	Mean aggregate size (mm) Di	Weight of aggregate (dry weight) Wi
1.	5.0 to 3.0	4.0	$W1-S1=Y1$
2.	3.0 to 1.0	2.0	$W2-S2=Y2$
3.	1.0 to 0.5	0.75	$W3-S3=Y3$
4.	0.05 to 0.25	0.375	$W4-S4=Y4$
5.	0.25 to 0.10	0.175	$W5-S5=Y5$
6.	0.10 to 0.00	0.050	$W6-S6=Y6$

Where,

$W1, W2, W3, W4, W5, W6$ – Dry weight of aggregates collected from different sieves 5, 3, 1, 0.5, 0.25, 0.1 and 0.05

$S1, S2, S3, S4, S5, S6$ – Weight of sand collected from different sieves 5, 3, 1, 0.5, 0.25, 0.1 and 0.05

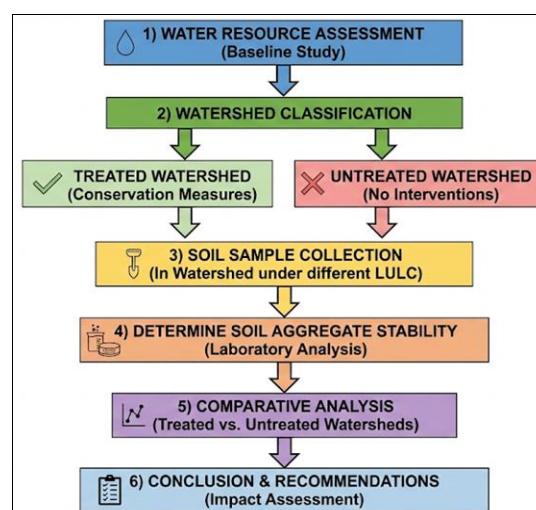


Fig 3: Flow diagram of methodology

Results and Discussion

Land use land cover (LULC) mapping of the watersheds

The LULC analysis indicates that the Hiware Bazar watershed is characterized by a structurally balanced and intensively

managed land-use system, dominated by current fallow (45.36%) and cropland (20.14%), reflecting regulated agricultural practices and effective soil–water management. Substantial forest cover (19.75%) and minimal barren land (11.18%) further signify successful watershed interventions, ecological stabilization, and higher land productivity. In contrast, the Daithane Gunjal watershed is overwhelmingly dominated by barren land (62.10%), with limited agricultural area (crop land + fallow $\approx$ 32.25%) and sparse forest cover, indicating degraded land conditions, low cultivation intensity, and suboptimal resource utilization. Hiware Bazar demonstrates a mature, integrated watershed management framework, whereas Daithane Gunjal exhibits pronounced land degradation but considerable potential for rehabilitation through afforestation and soil conservation measures. The figure 4 shows land use land cover of Hiwarebazar and Daithane Gunjal Watershed. The table no 2 shows Comparative Spatial Areal Coverage and Percentage of LULC of Hiware Bazar and Daithane Gunjal Watersheds.

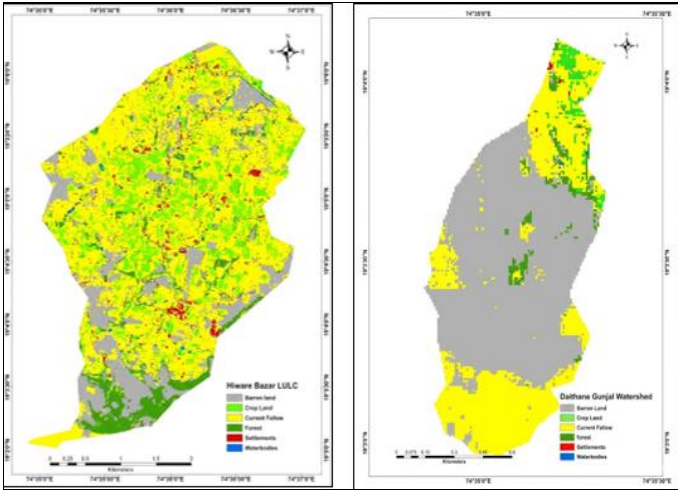


Fig 4: Land Use Land Cover Map of Hiware Bazar and Daithane Gunjal

Table 2: Comparative Spatial Areal Coverage and Percentage of LULC of Hiware Bazar and Daithane Gunjal Watersheds

Land Cover Class	Hiware Bazar Area (ha)	Hiware Bazar Area (%)	Daithane Gunjal Area (ha)	Daithane Gunjal Area (%)
Forest	254.40	19.75	6.34	5.44
Cropland	259.35	20.14	6.92	5.93
Current Fallow	584.12	45.36	30.71	26.32
Barren Land	143.95	11.18	72.45	62.10
Settlement	38.79	3.01	0.21	0.18
Waterbodies	6.97	0.54	—	—
Total	1287.60	100	116.63	100

Aggregate stability of soil

Aggregate stability in various Land use/land cover

The Mean Weight Diameter (MWD) of soil aggregates was measured at two depths (0–15 cm and 15–30 cm) under different land use/land cover (LULC) classes in Hiware Bazar and Daithane Gunjal watersheds. MWD values are expressed in millimeters (mm). Higher MWD values indicate better soil aggregation, improved soil structure, and greater resistance to erosion (Table 3).

MWD was consistently higher in the Hiware Bazar watershed than in Daithane Gunjal across all LULC classes and at both depths. This shows better soil structural stability in the treated watershed. Forest land recorded the highest MWD values in both watersheds. In Hiware Bazar, forest MWD ranged from 0.79 to 0.67 mm, while in Daithane Gunjal it ranged from 0.42 to 0.34 mm. The higher values under forest indicate well-aggregated and stable soils due to greater organic matter and minimum disturbance.

Cropland in Hiware Bazar showed clear improvement in MWD (0.84–0.71 mm) compared to Daithane Gunjal (0.55–0.39 mm). This suggests that watershed treatments and improved land

management practices enhanced soil aggregation. Current fallow land also had higher MWD in Hiware Bazar (0.50–0.42 mm) than in Daithane Gunjal (0.35–0.30 mm), indicating better soil condition in the treated area.

Barren land recorded the lowest MWD values in both watersheds, with particularly low values in Daithane Gunjal. This reflects poor soil structure and higher degradation due to the absence of vegetation cover and conservation measures. The results show that watershed interventions in Hiware Bazar significantly improved soil aggregation and structural stability across different land uses and soil depths.

Table 3: Statistics of MWD (mm) under Different LULC in Hiware Bazar and Daithane Gunjal Watersheds

LULC Type	Hiware Bazar		Daithane Gunjal	
Depth	0 - 15	15 - 30	0 - 15	15 - 30
Forest land	1.13	0.99	0.75	0.65
Cropland	0.84	0.70	0.55	0.39
Current fallow	0.50	0.42	0.35	0.30
Barren land	0.30	0.24	0.26	0.21

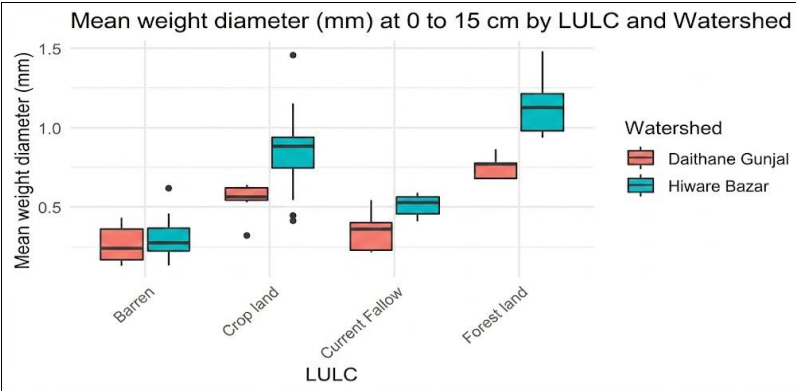


Fig 5: Box plot of MWD (mm) of both the watersheds at 0- 15 cm depth

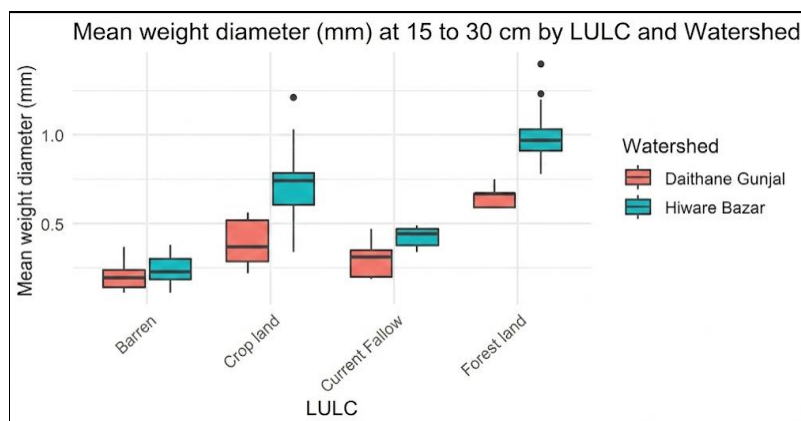


Fig 6: Box plot of MWD (mm) of both the watersheds at 15-30 cm depth

The mean weight diameter (MWD) of soil aggregates showed clear variation among different land use/land cover (LULC) types and between treated and untreated watersheds. Forest land consistently recorded the highest MWD values. This is mainly due to higher organic matter content, better root growth, and minimum soil disturbance, which promote stable aggregate formation. In contrast, barren land showed the lowest MWD values because of poor vegetation cover and low organic matter

input, leading to weak soil structure.

The implementation of soil and water conservation (SWC) measures improved MWD at both soil depths (0–15 cm and 15–30 cm) across all LULC classes. Treated areas showed better aggregation compared to untreated areas. The higher MWD values in the Hiware Bazar watershed than in Daithane Gunjal clearly indicate the positive effect of long-term watershed management on soil structural stability and resistance to erosion.

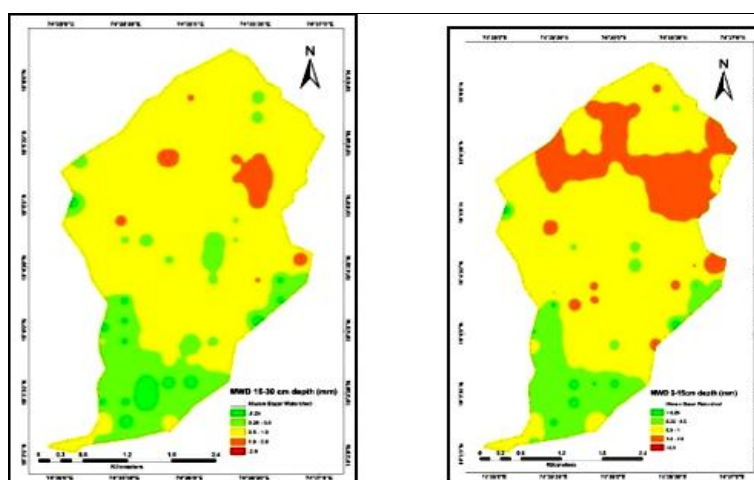


Fig 7: Spatial distribution maps of MWD of Hiware Bazar watershed at 0-15cm and 15-30 cm depths

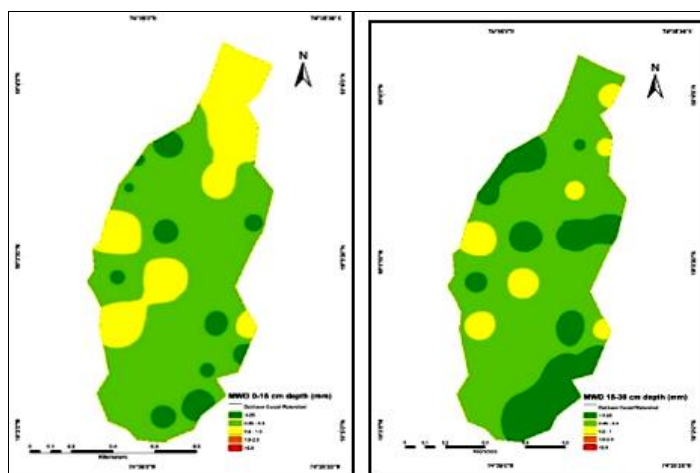


Fig 8: Spatial distribution maps of MWD of Daithane Gunjal at 0 to 15 cm and 15-30 cm depths

Conclusion

The analysis clearly demonstrates the beneficial impact of watershed management on land use and soil structural stability.

The Hiware Bazar watershed shows a balanced and productive LULC pattern, with 65.50% of its area under cropland and current fallow, substantial forest cover (19.75%), and limited barren land (11.18%), whereas Daithane Gunjal is dominated by barren land (62.10%) with only about 32.25% under agriculture. Correspondingly, soil aggregate stability, expressed as mean weight diameter (MWD), was consistently higher in Hiware Bazar across all LULC classes and depths. Forest land recorded the highest MWD values (1.13 and 0.99 mm at 0–15 and 15–30 cm) compared to Daithane Gunjal (0.75 and 0.65 mm), while cropland MWD improved markedly from 0.55–0.39 mm in Daithane Gunjal to 0.84–0.70 mm in Hiware Bazar. Current fallow land also showed higher MWD in Hiware Bazar (0.50–0.42 mm) than in Daithane Gunjal (0.35–0.30 mm), whereas barren land exhibited the lowest values in both watersheds (0.30–0.24 mm in Hiware Bazar and 0.26–0.21 mm in Daithane Gunjal). These quantitative differences confirm that long-term soil and water conservation measures and improved land management in Hiware Bazar have significantly enhanced soil aggregation, structural stability, and resistance to erosion, highlighting the strong linkage between effective watershed

interventions, land use optimization, and soil health.

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