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Research Article

Evaluating Saturated Hydraulic Conductivity under Different Land Use types, Gumara Watershed, Tana Sub-basin

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Abstract

Determination of hydraulic conductivity of a soil is very crucial for doing appropriate land management interventions and to assess the recharging potential of wells, movement of pesticides and nutrients through the soil profile. The aim of this work was to evaluate saturated hydraulic conductivity under different land uses of disturbed and undisturbed soil. This experimental study was carried out Gumara watershed under Tana sub-Basin. Soil saturated hydraulic conductivity measurement was performed on both disturbed and undisturbed soil samples using a constant head device and in-situ field measure, respectively on three land use types such as cultivated, grazing and forest. Result showed that saturated hydraulic conductivity was significantly ($p<0.05$) higher in disturbed soil than in-situ measurement conditions in all land uses. Furthermore, linear fit of disturbed to undisturbed soil of saturated hydraulic conductivity data resulted in a good R^2 across the selected land uses. Therefore, developing an equation which replaces the time taking in-situ saturated hydraulic conductivity measurement and that may have also a far reaching impact on efficient water management.

Keywords: Land use, land management, saturated hydraulic conductivity, disturbed, undisturbed soil.

Introduction

Hydraulic conductivity is the ability of soil material in transmitting water. Land use changes have a great effect on soil environment particularly in water holding and transmission capacity of soils (Hillel, 1998; Fereshte *et al.,* 2016). The knowledge of water retention capacity and, understanding the relation between water retention capacity and land uses effects are important for efficient soil and water management. Several researchers have demonstrated that land use types have an important effect on the soil hydraulic characteristics (Sonneveld *et al.,* 2003; Todd and Mays, 2005; Zhou *et al.,* 2008). Land conversion practices specifically from natural forest into cultivation and grazing, soils changes their properties, including loss of organic matter, increase in bulk density, and deteriorations in their structural and aggregate stabilities. Differences in hydraulic conductivity have been attributed to soil texture, aggregate stability, bulk density, organic matter content, surface roughness and these all emanated from the land use change (Schwartz *et al.,* 2000; Yimer *et al*., 2008; Molina *et al.,* 2014). Characteristic of soil water movement is affected by soil organic carbon content and porosity, which are significantly influenced by land-use type (Zhou *et al.,* 2008).

However, this study focused on saturated hydraulic conductivity which measures the saturated soil ability to transmit water or infiltration rate reaches steady state (Smith, 2002; McCuen, 2003; Elhakeem *et al.,* 2018). This information is very helpful to make appropriate land management interventions and to quantify the surface runoff, movement of pesticides and nutrients through the soil profile saturated hydraulic conductivity have shown large spatial variability at both large and small scales due to various combinations of the intrinsic soil properties (e.g. texture) and extrinsic factors such as land use (Tietje and Richter, 1992; Elhakeem and Papanicolaou, 2012). In-situ field measurement of saturated hydraulic conductivity is more accurate and reliable but, it's expensive in terms of time. Measuring saturated hydraulic conductivity using laboratory test in disturbed soil condition and approaching to field measurement or indirect estimation of hydraulic conductivity is very crucial (Vincent *et al.,* 2008). However, limited studies are available in Ethiopia that assesses the relation between hydraulic conductivities in disturbed and undisturbed soils. Therefore, this study was undertaken (1) to determine the saturated hydraulic conductivity under different land use and (2) to develop relationship between disturbed and undisturbed soil in terms of saturated hydraulic conductivity under different land use types.

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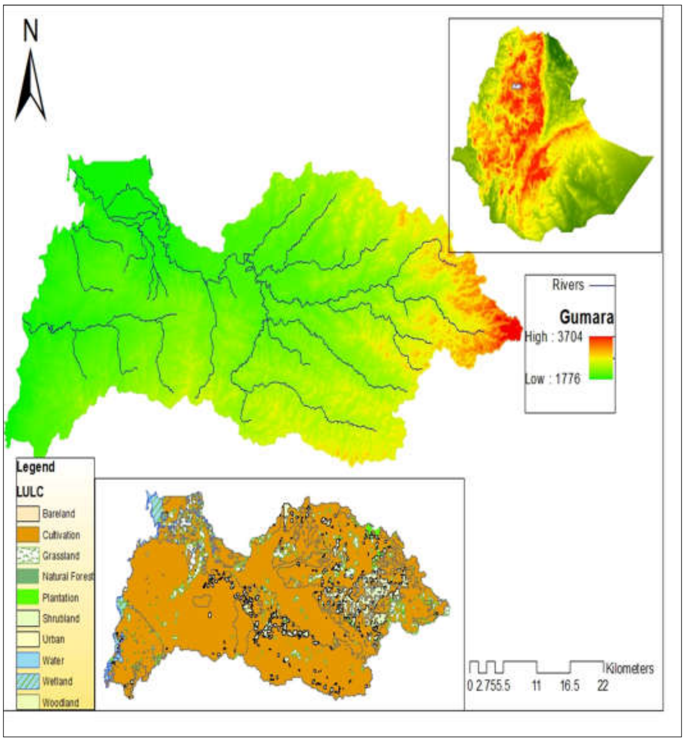
Materials and methods

Experimental site description: The Gumara watershed is found in east direction of Lake Tana the Northwestern Ethiopia Lake Tana basin (Fig. 1). The Gumara River is a river located between latitude of 11° 35' and 11° 55' N and longitude of 37° 40' and 38° 10' E. The watershed has a total drainage area of 1271 km^2 up to the gauging station (near woreta), a head of 25 km before it joins the lake. The total main stream length from its origin is approximately 132.5 km before the river joins Lake Tana. The watershed can be characterized by sub-humid mono seasonal climate and, having the average temperature and annual average rainfall of 21 °C and 500 mm, respectively. As shown in Fig. 1, more than 76% of the Gumara watershed is dominated by cultivated land followed by grazing land use (14%). Furthermore, dominant soil types are identified in the watershed, such as; Luvisols, Fluvisols, Leptosols and Vertisols (Ayenew, 2008; Abate, 2015).

Fig. 1. Geographical and land use type map of Gumara watershed.



Experimental design: The study was conducted on three land use types such as natural forest, grazing and cultivated land. A total 27 measurements (3 land uses X 3 position X 3 replication) were taken in disturbed and undisturbed soils. The undisturbed soil sample was done in the field by digging the soil or making a hole and then water was added in to the soil. While, the disturbed soil sample was conducted in laboratory test through a constant head test at the height of 40 cm and 7 cm diameter.

Field measurement and data collection: Two kinds of measurements (i.e. at laboratory and field level) were used for determination of hydraulic conductivity in disturbed and undisturbed soil samples under the selected land uses. For laboratory test, constant head was preferable to measure saturated hydraulic conductivity (Papanicolaou *et al.,* 2009) and the soils were taken from field is placed into a plastic tube. The bottom of the tube is covered with a mesh that lets water flow through but not soil particles. Water was then applied to the column of soil until it is saturated. Once the soil is saturated, additional water is pumped on to the top of the column and held several millimeters above the soil in the column. While the water head above the soil column is held constant by a small pump, water begins to drain out the bottom of the column through the mesh. The volume of water that is flowing out the bottom of the column is collected and measured over time. The water flow through the column was recorded for several consecutive times. The saturated flow rate has been attained while the water flow was steady time to time. Therefore, a saturated hydraulic conductivity was then computed for the soil sampled under the respective land uses. In-situ field measurement, infiltration based hydraulic conductivity measurements were taken in selected land uses using double ring infiltrometer. The rate of fall of water has been measured in the ring and recording of water levels were carried out in different time interval until the infiltration rate becomes steady state and that considered as the saturated hydraulic conductivity.

Statistical analysis: All the data obtained from the field and laboratory measurements were arranged and processed through Microsoft Excel spreadsheets before any statistical analyses carried out. The statistical analysis performed with the SAS statistical package with 2017 version. The General Linear Model procedure (GLM) was used for the analysis of variance. Fisher test (LSD) was also used for separating group of means in the ANOVA setting when the analysis of variance showed statistically significant differences ($p<0.05$). Regression analysis was used to establish relationships between parameters were considered.

Results and discussion

Soil texture: As shown in the Table 1 individual land uses coverage in the study watershed was varies. The largest area in the watershed covered by cultivated (76%) followed by grazing (14.4%) land uses. The population incremental trend of communities in the study watershed and their livelihood system depends on mixed farming system that could be the possible for largest area covered by the cultivated land use. These land uses effect on soil texture was observed in Table 1. Similarly, soil texture classes had shown significant differences among the land use types.

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Table 1. Land uses percentage in Gumara watershed and its effect on soil texture up 60 cm depth.

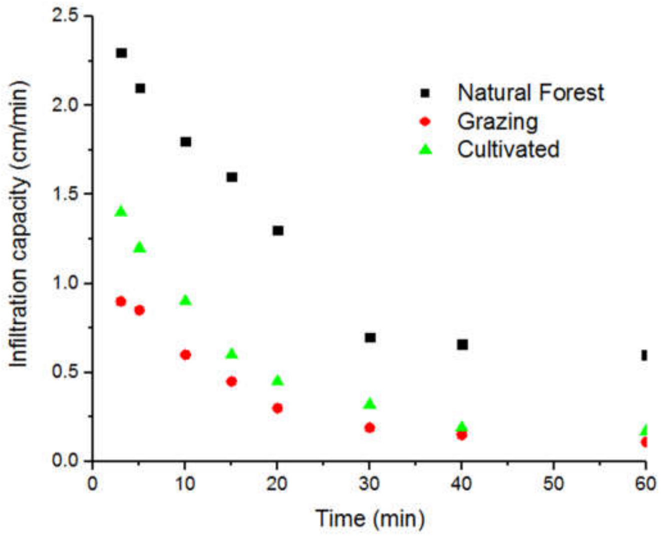
Land use	Percentage	Texture class	Percentage
Natural forest	8.2	Loam	1.30
		Heavy clay	6.50
		Sandy loam	0.39
		Silt clay	0.01
Grazing	14.4	Loam	3.19
		Heavy clay	9.87
		Sandy loam	1.34
		Silt clay	0.09
Cultivated	76	Loam	9.81
		Heavy clay	62.82
		Sandy loam	3.17
		Silt clay	0.37

Heavy clay soil texture class was dominating in all land uses, but the percentage was higher in cultivated than other land use type. Soil texture is one of the prominent factors in influencing water infiltration rate. As indicated by Schwartz *et al.* (2000), land uses had a greater effect on water movement in the soil profile than soil texture.

Evaluation of infiltration rate under different land uses: Land uses response to water infiltration has showed significant difference as indicated in Fig 2. Under the natural forest 2.26 cm min^{-1} brought better initial infiltration rate value followed by cultivated (1.46 cm min^{-1}) and grazing (0.94 cm min^{-1}). In infiltration capacity comparison, significance improvement was observed under natural forest by 80% and cultivated (35%) as compared to grazing land uses. The lower bulk density and higher organic matter content could be the possible reason for the higher infiltration rate and capacity value in natural forest land. This study was in line with (Bormann and Klaassen, 2008; Yimer *et al.,* 2008). Likewise, soil compaction and soil structural degradation in the surface soil might be attributed to the reduction in infiltration rate from natural forest to grazing land. This degradation brings a discontinuity micro pore space between the surface and subsurface soil particularly under grazing and cultivated land use types (Jime´nez *et al.,* 2006; Yimer *et al.,* 2008)

Saturated hydraulic conductivity: There was significance difference ($p<0.05$) in saturated hydraulic conductivity among the selected land uses in both disturbed and undisturbed soil conditions as shown in Table 2. The greatest measured saturated hydraulic conductivity was observed in natural forest (0.60±0.05 cm min^{-1}) followed by cultivated (0.17±0.04 cm min^{-1}) and grazing (0.11±0.06 cm min^{-1}) land uses under undisturbed soil. Likewise, saturated hydraulic conductivity under disturbed soil condition was higher in natural forest and on average 2.2 and 2.6 times compared to grazing and cultivated land uses, respectively.

Fig. 2. Shows infiltration rate from infiltration test examined on three land uses of the Gumara watershed.



In general, Ksat was showed elevated value in disturbed soil condition compared to in-situ measurement across all land uses. The positive effect of forest land use in saturated hydraulic conductivity in both soil conditions resulted in a better accumulation of organic matter; enhance soil water retention capacity and hydraulic conductivity as well. Unlike undisturbed condition, the Ksat in grazing land higher than cultivated (Table 2). Animal trampling on communal grazing land has reported (Ankeny *et al*., 1990; Yimer *et al*., 2008) as causing for increases in bulk density by compaction in the soil surface. Furthermore, in disturbed condition the soil might have better organic matter as a result of animals waste and that could be the possible reason. This finding has harmony with a study conducted by Schwartz *et al.* (2000) and West *et al.* (2008).

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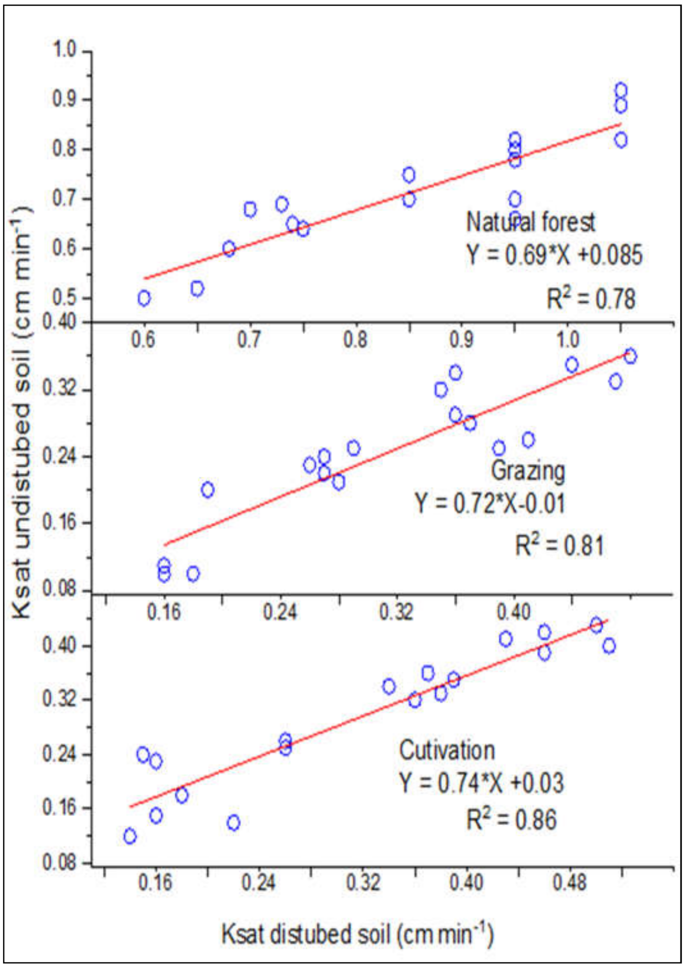
Table 2. Different land uses responses for saturated hydraulic conductivity value under disturbed and undisturbed soil.

Land use	Ksat (cm min^{-1})	
	Undisturbed soil	Disturbed soil
Natural forest	0.60±0.05^a	0.9 ±0.07^a
Grazing	0.11±0.04^b	0.41±0.06^b
Cultivated	0.17±0.06^b	0.34±0.05^c
CV (%)	24.3	16.8
LSD	0.2	0.4

Mean ± SD followed by the different letter in the column are significant (p=0.05); at land use type with respect to hydraulic conductivity under disturbed and undisturbed soil.

Relationships between disturbed and undisturbed soil of a saturated hydraulic conductivity: Saturated hydraulic conductivity in disturbed soil for each land use was plotted as a function of Ksat in undisturbed soil (Fig. 3). Linear regression type was applied to observe the relation between the two soil conditions in terms of saturated hydraulic conductivity. The intercept with the x-axis increase in Natural forest indication that more effective in Ksat. A saturated hydraulic conductivity in disturbed and undisturbed soils showed strong correlation for all land uses. Ksat was showed strong linear regression on a cultivated land (R^2=0.86) between disturbed and undisturbed soil. Less compaction due to tillage practice may a cause for less spatial variation of saturated hydraulic conductivity value and a better correlation in cultivated land.

Fig. 3. Saturated hydraulic conductivity relationships between disturbed soil plotted in X-axis and undisturbed soil in Y-axis under three land uses.



Conclusion

Effective soil and water management requires evaluation of saturated hydraulic conductivity under the different land uses. This paper is intended to serve as a contribution on the interaction between disturbed and undisturbed soil conditions in terms of saturated hydraulic conductivity under three land use systems. Experimental study result showed that saturated hydraulic conductivity was affected by different land use. Moreover, natural forest was responding higher Ksat value compared to other land uses. The fit of disturbed to undisturbed soil saturated hydraulic conductivity data resulted in a higher R^2. This finding indicated that the linear function was very crucial in describing a Ksat data in between mentioned soil conditions of the study area. Thus, the output of this work indicating that further investigating is needed to improve and generate wider evidence base.

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