EFFEC T OF LAND USE/LAND COVER CHANGE ON SOIL PROPERTIES IN THE HARE RIVER WATERSHED, ETHIOPIA

YECHALE KEBEDE* AND A. J. SOLOMON RAJU
Department of Environmental Sciences, Andhra University, Visakhapatnam - 530 003, INDIA
E-mail: kebyechenvi@gmail.com

INTRODUCTION

As is the case in many other developing countries, most of the population of Ethiopia lives in rural areas and depends directly on the land for its livelihood. However, the rapidly growing rural population has induced many effects on the resource base (Woldeamlak and Stroosnijder, 2003). One such effect is a very dynamic land use and land cover. This has been confirmed by studies carried out in different parts of the country (Solomon, 1994: Kebrom and Hedlund, 2000; Belay, 2002). The common issue addressed by many of these studies is the resource degradation as a response to the decrease in the area under natural vegetation, and its conversion into other types of land use/land cover. The underlining simple assumption is that de-vegetation leads to deterioration in the physical and chemical properties of soils, and degradation of the land. However, the assumption must be based on empirical evidences.

Woldeamlak and Stroosnijder (2003) reported that in Chemoga Watershed, Ethiopia, the land use types such as cultivated, fields, grazing lands and eucalyptus plantations showed a statistically significant difference in sand, Ca\(^{2+}\), Mg\(^{2+}\), Cation Exchange Capacity (CEC), SOM, total nitrogen content, available phosphorus, and Bulk Density when compared to the soils of natural forest. Mojiri et al. (2011) from Iran reported that land use changes and long term cultivation cause decrease in soil organic carbon, organic matter, total nitrogen and available potassium content. Gol et al. (2010) documented that bulk density, SOM and total nitrogen decreased in cultivated fields as compared to the forest soil in the Gakcay catchment, Turkey. Saikh et al. (1998a) from Orissa, India found out that conversion of forest into farmland led to a significant reduction in organic carbon, total N and C: N ratios, but not in total and available P levels. Geissen et al. (2009) however reported that the soils under different current land uses did not show any significant differences with respect to available phosphorus, organic carbon, and total Nitrogen and C/N ratio whereas the pH value was significantly higher under seasonal agriculture than under pasture in the tropical South-East Mexico.

In Ethiopia, there is abundant literature on the magnitude and rate of soil erosion in the highlands but information on changes in soil physical and chemical properties associated with land use is highly fragmentary (Woldeamlak and Stroosnijder, 2003). In the paper, we report on some physical and chemical properties of soils under different land use systems in Hare River Watershed, Ethiopia.

MATERIALS AND METHODS

Study area

The study area is located between 6º03' N and 6º18' NL, and 37º27' E and 37º37'EL (Fig. 1), covering about 234 km\(^2\) of area with a population of about 86,927 of which 65.8% live in highland while the remaining 34.2% live in the lowland part of Hare River Watershed. The watershed is one of the tributaries of

ABSTRACT

This study assessed the land use/land cover change and its subsequent effect on the properties of soils in Hare River Watershed in Ethiopia. The land use/cover change was assessed by analyzing Landsat images. Four major land use/cover types: Cultivated land, Grazing land, and Wood land and Forest (natural) were selected at three villages/sites. Forest was taken as a control to assess changes in soil properties resulting from the establishment of the other land use types. Soil samples taken at 0–15 and 15–30cm depth from all these four land use/cover types were analyzed for soil properties. Results showed significant difference in Bulk Density in all the four cover types. Forest soils had significantly higher SOM than grazing and woodland plots and higher total N than woodland. A significant difference among the different land uses was also observed in available P and sand content. There was no significant difference in soil silt fraction, clay, CEC, Ca\(^{2+}\), Mg\(^{2+}\), Na\(^{+}\), K\(^{+}\), pH and EC among the four land use types. Significant differences in CEC, Ca\(^{2+}\), Mg\(^{2+}\) and pH were observed between soils in the three sampled villages. The study suggests that accurate information on the effects of changes of land use/land cover on soil properties is imperative for designing a sound land use and environmental planning and management.

KEY WORDS

Land use change
Soil property
Forest
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*Corresponding author
the Abaya-Chamo basin in the rift valley. Topographically, it is characterized by slopes ranging from flat to steep slopes of which the sloppy topography comprises the largest proportion (Mohr, 1971). The area experiences the alpine and tropical climatic conditions (locally known as dega and Kola) agro-ecological belts. The mean average temperature throughout the year ranges between 14.3°C (in the highland) and 23.8°C (in the lowland). The rainfall varies between 872.5 mm in the lowland and 1286.5 mm in the highland. The predominant soil associations of the watershed include orthic acrisols and dystric nitosols, and eutric fluvisols. As to the vegetation, the main ones include Cordia abyssinica, Croton macrostachys, Syzygium guinnense and Eucalyptus trees.

Land use/cover change: Land cover changes in the study area over 25 years of period were extracted from Landsat Thematic Mapper (TM, 1985 and 2010) images. The images were geo-referenced to the Universal Transverse Mercator (UTM) geographic projection, using Clarke 1880 spheroid, datum Adindan (Ethiopia) and zone 37 N. As the study area is smaller than a full Landsat scene the images were trimmed to cover only the area of interest. Land use and land cover change analyses were performed with ERDAS imagine 8.6. A supervised maximum likelihood classification method was used to identify land use/land cover types. This has allowed the extraction of information on land cover condition and quantification of changes.

Selection of the sampling sites, soil sampling and analysis: Soil samples of both disturbed and undisturbed sites were collected from four different land use/land cover types representing forest (natural), cultivated land, grazing land and woodland (plantations dominated by Eucalyptus) from three sites/villages (Doko Dembo, Shamma Gede and Chano Chalba) located at the up, mid and downstream of the study watershed (Fig. 2). The criterion considered when choosing these sampling villages was land use, and not the types of soils, as the objective was to study variations in the soil properties with respect to differences in the land use types. Soil samples were taken at 0-15 cm (surface layer) and 15-30 cm (subsurface layer) depths in three replicates, which were located at about 50 m apart from each other. Each of the replicates consisted of seven sub-samples in composite, which were collected at random positions within a 15m × 15m.

The disturbed soil samples were taken with a soil auger for analysis of physical and chemical properties in the laboratory. The undisturbed soil samples were taken with steel core sampler of known volume to determine the BD. The collected soil samples were air dried, crumbled and passed through a 2 mm-mesh sieve before analysis. Then analytical methods were
employed following procedures described in Monrdep (1990). Texture (Particle size distribution) was determined by the Hydrometer method, Bulk density by the dry weight of a 100 mL undisturbed core sample taken at field-moist conditions, Soil pH by using a pH meter in a 1:2.5 soil: water ratio, Electrical conductivity (EC) by conductivity meter (Rhoades, 1996) and soil organic carbon by the Walkley-Black oxidation method. The percent soil organic matter (SOM) was calculated by multiplying the percent organic carbon by a factor of 1.724 (Nelson and Sommer, 1996). Total nitrogen (TN) was determined with a Kjeldahl digestion, distillation and titration method, Available P by the Olsen extraction method and exchangeable bases by the ammonium acetate extraction, and from the extracts, concentrations of Ca and Mg were determined by atomic absorption spectrophotometry, and K and Na by flame emission. The CEC was determined by summation of cations. Data were analyzed with SPSS statistical software. Analysis of variance (ANOVA) with the land use types and the sampled sites (villages) was conducted to test significance of mean differences in properties of soils (p<0.05). The soil properties that showed significant differences among the land uses were analyzed by employing the Scheffé post-hoc multiple comparison test (p<0.05) to estimate significant differences between the land-use systems.

Land use changes: The land use patterns in the Hare River Watershed, which were obtained by interpretation of Landsat Thematic Mapper (TM, 1985 and 2010) images are given in Table 1 and Fig. 3a, b and Fig. 4. By 1985, most of the area was occupied by farmland and settlement (57.3%), distantly followed by bushes and shrub lands (16.8%) and grazing land (8.2%). Riverine vegetation, forest and woodlands covered some 7.4, 6.2 and 4.1% of the total area of the watershed, respectively (Fig. 3a, and 4). Between 1985 and 2010 the area under farmland and settlement, and woodland increased, while forest, riverine vegetation, bushes and shrub lands and grazing lands decreased. The decline was greatest for bushes and shrub lands (4.4%), Riverine vegetation (2.6%) shrub lands (8.2%). By 2010, the farmland and settlement still covered the largest area (63.2% of total area) (Fig. 3b and 4).

The major change over the two and half decades was the increase of the cultivated area at the expense of other land use/cover types such as bushes and shrub lands, and grazing lands. The forest cover has lost about 350 ha (1.5%) during the study year, but the woodlands have increased by about 1200 ha. This increase is attributable to the afforestation activities during the deg regime, and the planting of trees by households. Eucalyptus is the widely planted species in
The afforestation activities by the farm households. The trees are planted around homesteads as well as in fields further away, where they are grown in larger blocks. By clearing the natural vegetation farmers were cultivating crops, but when the farmers felt the land fertility had declined to a bare minimum, Eucalyptus have been planted. This has implications for the current fertility status of soils under wood lands.

RESULTS AND DISCUSSION

Table 2 shows average values of soil properties for each of the four land use types, and grand averages of the four land use types in the three sampling sites. There were differences between the three villages. At Doko Dembo, soils were low in silt but high in SOM, and total nitrogen as compared to Shamma Gede and Chano Chalba. The nutrient status of the soil was better than in others. At Shamma Gede, BD, pH, Ca²⁺, SOM, available P, CEC, Ca²⁺, Mg²⁺, Na⁺ and K⁺ nutrient availability were much lower, however, highest amount of clay, in Chano Chalba soil, SiO₂, Al₂O₃, P₂O₅, Ca²⁺, Mg²⁺, K⁺ and Na⁺ were the highest, but least amount of clay. In Chano Chalba, soils were low in soil but high in SiO₂, Al₂O₃, P₂O₅, Ca²⁺, Mg²⁺, K⁺ and Na⁺ and total N (Table 2). In many cases, the forest soils showed the best properties for plant growth than soils under other land types.

Soil texture:

In the three villages, the sand fraction was lowest in forest plots and highest in the grazing lands (Table 2). The clay fractions, on the other hand, were highest in the forest plots and lowest in both the cultivated and woodland plots. The sand contents but not silt and clay content statistically differed among the land use types (Table 3). The scheffe test revealed that the forest soils differed from grazing in terms of sand content (Table 4). The general trend in soil texture after the conversion of forest into the other types of land use was an increase in the sand and a decrease in the clay content (Table 2). The ANOVA also revealed significant differences among the land use types (Table 4). The SOM content of soils under forests was the highest (Table 2). The values obtained were compared with the forest plot. The soils under cultivation, grazing and woodland in Doko Dembo had average SOM contents of 70.6%, 11.8% and 14.1% respectively of the forest plot; the corresponding values for the same land use types were 32.8%, 14.1% and 23.4% of the forest plot in Shamma Gede; and 56.9%, 25.0% and 34.8% of the forest plot in Chano Chalba. The SOM content of soils in Doko Dembo was much higher than that of Shamma Gede and Chano Chalba. The content of SOM in soils under different land uses has led to a drop in SOM contents. The ANOVA also revealed significant differences among the land use types (Table 3). The significant differences in SOM contents were the highest in grazing and forest, and woodland was between the forest and grazing. It seems that the conversion of forest into the other types of land uses has led to a drop in SOM contents. The ANOVA also revealed significant differences among the land use types (Table 3). The significant differences in SOM contents were the highest in grazing and forest, and woodland was between the forest and grazing. The significant differences in SOM contents were the highest in grazing and forest, and woodland was between the forest and grazing.

Bulk density:

The BD of the soils was generally low. It was lowest in areas under forest, and highest in areas of grazing and woodland (Table 3). The ANOVA indicated significant differences among the land use types (Table 4). Woodland soils had a higher BD than the other land use types (Table 4). The general trend in soil bulk density was an increase in the BD of the soils in the order of forest, woodland, cultivated and grazing lands (Table 4). In Doko Dembo, the BD of the woodland was the lowest, followed by the cultivated land, then grazing and forest (Table 4). The BD of the soils in the three villages (Table 4) is attributable to, among others, the differences in SOM content and the types of the soils.

Soil organic matter:

The SOM content of soils under forests was the highest (Table 2). The values obtained were compared with the forest plot. The soils under cultivation, grazing and woodland in Doko Dembo had average SOM contents of 70.6%, 11.8% and 14.1% respectively of the forest plot; the corresponding values for the same land use types were 32.8%, 14.1% and 23.4% of the forest plot in Shamma Gede; and 56.9%, 25.0% and 34.8% of the forest plot in Chano Chalba. The SOM content of soils in Doko Dembo was much higher than that of Shamma Gede and Chano Chalba. The content of SOM in soils under different land uses has led to a drop in SOM contents. The ANOVA also revealed significant differences among the land use types (Table 3). The significant differences in SOM contents were the highest in grazing and forest, and woodland was between the forest and grazing. The significant differences in SOM contents were the highest in grazing and forest, and woodland was between the forest and grazing. The significant differences in SOM contents were the highest in grazing and forest, and woodland was between the forest and grazing.

Table 2: Soil properties (0-30 cm) under the four land use types in Hare river watershed, Ethiopia

<table>
<thead>
<tr>
<th>Soil property</th>
<th>Doko Dembo Forest</th>
<th>Grazing Woodlands</th>
<th>Forest Average</th>
<th>Woodland Average</th>
<th>Shamma Gede Forest</th>
<th>Grazing Woodlands</th>
<th>Forest Average</th>
<th>Woodland Average</th>
<th>Chano Chalba Forest</th>
<th>Grazing Woodlands</th>
<th>Forest Average</th>
<th>Woodland Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand (%)</td>
<td>11</td>
<td>25</td>
<td>9</td>
<td>15</td>
<td>15.0</td>
<td>13</td>
<td>15</td>
<td>7</td>
<td>14</td>
<td>12.3</td>
<td>18</td>
<td>27</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>14</td>
<td>38</td>
<td>56</td>
<td>39</td>
<td>36.8</td>
<td>34</td>
<td>46</td>
<td>48</td>
<td>46</td>
<td>43.5</td>
<td>42</td>
<td>52</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>35</td>
<td>49</td>
<td>6</td>
<td>36</td>
<td>39.3</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>45.0</td>
<td>24</td>
<td>37</td>
</tr>
<tr>
<td>BD (g cm⁻³)</td>
<td>1.3</td>
<td>2.3</td>
<td>0.5</td>
<td>3.1</td>
<td>1.8</td>
<td>0.9</td>
<td>2</td>
<td>0.4</td>
<td>2.9</td>
<td>1.6</td>
<td>1.1</td>
<td>2.2</td>
</tr>
<tr>
<td>pH</td>
<td>5.6</td>
<td>5.5</td>
<td>5</td>
<td>5.1</td>
<td>5.3</td>
<td>5.1</td>
<td>5.4</td>
<td>4.9</td>
<td>4.8</td>
<td>5.1</td>
<td>7.5</td>
<td>10.3</td>
</tr>
<tr>
<td>EC (μS cm⁻¹)</td>
<td>0.2</td>
<td>0.1</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>SOM (%)</td>
<td>12</td>
<td>2</td>
<td>17</td>
<td>2.4</td>
<td>8.4</td>
<td>4.2</td>
<td>1.8</td>
<td>12.8</td>
<td>3</td>
<td>5.5</td>
<td>6.6</td>
<td>2.9</td>
</tr>
<tr>
<td>Total N (%)</td>
<td>0.4</td>
<td>0.7</td>
<td>0.8</td>
<td>0.2</td>
<td>0.6</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.7</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Avail. P (ppm)</td>
<td>38.3</td>
<td>18.9</td>
<td>6.3</td>
<td>2.4</td>
<td>16.5</td>
<td>15</td>
<td>8</td>
<td>2.1</td>
<td>1.3</td>
<td>6.6</td>
<td>46.7</td>
<td>24.6</td>
</tr>
<tr>
<td>CEC (meq.100g⁻¹)</td>
<td>10</td>
<td>12</td>
<td>24</td>
<td>8</td>
<td>13.5</td>
<td>12</td>
<td>4</td>
<td>15.0</td>
<td>45</td>
<td>15.0</td>
<td>13.5</td>
<td>77</td>
</tr>
<tr>
<td>Ca²⁺ (meq.100g⁻¹)</td>
<td>6.7</td>
<td>5.3</td>
<td>19.7</td>
<td>5.7</td>
<td>9.4</td>
<td>7.9</td>
<td>6.6</td>
<td>18.9</td>
<td>5.3</td>
<td>9.7</td>
<td>26.9</td>
<td>14.3</td>
</tr>
<tr>
<td>Mg²⁺ (meq.100g⁻¹)</td>
<td>1</td>
<td>4.9</td>
<td>2</td>
<td>1.4</td>
<td>2.3</td>
<td>2.8</td>
<td>8</td>
<td>3.1</td>
<td>2.6</td>
<td>4.1</td>
<td>16.6</td>
<td>23</td>
</tr>
<tr>
<td>Na⁺ (meq.100g⁻¹)</td>
<td>0.2</td>
<td>0.2</td>
<td>1.4</td>
<td>0.1</td>
<td>0.5</td>
<td>0.6</td>
<td>0.5</td>
<td>0.6</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>K⁺ (meq.100g⁻¹)</td>
<td>1.7</td>
<td>1.2</td>
<td>0.7</td>
<td>0.4</td>
<td>1.0</td>
<td>0.8</td>
<td>0.4</td>
<td>0.3</td>
<td>0.3</td>
<td>0.5</td>
<td>1.1</td>
<td>16.1</td>
</tr>
</tbody>
</table>
The intensity of erosion (which is more severe in Shamma Gede than in Doko Dembo and Chano Chalba) also influences the SOM content of soils. In Shamma Gede, the average SOM was 65.5% of Doko Dembo, and 94.8% of Chano Chalba. In the cultivated fields, the types of crops grown might also contribute to the observed differences. Land use practices that have detrimental effects on SOM contents have far reaching implications because of the multiple roles SOM plays in soil quality (Wild, 1996).

**Total nitrogen:** The total N content of the soil showed variation among the land use types, matching the SOM distribution. It reached a maximum of 0.8% in the surface soils under forest and woodland in that order. In Shamma Gede, the average SOM content of soils in Doko Dembo decreased from forest to grazing lands, cultivated land and woodland in that order. In Shamma Gede, and Chano Chalba both crop land and woodland have equal amount of total N (Table 3).

**Available phosphorus:** The available P content ranged from 2.4 ppm to 38.3 ppm in Doko Dembo, 1.3 ppm to 15.0 ppm in Shamma Gede, and 5.3 ppm to 46.7 ppm in Chano Chalba (Table 2), highest in cultivated fields and lowest in woodland plots in all the three villages. The amount of available phosphorus is also lowest in forest plots. A similar finding was also observed by Woldeamlak and Strosnijder (2003), who reported that the higher available P content of cultivated fields than forest suggests that trees in forests extract more phosphorus than field crops. Lisanework and Michelsen (1994) also further explained that the higher available P content of cultivated fields than forest showed that a high proportion of the P pool is retained and immobilized by microbes in the litter layers of forests. Another possibility is that the effects of applying manure by land users particularly around homesteads as a soil conditioner in cultivated fields has been substantial. Furthermore, available Phosphorus levels were lower in the forest soils than in the cultivated fields, despite the higher SOM contents of the forest soils indicating the significance of inorganic sources of P. Generally, the pattern of distribution of available P among the land use types suggests that the effect of deforestation and establishment of the other types of use on availability of this vital nutrient was not negative. A similar study in tropical India reported that insignificant change in available P following deforestation was observed (Saikh et al. 1998a).

In this study, although not statistically significant, the average amount of phosphorus in Shamma Gede is lesser than in Doko Dembo and Chano Chalba (Table 2). The difference is attributable to differences in SOM content, pH of the soils, severity of erosion and leaching, types of crops grown and intensity of cultivation.

**Exchangeable cations and CEC:** The CEC of the soils ranged from 8meq to 77meq per 100 g soil, lowest under woodland and highest under grazing. There was no statistically significant difference between soils among the land uses in terms of the CEC, but the difference among the sites was significant (Table 4, 5). The CEC of soils is determined by their SOM content and the amount and type of clay minerals present, with the role of SOM, far exceeding the role of clay.

The soils under the four land use types did not differ statistically in Ca$^{2+}$, but significantly differ in the three villages (Table 4); this was because of the higher CEC in Chano Chalba than the other two sites. Very similar patterns were observed for Mg$^{2+}$. It was highest in Chano Chalba and lowest in Doko Dembo. This may be attributed to the higher Ca$^{2+}$ content of the soils in Chano Chalba, which is held more strongly than Mg$^{2+}$ in the colloidal complex (Olaitan et al. 1986). The general trend in these two essential plant nutrients is a decrease with conversion of forest into the other types of land use.

The K$^+$ and Na$^+$ contents of the soils show statistically insignificant differences among the land use types and between the villages. These findings on the exchangeable base content of the soils under the different land use types agree with those of Saikh et al. (1998b), who reported insignificant changes in K$^+$ and Na$^+$ levels after conversion of forest to farmland.

**Soil pH:** The pH value of soils ranged between 10.3 in Chano Chalba and 4.8 in Shamma Gede. The highest was in grazing land and the lowest in woodland (Table 3). The soils are moderately acidic in Doko Dembo (5.5-6.6) and Shamma Gede (4.8-5.5), while those in Chano Chalba are alkaline (7.5 to 8.0)
The pH content of the soils show statistically significant differences among the sites, but difference among the land uses was insignificant (Table 4). The lower soil pH in Doko Dembo and Shamma Gede could be attributed to the more intense erosion and leaching processes.

Electrical conductivity: The EC content of the soils ranged from 6.1 to 0.1. However, EC showed statistically insignificant differences among the land use types and between the villages. This suggests that the absence of any effect that can be linked to land use dynamics in the watershed.

REFERENCES


