Assessment of geotechnical and physico-chemical properties of age-long greywater-contaminated soils in basement complex areas, southwest Nigeria

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Abstract
Bathroom-rich greywater coming directly in contact with virgin soil for years contaminates soil and alters its properties. The degree of alteration of soil properties may also depend on geological settings from which the soil was formed. The present study was designed to investigate the physico-chemical and geotechnical properties of greywater-contaminated soil (GCS) in different soils of basement complex formation. Soil samples were collected from greywater discharge zones and control soil (CS) in two locations (Mapo in Ibadan, Oyo State and Isolu in Abeokuta, Ogun State, Nigeria) at the depths of 0.5, 1.0 and 1.5 m from the surface, and the soil properties were analysed following standard procedures in the laboratory. The experiment consists of two modes: CS with no presence of greywater and GCS. The results of this study showed that alteration of most analysed properties depends greatly on sampling depth. There is increased in soil pH, cation exchange capacity, dry density (DD), saturated hydraulic conductivity ($K_{sat}$) and shear strength (SS) in GCS at Mapo over their control values, while porosity, Atterberg limits (ALs), plasticity index and moisture content (MC) were reduced relative to the CS at all sampling depths. However, only bearing ratio improved at each sampling depth in GCS at Isolu, while alterations in other analysed properties did not follow clear trend. Correlation coefficient showed positive correlation between % clay and AL, porosity and ALs; MC and ALs at 1% level, while negative correlation exists between DD and ALs, % sand and ALs as well as $K_{sat}$ and ALs at the two locations. Two-way ANOVA showed that there is a significant difference at 5% level ($p < 0.05$) based on sampling depths for most analysed properties except SS, organic matter and soil resistivity. Further investigation is needed to study the trend of alteration of soil properties with depth on GCS at other soil types and geological formations.

Keywords Soil · Greywater · Physico-chemical · Geotechnical · Correlation · ANOVA

Introduction
The soil has considerable but restricted capacity to process pollutants, so that when that capacity is reached, the soil may turn into simply a deposit or a vector in the transmission of pollutants to the environment (Gavrilescu 2014). However, the contamination of soils by wastes resulting from various daily human activities can be through various ways ranging from release of industrial effluent, accidental oil spillage, herbicides/pesticides application and release of domestic waste water to mention a few. Thus, wastes generated on daily basis can be broadly classified as industrial waste and domestic waste. Industrial wastes refer to waste generated from industrial activities, products and treatment of industrial products. These wastes can come in form of solid waste, wastewater or gaseous wastes. On the other hand, domestic wastes are those generated from household activities and can be in form of solid waste and liquid waste (Travis et al. 2008). One of the important domestic wastes is greywater, which is a wastewater originating from the laundry and bathroom excluding the toilet waste water (Sawadogo et al. 2014; Travis et al. 2008, 2010; Edwin et al. 2014; Maimon et al. 2014). The quality of greywater generated from households is dependent on the social and cultural behaviour of the residents of the people involved, availability of water and the consumption amount (Uddin et al. 2015). Most times,
greywater from bathroom sources contains large quantities of oils, surfactants, body fats and chemical originating from soap, tooth paste, hair shampoo and other cleaning products (De Gisi et al. 2015; Edwin et al. 2014; Sawadogo et al. 2014) but contains lower biological oxygen demand (BOD), thermotolerant coliform and electrical conductivity (Erickson et al. 2002; De Gisi et al. 2015). The composition and quantity of greywater discharged into the environment varied and depend on factors such as water source, type of settlement, life styles of the inhabitants, household practices and type of chemical products used for domestic cleanings and bathing (Kariuki et al. 2012; Katukiza et al. 2014; Oteng-Peprah et al. 2018).

There is a growing concern in many countries, including Nigeria, on the disposal of greywater into soil drainage. The practice constitutes health hazard to aquatic ecology and the transmission of pathogens from polluted water to human food chain (Mohamed et al. 2018a). This may not be unconnected to the distribution of pollutants such as chemical agents, surfactants and pathogens that drain into surface waters. Greywater may contain various physico-chemical contaminants and organic micropollutants (OMPs) at levels that can cause unfavourable effects on soil, plant, water, human beings and environment (Kopittke et al. 2011; Mohamed et al. 2013; Edokpayi et al. 2017). Continuous release of greywater on a particular area over a long period of time may lead to surface ponding, runoff and likely contamination of shallow groundwater sources (Tarchouna et al. 2010; Siggins et al. 2016; Edokpayi et al. 2017). Dissolved salts in greywater may also cause eutrophication in addition to pollution of surface water bodies, thus causing irreparable damage to aquatic system (Pinto et al. 2010; Turner et al. 2013; Katukiza et al. 2014). Long-term exposure of ecosystem to greywater discharge could lead to negative impacts on soil structural stability, soil enzyme activity and its hydraulic property which may adversely affect soil quality, plant quality and plant growth (Reichman and Wightwick 2013; Etchepare and van der Hoek 2014). The build-up of heavy metals and OMPs in soil contaminated with greywater may cause toxicity through the food, chain thereby causing detrimental health risks on humans and animals after long exposure period (Arjoon et al. 2013; Edokpayi et al. 2017). The surfactants constitute major component of greywater and are organic molecules consisting of hydrophilic and hydrophobic groups that alter soil physico-chemical and mechanical properties (Travis et al. 2010). In many countries, particularly in Nigeria, large volumes of these surfactants are on daily basis released without being treated on to natural soil and surface waters, which deplete the oxygen available for aquatic respiration (Mohamed et al. 2018a, b). Surfactant which can be anionic, cationic or non-ionic based on their different chemical properties can be adsorbed, transported or degraded in porous media (Weil-Shafran et al. 2006).

Surfactants exist as monomeric molecules in aqueous solution at low concentrations. However, at high concentration known as Critical Micelle Concentration (CMC), the surfactant molecules aggregate into micelles which results in eventual reduction of surface tension and interfacial tension of aqueous solution (Faisal Anwar 2011a, b; Cirelli et al. 2008; Peng et al. 2017). In few households in south-west Nigeria, greywater from bathrooms is usually disposed off directly into the open soil from bathroom outlets, thereby resulting in soil contaminations. The surfactant-rich greywater coming directly from bathroom outlets into the soil actually has low pollution load and high availability (Jefferson et al. 1999; Edwin et al. 2014; Friedler 2004). However, the reuse of this greywater for application such as toilet/urinal flushing, irrigation and potable water preservation purposes is not common in Nigeria despite the fact that this practice has been implemented in many countries (especially arid region) including nearby South Africa (Bakare et al. 2017). Nevertheless, the impact of the direct discharge of greywater on the soil of urban area is rarely analysed.

Contamination of urban and agricultural soils by organic hydrocarbon and industrial wastes affects a range of physical, chemical and engineering properties (Chew and Lee 2010; Nazir 2011; Misra and Sivongxay 2008; Karkush and Resol 2017; Kermani and Ebadi 2012; Karkush and Al-Taher 2017). However, effect of wastewater on soil depends on several factors such as soil structure, soil type, topography and quality of sewage effluents (Oron et al. 2014; Li et al. 2009).

The impact of greywater irrigation on some soil properties is well documented by previous studies (Abu-Zreig et al. 2003; Pinto et al. 2010; Xu et al. 2010; Weil-Shafran et al. 2006; Travis et al. 2010; Albalawneh et al. 2015; Misra et al. 2012; Bame et al. 2014). However, the impacts of greywater on engineering and physico-chemical properties were rarely studied. Therefore, the present study was set out to assess the impacts of age-long greywater discharges on soil geo-technical and physico-chemical properties on soils derived from basement complex rock formation. The specific objectives were to measure the effect of greywater discharges on selected soil physico-chemical and engineering properties at varying depths and study the interrelationship among the soil properties using multivariate analyses.

Materials and methods

Site description and geological setting

The study was carried out in Isolu and Mapo within Odeda and Ibadan North East local government areas, respectively, in south-west Nigeria. The locations of the soil sampling points were determined by a GPS and lie within longitude
3° 26′ 00″ E and 3° 54′ 00″ E and latitude 7° 12′ 00″ N and 7° 26′ 00″ N in the south-western Nigeria (Fig. 1). The two sampling locations fall within the humid/subhumid tropical climate of south-west Nigeria. The mean annual rainfall, mean annual potential evaporation and mean maximum temperature of Ibadan are 1270 mm, 1199 m and 32 °C, respectively (Akintola 1986). The mean annual rainfall, mean annual potential evaporation and temperature of Abeokuta are 1238 mm, 1100 mm and 27.1 °C, respectively (Akinyemi et al. 2011; Akinse and Gbadebo 2016). The rainy season in the two sampling locations starts from March and ends in October, while dry season occurs from
November to February under the influence of north-easternly winds from Sahara desert (Badmus and Olatinsu 2010). The two sampling locations are classified as Aw (tropical savanna climate) by Köppen and Geiger. The soil type in Isolu is Typic Palendalf/Eutric Luvisols, while that of Mapo belongs to Vertic Eutrudert/Vertic Cambisol (FAO 2005). The soils in Isolu and Mapo are classified locally as Abeokuta and Egbeda series, respectively (Smyth and Montgomery 1962). The soil sampling locations are shown in Fig. 1.

**Geological setting**

The sampling locations fall within the basement complex terrain of south-west Nigeria. The basement complex rock consists of crystalline igneous and metamorphic rocks, which form part of the African crystalline shield within the rocks belonging to the youngest of the three major provinces in West African creation (Jones and Hockey 1964). They are loosely categorized into three main subdivisions, namely the migmatite–gneiss complex, the schist belt and pan African (Ca 600 Ma) older granite series (Eluze 2000). These rocks are either exposed or covered by shallow mantle of superficial deposits. The dominant rock types in Ibadan are quartzites and gneiss–migmatite complex, while minor rock types include pegmatite, quartz, aplites, dolerite dykes, amphibolites and xenoliths (Okunlola et al. 2009). Banded gneiss constitutes over 75% of the rocks in and around Ibadan, while the augen gneiss and quartzites share the remaining in equal percentages (Okunlola et al. 2009). In the north, Abeokuta is characterized by pegmatite vein underlain by granite, in the western part by granite gneiss of less porous nature together with various quartzite intrusions, while the southern part enters the transition zone with the sedimentary formation of eastern Dahomey Basin (Key 1992). Figure 2 is the geological map showing the rock types that underlie the sampled areas and soil sampling locations. The dominant rock types in the two sampling locations (Isolu and Mapo) as shown in Fig. 2 are migmatite and quartzite, respectively.

![Fig. 2](image_url) Geological map showing soil sampling locations. Adapted from Jones and Hockey (1964)
Soil samples collections and analytical methods

The soil sampling locations fall within the residential area of Isolu and Mapo that fall within the basement complex formation of south-western part of Nigeria. Twelve (12) soil samples were collected at varying depths of 0–50 cm, 50–100 cm and 100–150 cm at the two sampling locations. At each sampling location, two sampling points were created. At each sampling point, soil samples were collected in duplicate for each sampling depth and average data from the two samples are presented. These were discharge zone of bathroom greywater coming directly from the outlets of bathroom and a control site where there is no presence of greywater falling on to the soil. Greywater-contaminated soil (GCS) was collected within the greywater discharge zone, while control soil sample (CS) was collected from control site at each sampling location. Times of soil exposure to bathroom greywater at the two sampling locations were more than 20 years. Soil samples were collected with the aid of soil auger, while 12 undisturbed core samples were also collected at varying depths for determination of $K_{sat}$ and MC. The soil samples were packed in a well-labelled polythene bags and conveyed to soil physics laboratory of the Institute of Agricultural Research & Training (IAR&T) Moor Plantation, Ibadan, for sample preparation and analysis. The soil samples were air-dried, gently crushed and sieved with a 2-mm sieve before analysis. Preservation of soil samples and all analyses were carried out using standard ASTM procedures.

The soil physico-chemical parameters of interest were particle size distribution, soil pH, OM, CEC and soil resistivity, while geotechnical/hydraulic properties are Atterberg limit test (PL and LL), plasticity index (PI), BR and SS, porosity, MC and $K_{sat}$. Particle size distribution was determined by modified Bouyoucous hydrometer as described by Gee and Or (2012) with textural classification done using the USDA textural triangle. A digital pH meter was used to measure pH in water of each soil sample based on ASTM G51-95 standard (ASTM G51-95 2012), while soil MC was determined using the method of weight loss in accordance with ASTM D1883-07 (ASTM D4959-2007). Soil resistivity was measured using the M.C. miller soil boxes according to the ASTM G57-05 (ASTM 2005) standard. The saturated hydraulic conductivity ($K_{sat}$) of core samples was measured using the constant head method based on Reynolds and Elrick (2002), while porosity was calculated as the ratio of pore volume of the test sample to the total volume. The CEC was determined using the ammonium acetate (NH$_4$OAC) displacement methods of Jackson (1958), while OM was determined using the K$_2$Cr$_2$O$_7$ – H$_2$SO$_4$ wet oxidation method as modified by Nelson and Sommers (1982). Dry density was calculated using the following relationship:

$$\rho_b = \frac{M_s (g)}{V_b (cm^3)}$$

where $\rho_b$ is the soil dry density (g cm$^{-3}$); $M_s$ is the mass of oven-dried soil (g); and $V_b$ is the volume of the soil (cm$^3$)≡ volume of the cylindrical core, where $V_b = \pi r^2 h$; $r$ and $h$ are the internal radius and the height of the cylindrical core.

Atterberg limits test was determined according to ASTM D4318-17E1 (ASTM D4318 2017) standard, while SS was determined according to ASTM D2850-15 (ASTM D2850 2015) standard. BR was determined based on ASTM D1883-16 (ASTM D1883 2016) standard.

Statistical analysis

Pearson’s correlation coefficient is commonly used to measure and determine the relationship between two continuous variables. The correlation coefficient is calculated for two continuous variables that have linear relationship and tells if the observed covariation/coexistence is positive or negative (Helsel and Hirsch 2002; Amfo-Otu et al. 2014). Analysis of variance (ANOVA) was one of the useful statistical tools for better interpretation of complex data set and can provide useful information about the ecological status of a particular region (Firdous et al. 2016). ANOVA was performed to determine whether the selected soil physico-chemical and geotechnical properties varied significantly with respect to varying depths. Pearson’s correlation analysis was also performed on soil data to examine the relationship between two parameters relating to the soil physico-chemical and geotechnical properties. Pearson’s correlation was used to explain relationship between samples parameters. All data were presented as mean ± standard deviation where the means were separated at the $p \leq 0.05$ level of significance.

Results and discussion

Physico-chemical and hydraulic properties

The results of analysed soil physico-chemical properties of the soil samples are presented in Table 1, while results of geotechnical and hydraulic properties are presented in Table 2. From Table 1, the percentage of fine particles of clay and silt in soils derived from migmatite rock (Isolu) ranges from 17.9 to 34.9% and 8.9 to 14.9%, respectively, and was classified as sandy loam/sandy clay loam/sandy clay based on varying depths. However, clay and silt particles in soil derived from Quartzite rock (Mapo) ranged from 12.5 to 30.9% and 8.9 to 13.9%, respectively, and were classified as sandy loam/sandy clay loam based on analysed depths. The soil pH ranged between 6.2 and 8.7 in Isolu soil samples, but
ranged from 5.2 to 9.4 in Mapo soil samples. The soil pH in water was more alkaline at depths 0.5 and 1.0 m but acidic at 1.5 m depth for both CS and GCS at Ibadan. However, at Isolu location, soils were found to be acidic at depths 0.5 and 1.5 m, while the soil pH was alkaline at 1.0 m depth in both CS and GCS. The pH of GCS at Ibadan increased for each sampling depth when compared with control pH value but only increased at 0.5 m depth for GCS at Isolu. The increase in soil pH for GCS at Ibadan agrees with results of Mohamed et al. (2018a), Siggins et al. (2016) and Shifa and Thomas (2017) that reported increase in pH of soil contaminated with laundry detergent. The decrease in soil pH of Isolu GCS relative to control pH value at 1.0 and 1.5 m is in line with decreased soil pH in soil irrigated with greywater reported by Mohamed et al. (2013). This decrease in soil pH may also be due to the presence of purifier substratum at higher depths above 0.5 m in Isolu. Furthermore, the pH of GCS (<9.0) at 0.5 m shallow depth in Isolu will not affect

### Table 1 Results of physico-chemical properties of analysed soil samples

| Description of the site | % Sand    | % Silt    | % CLAY  | pH in H2O | OM (g/kg) | CEC (cmol/kg) | Soil resistivity (ohm cm) |
|------------------------|-----------|-----------|---------|-----------|------------|---------------|--------------------------|
| 0.5 m Control Mapo      | 74.22     | 12.86     | 12.92   | 9.32      | 0.81       | 2.87          | 6.25                     |
| 1.0 m Control Mapo      | 66.22     | 12.86     | 20.92   | 8.31      | 0.81       | 0.99          | 6.25                     |
| 1.5 m Control Mapo      | 60.22     | 8.86      | 30.92   | 5.21      | 0.56       | 0.37          | 4.31                     |
| 0.5 m GCS Mapo          | 74.68     | 12.86     | 12.46   | 9.38      | 0.81       | 3.35          | 6.25                     |
| 1.0 m GCS Mapo          | 67.68     | 13.86     | 18.46   | 9.16      | 0.88       | 1.25          | 6.74                     |
| 1.5 m GCS Mapo          | 60.68     | 10.86     | 28.46   | 6.43      | 0.69       | 0.48          | 5.28                     |
| 0.5 m Control Isolu     | 71.68     | 8.86      | 19.46   | 6.20      | 0.56       | 1.23          | 4.31                     |
| 1.0 m Control Isolu     | 59.68     | 14.86     | 25.46   | 8.66      | 0.94       | 0.66          | 7.22                     |
| 1.5 m Control Isolu     | 53.68     | 12.86     | 33.46   | 6.74      | 0.81       | 0.35          | 6.25                     |
| 0.5 m GCS Isolu         | 72.22     | 9.86      | 17.92   | 6.95      | 0.62       | 1.40          | 4.79                     |
| 1.0 m GCS Isolu         | 58.22     | 14.86     | 26.92   | 8.45      | 0.94       | 0.55          | 7.22                     |
| 1.5 m GCS Isolu         | 52.22     | 12.86     | 34.92   | 6.56      | 0.81       | 0.31          | 6.25                     |

### Table 2 Results of geotechnical and hydraulic properties of analysed samples

| Description of the site | DD (Mg m⁻³) | Porosity (%) | MC m⁻³ m⁻³ | Ksat (cm/hr) | Liquid limit | Plastic limit | Plasticity Index | Shear strength KN/m² | Bearing ratio (%) |
|------------------------|-------------|--------------|------------|--------------|--------------|---------------|-------------------|-------------------|-------------------|
| 0.5 m Control Mapo      | 1.58        | 40.38        | 0.087      | 1.31         | 17.2         | 13.7          | 3.5               | 151.61            | 3.82              |
| 1.0 m Control Mapo      | 1.49        | 43.77        | 0.093      | 0.45         | 22.5         | 17.9          | 4.6               | 150.82            | 6.18              |
| 1.5 m Control Mapo      | 1.42        | 46.42        | 0.98       | 0.17         | 26.5         | 21.1          | 5.4               | 104.46            | 6.30              |
| 0.5 m GCS Mapo          | 1.59        | 40.00        | 0.083      | 1.53         | 16.9         | 13.4          | 3.4               | 151.70            | 3.68              |
| 1.0 m GCS Mapo          | 1.51        | 43.02        | 0.089      | 0.57         | 21.5         | 17.2          | 4.4               | 163.50            | 5.88              |
| 1.5 m GCS Mapo          | 1.44        | 45.66        | 0.097      | 0.22         | 26.2         | 20.9          | 5.3               | 128.04            | 7.11              |
| 0.5 m Control Isolu     | 1.52        | 42.64        | 0.084      | 0.56         | 18.9         | 15.0          | 3.8               | 105.43            | 3.96              |
| 1.0 m Control Isolu     | 1.45        | 45.28        | 0.096      | 0.30         | 26.9         | 21.4          | 5.5               | 175.19            | 8.70              |
| 1.5 m Control Isolu     | 1.40        | 47.17        | 0.107      | 0.16         | 30.9         | 24.6          | 6.3               | 151.70            | 9.89              |
| 0.5 m GCS Isolu         | 1.52        | 42.64        | 0.083      | 0.64         | 18.5         | 14.7          | 3.8               | 116.25            | 4.06              |
| 1.0 m GCS Isolu         | 1.43        | 46.04        | 0.094      | 0.25         | 27.9         | 22.2          | 5.4               | 175.19            | 9.20              |
| 1.5 m GCS Isolu         | 1.38        | 47.92        | 0.109      | 0.14         | 31.9         | 25.4          | 6.2               | 151.58            | 10.32             |
normal biological activity nor detrimental to plant health and thus suitable for irrigation purpose (Faisal Anwar 2011a, b). Mapo GCS at 0.5 m depth had highest pH value (9.4) with corresponding highest value of CEC (3.4 cmol/kg). This is in agreement with similar result by Faisal Anwar (2011a) and Sivongxay (2005). The OM content in Isolu samples ranged between 0.6 and 0.9 g/kg, while it ranged from 0.6 to 0.9 g/kg in Mapo soil samples. The reduced concentration of OM at the two locations is in line with result of Albalawneh et al. (2015) who reported reduced concentration of OM on treated greywater for irrigation purpose. The OM value at 0.5 m depth for both CS and GCS at Ibadan has the same numerical value, while there is slight increase in OM for GCS at Ibadan over CS at depths 1.0 and 1.5 m. However, the numerical values of OM content for Isolu CS and GCS at 1.0 and 1.5 m were the same, while Isolu GCS had its OM value increased slightly at 0.5 m depth relative to CS.

The CEC values ranged from 0.3 to 1.4 cmol/kg in Isolu samples and ranged between 0.4 and 3.4 cmol/kg in Mapo samples. The CEC value at each varying depth for GCS at Ibadan increased relative to CEC value of CS. This is in agreement with similar increase in CEC for surfactant-rich soil obtained by Mohamed et al. (2018a) and Siggins et al. (2016). For Isolu samples, the CEC value of Isolu GCS increased over that of CS only at 0.5 m depth. The porosity values for Isolu soil samples ranged from 42.6 to 47.9%, while it ranged from 40.0 to 46.4% for Mapo soil samples. The lowest value of porosity occurred at 0.5 m depth for Ibadan GCS which corresponds to depth with lowest MC value and highest $K_{sat}$ value. Highest porosity value was obtained at 1.5 m depth for Isolu GCS. The samples with lowest and highest values of porosity at the two sampling locations had minimum and maximum clay content value in analysed soils (Blum et al. 2014). There is reduction in porosity value for each varying depth for Ibadan GCS over CS, while the porosity of Isolu GCS increased slightly with respect to porosity values of CS at depths 1.0 and 1.5 m, respectively.

The soil resistivity ranged between 4.3 and 7.2 for Isolu samples and ranged from 4.3 to 6.7 ohm cm for Ibadan soil samples. The soil resistivity for GCS and CS at both locations falls below 10.00 ohm cm. A slight increase in soil resistivity was obtained for Ibadan GCS over control for 1.0 and 1.5 m depths, while there is slight increase in resistivity value for Isolu GCS when compared to that of CS only at 0.5 m depth. Highest values of soil resistivity were obtained in GCS at both sampling locations at 1.0 m depth. Highest values of soil porosity (46.4 and 45.7%) correspond to lowest values of soil resistivity (4.3 and 5.3 ohmcm) at 1.5 m depth for Ibadan CS and GCS. However, the inverse relationship between soil resistivity and porosity was not obtained in both CS and GCS at Isolu. This may be linked to assertion by Robain et al. (1996) that related resistivity variation with the structure of pedological materials (i.e. number of macropores to micropores in the soil) as well as concentration and composition of greywater (Faisal Anwar 2011a, b). The $K_{sat}$ values for GCS and CS decrease with depths at both locations. The $K_{sat}$ value for Isolu soil samples ranged from 0.14 to 0.56 cm/h, while it ranged from 0.17 to 1.53 cm/h in Ibadan samples. The lowest $K_{sat}$ (0.14 cm/h) was noticed at 1.5 m depth from Isolu GCS which had highest value of MC (0.109 m$^3$ m$^{-3}$), while the highest value of $K_{sat}$ was noticed in Ibadan GCS at 0.5 m with lowest MC value (0.083 m$^3$ m$^{-3}$). The increase in $K_{sat}$ for each depth for Ibadan GCS over control values agrees with similar findings by Singh et al. (2009), Nazir (2011), Faisal Anwar (2011a) and Shifa and Thomas (2017), while there is reduction in $K_{sat}$ values at depths 0.5 and 1.0 m for Isolu GCS over control $K_{sat}$ values.

Geotechnical properties

The Atterberg limits (PL, LL and PI) results for the soil samples are presented in Table 2. The plastic limits ranged between 14.7 and 25.4 for Isolu samples and between 13.4 and 20.9 for Mapo samples. The liquid limit ranged between 18.5 and 31.9 for Isolu samples and ranged from 16.9 to 26.5 for Mapo samples. The LL and PL values of both CS and GCS at both sampling locations increased with varying depth. The LL and PL values of Mapo GCS at each sampling depth reduced compared to their values in CS. However, reduction in LL and PL values in Isolu GCS relative to their values in CS occurred only at 0.5 m depth. The PI value for Isolu samples ranged between 3.8 and 6.3 and between 3.4 and 5.4 for Mapo soil samples. The degree of plasticity of all analysed soil samples at the two locations belongs to low plastic soil with PI < 7.0. However, the highest and lowest values of LL, PL and PI were found in Isolu GCS at 1.5 m depth (which is of sandy clay texture) and at 0.5 m depth for Mapo GCS, respectively. A reduction in soil PI may lead to better compaction, an important property to consider for soils to be used for construction purposes (Kermani and Ebadi 2012). However, there is increase in ALs values at depths 1.0 and 1.5 m for Isolu GCS over Isolu CS. The DD values ranged from 1.40 to 1.52 Mg/m$^3$ in Isolu samples, while it ranged from 1.42 to 1.59 Mg/m$^3$ in Mapo soil samples. The lowest value of DD for the two locations was found at 1.5 m depth for Isolu CS which is sandy clay (SC) in texture, while highest DD was obtained in Mapo GCS at 0.5 m depth with sandy loam (SL) texture and lowest MC value. This agrees with finding of Shifa and Thomas (2017) that reported highest DD at lowest MC.

The lowest value of DD for sandy clay (SC) texture at 1.5 m depth for Isolu CS agrees with finding of Khodary et al. (2018) who reported that DD of clayey soil is highly affected by oil contamination when compared to sandy soil.
The shear strength in KN/m² for Isolu samples ranged from 105.4 to 175.2 and from 104.5 to 163.5 KN/m² for Mapo soil samples. The lowest value of SS (104.5) was found in Mapo CS at 1.5 m depth, while highest value of SS (175.2) was found at 1.0 m depth in both CS and GCS at Mapo sampling location. The SS value at all depths increased for GCS at Mapo compared to CS, while a significant increase in SS value was noticed in Isolu GCS at 0.5 m depth. Our result is in contrast with reduced SS obtained by Rahman et al. (2013) for surfactant-enriched silty soils as well as that of Karskush and Kareem (2017) who reported decrease in SS in fuel oil-contaminated soils.

The bearing ratio (in %) for Isolu samples ranged from 3.96 to 10.32, while it ranged from 3.68 to 7.11 for Mapo soil samples. The BR values in GCS and CS at both locations increase with depths. However, the BR values in Mapo GCS reduced at depths 0.5 and 1.0 m when compared with control values, while BR value for each varying depth increases in Isolu GCS relative to BR values of CS at those depths. The MC of Isolu soil samples in m³ m⁻³ ranged between 0.083 and 0.110, while it varies from 0.083 to 0.098 for Mapo soil samples. GCS at Mapo had slight reduction in MC value for each measuring depth compared with control value, while reduced values of MC for Isolu GCS occurred only at 0.5 and 1.0 m depths relative to MC values of Isolu CS.

Results of statistical analyses

The significance of the observed correlation coefficient results for each sampling location is presented in Tables 3 and 4. Table 5 shows the ANOVA table based on sampling depths. From Tables 3 and 4, out of the 120 correlations found between two parameters, 54 were found to have significant at 1% (p < 0.01), while 15 were found to have significant at 5% level (p < 0.05) for Isolu location. For Mapo sampling location, 78 were found to have significant at 1% level (p < 0.01), while 15 were found to have significant at 10% level.

For Isolu location, negative correlation exists between % sand and % clay (−0.940**), % sand and MC (−0.946**), as well as between % sand and porosity (−0.947**). Strong negative correlation also exists between % sand and ALs as well as between % sand and PI (−1.000**). Positive correlation exists between % sand and DD (0.947**). The correlation between % sand and % clay agrees with the results of Coffin and Lauenroth (1992), Kaiser et al. (1992), and Pan et al. (2012). Negative correlation between % sand and MC is in line with similar results by Senjobji and Ogunkunle (2011) and Olorunfemi et al. (2016). The strong negative correlation between % sand and ALs agrees with similar results by Deng et al. (2017) and Igwe et al. (2013), while correlation between % sand and PI (−1.000**) is in line with similar result by Roy and Bhalla (2017) who reported that increase in sand content results in decreased PI.

A very strong positive correlation exists between % clay and ALs (0.939** and 0.940**) (LL and PL). The same hold for % clay and PI (0.942**), % clay and porosity (0.986**) as well as % clay and MC (0.923**), but negative correlation exists between % clay and DD (−0.986**), % clay and $K_{\text{sat}}$ (−0.844**), and % clay and CEC (−0.844**).

Positive correlation between % clay and LL, PL and PI is expected because % clay is the factor most closely correlated with ALs and also major contributor to the plasticity of soils (Mitchell 1976; Igwe et al. 2013; De Jong et al. 1990; Keller and Dexter 2012; Hemmat et al. 2010). The negative correlation between % clay and $K_{\text{sat}}$ may be due to the fact that clay fraction governs the hydraulic behaviour of soil matrix (Benzon et al. 1994) and agrees with similar result obtained by Igwe et al. (2013), Pan et al. (2012) and Kisku et al. (2017). Positive correlation between % clay and porosity may be due to high microporosity found in clayey soil (Blum et al. 2014). Positive correlation between % clay and MC with subsequent negative correlation with DD agrees with Igwe et al. (2013) and Dave et al. (2017). This buttressed the fact that the higher the fine particles (clay), the higher the MC but lower the DD (Dave et al. 2017). However, negative correlation found between CEC and % clay is in contrast with positive correlation between % clay and CEC found earlier by Lambooy (1984) and Olorgenemi et al. (2016). This may be due to low MC and high sand content of analysed soil samples. Porosity exhibits strong positive correlation with MC (0.901**) but negative correlation with $K_{\text{sat}}$ (−0.885**). Positive correlation between porosity and MC agrees with result of Zheng et al. (2015) who obtained positive relation between maximum soil MC and soil porosity. Negative correlation between porosity and $K_{\text{sat}}$ is expected as $K_{\text{sat}}$ has inverse relation with clay content and water retention parameters (Pan et al. 2012). Positive correlation exists between DD and $K_{\text{sat}}$ (0.885**), while DD exhibited a significant negative correlation with PL, LL and PI. Positive correlation between DD and $K_{\text{sat}}$ is in agreement with similar result by Gallage et al. (2013), while negative correlation obtained between DD and ALs agrees with earlier result by Sridharan and Nagaraj (2005). The negative correlation between DD and ALs is expected because soil with higher plastic limit has higher MC but lower DD; hence, positive correlation at 1% level exists between MC and ALs as well as between MC and PI (0.944**) (Sridharan and Nagaraj 2005; De Jong et al. 1990).

Negative correlation at 5% level exists between MC and $K_{\text{sat}}$ (−0.658*), while positive correlation was found between MC and CBR (0.914**). Positive correlation found between MC and CBR agrees with the result of Tan et al. (2016), while negative correlation between MC and $K_{\text{sat}}$ is in line with earlier results by Mitchell (1976) and Benzon.
|                  | Sand | Silt | Clay | Dry density | Porosity | MC | Hydraulic conductivity | Liquid Limit | Plastic Limit | Plasticity index | Soil resistivity | pH | Organic matter | Shear strength | Bearing ratio | CEC |
|------------------|------|------|------|-------------|----------|----|------------------------|--------------|--------------|------------------|-----------------|----|----------------|----------------|--------------|-----|
| Sand             | 1    |      |      |             |          |    |                        |              |              |                  |                 |    |                |                |              |     |
| Silt             | -0.488 | 1   |      |             |          |    |                        |              |              |                  |                 |    |                |                |              |     |
| Clay             |      | -0.940 | 0.162 | 1           |          |    |                        |              |              |                  |                 |    |                |                |              |     |
| Dry density      |       | 0.947 | -0.218 | -0.966 | 1           |    |                        |              |              |                  |                 |    |                |                |              |     |
| Porosity         |       |       | -0.947 | 0.218 | 0.986 | -1.000 | 1                              |              |              |                  |                 |    |                |                |              |     |
| MC               |       |       |       | 0.946 | -0.378 | 0.923 | -0.901**                 | 0.901** | 1                          |                  |                 |    |                |                |              |     |
| Hydraulic conductivity | 0.704 | 0.123 | -0.844 | 0.885 | -0.885 | -0.68 | 1                              |              |              |                  |                 |    |                |                |              |     |
| Liquid limit     |       |       |       | -1.000 | 0.490 | 0.939 | -0.946**                  | 0.946** | -0.702 | 1                             |                  |                 |    |                |                |              |     |
| Plastic limit    |       |       |       | -1.000 | 0.489 | 0.940 | -0.946**                  | 0.946** | -0.703 | 1                             | 1.000** | 1              |    |                |                |              |     |
| Plasticity index |       |       |       | -1.000 | 0.483 | 0.942 | -0.949**                  | 0.949** | -0.709 | 1                             | 1.000** | 1.000** | 1              |                |              |     |
| Soil resistivity |       |       |       | -0.488 | 1.000** | 0.161 | -0.218 | 0.217 | 0.378 | 0.123 | 0.490 | 0.489 | 0.483 | 1                              |              |              |     |
| pH               | 0.058 | 0.841** | -0.394 | 0.342 | -0.342 | -0.152 | 0.600* | -0.056 | -0.057 | -0.064 | 0.841** | 1                             |                  |                 |    |                |                |              |     |
| Organic matter   | -0.486 | 1.000** | 0.160 | -0.216 | 0.216 | 0.379 | 0.124 | 0.488 | 0.487 | 0.481 | 1.000** | 0.841** | 1                             |                  |                 |    |                |                |              |     |
| Shear strength   | -0.486 | 1.000** | 0.160 | -0.216 | 0.216 | 0.376 | 0.124 | 0.488 | 0.487 | 0.482 | 1.000** | 0.842** | 1.000** | 1                             |                  |                 |    |                |                |              |     |
| Bearing ratio    | -0.978 | 0.634* | 0.859** | -0.887 | 0.887 | 0.914 | -0.628**                  | 0.979** | 0.977** | 0.634** | 0.115 | 0.633* | 0.633 | 1                             |                  |                 |    |                |                |              |     |
| CEC              | 0.704 | 0.122 | -0.844 | 0.886 | -0.886 | -0.658 | 1.000** | -0.702 | -0.703 | -0.710** | 0.123 | 0.600* | 0.123 | 0.124 | -0.629* | 1     |

*Correlation is significant at the 0.05 level (2-tailed); **correlation is significant at the 0.01 level (2-tailed)

Location = Isolu
Table 4 Correlation coefficient of analysed parameters in Ibadan (Vertic Cambisol)

|                | Sand | Silt | Clay | DRY density | Porosity | MC | Hydraulic conductivity | Liquid limit | Plastic limit | Plasticity index | Soil resistivity | pH | Organic matter | Shear strength | Bearing ratio | CEC |
|----------------|------|------|------|-------------|----------|----|------------------------|--------------|---------------|------------------|----------------|-----|----------------|---------------|--------------|-----|
| Sand           | 1    |      |      |             |          |    |                        |              |               |                  |                |     |                |               |              |     |
| Silt           | 0.575| 1    |      |             |          |    |                        |              |               |                  |                |     |                |               |              |     |
| Clay           | −0.976** | −0.741** | 1 |             |          |    |                        |              |               |                  |                |     |                |               |              |     |
| Dry density    | 0.996** | 0.616* | −0.983** | 1 |          |    |                        |              |               |                  |                |     |                |               |              |     |
| Porosity       | −0.996** | −0.616* | 0.983** | −1.000** | 1 |    |                        |              |               |                  |                |     |                |               |              |     |
| MC             | −0.966** | −0.599* | 0.954** | −0.966** | 0.966** | 1 |                        |              |               |                  |                |     |                |               |              |     |
| Hydraulic conductivity | 0.974** | 0.474 | −0.927** | 0.976** | −0.976** | −0.944** | 1 |                        |              |               |                  |                |     |                |               |              |     |
| Liquid limit   | −1.000** | −0.575 | 0.975** | −0.996** | 0.996** | 0.966** | −0.973** | 1 |                        |              |               |                  |                |     |                |               |              |     |
| Plastic limit  | −1.000** | −0.571 | 0.974** | −0.996** | 0.996** | 0.966** | −0.974** | 1 | 1.000** |               |                  |                |     |                |               |              |     |
| Plasticity index | −1.000** | −0.576* | 0.976* | −0.997** | 0.997** | 0.965** | −0.976** | 1 | 1.000** | 1.000** |                  |                |     |                |               |              |     |
| Soil resistivity | 0.575 | 1.000** | −0.740** | 0.615* | −0.616* | −0.584* | 0.473 | −0.574 | −0.570 | −0.576 | 1 |                |               |     |                |               |              |     |
| pH             | 0.822** | 0.938** | −0.927** | 0.849** | −0.849** | −0.825** | 0.742** | −0.822** | −0.819** | −0.823** | 0.938** | 1 |                |               |     |                |               |              |     |
| Organic matter | 0.566 | 1.000** | −0.733** | 0.608* | −0.608* | −0.591* | 0.464 | −0.565 | −0.561 | −0.576 | 1.000** | 0.934** | 1 |                |               |     |                |               |              |     |
| Shear strength | 0.576 | 1.000** | −0.741** | 0.617* | −0.617* | −0.601* | 0.475 | −0.575 | −0.571 | −0.577* | 1.000** | 0.939** | 1.000** | 1 |                |               |     |                |               |              |     |
| Bearing ratio  | −0.940** | −0.283 | 0.848** | −0.919** | 0.919** | 0.894** | −0.954** | 0.940** | 0.941** | 0.941** | −0.282 | −0.596* | −0.272 | −0.284 | 1 |                |               |     |                |               |              |     |
| CEC            | 0.974** | 0.474 | −0.927** | 0.976** | −0.976** | −0.944** | 1.000** | −0.973** | −0.974** | −0.976** | 0.473 | 0.742** | 0.465 | 0.476 | −0.954** | 1 |                |               |     |                |               |              |     |

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

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

*Location = Ibadan
et al. (1994). A very strong positive correlation exists between $K_{\text{sat}}$ and CEC (1.000**), while negative correlation exists between $K_{\text{sat}}$ and LL, PL and PI. Positive correlation between $K_{\text{sat}}$ and CEC exists because rate of water intake into the soil has direct relationship with amount of Ca$^{2+}$ and Mg$^{2+}$ in soil (Benzon et al. 1994; Igwe et al. 2013). Negative correlation between $K_{\text{sat}}$ and ALs is expected because with all other factors being equal, the plasticity of soil has inverse relationship with $K_{\text{sat}}$ (Terzaghi 1925). A very strong positive correlation exists between LL and PL (1.000**), LL and PI (1.000**) but negatively correlated at 5% level with CEC (− 0.702). Positive correlation also exists between LL and PI (1.000**), while negative correlations at 5% level exist between PL and CEC (− 0.703*), PI and CEC (− 0.710*). Strong positive correlation between LL and PL agrees with Stanchi et al. (2015) who reported similar result for Aosta valley soils. Positive correlation between LL and PI was also reported by Oyediran and Durojaiye (2011). Positive correlation between PL and PI agrees with Larney et al. (1988) and Tsegaye et al. (2017). However, our results of negative correlations between CEC and ALs, CEC and PI are in contrast with positive correlation between soil ALs and CEC reported by Deng et al. (2017). Soil resistivity exhibits strong positive correlations with OM (1.000**), soil resistivity and shear strength (1.000**), and positive correlation at 5% level exists between soil resistivity and CBR (0.634*). Positive correlation between soil resistivity and OM agrees with Werban et al. (2009), while positive correlation between soil resistivity and SS is in line with similar result obtained by Syed Osman et al. (2014). A significant positive correlation exists between pH and OM (0.841**), while positive relationship at 5% level exists between pH and CEC (0.600*). The positive relation between pH and OM agrees with Werban et al. (2009), while positive correlation between pH and CEC corroborates the dependence of CEC on pH (Vogelmann et al. 2010; Aprile and Lorandi 2012). A very strong positive correlation at 1% level exists between OM and SS (1.000**), while positive correlation at 5% level exists between SS and CBR (0.633*). Positive correlation between OM and SS may be due to the improvement of soil aggregate stability by organic matter content (Ekwue 1990).

For Mapo sampling location, most of correlations that exist between two parameters in Isolu also exist at 1% level. In addition, positive correlation also exists between % sand and $K_{\text{sat}}$ ($r=0.974$, $p<0.01$); % sand and pH ($r=0.822$, $p<0.01$) and % sand and CEC ($r=0.974$, $p<0.01$). Positive correlation between % sand and $K_{\text{sat}}$ agrees with Igwe et al. (2013), Kisku et al. (2017) and Nayak et al. (2004). This means that increase in sand content leads to increase in $K_{\text{sat}}$. However, positive correlation between % sand and CEC is in contrast with earlier reported negative correlation between % sand and CEC by Ifeanyi and Agwu (2014). Negative correlation exists between % clay and % silt ($r=-0.74$, $p<0.01$) % clay and soil resistivity ($r=-0.740$, $p<0.01$) % clay and pH ($r=-0.927$, $p<0.01$), % clay and OM ($r=-0.733$, $p<0.01$) and % clay and SS ($r=-0.741$, $p<0.01$). Negative correlation between % silt and % clay agrees with similar result by Tsozue et al. (2016), while negative correlation between % clay and OM agrees with similar results obtained by Pilania and Panchal (2016). Negative correlation between clay content and soil resistivity is expected because higher clay content is an indication of

### Table 5 Mean separation based on soil depth

| Parameters       | 0.5 m       | 1.0 m       | 1.5 metres |
|------------------|-------------|-------------|------------|
| Sand             | 73.11 ± 1.0655$^a$ | 63.74 ± 3.7587$^b$ | 56.49 ± 3.7635$^c$ |
| Silt             | 11.69 ± 2.6428$^a$ | 13.44 ± 2.6613$^b$ | 11.57 ± 1.7349$^a$ |
| Clay             | 15.20 ± 3.5051$^a$ | 22.82 ± 3.7265$^b$ | 31.95 ± 2.6550$^c$ |
| Dry density      | 1.56 ± 0.0367$^a$ | 1.47 ± 0.0315$^b$ | 1.41 ± 0.0223$^a$ |
| Porosity         | 41.13 ± 1.3824$^a$ | 44.43 ± 1.1895$^b$ | 46.84 ± 0.8397$^a$ |
| MC               | 0.085 ± 0.0029$^a$ | 0.092 ± 0.0035$^b$ | 0.103 ± 0.0058$^a$ |
| Hydraulic conductivity | 1.11 ± 0.4796$^a$ | 0.40 ± 0.1537$^b$ | 0.17 ± 0.0293$^b$ |
| Liquid limit     | 17.93 ± 0.7005$^a$ | 24.16 ± 2.5247$^b$ | 29.01 ± 2.5267$^b$ |
| Plastic limit    | 14.25 ± 0.5555$^a$ | 19.25 ± 1.9928$^c$ | 23.11 ± 2.0060$^b$ |
| Plasticity index | 3.64 ± 0.1506$^a$ | 4.93 ± 0.5175$^b$ | 5.90 ± 0.5210$^b$ |
| Soil resistivity | 5.68 ± 1.2830$^a$ | 6.53 ± 1.2940$^b$ | 5.62 ± 0.8421$^a$ |
| pH               | 8.37 ± 1.9646$^a$ | 8.33 ± 1.6032$^b$ | 6.34 ± 0.7048$^b$ |
| Organic matter   | 0.74 ± 0.1663$^a$ | 0.85 ± 0.1696$^a$ | 0.73 ± 0.1090$^a$ |
| Shear strength   | 137.97 ± 31.0022$^a$ | 158.38 ± 31.4054$^a$ | 136.37 ± 20.4488$^a$ |
| Bearing ratio    | 3.90 ± 0.2027$^a$ | 6.98 ± 1.6439$^b$ | 8.54 ± 1.7160$^b$ |
| CEC              | 2.44 ± 1.0504$^a$ | 0.88 ± 0.3360$^b$ | 0.37 ± 0.0645$^b$ |

*Values show mean ± standard deviation. Values along the same row with the same superscript are not significantly different at 5% ($p > 0.05$) level.
low resistivity value (Werban et al. 2009; Triantafilis and Lesh 2005). A very strong positive correlation between % silt and SS \( (r = 1.000, p < 0.01) \) buttressed the similar result by Infante et al. (2016) who reported maximum shear strength for silty sand soils. Negative correlation exists between pH and MC \( (r = -0.825, p < 0.01) \), pH and porosity \( (r = -0.849; p < 0.01) \), but positive correlation between pH and DD \( (r = 0.849, p < 0.01) \). Positive correlation also exists between pH and \( K_{sat} \) \( (r = 0.742, p < 0.01) \), while negative correlation exists between \( K_{sat} \) and CBR \( (r = -0.954, p < 0.01) \). However, pH exhibits negative correlations with PL, LL, PI all at 1% \( (p < 0.01) \) level but at 5% level \( (p < 0.05) \) with CBR \( (r = -0.596; p < 0.05) \). Negative correlation at 5% \( (p < 0.05) \) level exists between MC and OM and SS \( (r = -0.591, p < 0.05 \) and \( r = -0.601, p < 0.05 \), respectively).

**Results of ANOVA based on sampling depths**

Table 5 shows result of mean separations for the ANOVA showing comparison based on soil depth for the analysed soil parameters. From Table 5, the differences in % sand, % clay, soil pH, CEC, porosity, MC, \( K_{sat} \), ALs, PI and BR were significant based on depths of sampling at 5% level \( (p < 0.05) \), while there is no significant difference in % silt, soil resistivity, OM content and shear strength among the sampling depths.

**Conclusions**

The study showed that alteration of analysed soil parameters depends greatly on depth. Contamination of soil by greywater caused increased \( K_{sat} \), soil pH, CEC, DD and SS at each measured depth relative to control values at Mapo sampling location but reduction in porosity, ALs, PI and MC. The LL, PL and BR values of both CS and GCS at both locations increase with increasing sampling depth. However, the LL and PL values of Mapo GCS at each sampling depth reduced compared to their values in CS but only at 0.5 m in Isolu GCS. However, the BR of Isolu GCS at each sampling depth increased relative to BR value in CS at Isolu location. The soil resistivity values for all analysed samples at the two locations fall below 10 O-cm. The highest and lowest \( K_{sat} \) values were noticed in Isolu GCS at 0.5 m and 1.5 m, respectively. Highest value of CEC which occurred in Mapo GCS at 0.5 m depth corresponds to soil sample with highest pH value. The result of this study further corroborates the inverse relationship between \( K_{sat} \) and porosity as well as direct relation between % clay and porosity. Highest DD at lowest MC was obtained at 0.5 m depth in Mapo GCS. The GCS at Mapo showed improved geotechnical properties for construction purpose. There is strong positive correlation at 1% level \( (p < 0.01) \) between % clay and AL, porosity and AL, MC and AL but strong negative correlation between DD and AL, % sand and AL as well as between \( K_{sat} \) and AL in the two locations. Very strong positive correlations at 1% level also exist between \( K_{sat} \) and CEC as well as soil resistivity and OM and SS in both locations. ANOVA result showed that most analysed parameters except SS, soil resistivity and OM content varied significantly at 5% level based on sampling depths. More research should be carried out to assess the effects of greywater discharges on selected soil geotechnical and physico-chemical properties in other soil types and other geological formations of Nigeria.

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**Compliance with ethical standards**

**Conflict of interest** The authors declare that there is no conflict of interest.

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**References**

Abu-Zreig M, Rudra PR, Dickinson TW (2003) Effects of application of surfactants on hydraulic properties of soils. Biosyst Eng 84(3):363–372

Akinse AG, Gbadebo AM (2016) Geological mapping of Abeokuta Metropolis, Southwestern Nigeria. Int J Sci Eng Res 7(8):979–983

Akitolota JO (1986) Rainfall distribution in Nigeria, 1892–1983. Impact Publishers, Ibadan

Akinwemi OD, Bello R, Ayodeji AT, Akanbi DE, Ibine MM, Popoola JA (2011) Evaluation of water quality in Abeokuta, southwest Nigeria. Int J Water Resour Environ Eng 3(13):341–369. https://doi.org/10.5897/ijwree11.099

Albalawneh A, Chang T, Chou C (2015) Impacts on soil quality from long term irrigation with treated greywater. Paddy Water Environ, https://doi.org/10.1007/s10333-015-0499-6

Amfo-Otu R, Agyenim JB, Nimba-Bumah GB (2014) Correlation analysis of groundwater colouration from Mountainous Areas, Ghana. Environ Res Eng Manag 1(67):16–24
in the hilly granitic region of southern China. Solid Earth 8:499–513. https://doi.org/10.5194/se-8-499-2017

Edokpayi JN, Odiyo JO, Durowoju OS (2017) Impact of wastewater on surface water quality in developing countries: a case study of South Africa, Chapter 18. Intech Open Science, London. https://doi.org/10.5772/66561

Edwin GA, Gopolatsam P, Muthu N (2014) Characterization of domestic greywater from point source to determine the potential for urban residential reuse: a short review. Appl Water Sci 4:39–49. https://doi.org/10.1007/S13201-013-0128-8

Ekwue EL (1990) Organic-matter effects on soil strength properties. Soil Tillage Res 16:289–297

Elueze AA (2000) Compositional appraisal and petrotextonic significance of the Imelu bandaged ferruginous rock in Ilesha schist Belt, south western, Nigeria. J Min Geol 36(1):9–18

Eriksson E, Auffarth K, Henze M, Ledin A (2002) Characteristics of grey wastewater. Urban Water J 4:85–104

Etchepare R, van der Hoek JP (2014) Health risk assessment of organic micropollutants in greywater for potable reuse. Water Res. https://doi.org/10.1016/j.watres.2014.10.048

Faisal Anwar AHM (2011a) Effect of laundry greywater irrigation on soil properties. J Environ Res Dev 5(4):863–869

Faisal Anwar AHM (2011) Effect of greywater irrigation on soil characteristics. In: 2nd international conference on environmental science and development

FAO (2005) IUSRS working group WRB 2015. World reference base for soil resources 2014, update 2015. International soil classification system for naming soils and creating legends for soils maps. World soil resources reports, No 106. FAO Rome

Firdous S, Begum S, Yasin A (2016) Assessment of soil quality parameters using multivariate analysis in the Raval lake watershed. Environ Monit Assess 188:533–546. https://doi.org/10.1007/s10661-016-5527-5

Friedler E (2004) Quality of individual domestic and greywater streams and its implication for on-site treatments and reuse possibilities. Environ Technol 25:997–1008

Gallage C, Kodikara J, Uchimura T (2013) Laboratory measurement of hydraulic conductivity functions of two-unsaturated sandy soils during dry and wetting process. Soils Found 53(3):417–430

Gavriluscu M (2014) Colloid-mediated transport and the fate of contaminants in soils. In: Fanun M (ed) The role of colloidal systems during dry and wetting process. Soils Found 53(3):417–430

Helsel DR, Hirsch RM (2002) Statistical methods in water resources, chapter A3, USGS. http://water.usgs.gov/pubs/twri4a3/

Hemmat A, Aghilinategh N, Rezainejad Y (2010) Long term impacts of municipal solid waste compost, sewage sludge and farmyard manure application on organic carbon, bulk density and consistency limits of calcareous soils in central Iran. Soil Tillage Res 108:43–50

Ifieanyi IU, Agwu OP (2014) The effect of spent engine oil discharge on soil properties in an automobile mechanic village in Nekede, Imo state, Nigeria. IOSR J Environ Sci Toxicol Food Technol IOSR-JESTFT 8(11):28–32

Igwe CA, Zarei M, Stahr K (2013) Soil hydraulic and physico-chemical properties of Ultisols and Inceptisols in south-eastern Nigeria. Arch Agron Soil Sci 59(4):491–504. https://doi.org/10.1080/03650340.2011.649475

Infante DJU, Martinez GMA, Arrua PA, Eberhardt M (2016) Shear strength behaviour of different geosynthetic reinforced soil structure from direct shear test. Int J Geosynth Ground Eng 2:17. https://doi.org/10.1007/s40891-016-0058-2
Jackson MLC (1958) Soil chemical analysis practice. Haline Eagle Wood Cliff Limited, Englewood Cliffs, p 230

Jefferson B, Laine A, Parsons S, Stephenson T, Judd S (1999) Technologies for domestic wastewater recycling. Urban Water 1(4):285–292

Jones HA, Hockey RD (1964) The geology of southwestern Nigeria. Geological survey of Nigeria. Bull 31:22–24

Kaiser E, Mueller T, Joergensen R, Insam H, Heinemeyer O (1992) Evaluation of methods to estimate the soil microbial biomass and the relationship with the soil texture and organic matter. Soil Biol Biochem 24:675–683

Karikzi FW, Ngangä VG, Kotuk K (2012) Hydrogeochemical characteristics, plant nutrients and metals in household greywater and soils in Homa Bay Town, Open Environ. Eng J 5:103–109

Karkush MD, Al-Taher TAA (2017) Geotechnical evaluation of clayey soil contaminated with industrial wastewater. Arch Civ Eng 63(1):48–62

Karkush MO, Resol DJ (2017) Remediation of sandy soil contaminated with industrial wastewater. Int J Civ Eng 15(3):441–449

Karskush MO, Kareem ZA (2017) Investigation of the impact of fuel oil on the geotechnical properties of cohesive soil. Eng J 21(4):128–137. https://doi.org/10.4186/ej.2017.21.4.127

Katukiza AY, Ronteltap M, Niwagaba CB, Kansiime F, Lens PNL (2018) Investigating the impact of greywater characteristics, treatment systems, reuse strategies and user perception—A review. Water Air Soil Pollut 229:255. https://doi.org/10.1007/s11270-018-3909-8

Keller T, Dexter AR (2012) Plastic limits of agricultural soils as functions of soils texture and organic matter content. Soil Res 50:7–17

Kermani M, Ebadi T (2012) The effect of oil contamination on the geotechnical properties of fine grained soils. Soil Sediment Contam 21(5):655–671

Key R (1992) An introduction to the crystalline basement of Africa. In: Wright E, Burgass W (eds) Hydrogeology of the crystalline basement aquifers in Africa, vol 66. Geological Society of Special Publication, London, pp 29–57

Khodary SM, Negm AM, Tawfik A (2018) Geotechnical properties of the soils contaminated with oils, landfill, leachate and fertilizers. Arab J Geosci 11:13. https://doi.org/10.1007/s12517-017-3372-7

Kisku TK, Datta A, Basak N, Mandi S, Hembram S, Roy R (2017) Evaluation of saturated hydraulic conductivity from soil properties in an Inceptisol using different land cover and depths. J Appl Nat Sci 9(3):1482–1488

Kopittke PM, Blamey FPC, Kinrade TB, Wang P, Reichman SM, Menzies NW (2011) Separating multiple, short- term, deleterious effects of saline solutions on the growth of cowpea seedlings. New Phytol 189:1110–1121

Lambooy AM (1984) Relationship between cation exchange capacity, clay content and water retention of Highveld soils. S Afr J Plant Soil 1(2):33–38. https://doi.org/10.1080/02571862.1984.10634106

Larney FJ, Fortune RA, Collins JF (1988) Intrinsic soil physical parameters influencing intensity of cultivation procedures for sugar beet seedbed preparation. Soil Tillage Res 12(3):253–267

Li F, Wichmann K, Otterpohl R (2009) Review of the technological approaches for greywater treatment and reuses. Sci Total Environ 407(11):3439–3449

Maimon A, Friedler E, Gross A (2014) Parameters affecting greywater quality and its safety for reuse. Sci Total Environ 487:20–25. https://doi.org/10.1016/j.scitotenv.2014.03.133

Misra RK, Sivongxay A (2008) Reuse of laundry greywater as affected by its interaction with saturated soil. J Hydrod 366:55–61

Misra RK, Patel JH, Baxi VR (2012) Reuse potential of laundry greywater for irrigation based on growth, water and nutrient use of tomato. J Hydrod 386(1–4):95–102

Mitchell JK (1976) Fundamentals of soil behaviour. Wiley, New York

Mohamed RMSR, Kassim AHM, Anda M, Dallas S (2013) A monitoring of environmental effects from household greywater reuse for garden irrigation. Environ Monit Assess 185:8473–8488. https://doi.org/10.1007/s10661-013-3189-0

Mohamed RM, Al-Gheethi AA, Noramira J, Chan CM, Amir, Hashim MK, Sabariah M (2018a) Effect of detergents from laundry greywater on soil properties: a preliminary study. Appl Water Sci 8:16. https://doi.org/10.1007/s13201-018-0664-3

Mohamed R, Al-Gheethi A, Abdulrahman A, Bin Sainudin MS, Bakar SA, Kassim AHM (2018b) Optimization of ceramic waste filter for bathroom greywater treatment using central composite design (CCD). J Environ Chem Eng 6:1578–1588

Nayak AK, Chinchmalapatpute AR, Rao GG, Khandelwal MK, Nath A (2004) Inter-relationship between water retention, transmission and some soil parameters of typical black soil of Gujarat state. Agroperiodol 14(1):38–44

Nazir AK (2011) Effect of motor oil contamination on geotechnical properties of over consolidated clay. Alexander Eng J 50:331–335

Nelson DW, Sommers IE (1982) Total carbon, organic carbon and organic matter. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis, part-chemical and microbiological properties, 2nd edn. ASA, SSSA, Madison, pp 539–579

Okumola OA, Adeibge OC, Oluwatoke OO (2009) Compositional and petrogenetic features of schistose rocks of Ibadan area, south western Nigeria. Earth Sci Res J 13(2):29–43

Olorunfemi IE, Fasinminrin JT, Ojo AA (2016) Modeling cation exchange capacity and soil water holding capacity from basic soil properties. Eurasian J Soil Sci 5(4):266–274

Oron G, Adel M, Agmon V, Friedler E, Halperin R, Leshem E, Weinberg D (2014) Greywater use in Israel and worldwide: standards and prospects. Water Res 58:92–101

Oteng-Peprah M, Acheampong MA, de Vries NK (2018) Greywater characteristics, treatment systems, reuse strategies and user perception—a review. Water Air Soil Pollut 229:255. https://doi.org/10.1007/s11270-018-3909-8

Oyediran IA, Durojaiye HF (2011) Variability in the geotechnical properties of some residual clay soils from South West Nigeria. Int J Sci Eng Res 2(9):1–6

Pan W, Boyles RP, White JG, Heitman JL (2012) Characterizing soil physical properties for soil moisture monitoring with the north Carolina environment and climate observing network. J Atmos Ocean Technol 29:933–943. https://doi.org/10.1175/JTECH-D-11-00104.1

Peng Z, Darnault CJG, Tian F, Baveye PC, Hu H (2017) Influence of Anionic surfactant on saturated hydraulic conductivity of loamy sand and sandy loam soils. Water 9:433. https://doi.org/10.3390/w9060433

Pilania PK, Panchal NS (2016) Influence of soil properties on plant density and species richness of saline desert. An Biol 38:81–90. https://doi.org/10.6018/analesbio.38.08

Pinto U, Maheshwari BL, Grewal HS (2010) Effects of greywater irrigation on plant growth, water use and soil properties. Resour Conserv Recycl 54(7):429–435

Rahman ZA, Sahibin AR, Lihan T, Idris WMR, Sakina M (2013) Effects of surfactants on geotechnical characteristics of silty soil. Sains Malays 42(7):881–891

Reichman SM, Wightwick AM (2013) Impacts of standard and ‘low environmental impact’ greywater irrigation on soil and plant nutrients and ecology. Appl Soil Ecol 72:195–202. https://doi.org/10.1016/j.apsoil.2013.07.012

Reynolds WD, Elrick DE (2002) Constant head soil core (Tank) method. In: Dane JH, Topp GC (eds) methods of soil analysis
part 4, physical methods, SSSA book series 5. Soil Science Society of America, Madison, pp 804–808
Robain H, Descloitres M, Ritz M, Atangana QY (1996) A multiscale electrical survey of a lateritic soil system in the rainforest of Cameroon. J Appl Geophys 34(4):237–253
Roy S, Bhalla SK (2017) Role of geotechnical properties of soil on civil engineering structures, resources and environment. Resour Environ 7(4):103–109
Sawadogo B, Sou M, Hijkata N, Sangare D, Maiga AH, Funamizu N (2014) Effect of detergents from greywater on irrigated plants: case of Okra. Journal of Arid land studies 24(1):117–120
Senjobi BA, Ogunkunle AO (2011) Effects of different land use types and their implications on land degradation and productivity in Ogun State, Nigeria. J Agric Biotech Sustain Dev 3(1):7–18
Shif N, Thomas U (2017) A study on the effect of surfactants on soil-water system. In: International conference on geotechnical engineering for infrastructure projects, 27–28 Feb, 2017
Siggins A, Burton V, Ross C, Lowe H, Horswell J (2016) Effects of long term greywater disposal on soil: a case study. Sci Total Environ 557–558:627–635. https://doi.org/10.1016/j.scitotenv.2016.03.084
Singh S, Srivastava RK, John S (2009) Studies on soil contamination due to used motor oil and its remediation. Can Geotech J 46(9):1077–1083
Sivongxay A (2005) Hydraulic properties of Toowoomba soils for laundry water reuse. Thesis, B. Eng. Environmental, University of Southern Queensland
Smyth AJ, Montgomery RF (1962) Soils and land use in central western Nigeria. Government Printer, Ibadan, p 265
Sridharan A, Nagaraj HB (2005) Plastic limit and compaction characteristic of fine grained soils. Ground Improv 9(1):17–22
Stanchi S, Damico M, Zanini E, Freppaz M (2015) Liquid and Plastic limits of mountain soils as a function of the soil and horizon type. Catena 135:114–121
Syed Osman SB, Mohammed NF, Fahad IS (2014) Correlation of electrical resistivity with some soil parameters for the development of possible prediction of slope stability and bearing capacity of soil using electrical parameters. Pertanika J Sci Technol 22(1):139–152
Tan Y, Hu M, Li D (2016) Effects of agglomerate size on California bearing ratio of lime treated lateritic soils. Int J Sustain Built Environ 5:168–175
Tarchouna LG, Merdy P, Raynaud M, Pfeifer H, Lucas Y (2010) Effects of long-term irrigation with treated waste water. Part 1: evolution of soil physico-chemical properties. Appl Geochem 25:1703–1710. https://doi.org/10.1016/j.apgeochem.2010.08.018
Terzaghi K (1925) Principles of soil mechanics: 1-phenomena of cohesion of clays. Eng N Rec 95(19):742–746
Travis MJ, Weisbrod N, Gross A (2008) Accumulation of oil and grease in soils irrigated with greywater and their potential role in soil water repellency. Sci Total Environ 394:68–74
Travis MJ, Wiel-Shafran A, Weisbrod N, Adar E, Gross A (2010) Greywater reuse for irrigation: effect on soil properties. Sci Total Environ 408(12):2501–2508
Triantafillis J, Lesh SM (2005) Mapping clay content variation using electromagnetic induction techniques. Comput Electron Agric 46:203–207
Tsegaye T, Fikre H, Abebe T (2017) Correlation between compaction characteristics and Atterberg limits of fine grained soils found in Addis Ababa. Int J Sci Eng Res 8(6):357–364
Tsouez D, Tematipo P, Azinwi Tamfuh P (2016) Relationship between soil characteristics and fertility implications in two typical Dys-trandept soils of the Cameron western highland. Int J Soil Sci 11:36–48. https://doi.org/10.3923/ijss.2016.36.48
Turner RDR, Will JD, Dawes LA, Gardner EA, Lyons DJ (2013) Phosphorus as a limiting factor on sustainable greywater irrigation. Sci Total Environ 456–457:287–298
Uddin SMN, Li Z, Adamowski JF, Ulbrich T, Mang H-P, Ryndin R, Norvanchig J, Lapegue J, Wriege-Bechhold A, Cheng S (2015) Feasibility of a ‘greenhouse system’ for household greywater treatment in nomadic-cultural communities in peri-urban Ger areas of Ulaanbaatar, Mongolia: an approach to reduce greywater-borne hazards and vulnerability. J Clean Product 114:431–442
Vogelmann ES, Reichert JM, Reinert DJ, Mentges MI, Vieira DA, Peixoto de Barros CA, Fasimnirin JT (2010) Water repellency in soil of humid subtropical climate of Rio Grande de soil, Brazil. Soil Tillage Res 110(1):126–133
Weil-Shafran A, Ronen Z, Weisbrod N, Adar E, Gross A (2006) Potential changes in soil properties following irrigation with surfactant-rich greywater. Ecol Eng 26:348–359
Werban U, Kuka K, Merbach I (2009) Correlation of electrical resistivity, electrical conductivity and soil parameters at a long term fertilization experiment. Near Surf Geophys 7:5–14
Xu J, Wu L, Chang AC, Zhang Y (2010) Impact of long-term reclaimed wastewater irrigation on agricultural soils: a preliminary assessment. J Hazard Mater 183:780–896. https://doi.org/10.1016/j.jhazmat.2010.07.094
Zheng H, Gao J, Teng Y, Feng C, Tian M (2015) Temporal variations in soil moisture for three typical vegetation types in inner Mongolia. Northern China. PLOS ONE 10(3):e0118964. https://doi.org/10.1371/journal.pone.0118964

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