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Determination of some physical and mechanical properties of Calabrian pine (*Pinus brutia* Ten.) trees grown in the Denizli area of Turkey

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The most extensive distribution of Calabrian pine (*Pinus brutia* Ten.) trees in the world is found in Turkey. This species varies depending on the regions in Turkey for growth features, such as climate, soil structure and slope. In this study, the technological properties of Calabrian pine (*Pinus brutia* Ten.) grown in the Denizli area were studied. Within the scope of the study, their physical properties, such as air-dried and oven-dried specific densities, swelling and shrinkage values were determined. Their mechanical properties, such as bending strength, modulus of elasticity in bending, parallel compressive strength to the fibers, parallel tensile strength to the fibers and shear strength in a radial direction were determined. The values obtained were compared with the Calabrian pine (*P. brutia* Ten.) trees grown in different regions.

**Key words:** Denizli, *Pinus brutia* Ten., physical properties, mechanical properties.

INTRODUCTION

Firstly, the rational and economic use of wood should be provided for meeting the demand for lumber from Turkey's forests, which is supplied by importing from abroad. The most effective way to solve the problem would be to set forth the various properties of Turkey's original tree species and to process the wooden raw materials according to these properties to provide for the manufacturing of products that can ensure the best performance in their place of use. Although, it is known that the properties of Turkey's original tree species have both genetic and ecologic elements and vary depending on the regions, very few studies have been made on this subject (İltér et al., 2011). This species of Calabrian pine (*Pinus brutia* Ten.), by taking into consideration its distribution around the world and its intensity of distribution in Turkey, has been mentioned in the international literature as “Turkish red pine” and is one of Turkey's original tree species with a high economic value. Calabrian pine has been established in pure forests in the Mediterranean, Aegean and Marmara Regions of Turkey, while it is found sporadically and in groves in the coastal and inner parts of the Western and Central Black Sea regions (İltér et al., 2011). The first studies related to the technical properties for broadening the areas of usage of this species of Calabrian pine, which is widespread in Turkey, date back to the 1950s (Berkel, 1957). Calabrian pine wood has a porous structure and since it is of medium density, it is appropriate for the production of wood-polymer composites (Yildiz, 1993). Since Calabrian pine has excessive resin in its structure, resin production from Calabrian pine does not cause any significant changes in its physical properties and produces an

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increase in its mechanical properties (Oktem and Sozen, 1996). Calabrian pine can be split open easily. This characteristic of Calabrian pine enables it to be used in cooperage and shipbuilding (Bektas et al., 2003). The habitat is significant in the formation of the technological properties of trees. Consequently, the properties of Calabrian pine, just as for other tree species, vary according to growth regions (Bektas et al., 2003). For instance, as a result of the anatomical, physical and mechanical studies made on the Calabrian pine grown in the Dağta, Marmaris region, it was understood that it could be utilized in producing wire poles, mine poles, constructive materials, yachts and boats, packing cases, fence pickets, cultivation tools, cases, and in the paper and cellulose industry (Bozkurt et al., 1993). Care should be taken in the area where Calabrian pine is grown, especially in places where it is exposed to the bending impact. The Hatay, Adana and Antalya regions could be recommended if Calabrian pine will be used in the areas that require static bending strength, such as mine poles, construction forms and bridges (Ilter et al., 2011).

While it was emphasized in the research studies made that regional differences were significant, a determination has not been made for the trees growing in the Denizli area, the starting point in the western Mediterranean region where the optimal growing conditions for Calabrian pine occur.

In this study, it was aimed to increase the industrial use of Calabrian pine by determining the technological properties of the Calabrian pine species grown in the Denizli area. For this purpose, the trees grown in the areas remaining between Beyağac – Çameli – Acipayam, where the most habitats in the Denizli area are found, have been studied.

### MATERIALS AND METHODS

Four sample trees were selected by considering the habitat characteristics, such as direction, slope, altitude, diameter, density, etc. in the Eskere – Ağçataş area, where the largest distribution of Calabrian pine is found. The areas from which the sample trees were taken and the general properties of tree species were determined according to the TS 4176 (ISO 4471) standards. The geographical and structural properties of the Calabrian pine (P. brutia Ten.) selected for the experimental materials used in the study have been given in Table 1.

#### Table 1. Geographical and structural information for the trees used in the tests.

<table>
<thead>
<tr>
<th>Geographical and structural properties of calabrian pine trees</th>
<th>Regional Directorate</th>
<th>Operations Directorate</th>
<th>Sub-district Directorate</th>
<th>Division</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Altitude (m)</th>
<th>Exposure</th>
<th>Age</th>
<th>Height (m)</th>
<th>Soil structure</th>
<th>Age</th>
<th>North</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denizli</td>
<td>Eskere (Beyagac)</td>
<td>Karacaoren</td>
<td></td>
<td>56</td>
<td>37° 12’ 04”.4 N</td>
<td>28° 43’ 04”.6 E</td>
<td>950</td>
<td></td>
<td></td>
<td></td>
<td>Serpentine</td>
<td>120</td>
<td>Akçatas</td>
</tr>
</tbody>
</table>

After marking the bark on the north side of the trees, they were cut 0.30 m above the soil and their full-length was measured. Wheel-shaped sections 15 cm long were removed from the trunks of each sample tree once every 2 m by starting from 0.30 m high and 2-m. Long trunk sections were removed from each sample tree between 2 and 4 m. The north direction was marked on the transversal section of each piece and they were enumerated according to the sequence of removal. The 2 m long trunk sections were cut to a width of 6 cm in a north-south direction and east-west direction to determine the physical and mechanical properties. The pieces obtained were kept in a dry place for 3 months until they reached equilibrium moisture content (EMC).

Specimens were prepared from the 6 cm wide, 2-m long trunk sections for testing compressive strength, bending strength, tensile strength, shear strength, shrinkage and swelling and 15 cm high specimens from the trunk sections were prepared for testing air-dried and oven-dried density (Figure 1). All the specimens obtained were conditioned at a temperature of 20±2°C and a relative humidity of 65±5% until they reached an EMC.

#### Analysis of physical properties

Strips 2 cm wide in the north-south and east-west directions were removed from the 15 cm long tree trunk sections obtained from the sample trees for density measurements. Specimens measuring 20×20×30 mm were used according to the TS 2471 (ISO 3130) and TS 2472 (ISO 3131) standards to determine the air-dried (δ1) and oven-dried (δ2) densities of Calabrian pine.

Specimens prepared from the 1 m long tree trunks of Calabrian pine wood were used for the dimensional tests. Specimens measuring 30×30×15 mm were prepared according to the TS 4083 (ISO 4469) and TS 4084 (ISO 4859) standards to determine the amount of efficiency in the tangential and radial directions. For the dimensional swelling test (α), the dimensions of the specimens were measured separately in the tangential and radial directions via digital calipers after being kept in a climatization chamber at a temperature of 20±2°C and a relative humidity of 65±5% until they reached the EMC of 12±2% (L2). Later, when the same specimens reached the EMC of 21±2% in a climatization chamber at a temperature of 20±2°C and a relative humidity of 90±5%, they were measured again at the first measurement place (L1) (Sogutlu, 2004).
The dimensional swelling percentages ($\alpha$) were calculated according to Formula 1.

$$\alpha / = \frac{L_2t - L_1t}{L_1t} \times 100$$

(1)

The amount of volumetric swelling ($\alpha_v$) was obtained from the sum of the percentages of swelling in the tangential and radial directions ($\alpha_t$, $\alpha_r$) according to Formula 2.

$$\alpha_v = \alpha_t + \alpha_r$$

(2)

The amounts of dimensional shrinkage ($\beta$) were determined according to the principles stated in the TS 4083. The specimens were kept in a climatization chamber at a temperature of 20±2°C and a relative humidity of 90±5% until they reached the EMC and were measured separately in the tangential and radial directions ($L_1$). Later, when the same specimens reached the EMC of 7±2% at a temperature of 20±2°C and at a relative humidity of 30±5%, they were measured again at the first measurement place ($L_2$) (Sogutlu, 2004). The dimensional shrinkage percentages ($\beta_t$, $\beta_r$) were calculated according to Formula 3.

$$\beta / = \frac{L_2r - L_1r}{L_1r} \times 100$$

(3)

Separate values were calculated for the percentage of shrinkage in the tangential and radial directions ($\beta_t$, $\beta_r$). The amounts of volumetric shrinkage ($\beta_v$) were obtained from the sum of the percentages of shrinkage in the tangential and radial directions according to Formula 4.

$$\beta_v = \beta_t + \beta_r$$

(4)

A total of 24 specimens were utilized for each test to determine the physical properties. Of these, the results of 16 specimens that fulfilled the homogeneity of normality were evaluated.

Analysis of mechanical properties

Test specimens were prepared from the sample lumber in the dimensions of 6×200 cm for testing the mechanical properties of compressive strength, bending strength, tensile strength and shear strength (Table 2).

All the specimens were able to reach the EMC by being conditioned at a temperature of 20±2°C and a relative humidity of 65±5%. Subsequently, the tests were carried out via the tensile compression testing machine. The pace of the test was adjusted so that the specimens would break in 1.5 to 2 min and the strength at the instant of failure ($F_{max}$) was measured. A total of 20 specimens were utilized for each test to determine the mechanical properties. Of these, the results of 12 specimens that fulfilled the homogeneity of normality were evaluated.

Statistical analysis

Normality analysis was applied to the results obtained and extreme values were attained. Next, the one-sample T-test was applied for each test implementation separately and the statistical significance of the values was evaluated at an interval of confidence of 95%.

RESULTS AND DISCUSSION

According to the analysis results, all tests were found to be statistically significant (p<0.05). The analysis results of the tests carried out to determine the physical properties have been given in Table 3 and to determine the mechanical properties have been given in Table 4.

In Table 5, the values obtained in the study were compared with the values obtained in a study carried out by the Central Anatolia Forestry Research Institute of the Ministry of Forestry of the Republic of Turkey (Ilter et al., 2011).

According to the values of Calabrian pine trees grown in the Denizli area given in Table 5, the air-dried and oven-dried density values (0.567 g/cm$^3$, 0.532 g/cm$^3$) were higher than the trees in the Kahramanmaras area, but lower than in the Antalya and Samsun areas. However, the differences among the values were not very significant.

According to the swelling and shrinkage percentages, while the trees grown in Denizli area had the lowest values in a tangential direction, they had the highest values in a radial direction and volumetrically. The longitudinal values could not be compared, since they were not analyzed in the research carried out by the Institute. According to these results, if businesses prefer Calabrian pine, then they could utilize the trees grown in the Denizli area by using the tangential directions on large surfaces for outdoor furniture.

According to the mechanical properties, the Calabrian pine grown in Denizli area had the lowest values in bending strength and shear strength in a radial direction. This situation could result from the anatomical structure, especially from the chemical structures of Calabrian pines. According to the literature, properties of wooden material, such as density, temperature, moisture, knots and fiber direction affect its bending strength (Bozkurt and Erdin, 1997). However, the differences in resin and cellulose-lignin percentages are significant on bending strength (Ilter et al., 2011). The chemical components of
Calabrian pine woods should be analyzed in order to reach a firm conclusion on this issue.

The highest values from the mechanical test results were obtained in parallel compressive strength to the fibers and parallel tensile strength to the fibers. According to this result, the Calabrian pine trees grown in the Denizli area do not have sufficient strength for longitudinal strength to the fibers. If it is preferred as a construction material, especially for building construction and roofs, it should not be preferred for practices in a horizontal direction, such as beams.

**Conclusion**

In this study, some of the technological properties of Calabrian pine (*P. brutia* Ten.) trees grown in the Denizli area were investigated. Oven-dried and air-dried density values were significant criteria for determining the amount of raw material in its structure (Bozkurt and Erdin, 1997). These values are used to determine the productivity of cellulose in paper production and wood density should be between 0.300 to 0.600 g/cm³ for commercial wood pulp (Gunduz, 1999). Therefore, the Calabrian pine trees grown in the Denizli area used in this study as the research material were found to be suitable for paper production. As its shrinkage and swelling values were low in a tangential direction but high in a radial direction and volumetrically compared to the other areas, by taking into account the use of direction, Calabrian pine could be preferred for outdoor applications such as arbor, benches and bridges, and for the furniture in damp places, such as bathrooms, saunas and kitchens. In this study, it was found that Calabrian pine trees grown in the Denizli area were less resistant against longitudinal loads to the fibers.

On the other hand, as they obtained better results against loads parallel to the fibers and tensile strength compared to the other areas, the use of Calabrian pine in the right direction should be considered in uses that require resistance to loads, such as prefabricated houses, roofs, wardrobe closets, bookcases and

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**Table 2.** Tests and types of specimens for determining the mechanical properties.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Standards</th>
<th>Type of specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel compressive strength to the fibers (σ₁)</td>
<td>TS 2595 (ISO 3797)</td>
<td></td>
</tr>
<tr>
<td>MoR (σₑ) and MoE (E)</td>
<td>TS 2474 (ISO 3133), TS 2478 (ISO 3349)</td>
<td></td>
</tr>
<tr>
<td>Shear strength in radial direction (σₘ)</td>
<td>TS 3459 (ISO 3347)</td>
<td></td>
</tr>
<tr>
<td>Parallel tensile strength to the fibers (σₑ)</td>
<td>TS 2475 (ISO 3345)</td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Descriptive statistics for the physical properties.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Sample size (N)</th>
<th>Arithmetic mean (μ)</th>
<th>Standard deviation (SD)</th>
<th>Variance (V)</th>
<th>Coefficient of variation (CV)</th>
<th>Min. value</th>
<th>Max. value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-dried density $\delta_{12}$ (g/cm$^3$)</td>
<td>16</td>
<td>0.567</td>
<td>0.032</td>
<td>0.001</td>
<td>5.643</td>
<td>0.520</td>
<td>0.630</td>
</tr>
<tr>
<td>Oven-dried density $\delta_0$ (g/cm$^3$)</td>
<td>16</td>
<td>0.532</td>
<td>0.033</td>
<td>0.001</td>
<td>6.203</td>
<td>0.490</td>
<td>0.600</td>
</tr>
<tr>
<td>Swelling $\alpha$ (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\alpha_t$</td>
<td>16</td>
<td>7.813</td>
<td>1.059</td>
<td>1.122</td>
<td>13.554</td>
<td>6.330</td>
<td>9.510</td>
</tr>
<tr>
<td>$\alpha_r$</td>
<td>16</td>
<td>8.866</td>
<td>0.421</td>
<td>0.177</td>
<td>4.748</td>
<td>8.100</td>
<td>9.640</td>
</tr>
<tr>
<td>$\alpha_v$</td>
<td>16</td>
<td>16.679</td>
<td>0.888</td>
<td>0.788</td>
<td>5.324</td>
<td>15.210</td>
<td>17.910</td>
</tr>
<tr>
<td>$\alpha_l$</td>
<td>16</td>
<td>0.659</td>
<td>0.175</td>
<td>0.031</td>
<td>26.555</td>
<td>0.410</td>
<td>1.00</td>
</tr>
<tr>
<td>Shrinkage $\beta$ (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta_t$</td>
<td>16</td>
<td>6.753</td>
<td>0.859</td>
<td>0.738</td>
<td>12.720</td>
<td>5.300</td>
<td>8.65</td>
</tr>
<tr>
<td>$\beta_r$</td>
<td>16</td>
<td>6.924</td>
<td>0.475</td>
<td>0.226</td>
<td>6.860</td>
<td>6.180</td>
<td>7.720</td>
</tr>
<tr>
<td>$\beta_v$</td>
<td>16</td>
<td>13.677</td>
<td>0.963</td>
<td>0.928</td>
<td>7.041</td>
<td>12.240</td>
<td>15.630</td>
</tr>
<tr>
<td>$\beta_l$</td>
<td>16</td>
<td>0.681</td>
<td>0.131</td>
<td>0.017</td>
<td>19.236</td>
<td>0.530</td>
<td>1.040</td>
</tr>
</tbody>
</table>

T, Tangential; r, Radial; v, Volumetric; l, Longitudinal.

Table 4. Descriptive statistics for the mechanical properties.

<table>
<thead>
<tr>
<th>Properties</th>
<th>N</th>
<th>$\bar{X}$ (μ)</th>
<th>SD</th>
<th>V</th>
<th>CV</th>
<th>Min. value</th>
<th>Max. value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of elasticity in bending (MoE) ($E$) (N/mm$^2$)</td>
<td>12</td>
<td>9650.755</td>
<td>577.059</td>
<td>332997.583</td>
<td>5.979</td>
<td>8728.960</td>
<td>10743.720</td>
</tr>
<tr>
<td>Bending strength (MoR) ($σ_e$) (N/mm$^2$)</td>
<td>12</td>
<td>95.893</td>
<td>5.516</td>
<td>30.431</td>
<td>5.752</td>
<td>87.110</td>
<td>105.260</td>
</tr>
<tr>
<td>Shear strength in radial direction ($σ_m$) (N/mm$^2$)</td>
<td>12</td>
<td>6.613</td>
<td>0.525</td>
<td>0.275</td>
<td>7.939</td>
<td>5.623</td>
<td>7.320</td>
</tr>
<tr>
<td>Parallel compressive strength to the fibers ($σ_{B//}$) (N/mm$^2$)</td>
<td>12</td>
<td>60.674</td>
<td>3.297</td>
<td>10.872</td>
<td>4.036</td>
<td>56.640</td>
<td>65.570</td>
</tr>
<tr>
<td>Parallel tensile strength to the fibers ($σ_{ç\perp}$) (N/mm$^2$)</td>
<td>12</td>
<td>81.697</td>
<td>15.401</td>
<td>237.131</td>
<td>18.851</td>
<td>61.460</td>
<td>113.520</td>
</tr>
</tbody>
</table>

Table 5. Comparison of the properties of Calabrian pine grown in other areas.

<table>
<thead>
<tr>
<th>Area (City)</th>
<th>(\delta_{12}) (g/cm$^3$)</th>
<th>(\delta_0) (g/cm$^3$)</th>
<th>(\alpha_t) (%)</th>
<th>(\alpha_r) (%)</th>
<th>(\alpha_v) (%)</th>
<th>(\alpha_l) (%)</th>
<th>(\beta_t) (%)</th>
<th>(\beta_r) (%)</th>
<th>(\beta_v) (%)</th>
<th>(\beta_l) (%)</th>
<th>(σ_e) (N/mm$^2$)</th>
<th>(σ_m) (N/mm$^2$)</th>
<th>(σ_{B//}) (N/mm$^2$)</th>
<th>(σ_{ç\perp}) (N/mm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denizli</td>
<td>0.567</td>
<td>0.532</td>
<td>7.813</td>
<td>8.866</td>
<td>16.679</td>
<td>0.659</td>
<td>6.753</td>
<td>6.924</td>
<td>13.677</td>
<td>0.681</td>
<td>95.893</td>
<td>6.613</td>
<td>60.674</td>
<td>81.697</td>
</tr>
<tr>
<td>Samsun</td>
<td>0.588</td>
<td>0.558</td>
<td>8.670</td>
<td>6.430</td>
<td>15.630</td>
<td>-</td>
<td>7.690</td>
<td>6.831</td>
<td>12.590</td>
<td>-</td>
<td>102.311</td>
<td>6.831</td>
<td>53.588</td>
<td>72.430</td>
</tr>
<tr>
<td>Kahramanmaraş</td>
<td>0.530</td>
<td>0.500</td>
<td>8.120</td>
<td>5.590</td>
<td>14.170</td>
<td>-</td>
<td>7.720</td>
<td>7.174</td>
<td>11.750</td>
<td>-</td>
<td>99.9740</td>
<td>7.174</td>
<td>50.607</td>
<td>77.203</td>
</tr>
</tbody>
</table>
transport boxes. In conclusion, the Calabrian pine (*P. brutia* Ten.) trees grown in the Denizli area have the technological values that could compete with trees grown in other areas.

**ACKNOWLEDGEMENT**

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**REFERENCES**


The application of some biodiversity indices in the Tortum Stream, Erzurum, Turkey

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Faculty of Fisheries, Ataturk University, 25240 Erzurum, Turkey.

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INTRODUCTION

Benthic algal communities have developed in virtually all substrates that receive light, whether in small streams or large rivers. These communities have generated important part of water ecosystems due to their role in food chain and their quick response and direct to a lot of change in environmental parameters. Cell structure of diatom is directly connected to physicochemical parameters of water, so diatom is an indicator for identification of river water quality. Therefore, it is used as a tool to make comparison between aquatic ecosystems (Allan and Castillo, 2007).

The use of phytoplankton communities or other aquatic organisms as bioindicators goes back to very ancient times. For the first time, in 1954, benthic organisms were used as bioindicators by Patric due to their easy adaption to changes in the chemical and physical displacement (Thunmark, 1945; Nygaard, 1949; Lepistö and Rosenström, 1998).

In Turkey, the earliest study in which diatoms were used to evaluate the water quality changes was carried out by Kalyoncu and Barlas (1997) in which he gave more information about that study (saprobic index etc.). Organic pollution is usually closely related to enhance nutrient concentrations. Based on the significant correlation with nutrients and organic pollution variables, this study suggests that Saprobiic Index (SI), Trophic Index (TI) and Swiss Diatom Index (DI-CH) are integrating the effects of enrichment of organic pollution. In another study, among the observed diatom indices, TI and DI-CH better reflect the changes in water quality than the SI (Kalyoncu et al., 2009). The diatom community is closely related to water quality and bio-invitational methods can be used in the river monitoring system in Turkey (Solak et al., 2012). Tortum River Basin has about 1900 km² area covering both Tortum and Uzundere towns and it is formed by Tortum Stream and its tributaries (Pırlak, 1993).

The aim of the present study was to evaluate the use of epilithic diatoms as indicators of water quality in the Tortum Stream and its tributaries.

MATERIALS AND METHODS

Study area

The Tortum Stream is located in the north part of the Eastern
The number of species is derived from a mathematical formula by Shannon in 1948 (Türkmen and Kazancı, 2010):

\[ S\left( H' \right) = -\sum_{i=1}^{S} p_i \log_e p_i, \quad p_i = \frac{n_i}{n} \]

Where \( s \) is the total number of species and \( p_i \) is the number of individuals belonging to \( i \) species \((n_i) / \text{total number of individuals (n)}\) (Hill, 1973; Krebs, 1998; Kwak and Peterson, 2007; James and Aderaje, 2010).

**Simpson diversity index (D)**

\[ 1 - D = \sum_{i=1}^{S} \frac{n_i(n_i - 1)}{N(N - 1)} \]

Where \( n_i \) is the number of individuals belonging to \( i \) species and \( N \) is the total number of species (Hill, 1973; Krebs, 1998; Kwak and Peterson, 2007; James and Aderaje, 2010).

**Simpson dominance index (C)**

\[ C = \sum_{i=1}^{S} \left( \frac{p_i^2}{1} \right) \]

Where \( s \) is the number of species and \( p_i \) is the relative abundance of species \( i \) (Hill, 1973; Krebs, 1998; Kwak and Peterson, 2007; James and Aderaje, 2010).

**Margalef diversity index (Dmg)**

\[ D_{mg} = S - 1 / \log N \]

Where \( S \) is the number of species and \( N \) signifies the number of individual in a sample (James and Aderaje, 2010).

**Menhinick diversity index (Dmn)**

\[ D_{mn} = S / \sqrt{N} \]

Where \( S \) is the number of species and \( N \) signifies the number of individual in a sample (Menhinick, 1964; James and Aderaje, 2010).

**McIntosh diversity index (M_c)**

\[ M_c = \left[ N - \sqrt{\left( \sum n_i^2 \right)} \right] / \left[ N - \sqrt{N} \right] \]

Where \( n_i \) is the number of individuals belonging to \( i \) species and \( N \) is the number of species (Türkmen and Kazancı, 2010).

**Pielou evenness index (J')**

\[ J' = H' / \log_e S \]

Where \( S \) is the number of species and \( H' \) is the Shannon-Wiener Diversity Index (Hill, 1973; Krebs, 1998; Kwak and Peterson, 2007; James and Aderaje, 2010).
Table 1. The list of diatoms in Tortum Stream.

<table>
<thead>
<tr>
<th>Phylum: Heterokontophyta</th>
<th>Order: Rhopalodiales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classis: Bacillariophyceae</td>
<td></td>
</tr>
<tr>
<td>Order: Achantes</td>
<td></td>
</tr>
<tr>
<td>Family: Cocconeidaceae</td>
<td></td>
</tr>
<tr>
<td>Cocconeis placenta Ehrenberg</td>
<td></td>
</tr>
<tr>
<td>Order: Bacillariaceae</td>
<td></td>
</tr>
<tr>
<td>Family: Bacillariaceae</td>
<td></td>
</tr>
<tr>
<td>Hantzschia amphioxys(Ehrenberg) Grunow</td>
<td></td>
</tr>
<tr>
<td>Nitzschia amphibian Grunow</td>
<td></td>
</tr>
<tr>
<td>Family: Surirellaceae</td>
<td></td>
</tr>
<tr>
<td>Suriella brebissonii Krammer &amp; Lange-Bertalot</td>
<td></td>
</tr>
<tr>
<td>Order: Cymbellaceae</td>
<td></td>
</tr>
<tr>
<td>Cymbella affinis Küting</td>
<td></td>
</tr>
<tr>
<td>C. lensolata Cuspidata Pantocsek</td>
<td></td>
</tr>
<tr>
<td>C. turgidula Grunow</td>
<td></td>
</tr>
<tr>
<td>Encyonema minutum Hilse</td>
<td></td>
</tr>
<tr>
<td>Family: Gomphonemataceae</td>
<td></td>
</tr>
<tr>
<td>Didymosphaenia geminata (Lyngbye) M. Schmidt</td>
<td></td>
</tr>
<tr>
<td>Gomphonema angustadum Küting</td>
<td></td>
</tr>
<tr>
<td>G. capitatum Ehrenberg</td>
<td></td>
</tr>
<tr>
<td>G. olivaceum (Hornemann) Brébisson</td>
<td></td>
</tr>
<tr>
<td>G. parvalu (Kützing) Küting</td>
<td></td>
</tr>
<tr>
<td>Family: Rhicospheneiaceae</td>
<td></td>
</tr>
<tr>
<td>Rhicosphenea curvata (Kützing) Grunow</td>
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<tr>
<td>Order: Naviculales</td>
<td></td>
</tr>
<tr>
<td>Family: Naviculaceae</td>
<td></td>
</tr>
<tr>
<td>Caloneis bacillum (Grunow) Cleve</td>
<td></td>
</tr>
<tr>
<td>Navicula cryptocephala Küting</td>
<td></td>
</tr>
<tr>
<td>Family: Pleurosigmataceae</td>
<td></td>
</tr>
<tr>
<td>Gyrosigma acuminatum (Kützing) Rabenhorst</td>
<td></td>
</tr>
<tr>
<td>Family: Stauroneidaceae</td>
<td></td>
</tr>
<tr>
<td>Craticula cuspidata (Kützing) D.G.Mann</td>
<td></td>
</tr>
</tbody>
</table>

McIntosh evenness index (M_E)

\[
M_E = \left[ N - \sqrt{\left( \sum n_i^2 \right)} \right] / \left[ N - \left( N / \sqrt{S} \right) \right]
\]

Where \( n_i \) is the i. türe ait birey sayısı, \( S \) is the number of species and \( N \) is the number of individual (Türkmen and Kazancı, 2010).

RESULTS

In this study, a total of 3 classes, 10 orders, 15 families and 36 taxa, were identified belonging Bacillariophyceae (Table 1). While low species diversity was identified in summer, high species diversity was found between winter and spring (Table 2). During the study period, the highest total number of individuals was found in station 1 and the lowest total number in station 6. Total number of individuals was about 50% higher in the downstream sampling stations than in the upstream sampling stations. The number of species varied depending on station with an average of 24 species (Figure 2). The values of Shannon-Wiener Diversity Index ranged from 0.46 to 1.92. The lowest value was for station 2 and the highest for station 7. The values of Simpson Diversity Index were between 24.26 and 24.86. The lowest value was for station 2 and the highest value for station 7 (Figure 3).

In this study, Cocconeis placenta reached a significantly high abundance level in all of the stations. In addition, both Shannon-Wiener Diversity and Simpson Diversity indexes were shown to be of eutrophication assessment in the stream ecosystem (Table 3). The values of Margalef Diversity Index ranged from 4.01 to 4.88. The lowest value was for station 2 and
Table 2. Monthly variation in species diversity (‘+’ indicates species, E not encountered).

<table>
<thead>
<tr>
<th>Species</th>
<th>Jun</th>
<th>Jul</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
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</thead>
<tbody>
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<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Caloneis bacillum (Grunow) Cleve</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
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</tr>
<tr>
<td>Cocconeis placenta Ehrenberg</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Craticula cuspidata (Kützing) D.G.Mann</td>
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<td>+</td>
<td>E</td>
<td>E</td>
<td>+</td>
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<td>+</td>
<td>+</td>
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<td>E</td>
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<td>E</td>
</tr>
<tr>
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<td>E</td>
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<td>E</td>
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<td>+</td>
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<tr>
<td>C. turgida Grunow</td>
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<td>+</td>
<td>E</td>
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<td>E</td>
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</tr>
<tr>
<td>Epithemia adnata (Kützing) Brebisson</td>
<td>E</td>
<td>E</td>
<td>E</td>
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<td>E</td>
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<td>E</td>
</tr>
<tr>
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<td>E</td>
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<td>E</td>
</tr>
<tr>
<td>Fragilaria arcus (Ehrenberg) Cleve</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>F. capucina Desmazieres</td>
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<td>E</td>
<td>E</td>
<td>E</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Gomphonema angustadium Kützing</td>
<td>E</td>
<td>+</td>
<td>+</td>
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<td>+</td>
<td>+</td>
<td>+</td>
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<td>+</td>
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<td>+</td>
</tr>
<tr>
<td>G. capitatum Ehrenberg</td>
<td>E</td>
<td>E</td>
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<td>E</td>
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</tr>
<tr>
<td>G. parvula (Kützing) Kützing</td>
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</tr>
<tr>
<td>G. olivaceum (Hornemann) Brébisson</td>
<td>E</td>
<td>E</td>
<td>E</td>
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<td>E</td>
<td>E</td>
<td>+</td>
<td>E</td>
<td>E</td>
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<td>E</td>
</tr>
<tr>
<td>Gyrosigma acuminatum (Kützing) Rabenhorst</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>+</td>
<td>E</td>
<td>E</td>
<td>E</td>
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<td>E</td>
<td>E</td>
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<td>E</td>
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<td>+</td>
<td>+</td>
<td>+</td>
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<td>Navicula cryptocephala Kützing</td>
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<td>Suriella brebissoni Krammer &amp; Lange-Bertalot</td>
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<td>+</td>
<td>E</td>
<td>E</td>
<td>E</td>
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<tr>
<td>Ulnaria capidata (Ehrenberg) P. Compere</td>
<td>E</td>
<td>E</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>E</td>
<td>+</td>
<td>E</td>
<td>E</td>
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<td>+</td>
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<tr>
<td>U. ulna (Nitzsch) P. Compere</td>
<td>E</td>
<td>E</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>E</td>
<td>+</td>
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<td>+</td>
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</tbody>
</table>

Figure 2. Total number of individual and species for each station.
Table 3. Changes in dominant species to sample stations.

<table>
<thead>
<tr>
<th>Station</th>
<th>Species</th>
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<tr>
<td>1</td>
<td>Cocconeis placenta</td>
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<tr>
<td>2</td>
<td>Cocconeis placenta</td>
<td>0.731</td>
</tr>
<tr>
<td>3</td>
<td>Cocconeis placenta</td>
<td>0.075</td>
</tr>
<tr>
<td></td>
<td>Caloneis bacillum</td>
<td>0.044</td>
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<td>4</td>
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<tr>
<td></td>
<td>Navicula cryptocephala</td>
<td>0.047</td>
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<tr>
<td>5</td>
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<td>6</td>
<td>Navicula cryptocephala</td>
<td>0.015</td>
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<tr>
<td></td>
<td>Cymbella affinis</td>
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<tr>
<td></td>
<td>Cocconeis placenta</td>
<td>0.029</td>
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<tr>
<td>7</td>
<td>Diatoma vulgaris</td>
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<td></td>
<td>Ulnaria capidata</td>
<td>0.056</td>
</tr>
<tr>
<td>8</td>
<td>Cocconeis placenta</td>
<td>0.110</td>
</tr>
<tr>
<td></td>
<td>Craticula cuspidata</td>
<td>0.533</td>
</tr>
<tr>
<td>9</td>
<td>Cocconeis placenta</td>
<td>0.266</td>
</tr>
<tr>
<td></td>
<td>Ulnaria ulna</td>
<td>0.011</td>
</tr>
</tbody>
</table>

The highest value for station 6. These stations did not have a domestic land but they were under the stresses of dams conclusion and quarries. The values of Menhinick Diversity Index were between 0.03 and 0.08. The lowest value was for station 1 and 2 and the highest value for station 6. The values of McIntosh Diversity Index were between 288.295 and 736.85. The lowest value was calculated for station 6 and the highest value for station 2 (Figure 4).

Pielou Evenness Index was between 0.15 and 0.60. The lowest value was station 2 and the highest value was for stations 3 and 6. Both of them found similar value due to dam construction. The McIntosh Evenness Index was between 0.25 and 1.26. The lowest value was station for 2, 3, 4, 8 and 9 and the highest value was for station 5 and 7 (Figure 5). In this study, Shannon-Wiener and Simpson Diversity Indices, Margalef and Menhinick Diversity Indices were similar to each other (Figure 6). The number of species was similar for stations 1, 2, 5 and for stations 3, 8, 9, 7, 4 in the Tortum Stream and its tributaries. However, station 6 was not similar with the other stations (Figure 7).

DISCUSSION

The present study identified 36 species from Bacillariophyceae, whereas Kivrak and Gürbüz (2010) found 113 taxa in the same habitat during the period of 2005-2006. Our results show that diatom species could be under the stress of dam construction. According to Simson et al. (2003), natural disasters for example, erosion are in charge of increase of sediment concentration in this circumstance which is a trigger of water quality change. In parallel with these changes are negative effects diatom assemblages and species diversity.
In our study, *C. placentula* was the dominant taxa in all the stations. Kivrak and Gürbüz (2010) identified *C. plasentula* var. *euglypta*. These taxa were adapted to organic pollution (Soininen, 2002). *Caloneis bacillum* was found commonly in the station 3, *Navicula cryptocephala* was in the station 4, *Cymbella affinis* was in station 6, *Diatoma vulgaris* and *Ulnaria capidata* were in the station 7, *Craticula cuspidata* was in the station 8 and *Ulnaria*...
ulna was in the station 9. This study showed that organic pollution-tolerant species were found in the stations which were located around the settlement and cultivation areas. On the other hand, dam construction and fast flow rate influence species diversity in the Tortum Stream.

In the present study, species diversity increased according to biodiversity indices in part of downstream and Tortum Stream's tributaries. The result of site 7 point out that around the station has been stressed both domestic and waste water pollutions. The structure of the ecosystem of rivers, streams on biodiversity, hydrological diversity and human activities are effective (Allan and Castillo, 2007). Pei and Liu (2011) suggested that dominant species were the upper more than middle part
of Niyang River and they reported that useful indices can determine the ecological characteristics of lotic systems.

**Conclusion**

In conclusion, Tortum Stream and its tributaries were affected by domestic waste, agricultural waste, dam constructions and quarries. They created pressure on the ecosystem of the stream to reduce organic pollution-tolerant species. We suggest that precaution such as sewer system, demolition waste management (for example, dams and quarries) and control of illegal quarries should be taken in order to reduce detrimental effects of lotic ecosystem.

**ACKNOWLEDGEMENT**

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**REFERENCES**


Application of vertical electrical soundings to characterize aquifer potential in Ota, Southwestern Nigeria

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A knowledge of hydrogeophysical parameters of aquifers is essential for groundwater resource assessment, development and management. Traditionally, these parameters are estimated using pumping test carried out in boreholes or wells; but this is often costly and time consuming. Surface geophysical measurements can provide a cost effective and efficient estimates of these parameters. In the present work, geoelectrical resistivity data has been used to characterize and evaluate the aquifer potential at Covenant University, Ota, southwestern Nigeria. Some thirty-five vertical electrical soundings (VESs) were conducted using Schlumberger array with a maximum half-current electrode spacing (AB/2) of 240 m. The geoelectrical parameters obtained were used to estimate longitudinal conductance and transverse resistance of the delineated aquifer. Both the longitudinal conductance and transverse resistance, which qualitatively reflects the hydraulic properties of the aquifer, indicate that the aquifer unit is characterized with high values of hydraulic parameters; consequently a good groundwater potential. Thus, groundwater resource development and management in the area can be effectively planned based on these parameters.

Key words: Hydrogeophysics, geoelectrical parameters, resistivity survey, aquifer potential.

INTRODUCTION

Geophysical methods are increasingly becoming relevant in hydrological applications (Hubbard et al., 1997; Rubin and Hubbard, 2005; Vereecken et al., 2006). Conventional hydrogeologic investigation requires estimates of hydraulic parameters using traditional approaches such as pumping test, slug test and laboratory analyses of core samples. Pumping tests can produce reliable estimates of hydraulic parameters, but the estimates are largely volumetric averages. Laboratory analyses can provide information at a very fine scale, but there are many questions about the reliability of the hydraulic parameters estimates obtained with those analyses. Slug test has the most potential of the traditional approaches for detailed characterization of the variability of hydraulic parameters, but most sites do not have the extensive well network required for effective application of this approach (Butler, 2005). These traditional methods are time-consuming and invasive.

Non-invasive (or minimally invasive) geophysical methods can be used to characterize an image flow and transport processes within the subsurface. Spatial and temporal patterns of hydrological states can be retrieved from the geophysical parameters; thus, estimates of the hydrological and petro-physical parameters that determine flow and transport processes can be made. Geoelectrical resistivity technique is one of the most

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common geophysical tools used for hydrological investigations. The technique has been widely used in groundwater exploration to determine depth to water-table, aquifer geometry and groundwater quality by analyzing measured apparent resistivity field data. Numerical inversion techniques are often used to obtain the inverse model of the electrical resistivity distribution of the subsurface from the measured apparent resistivity data. This is achieved by solving the nonlinear and mixed-determined inverse problem whose solution is inherently non-unique and sometimes unstable. Typically, the resolution of the inversion result differs spatially, so that some regions may be well resolved while others are prone to exhibit artefacts and interpretation errors (Day-Lewis et al., 2005; Aizebeokhai, 2009).

In general, the inverse geophysical models can be used to estimate the hydraulic properties of aquifer by using analytical relationships between hydraulic parameters and geoelectrical parameters (Niwas and de Lima, 2003). In the present work, some thirty-five vertical electrical soundings (VESs) were conducted in Covenant University campus, Ota, southwestern Nigeria. The survey was carried out between the months of April and May, 2013 as part of the preliminary investigations to evaluate groundwater resource potential in the area. Schlumberger array was used in conducting the measurements with a maximum half-current electrode spacing (AB/2) of 240 m. The geoelectrical parameters obtained from the survey, which characterized the aquifer unit, were used to estimate the longitudinal conductance and transverse resistance of the delineated aquifer. The longitudinal conductance and transverse resistance of a porous medium characterise the hydraulic properties (conductivity and transmissivity) of the medium. The electrical resistivity (or its inverse conductivity) of a porous medium does not directly gives information about the hydraulic conductivity of the medium since the bulk electrical resistivity primarily depends on porosity, water saturation and dissolved ions.

**Study area**

The study area (Figure 1) falls within the eastern Dahomey (or Benin) Basin of southwestern Nigeria which stretches along the continental margin of the Gulf of Guinea. The area is generally a gently sloping low-lying area characterized by two major climatic seasons namely, dry season spanning from November to March and raining (or wet) season between April and October. Occasional rainfalls are usually witnessed within the dry season, particularly along the region adjoining the coast. Mean annual rainfall is greater than 2000 mm and forms the major source of groundwater recharge in the area. In general, the rocks are Late Cretaceous to Early Tertiary in age (Jones and Hockley, 1964; Omatsola and Adegoke, 1981; Billman, 1992; Olabode, 2006). The stratigraphy of the basin has been grouped into Abeokuta Group, Imo Group, Oshoshun, Ilando and Benin Formations (Figure 2). The Cretaceous Abeokuta Group consists of Ise, Afowo and Araromi Formations, and mainly composed of poorly sorted ferruginized grit, siltstone and mudstone with shale-clay layers. Overlying the Abeokuta Group is the Imo Group which is subdivided into the limestone-dominated Ewekoro Formation and the shale-dominated Akinbo Formation. The Akinbo Formation...
is overlain by the Oshoshun Formation and then Ilaro Formation which is predominantly a sequence of coarse sandy estuarine, deltaic and continental beds; the Ilaro Formation displays rapid lateral facies changes. Overlying the Ilaro Formation is the Benin Formation which is predominantly coastal plain sands and Tertiary alluvium deposits. The local geology is predominantly coastal plain sands which are underlain by a sequence of coarse sandy estuarine, deltaic and continental beds largely characterised by rapid changes in facies.

**METHODOLOGY**

**Vertical electrical soundings**

A total of thirty-five vertical electrical soundings (VES) were conducted within the study area so as to delineate the subsurface lithological configuration, depth to aquifer(s) and aquifer characteristics. An ABEM Terrameter (SAS 1000 series) was used for the apparent resistivity measurements. Schlumberger electrode configuration was adopted for the resistivity soundings due to its high lateral resolution. The maximum half-current electrode separation (AB/2) used ranges from 130 to 240 m, with an average of 180 m. The spread was sufficient for the effective depth of investigation anticipated. Most of the VESs were conducted along three main profiles (Figure 3). Care was taken to minimize electrode positioning error. A minimum stack of 3 and maximum of 6 were used for measurement. The root-mean squares error associated with the data measurement was minimal, generally less than 0.3%. Measurements with root-mean squares error up to 0.5% or more were repeated after re-checking electrodes contact.

The observed apparent resistivity data were processed by plotting the apparent resistivity values against half-current electrode spacing (AB/2 or half the spread length) at each station on a bi-logarithmic (log – log) graph sheets. Partial curve matching of the field curves with relevant Schlumberger developed master and auxiliary curves was carried out to obtain estimates of the number of layers and their respective resistivities and thicknesses. The geoelectric parameters obtained from this manual interpretation were then used as the initial models for the computer inversion using the Win-Resist code. This computer code uses iterative process by matching the computed data with the observed field data to obtain the inverse models. The iterative process is an attempt to reduce the root-mean squares errors and improve the goodness of fit between the measured data and computed data. The root-mean squares error observed in the inversion range between 1.4 and 2.8%.

**Hydraulic parameters estimation**

The relationship between the hydraulic conductivity $K$ and geoelectrical resistivity $\rho$ of an aquifer is strongly controlled by the nature of the aquifer substratum (Niwas and Singhal, 1985; Niwas...
and de Lima, 2003). For a highly resistive substratum, both the current and the hydraulic flows are dominantly horizontal in a typical unit column of the aquifer, and the relationship between $K$ and $\rho$, is inverse. If the substratum is highly conductive, the hydraulic flow will still be horizontal while the current flow in a characteristic unit column is dominantly vertical; thus, a direct relation exist between $K$ and $\rho$. If the aquifer material is cut in the form of a vertical prism of the unit cross-section from top to bottom, fluid flow and current flow in the aquifer material obeys Darcy’s law and Ohm’s law respectively. Thus, for current and fluid flows in a lateral direction, the transmissivity of the aquifer is given as:

$$T = (K\rho)S$$  \hspace{1cm} (1)$$

where $\rho$ is the bulk resistivity and $S$ is the longitudinal unit conductance of the aquifer material with thickness $b$ given by $b/\rho$. For a lateral hydraulic flow and current flowing transversely, the transmissivity of the aquifer becomes:

$$T = (K\rho)R$$  \hspace{1cm} (2)$$

where $R$ is the transverse unit resistance of the aquifer material given by $b\rho$. If the aquifer is saturated with water with uniform resistivity, then the product $K\rho$ or $K/\rho$ would remain constant. Thus, the transmissivity of an aquifer is proportional to the longitudinal conductance for a highly resistive basement where electrical current tends to flow horizontally, and proportional to the transverse resistance for a highly conductive basement where electrical current tends to flow vertically (Niwas et al., 2011). The above equations may therefore be written as:

$$T = \alpha S; \hspace{0.5cm} \alpha = K\rho$$  \hspace{1cm} (3)$$
and

\[ T = \beta R; \quad \beta = K / \rho \]

(4)

where \( \alpha \) and \( \beta \) are constants of proportionality. From these relations, the model resistivity values obtained from the inversion process were used to estimate the longitudinal unit conductance and transverse unit resistance of the aquifer unit.

**RESULTS AND DISCUSSION**

Some representative of the output from the computer interpretation of the observed apparent resistivity data are presented in Figure 4. Five to seven layers were generally delineated from the iterated sounding curves. The geoelectrical parameters of the layers correlated for each Traverse are presented in Tables 1 to 3; the
The geoelectric parameters are largely consistent among the interpreted sounding curves. The lithologies of the interpreted layers were inferred based on the local geology and available information. The resistivity of the top soil (sandy clay) varies...
The thickness of this layer ranges from 0.5 to 1.5 m. The resistivity of the top soil largely depends on clay volume, moisture content and degree of compaction. The resistivity of the underlying geoelectric layer ranges from 310.0 $\Omega$m to 909.2 $\Omega$m with thickness ranging from 2.2 – 13.0 m, while those of the third geoelectric layer are 76.0 – 1509.8 $\Omega$m and 3.3 – 10.6 m. The second and third layers are laterally continuous and are basically the same lithologic unit, lateritic clay, with different degree of compaction and water saturation. The variability in the resistivity and thickness of these units are shown in Tables 1 to 3. These layers are largely impermeable, especially in areas where they are compacted, and percolation through these layers relatively poor and slow. Consequently, the top soil and possibly the second layer occasionally form parched aquifer; and most parts of the areas are usually flooded due to poor percolation of the underlying layers (Aizebeokhai et al., 2010).

The fourth geoelectric layer, an intercalation of silt, sand and clay, was delineated in all the soundings in Traverse 1 and some of the soundings in Traverses 2 and 3. The range of model resistivity of this layer is 288.9 – 1140.5 $\Omega$m with thickness ranging from 4.3 – 17.5 m. This layer is thought to be laterally discontinuous based on the geoelectric layers delineated. However, it may be masked in some cases due to the resistivity contrast between the third and fifth geoelectric layers. Underlying this geoelectric layer is a very high resistive substratum with resistivity ranging from 787.7 – 4641.6 $\Omega$m and thickness ranging between 8.2 and 48.1 m.

The sixth geoelectric layer delineated is the main aquifer unit which consists of unconsolidated coarse grain sands. The aquifer unit is confined by the overlying high resistive unit, the depth to the aquifer delineated from the geoelectric parameters ranges from 17.7 – 73.6 m (Table 4). Its resistivity, ranging between 245.1 $\Omega$m and 583.1 $\Omega$m, and thickness ranging between 10.4 m and 21.9 m, are more uniform among the geoelectric layers delineated (Table 4). Underlying the aquifer unit is a high conductive clay/shale layer with model resistivity ranging between 22.9 $\Omega$m and 239.4 $\Omega$m. The resistivity of this unit is also largely uniform.

The geoelectric parameters of the aquifer were used to compute the longitudinal conductance and transverse resistance of the aquifer unit (Table 4). These parameters are indicative of the spatial

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<th>Location</th>
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<th>Top Soil (Sandy Clay)</th>
<th>Lateritic Clay</th>
<th>Lateritic Clay (Compacted)</th>
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<th>Laterite (Confining Bed)</th>
<th>Sand (Main Aquifer)</th>
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<tr>
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<td>Bottom Depth (m)</td>
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<tr>
<td>VES 3</td>
<td>Location</td>
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<td>Bottom Depth (m)</td>
<td>Resistivity ($\Omega$m)</td>
<td>Thickness (m)</td>
<td>Bottom Depth (m)</td>
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<td>VES 1</td>
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<tr>
<td>VES 4</td>
<td>Location</td>
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<td>Thickness (m)</td>
<td>Bottom Depth (m)</td>
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</table>
variability of the hydraulic properties (hydraulic conductivity and transmissivity) of the aquifer units. Zones with high longitudinal conductance are generally characterized as areas with low permeability with high clay volume, consequently low hydraulic conductivity. Similarly, areas with low value of longitudinal conductance corresponds to high permeability and hydraulic conductivity. The computed longitudinal conductance for the delineated aquifer unit is generally low, ranging between 0.0211 $\Omega^{-1}$ and 0.0612 $\Omega^{-1}$. This shows that the confined aquifer is characterized with high hydraulic parameters with high permeability and low clay volume. Thus, the aquifer unit is characterized with high hydraulic conductivity and high transmissivity as indicated by the computed longitudinal conductance.

Moreover, many hydrological studies have shown that the transverse resistance parameter can be used to effectively characterize aquifer properties. The transverse resistance of an aquifer increases with increasing transmissivity and yield. The distribution of the transverse resistance range between $2871.44 \Omega m^2$ and $10537.80 \Omega m^2$ in the area is presented in Table 4. High values of transverse resistance are generally observed, indicating high transmissivity and high yield of the aquifer units.

### Conclusion

Vertical electrical soundings have been used to delineate and characterize the aquifer unit as part of the preliminary investigations to assess groundwater resource potential and development at Covenant University, Ota, southwestern Nigeria. The geoelectrical parameters obtained were used to estimate the longitudinal conductance, and transverse resistance which are reflective of the hydraulic properties of the aquifer. The computed longitudinal conductance indicates high permeability and low clay volume in the aquifer unit and thus high hydraulic conductivity for the delineated aquifer unit. Similarly, the computed transverse resistance shows that the aquifer unit is characterized with high transmissivity and yield.
and yield. Thus, groundwater resource development and management can be effectively planned for.

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Related Journals Published by Academic Journals

■ African Journal of Pure and Applied Chemistry
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■ Journal of Oceanography and Marine Science
■ Journal of Environmental Chemistry and Ecotoxicology
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