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Original article

# The epipelic algal distribution of upper bonny estuary, Amadi-Ama creek, Niger delta in relation to sediment quality indices

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The epipelic algal distribution in Amadi-Ama creek with respect to the sediment parameters were investigated from January 2009-December 2010(2years).Epipelic algal and sediment samples were collected from six sampling stations and analysed following standard limnological method of APHA. A total of 9709count/ml and 9584count/ml epipelic algae consisting of five(5) taxa and 79 species were identified in 2009 and 2010 respectively(Table1).Epipelic algal abundance followed the order: Bacillariophyceae > Cyanophyceae > Chlorophyceae >Euglenophyceae> Chrysophyceae. Spatially, the highest abundance of epipelic algae was recorded in station 3 in 2009 (2189count/ml) and 2010 (2262count/ml) representing 22.55% and 22.96% respectively. The most dominant species of epipelic algae observed was *Cyclotella operculata.* Apart from temperature, other sediment parameters such as pH, conductivity, nitrate, sulphate, phosphate and chlorophyll'a' exhibited spatial difference significantly ($p<0.05$). The high phosphate levels above the USEPA permissible limit in natural aquatic bodies indicate organic pollution. The observed chlorophyll'a' level in this study placed Amadi-Ama creek between mesotrophic and euthrophic level of productivity.

## 1. Introduction

Epipelic algae are primary producers that dwell on the intertidal or subtidal mud surfaces of estuarine, coastal and marine environments (Chindah, 1998). The epipelic algae ranked almost the least in the trophic organization. They are capable of utilizing solar energy to synthesize complex and high energy food substances by combining simple and low density compound such as carbon dioxide and water. Algae belong to a highly diverse group of photoautotrophic organisms with chlorophyll'a' and unicellular reproductive structures, which are important for aquatic habitats (Chindah et al.,2004). These food materials are usually covered or inundated by water in streams, Creeks and lakes temporarily or permanently in sediments which are integral parts of the aquatic environments providing habitat, feeding and rearing areas for shellfish and other fauna.

Epipelic algae can perform a range of ecosystem functions, which include biostabilisation of sediments, regulation of benthic-pelagic nutrient cycling, and primary production. There is a growing need to understand their ecological role in light of current and future alterations in sediment loading resulting from land-use change and land management practices (Poulickova *et al*.,2008).Epipelic algae range from minute to multi-cellular forms of diatoms, epipelic, blue and green algae. Species types, biomass, community structure and abundance pattern depend on water body, nutrient status and seasonal changes.

Mucha et al.,(2003) described sediment as the ultimate sink of contaminants in the aquatic ecosystem and also added that the sediments of Bonny Estuary are contaminated and the contaminants consist of the organic and inorganic compounds released into the Estuary. Chindah et al.,(2004) and Izoafuo et al.,(2004) reported low nutrients in the sediments of the Bonny Estuary and ascribed it to high metabolic rate in the Niger Delta water bodies where nutrients released are easily used up and low retention and gentrification). The knowledge of the state of water quality of a water body in rivers and creeks due to changes produced by human activities is usually the first step in establishing an efficient water management system which is essential for the preservation of the ecosystem (Douterelo *et al.,* 2004). Investigation by Guy (1992) revealed that the abundance and distribution of aquatic organisms precisely plankton and epipelic algae is a function of the physicochemical variables or parameters of such a water body or aquatic ecosystem. Odum *et al*.,(1993) observed that species diversity tends to be low in physically controlled ecosystem (subjected to strong physicochemical limiting factors) and high in biologically controlled ecosystems. Storm water affect dispersal of sediment and that it is most pronounced when bottom currents exceed level necessary to erode sediment and fauna (Powell and Chindah, 1990). Studies have showed that there were good correlations between epipelic algal biomass and standing crop and some of the nutrient parameters especially nitrate-nitrogen and phosphate in the various areas of Niger Delta waters studied (Chindah, 1998).

At present, there are no sufficient reports on the epipelic algal community of Amadi Ama creek in terms of distribution and abundance. Therefore, the aim of this study was to investigate the epipelic algal distribution and abundance with respect to the environmental parameters.

## 2. Materials and methods

### 2.1. Study area

The Amadi-Ama creek is one of the tributories of the upper Bonny Estuary, brackish and tidal in nature with fresh waters intrusion from the surrounding inland waters and flood during the wet season. The Bonny River Estuary lies on the South-Easthern edge of the Niger Delta between longitudes $6^o$58'and $7^o$14'East and latitudes $4^0$19' and $4^0$34'North with an estimated area of 206km$^2$ and extends 7km offshore to a depth of about 7.5metres (Scott, 1966,). Amadi-Ama Creek is located in Port Harcourt Local Government Area of Rivers State and lies between longitude $5^0$ 60'E-$6^0$ 60'E and latitude $6^0$ 06'N-6 07'(Fig.1).Like all parts of south-south Nigeria, the Amadi-Ama creek is exposed to two distinct seasons which include the wet seasons(May-October and the dry season(November-March). The creek deposits are varied which are reflected in the nature and the distribution pattern of the vegetation in the area. The creek is subject to tidal influence. Water flows in one direction rapidly during the flood period but slightly reversed at the peak of the dry season due to the rising tide.

### 2.2. Sampling stations

The six sampling stations chosen along the creek course were at least 500m apart. The stations chosen include Station 1:((Amadi), Station 2 (Nkpogu), Station 3(Oginigba), Station 4(Woji), Station 5(Azubie), Station 6(Abuloma Jetty)(Fig.1).The stations were established through a reconnaissance survey undertaken using boat from the eastern by-pass through the Amadi axis and and on foot along the creek banks from the Rumukalagbo to the Nkpogu axis through Woji to Abuloma jetty.

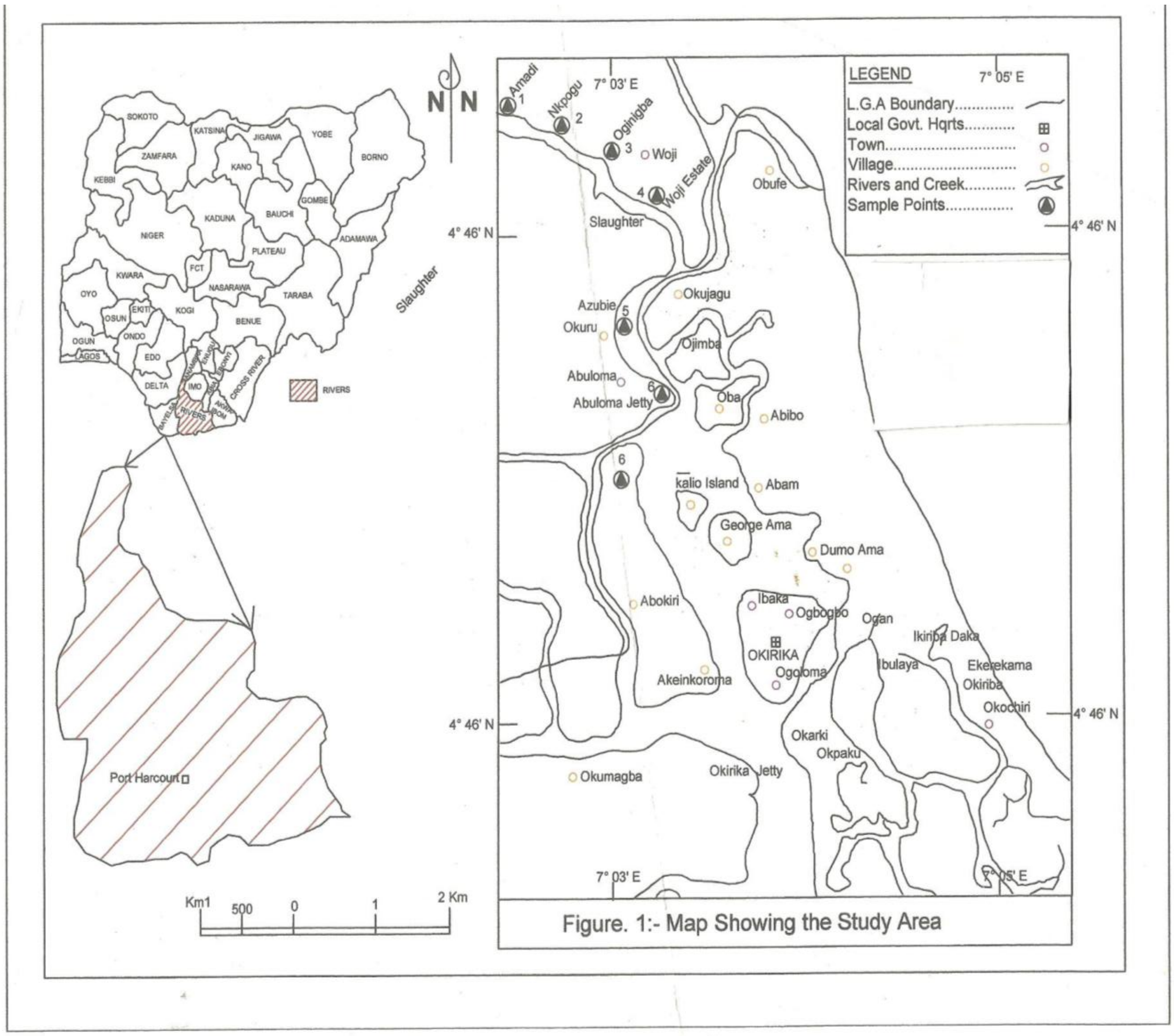


**Fig. 1.** Map showing the study area.

### 2.3. Sample collection and analysis

The epipelic algae samples were collected with a 2x2cm quadrat at six (6) random points at 1meter interval. These samples were also used for standing crop and biomass (pigment) analysis. Each quadrat was carefully scrapped with a sharp scalpel to a depth of 0.2cm and sediment including the associated algae from the 6 quadrat composited to represent a sample and emptied into sampling bottles containing 4% formalin each. Samples were placed upright in a wooden track and stored in an ice-chest (at temperature below $5^0C$) prior to analysis in the laboratory. Epipelic algal identification and enumeration were carried out in the laboratory under a binocular compound microscope with magnification, 400 x 40 and modified Standard Methods (APHA 1998) using identification key.

The sediment samples were collected with Beckmans grab monthly to determine sediment parameters during the low tides. The collected samples were then transferred to already labeled water proof bags and taken to the laboratory where they were air dried under a room temperature and kept for further analysis. Samples for chlorophyll'a,' and other parameters were analysed following standard methods (APHA, 1998).

### 2.4. Calculation

The abundance of epipelic algae was calculated counts/ml of the original sample using the equation modified by Boyd (1981):

$$D = \frac{T\ (1000 \times \text{volume of concentration} \times \text{Volume of concentrate}}{AN \times \quad \text{volume of sample}}$$

Where:

D= Density of plankton (1nd/m1)

T = Total number of plankters counted

A = Area of grid in $mm^2$

N = Number of grids employed

1000 = Area of counting chamber in $mm^2$ (Boyd, 1981).

### 2.5. Statistical analysis

Data obtained for epipelic algae and sediment parameters were subjected to analysis of variance (ANOVA), Duncan multiple range test (DMR) and pearson correlation coefficient for analysis using SAS (2003) and Microsoft Excel (2003) packages.

## 4. Results and discussion

A total of 9709count/ml and 9584count/ml epipelic algae consisting of the five(5) taxa, Bacillariophyceae, Chlorophyceae, Cyanophyceae, Chrysophyceae and Euglenophyceae and 79 species were identified in 2009 and 2010 respectively(Table1).Epipelic algal abundance followed the order: Bacillariophyceae > Cyanophyceae > Chlorophyceae> Euglenophyceae> Chrysophyceae. Epipelic algae perform a range of ecosystem functions, which include biostabilisation of sediments, regulation of benthic-pelagic nutrient cycling, and primary production.There is a growing need to understand their ecological role in light of current and future alterations in sediment loading resulting from land-use change and land management practices (Poulickova *et al*. 2008). These species number observed in this study is low compared to the 126 species reported in the New Calabar/ Bonny River by Chindah (1998), 129 algae species by Davies (2009) in Okpoka creek, and the 110 species recorded by Chindah et al.,(1999) in the upper reaches of New Calabar River. Guzkowska and Gasse (1990) reported that Bacillariophyceae presence in an area could be an indication of pollution. Frankorich et al (2006) used the distribution of algae precisely Bacillariophyceae to reflect the average biological condition of water bodies. The dominance of Bacillariophyceae in Amadi-Ama creek in this study suggests that Amadi –Ama creek is stressed or polluted. In this study, it was observed that the most dominant species of epipelic algae is *Cyclotella operculata* followed by C. *comta, C.glomerata, Euglenaacus and Anabaaena flos-aqua*. This observation is contrary to the observations of Chindah (1998) in Bonny /New Calabar River, Tiseer et al (2008), in Samara stream (zaria) which could be attributed to difference in environmental factors such as influx of anthropogenic wastes, type and nature of sediments and difference in physicochemical parameters of the aquatic ecosystem.

**Table 1a**
Epipelic Algal Species Abundance and Composition in the Study Area (Jan 2009-Dec 2010).

| S/N | Bacillariophyceae | Total 2009 | % | Total 2010 | % |
|---|---|---|---|---|---|
| 1. | *Amphipropra Ornata* | 111 | 1.14 | 108 | 1.10 |
| 2. | *Asterinella Formosa* | 104 | 1.07 | 97 | 0.98 |
| 3. | *Achnanthes gracilina* | 114 | 1.17 | 91 | 0.92 |
| 4. | *Cyclotella Antigua* | 99 | 1.02 | 100 | 1.01 |
| 5. | *C. cumta* | 828 | 8.53 | 692 | 7.02 |
| 6. | *C. glomerata* | 638 | 6.57 | 893 | 9.06 |
| 7. | *C. operculata* | 1319 | 13.59 | 1250 | 12.69 |
| 8. | *C. Striata* | 131 | 1.35 | 102 | 1.04 |
| 9. | *Gmbella Affinis* | 118 | 1.22 | 103 | 1.05 |
| 10 | *C. Species* | 110 | 1.13 | 85 | 0.86 |
| 11 | *Diatoma species* | 101 | 1.04 | 102 | 1.04 |
| 12 | *D. Elongatum* | 104 | 1.07 | 104 | 1.06 |
| 13 | *Diploneis Sp.* | 107 | 1.10 | 99 | 1.00 |
| 14 | *Eunotia tenella* | 114 | 1.17 | 94 | 0.95 |
| 15 | *E. fallax* | 102 | 1.05 | 99 | 1.00 |
| 16 | *Fragilaria internizula* | 112 | 1.15 | 97 | 0.98 |
| 17 | *Frustulia rhombodies* | 105 | 1.08 | 90 | 0.91 |
| 18 | *Gomphonitzschia ungeri* | 90 | 0.93 | 97 | 0.98 |
| 19 | *Gyrpsigma attenuatum* | 102 | 1.05 | 86 | 0.87 |
| 20 | *G. spenceri* | 99 | 1.02 | 104 | 1.06 |
| 21 | *Himidisius species* | 114 | 1.17 | 100 | 1.01 |
| 22 | *Melosira moniliformis* | 119 | 1.23 | 102 | 1.04 |
| 23 | *Navicula bacillum* | 102 | 1.05 | 98 | 0.99 |
| 24 | *N. cuspidata* | 109 | 1.12 | 79 | 0.80 |
| 25 | *N. Cuspidata* | 96 | 0.99 | 85 | 0.86 |
| 26 | *N. minima* | 100 | 1.03 | 96 | 0.97 |
| 27 | *Nitzschia paradox* | 103 | 1.06 | 102 | 1.04 |
| 28 | *N. gracillis* | 95 | 0.98 | 90 | 0.91 |
| 29 | *N. Ricta hantsch* | 106 | 1.09 | 88 | 0.89 |
| 30 | *Pinnulariamacilenta* | 102 | 1.05 | 90 | 0.91 |
| 31 | *P. Interrupta* | 93 | 0.96 | 93 | 0.94 |
| 32 | *Snedra ulna* | 88 | 0.91 | 119 | 1.21 |
| 33 | *S.acus* | 95 | 0.98 | 100 | 1.01 |
| 34 | *Thalassiosira species* | 88 | 0.91 | 102 | 1.04 |
| | Total | **5837** | | **5268** | |
| | % | 60.12 | | 54.97 | |

| S/N | Chlorophyceae | Total 2009 | % | Total 2010 | % |
|---|---|---|---|---|---|
| 35. | *Actinastrum species* | 102 | 1.05 | 132 | 1.34 |
| 36. | *Akinstrodemus falcatus* | 92 | 0.95 | 127 | 1.29 |
| 37 . | *Cosstrum microporun Nag* | 92 | 0.95 | 127 | 1.29 |
| 38. | *Coestrum reticulalum D* | 92 | 0.95 | 121 | 1.23 |
| 39. | *Cosmarium conatum* | 86 | 0.89 | 126 | 1.28 |

| | | | | | |
|---|---|---|---|---|---|
| 40. | *Cladophora species* | 97 | 1.00 | 124 | 1.26 |
| 41. | *Closterium juncidiim ralf* | 94 | 0.97 | 96 | 0.97 |
| 41 | *Closterium lancelatum* | 93 | 0.96 | 119 | 1.21 |
| 43. | *Closterium gracille* | 86 | 0.89 | 121 | 1.23 |
| 44. | *C. Closteridium* | 89 | 0.92 | 126 | 1.28 |
| 45. | *Drapamaldia species* | 89 | 0.92 | 111 | 1.13 |
| 46. | *Euastrum elegans* | 104 | 1.07 | 108 | 1.10 |
| 47. | *Enteromorpha interstinalis* | 96 | 0.99 | 105 | 1.07 |
| 48. | *Staurastrum gracille* | 94 | 0.97 | 107 | 1.09 |
| 49. | *S. brachiatum* | 96 | 0.99 | 108 | 1.10 |
| | *Total* | 1442 | | 1742 | 17.68 |
| | *%* | 14.38 | | 17.68 | |
| | *Cyanophyceae* | | | | |
| 50. | *Anabaena flos-agua* | 116 | 1.19 | 137 | 1.39 |
| 51. | *A. species* | 106 | 1.09 | 132 | 1.34 |
| 52. | *Aphanizomenon fins aquae* | 101 | 1.04 | 102 | 1.04 |
| 53. | *Dactylococcopsis Rhapoides kutz* | 76 | 0.78 | 97 | 0.98 |
| 54. | *Gloeotrichia echinulula* | 92 | 0.95 | 95 | 0.96 |
| 55. | *Merismopedia elegans* | 85 | 0.88 | 74 | 0.95 |
| 56. | *M. punctuata* | 81 | 0.83 | 98 | 0.99 |
| 57. | *Microcystis aetuginesa flos-aquae* | 84 | 0.82 | 117 | 1.19 |
| 58 | *M. aeruginesa kutz* | 84 | 0.87 | 97 | 0.98 |
| 59. | *M. pulverea* | 84 | 0.87 | 95 | 0.96 |
| 60 | *Phormedium tenue* | 97 | 1.00 | 97 | 0.98 |
| 61. | *P. fragile* | 70 | 0.72 | 106 | 1.08 |
| 62. | *P. ambigum* | 72 | 0.74 | 97 | 0.98 |
| 63. | *Oscillatoria limosa* | 72 | 0.74 | 86 | 0.87 |
| 64. | *O. brevis* | 70 | 0.72 | 89 | 0.90 |
| 65. | *O.tenuis* | 76 | 0.78 | 94 | 0.95 |
| 66. | *O.formosa* | 86 | 0.89 | 84 | 0.85 |
| | Total | 1440 | | 1674 | |
| | % | 14.83 | | 16.99 | |
| S/N | Chrysophyceae | Total 2009 | % | Total 2010 | % |
| 67 | *Chromulina Ovalis* | 9 | 0.09 | 40 | 0.41 |
| 68 | *Uroglenopsis species* | 85 | 0.88 | 72 | 0.73 |
| | Total | 94 | | 112 | |
| | % | 0.97 | | 1.14 | |
| S/N | Euglenophyceae | Total 2009 | % | Total 2010 | % |
| 69. | *Eugelna acus* | 90 | 0.93 | 104 | 1.06 |
| 70 | *E. granulate* | 80 | 0.82 | 96 | 0.97 |
| 71 | *E. Oxyuris var* | 76 | 0.78 | 82 | 0.83 |
| 72 | *Lopicindis capito* | 77 | 0.79 | 87 | 0.88 |
| 73 | *Phacus acuminatus* | 89 | 0.92 | 94 | 0.95 |
| 74. | *P. undulates* | 81 | 0.83 | 93 | 0.94 |
| 75. | *Strombomonasa cacuminatumi* | 92 | 0.95 | 96 | 0.97 |
| 76. | *Tracehlomonas Africana* | 90 | 0.93 | 90 | 0.91 |
| 77. | *T. hispida stein* | 78 | 0.80 | 88 | 0.89 |
| 78. | *T. plantonica Var.* | 83 | 0.85 | 102 | 1.04 |
| 79. | *T. volvocina Var.* | 83 | 0.85 | 85 | 0.86 |
| | Total | 896 | | 1058 | |
| | % | 9.23 | | 10.74 | |
| | Grand Total | 9709 | | 9584 | |
| | (%) | 100 | | 100 | |

**Table 1b**
Relative Abundance Of Epipelic Algae in the Area (Jan 2009- Dec.2010)

| | Number of species per year | | | |
|---|---|---|---|---|
| **CLASS** | **2009** | **2010** | **TOTAL** | **%** |
| Bacillariophyceae | 34 | 34 | 68 | 43.04 |
| Chlorophyceae | 15 | 15 | 30 | 18.99 |
| Cyanophyceae | 17 | 17 | 34 | 21.52 |
| Chrysophyceae | 2 | 2 | 4 | 2.53 |
| Euglenophyceae | 11 | 11 | 22 | 13.92 |
| Total | 79 | 79 | 158 | 100.00 |

Spatially, the highest abundance of epipelic algae was observed in station 3 in both 2009 (2189count/ml) and 2010 (2262count/ml) representing 22.55% and 22.96% respectively (Table 2). The observed high abundance of epipelic algae in Station 3 could be attributed to the accumulated wastes like cow dung and poultry droppings constantly washed into the creek at this station and increased chlorophyll'a'. These high organic materials enhance phytoplankton growth (Lowkman and Jones, 1999). The low abundance of epipelic algae observed in station 6 could be attributed to decreased chlorophyll'a' level and other parameters which could be unfavorable in the station.

**Table 2a**
Spatial Mean Values of Epipelic Algae in the Area( January-December(2009)

| Station | Bacillar-iophycea | Chlorophyceae | Cyanophyceae | Eugenophyceae | Chrysophyceae | Total | % |
|---|---|---|---|---|---|---|---|
| 1 | 1166 | 309 | 299 | 183 | 20 | 1977 | 20.36 |
| 2 | 1042 | 259 | 253 | 156 | 22 | 1732 | 17.84 |
| 3 | 1309 | 317 | 348 | 200 | 15 | 2189 | 22.55 |
| 4 | 960 | 196 | 201 | 140 | 13 | 1510 | 15.55 |
| 5 | 729 | 189 | 191 | 118 | 9 | 1236 | 12.73 |
| 6 | 631 | 172 | 148 | 99 | 15 | 1059 | 10.91 |
| TOTAL | 5837 | 1442 | 1440 | 896 | 94 | 9709 | 100.00 |

**Table 2b**
Spatial Mean Values of Epipelic Algae in the Area( January---December(2010)

| Station | Bacillar-iophycea | Chlorophyceae | Cyanophyceae | Eugenophyceae | Chrysophyceae | Total | % |
|---|---|---|---|---|---|---|---|
| 1 | 962 | 351 | 361 | 217 | 30 | 1921 | 19.5 |
| 2 | 916 | 313 | 344 | 200 | 19 | 1792 | 18.19 |
| 3 | 1288 | 399 | 334 | 221 | 20 | 2262 | 22.96 |
| 4 | 702 | 219 | 244 | 140 | 16 | 1321 | 13.41 |
| 5 | 708 | 234 | 202 | 152 | 12 | 1308 | 13.27 |
| 6 | 692 | 226 | 189 | 128 | 15 | 1250 | 12.69 |
| TOTAL | 5268 | 1742 | 1674 | 1058 | 112 | 9854 | 100.00 |

Table 3 showed the spatial mean values of sediment parameters in the study area. Temperature showed no spatial significant difference which is typical of tropical waters. The highest pH values were recorded in stations 4(4.43±1.09Ntu) and 1(4.27±1.13Ntu) in 2009 and 2010 respectively with significant difference. This could be due to difference in the level of decomposition in the stations. The spatial significant difference exhibited by conductivity could be attributed to difference in influx of allochotonous and inorganic wastes introduced into the creek. The highest nitrate values were recorded in station 1 in 2009(1.63±0.66m/l) and 2010(1.48±0.60mg/l) respectively. Sulphate values also showed similar level of significant difference with the highest value observed in station 3. The observed low concentration has also been observed by Chindah et al (1998) in the New Calabar River, Chindah and Onyebuchi (2003) in a Swamp forest Stream in the lower Niger Delta and Chindah (2004) in a Tropical Estuary in Niger Delta. The high phosphate levels above the USEPA permissible limit in natural aquatic bodies indicate organic pollution from anthropogenic sources (USEPA, 2002). Chlorophyll 'a' concentration in station 3 appeared highest in both first and second years of study. This could be caused by increased nutrient load in the station noted by Chindah(2004) in Bonny River system. Also, the presence of the highest epipelic algal abundance in station 3 than any other station in this study is indicative of a stressed environment.

**Table3a**

Spatial Values of Sediment Parameters in Amadi-Ama Creek(Jan-Dec.2009)

| PARAM/STN | 1 | 2 | 3 | 4 | 5 | 66 |
|---|---|---|---|---|---|---|
| Temperature | 29.35±0.81a | 29.23±1.02a | 29.12±1.09a | 28.87±1.18a | 29.07±0.98a | 29.45±0.45a |
| | 28.00-30.20 | 27.80-30.50 | 27.20-30.20 | 27.24-30.30 | 27.60-30.10 | 28.44-30.40 |
| PH | 2.81±0.41c | 3.78±0.47ab | 4.22±0.87ab | 3.99±0.55ab | 4.43±1.09a | 3.36±0.49c |
| | 2.00-3.30 | 3.10-4.30 | 3.10-6.10 | 3.10-5.00 | 3.20-6.40 | 2.60-4.20 |
| CONDUCT | 4116.67±1780c | 4416.67±1674b | 4516.7±17ab | 5424±1144a | 4708.3±16ab | 4887.5±12ab |
| | 1000-7200 | 1200-7500 | 1500-6900 | 3700-7000 | 2000-7000 | 3250-6900 |
| NITRATE | 1.63±0.66a | 1.17±0.38b | 0.90±0.27b | 0.99±0.26B | 0.87±0.30b | 0.99±0.17b |
| | 0.90-2.80 | 0.80-1.80 | 0.50-1.60 | 0.80-1.70 | 0.60-1.66 | 0.80-1.40 |
| SULPHATE | 245.17±227.33b | 280.92±145a | 310.3±137a | 236.7±65b | 267.92±15b | 288.37±14a |
| | 78.0-920 | 96.0-700 | 180.5-720 | 180-400 | 30.0-600 | 190.0-619 |
| PHOSPHATE | 1.65±0.19a | 1.56±0.29ab | 1.68±0.25a | 1.43±0.26b | 1.44±0.12b | 1.65±0.12a |
| $PO_4^{2-}$ | 1.30-1.95 | 1.20-1.80 | 1.3-1.95 | 0.90-1.80 | 1.20-1.60 | 1.40-1.80 |
| CHL'a' | 2.22±1.26b | 1.87±1.22b | 3.50±0.49a | 1.97±1.14b | 1.93±0.85b | 1.68±0.76b |
| | 0.00-3.26 | 0.00-3.90 | 2.5-4.10 | 0.00-3.40 | 0.0-3.00 | 0.0-2.80 |

**Table3b**

Spatial Mean Values of Sediment Parameters in Amadi-Ama Creek(Jan-Dec2010)

| PARAM/STN. | 1 | 2 | 3 | 4 | 5 6 | 6 |
|---|---|---|---|---|---|---|
| Temperature | 28.75±1.67a | 28.90±1.56a | 29.0±1.43a | 28.91±1.56a | 28.73±1.37a | 28.93±1.81a |
| | 26.0-30.10 | 26.40-30.30 | 26.90-30.10 | 26.40-30.40 | 26.60-30.10 | 26.0-31.10 |
| PH | 4.27±1.13a | 4.01±0.83b | 3.78±0.84ab | 3.96±0.66a | 4.03±1.04b | 3.24±0.51a |
| | 2.60-6.00 | 3.10-5.33 | 2.60-5,00 | 2.50-4.90 | 2.10-5.30 | 2.10-4.20 |
| CONDUCT | 4716.7±2067b | 5275±1553a | 5460.8±1199a | 5020.8±1619a | 5175±1799a | 4595.8±187b |
| | 3000-8200 | 3400-8000 | 3900-7000 | 3100-7200 | 3200-8200 | 1000-8400 |
| NITRATE | 1.48±0.60a | 1.01±0.40b | 0.79±0.26b | 0.83±0.29b | 0.73±0.17b | 1.00±0.57b |
| | 0.70-2.20 | 0.60-1.90 | 0.30-1.30 | 0.50-1.50 | 0.50-1.00 | 0.40-2.50 |
| SULPHATE | 225.41±238c | 270.88±14b | 297.9±141.2a | 238.05±77.36c | 290.96±122a | 286.3±15b |
| | 79.20-950 | 90.0-680 | 195-730 | 160.5-430 | 201-580 | 150-600.1 |
| PHOSPHATE | 1.64±0.21ab | 1.54±0.10b | 1.60±0.21ab | 1.50±0.21b | 1.49±0.17b | 1.74±0.14a |
| | 1.30-1.90 | 1.40-1.70 | 1.40-2.10 | 1.10-1.85 | 1.20-1.80 | 1.45-1.94 |
| CHL'a' | 5.25±0.57b | 5.24±0.52b | 6.15±0.24a | 4.93±0.61bc | 4.74±0.49c | 4.23±0.73d |
| | 3.90-6.10 | 4.0-6.00 | 5.90-6.50 | 4.00-5.90 | 3.90-5.40 | 2.90-5.20 |

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