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# Physico-chemical properties of riparian soil along the three zones of the Dikhu River, Nagaland, north-east India

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## Abstract

Various physico-chemical properties of the riparian soil were studied along the upper, middle and lower zones of the Dikhu river, Nagaland from three layers of soil at 0-10 cm, 10-20 cm and 20-30 cm depth. Maximum of clay content, SOC, total nitrogen and phosphorus were recorded at middle zone and minimum of all these parameters were recorded at lower zone of the riparian forest. There showed a significant positive correlation between SOC with soil moisture content, soil bulk density, silt content and total nitrogen. Whereas, negative correlations was exhibited between soil organic Carbon with soil temperature, soil porosity, clay, sand, soil pH, Phosphorous and Potassium. One way ANOVA test exhibited significant variations in soil properties between zones and parameters such as soil moisture, sand, silt and clay content, bulk density, organic matter, total nitrogen and potassium varies significantly with increasing soil depth.The study emphasized the need for protection of riparian zones, proper land use planning and adoption of sustainable farming systems within the riparian zone to prevent from further deterioration of the riparian soil.

**Keywords:** riparian forest, riparian soil, organic carbon, soil texture, Dikhu River

## Introduction

Riparian areas are also critically important as a biogeochemical buffer between uplands and streams (Corley *et al.* 1999) [7]. Riparian zones play an important role in shaping stream ecosystems, influencing habitat complexity, biodiversity and energy and nutrients flows (Naiman *et al.* 1998) [24]. Riparian forests are considered as areas of particularly high diversity because they encompass sharp environmental gradients and diverse ecological processes (Ricklefs 1989) [30].The distribution of biomass in streamside plant communities affects multiple ecological functions. Riparian forests may store large quantities of carbon because of their relatively high rates of productivity and/or the saturated conditions that can favor the storage of belowground carbon (Thuille *et al.* 2000) [40].

Riparian zones have important geomorphic and hydrological roles that can support high levels of biological productivity (Van and Jackson 1990) [41]. Although riparian areas may occupy only a small area of a watershed, they represent on extremely component of the overall landscape (Elmore and Beschta 1987) [13]. Healthy riparian zones may help control transport of sediments and chemicals to stream channels (Lowrance *et al.* 1984). Most riparian zones have long been negatively influenced by human activities.

Accelerated decomposition rates result in rapid nutrient release to riparian soils (Edmends 1980) [12]. Information on soil characteristics is essential for understanding riparian ecosystem patterns on the landscape and for assessing the effects of various land management activities on those ecosystems (Malanson 1993) [21]. Soil properties are commonly used to classify and delineate riparian ecosystem types (Weixelman *et al.* 1997) [43]. They are equally important for evaluating ecosystem or range condition (Wilson and Tupper 1982) [44], although they are less frequently used for that purpose. Soil characteristics used to classify riparian ecosystems serve as indicators of the influence of regional factors such as climatic regime, geomorphic position, and hydrology on soil development, and for riparian ecosystems usually include soil type from pedon descriptions, depth to water table or saturation, and soil texture. In contrast, soil characteristics used to evaluate ecosystem condition serve as indicators of the combined influences of human-caused and natural disturbance on soil physical and chemical properties and biotic processes within ecosystem types (Breckenridge *et al.* 1995) [5].

The carbon nitrogen ratio is generally wide and decrease as decomposition occurs in the forest soils, where in other soils this ration is usually much lower (Pritchett and Fisher 1987) [28]. Trees may play a major role in increasing soil fertility through the ecological and physiochemical changes they induce in soil (Singh *et al.*2002) [33]. Trees cover in turn influences the improvement of physical properties of soil (Rathod and Devar 2003) [29]. Riparian zones typically have higher soil moistureand nutrient content than neighboring upland systems and this may favor plant biomass production (Megonigal *et al.* 1997) [22]. During inundation, however, soils become anoxic and toxic ions, e.g. of manganese and iron, accumulate in bio-available forms as a result of soil microbial processes (Blom and Voesenek 1996). In addition to changes in temperature and light that occur during submergence, such alterations to the soil can restrict normal plant metabolic processes, including respiration, photosynthesis and nutrient uptake (Hook 1984) [17]. Soil compaction may also result from flooding, increasing resistance to the growth of plant roots (Blom and Voesenek 1996) [3]. Additionally, flooding can cause mechanical damage to plants via hydraulic influence on stems

(Young *et al*. 2001) [45] or through erosion and abrasion of sediments (Naiman and Decamps 1997) [25]. Deposition of sediments associated with flooding may bury seedlings or impede germination of propagules (Sluis and Tandarich 2004) [34] but can also create areas of bare substrate suitable for plant colonization (Stromberg 2001) [36].

Riparian forest in Dikhu River, remains relatively unprotected from poor agricultural practices by way of shifting cultivation, residential and commercial construction, rock quarrying, forest fire and logging. These result in accelerating both onsite and offsite degradation due to erosion, runoff, nutrient losses, siltation, loss of bio-diversity and disruption in watershed hydrology causing fragmentation of riparian forest. Evaluating the effect of riparian forest degradation on the physical and chemical properties of soil can help to guide the conservation policies and restoration efforts. Therefore attempt has been made to compare the changes in soil properties along the three zones of the riparian forest of Dikhu river, Nagaland.

## Methods and Materials

### Estimation of the physical and chemical parameters of riparian soil

Soil physico-chemical properties have been carried out by establishing 100 x 100 m$^2$ experimental plots in each zone. Soil samples were collected monthly from each zone (August 2014 to July, 2015) and further segregated the data in four season's *viz*., autumn, spring, summer, and winter. The collection of soil samples was done randomly by using properly labeled poly-bags at three layers of soil depth i.e. 0-10 cm, 10-20 cm and 20-30 cm. In order to homogenize the soil samples, the collected soil samples were composited and a portion of each composite sample was sieved through a 10 mm mesh. To measure the dry soil properties, leftover soil was air-dried in a ventilated laboratory room and sieved through 2 mm and 0.25 mm mesh. Altogether 36 layers of soil sampled from each zones were collected. Soil pH of 1:2.5 (v/v) soil: water suspension was measured by using a pH glass electrode, soil moisture content (Gravimetric method), soil bulk density (Core method), soil texture by using Pipette Method (Piper and Jackson 1950). Organic carbon was estimated by Walkley and Black (1934) [42]. Total nitrogen concentration was analyzed by sulphuric acid digestion followed by distillation and titration using Kjeldahl method using Kelplus-KES 20LR AL model. Available phosphorous was determined using sulphuric acid digestion followed by colorimetric determination (Bray and Kurtz 1945) [4]. Potassium concentration by using Flame Photometer after the sample has been digested with sulphuric acid following Jackson (1973) [19].

## Results and Discussion

Table 1 show the seasonal variation in physico-chemical properties (mean ± S.E.) of the riparian soil of the Dikhu River. Table 2 represents the average physico-chemical properties (mean ± S.E.) of the riparian soil and Table 3 depicts the Pearson's correlation coefficients between the various physico-chemical properties of the riparian soil of Dikhu River, Nagaland.

**Table 1:** Seasonal physico-chemical properties (mean ± S.E.) of the riparian soil of the Dikhu River, Nagaland.

| Soil Parameters | Seasons | Upper Zone | | | Middle Zone | | | Lower Zone | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0-10 cm | 10-20 cm | 20-30 cm | 0-10 cm | 10-20 cm | 20-30 | 0-10 cm | 10-20 cm | 20-30 cm |
| Soil Temperature (${}^{0}$C) | Autumn | 26.74±0.03 | 26.66±0.04 | 26.66±0.03 | 27.63±0.06 | 27.53±0.07 | 27.54±0.06 | 26.81±0.19 | 26.73±0.19 | 26.78±0.19 |
| | Winter | 20.82±0.35 | 20.8±0.37 | 20.81±0.41 | 21.87±0.12 | 21.82±0.13 | 21.78±0.12 | 23.22±0.39 | 22.82±0.44 | 22.95±0.39 |
| | Spring | 23.76±0.69 | 23.74±0.69 | 23.77±0.68 | 22.57±0.99 | 22.55±1.00 | 22.58±1.00 | 22.51±0.95 | 22.47±0.97 | 22.3±0.95 |
| | Summer | 27.9±0.37 | 27.88±0.37 | 27.92±0.37 | 27.47±0.79 | 27.34±0.79 | 27.36±0.78 | 27.93±0.89 | 27.93±0.87 | 27.93±0.89 |
| Soil Moisture (%) | Autumn | 31.46±0.95 | 28.61±1.00 | 26.62±0.83 | 35.55±1.07 | 28.25±1.49 | 24.04±0.80 | 26.92±1.21 | 28.55±1.47 | 31.25±0.67 |
| | Winter | 27.83±0.6 | 25.68±0.75 | 25.96±0.12 | 23.32±0.63 | 23.25±0.66 | 25.16±1.01 | 15.82±0.03 | 14.61±0.33 | 14.38±0.27 |
| | Spring | 23.38±0.63 | 25.58±1.24 | 22.72±0.11 | 22.82±1.13 | 22.48±1.55 | 21.42±1.2 | 18.93±0.60 | 18.06±0.31 | 17.78±0.20 |
| | Summer | 30.75±0.37 | 25.46±0.13 | 25.08±0.78 | 34.95±2.37 | 30.6±1.1 | 30.38±1.26 | 22.31±1.42 | 22.65±1.31 | 21.18±0.77 |
| Soil Bulk Density (g/cm$^3$) | Autumn | 0.11±0.02 | 0.15±0.008 | 0.16±0.006 | 0.18±0.01 | 0.19±0.01 | 0.16±0.006 | 0.15±0.009 | 0.16±0.008 | 0.15±0.008 |
| | Winter | 0.12±0.01 | 0.15±0.008 | 0.15±0.008 | 0.16±0.007 | 0.16±0.007 | 0.16±0.008 | 0.12±0.01 | 0.15±0.008 | 0.11±0.02 |
| | Spring | 0.12±0.02 | 0.15±0.007 | 0.15±0.03 | 0.18±0.01 | 0.16±0.007 | 0.19±0.01 | 0.18±0.01 | 0.16±0.009 | 0.19±0.01 |
| | Summer | 0.16±0.007 | 0.16±0.009 | 0.19±0.01 | 0.16±0.008 | 0.12±0.01 | 0.16±0.007 | 0.08±0.02 | 0.16±0.008 | 0.15±0.008 |
| Soil Porosity (%) | Autumn | 61.35±3.04 | 56.75±1.37 | 53.36±0.83 | 59.96±1.02 | 55.25±2.19 | 55.54±0.39 | 55.85±1.33 | 59.52±3.17 | 61.25±2.07 |
| | Winter | 68.26±3.41 | 60.19±1.21 | 64.66±1.35 | 65.04±0.75 | 62.63±0.07 | 60.25±0.43 | 64.05±2.73 | 63.55±2.93 | 59.82±2.65 |
| | Spring | 63.12±1.83 | 62.39±1.4 | 65.86±5.86 | 53.05±2.40 | 56±1.46 | 50.85±5.19 | 59.72±3.29 | 57.98±2.58 | 51.98±1.35 |
| | Summer | 59.74±1.20 | 55.99±0.93 | 55.91±2.08 | 61.18±1.34 | 60.36±5.3 | 56.15±1.15 | 55.09±0.86 | 60.98±1.48 | 62.05±2.33 |
| Sand (%) | Autumn | 70.6±2.83 | 68.5±20 | 68.93±1.67 | 68.53±1.41 | 62.93±2.12 | 62.86±0.56 | 76.46±3.29 | 72.3±0.51 | 72.16±0.42 |
| | Winter | 76.36±0.81 | 75.66±1.87 | 73.43±1.77 | 72.8±1.05 | 68.3±1.11 | 66.96±1.06 | 69.6±1.77 | 72.33±1.51 | 71.2±2.05 |
| | Spring | 73.13±1.26 | 74.83±1.18 | 74.6±3.78 | 74.63±1.04 | 69.13±0.49 | 63.7±1.81 | 65.83±4.46 | 71.26±3.03 | 65.3±1.00 |
| | Summer | 71.83±2.28 | 70.5±0.66 | 69.93±2.39 | 71.5±3.37 | 70.66±1.93 | 63.06±1.43 | 74.2±5.35 | 67.06±0.83 | 67.13±0.03 |
| Silt (%) | Autumn | 23.26±2.43 | 25.33±1.72 | 24.2±0.90 | 25.7±0.68 | 30.2±2.34 | 29.8±0.26 | 18.83±2.62 | 21.86±1.65 | 21.16±1.62 |
| | Winter | 18.86±0.96 | 19.83±1.27 | 22±1.76 | 20.83±1.05 | 25±1.61 | 26.06±1.16 | 24.53±1.64 | 21.86±0.23 | 22.8±0.61 |
| | Spring | 21.1±0.95 | 20.33±0.99 | 19.76±3.01 | 19.93±0.79 | 25.86±0.63 | 28.96±1.32 | 25.63±3.64 | 20.7±2.32 | 25.4±0.58 |
| | Summer | 22.33±2.31 | 24.66±0.50 | 24.33±2.75 | 24.33±3.05 | 23.73±2.13 | 30.96±1.14 | 23.43±0.73 | 25.9±1.36 | 24.9±1.28 |
| Clay (%) | Autumn | 6.13±0.66 | 6.16±0.71 | 6.86±0.88 | 5.76±0.77 | 6.86±0.28 | 7.33±0.29 | 4.7±0.68 | 5.83±1.40 | 6.66±1.20 |
| | Winter | 4.46±0.27 | 4.5±0.60 | 4.56±0.14 | 6.36±0.56 | 6.7±0.55 | 6.96±0.56 | 5.86±1.27 | 5.8±1.30 | 6±1.45 |
| | Spring | 5.76±0.40 | 4.83±0.20 | 5.63±0.88 | 5.43±0.26 | 5±0.15 | 7.33±0.72 | 8.53±0.86 | 8.03±0.72 | 9.3±0.47 |
| | Summer | 5.83±0.23 | 4.83±0.16 | 5.73±0.38 | 4.16±0.46 | 5.6±0.2 | 5.96±0.49 | 7.3±0.75 | 7.03±0.57 | 7.96±1.32 |
| Soil pH | Autumn | 5.92±0.22 | 6.15±0.21 | 6.22±0.21 | 5.88±0.1 | 5.83±0.09 | 5.81±0.11 | 6.65±0.27 | 6.75±0.3 | 6.72±0.19 |
| | Winter | 6.8±0.07 | 6.58±0.23 | 7.17±0.03 | 5.42±0.32 | 4.83±0.16 | 5.02±0.16 | 7.29±0.06 | 7.48±0.06 | 7.19±0.03 |
| | Spring | 6.35±0.21 | 5.97±0.15 | 6.05±0.06 | 6.05±0.28 | 6.09±0.28 | 6.38±0.08 | 5.52±0.13 | 6.52±0.36 | 6.32±0.36 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Summer | 6.35±0.14 | 6.15±0.27 | 6.45±0.12 | 6.32±0.13 | 5.55±0.14 | 5.72±0.2 | 5.81±0.19 | 6.01±0.01 | 6.12±0.20 |
| Soil Organic Carbon (%) | Autumn | 0.07±0.08 | 1.16±0.14 | 1.48±0.19 | 1.08±0.10 | 1.55±0.24 | 1.69±0.23 | 0.99±0.03 | 0.59±0.13 | 0.64±0.07 |
| | Winter | 1.33±0.07 | 0.82±0.11 | 1.04±0.02 | 1.02±0.06 | 1.12±0.14 | 1.71±0.06 | 0.58±0.13 | 1.75±0.03 | 1.72±0.09 |
| | Spring | 1.32±0.14 | 1.25±0.10 | 1.09±0.24 | 1.65±0.22 | 1.07±0.11 | 1.12±0.14 | 1.28±0.20 | 0.96±0.10 | 0.91±0.12 |
| | Summer | 1.42±0.18 | 1.53±0.38 | 1.49±0.27 | 1.99±0.20 | 1.21±0.02 | 0.91±0.23 | 1.05±0.05 | 1.13±0.06 | 0.76±0.05 |
| Total Nitrogen (%) | Autumn | 0.19±0.01 | 0.25±0.02 | 0.25±0.02 | 0.25±0.009 | 0.32±0.01 | 0.22±0.02 | 0.05±0.008 | 0.15±0.008 | 0.15±0.008 |
| | Winter | 0.3±0.01 | 0.32±0.03 | 0.31±0.01 | 0.25±0.008 | 0.26±0.02 | 0.28±0.01 | 0.17±0.03 | 0.25±0.02 | 0.21±0.02 |
| | Spring | 0.22±0.01 | 0.32±0.02 | 0.29±0.03 | 0.18±0.03 | 0.26±0.02 | 0.28±0.01 | 0.11±0.02 | 0.18±0.01 | 0.15±0.01 |
| | Summer | 0.18±0.01 | 0.22±0.01 | 0.22±0.01 | 0.31±0.01 | 0.38±0.01 | 0.32±0.01 | 0.28±0.06 | 0.18±0.01 | 0.15±0.02 |
| Phosphorous (%) | Autumn | 55.76±7.79 | 54.97±7.37 | 53.99±7.63 | 12.56±1.37 | 11.78±1.23 | 11.61±1.22 | 28.6±4.09 | 27.55±3.98 | 27.33±3.99 |
| | Winter | 55.77±3.4 | 54.13±3.34 | 53.88±3.34 | 12.72±0.99 | 12.27±0.93 | 12.09±0.91 | 29.96±3.38 | 28.99±3.43 | 28.74±3.48 |
| | Spring | 60.58±3.76 | 58.59±4.07 | 57.96±3.83 | 13.36±1.62 | 12.92±1.39 | 12.66±1.41 | 35.96±3.63 | 34.99±3.69 | 34.59±3.68 |
| | Summer | 49.31±8.39 | 47.65±8.15 | 47.72±8.21 | 17.15±1.28 | 16.96±1.29 | 16.75±1.3 | 29.96±2.95 | 28.83±2.86 | 28.48±2.83 |
| Potassium (kg/ha) | Autumn | 451.36±35.98 | 308.37±28.56 | 308.37±47.13 | 707.09±35.93 | 504.37±31.04 | 440.16±16.44 | 485.33±25.29 | 507.73±25.28 | 435.72±6.61 |
| | Winter | 436.05±44.25 | 413.02±18.00 | 406.18±12.22 | 748.90±80.72 | 613.38±63.03 | 553.28±46.46 | 1042.72±14.09 | 1043.09±28.37 | 1005.01±27.68 |
| | Spring | 523.04±31.48 | 391.25±44.25 | 338.60±54.24 | 907.20±43.81 | 504±26.31 | 470.40±12.42 | 1050.56±24.64 | 794.45±89.76 | 820.58±99.86 |
| | Summer | 361.01±10.57 | 266.93±9.87 | 191.52±13.59 | 809.01±42.39 | 542.08±26.31 | 519.30±23.67 | 906.45±71.79 | 568.21±48.09 | 545.44±42.72 |

**Table 2:** Average physico-chemical properties (mean ± S.E.) of the riparian soil of the Dikhu River, Nagaland.

| | **Upper zone** | | **Middle zone** | | **Lower zone** | |
|---|---|---|---|---|---|---|
| Soil parameters by depth (cm) | Mean | (S.E.) | Mean | (S.E.) | Mean | (S.E.) |
| Soil Temperature ($^{0}$C) | | | | | | |
| 0-10 | 24.80$^{a}$ | 0.50 | 24.89$^{a}$ | 0.54 | 25.11$^{a}$ | 0.51 |
| 10-20 | 24.77$^{a}$ | 0.50 | 24.81$^{a}$ | 0.54 | 24.99$^{a}$ | 0.52 |
| 20-30 | 24.79$^{a}$ | 0.50 | 24.82$^{a}$ | 0.54 | 24.99$^{a}$ | 0.52 |
| Soil Moisture (%) | | | | | | |
| 0-10 | 29.41$^{b}$ | 0.62 | 29.16$^{b}$ | 1.24 | 18.75$^{a}$ | 0.82 |
| 10-20 | 26.33$^{a}$ | 0.47 | 26.14$^{a}$ | 0.83 | 18.66$^{a}$ | 0.99 |
| 20-30 | 25.09$^{a}$ | 0.37 | 25.25$^{a}$ | 0.75 | 21.15$^{a}$ | 1.09 |
| Soil Bulk Density (g/cm$^{3}$) | | | | | | |
| 0-10 | 0.13$^{a}$ | 0.01 | 0.14$^{a}$ | 0.01 | 0.13$^{a}$ | 0.01 |
| 10-20 | 0.15$^{b}$ | 0.004 | 0.16$^{a}$ | 0.01 | 0.14$^{a}$ | 0.004 |
| 20-30 | 0.16$^{a}$ | 0.01 | 0.17$^{a}$ | 0.01 | 0.14$^{a}$ | 0.01 |
| Soil Porosity (%) | | | | | | |
| 0-10 | 63.12$^{b}$ | 1.32 | 59.81$^{b}$ | 0.17 | 53.81$^{a}$ | 1.30 |
| 10-20 | 58.83$^{a}$ | 0.73 | 58.56$^{ab}$ | 0.25 | 54.96$^{a}$ | 1.32 |
| 20-30 | 59.95$^{ab}$ | 1.78 | 55.70$^{a}$ | 0.23 | 52.97$^{a}$ | 1.23 |
| Sand % | | | | | | |
| 0-10 | 72.98$^{a}$ | 1.06 | 71.86$^{c}$ | 1.07 | 71.52$^{a}$ | 2.09 |
| 10-20 | 72.37$^{a}$ | 1.1 | 67.75$^{b}$ | 1.10 | 70.74$^{a}$ | 0.99 |
| 20-30 | 71.72$^{a}$ | 1.29 | 64.15$^{a}$ | 0.74 | 68.95$^{a}$ | 0.98 |
| Silt % | | | | | | |
| 0-10 | 21.39$^{a}$ | 0.91 | 22.70$^{a}$ | 1.02 | 23.10$^{a}$ | 1.29 |
| 10-20 | 22.54$^{a}$ | 0.90 | 26.20$^{b}$ | 1.06 | 22.58$^{a}$ | 0.90 |
| 20-30 | 22.57$^{a}$ | 1.12 | 28.95$^{c}$ | 0.07 | 23.56$^{a}$ | 0.69 |
| Clay % | | | | | | |
| 0-10 | 5.43$^{a}$ | 0.33 | 6.60$^{a}$ | 0.58 | 5.55$^{a}$ | 0.26 |
| 10-20 | 6.04$^{ab}$ | 0.27 | 6.67$^{a}$ | 0.53 | 5.08$^{a}$ | 0.29 |
| 20-30 | 6.90$^{b}$ | 0.28 | 7.48$^{a}$ | 0.62 | 5.70$^{a}$ | 0.37 |
| Soil pH | | | | | | |
| 0-10 | 6.32$^{a}$ | 0.09 | 5.92$^{a}$ | 0.12 | 6.32$^{a}$ | 0.14 |
| 10-20 | 6.22$^{a}$ | 0.11 | 5.57$^{a}$ | 0.11 | 6.69$^{a}$ | 0.14 |
| 20-30 | 6.47$^{a}$ | 0.09 | 5.73$^{a}$ | 0.10 | 6.59$^{a}$ | 0.12 |
| Soil Organic Carbon (%) | | | | | | |
| 0-10 | 1.20a | 0.07 | 1.44$^{a}$ | 0.10 | 0.95$^{a}$ | 0.07 |
| 10-20 | 1.19a | 0.11 | 1.24$^{a}$ | 0.08 | 1.07$^{a}$ | 0.08 |
| 20-30 | 1.28a | 0.10 | 1.36$^{a}$ | 0.10 | 0.99$^{a}$ | 0.08 |
| Total Nitrogen (%) | | | | | | |
| 0-10 | 0.22$^{a}$ | 0.01 | 0.25$^{a}$ | 0.01 | 0.15$^{a}$ | 0.02 |
| 10-20 | 0.28$^{b}$ | 0.01 | 0.31$^{a}$ | 0.01 | 0.19$^{a}$ | 0.01 |
| 20-30 | 0.27$^{b}$ | 0.01 | 0.28$^{ab}$ | 0.01 | 0.16$^{a}$ | 0.01 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Phosphorous (%) | | | | | | |
| 0-10 | $31.12^a$ | 1.76 | $55.35^a$ | 3.06 | $13.95^a$ | 0.71 |
| 10-20 | $30.09^a$ | 1.75 | $53.84^a$ | 2.98 | $13.48^a$ | 0.68 |
| 20-30 | $29.78^a$ | 1.75 | $53.39^a$ | 3 | $13.27^a$ | 0.68 |
| Potassium (kg/ha) | | | | | | |
| 0-10 | $871.27^b$ | 43.46 | $793.05^b$ | 28.63 | $442.89^b$ | 18.53 |
| 10-20 | $728.38^a$ | 44.09 | $540.97^a$ | 20.44 | $345.15^a$ | 16.88 |
| 20-30 | $701.70^a$ | 46.45 | $495.79^a$ | 15.29 | $311.19^a$ | 22.05 |

**Table 3:** Pearson's correlation coefficients between the various physic-chemical properties of the soil.

| **Parameters** | **Soil T** | **Soil M** | **BD** | **SP** | **Clay** | **Silt** | **Sand** | **pH** | **O C** | **TN** | **P** | **K** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil T | 1 | | | | | | | | | | | |
| Soil M | -.947 | 1 | | | | | | | | | | |
| BD | -.319 | .606 | 1 | | | | | | | | | |
| SP | -.200 | -.125 | -.865 | 1 | | | | | | | | |
| Clay | .962 | -.823 | -.047 | -.461 | 1 | | | | | | | |
| Silt | -.090 | .404 | .973 | -.958 | .187 | 1 | | | | | | |
| Sand | -.131 | -.193 | -.898 | .998 | -.398 | -.976 | 1 | | | | | |
| pH | .518 | -.764 | -.976 | .735 | .263 | -.899 | .781 | 1 | | | | |
| O C | -.817 | .959 | .807 | -.402 | -.627 | .648 | -.465 | -.916 | 1 | | | |
| TN | -.938 | 1.000* | .629 | -.153 | -.806 | .430 | -.222 | -.783 | .966 | 1 | | |
| P | -.295 | -.027 | -.812 | .995 | -.546 | -.925 | .986 | .665 | -.310 | -.056 | 1 | |
| K | .901 | -.715 | .123 | -.605 | .985 | .351 | -.548 | .095 | -.486 | -.694 | -.680 | 1 |

Soil T = soil temperature, Soil M = soil moisture, BD = bulk density, SP = soil porosity, OC = organic carbon, TN = total nitrogen, P = phosphorous, K = potassium

**Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

## Soil temperature

Soil temperature depends on the ratio of the energy absorbed to that lost. Soil has a temperature range between -20 to 60 $^0$C. The temperature of the soil is the most important property because it shows its effect on the chemical, physical and biological processes related to growth of plants. Soil temperature changes with season, time of day, and local conditions of climate. Average soil temperature was found to be highest at lower zone (24.99 ± 0.52 $^0$C) and lowest at upper zone (24.77 ± 0.50 $^0$C). Seasonally, soil temperature was recorded maximum in summer (27.93 $^0$C) at lower zone minimum at middle zone (21.78$^0$C) during winter. One way ANOVA test showed insignificant difference ($p<0.01$) between zones of the forest. The soil temperature decreased with the increased of depth. It may be due to solar radiation directly heating on the surface soil. Tiwari *et al*. (2016) [39] reported that soil temperature was highest on the top layers of soil (0-10 cm) and decreased with increased of depth. Kaspar and Bland (1992) reported that temperature of the surface soil layer is influenced by the fluctuations in air temperature near the ground and the decline in soil temperature with increasing soil depth depends to some extent on the metabolic activities of the plant roots (especially, fine roots) and microbes inhibiting this layers. Soil temperature of upper zone was less because the soil in under shed by trees and plants and highest at lower zone because of the degraded nature of the forest.

## Soil Moisture

Absorption of the nutrient by soil is largely depends on moisture content of the soil moisture of soil also shows its effect on the texture of soil. Soil moisture was found to be highest at upper zone (29.41 ± 0.62%) and lowest at lower zone (18.66 ± 0.99%). Depth wise soil moisture showed significant difference ($p<0.05$) at upper and middle zones. Simultaneously the moisture content was also found significant difference between zones by one way ANOVA test ($p<0.01$; F=5.76 and p=0.007). Soil moisture content in general gradually decreased with the increase in soil depth is also reflected in the present study and was also revealed by Hoque (1998) [18]. Lowest moisture content at lower zone may be due to lack of vegetation. The soil moisture content was maximum in autumn season was (35.55%) at 0-10 cm layer of middle zone and minimum in winter (14.38%) at 20-30 cm layer at middle zone. Similar with our observation was reported by Devi (2008) [10] which revealed that maximum soil temperature during rainy season with peak value in the month of August and minimum during winter season with the lowest value in the month of December in pine and oak forest stand in Manipur.

## Soil Bulk Density

Soil bulk density was maximum at middle zone (0.17 ± 0.01) and minimum at lower zone (0.13 ± 0.01). The highest bulk density was found to be recorded in autumn season (0.18 gm/cm$^3$) at 0-10 cm layer of middle zone and lowest during summer (0.11gm/cm$^3$) at 0-10 cm layer of lower zone. Depthwise, bulk density showed significant difference amongst the layers at upper zone ($p<0.05$) but not significant at middle and lower zones. One way ANOVA test showed no significant differences amongst the zones. Low bulk density at lower zone may be due to the open surface soil and absence of root activities due to lack of vegetation. The value of bulk density increases with increase in the depth of the soil. This is due to the compact nature of the below-ground soil. Significant negative correlation of bulk density was exhibited with soil particle density (r = -0.865), silt (r = -0.958) and sand (r = -0.898). There exists a positive correlation with most of the nutrients except pH and phosphorus which shows negative correlation with bulk density. Among the chemical properties, increase of organic carbon content resulted in the increase of soil carbon density, soil bulk density (Zhang *et al*. 2013) [46].

## Soil Porosity

Soil porosity was found to be maximum at upper zone (63.12 ±1.32) and minimum at lower zone (52.97 ± 1.23). Seasonally, highest soil porosity was obtained in winter at upper zone (68.26%) at 0-10 cm layer depth and lowest of 51.98% at 20-30 cm layer depth at upper zone in spring. Soil porosity was found to be highly significant (at $p<0.05$) depth wise at upper and middle zones but not significant at lower zone. One way ANOVA test showed no significant differences between the zones. The soil porosity was found to be higher in the upper zone and decreased with increased in depth. Similar observation was made by Muhammad *et al*. (2011) which observed total porosity between 52.97 and 63.12.Soil porosity was lower in the human habited area due to high bulk density. Soil porosity is negatively related to bulk density. Human habited area has less porosity as compared to other zones because of the compaction of the soil as a result of human activities. It was also found that the bulk density is more in upper zone which is directly to soil porosity. Subsurface layers have reduced organic matter, aggregation and root penetration compared to surface layers and therefore contains less pore space.

## Sand, Silt and Clay percentage

Sand was estimated to be maximum (72.98 ± 1.06%) at upper zone and minimum (64.15 ± 0.74%) at middle zone. Seasonally, maximum sand content was recorded highest at upper zone in winter season (76.36%) at 0-10 cm layer depth and minimum at middle zone in summer (63.06%) at 20-30 cm layer depth. Sand content negatively correlated with OC (r = -.465). This indicates that soil with high percentage of sand will have less organic matter. Depth wise, sand content showed significant difference ($p<0.05$) at middle zone but not found significant at upper and lower zone. Consequently, one way (ANOVA) test also showed significant difference amongst the zones ($p<0.01$ where F=6.42 and p=0.004). Silt was maximum (28.95 ± 0.07) in middle zone and minimum (21.39 ± 0.91) in upper zone. Seasonally, maximum silt content was obtained to be highest in summer at middle zone (30.96%) at 20-30 cm layer of depth middle zone and minimum in autumn (18.83%) at 0-10 cm layer depth at lower zone. Depth wise silt content was found to be significantly different ($p<0.05$) at middle zone whereas no such significant difference was observed at both upper and lower zones. Simultaneously, one way (ANOVA) test also showed a significant difference ($p<0.01$; where F=8.22, p=0.001) amongst the zones. Clay content was maximum at middle zone (6.90 ± 0.28%) and minimum at upper zone (5.08 ± 0.29%). Seasonally, maximum clay content was recorded to be highest at lower zone in spring season (9.30%) in 20-30 cm layer depth and minimum of 4.16% was exhibited at middle zone in summer at 0-10 cm layer depth. Depth wise clay content showed significant difference ($p<0.05$) at middle zones. No significant differences between the zones were observed for clay content. From the results it was observed that the percentage of silt was higher at the middle zone and minimum at upper zone in all the seasons. This may be due to the fact that the riparian areas contain higher concentrations of minerals. The percentage of sand was found highest at upper zone and minimum at middle zone in all the seasons. The percentage of clay was found to be highest at middle zone and minimum at upper zone. The soil texture in intact riparian forest shows the dominance of silt and clay soils which is ideal for plant growth. In the case of upper zone, the percentage of sand was higher due to various activities which cause high compaction thereby causing high bulk density. Similar observations was also made by Dilaha *et al*. (1989) where they reported silty soil nature in riparian soils.

## Soil pH

The most significant property of soil is its pH level, its effects on all other parameters of soil. Therefore, pH is considered while analyzing any kind of soil. Soil pH is a principle of soil chemical because it strongly influences available nutrients and activity of soil organisms Leonard *et al*. (2004).Soil pH was maximum at lower zone (6.69 ± 0.14) and minimum at middle zone (5.57 ± 0.11). Seasonally, pH of soil was found to be maximum (autumn) at lower zone 7.48 ± 0.06 in layer 10-20 cm and minimum (winter) at middle zone 4.83 ± 0.16 in layer 10-20 cm. The low pH at middle zone might be due to the presence of high organic carbon content at this zone. pH showed significant negative correlation with organic carbon (r = -0.916) and bulk density (r = -0.976). Similar observations were made by Qian *et al*. (2017) where soil pH ranged from 4.76 to 7.79 in riparian areas of inflowing stream of Taihu lake. He also recorded that soil pH decreases with soil depth in riparian soil. The soil in the Dikhu riparian forest was found to be nearly acidic. In all the seasons Lower zone has the highest pH as compared to the other two zones. Depth wise, pH was found to be insignificant. Also, one way ANOVA test showed no significant difference amongst the zones.

## Soil Organic Carbon (SOC)

It is also a valuable property of soil. If the soil is poor in organic matter, then it enhances the process of soil erosion (Tale *et al*. 2015) [38]. In forests, litter is the main source of OM and its quality and quantity depends on dominant plants species (Quan *et al*. 2014). Riparian soil organic carbon is strongly influenced by soil structures, soil properties; aquatic plants root depth, effective water retention capacity and soil biological diversity (Capon *et al*.2013) [6]. Soil carbon content is an indicator of soil quality and affects not only productivity, but also the microbial (fungi and bacteria) and invertebrates communities (Rousseau *et al*. 2012) [31] besides regulating climate by carbon storage (another ecosystem services provided by riparian forest soils). Average soil organic carbon was found to be highest at middle zone (1.44 ± 0.10 %) and lowest at lower zone (1.07 ± 0.08 %). Seasonally, maximum soil organic carbon of 1.99% was recorded during summer at middle zone at 0-10 cm layer depth whereas minimum of 0.17% was exhibited at upper zone during autumn at 0-10 cm layer depth. No significant difference was observed depth wise amongst the zones. Similarly for one way ANOVA test also, no significant difference was observed between the zones. SOC was found to be significant positively with soil moisture (r = + 0.959), bulk density (r = + 0.807), total nitrogen (r = + 0.966) and negatively correlate with pH (r = - 0.916). In the present study, riparian degradation at lower zone lowered soil carbon content returned to the soil system due to reduction in vegetation cover and oxidation of soil organic matter because of the continuous shifting cultivation along the riparian zone, uncontrolled grazing and also loss of organic matter by runoff. Similar was observed by Danielle *et al*. (2016) [9] in eastern Amazon of Brazil. These results are also in conformity with other works which reported that soil organic content varies with different land use practices (Girmay *et al*. 2008) [14]. Variability in total nitrogen also linked with difference in organic C content as OC was found to be positively correlated with total nitrogen (r = +.966). In the present study, intensities in cultivation and erosion make the soil rich in nitrogen content. Similar condition was also observed by Moges and Holden (2008) [23].

### Total Nitrogen

Some riparian zones have the ability to retain large amounts of Nitrogen. Groffman *et al*. (1992) [15] found that plant uptake was the dominant sink for nitrate during the growing season in riparian soils. The ability of a riparian zone to remove large quantities of nitrate from water or soil is influenced by the type and quantity of existing vegetation and by soil conditions (Correll 1991) [8]. Riparian zones contain potential hotspots of denitrification due to the presence of high water tables that may produce the anoxic conditions required for the process to occur (Bilby 1988) [2, 24]. Total nitrogen was found to be highest at middle zone (0.32 ± 0.01) and lowest at lower zone (0.15 ± 0.02). Seasonally, maximum total nitrogen was obtained at middle zone in summer (0.38 %) at 10-20 cm layer of depth whereas minimum of 0.05% was obtained at lower zone in autumn at 0-10 cm layer depth. Total nitrogen showed significant difference ($p<0.05$) depth wise in both upper and middle zones and not found significant at lower zone. Simultaneously, one way ANOVA test also showed significant difference at $p<0.01$ level amongst the three zones where F= 9.98 and p=0.000. More content of nitrogen in the sub surface layer of 10-20 cm compared to lower layer may be due to increased amount of litter and organic matter in the surface layer. Nitrogen content showed significant positive correlation with organic carbon (r = + 0.966) and negatively correlate with clay content (r = -0.806). Gupta and Sharma (2008) [16] reported a significant positive relationship between N and K with organic matter since the availability of both the nutrients depends on the organic matter. Similar to present findings was obtained by Qian *et al*. (2017). Variability in total nitrogen along the three zones may be due to differences in soil organic carbon, intensities of cultivation, application of manures, pesticides and fertilizers rich in nitrogen in the soils (Moges and Holden 2008) [23].

### Phosphorous

Phosphorus is a most important element present in every living cell (Tale *et al*. 2015) [38]. It is one of the most important micronutrient essential for plant growth. Phosphorus most often limits nutrients remains present in plant nuclei and act as energy storage. P retention in riparian soils is influenced by soil organic matter, pH, Fe and Al content, and these factors exhibit spatial variability across a landscape (Lyons *et al*. 1998) [20]. The content of available phosphorus showed a decreasing pattern with increase in depth. Phosphorous was found to be highest at upper zone (955.35 ± 3.06 %) and lowest at middle zone (13.27 ± 0.68%). Seasonally, Phosphorous was found to be highest at upper zone in spring (60.58%) at 0-10 cm layer depth and lowest (11.61%) at 20-30 cm layer depth at middle zone in autumn. Depth wise, P was found insignificant amongst the layer but it was found significant at $p<0.01$ (F=30.95; p=0.000) amongst the three zones. One way ANOVA test showed significant difference ($p<0.01$; where F= 30.95 and p=0.000) between the zones. Lower phosphorus content at middle zone may be due to phosphorus fixation in the forested areas. Highest content of phosphorus at upper zone may be due to majorly dominated by *Melia azedarach* at this zone. Since the organic carbon was higher at middle zone, it exhibit relatively low levels of phosphorus at this zone. Similar was observed by Sharma and Sharma (2004) [32]. Compared to inland and seasonal flood forest, soil in riparian forest has higher amount of available phosphorus which may be due to the influence of water content in the soil since the riverine forest is frequently inundated during flood in rainy season thereby helping in the uptake of phosphorus by the soil.

### Potassium

Potassium plays an important role in different physiological processes of plants; it is one of the important elements for the development of the plant (Solanki *et al*. 2012) [35]. The amount of potassium in soil is directly related to the parent rock material. Variations in potassium content may be related to elevation and associated climatic conditions. Potassium was found highest at upper zone (871.27 ± 43.46 kg/ha) and lowest at lower zone (311.19 ± 22.05 kg/ha). Seasonally, Potassium was found maximum at upper zone in spring season (1050. 56 kg/ha) at 0-10 cm layer depth and minimum in spring (191.49 kg/ha) at 20-30 cm layer depth at lower zone. Potassium concentration was found significant depth wise amongst the three layers at $p<0.05$ level in all the zones. Simultaneously one way test of ANOVA also revealed that K showed significant difference amongst the three zones at $p<0.01$ level where F= 16.68 and p= 0.000. There exist a significant negative correlation between K and organic matter (r = -0.720) and also with nitrogen (r = -0.694). This may be due to the fact that the availability of K depends through decomposition of organic matter. Variation in levels of K could be attributed to the relative pumping of potassium from the subsoil by vegetation in the forest land. Lower levels of potassium may be due to the degradation and losses by leaching due to reduced vegetation cover at lower zone. Similar pattern was confirmed by Njue *et al*. (2016) [26].

### Conclusion

Determining of soil physico-chemical properties is important as it has in general a positive relation with net ecosystem productivity. In our present study, it was observed that there exhibit significant variations in soil properties between zones and parameters such as soil moisture, sand, silt and clay content, bulk density, organic matter, total and available nitrogen, and potassium varies significantly with increasing soil depth. The various anthropogenic pressures on the riparian forest of the Dikhu river is accelerated by the poverty of the villagers staying in these areas since they rely on these areas for food production and their livelihood by way of deforestation. The slash-and-burn practices for their shifting cultivation lead to deterioration in soil physico-chemical properties. In this context, promoting of no-fire farming systems to replace slash-and-burn agriculture is critically necessary in order to protect from further degradation of riparian forest found in Nagaland. The adoption of the no-fire system in these riparian zones is capable of not only greatly improving the soil protection and infiltration but also promoting the natural restoration of the degradation of the riparian forest. Furthermore, different strategies to encourage restoration of the degradation of riparian forest and their effectiveness in promoting the provision of various ecosystem services provided the riparian forest should be study for further researches. Degradation of the riparian forest at the lower zones has a serious negative effect on soil properties. The study suggests the necessity of control measurement for the quality of soil from the increasing human encroachments such as cultivations, human settlements etc along the riparian zone. The results from this study indicate there is a need for protection of riparian zones, proper land use planning and adoption of sustainable farming systems within the riparian zone in order to prevent from further deteriorating of the riparian soil.

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## References

1. Anderson JM, Ingram JSI. Tropical Soil Biology and Fertility. A Handbook of Methods. Department of Plant Sciences, University of Oxford, Oxford OXI 3RB UK. Forest in the Catskill Mountains, USA. Soil Biology and Biochemistry. 1993; 30(7): 853-864.
2. Bilby RE. Interactions between Aquatic and Terrestrial Systems. In Raedeke, Kenneth J. (ed.) Streamside Management: Riparian Wildlife and Forestry Interactions. University of Washington. College of Forest Resources. Contribution Number. 1988; 59:13-29.
3. Blom CWPM, Voesenek LACJ. ‘Flooding: the survival strategies of plants. Trends in Ecology and Evolution. 1996; 11:290-95.
4. Bray RH, Kurtz LT. Determination of total, organic, and available forms of phosphorus in soils. Soil Science. 1945; 59:39-45.
5. Breckenridge RP, Kepner WG, Mouat DA. A process for selecting indicators for monitoring conditions of rangeland health. Environmental Monitoring and Assessment. 1995; 36:45-60.
6. Capon SJ, Chambers LE, Mac Nally R, Naiman RJ, Davies, P, Marshall N *et al*. Riparian ecosystems in the 21st century: hotspots for climate change adaptation. Ecosystems. 2013; 16:359-381.
7. Corley CJ, Frasier GW, Trlica MJ, Smith FM. Taylor Jr EM. Nitrogen and phosphorous in runoff from two montane riparian communities. Journal of Range Management. 1999; 52:600-605.
8. Correll DL. Human impact on the functioning of landscape boundaries. In Holland, Marjorie M., Paul G. Risser, and Robert J. Naiman (eds.) Ecotones: The Role of Landscape Boundaries in the Management and Restoration of Changing Environments. Chapman and Hall. New York, 1991, 90-109.
9. Danielle C, Rousseau GX, Engel VL, Zelarayan M, Oliveira EC, Carolina A *et al*. Degradation of Riparian Forest Affects Soil Properties and Ecosystem Services Provision in Eastern Amazon of Brazil. John Wiley and Sons. Ltd, 2016. DOI: 10.1002/ldr.2547.
10. Devi KU. A study on litter dynamics, litter decomposition and soil respiration in the Sub-tropical pine forest of Imphal West District, Manipur. Ph. D. Thesis, Manipur University, 2008.
11. Dillaha TA, Reneau RB, Mostaghimi S, Lee D. Vegetative Filter Strips for Agricultural Nonpoint Source Pollution Control. American Society of Agricultural Engineers. 1989; 32:513-519.
12. Edmends RL. Litter decomposition and nutrient release in Douglas-fir, Red alder, Western hemlock and Pacific silver-fir ecosystems in Western Washington. Canadian Journal of Forestry Research. 1980; 10:327-337.
13. Elmore W, Beschta R. Riparian areas: perception in management. Rangelands. 1987; 6:260-265.
14. Girmay G, Singh BR, Mitiku H, Borresen T, Lal R. Carbon Stocks in Ethiopian Soils in Relation to Land Use and Soil Management. Land Degradation and Development. 2008; 19:351-367. http://dx.doi.org/10.1002/ldr.844.
15. Groffman PM, Arthur JG, Robert CS. Nitrate Dynamics in Riparian Forests: Microbial Studies. Journal of Environmental Quality. 1992; 21:666-671.
16. Gupta MK, Sharma SD. Effect of tree plantation on soil properties, profile morphology and productivity index I. Poplar in Uttarakhand. Annual Forest. 2008; 16(2):209-224.
17. Hook DD. Adaptation to flooding with fresh water in T.T. Kozlowski (ed.), Flooding and Plant Growth, Academic Press, Orlando, 1984, 265-94.
18. Hoque AKM. Evaluation of physical parameters of different soil series of Haluaghat Upazila. M. Sc. (Ag) Thesis, Dept. of Soil Sci., BAU, Mymensingh, 1988, 1-60.
19. Jackson ML. Soil chemical analysis, 2nd Ed. Prentice Hall, India Pvt. Ltd. New Delhi, 1973, 111-182.
20. Lyons JB, Josef HG, Jose AA. Spatial and temporal variability of phosphorus retention in a riparian forest soil. Journal of Environmental Quality. 1998; 27:895-903.
21. Malanson GP. Riparian landscapes. Cambridge University, 1993. Press, 296. ISBN 0521384311, 9780521384315.
22. Megonigal JP, Conner WH, Kroeger S, Sharitz RR. Aboveground production in Southeastern Floodplain Forests: A test of the Subsidy-Stress Hypothesis. Ecology. 1997; 78:370-384.
23. Moges A, Holden NM. Soil Fertility in Relation to Slope Position and Agricultural Land Use: A Case Study of Umbulo Catchment in Southern Ethiopia. Environmental Management. 2008; 42:753-763. http://dx.doi.org/10.1007/s00267-008-9157-8.
24. Naiman RJ, Bilby RE. River ecology and management: lessons from the Pacific coastal ecoregion. New York: Springer-Verlag, 1998.
25. Naiman RJ, Decamps H. ‘The ecology of interfaces: riparian zones’, Annual Review of Ecology and Systematics. 1997; 28:621-58.
26. Njue N, Koech E, Hitimana J, Sirmah P. Influence of Land Use Activities on Riparian Vegetation, Soil and Water Quality: An Indicator of Biodiversity Loss, South West Mau Forest, Kenya. Journal of Forestry. 2016; 6:373-385.
27. Piper CS. Soil and plant analysis. The University of Adelaide, Australia, 1950.

28. Pritchett WL, Fisher RF. "Properties and Management of Forest Soils", 2nd edition. John Wiley and Sons. New York, 1987.
29. Rathod R, Devar KV. Effect of different plantations on soil physical properties, Karnataka. Journal of Agricultural Science. 2003; 16(3):487-488.
30. Ricklefs RE. Ecology 3rd Edition W.H. Freeman, New York. Riparian zones: Focus on links between land and water. Bio Science. 1989; 4:540-551.
31. Rousseau GX, Deheuvels O, Rodriguez AI, Somarriba E. Indicating soil quality in cacao-based agroforestry systems and old-growth forests: the potential of soil macro fauna assemblage. Ecological Indicators. 2012; 23:535-543. DOI:10.1016/j.ecolind.2012.05.008.
32. Sharma JC, Sharma Y. Effect of Forest Ecosystems on Soil Properties - A Review. Agricultural Review. 2004; 25(1):16-28.
33. Singh G, Singh B, Kuppusamy V, Bala N. Variations in foliage and soil nutrient composition in Acacia tortilis plantation of different ages in North-Western Rajasthan, Indian Forester. 2002; 128:514-521.
34. Sluis W, Tandarich J. Siltation and hydrologic regime determine species composition in herbaceous floodplain communities. Plant Ecology. 2004; 173:115-24.
35. Solanki HA, Chavda NH. Physico-chemical analysis with reference to seasonal changes in soils of Victoria Park Reserve Forest, Bhavnagar, Gujarat. Research Gate. 2012; 8:62-68. https://www.researchgate.net/publication/249649429.
36. Stromberg JC. Restoration of riparian vegetation in the south-western United States: importance of flow regimes and fluvial dynamism. Journal of Arid Environments. 2001; 49:17-34.
37. Sweeney BW. Effects of streamside vegetation on macro invertebrate communities of White Clay Creek in eastern North America. Proceedings of the Academy of Natural Sciences Philadelphia. 1993; 144:291-340.
38. Tale KS, Ingole S. A Review on Role Physico-chemical Properties in Soil Quality. Chemical Science Review and Letters. 2015; 4(13):57-66.
39. Tiwari AK, Singh PK, Chandra S, Ghosh A. Assessment of groundwater level fluctuation by using remote sensing and GIS in West Bokaro coalfield, Jharkhand, India. ISH Journal of Hydraulic Engineering. 2016; 22:59-67.
40. Thuille A, Buchman N, Schulze ED. Carbon stocks and soil respiration rates during deforestation, grassland use and subsequent Norway spruce afforestation in the Southern Alps, Italy. Tree Physiology. 2000; 20:849-857.
41. Van B, Jackson W. Concepts is stream riparian rehabilitation, Trans. 51st North American. Wildlife and Natural Resources Conference, 1990, 281-289.
42. Walkley AJ, Black IA. Estimation of soil organic carbon by the chromic acid titration method. Soil Science. 1934; 37:29-38.
43. Weixelman DA, Zamudio DC, Zamudio KA, Tausch RJ. Classifying ecological types and evaluating site degradation. Journal of Range Management. 1997; 50:315-321.
44. Wilson AD, Tupper GJ. Concepts and factors applicable to the measurement of range condition. Journal of Range Management. 1982; 35(6):684-689.
45. Young WJ, Schiller CB, Harris JH, Roberts J, Hillman TJ. River flow, processes, habitats and river life', in W.J. Young (ed.), Rivers as Ecological Systems: The Murray- Darling Basin, Murray-Darling Basin Commission, Canberra, 2001, 45-99.
46. Zhang Y, Qin JH, Zhao YC. Change of soil physical and chemical properties, organic carbon and nutrients of different soil profile on different forest in Binggou of Heihe Basin. Journal of Soil and Water Conservation. 2013; 17(2):126-130.