GIS-Based Land Capability Classification in Relation to Existing Land Use/Land Cover in Weja Sub-Watershed, Southern Ethiopia

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Abstract

The main objective of this study was classifying the land of the study area (Weja sub-watershed) according to its capability and compare with the existing land use/land cover using GIS and Remote Sensing (RS). Land use/land cover was determined from Landsat satellite image by applying supervised classification method in Erdas Imagine 9.1 software. Digital Elevation Model (DEM) data of 30 m resolution was used to derive slope. Information on land and soil characteristics, and the specified limitations and criteria were captured in a spatial digital format. Based on the specified parameters, the limitations were separately mapped out in the form of thematic layers suitable for analysis in Arc GIS. Intersect overlay analysis method was applied to obtain the spatial and attribute information of all the input parameters using Arc GIS 10.3 software. Five land capability classes were arrived at classes II, III, IV, VI and VII. The result revealed that out of the five land capability classes, 479.25 ha (58.78%) were categorized in the range of land classes II to IV. The remaining 336.06ha (15.73%) of the study was categorize as class VI and VII. The GIS overlay analysis of the existing land use/land cover and the land capability map indicates that, 364.57ha (44.71%) cultivated land falls under land capability class II-IV respectively. The remaining 107.57 (13.2%) of the cultivated land in the study area falls under land capability class VI and VII, which is not at all suitable for annual cropping. The study result indicated that the existing land use and land cover were not as per the capability of the land.

Keywords: Land capability classes, Sustainable, Land use/Land cover, GIS, Overlay analysis, Digital Elevation Model (DEM).
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1. INTRODUCTION

With the rapidly increasing population pressure and demand for land, the challenges concerning the proper use of land resource and improved land management are becoming important issues all over the world (FAO, 2008). Due to over exploitation and mismanagement of natural resources together with socio-economic factors, the problem of land degradation is on the rise (Sachin, 2011). Throughout the world today, land degradation is among the major problems facing human being. In developing countries, majority of the population lives in rural areas and its livelihood depends on land resources to produce agricultural output. However, developing countries' economy is currently threatened by agricultural productivity decline due to land degradation. In Africa alone, it is estimated that 5 - 6 million hectares of productive land are affected by land degradation each year (Berry, 2003). Obviously, erosion is a more serious problem to developing countries including Ethiopia (Stocking and Niamh, 2000). Soil erosion by water is the major cause for land degradation in the Ethiopian highland (Carucci, 2000; Girma, 2001). The average annual rate of soil loss is estimated to be 42 tons/ha, and can be even higher on steep slopes with soil loss rates greater than 300 tons/hectare/year or about 250 mm/year where vegetation cover is scant (Nyssen et al., 2003; Shibru, 2003; Hurni, 1993).

The degradation of land resource due to overexploitation and misuse and consequent economic, social and environmental impacts has intensified the pressure on the land resources of the country (Menale et al., 2008; Akililu and Graaff, 2007; EFAP, 1994). Land degradation is a major cause of poverty in Ethiopia and the farming populations have experienced a decline in real income due to demographic, economic, social, and environmental changes (Mitiku et al., 2002; Hurni et al., 2010). Land resources should be managed in a sustainable manner so that its production capacity is maintained or improved for future generations (Kanwar, 1994). It has been essential in a country like Ethiopia where majority of the population depends on agriculture (Gizachew and Tiringo, 2014). For a more permanent productivity, land should be used wisely within its capability. The use of land is not only determined by the user but also by the land capability (Panhalkar, 2011; Sachin, 2011). Therefore, the knowledge of land capability classification is a prerequisite and important for planning, implementation and execution of soil and water conservation programs (Tideman, 2000).

2. Materials and Methods

2.1 Location

The study area, Weja sub-watershed, is located in Wolaita Zone of Southern Nations, Nationalities and Peoples Regional State, Ethiopia (Figure 1). It is located at about 7km north of Sodo town and 368 km South of Addis Ababa. It's geographically located between 06°53' 18" and 06°54'18" N latitude and between 37°43' 37"and 37°46' 23" E longitude.

2.2 Study site description

The study site is characterized by diverse topography conditions composed of rugged undulating mountain and rolling hills. The elevation of the study area ranges from 1915 to 2922 m.a.s.l., mean annual rainfall ranges from 950mm to 1800mm and, mean annul temperature ranges from 10.80 to 280. The pattern of rainfall distribution is bimodal. The first rainy period (Belg) occurs in March to May, while the second rainy period (Kremt) covers July to October, with its peak in July/August.

The dominant soil types are Eutric Nitosols associated with Humic Nitosols. These are dark reddish-brown soils with an extremely deep profile (Weigel, 1986). The major land use types in the study area are cultivated, grazing, bare land, conserved and bush lands. In these land use types, trees, herbs and grasses are observed. Agriculture is characterized by subsistence mixed crop-livestock farming in the study area. Most of the area around the homestead is covered with perennial Enset (Ensete ventricosum), which is a staple food together with cereals, roots and tuber crops (Mulugeta et al., 2006). Found close to the houses are a mixture of spices and a cabbage plot that covers a narrow strip of land.

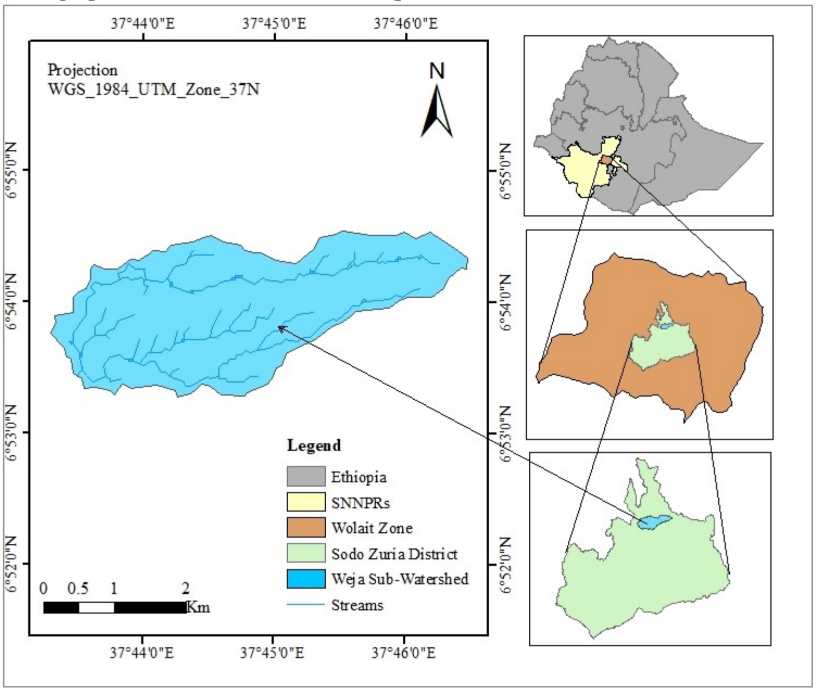


Figure 1: Map of the Study Area

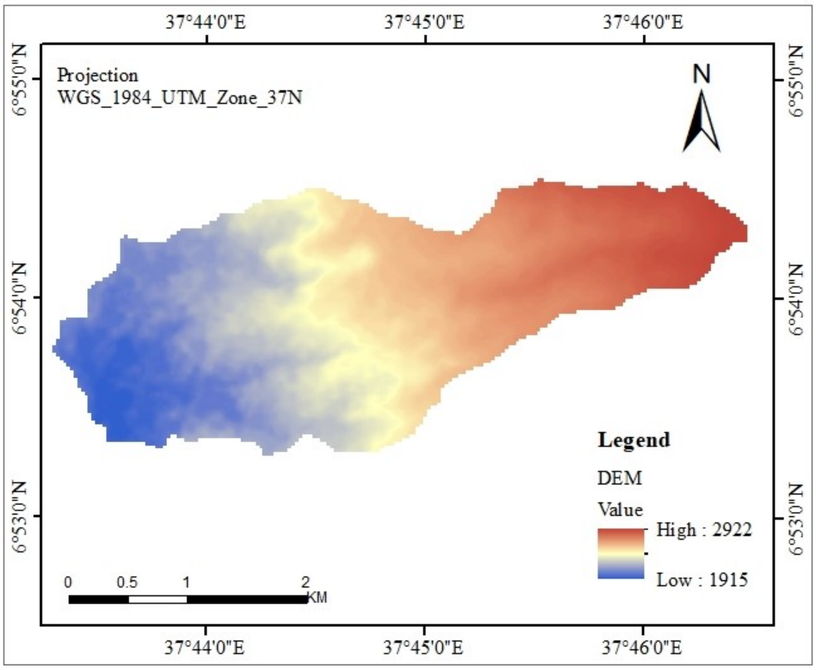


Figure 2: Elevation Map of the Study Area

2.3 Methods

Watershed delineation

The delineation process requires a Digital Elevation Model (DEM) in ESRI grid format. The 30 m spatial resolution DEM was used to delineate the watershed. Flow directions for individual DEM cells were created using flow direction and accumulation tool in Arc GIS. Arc GIS computes flow direction for individual DEM cells and uses stream threshold area in hectares to create streams based on these directions. Automatic watershed delineation was employed using watershed delineator tool in Arc GIS based on an automatic procedure.

Soil survey

A semi-detailed soil survey was done following the techniques developed by Dent and Young, (1981). Using transect walk, a representative soil profiles location was selected in the sub-watershed depending upon soil heterogeneity in physiography. Thus, one representative pit was opened for every 50 ha as per the recommendations of FAO (1976). A total of sixteen soil profiles were opened for soil profile description and laboratory analyses. The auger observations for the soil depth and surface texture were grouped into the USDA (2014) depth and texture classes. Points with the same soil depth class and surface soil texture in a given slope class was considered as a single land mapping unit.

Soil profile description was conducted according to the methods given in the Soil Survey Manual (FAO, 2006). Different soil properties, diagnostic horizons and depth of horizons were described and recorded in the field. Surface stoniness was estimated and recorded as percentage coverage of the areas.

Land capability classification methods

In this study the USDA land capability classification developed by Klingbiel and Montgomery (1961) was used with some modification. Initially, the various land resources such as soil and topographic factors that determine the capability class of a land were carefully assessed.

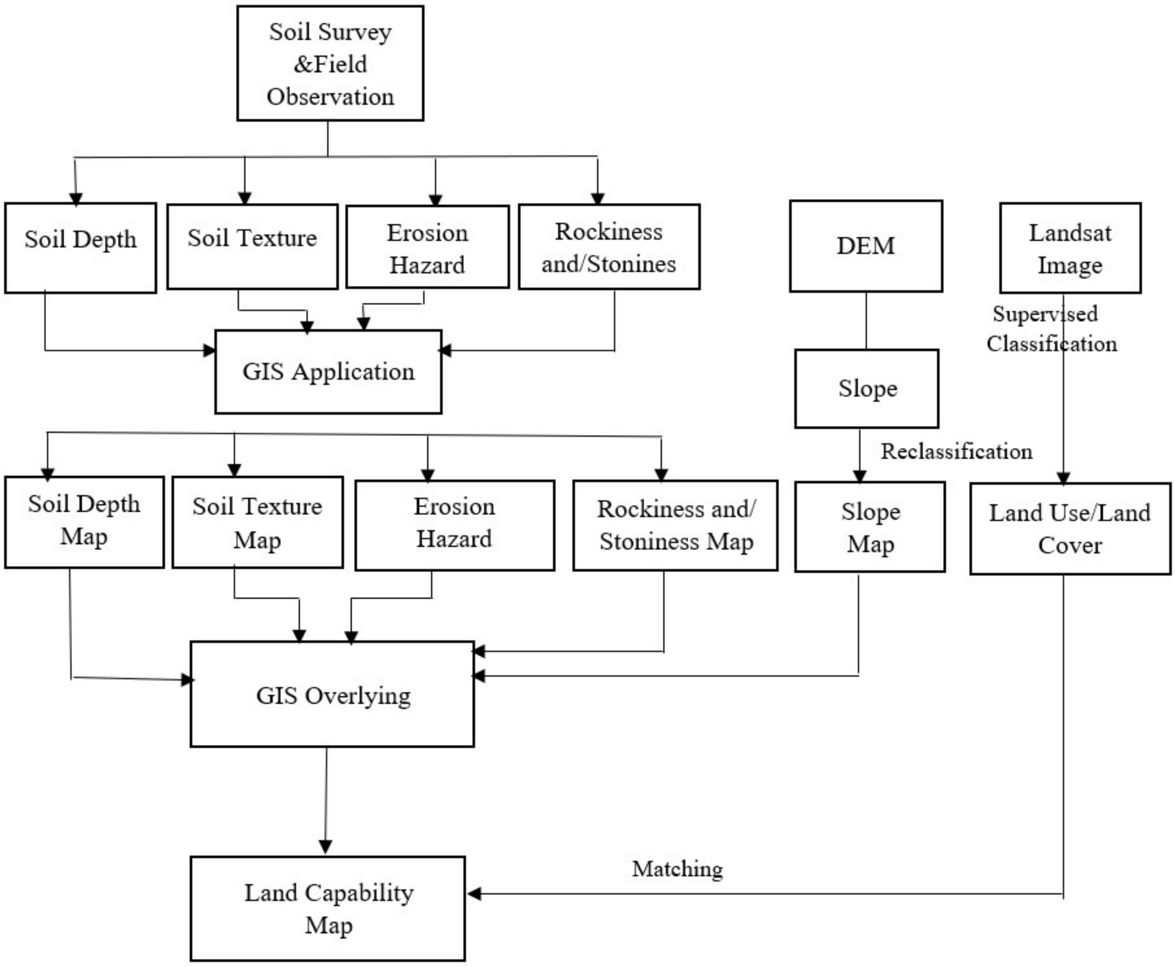
The assessment was based on a semi-detailed survey of the physical and chemical properties of the soils and land characteristics. The boundaries of soil mapping units were carefully determined and geo-referenced using GPS and established polygons of land mapping unit. At this stage, several soil and land characteristics, which are referred to as limitations that were used to place a land to a certain capability class were identified. The soil and land characteristics limitations associated with the land mapping units were added as attributes for further analysis.

The limitations were separately mapped out in the form of thematic layers suitable for analysis in Arc GIS. Slope was assessed separately from the DEM. The slope derived from the DEM was classified based on USDA classification system using the "Reclassification" tool, which is an attribute generalization technique in Arc GIS. The classified raster data layers were then converted to feature (vector) data layers for the overlaying analysis.

Using data management tools in Arc Tool box, generalization of the feature (vector) data layers was performed to make a clearer slope map. These slope classes were then used with the land characteristic capability classes to determine the final topographic capability classes. Based on the soil and topographic capability classes the final land capability classes were established within a GIS by employing overlay analysis.

Land use/land cover classification

Land use/land cover classification was done using Landsat satellite image for identifying the existing land use/land cover types. The classification was carried out using Erdas Imagine 9.1 software. The Landsat image was imported into Erdas Imagine 9.1 and geo-referenced by geographic coordinates. Then true color composite image was created by combining the spectral bands for land cover analysis. In this study land use/ land cover classification was performed by employing supervised classification. For this purpose, ground-truthing was conducted during field work using Global Positioning System (GPS) for image interpretations. Then classification to vector tool was used to convert classification results to Erdas polygon vector layers and finally exported to Arc GIS 9.3 as a shape file to create the final land use /land cover map.



3. Result and Discussion

3.1 Land capability classes

Five land capability classes were arrived at (classes II, III, IV, VI and VII). The result indicated that out of the five land capability classes, class II land occupy 158.13ha (19.40%) of the total area having limitation of moderate sheet erosion (Table 1). Class III land is the smallest in the study area occupy 103.32ha (12.67%) of the total area having limitation of moderate sheet erosion. Class IV is the dominant class in the study area covers an area of 217.8 ha (26.71%) having limitations of moderately slopping with severe sheet erosion and rills and sufficient rockiness cover. Class VI land is the largest class identified in the study area next to class IV occupying an area of 207.81ha (25.49%) having limitations of strongly sloppy, very severe sheet erosion and rills, severe rockiness and stoniness limitations. This class is commonly found in the north and northeastern parts of the study area where slope gradient is greater than or equal to 30%.

The remaining 128.25ha (15.73%) of the study was categorize as class VII land, having limitation of shallow soil depth, steep slope, very severe sheet and rills erosion and very severe rockiness and stoniness limitation. Class VII land is more confined to strongly sloppy and steep sloppy area in the north and northeast parts of the study area. The geographical extent of each land capability class is shown in Figure 4.

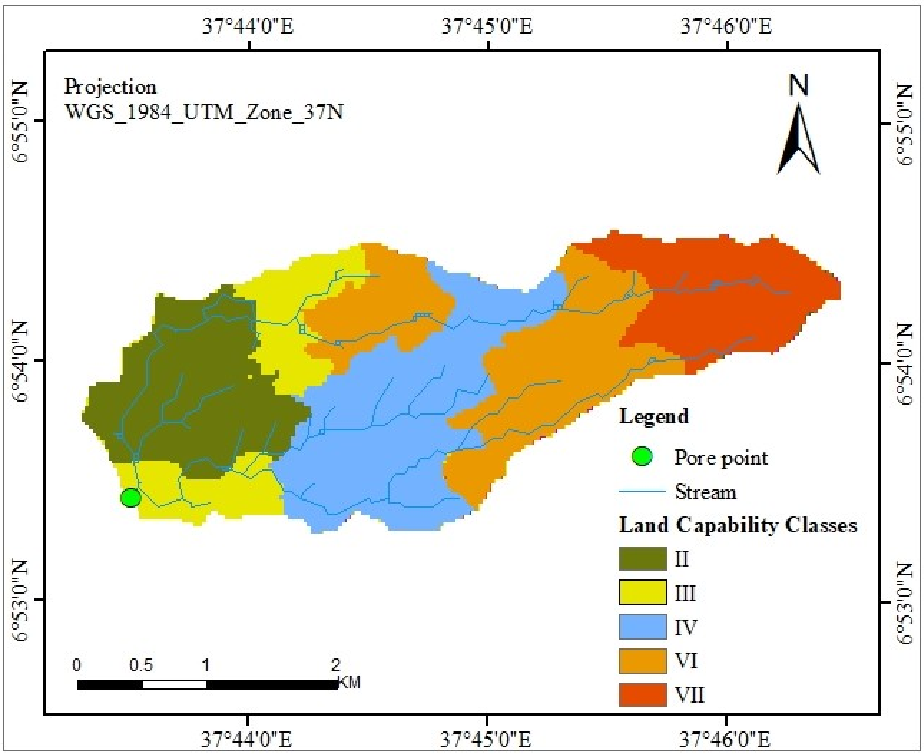


Figure 4: Land Capability Classes of the study area

Table 1: Land capability classes and their extent in hectares

No.	Land Capability Classes	Area(ha)	Percentage of the total area
1	II	158.13	19.40
2	III	103.32	12.67
3	IV	217.8	26.71
4	VI	207.81	25.49
5	VII	128.25	15.73
Total		**815.31**	**100**

Out of the five land capability classes, the first three classes (class II, III and IV) are considered as arable land for crop cultivation with "moderate to low" potential (Klingbiel and Montgomery, 1961; Scotney *et al*, 1991; Guy and Smith, 2002). These three land capability classes cover 479.25ha (58.95%) mainly found in the lower parts and central parts of the study area (Figure 4). The remaining 41.05% (221.6 ha) of the study area falls under class VI and VII lands and these lands were found to be non-arable land.

Land in class II has very few permanent limitations. Land in this capability class has moderate limitations that restrict the range of crops grown. The limitations are moderate and can be managed and cropped with little difficult. Erosion hazard was recorded as moderate sheet erosion with very few signs of rills. Lands in class III have more restriction than those in class II when used for cultivated crops and as “Moderate potential arable” land. Slopes in this class land are moderately slopping and erosion hazard was recorded moderate sheet erosion and frequent signs of rills. Land capability class IV, although arable with severe limitation, is classified as “low potential arable".

3.2 Land Use/Land Cover

Using the application of supervised image classification methods, four major land use/land cover types were identified. These include forest land, cultivated land, settlement and bare land, based on the Landsat images of the year 2015. The land use/land cover analysis indicated that the dominant land use/land cover class is cultivated land covering an area of 330.86ha which accounts for (61.27%) of the total study area, and forest land (28.33%) cover an area of 153.01ha from the total study area and followed by settlement cover an area of 51.78ha (9.59%) while the least area coverage occupied by the bare land which accounts for only 4.81ha (0.89%) as indicated in Table 14.

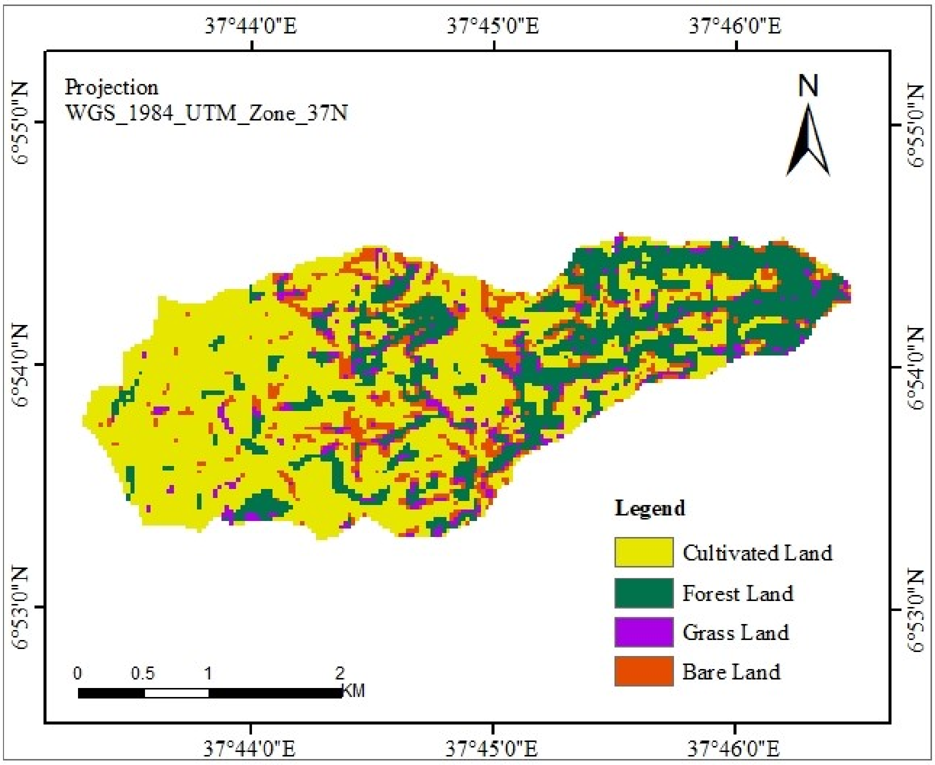


Figure 5: Land use/land cover map of the study area

Table 2: Land use/land cover and their extent in hectare

No	Land Use/Land Cover	Total Area (ha)	Percentage of the total area
1	Cultivated Land	472.14	57.91
2	Forest Land	211.32	25.92
3	Grass land	86.22	10.58
4	Bare Land	45.63	5.60
Total		**815.31**	**100**

3.3 Comparison of Existing Land Use with Land Capability Classes

The land capability classification result indicates that 58.95% (318.4 ha) of the study area falls under class II to IV lands. Lands categorized in these classes are suitable for crop cultivation with appropriate conservation measure. However, as one moves from class II to class IV, the cultivable land becomes more and more vulnerable to erosion and therefore requires more and more intensive conservation measure. The land use /land cover map has shown that 61.27 % (330.86 ha) of the total study area is currently used for crop cultivation. The remaining 38.73% (230.86 ha) is collectively covered by forest, settlement and bare land.

The GIS overlay of the existing land use/land cover and the land capability map indicates that, only 8.22% (27.20 ha) cultivated land falls under land capability class II where crop cultivation can be carried out with the help of simpler conservation measures. Land capability class III occupies 19.19% (63.48 ha) of the cultivated land, where crop cultivation requires a complex and intensive conservation practices to sustain cropping. The largest portion of cultivated land falls under land capability class IV, which accounts 42.82% (141.66 ha) of the study area i.e., marginal land that can be used for crop cultivation only with the support of intensive conservation measure and it requires very careful management and higher input. The remaining 29.78% (98.53ha) of the cultivated land in the study area already falls under land capability class VI and VII, which is not at all suitable for annual cropping.

Table 3: Area and percent proportion for each capability class under different land use types

No.	Land Capability Class	Land Cover	Area (ha)	Area (%)
1	II	Cultivated Land	140.58	17.24
		Forest Land	8.1	0.99
		Grass land	6.21	0.76
		Bare land	3.24	0.40
2 .	III	Cultivated Land	81.52	10.00
		Forest Land	10.33	1.27
		Grass land	7.00	0.86
		Bare land	4.48	0.55
3	IV	Cultivated Land	142.47	17.47
		Forest Land	34.20	4.19
		Grass land	29.16	3.58
		Bare land	11.97	1.47
Sub-total			**479.25**	**58.78**
4	VI	Cultivated Land	73.35	9
		Forest Land	83.7	10.27
		Grass land	31.95	3.92
		Bare land	18.81	2.31
5	VII	Cultivated Land	34.22	4.20
		Forest Land	74.99	9.20
		Grass land	11.90	1.46
		Bare land	7.13	0.87
Sub-total			**336.06**	**41.22**

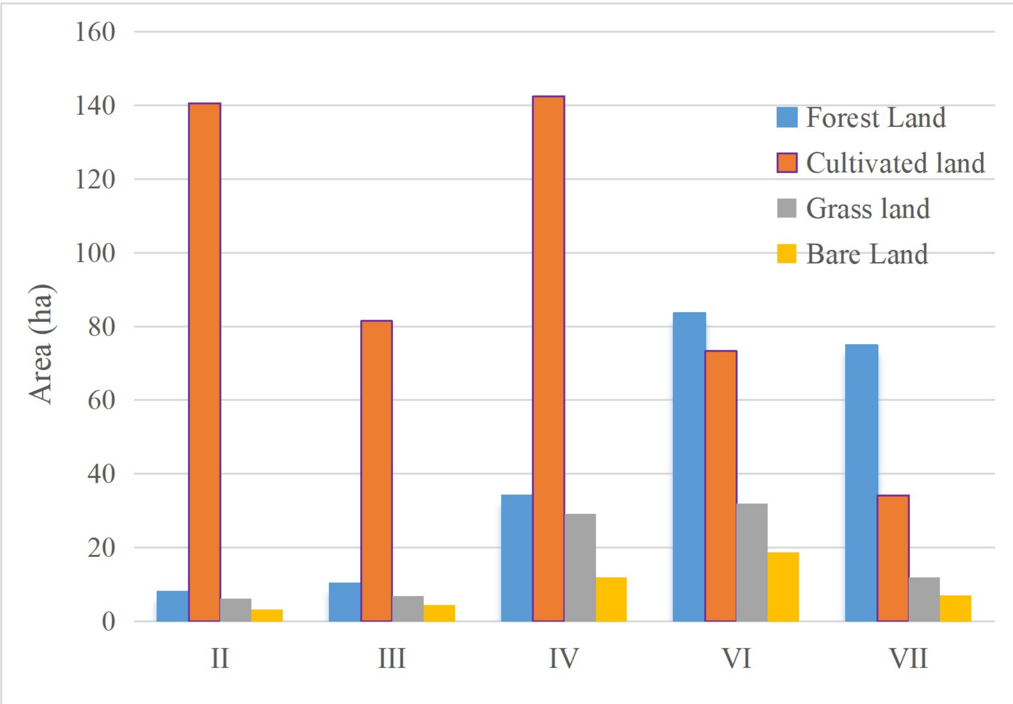


Figure 6: Land capability classes under different land use

4. Conclusions and Recommendations

4.1 Conclusions

The land capability classification result indicates that 58.95% (318.4 ha) of the study area falls under class II to IV lands and were found to be moderate to low potential arable land. The remaining 41.04% (221.6 ha) of the study area falls under class VI and VII lands and these lands are not at all suitable for annual crop cultivation.

The GIS overlaying analysis of the existing land use/land cover map and the land capability map indicates that only 8.22% (27.20 ha) cultivated land falls under land capability class II where crop cultivation can be carried out with the help of simpler conservation measures. Land under capability class III, which accounts for 19.19% (63.48 ha) of the cultivated land. Cultivated land under capability class IV, which accounts for 42.82% (141.66 ha) of the total cultivated land, can be sustained if only it is supported by intensive conservation measure. 29.78% (98.53ha) of cultivated land falls under land capability class VI and VII, which is not at all suitable for annual cropping. The study result has shown that existing land use/land cover is not as per the capability of the land.

4.2 Recommendation

Under good management, lands under class II and III are moderately to high productive land for a fairly wide range of crops. Class III land are more severe limitations and requires more intensive conservation practices to sustain production. Therefore, class II and III lands should be protected from non-agricultural development. Although, agricultural land in the study area is limited as compared to the size of the community, class IV (marginally productive land) should also be reserved for agricultural uses with intensive and careful management.

Lands under class VI and VII are not at all suitable for annual crop and hence should be immediately put out of production and need to be protected from any human interventions. With a proper management it can be used for the growth of valuable grass and/or tree cover. Generally, this study may not provide the ultimate explanation for all problems related to land and cannot be an end in itself without being supported by other relevant land resource, economic and social study. Hence further studies such as suitability assessment and socioeconomic study are required to implement land use planning.

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