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Rock Characterization based on the Schmidt Hammer Rebound Values: A Case Study of Jawaharlal Nehru University, New Delhi, India

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Abstract: **The campus of Jawaharlal Nehru University (JNU), New Delhi, India provides a remarkable location to employ Schmidt Hammer in the characterization of the physical strength of rocks. The present study is based on the quantification of rock hardness and the assessment of its relationship with four topographic attributes which determine weathering and erosion rates viz., vegetation cover, elevation, slope, and stream frequency. This study also sheds light onthe interplay of rock structure and denudational agents that may have given shape to diverse geomorphological features inside the university campus. Integrated fieldwork and remote geospatial techniques areutilized and thereby, the signatures of exfoliation, granular disintegration, case hardening, and honeycomb weathering are observed in the study area. A negative yet weak correlation is found between rock hardness and elevation, slope, and stream frequency. On the contrary, rock hardness and vegetation cover are found to be positively correlated.**

Index Terms:**Aravalli Hills, Geomorphic Processes, Weathering, Rock Hardness, GIS,Remote Sensing.**

I. INTRODUCTION

Invented in the late 1940s by Ernst Heinrich Wilhelm Schmidt, theSchmidt Hammer(SH) was originally used to assess the hardness of concrete (Goudie, 2006). By the 1960s, geomorphologists found its utility in rock mechanics, mainly for estimating the uniaxial compressive strength (UCS) and Young's modulus of elasticity (Et) of rock materials (Karaman&Kesimal, 2014; Aydin &Basu, 2005). Compressive strength, measured in N/mm^2, is an indicator of the load that a material can endure before compressing. SH test is an *in-situ* non-destructive method and being cheap and quick, it soon became an important method for rock material characterization (Basu& Aydin, 2004). SH is capable of giving an accurate measure of rock surface hardness which is useful in the study of weathering, erosion and landform development (Day, 1980).

When the SH is pressed against a surface, its piston is released onto the plunger which makes the piston to rebound. The distance covered by the piston after the rebound is taken as the rebound value (R) (Goudie, 2006). The hard rock is recorded with the high R-value (Aydin &Basu, 2005). Some studies have also used this instrument to perform the relative dating of fluvial terraces (Stahl et al., 2013) and moraines (Aa &Sjåstad, 2000) as well as in the study of landslides (Ietto et al., 2007). that the investigation shows that the older rocks would give comparatively lower R-values, as a prolonged period of weathering would leave them with a weaker surface. Even though the Schmidt hammer exhibits potential for measuring rock weathering, and thus for interpreting relative age, it should be viewed only as a rapid and inexpensive technique for preliminary assessmentof surface resistance (MacCarroll, 1989) and should be combined with other methods such as Equotip for accurately assessing the rock hardness (Goudie, 2011; Viles et al., 2011). The R-values obtained in SH tests can be a useful tool for selecting surfaces for Terrestrial Cosmogenic Nuclide (TCN) dating (Sánchez et al., 2009). As TCN requires sophisticated laboratory procedures whereas SH methods offer as abasic option to obtain the ages, both methods can be mutually

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employed toreconstruct Holocene geochronologies (Matthews & Winkler, 2011).

This study aims to understand the characteristics of rocks scattered all over the campus of Jawaharlal Nehru University (JNU) or alternatively put, the northern extension of Aravalli Hills. The major focus is on the quantification of rock hardness in relation to various topographic attributes which determine the rates of weathering and erosion viz., vegetation cover, elevation, slope, and stream frequency. This paper also intends to provide an explanation of how the interplay of rock structure and denudational agents may have given shape to quartzitictors, caverns, and other geomorphological features that can be witnessed today in various parts of the campus.

II. STUDY AREA

JNU (28°32’51” N and 77°11’15” E) is situated in northern India lying in the watershed of river Yamuna.In addition, itis nestled in the residual Aravalli hills, one of the oldest orogens of the world (Fig. 1). The university campus sprawls over an area of more than 1000 acres (4 km^2) and is characterized by lush flora and fauna in the bustling city of Delhi (Srivastava et al., 2011). As this region is a north-eastern extension of the Aravalli hills, therefore, its geomorphic history is closely related to the origin, evolution, denudation, peneplanation, and rejuvenation of the Aravallirange (Sharma, 1981). The geological formation of the JNU campus is of Delhi Supergroup comprising gneisses, quartzites and sandstones (Chatterjee et al, 2009 & Sarkar et al., 2016). Consequently, the presence of highly metamorphosed rocks all around the campus holds great significance for geomorphologists.

The study area experiences a subtropical and continental type of climate with four distinct seasons namely (average temperature in brackets), summer (38°C), monsoon (29°C), autumn, and winter (14°C). The annual rainfall is about 760 mm, during the monsoon months of July, August, and September. Such a hot and humid climate greatly aids in the chemical and mechanical weathering of landforms which isresponsible for the wearing down of the rocks.

III. MATERIALS & METHODS

A. SH Testing

The ND Digi-Schmidt 2000 type of SH is employed in this study to quantify the hardness of the rocks in situ (see Fig. 2a, b,c). It is equipped with a sensor that measures the R-values of a

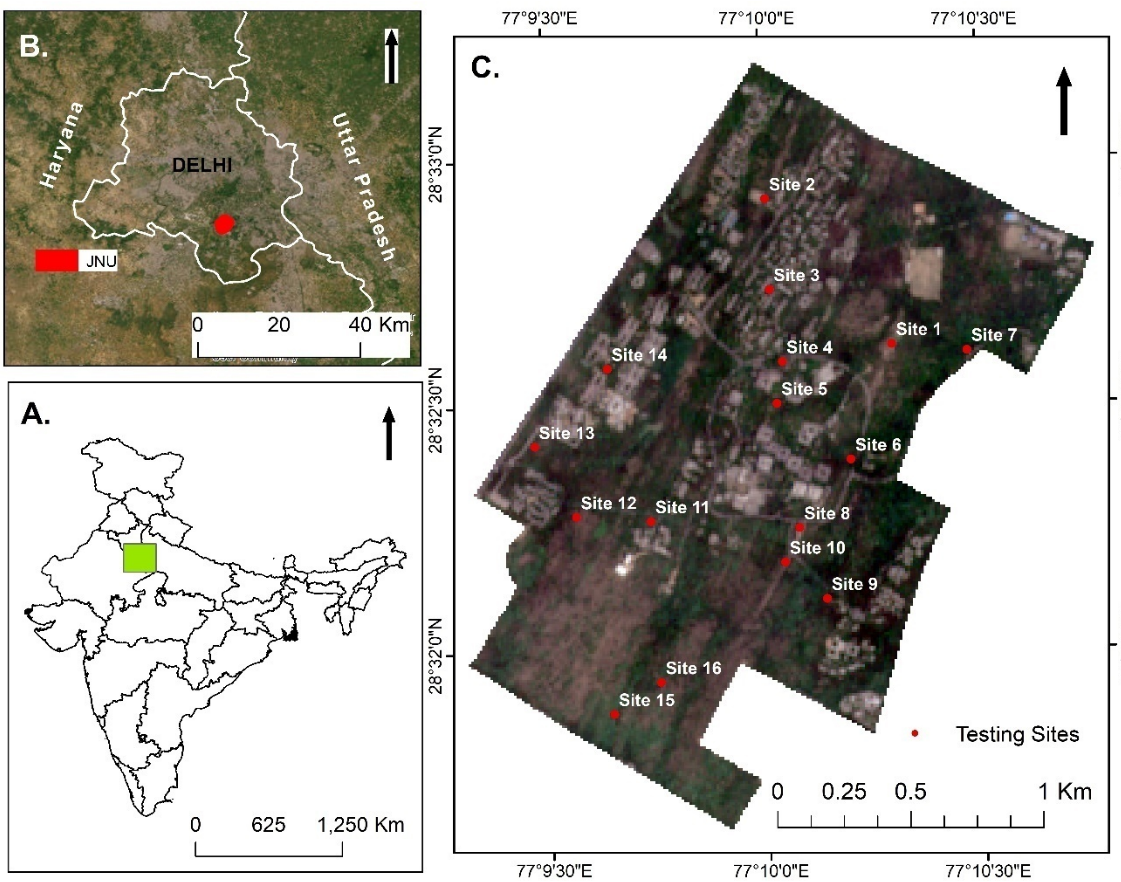

Fig.1. A. Administrative map of India showing state boundaries; **B.** Delhi and surrounding states; **C.** Location of Study Area- Jawaharlal Nehru University campus & sites where rocks were tested. *A true colour composite of Sentinel-2A satellite imagery taken on 06 June 2022, Tile number- T43RGM, 10m resolution*.

test impact to a high resolution and repeatability. The impact energy of the hammer is 2.207 Nm, the measuring range of compressive strength is 10 to 70 N/mm^2, the accuracy of measurement is ± 0.2 R, reproducibility is ±0.5 R and it can be used in a temperature range of -10 to +60 °C.

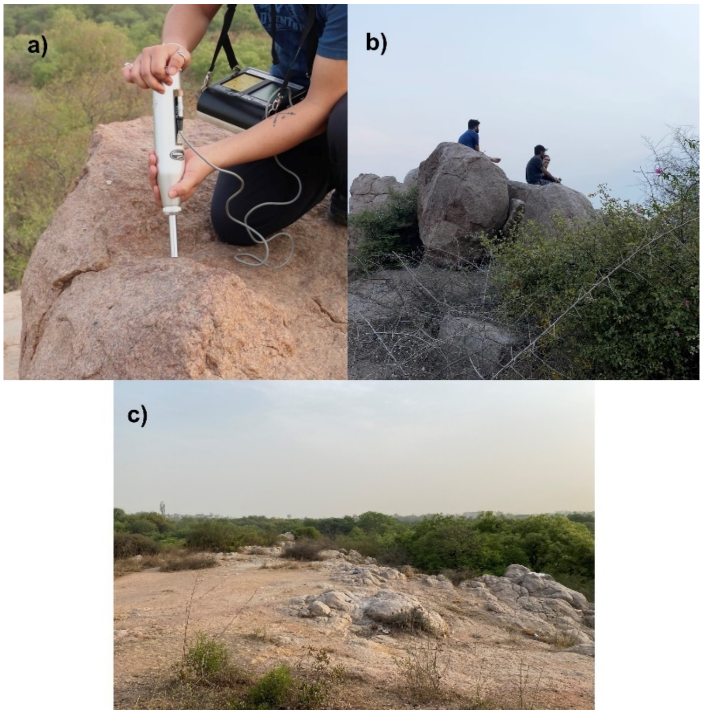

Fig.2. Field photographs show: (a) Digi-Schmidt in action; **(b)**Quartzitic Tors at Site 1 (Parthasarthy Rocks), people sitting on the tors give a fair idea of their size; **(c)** Site 1: the area surrounding the tors.

A cluster of overlying rocks, boulders, and exposed bedrock at a particular place is taken as a single 'site' where tests are performed. Most of the SH tests are performed on granitic, gneissic,and quartzitic rocks, with a few tests conducted onsandstones. Sixteen well-distributed sites were identified across the university campus. Depending on the size of the site, the number of rocks to be tested was decided. The SH was pressed at least 10 times at 10 different places (at least 2 cm apart from each other) on a single rock in order to take values from each side (e.g., Niedzielski et al., 2009). Any discontinuities or fissures on the rock surface were carefully avoided, thus, selecting places that are visually uniform, away from any visible discontinuities or edges. SH was kept perpendicular to the rock surface and any obliquity was avoided while blowing the SH as it leads to a loss of energy and thus, gives an erroneous R-value. The mean R-value of all the test impacts was noted alongside the minimum and maximum R-values, compressive strength, and standard deviation. Providing the site aspect is not feasible because the sites cover a large area and face many directions due to the undulating nature of the terrain.

Atmospheric humidity and moisture content of the rock tend to affect the SH R-values and it has been observed that generally, the R-value declines with a rise in rock moisture (Sumner & Nel, 2002). Whereas temperature differences have not been found to have any significant impact on the R-values, this negative correlation is not linear and is poorly understood. To minimize the problem of moisture, the testing was performed in the month of April when the study area has a relative humidity as low as 20%. On average, April is the least humid month in Delhi.

B. Computation of Topographic Attributes and their Relationship with Rock Hardness

The Geographic Information System (GIS) and Remote Sensing (RS) techniques are used to analyze the topography of the study area. Vegetation cover and its health are measured using a Sentinel-2A satellite image taken on 6 June 2022 (10m spatial resolution; downloaded from https://earthexplorer.usgs.gov/, where the Normalized Difference Vegetation Index (NDVI) is computed using the Map Algebra feature in the ArcGIS software. NDVI values vary between -1 to +1 with a rise in values signifying higher greenness (Tucker, 1979; Viana et al., 2019). It is given by the following formula:

$$NDVI = \frac{Near\ Infrared\ Band - Red\ Band}{Near\ Infrared\ Band + Red\ Band}$$

The ALOS PALSAR Digital Elevation Model (DEM) (downloaded from https://search.asf.alaska.edu/#/) which has a spatial resolution of 12.5m is used to derive the information pertaining to the elevation, slope, and stream frequency of the JNU campus. Streams were generated by putting an appropriated Critical Threshold (>=500) and henceforth, the Line Density tool is used to create the stream frequency layer.

The R-values of all the rocks at a particular site are averaged and thus, interpolated based on the Inverse Distance Weighted (IDW) interpolation to create a Rock-Hardness raster layer of the study area. More than three hundred points are created with the help of the Fishnet feature, from where the R-values, as well as the values of NDVI, elevation, slope, and stream frequency, are extracted using the 'extract multi values to points' feature and imported into MS Excel (e.g., Das et al., 2022). Here, the correlation and linear regression are worked out, keeping rock hardness as a dependent variable and these four topographic aspects as independent variables.

IV. RESULTS & DISCUSSIONS

A. Rock Characterization

Rocks can be categorized into six classes based on the SH R-values viz., very weak (10-35), weak (35-40), moderately strong (40-50), strong (50-60), and very strong (>60) (Selby, 1993; Goudie, 2006). Fig. 3 shows the distribution of R-values throughout the study area. The zones represented by the shades of red have high R-values which means that the rocks are strong and have higher surface hardness as compared to the zones shown in green colours where the R-values are least. Yellow represents the zone of moderately strong rocks. It is evident that the southern part of the campus has the weakest rocks, whereas the strongest ones are present in the northern and central parts.

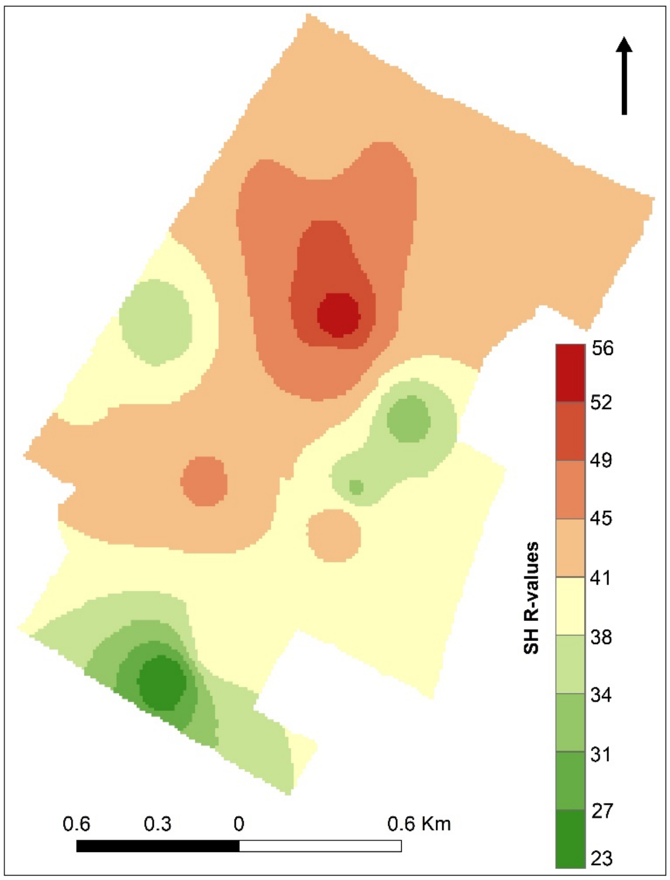

Fig.3. Spatial distribution of R-values and rock hardness across the study area.

Given their large size, the highest number of rock tests are done at Site 15 (JNU Caves) and Site 1 (Parthasarthy Rocks) respectively. From Table I, it is clear that the lowest mean R-values (11) are obtained from Site 15 where the weathering is also seen to be more pronounced. Conversely, the strongest rocks (R=57.4) exhibiting the least weathering are found at Site 4 which is located near the Administrative Block, in the middle of the campus. An interesting pattern is observed at Site 1. The quartzitic tors occupying the central location of the site are the largest and gave higher R-values (50.2) as compared to the surrounding rocks (Fig. 2b). This trend is accompanied by a decline in the size and hardness of rocks and boulders as one moves away from the centre.These highly metamorphosed quartzites, which now lie exposed, once formed the core of the Aravalli hills.It is argued that the rocks in the centre are the hardest, so they withstood the vagaries of time and therefore, still stand high.

The minimum and maximum R-values have significant differences (Table I) indicating a non-uniformity in surface hardness and weathering in the same rock. This results from the fact that rocks are composed of a variety of minerals that decompose (by chemical weathering) and disintegrate (by mechanical weathering) at different rates(Fig. 4g). As a result, some tested rocks (S3R18, S9R33, S15R53 & S16R64) gave a high deviation (>17) from the mean R-value. This can be attributed to a multitude of phenomena, some of which are also discussed in this section. Aspect acts as one of the factors determining the degree and rate of weathering. As the study area is positioned in the Northern Hemisphere, the higher intensity of insolation received by the southern face of the rocks during daytime enhances weathering because rocks expand and contract with high and low temperatures, respectively.This is seen in most of the rocks on which the SH is performed.

During the field investigation, it is observed that the texture indeed had an impact on the SH R-values. Rough surfaces give lesser readings than smoother surfaces (e.g., Williams &Robbinson, 1983). This happens as some energy is lost during SH impact to clear the surface irregularities (Goudie, 2006). In most of the rocks (see Fig. 4e and 4f) the top is polished and smoothened by weathering and subsequent erosion, thus giving a high R-value, whereas the rock base was observed to be very rough, exhibiting a lesser R-value. Possibly, the parts of the rocks closer to the ground experience more erosion by running water which erodes it at a high pace and the texture becomes rough. However, this is determined by the properties of the rock-formingminerals as well. With no exception, exposed bedrock gave higher R-values than the surrounding rocks and boulderslying detached (Fig. 4h and 4i). Perhaps, it is due to insolation and wind that the uppermost parts become drier and thus, give higher R-values.

Honeycomb weathering and tafoni/cavern formations, which are characteristic of sandstone weathering, are found at Site 15, popularly known as JNU caves (Fig. 4a and 4b). As discussed before, the R-values of rocks from this site are very low, which explains the formation of such features. As the rocks are inherently weak, they experienced greater weathering. However,such formations are usually considered to be polygenetic in origin and are the result of a complex interaction of physical and chemical weathering processes, which include salt weathering and cyclic wetting and drying (McBride & Picard, 2000). Case hardening also plays a significant role.

Archaeological evidencereveals that this used to be a sandstone mining site in historic times (Sharma, 1981) and thus, the fractured rocks paved way for enhanced weathering in due course of time.

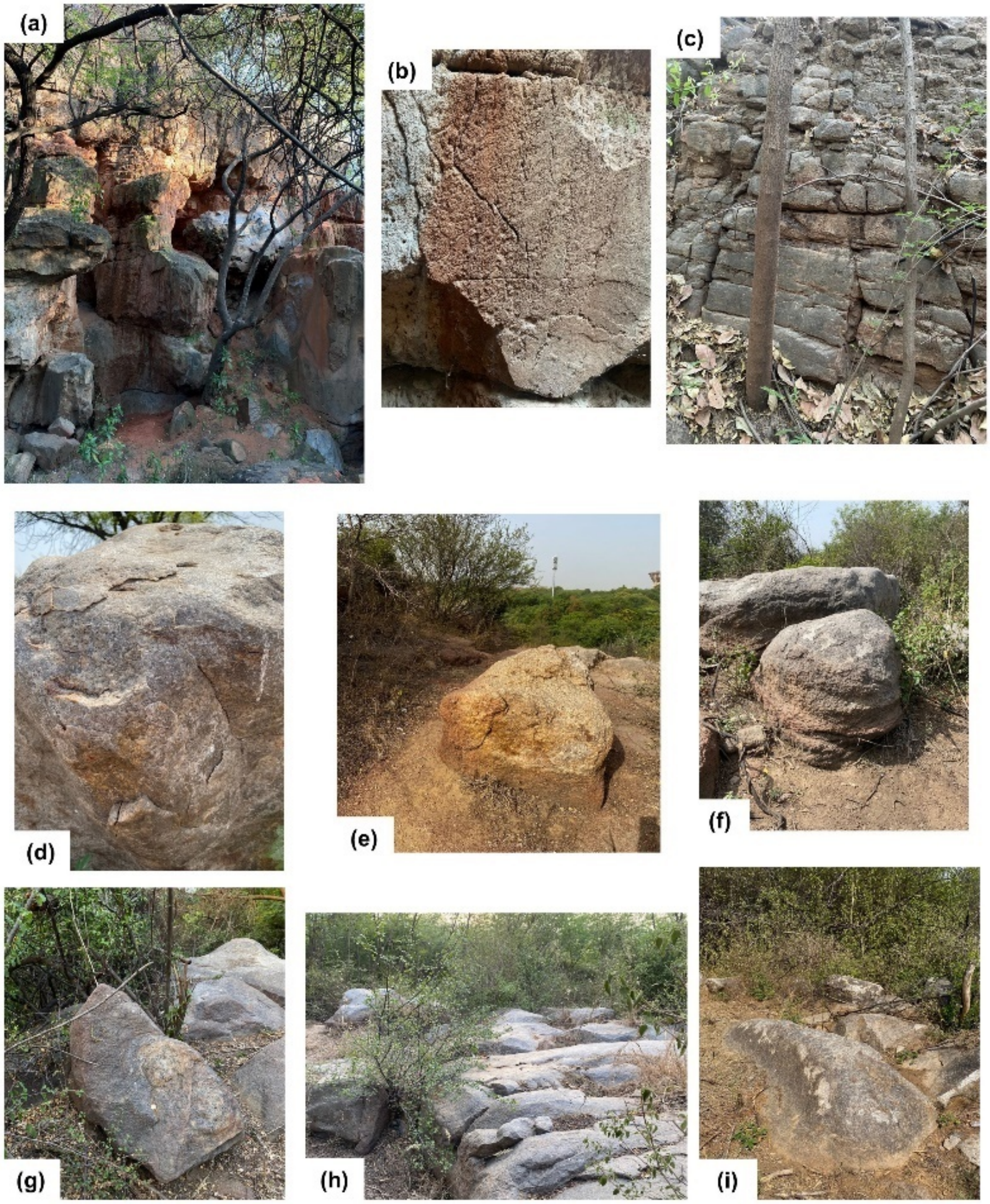

Fig.4. **(a)** Tafone & cavern formations at Site 15 (JNU caves); **(b)** Honeycomb weathering (S15R54); **(c)** Granular weathering (S6R24); **(d)** Exfoliation (S12R44); **I** and **(f)** Rough rock bases, more pronounced weathering near the ground (S1R10, S12R43); **(g)** Differential composition of minerals and thus, varying weathering rates and texture, in a single rock (S9R33); **(h)** and **(i)** Exposed bedrocks gave larger R-value (S12R45). *Source- Field survey, April 2022*.

Exfoliation, a form of mechanical weathering where a rock layer peels off like an onion, is observed at Site 12 (Fig. 4d). The R-values here are in the order of 40-50. The tors of Site 1 (ParthasarthyRocks), overlie an unaltered bedrock and are also thought to be formed due to the mechanical weathering of former rocks (Sharma, 1981). It so happens as the confining pressure on buried rocks declines with the removal of overlying material. Rocks expand and upheaval takes place which is accompanied by the disintegration of rock-forming minerals – ultimately producing spheroidal tors. Another form of mechanical weathering- granular disintegration is seen on the vertical side of a large rock facing the Ring road at Site 6 (Fig. 4c) where the R-values are as low as 21. It can be said that weathering by chemical decomposition and mechanical disintegration are not mutually exclusive and often operate simultaneously in natural settings (Lutgens et al., 2017).

Table I. Detailed SH data obtained from 16 testing sites.

Site	Coordinates	Rock Sample	Mean R-value (10 impacts)	Compressive Strength (N/mm^2)	Minimum R-Value	Maximum R-value	Standard Deviation
S1 Parthasarthy Rocks	28°32'37" N 77°10'18" E	R1	42.7	28.6	18	59	15.8
		R2	42.3	28.1	14	61	17.1
		R3	36.4	21.7	14	61	17.1
		R4	48.3	35.4	21	72	13.4
		R5	47.2	34	10	65	16.8
		R6	46.7	33.4	11	62	16.1
		R7	50.2	37.8	25	67	14.8
		R8	46.5	33.2	18	65	14
		R9	30.6	16.3	10	55	17.5
		R10	31	16.7	12	51	14.8
S2 Kamal Complex	28°32'54" N 77°10' E	R11	47.7	34.7	25	61	11.5
		R12	52.8	41.1	28	65	14
		R13	41.1	26.8	11	56	14.6
		R14	31.5	17.2	13	58	15.8
		R15	47.7	34.7	26	64	11.7
S3 Periyar Hostel	28°32'44" N 77°10'1" E	R16	52.7	40.9	38	62	8.7
		R17	53.2	41.6	28	68	12
		R18	42.7	28.6	12	73	21.5
S4 Admin Block	28°32'35" N 77°1'3" E	R19	57.4	47.2	13	72	16.8
		R20	54.1	42.8	32	68	12.4
S5 Biotech	28°32'31" N 77°10'2" E	R21	49.6	37	33	63	12
		R22	50.6	38.3	23	75	16.5
		R23	41.7	27.5	17	57	13.5
S6 Ring Road (Near PSR)	28°32"24 " N 77'10"12 " E	R24	37.6	23	14	55	13.6
		R25	28.4	14.1	15	44	10.8
		R26	27.7	14.3	12	40	9.6
S7 Damodar Hostel	28'32"36 " N 77'10"29 " E	R27	42.9	28.8	29	56	10.7
		R28	43.6	29.6	19	62	12.4
S8 Ring Road (Near CSRD)	28'32'15 " N 77°10'5" E	R29	32.4	18.2	15	52	12.9
		R30	31.5	17.2	16	47	11.3
		R31	36.5	21.8	12	63	15.9
S9 Brahmaputra Hostel	28°3'6" N 77°10'9" E	R32	47.9	34.9	24	73	15.5
		R33	28.5	14.2	10	55	17.7
		R34	47.5	34.4	16	68	16.3
		R35	31.4	17.1	18	54	11.2
		R36	50.2	37.8	35	68	13.4
S10	28°32'12 " N 77°10'3" E	R37	42.8	28.7	32	58	9.2
		R38	49.8	37.2	40	62	6.7
		R39	39.1	24.5	10	61	15.2
S11	28°32'16 " N 77°10'44 " E	R40	43.6	29.6	18	60	13.9
		R41	45.7	32.2	20	62	14.5
		R42	49.4	36.7	23	62	11.1
S12	28°32'17 " N 77°9'34" E	R43	40.2	25.8	23	66	17.4
		R44	45.5	32	10	68	15.7
		R45	47	33.8	10	61	16.4
S13	28°32'26 " N 77°9'2"E	R46	33.7	19.6	22	64	14.3
		R47	47	33.8	27	60	12.5
		R48	42.8	28.7	18	60	14.7
S14	28°32'35 " N 77°9'3E	R49	33.4	19.2	14	68	17.4
		R50	22.3	8.8	16	42	8.4
		R51	47.4	34.3	20	64	15.5
S15 (JNU Caves)	28°31'52 " N 77°9'39" E	R52	20.1	6.7	12	44	9.8
		R53	28.9	14.6	10	63	22.2
		R54	16.3	<10	10	22	4.3
		R55	41.8	27.6	12	57	16.9
		R56	20.7	7.3	10	56	13.5
		R57	14.5	<10	10	19	3.3
		R58	13.3	<10	10	20	3.9
		R59	13	<10	10	20	3.9
		R60	11	<10	10	12	1
		R61	32.4	18.2	12	59	17.3
		R62	44	30.1	12	67	17.7
S16	28°31'56 " N 77°9'45" E	R63	42.4	28.3	24	57	9.6
		R64	39.6	25.1	13	66	18.1
		R65	41.6	27.3	25	55	12.3

B. Examination of Topography and its Relationship with Rock Hardness

Maps of four topographic attributes of the JNU campus are generated in the ArcGIS software viz., vegetation cover, absolute relief, slope, and stream frequency (see Fig. 5).

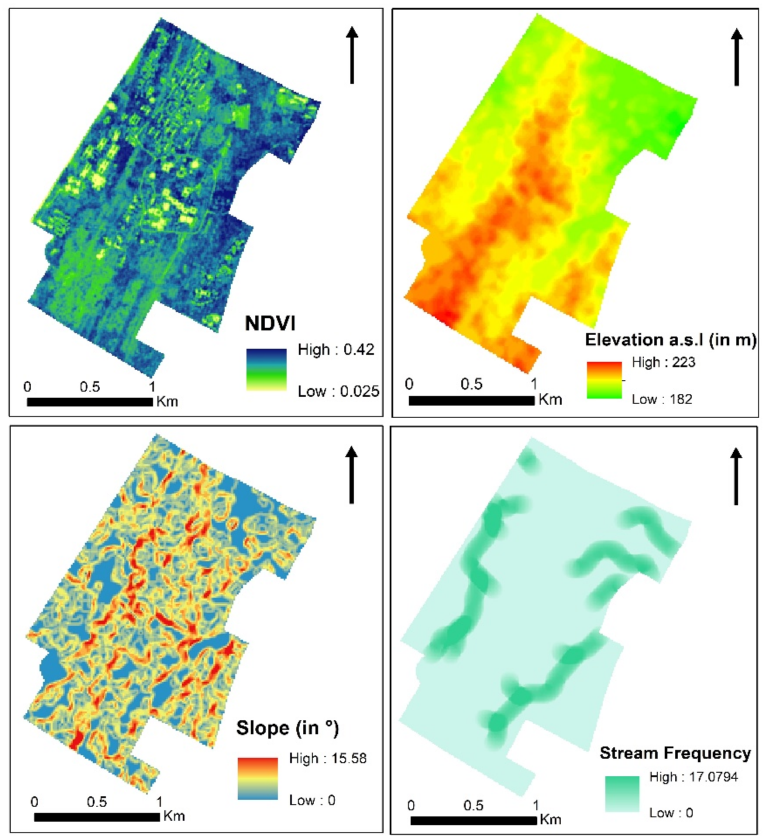

Fig.5. Four topographical attributes of JNU- vegetation cover (shown by NDVI), absolute relief (shown by elevation above mean sea level), slope, and stream frequency (per square km).

Vegetation contributes significantly to the weathering processes such asby root-wedging (Egli et al., 2008). In the tropics, open vegetation (like meadows or clearings) leads to enhanced erosion but a reduction in chemical weathering; dense vegetation has the opposite effect(Ivory et al., 2014). Fig. 6a shows a positive correlation between R and NDVI values, that is, the rock hardness in the study area is increasing with the increasing density of vegetation.

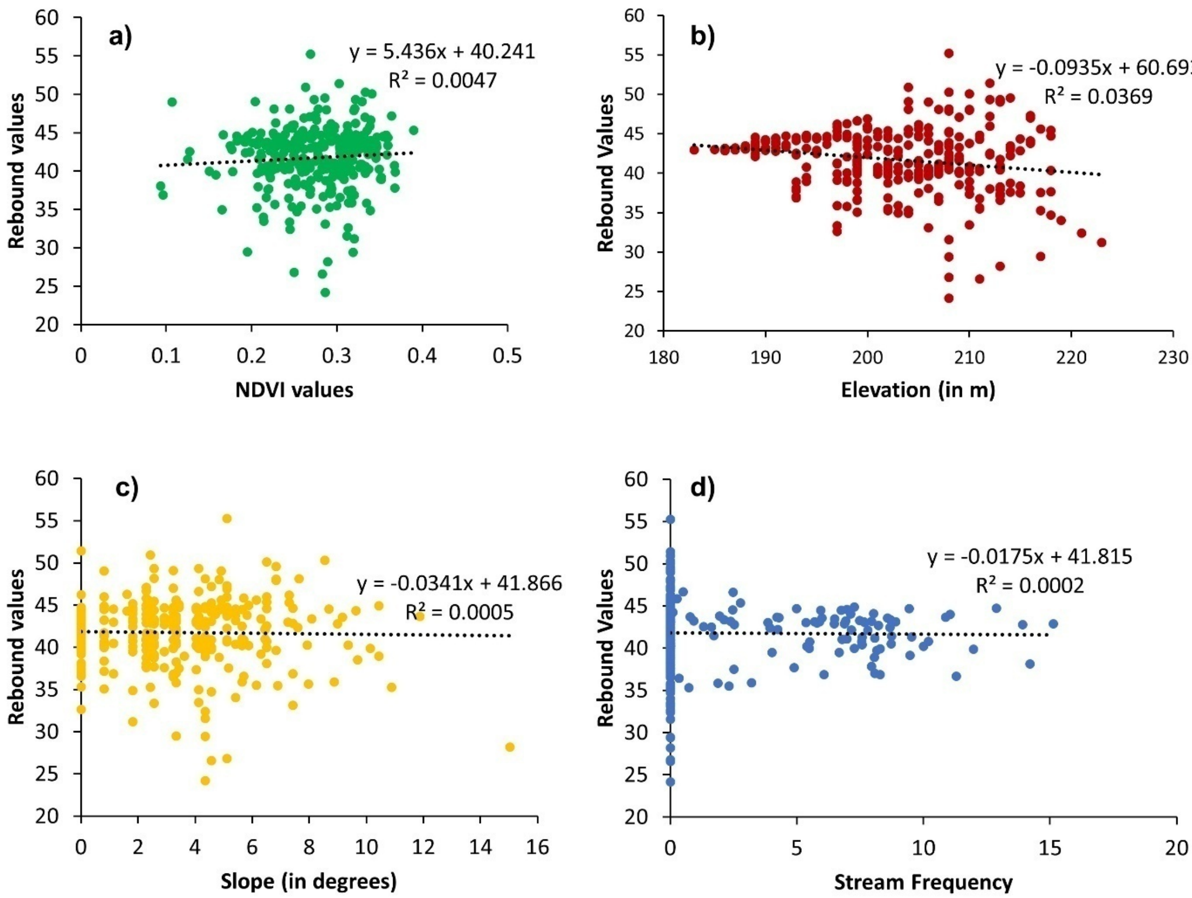

Fig.6. Scatter plots of R-values and **(a)** NDVI, **(b)** Elevation, **(c)** Slope, **(d)** Stream frequency.

Granites and other hard rocksusually form topographic highs in a landscape (Braun et al., 2014) due to their hardness and high resistance to erosion. However, this study finds a negative correlation between rock hardness and elevation on the JNU campus (Fig. 6b).

As the slope gradient increases, the soil thickness as well as weathering degree decline (Brosens et al., 2020). However, steep slopes are also characterized by little or no vegetation cover which can expose the rocks to denudational processes (Cerda, 1998) thus, decreasing their strength. Fig. 6c indicates a similar result where the rock hardness is decreasing with increasing slope gradient.

Stream frequency or drainage frequency is expressed as the total number of streams per unit area (generally one square km) (Horton, 1932). It has a strong correlation with drainage density (length of streams per unit area) (Melton, 1958). High stream frequency is representative of greater erosion, sparse vegetation, impermeable surface, and high relief. I also find a negative correlation between rock hardness and stream frequency (Fig. 6d).

It is worth noting that the coefficient of determination (R squared) in all four regression models is low. This means that the selected topographic variables explain a minimal variability in the rock hardness and so there must be other factors involved (e.g., temperature, rainfall, mineral composition, etc.). Nonetheless, the highest R squared (3.6%) is obtained when elevation is taken as the independent variable, therefore, more variability is explained by this model.

CONCLUSION

Most of the tested rocks exhibit a very weak to a moderately-strong level of hardness. The hardest rocks are present in the vicinity of the Administrative Block (middle of the campus).Quartzites that occupy the central position at ParthasarthyRocks are some of the hardest. Whereas the caves located in the southern part are marked by weak and heavily weathered sedimentary rocks - sandstones. Tafone, a resultant of honeycomb weathering, can be seen all over the cave walls.The role played by anthropogenic activities like mining in enhancing weathering and reducing rock hardness becomes apparent at this site. Signatures of exfoliation and granular weathering are also observed inside the campus. The base of most of the rock is found to be coarse-textured and comparatively more weathered than their top and side faces.

The rock hardness is found to be negatively correlated with elevation, slope gradient, and stream frequency of the study area but shows a positive correlation with the vegetation cover. Linear regression models show that the highest variability in rock hardness is explained by elevation as an independent variable, however, several other factors also playa significant role that wasnot possible to cover in this study. These results, nonetheless, are useful for engineers and decision-makers for carrying on construction activities on the JNU campus and for geoscientists to understand the interplay of lithology, weathering, and erosional processes.

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