# Determination of Physical Properties of Soil from the Athi-Thwake River Catchment Area, Makueni County, Kenya

**Sarah M. Kariuki[1], Deborah A. Abong'o[2], Joyce G. N. Kithure[3], John P. O. Obiero[4]**

[1]Department of Chemistry, Faculty of Science & Technology, University of Nairobi, P.O Box 30197-00100, Nairobi, Kenya
Corresponding Author Email: *kariukim88[at]gmail.com*

[2,3]Department of Chemistry, Faculty of Science & Technology, University of Nairobi, P.O Box 30197-00100, Nairobi, Kenya

[4]Department of Environmental & Biosystems Engineering, University of Nairobi, P.O Box 30197-00100, Nairobi, Kenya

**Abstract:** ***This study evaluated the texture, particle size, density, and total organic carbon (TOC) of soil samples from ten selected sites in the Athi-Thwake River catchment area during the wet (November 2021) and dry (January 2022) seasons in Makueni County. Soil textures were analyzed using a hydrometer, and results were compared with World Health Organization guidelines. The predominant soil particle sizes were sand (68%), clay (24%), and silt (8%), with textures including clay, sandy clay, sandy clay loam, and sandy loam. Total organic carbon percentages ranged from 1.12% to 3.41%, with higher values in clay soils. Particle density across the sites remained consistent, ranging from 1.83 ± 0.02 g/cm³ to 2.66 ± 0.05 g/cm³, indicating similar compaction levels. The soil in the catchment area is classified as "light soil," with a higher proportion of sand, which enhances drainage and aeration. Moderate TOC values (0.7%–4.0%) generally suggest improved soil quality, promoting better soil structure, water retention, and nutrient availability. Overall, the physical properties of the soil in the Athi-Thwake River catchment are suitable for agriculture.***

**Keywords:** Texture, particle size**,** density, soil, Athi-Thwake River catchment, Makueni County

## 1. Introduction

Soil is composed primarily of minerals which are derived from parent material like rock. It is developed as a result of pedogenic process through weathering of rock, consisting of inorganic and organic constituents, possessing definite chemical, physical, mineralogical and bacteriological properties, having variability from depth to surface of earth, and provides a medium for plant growth (1). Soil promotes the growth of plants, protect watersheds (2,3). The potential properties such as the topography, hydrology and climate that may alter the potential utility of the soil properties (4).

The physical, chemical and biological properties of soil are fundamental. The physical properties of soil, are to great extent fixed and will not change over the years. These properties play a vital role in the sustainable productivity of soil. They greatly influence their use and behaviour towards plant growth, the plant support, root penetration, drainage aeration, retention of moisture and plant nutrients are linked with the physical properties of the soil. These properties also depend on the amount, size, shape, arrangement, mineral composition of its particles, organic matter content and pore spaces. The important physical properties of soil include soil texture, structure, surface area, density, porosity, colour and consistence.

Soil texture may be categorized as sand-sized, clay-sized and silt-sized particles which constitute the mineral content of soil fraction (5). The texture magnificence of soil shows the coarseness or fineness of the soil particles. The millimeters particle length relative quantities of the clay (less than zero 0.002 millimeters), sand (0.05-2 millimeters), and silt (0.002-0.05 millimeters). Debris which can be large than two millimeters such as mineral fragments (boulders, stones, cobbles and pebbles) are not taken into consideration within the textural magnification due to the fact they are fantastically inert (6).

This study was part of sediment load and control analysis study for Thwake Multipurpose Dam at the Athi and Thwake Rivers confluence guided by one situational analysis on mapping of soil erosion in Athi- Thwake River catchment (7). The Thwake Dam is located in an arid and semi-arid area characterized by low levels of rainfall averaging about 690 mm per annum. It is destined to provide water for families, domestic, irrigation, hydroelectric power generation and recreational purposes.

Therefore, it is important to determine the physical properties of soil from Athi-Thwake River catchment area. Soil physical properties that include soil particle size, texture, density and total organic carbon are important components of soil health that influences water and nutrients movements, aeration, soil temperature, nutrients cycling and root growth that affect crop yield and environmental quality (8–10). For example, increase in density due to increased soil compact results in decreased pore volume that reduces water filtration, increased aeration stress, lower soil temperature and nutrients cycling, increased denitrification (9). Since, the dam is destined to provide water for domestic use, irrigation, hydroelectric power generation and recreational purposes (11) it was important to provide the baseline data on the soil physical properties.

The physical properties of soil are very important for agricultural production and the sustainable use of soil. The amount and rate of water, oxygen and nutrients absorption by plants depend on the ability of the root to absorb the soil solution as well as the ability of soil to supply it to the roots (9).

## 2. Materials and Methods

### 2.1 The Study Area

The construction of the Thwake Multipurpose dam was proposed and implemented by Kenya's Ministry of Water, Sanitation and Irrigation. The Dam (Figure 1) is located in Makueni County at a distance of about 180 km from Nairobi County and can be accessed from Wote Town through Mavindini via Mikisi Primary School (11). The Thwake Dam project area is located on a slightly uneven landscape with a consistent slope towards the northeast. The total length of the area of study 22 km and a catchment area of 10,000 km$^2$ and it lies between Latitude 1$^0$47ˋ42.8” S and Longitude 37º50’17.3” E. The area is classified as an arid and semiarid area, characterized by very low levels of rainfall averaging about 690 mm per annum (11).

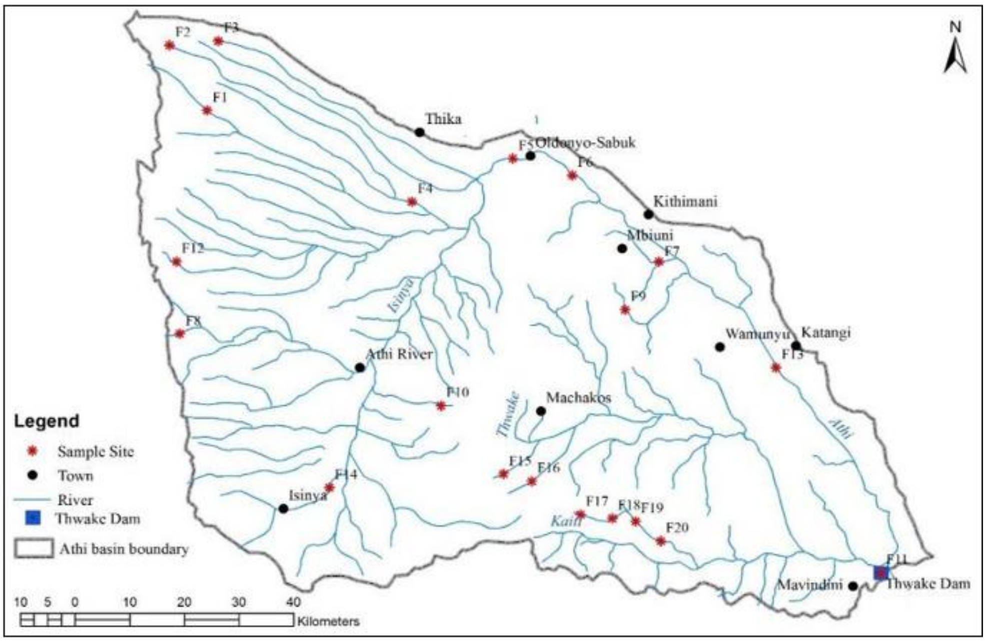


**Figure 1:** Map of Athi -Thwake River Catchment Area Showing Sampling Site

### 2.2 Site Selection and Sample Collection

As shown in Figure 1, soil samples were collected from 10 sites in November 2021. At each site, samples were collected from five locations within the selected farms by digging to a depth of 0-30 cm using a hoe and 800g of soil samples were scooped using a spade. The soil samples were thoroughly mixed on sterilized aluminum foil to form a composite sample. From this composite, four sets of 1,000 g samples were taken. The sampling site with coordinates and human activities in the study area as shown in Table 1. Four sets of 1000 g samples were taken from each of the sampling sites. For each site, two sets were designated as Batch A. These sets were individually wrapped in sterilized aluminum foil, marked, and put in marked self-sealing polyethylene bags. They were taken to the Kenya Agricultural and Livestock Research Organization (KARLO), for Physical properties analysis, these included particle size, texture, specific gravity, total organic carbon and soil density analysis.

**Table 1:** Description of the sampling sites, coordinates and human activities in the study area

| Local Name | Site | Latitude | Longitude | Altitude (m) | Description |
|---|---|---|---|---|---|
| Kikesa | $F_{7}$ | 1°15'44.5"S | 37°27'51.4"E | 1192 | Shrub (Acacia), banana plantation, maize, Millet, sorghum and beans and flat area |
| Mwala | $F_{9}$ | 1°21'33.8"S | 37°23'48.3"E | 1438 | Fruits and crop production like mango, maize, beans and traditional foods like cassava, sweat potatoes and sorghum, types of livestock are zebu cattle, dairy cattle and small-scale poultry. |
| Mavindini, Ngosini East | $F_{11}$ | 1°47'40.5"S | 37°49'47.8"E | 921 | Shrubs and indigenous trees. rocky and Hilly area. |
| Oloika, Road, Kiserian | $F_{13}$ | 1°23'53.3"S | 36°41'27.2"E | 1879 | Horticultural farming through irrigation and green house, types of livestock goats. flat area |
| Lubwa, kwa Kavoo | $F_{15}$ | 1°37'31.8"S | 37°12'30.6"E | 1642 | Acacia trees (Shrubs). flat area |
| Lubwa, muumandu area | $F_{16}$ | 1°38'15.7"S | 37°15'18.6"E | 1764 | Acacia trees (Shrubs). flat area |
| Machakos Wote Road, Lanzoni | $F_{17}$ | 1°41'42.2"S | 37°20'06.0"E | 1620 | Shrubs, mangoes, plantation, banana plantation. hilly area |
| Machakos Wote Road, Kola | $F_{18}$ | 1°43'05.0"S | 37°22'06.4"E | 1564 | shrubs, mangoes plantation, banana plantation, maize plantation. hilly area |
| Makongo | $F_{19}$ | 1°42'43.6"S | 37°24'04.1"E | 1570 | Acacia(shrub), hilly and Rocky and sand collection area. |
| Machakos Wote Road, mukuyuni | $F_{20}$ | 1°43'17.3"S | 37°25'08.4"E | 1400 | Acacia trees (Shrubs). hilly area |

### 2.3 Chemicals and Reagents

Distilled water and sodium hexametaphosphate ($NaPO_3$) used as the soil dispersing agent

### 2.4 Instrument and Apparatus

Equipment used included an analytical balance (Shimadzu, serial no. C054-E032Q), a hydrometer (model 152H), a 1000 mL graduated cylinder for control, a thermometer with 0.1 °C divisions, beakers, a stopwatch, U.S. standard sieves, a pestle and mortar, a Labotec mechanical soil pulverized, a Gilson Performer mechanical sieve shaker, a brush, stoppers, a hot plate for maintaining high temperatures, a vacuum pump, evaporating dishes, density bottle and a spatula.

### 2.5 Soil Texture analysis by hydrometer determination

Approximately 50 g of finely sieved soil particles was taken into a beaker, 125 ml of sodium hexametaphosphate, (w/v [40 g/L] solution) was added as the dispersing agent, the mixture stirred thoroughly and left to stand so as to soak for 10 minutes. 125 ml of sodium hexametaphosphate was poured into the measuring cylinder designated for control, and then deionized water was increased to reach the mark then thoroughly stirred. Following that, thermometer and hydrometer were placed into the control container, and the necessary adjustments for zero correction were made while recording the temperature.

The slurry of soil was introduced into the mixer by addition of deionized water as necessary till the mixing cup was half full; the solution was mixed for 2 minutes. The slurry was transferred into a 1000 milliliters sedimentation cylinder that was empty deionized water was added to the mark. The cylinder was alternately inverted and turned upside approximately 30 times, when covered with a stopper or palm of the hand. When it settled down, the time was recorded, the stopper was removed from the cylinder and the hydrometer slowly was inverted.

A meniscus was formed between the stem of the inverted hydrometer and the suspension. The hydrometer was removed and introduced into the control cylinder, it was then gently spinned to expel any adhering particles and then the hydrometer readings were recorded. The soil water suspension temperature readings were also recorded. The soil water suspension temperature was recorded and the readings rounded off to 0.5 °C.

### 2.6 Soil Particle Size Distribution Determination

A dry sieving method is crucial for determining the size of soil particles, which quantitatively measures the particle size distribution of all components within a particular soil. It was used to access the distribution of particle sizes exceeding a diameter of 0.075 mm. Table 2 provides a list of the United States of America standard sieve numbers along with their corresponding opening sizes used to determine sieve particle size (12).

Mortar and piston were used to finely pulverized the soil samples; 600 g of oven dried soil samples was used to determine the particles size using sieve determination. 500 g was weighed from the previous oven dried soil sample taken, the stack of sieves was used, particles with larger openings, denoted by lower sieve numbers, were arranged above those with smaller openings, indicated by higher sieve numbers.

A pan was positioned beneath sieve number 200, which was the third and the last sieve, and the portion of soil particles passing through it was attentively collected.

The sieve was brushed to poke out any soil particles stuck in the opening. The pan and all the sieves were weighed separately and recorded. The soil samples were poured from the topmost sieve and a cover placed on it. The filled stack was placed in a sieve shaker, all clamps fixed in place, the shaker started once the timer was set for 15 minutes. The weight of each sieve and soil retained taken once the shaker stops.

The particle sizes were calculated by addition of all the weight retained in all the sieves, cumulative percentage passing and a graph of particle size distribution against cumulative percentage passing was determined using United States of America’s Department of Agriculture Soil Texture Triangle From, the Soil Texture Triangle, the soil particles sieve and sizes were obtained using Table 2 (13).

**Table 2:** The U.S. Standard Sieve numbers for Soil Particles Sizes Conversion.

| Sieve numbers | Sieve Opening (mm) | Sieve numbers | Sieve Opening (mm) |
|---|---|---|---|
| 4 | 4.75 | 35 | 0.5 |
| 5 | 4 | 40 | 0.425 |
| 6 | 3.35 | 45 | 0.355 |
| 7 | 2.8 | 50 | 0.3 |
| 8 | 2.36 | 60 | 0.25 |
| 10 | 2 | 70 | 0.212 |
| 12 | 1.7 | 80 | 0.18 |
| 14 | 1.4 | 100 | 0.15 |
| 16 | 1.18 | 120 | 0.125 |
| 18 | 1 | 140 | 0.106 |
| 20 | 0.85 | 200 | 0.075 |
| 25 | 0.71 | 270 | 0.053 |
| 30 | 0.6 | 400 | 0.038 |

Source (13).

### 2.7 Soil Specific Gravity Determination

The weight of each cleaned and dried 500 ml volumetric flask, filled with distilled water, was recorded as (W1).

Using a thermometer, the water temperature was measured and noted as (T = T1°C). A 100 g sample soil that had been air-dried was weighed in an evaporating dish and then transferred to the volumetric flask (W2).
Deionized water was used for dissolving the solution to about two-thirds of the flask. Trapped air from the mixture of soil and air was removed using a vacuum before adding more water to the 500 ml level. Total weight of the flask, soil, and water was recorded as (W3) after drying the exterior of the flask. The water-soil mixture was then transferred to a pre-weighed evaporating dish, and a squeeze water bottle was used to rinse the interior of the volumetric flask to ensure all soil was removed. The evaporating dish was then placed in a

hot oven and dried until a consistent weight (W4) was achieved. Equation 1 below was used to calculate the specific soil gravity (Gs):

$$Gs = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \quad \text{Equation 1}$$

The soil that had a correct specific gravity passed through United State of America (U.S) standard sieve number 7 [14]
$W_1$ weight of the density bottle
$W_2$ weight of the dried soil sample
$W_3$ combined mass of density bottle, water and soil
$W_4$ weight of density bottle and water

### 2.8 Soil Particle Density Determination

A cleaned and dried pycnometer was weighed (Wa), then 10 g of the soil sample that was sieved through a 2-mm sieve after drying in air as indicated in (Table 2), was then added. Any soil spilled on the neck and the exterior of the pycnometer was cleaned off. The combined weight of the pycnometer and soil was recorded as (Ws). Duplicate samples were dried at 105°C by using an oven with an aim of measuring its water content.

The pycnometer was filled about halfway with distilled water to ensure that all soil samples entered the flask for measurement. To eliminate air bubbles, the water was gently boiled for a few minutes, with regular, gentle stirring to prevent soil loss due to foaming. Both the pycnometer and the solution within it were cooled to room temperature, cooled distilled and boiled water was poured to fill the pycnometer. The stopper was carefully inserted and seated. The exterior of the flask was meticulously dried with a dry cloth, making sure not to remove water from the capillary.

The pycnometer and its contents were weighed (Wsw), and the temperature was recorded once it reached room temperature. Next, the soil was extracted from the apparatus and thoroughly washed. Then cooled and l distilled water at a similar temperature as before was added into the apparatus.

The stopper was reinserted, the exterior was dried carefully with a cloth, and the pycnometer and its contents were weighed (Ww), ensuring the temperature remained constant. The calculation from the analysis of the soil density was as depicted in equation 2 below:

$$\rho = \rho_w (W_s - W_a)/[\{W_s - W_a\} - \{W_{sw} - W_w\}] \quad \text{Equation 2}$$

Where:
$\rho_w$ = water density in grams per cubic centimeters at temperature observed
$W_s$ = the weight of pycnometer plus soil sample corrected to oven-dry water content
$W_a$ = the weight of pycnometer filled with air
$W_{sw}$ = the weight of pycnometer filled with soil and water, and
$W_w$ = the weight of pycnometer filled with water at temperature observed

### 2.9 Total Organic Carbon (TOC) Determination

The total organic carbon was determined using a LOCO SC-444 Analyzer.

## 3. Results and Discussions

The soil texture, the total organic carbon (TOC), texture grade, soil classification and density of soil samples were analyzed in triplicates (n=3). The average in each site and parameter in the 10 different sites were calculated and results are as in Table 3.

**Table 3:** The Mechanical Particle-Size Classes

| Site | Sand % | Clay % | Silt % | Texture Grade | Total organic carbon % | Class | Particle density (g/cm$^3$ |
|---|---|---|---|---|---|---|---|
| F7 | 40 | 50 | 10 | SC | 1.30 ±0.02 | Low | 2.66±0.05 |
| F9 | 50 | 32 | 18 | SCL | 1.67 ±0.03 | Moderate | 2.47±0.01 |
| F11 | 42 | 42 | 16 | SC | 1.56 ±0.01 | Moderate | 2.41±0.01 |
| F13 | 20 | 62 | 18 | C | 3.41 ±0.05 | Adequate | 2.59±0.02 |
| F15 | 54 | 36 | 10 | SC | 2.46 ±0.03 | Moderate | 2.67± 0.03 |
| F16 | 50 | 42 | 8 | SC | 1.76 ±0.01 | Moderate | 2.62±0.01 |
| F17 | 40 | 56 | 4 | C | 1.48±0.01 | Moderate | 2.62±0.02 |
| F18 | 68 | 24 | 8 | SCL | 1.40 ±0.04 | Moderate | 2.43±0.03 |
| F19 | 56 | 36 | 8 | SC | 2.30 ± 0.01 | Moderate | 2.61±0.01 |
| F20 | 78 | 14 | 8 | SL | 1.12 ±0.02 | Low | 1.83±0.02 |
| S-Sandy, C-clay, CL-Clay Loam, LS-Loamy Sand, SL-Sandy Loam, SC- Sandy Clay, SCL- Sandy Clay Loam | | | | | | | |

### 3.1The Soil Texture Grade

The soil particles in the Athi-Thwake Rive catchment area were classified as law (20 %), moderate (70 %) and adequate (10 %). The texture grades in the study area were in four categories, these include sand clay (50 %), sandy clay loam (10 %), clay (20 %) and sandy loam (10 %) (Table 3).

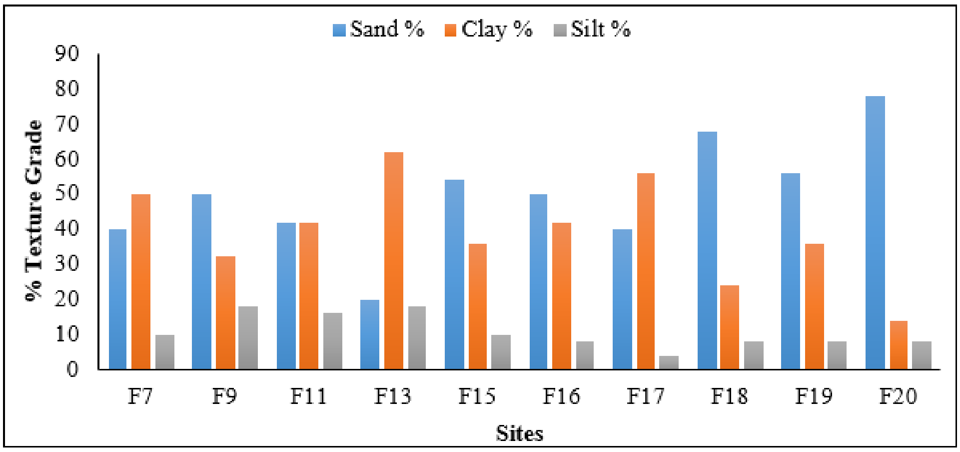


**Figure 2:** Soil samples texture in the Athi -Thwake catchment area

The United States of America's Department of Agriculture (USDA) soil texture triangle (Figure 2) shows the percentages of silt, clay and sand in soil sample with its texture classification (Table 3). Hence from Figure 2, the Athi-Thwake River catchment area has sand and clay as the main particles. The soil samples from Sites F15, F16, and F19 exhibited a "sandy clay" texture grade (Table 3). This indicates a soil composition with a higher proportion of sand particles and a significant amount of clay particles. The finding of this study supports this observation, noting that soils with a sandy clay texture tend to have good water drainage due to their high sand content but also share some characteristics of clay soils, such as susceptibility to compaction and waterlogging (8).

For sites F9 and F18, the soil texture grade was identified as "sandy clay loam" (Table 3) suggesting an even distribution of clay, sand, and silt particles. These soils are characterized by good drainage, reasonable fertility, and suitability for a wide range of plant life, as highlighted by (14).

At site F20, the soil samples displayed a "sandy loam" texture grade (Table 3), signifying a soil composition with a relatively higher percentage of sand particles, along with a moderate amount of silt and a smaller proportion of clay (Figure 3). As emphasized by (15), soil texture is crucial in examining the biological, physical, and chemical features of the soil. The soil size was sand-sized > clay-sized > silt-sized particles which constituted the mineral content of soil fraction in the catchment area. The soil in Athi-Thwake River catchment is "light soil". "Light soil" typically describes soil that has a higher proportion of sand compared to clay, while "heavy soil" consists predominantly of clay (5).

### 3.2 Soil Organic Carbon Content

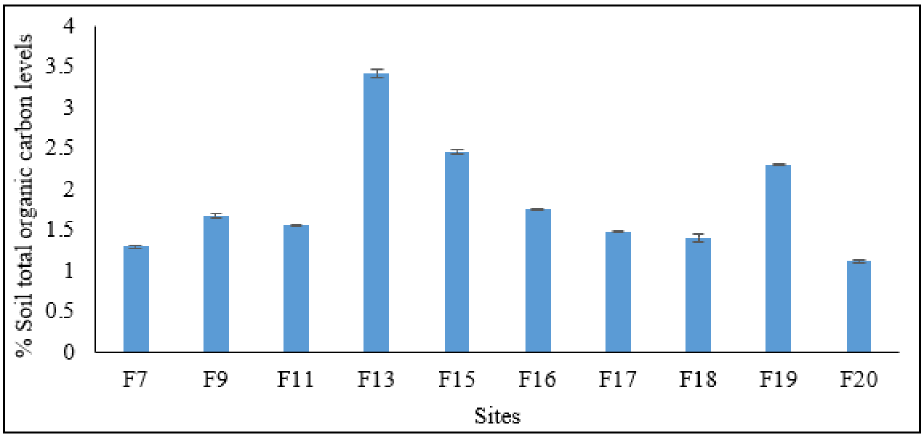


**Figure 3:** The percentage total organic carbon levels in Athi -Thwake catchment area

Site F13 had the highest percentage total carbon content of 3.41± 0.05, which is adequate while Site 20 had 1.12 ± 0.02 that is low in class (Table 3). From Figure 3, the context of soil quality and fertility depends on the levels of organic carbon. The higher the total organic carbon (TOC) values generally signify improved soil quality, as organic matter can enhance the soil structure, the water-retention capabilities, and availability of nutrients (16). However, extremely high TOC values can also signal potential issues, such as pollution or contamination, especially when organic matter accumulates due to excessive organic material inputs, such as agricultural runoff, as discussed by (16). The total organic carbon content was within the range of 0.7 % -4.0 % [20], this was moderated total organic carbon contents (Table 3). Total organic carbon acts as the main supply of energy for microorganisms in soil and is a trigger for availability of nutrient through mineralization for plant growth in the catchment area (17).

### 3.3 The Soil Density

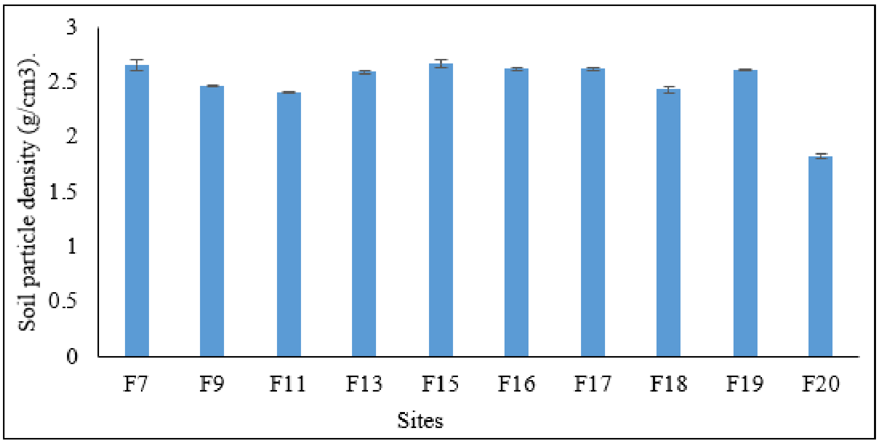


**Figure 4:** Soil particle density in Athi -Thwake Rivers catchment area

The soil particle density was evenly distributed in the catchment area, with Sites F15 showing the highest value of 2.67± 0.03 g/cm$^3$ and F20 having lowest levels 1.83±0.02 g/cm$^3$ (Table 3). From Figure 4, the values of the soil particle density showed that samples have higher variability or lower precision than others as highlighted by (18). The particle density of soils influences their pore space, affecting plant root penetration, soil aeration and water flow between particles. As noted by (19), soils with higher particle densities typically have less pore space. Therefore, soil should have density value below the critical value of 3.0 g cm$^3$ in order to support root growth. Increase in density of soil leading to decrease of the soil porosity (19). The soil density in the catchment area was within the typical particle density for soil ranging from 1.83 ± 0.02 g/cm$^3$-2.67± 0.03 g/cm$^3$, that can support root growth (19).

## 4. Conclusion and Recommendation

### 4.1 Conclusions

The sites exhibit diverse soil textures of sand-sized > clay-sized > silt-sized particles which constituted the mineral content of soil fraction in the catchment area. The soil particles sizes were sand (68 %) clay (24 %) and silt (8 %). The Athi-Thwake River catchment has “light soil”. "Light soil" typically describes soil that has a higher proportion of sand compared to clay. There were moderate total organic carbon contents within the range of 0.7 % -4.0 %, the values generally signify improved soil quality, as organic matter can enhance the soil structure, the water-retention capabilities, and availability of nutrients. The soil particle density was evenly distributed in the catchment area. The soil density in the catchment area was within the typical particle density for soil ranging from 1.83 ± 0.02 g/cm$^3$-2.67± 0.03 g/cm$^3$, that can support good plant root growth. The levels of physical properties in the Athi-Thwake River catchment area soil is generally best for agriculture.

### 4.2 Recommendation

Based on the soil texture and organic carbon content, it is advisable to adopt soil management strategies such as organic amendments to enhance soil structure and fertility, particularly in sandy soils, which are prone to nutrient leaching.

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## Author Profile


**Sarah M. Kariuki** Msc. Analytical Chemistry

**Prof. Deborah A. Abong'o** Associate Professor, BSc, MSc, PhD. Her area of interest is Analytical Chemistry & Environmental Chemistry,

**Dr. Joyce G.N. Kithure** SENIOR LECTURER, BSc, MSc, PhD. Her area of interest is Analytical Chemistry & Environmental Chemistry.

**Dr. John P.O. Obiero** Senior Lecturer (Irrigation and Water Resources Engineering**)**, (Chairman EBE, Aug 2023-to current)