USING SOIL ADJUSTED VEGETATION INDEX TO ASSESS LAND DEGRADATION ALONG SECTIONS OF MUTONGA RIVER CANYON

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ABSTRACT
Mutonga River canyon forms an important social economic strip spanning about 8 km East and West along upper Mutonga River Bridge. The 8 km strip is an area of dense human activities comprising of quarry stone mining and settlements. The canyon contains extensive stone mining sites as well as a permanent river serving the communities of Meru County in the upstream and Tharaka-Nithi County in the downstream respectively. Uncontrolled quarrying along the canyon's river bank has resulted to geomorphic failures in the recent past leading to fatal landslides in 2002 and 2010. To assess the extent and effects of these mining activities on the canyon's slope stability, satellite images of years 2014 and 2017were comparatively used. The severity of degradation was then assessed using Soil Adjusted Vegetation Index (SAVI). Calculated vegetation cover threshold values across the two epochs were taken as indicators of degradation. The study revealed that the strip along Mutonga river Canyon has undergone massive de-vegetation and slope de-stabilization. Soil creep from the quarry sites has also resettled into the watercourse way reducing the river depth, benthic life and degrading river water quality.
Keywords: SAVI, Satellite Image, Canyon, Degradation, Quarry

INTRODUCTION
Land degradation is an increasing global environmental challenge especially in developing countries. Due to reliance on environmental goods for livelihood, land degradation is common in high potential as well as arid and semi-arid lands of Kenya. It is common that most people continue to be exposed to environmental conditions that can adversely expose them to health problems. In this study land degradation is the removal of vegetation or any cover on the earth's surface. Bare land is one of the most important and typical land covers all over the world (Hui et al, 2017). Quarry and related activities have been singled as human endeavours irreversibly impacting on the canyon's slope instability, water quality and riverine vegetation loss. Mutonga River originates from the eastern slopes of Mt. Kenya and flows downstream (Plate 1)

Quarrying activities have expanded in the last five years along Mutonga river canyon. The belt is an important Kaolinitic quarry site with over 60 percent of supplied quarry building stones within Meru and Tharaka-Nithi counties sourced from the canyon. Increased stone mining has been witnessed in this area with the entry of local and international stone machine quarry companies. Notably, the introduction of stone dressing machines has brought competition to the traditional quarries. Dense concentration of stone quarrying related activities has encroached on the escarpments, riverine vegetation and natural lands along the stretch (Plate1&2). Conversion of natural land into loose surface may have negative impacts on riverine ecosystem and related hydrological characteristics. Reported impacts of geomorphic failure have in the recent past resulted to fatal landslides claiming the life of quarry workers. Land degradation is now common along this stretch due to excavation and dumping of quarry wastes.


Plates 1&2: Section of Mutonga River along the Canyon

Plates 3, 4 and 5: Encroachment on Canyon's escarpment, vegetation and settlements

Although few studies on environmental related impacts have been done, none has incorporated remote sensing images or approaches to explore the spatial and temporal impacts of the expanding quarry activities. The study sought to bridge this conceptual gap by assessing the spatial and temporal dynamics of quarrying related land degradation impacts on the canyon's slope retreat and water course way's morphology. Due to the need to assess environmental risks, theoretical and applied research using GIS tools and advanced methods of data visualization have increased (Eric, S et al, 1999; Kibetu, 2011). In the same vein, this study integrates remote sensing data and spatial analysis to assess human induced spatial and temporal changes to hydro-geomorphic features along Mutonga Canyon. To achieve this goal Soil Adjusted Vegetation Index (SAVI) was used to highlight vegetation features, their spatial distribution and changes between 2014 and 2017. Vegetation cover was taken as a proxy to land degradation since quarry sites are often cleared of plant cover for excavation. This exposes the underlying surface to human activities. Although SAVI is one of the many vegetation indices applied to get vegetation information from satellite imagery, its advantage over the Normalised Difference Vegetation Index (NDVI) is that it works well when used in areas with low plant cover (Jensen, 2000; Ray 2006). It was thus chosen since quarry sites often have little plant cover to that found in many urban areas. SAVI has been used in combination with other indices to delineate built up land features (Xu, 2008), bare areas (Zhao and Chen, 2014) and vegetation cover (Kibetu, 2018)

The objective of this study was to assess the extent and effect of quarry activities on canyon's slope stability and hydrological characteristics of river Mutonga. The likely conditional effects on the surrounding of any natural land may include increased surface run-off, pollution and reduced water quality (Melesse et al, 2007). To assess the spatial and temporal aspects of land degradation, remote sensing based SAVI index calculated through rationing of the near infrared and red bands of multi-dated land sat images were used. The results were then validated through field ground truth sampling of the selected quarry sites.

Study Area

The stretch is located along the equator approximately on Longitude 37^{0} $38^{'}$ $03^{''}$ East and Latitude 0^{0} $10^{'}$ $40^{''}$ South. The quarry site lies on the border between Tharaka Nithi and Meru County respectively. The area is characterised by well drained kaolinitic clay soils with undulating sloppy landscape. Upper Mutonga Canyon contains economically viable litho logical IB2 rocks widely exploited for construction and building materials. The area is found on an elevation of 1188m to 1453 m above sea level.

MATERIALS, DATA AND METHODS

Data sets

Sentinel 1A image data dated 11^{th} July 2014 and 17^{th} July 2017 respectively were used. The 10M resolution bands 4 and 5 of spectral ranges (0.63-0.69µm) and (0.78-0.90µm) corresponding to red and near infrared bands were used in calculating Soil Adjusted Vegetation Index. Soils data was downloaded as shape file from the Kenya Open data portal. The Digital Elevation Matrix model (DEM) was generated from the 30 meters Shuttle Radar Terrain Mission Satellite. Field survey data was collected through observation and interviews.

Soil Adjusted Vegetation Index (SAVI)

SAVI is an enhanced remote sensing index which applies wavelengths of 0.65 µm and 0.83 µm (R and NIR bands). It can better map areas with low plant cover preferentially those with less than 15 percent vegetation cover. This is because Soil Adjusted Vegetation Index (SAVI) is sensitive in detecting vegetation in the low plant-covered areas compared to the Normalised Difference Vegetation Index due to fact that it largely uses the increased data dynamic ranges making discrimination of vegetation easier.

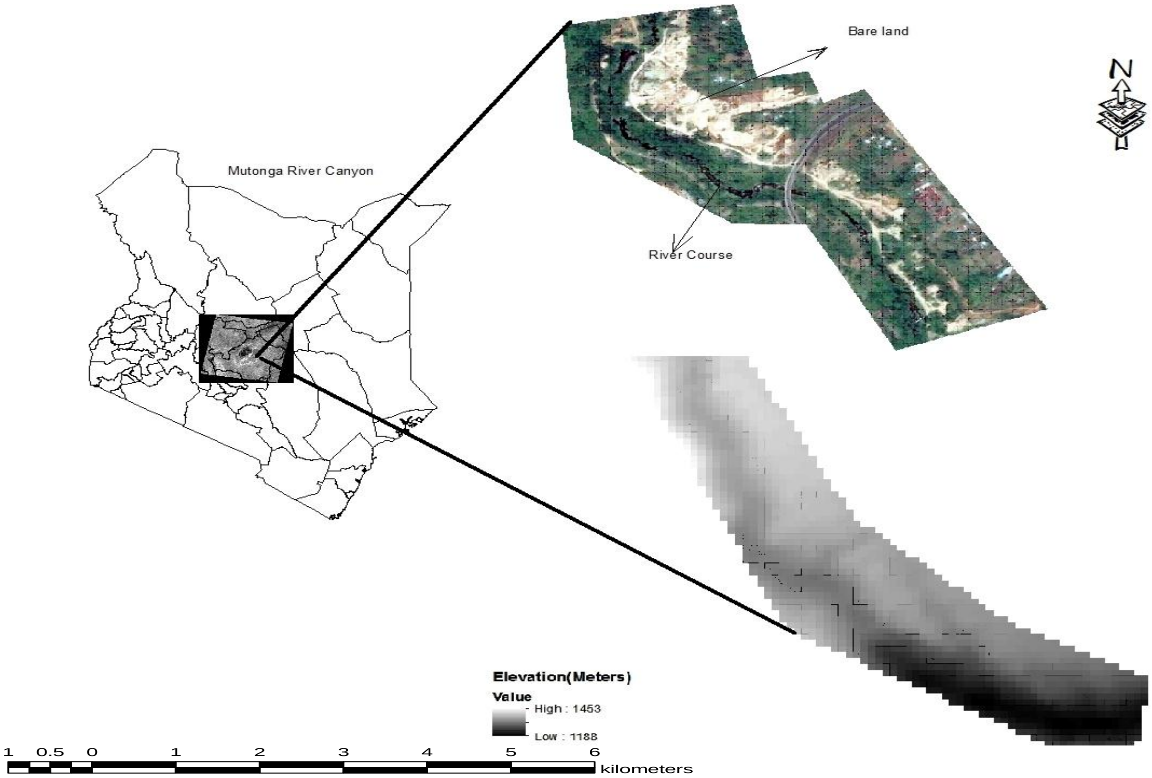


Figure1: Location of the study

In this case SAVI was calculated using equation proposed by Huete, 1988 as:

SAVI = (NIR-Red) *(1+L) / (NIR+ Red+ L)
In this equation, L is a correction factor whose value range 0 to 1; where 0 is used for areas with very high vegetation densities and 1 for those with very low vegetation densities respectively.

Normalised Difference Built-Up Index (NDBI)
Settlement was identified as one of the other key land use and human activity along the Mutonga canyon stretch. The slope tops are covered with built up areas linearly aligned along roads leading to the quarries. The NDBI index used was based on the equation proposed by Zha *et al*, (2003):

NDBI = MIR-NIR / MIR+NIR

The normalised difference built up index uses Near Infra Red band of range 0.76-0.90um and the Mid Infra Red band of 2.08-2.35 um spectral wavelengths. The two spectral wavelength range are used because built up areas reflect more in the two bands than others.

Assessing dynamics of Degradation based on SAVI and NDBI indices
To quantify the spatial extent of exposed bare land, the study applied SAVI and normalised difference built- up index (NDBI) results comparatively. The study area's changes introduced by the increased human activities can best be analysed using specialised indices.

Accuracy Assessment
To assess the accuracy of the resultant products, difference between index based and supervised classification results were verified using the area ratio and match rate formulas. The formula has applied by Hui et al, 2017 in the accuracy assessment of their index based map products for Wuhan city, China were modified for this study. The original formulas modified to include the area ratio and match rates for SAVI and NDBI images as used by Hui et al is as shown below:

Ra = Ba/Br (1)
Rm = (Ba\Br)/Br or Rm = (Ba\Br)/Ba (2)

Where Ba indicates the bare land in the automatic mapping result, while Br represents the bare land in the supervised classification result.

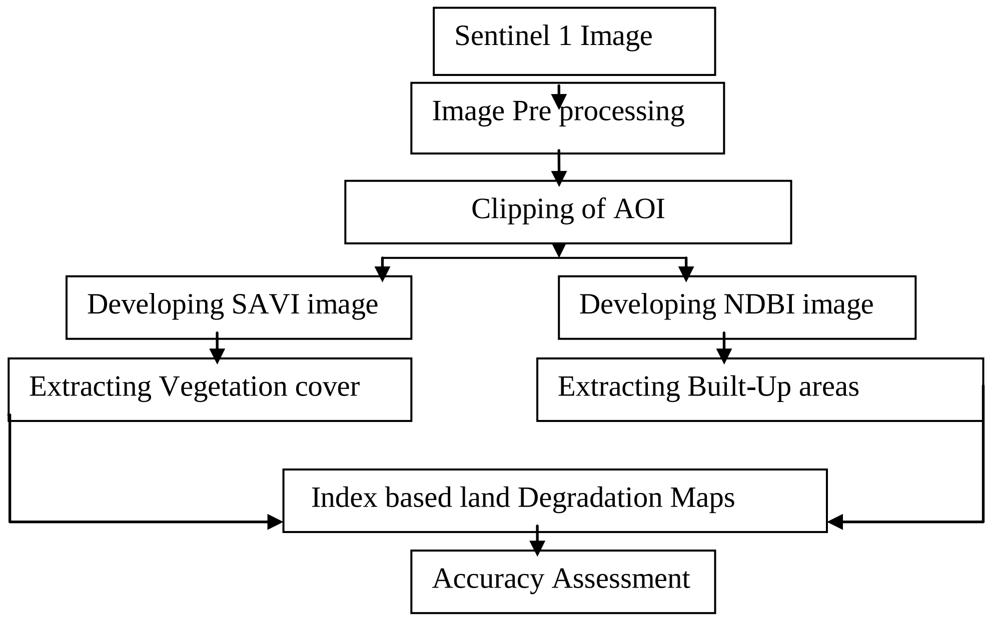


Figure 3: Schema used in assessing land degradation from image data

RESULTS AND DISCUSSION

Geomorphic slope stability Dynamics

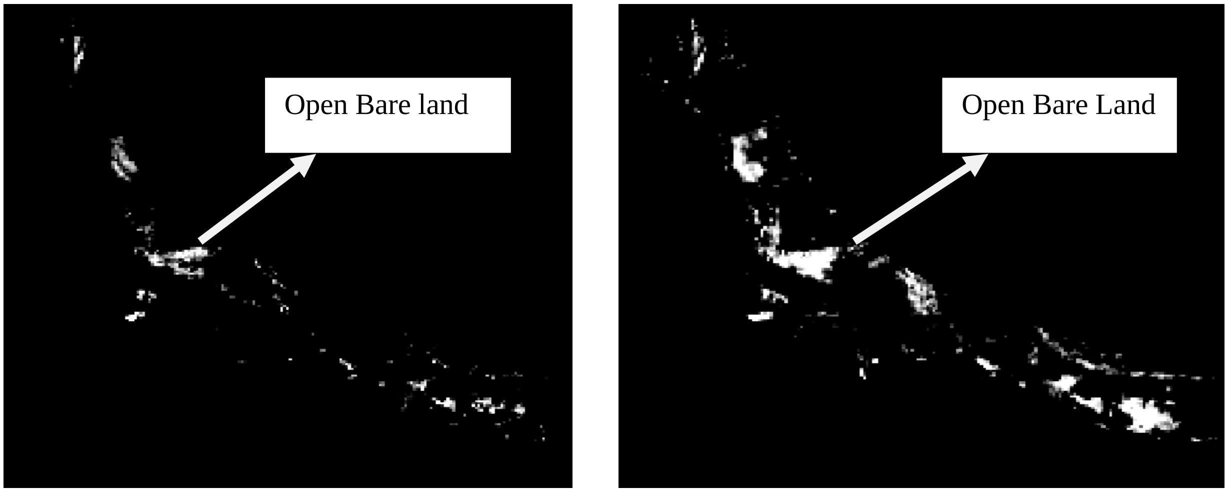
The stretch has witnessed extensive excavation especially on the western arm where more quarrying activities have been observed. The SAVI based images from the two time series showed a substantial decrease in plant cover across the time considered. This was associated with increased on set of quarry site between 2014 and 2017. The western arm compared of the canyon had intense quarry activities compared to the eastern edge (see figure.2).Encroachment towards the mainland by the miners has seen the slope of the quarry escarpment retreat and drop sharply towards the canyon floor. The major cause of slope failure was disturbance introduced by quarrying activities, haulage trucks and related human activities. Manual quarry sites exhibited massive slope retreats with steep sided concave escarpments observed compared to the mechanized quarries. The Eastern Canyon has expansive mechanized quarries due to the restrictive sloppy cliffs which reduce manual stone extraction.

Notable was the effects of human settlement and farming on the slope top with also catalyzed vegetation loss and exposed soil cover. Increased quarrying has been witnessed along the western arm of the canyon. As can be visualised from the two temporal SAVI Boolean maps, there was escalated degradation catalysed by expansion of quarrying activities. The total devegetated area due to quarrying increased from 1651.90 hectares to 1828.43 hectares during the 2014-2017 period reviewed (table .1). This translates to 10.68% increased in degraded land along the stretch during the same three year period.

The increase was observed along the western arm of the canyon. This is attributed to the rising elevation and the low rolling landscape compared to the Eastern arm. This makes it less costly to excavate and move quarry stones from the sites. Escalated anthropogenic activities and mechanized quarry excavations can be attributed to the weakening of the canyon’s geomorphic structure and cliff resulting to slope failure and rock falls.

Spatial-temporal Variations in Open Water Characteristics

To assess characteristics of Mutonga river water quality, a spatial-temporal analytical frame was considered. In this case normalised digital water index (NDWI) was used to map the reflectance associated with clear deep open water. The index based map extracted open water course across the three year period (2014 - 2017). The river’s water characteristics considered in this study were clarity (turbidity) and depth of the water course across the 8 km stretch. Resultant Boolean maps showed increased sediment loadings causing the river course to appear whitish discontinuous meanders. Sediments source was noted to be quarry dust and boulders deposited on the western arm of the river course (Fig. 4).



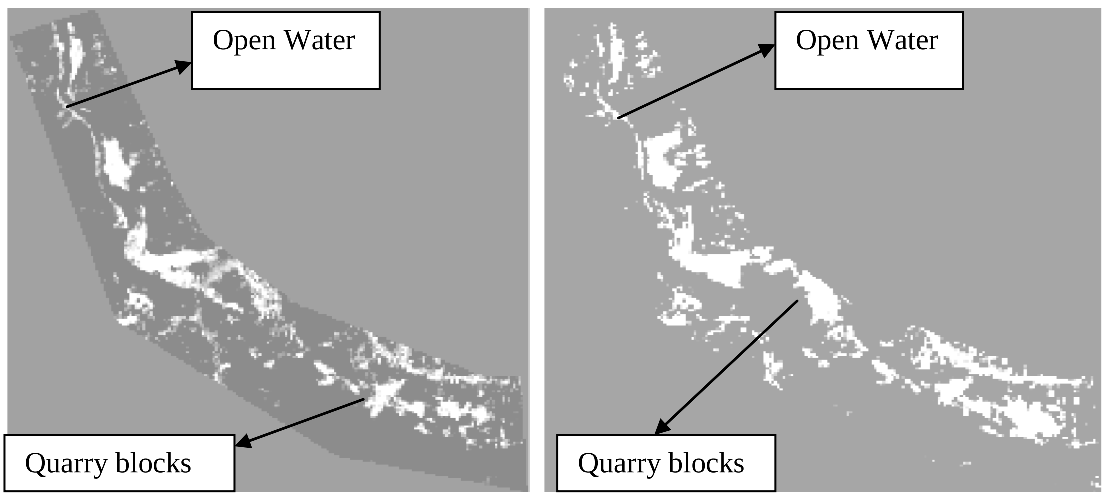
SAVI Map of 2014 SAVI Map of 2017

Figure 3: Resultant Soil Adjusted Vegetation Index Boolean Images of 2014 and 2017.

Table 1: Changes in Land Use/Cover between 2014 and 2017*

LULC	Area (Ha) 2014	%	Area (Ha) 2017	%	Area that Changed (2014-2017)
De-vegetated area	1651.90	40.8	1828.43	45.2	176.53
Built up area	243.50	6.01	325.42	8.04	81.92

*Area calculation based on subset region of Interest



NDWI Map of 2014 NDWI Map of 2017

Figure 4: Maps showing variations in Normalised Digital Water Index for 2014 and 2017

The variation in water quality was visually verified during field data collection. It was observed that soil creep from the overhanging quarry cliffs and sediment loadings from quarry banks were settling on the river floor and bed. This explains the reduced water depth and shrinking river banks due to encroached sediment loads. All these were attributed to human activities associated with quarry related activities along the entire stretch especially the upper western arm of the canyon. This explains the difficulty in delineating open water from the quarries due to almost similar spectral reflectance by the two difference land use/cover

CONCLUSION

The observed land degradation along the canyon has been accelerated by human activities associated with quarrying. The satellite image-based spatial-temporal assessment of soil and vegetation cover loss showed a remarkable variation in the intensity of degradation across the stretch. More open land was observed along the Eastern arm of the canyon as compared to the Western edge. Based on the analysis, land degradation is asymmetrical across the 8 km stretch with elevation and ease of accessibility accounting for the observed variations. The study recommends enactment of context-specific land use/cover policies as well as mining regulations for shared resources across the two counties. Furthermore constant monitoring of land use will inform appropriate resource use, rehabilitation and geomorphic hazards mitigation measures for sustainable livelihoods. There is a need to address concerns of micro-environmental degradation pointed out by this study especially along the canyon stretch through slope stabilization. Environmental audits to ascertain the severity of the on-going quarry activities across the canyon will help decision makers regulate the licensing of quarry stone mining.

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