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# Climate Change Resilience Strategies in Trans Amadi Industrial Area Port Harcourt, Rivers State, Nigeria

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***Authors' contributions***

*This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.*

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## ABSTRACT

This study assessed climate change adaptation, mitigation and resilience strategies in the Trans Amadi Industrial area of Port Harcourt, Rivers State, Nigeria. The study utilised satellite image and field surveys to obtain information. An inventory of tree species used in urban greening activities was conducted. Carbon dioxide levels in the area were measured using the Aeroqual 500 series air pollution meter while Meteorological data from 2006 to 2015 was obtained from the Nigeria Meteorological Agency (NIMET) and complemented with field measurements. Results from the study indicated that there were increased carbon dioxide and temperature levels in Trans Amadi from 363.3 ppm to 369 ppm and from 28.3°C to 30.8°C respectively. 55.4% of respondents have resilience strategies in place however 51.5% of these strategies were not sufficient. A total of 74 different species of trees distributed in 29 unique families were inventoried. The findings discussed were in line with global concerns and efforts regarding climate change and global warming measures.

*Keywords: Climate change; adaptation; urban greening; mitigation; resilience; Trans Amadi.*

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## 1. INTRODUCTION

Climate is generally defined as the weather condition prevailing in an area over a long period. The Intergovernmental panel on climate change (IPCC, 2007) defines climate change as any change in climate over time, whether due to natural variability or as a result of anthropogenic activities. History shows that that the environment is always changing, however, in the last 200 years, observations show that it is changing at a faster rate. Reports by the Department of Ecology, the State of Washington (2017) show that rising global Carbon dioxide ($CO_2$) levels and other heat-trapping gases in the atmosphere are warming the surface of the earth resulting in rising sea levels, melting ice caps, flooding, droughts and wildfires. The increase in the concentration of these heat-trapping gases such as Methane ($CH_4$), Nitrous Oxide ($NO_2$), Carbon dioxide ($CO_2$) and Water Vapour ($H_2O$) by anthropogenic activities such as oil and gas exploration are a serious cause for concern. Of these gases, the effect of $CO_2$ emission stands out because it lasts much longer in the atmosphere. Secondly, the overall amount of $CH_4$ and $NO_x$ released by human activities are in small quantities when compared to $CO_2$ while $H_2O$ persist only for a few days in the atmosphere.

Rivers State, the fourth highest oil producing state in Nigeria is also experiencing the effect of this global phenomenon and must take measures to reduce these impacts. These measures include mitigation, adaptation or resilience strategies. Trans Amadi Industrial Area, the centre of oil and gas activities in the State, has experienced its share of climate change impacts [1]. This is expected because the area hosts multi-national oil and gas companies, banks and other financial institutions, manufacturing companies, construction and other allied services companies with significant energy consumption and high industrial emissions, which exacerbates the impact.

Econo-Climate is a concept used to describe the relationship between climate change and the economy. It is a global concept that applies in Port Harcourt, Nigeria. According to Efe and Weli [2], the weather in the area determines the price and the demand and supply of goods. Considering the economic importance of Trans Amadi Industrial Area and the role it plays in the employment of the youth population and consequently in the safety and security of the city, it is very important to ascertain the climate change resilience strategies in the area. Failure to do so would leave the livelihood of at least 20% of the State to chance. This would lead to economic suicide not just for the State Government but its citizens as a result of the collateral impacts of climate change. Adaptation and Resilience strategies are the key to economic survival.

This study focused on climate change resilience strategies in the Trans Amadi Industrial Area, Port Harcourt, Rivers State, Nigeria.

## 2. MATERIALS AND METHODS

### 2.1 Description of the Study Area

The Trans Amadi Industrial Area, Port Harcourt, Rivers State, Nigeria is the hub of the Nigerian Oil and Gas Industry. The study area lies between latitudes 4'48'00'' N to 4'49'30''N, and longitudes 7'00 45'E' to 7'03'45'' E, (Fig. 2.1). It is densely populated with companies and very few residential areas. It plays host to several International oil companies (IOC) including Total Exploration and Production, Halliburton Energy Services Ltd, Schlumberger Nig. Ltd, banks and financial institutions. It also hosts manufacturing companies, including Nigerian Bottling Company; makers of Coca Cola, PABOD Breweries; makers of Grand Lager, Hero Lager and Grand Malt, construction companies such as O.K. Isokariari, etc. The Rivers State Zoological Gardens, an abattoir and a Government technical college are also part of the major land marks of the area. Communities such as Oginigba, Azubie, Rainbow town, some sections of Elekahia and Nkpogu are also part of the Trans Amadi area.

Trans Amadi enjoys a tropical monsoon climate. It is characterized by heavy rainfall between 2000 mm to 2500 mm annual rainfall most of which falls between the months of April and October. The area has high temperatures throughout the year, as well as constant high humidity [1]. The average elevation ranges between 20 m and 30 m above sea level. Vegetation found in the study area includes thick mangrove forests and light rain forests.


**Fig. 2.1. Map of study area**

Five major roads in the area, and the Rivers State Zoological garden were chosen for field survey sites (Fig. 2.2).

Road 1. Weja road from Elekahia /Nkpogu junction, to Zoo/Slaughter junction, length 3.3 km
Road 2. Wobo House Junction through Ordinance junction, to Sasun Hotel /Peter Odili roundabout, length 2.4 km
Road 3. Wobo House Junction to Pabob Breweries/ Oginigba Junction, to Zoo/Slaughter roundabout, length 4.8 km
Road 4. Peter Odili road from Amadi ama roundabout, to Okuru/ JDP Junction, length 2.7 km
Road 5. Rivoc road

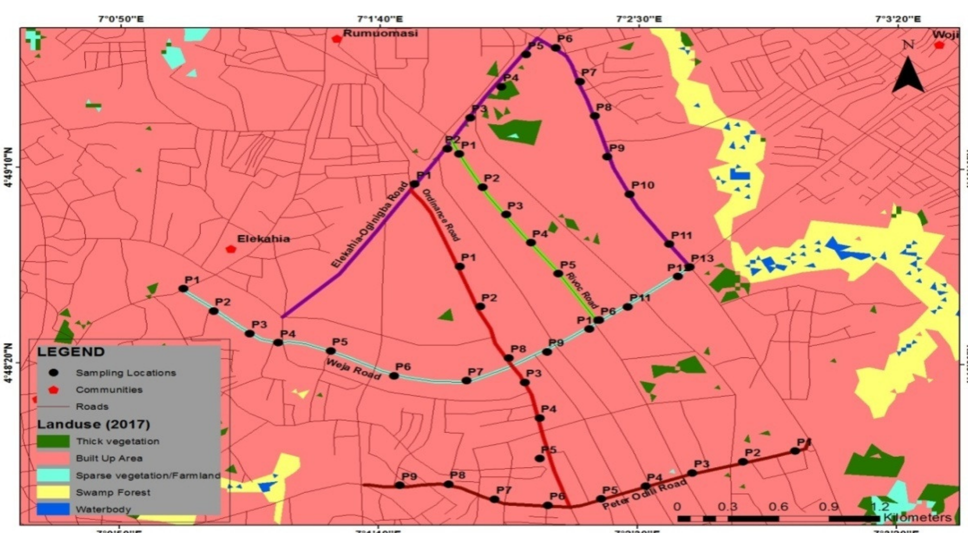


**Fig. 2.2. Sampling locations in the study area**

### 2.2 Remote Sensing and Satellite Image Acquisition

Landsat images of January 2016 covering the study area, was obtained from the United States Geological Survey (USGS) website, through its Earth resources observation and science centre. At this time of the year, the cloud cover effect is usually at its lowest. The downloaded image was imported into ArcGIS10.5, and this was used to generate the different maps used for the study.

### 2.3 Field Sampling

#### 2.3.1 Tree species assessment

Five major roads in the study area were selected using a purposeful sampling technique, a non-probabilistic approach. Quadrants of 100 m x 30 m were plotted at 200 m intervals and all urban greening tree samples found within the plot were sampled. However, in the zoological garden, all the tree species were sampled. Coordinates of all sample locations were taken using a handheld Garmin model GPS receiver. The trees were assessed using the systematic random sampling technique along five major transects. This approach achieved an even distribution and reproducibility of results. It is a modified random sampling technique that has an added advantage of simplicity. Some species were identified on the field while some leaves and trees were collected, stored in paper bags, and labeled for identification. The names of each species, the number of each species, and the geographic coordinates at the collection point were part of the data collected. The family names for each species were obtained from reference books.

### 2.4 Sampling of Carbon Dioxide Emission and Meteorological Data

The Carbon dioxide ($CO_2$) concentrations and meteorological characteristics within the study Area were measured at eleven (11) stations in the upwind and downwind directions. Random selection approach was used. The measurements were taken for each of the parameters at approximately 20 minute interval for 6 hours at a distance of 1.5 m above ground level. The Aeroqual 500 series equipment that was used for the measurement of the gases was held at an arm's length from the body approximately 1.5 meters. It is a digital environmental monitor, with a non dispersive infra red (NDIR) sensor type. The range of measurement for the gaseous concentrations is five thousand (5000) parts per million (ppm), and the detection limit is twenty (20) ppm.

During the measurements, particular attention was given to the upwind and downwind directions since experience has shown that in general, pollutants are carried by the wind, mostly from the upward to the downwind direction. The wind direction and other meteorological characteristics of the area such as relative humidity and temperature were measured with a Met One weather station. Coordinates of all sample locations were taken using a handheld Garmin model GPS receiver.

Secondary data were obtained from the Nigeria meteorological agency (NIMET) records of rainfall and temperature of Port Harcourt from 2006-2015, while the unpublished works of Okpechi [3] field survey measurements of Carbon dioxide ($CO_2$) and temperature in the Trans Amadi industrial area, were also used. Purposeful sampling was used to determine the consideration of the absence or presence of trees.

## 3. RESULTS AND DISCUSSION

### 3.1 Plant Species Inventory

Species inventories in the area recorded a total of 74 different species distributed into 29 unique families (Table 3.1). The different roads had varying number of species. Road one had 69 species, road two, 63 species, road three, 72 species, road four, 63 and road five, 59 species. The Rivers State Zoological Garden had 24 species. The species diversity and evenness for roads one to five were also calculated. The total road length was 13.2 km and total number of road segments was forty four (44) while the Zoological garden was taken as one segment. The geographic coordinates of the sampling points are shown in Table 2.1.

The results showed that the Trans Amadi as an industrial area has a good road network and relative vegetation cover. The number of tree species varied from plot to plot and from road to road. Road three had the highest number of trees of 72 species. Most of these trees were planted between Wobo House junction and PABOD Breweries junction. Rivoc road had the lowest number of species (59). It is also the shortest of all the roads as well the most densely populated road of the five. These trees were

**Table 2.1 GPS points of sampled roads**

| Points | Name of Road/Landmark | Latitude (Northings –N ) | Longitude (Eastings –E ) |
|---|---|---|---|
| 1 | Weja by Nkpogu junction | 4.80932 | 7.01692 |
| 2 | St. Matthew Ang. Church | 4.80925 | 7.01898 |
| 3 | Fidelity Bank/The Promise fast food | 4.80767 | 7.02092 |
| 4 | Bewac Junction | 4.80701 | 7.02246 |
| 5 | Chicken Republic | 4.80644 | 7.02527 |
| 6 | Eastern Wrought Iron ltd. | 4.80469 | 7.02867 |
| 7 | Ricoh Trinicle/ First Bank | 4.80434 | 7.03255 |
| 8 | Ordinance road junction | 4.80597 | 7.03483 |
| 9 | Opp. Jubaili Engineering Ltd | 4.80641 | 7.03688 |
| 10 | Cummis West Africa Ltd | 4.80804 | 7.03914 |
| 11 | Stallion Motors | 4.80963 | 7.04121 |
| 12 | Weje road from Slaughter | 4.81178 | 7.04387 |
| 13 | Total Petrol Station | 4.81561 | 7.03098 |
| | **Road 3 Wobo House to Pabod Junction to Zoo/Slaughter round about** | | |
| 1 | Rivers State Gas Turbine | 4.81812 | 7.03022 |
| 2 | Rivoc | 4.82060 | 7.03163 |
| 3 | Redemption way Junction | 4.82284 | 7.03293 |
| 4 | Pabod Brewery | 4.82525 | 7.03437 |
| 5 | Pabod fence | 4.82754 | 7.03570 |
| 6 | Oginigba road | 4.82802 | 7.03727 |
| 7 | Eterna Filling station | 4.82563 | 7.03858 |
| 8 | West African Glass | 4.82318 | 7.03938 |
| 9 | Former Michelin Company | 4.82027 | 7.04007 |
| 10 | Zenith Bank | 4.81762 | 7.04128 |
| 11 | Coca Cola | 4.81408 | 7.04341 |
| | **Area 5 rivoc road** | | |
| 1 | Rivoc road | 4.82045 | 7.03213 |
| 2 | Rivoc road | 4.81811 | 7.03338 |
| 3 | Rivoc road | 4.81616 | 7.03465 |
| 4 | Isokari and Sons | 4.81416 | 7.03598 |
| 5 | Ponticell | 4.81196 | 7.03748 |
| 6 | Rivoc junction by Ecobank | 4.80867 | 7.03966 |
| **Road 2. WOBO house to Sasun hotel juction** | | | |
| 1 | Berger paints | 4.81247 | 7.03217 |
| 2 | Murphy Shipping and Commercial Services | 4.80962 | 7.03328 |
| 3 | Ordinance road junction | 4.80424 | 7.03568 |
| 4 | Vee-Hotels | 4.80171 | 7.03649 |
| 5 | NCCF Corpers Lodge | 4.79882 | 7.03649 |
| | **Road 4. peter odili by okuru juncion** | | |
| 1 | Peter Odili road | 4.79935 | 7.03719 |
| 2 | Oleum Filling station | 4.79864 | 7.04742 |
| 3 | Hago Heights building | 4.79782 | 7.04470 |
| 4 | Resto park Filling Station | 4.79687 | 7.04219 |
| 5 | Studio 10 Building/ Tehila Children Hospital | 4.79596 | 7.03980 |
| 6 | 4-Power Consortium | 4.79550 | 7.03695 |
| 7 | Everyday Supermarket | 4.79592 | 7.03409 |
| 8 | Salvation Min. Building | 4.79699 | 7.03162 |
| 9 | By Amadi Round about | 4.79689 | 7.02900 |
| 10 | Zoo Garden | 4.81276 | 7.04536 |

planted for the purpose of urban greening thereby protecting and preserving the environment. Scientists generally agree that plants absorb carbon dioxide and give out oxygen during photosynthesis. $CO_2$ is indeed the principal green house gas incriminated in global warming and climate change [4]. Therefore, tree planting has become a cost effective way of removing carbon dioxide from the atmosphere and reducing temperatures. Ayodele [5] also analysed this and recommends urban greening as a strategy which can keep the built environment cool, green and miti gate against further temperature increase. Mathey [6] agrees that trees play a key role in mitigating thermal load in urban areas and that species differ significantly in their ability to reduce air and surface temperatures, as well as to increase relative humidity. Trees showing both a high leaf-area density and a high rate of transpiration are more effective in cooling the air temperatures. It was thought that vegetation removes a quarter of the $CO_2$ generated by all human activities but a new study by Sun et al. [7] suggests a higher percentage. The appreciable vegetation cover in the area is believed to remove significant proportion of $CO_2$ thereby modulating the general climatic conditions. This position is supported by Sorensen [8], Westphal [9] and Ayodele [5]. Their studies showed that urban green spaces and infrastructure provide environmental benefits of climate regulation and ecosystem services provision, and even social and economic benefits, conferring a positive effect on health and healing times, supports development of children, increasing workers productivity, making cities safer and more desirable, and even increases the property values.

**Table 3.1. List of all the plant species identified in the study area**

| S/N | Specie name | Family | Common name |
|---|---|---|---|
| 1 | *Acoelorrhaphe wrightii* (Wendland) | Arecacea | Everglades palm |
| 2 | *Acalypha wilkesiana* (L) | Euphorbiaeceae | Bristly copperleaf |
| 3 | *Aframomum melegueta* (K.Schumann) | Zingiberaceae | Alligator pepper |
| 4 | *Albizia zygia* (P.Browne) | Fabaceae | Okra Tree |
| 5 | *Albizia ferruginea* (Guill and Perr) | Fabaceae | Okra Tree |
| 6 | *Albizia identifolia* (W.Wight) | Fabaceae | Okra Tree |
| 7 | *Alchornea cordofolia* (Schumach andThonn) | Euphobiaceae | Christmas Bush |
| 8 | *Amorphophallus konjac* (A.Dearden and A. Vogel | Araceae | Corpse flower |
| 9 | *Annona muricata* (Alstonia Scholaris) | Annonaceae | Sour sop |
| 10 | *Anthonotha macrohylla* (D.C Singh) | Fabaceae | African nut |
| 11 | *Bambosa vulgaris* (J.C Wendl) | Poaceae | Indian bamboo |
| 12 | *Blighiawel witschii* (L) | Sapindaceae | Ackee |
| 13 | *Caesal piniapul cherima* (L) | Fabaceae | Peacock flower |
| 14 | *Carica papaya* (Lanzarra P. and Pizzetti) | Caricaceae | Pawpaw |
| 15 | *Caryo tamono stachya* (L) | Aracaceae | Fishtail palm |
| 16 | *Millicia excels* (Thomas D.G) | Moraceae | Iroko Tree |
| 17 | *Chrysophyll malbidium* (L) | Anacardiaceae | African star apple |
| 18 | *Citrus Sinensis* (Pinus Strobus) | Mytaceae | Orange |
| 19 | *Cocosnu cifera* (Lanzarra P. and Pizzetti) | Aracea | Coconut |
| 20 | *Codiaeum variegatum* (Gullen and Cook) | Euphorbiaceae | Joseph's coat |
| 21 | *Cola pachycarpa* (K.Schumann) | Sterculiaceae | Monkey colanut |
| 22 | *Cordiase bestena* (L) | Boraginaceae | Sicote or Ginger tree |
| 23 | *Dacryodes edulis* (Anthony Joseph R.) | Anacardiaceae | Bush Butter, Butter fruit, African plum, bush pear |
| 24 | *Delonix regia* (Bojer Hooker) | Fabaceae | Royal Poinciana/flamboyant |
| 25 | *Dracaena arborea* (Ferreyra, rius and Casati) | Asparagaceae | Sander's Dracaena |
| 26 | *Elaeis guineensis* (Lanzarra P. and Pizzetti) | Araceae | Oil palm |
| 27 | *Eugenia caryophyllata* (J.W Dawson) | Mytaceae | Pitanga,Suriname cherry, Brazilian cherry |
| 28 | *Euphorbia tirucalli* (L) | Euphobiaceae | Indian tree spurge |

| S/N | Specie name | Family | Common name |
|---|---|---|---|
| 29 | *Ficus mucuso* (Ficus S.A and Gullick R.M) | Moraceae | Fig |
| 30 | *Ficuso vata* (John A. Strijk) | Moraceae | Fig |
| 31 | *Ficus benjamina* (L) | Moraceae | Weeping fig |
| 32 | *Ficus exesparata* (F.Loureiro) | Moracceae | Forest Sandpaper fig |
| 33 | *Ficus retusa* (W.C Shieh J.C Liao) | Moraceae | Cuba-Laurel |
| 34 | *Gliricidia sepium* (Kunth walp) | Fabaceae | Nicaraguancocoa shade |
| 35 | *Gmelina arborea* (J.T Thompson) | Laminae | Gmelina Tree |
| 36 | *Hevea brazilenius* (Willd, A.Juss) | Euphorbiaceae | Rubber tree |
| 37 | *Hibiscusrosa-sinesis* (Linnaeus) | Malvaceae | Hibiscus |
| 38 | *Holarrhena floribunda* (G.Don) | Apocyanaceae | Hollarrhena tree |
| 39 | *Hura crepitans* (L) | Euphobiasceae | Sandbox tree |
| 40 | *Irvingia gabonensis* (Aubry-Lecomte, O'Rorke) | Irvingiaceae | Bush mango |
| 41 | *Ixora coccinea* (P.Chomnunti) | Rubiaceae | Ixora |
| 42 | *Lantana camara* (Lantana Camara) | Lamiaceae | Lantana |
| 43 | *Luecaenaleu cocephala* (Lamarck) | Fabaceae | Lead tree, Coffee bush, hedge acacia |
| 44 | *Mangifera indica* (Linnaeus) | Anacardiaceae | Mango |
| 45 | *Millettia thonningii* (Schum & Thon) | Fabaceae | |
| 46 | *Moringa oleifera* (L) | Anacardiaceae | Moringa |
| 47 | *Murraya panniculata* (Linnaeus) | Rutaceae | Mock lime |
| 48 | *Musa paradesica* (L) | Araceae | Plantain |
| 49 | *Musa sepiatum* (L) | Araceae | Banana |
| 50 | *Musanga cecropioides* (L) | Urticaceae | Umbrella tree |
| 51 | *Mussaenda erythrophylla* (L) | Rubiaceae | Ashanti blood or red flag bush |
| 52 | *Myrianthu sarboreus* (Ojinnaka) | Urtcaceae | Monkey fruit |
| 53 | *Napoleona imperialis* (L) | Lecythidaeceae | Napoleon's hat |
| 54 | *New boudialaevis* (L) | Bignoniaceae | Boundary tree |
| 55 | *Pentha cletramacro phyla* (Benth) | Fabaceae | African Oil Bean |
| 56 | *Persea americana* (Miller) | Annonaceae | Avocado pear |
| 57 | *Pinus caribaca* (L) | Pinaceae | Whistling pine |
| 58 | *Plumeriarubra* (L) | Apocyannaceae | Nosegay or frangipani |
| 59 | *Polyalhialongo folia* (Col 2011) | Annonaceae | Masquerade tree |
| 60 | *Psidium guavaja* (L) | Mytaceae | Guava |
| 61 | *Rahia farifera-palmpedia* (L) | Arecaceae | Raffia palm |
| 62 | *Ravena lamadaga scranesis* (Iyan R. Scales) | Aracaeae | Traveller's tree or Traveller's palm |
| 63 | *Roystonea regia* (O.F Cook) | Arecaceae | Florida royal palm |
| 64 | *Sennalata* (Linnaeus) | Fabaceae | Emperor's candlesticks |
| 65 | *Senna siamea* (Irwin) | Fabaceae | Yellow Cassia |
| 66 | *Senna aversiflora* (Senasp 2006) | Fabaceae | |
| 67 | *Streculia setigera* (Shetty and Singh) | Sterculiaceae | Mallow |
| 68 | *Terminalia catappa* (L) | Combretaceae | Almond tree |
| 69 | *Terminalia ivorensis* (Ntima O.) | Combretaceae | Country-almond or Indian -almond |
| 70 | *Thevetia peruviana* (L) | Apocyanaceae | Yellow Oleander/peelakaner |
| 71 | *Thuja orientalis* (L) | Cupressaceae | Tree of life |
| 72 | *Trema orientalisk* (Linnaeus) | Cannabacceae | Charcoal-Tree |
| 73 | *Triplochiton scleroxyyloni* (K.Schumann | Sterculiaceae | African maple |
| 74 | *Uvario dendron molundense* (W.F Wight) | Annonaceae | Lemonwood or degame |

### 3.2 Results of $CO_2$ and Meteorological Data

The measured values for $CO_2$ levels and the meteorological parameters showed that values of $CO_2$ ranged from 317- 399 ppm with a mean 367.4 ppm, which can be converted to percentage by dividing the values by 10,000 to obtain 0.04% of $CO_2$. This is higher than the normal background concentration in outdoor ambient air for $CO_2$ which is 250-350 ppm or 0.03%.

The wind speed ranged from 0.3 – 4.5 m/s with a mean of 1.8 m/s, Relative Humidity ranged from 52.6 – 69.1%, with a mean of 61.35% and temperature ranged from 30.2 – 37.3°C with a mean of 30.75.°C during the study period. These results are shown in Tables 3.2 - 3.4 and Figs. 3.2 - 3.5.

### 3.3 Resilience Strategy

Data showed that 55.4% of the population in the Trans Amadi Industrial Area have a strategy in place, while 44.6% have no strategy in place. However, 51.5% of the strategies are not effective, 31.5% are effective, and only 10% are very effective. A majority of the resilience strategies included proper waste treatment and management with 20%, followed by 9.2% that combined use of trees with proper waste management and 6.9% that used an emission reduction strategy. Data showed that 41.5% listed lack of government support as the major constraints to resilience strategy implementation followed by lack of resilience strategy awareness at 28.5% while lack of finance was at 7.7%.

### 3.4 $CO_2$ Level

The $CO_2$ concentration levels shown in Table 3.3 are generally high ranging 317-399 ppm. These are higher than the World Health Organization (WHO) limit of 350 ppm. The highest $CO_2$ emission level was found along Rivoc road while the lowest was in the zoological garden. This low $CO_2$ value correlates with the number of plant species and vegetal cover on the roads. This can be attributed to the absence of industrial activities, and the high population of plants relative to the other areas. High levels of $CO_2$ emission are attributed to industrial activities, but also are indicative of the absence of an effective resilience strategy. Analysis of the air quality results from Trans Amadi, obtained from the unpublished works of Okpechi [3] and shown in Table 3.3 showed a general increase in all parameters, except relative humidity: $CO_2$ concentration changed from 363.8 ppm to the current mean of 367 ppm, temperature from 27.9°C to 30.8°C, wind speed from 1.48 m/s to 1.8 m/s, while relative humidity decreased from 68.03% to 61.35%. These results are in agreement with a changing climate due to global warming. Similarly, results using ten years of climate data of rainfall and temperature in Port Harcourt from 2006 to 2015 confirm the increasing temperature. On a global scale, increasing $CO_2$ emission hit its peak in 2016, when the Earth's atmospheric $CO_2$ broke a record of 400ppm and remained above that level all year. This ushered the world into a new era according to the Scripps institution of oceanography's $CO_2$ program (San Diego). Global increase in $CO_2$ is mainly due to industrialization, as nearly a third of the Worlds energy consumption, and 36% of carbon dioxide emissions are attributable to manufacturing industries alone according to the report tracking energy efficiency and $CO_2$ emission by the International Energy Agency [10]. This high $CO_2$ level is a cause for concern and calls for urgent action for several reasons. One of which is $CO_2$'s long shelf life, Scientists believe that $CO_2$ can remain in the atmosphere for100-200 years. This concern was also expressed by Meehl et al. [11] in their work on Global climate projection. Their contribution to the 4th assessment report of the Intergovernmental panel on climate change, indicated that temperature increase due to $CO_2$ concentration are not expected to decrease significantly, even if carbon emissions were to completely stop. Recent studies show that any temperature increase of more than 2°C will have a global impact. IPCC [12] has a target of annual global $CO_2$ emissions reductions of approximately 28 gigaton in 2006, to 20 gigatons by 2050, and 10 gigatons by 2100.

### 3.5 Climate Change Resilience Strategies in the Study Area

The three major resilience strategies in Trans Amadi, from the results obtained, are waste management and treatment, emission reduction, and tree planting, in descending order. This was at variance with the field survey and personal observation of indiscriminate solid waste disposal practices along the roads, and a high plant population of urban greening trees, in the study. Several reasons could be responsible for this: first, most companies are more concerned about effluent treatment and have installed effluent

**Table 3.2. Atmospheric $CO_2$ concentrations and climatic characteristics in the Trans Amadi**

| S/N | Sample station description | GPS coordinate | $CO_2$ Conc. (ppm) | Climatic data | | |
|---|---|---|---|---|---|---|
| | | | | **Wind speed (m/s)** | **Relative humidity (%)** | **Temp. (°C)** |
| S1 | Elf/Oginigba Junction by traffic light | N 04° 49′ 04.8” E 007° 01′ 48.5” | 337 | 4.5 | 65.3 | 33.1 |
| S2 | Rivoc Road Junction by Oginigba Trans Amadi link road | N 04° 49′ 14.8” E 007° 01′ 54.7” | 398 | 1.8 | 66.0 | 32.2 |
| S3 | Redeemed Junction by Oginigba Trans Amadi Link road | N 04° 49′ 04.8” E 007° 01′ 59.4” | 390 | 0.3 | 61.6 | 34.2 |
| S4 | Along Oginigba Trans Amadi link road | N 04° 49′ 23.0” E 007° 02′ 05.6” | 377 | 2.9 | 60.3 | 32.7 |
| S5 | Oginigba Slaughter road Junction | N 04° 49′ 33.8” E 007° 02′ 10.6” | 339 | 1.7 | 55.1 | 33.7 |
| S6 | Oginigba slaughter road directly opposite Pabod Breweries | N 04° 49′ 38.5” E 007° 02′ 16.5” | 388 | 0.6 | 52.6 | 36.3 |
| S7 | Oginigba/Slaughter road opposite police station | N 04° 49′ 40.5” E 007° 02′ 24.1” | 390 | 0.8 | 62.5 | 35.1 |
| S8 | Trans Amadi slaughter round about | N 04° 48′ 44.3” E 007° 02′ 40.8” | 341 | 0.9 | 56.3 | 37.3 |
| S9 | Inside Port Harcourt zoo | N 04° 48′ 45.5” E 007° 02′ 45.0” | 317 | 2.4 | 69.1 | 30.2 |
| S10 | Trans Amadi/slaughter – mothercat road | N 04° 48′ 31.7” E 007° 02′ 28.5” | 361 | 1.6 | 63.0 | 32.4 |
| S11 | Trans Amadi-slaughter | N 04° 48′ 21.5” E 007° 02′ 09.5” | 399 | 2.5 | 63.0 | 33.4 |
| | **Range** | | **317- 399** | **0.3 – 4.5** | **52.6 – 69.1** | **30.2 – 37.3** |
| | **Mean** | | **367.42** | **1.82** | **61.35** | **30.75** |

**Table 3.3. Analysis of meteorological parameters and atmospheric pollutants concentrations in the Trans-Amadi Industrial layout**

| Parameters | Stations | | | | | | | | | | Cumulative mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| **Wind direction** | **South-west** | **South-west** | **South-west** | **South-west** | **South-west** | **South-west** | **South-west** | **South-west** | **South-west** | **South-west** | |
| **Wind speed m/s** | 1.6 | 1.4 | 1.4 | 1.6 | 1.4 | 1.3 | 1.4 | 1.6 | 1.3 | 1.6 | |
| Afternoon | 1.5 | 1.4 | 1.3 | 1.6 | 1.3 | 1.3 | 1.4 | 1.6 | 1.5 | 1.5 | |
| Evening | 1.6 | 1.5 | 1.6 | 1.6 | 1.6 | 1.5 | 1.6 | 1.4 | 1.6 | 1.5 | |
| **Mean** | **1.6** | **1.4** | **1.4** | **1.6** | **1.4** | **1.4** | **1.5** | **1.5** | **1.5** | **1.5** | **1.48** |
| **Temperature ($^0$C)** | 26 | 27 | 26.7 | 24.6 | 26 | 27 | 26 | 28 | 27 | 26 | |
| Afternoon | 30 | 30.1 | 29.6 | 28.6 | 28 | 29 | 30 | 29 | 28 | 30.1 | |
| Evening | 28 | 28 | 29.4 | 25.8 | 27 | 28 | 28 | 29 | 28 | 28 | |
| **Mean** | **28** | **28.4** | **28.6** | **26.3** | **27** | **28** | **28** | **28.7** | **27.7** | **28** | **27.87** |
| **RH (%)** | 69.2 | 68.7 | 67.9 | 69.4 | 69.8 | 68.2 | 68.7 | 68.4 | 67.8 | 70.1 | |
| Afternoon | 68.4 | 65.6 | 69 | 68 | 66.8 | 66.8 | 66 | 66.8 | 66 | 64.2 | |
| Evening | 69 | 67.8 | 66.4 | 67.6 | 67.6 | 67.9 | 69 | 69.2 | 69 | 68 | |
| **Mean** | **68.9** | **67.4** | **67.9** | **69.4** | **68.1** | **67.6** | **67.9** | **68.1** | **67.6** | **67.4** | **68.03** |
| **$CO_2$** | 336.33 | 342 | 399.10 | 366 | 360 | 336.33 | 365.33 | 361.67 | 399 | 360 | |
| Afternoon | 337 | 360 | 376.33 | 370 | 360 | 399.10 | 353 | 353.66 | 382 | 361.67 | |
| Evening | 353.67 | 365.67 | 357.00 | 349.67 | 370.50 | 382.10 | 350.67 | 365.67 | 363.33 | 376.33 | |
| **Mean** | **342.33** | **355.89** | **377.48** | **361.89** | **363.5** | **372.51** | **356.33** | **360.33** | **381.44** | **366** | **363.77** |

*Source: Okpechi (2016)*

treatment plants (ETP) as a waste management strategy while solid waste disposal is seen as less critical; it should be noted that by recycling and reducing waste by keeping trash and other waste materials from incinerators and landfills, where it can produce powerful GHG emissions. The decomposition of organic matter in a landfill leads to the production of methane gas, an important GHG that traps more heat in the atmosphere than $CO_2$, second, the majority of the greening of the area was done by the Rivers State Government in 2008, and not by the individuals or companies. This absence of citizen participation/low interest in the urban greening was evident in the number of species observed in the road median where trees were originally planted. The government has not seen the need to replace these missing trees. Instead, the more vegetal cover was recently removed, due to the major road reconstruction and expansion work, on the road one in the study area. This was also the position taken by the majority of the respondents, in the unpublished study by Uwamahoro [13], on building resilience to climate change for farmers in some part of Rivers State. However, Konrad [14] disagrees that government has a major role to play in climate change adaptation. The report limited the role of the State to information, regulation and fostering economic growth. It argued that those who bear the cost and enjoy the benefit of the decision (the individual, companies or communities) are the major factors in climate change adaptation decisions. Tompkins and Adger [15] found that to improve the capacity to adapt, it is necessary to involve the community in the management of their natural resources, and assist them in developing networks for coping with shocks and developing resilience of the ecosystem. The assumption is that successful climate resilience action would need a multi-stakeholder engagement.

**Table 3.4. Mean annual data for rainfall and temperature (2006-2015)**

| Year | Mean annual rainfall (mm) | Mean annual temp. °C |
|---|---|---|
| 2006 | 171.3 | 27.3 |
| 2007 | 239.5 | 27.5 |
| 2008 | 175.1 | 27.0 |
| 2009 | 213.5 | 26.7 |
| 2010 | 141.8 | 26.6 |
| 2011 | 184.8 | 27.4 |
| 2012 | 187.4 | 27.6 |
| 2013 | 188.3 | 27.8 |
| 2014 | 214.6 | 27.8 |
| 2015 | 173.3 | 28.3 |

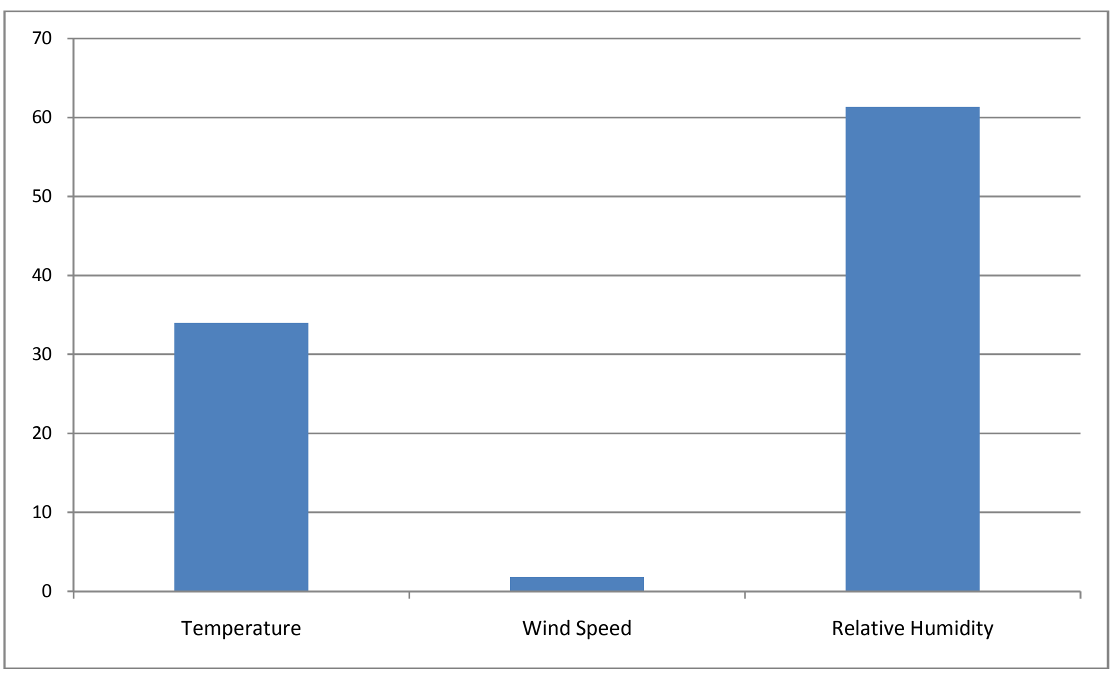


**Fig. 3.1. Meteorological characteristics within an area**

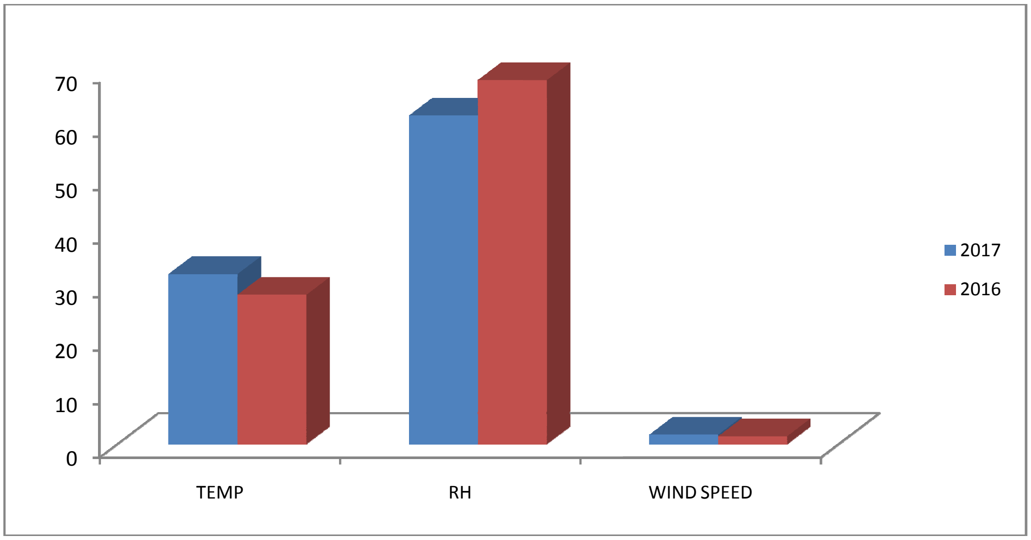


**Fig. 3.2. Meteorological data compared**

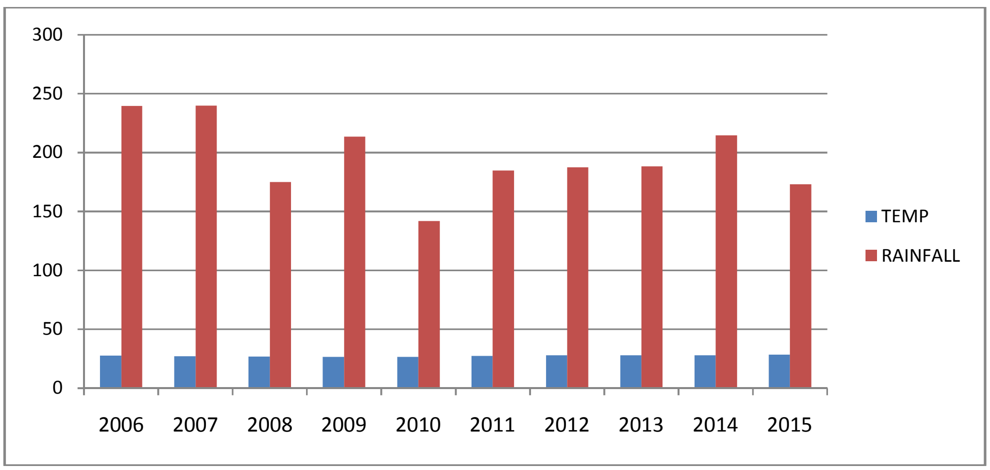


**Fig. 3.3. Nimet climate data for 2006 to 2015**

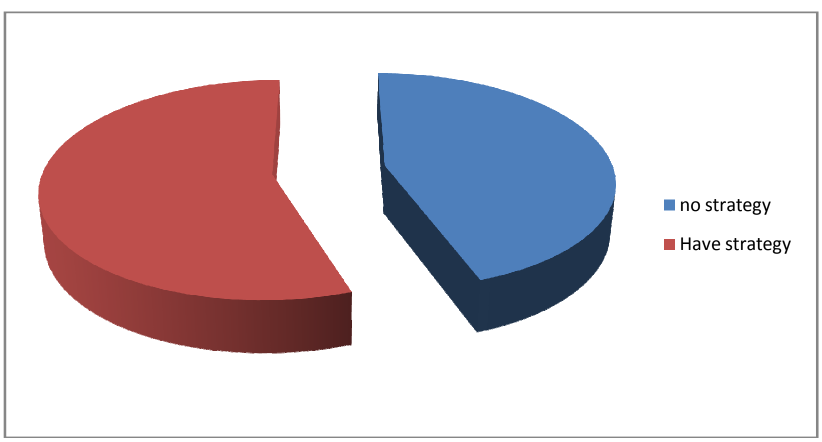


**Fig. 3.4. Companies with resilience strategy**

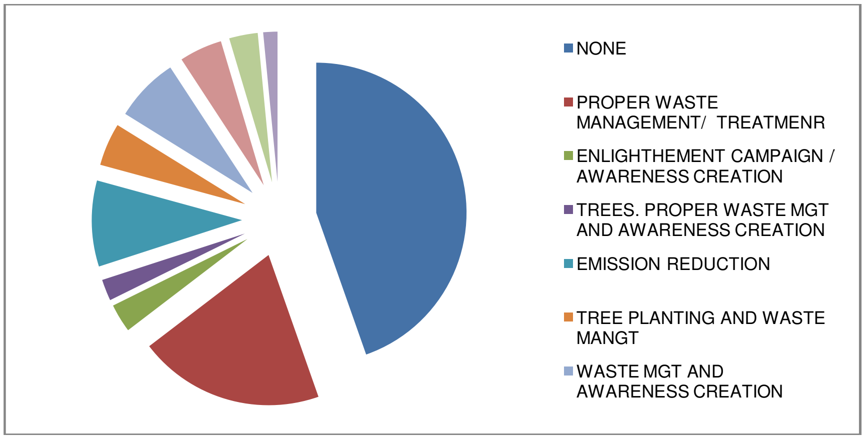


**Fig. 3.5. Resilience strategies of companies in Trans Amadi**

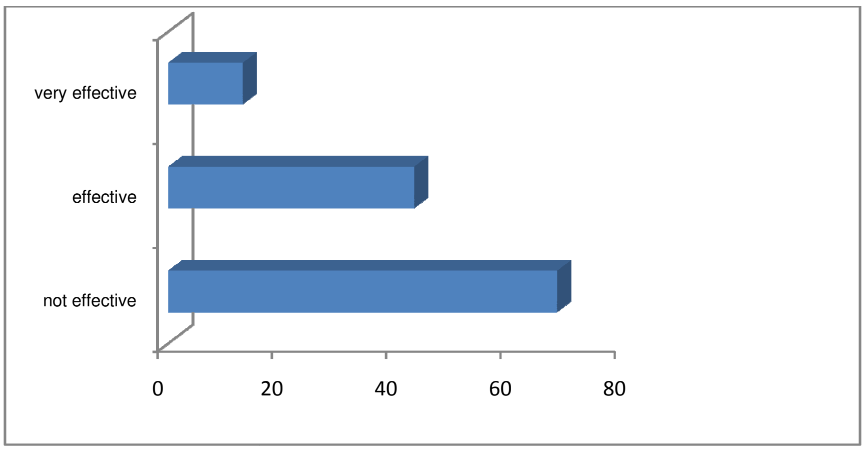


**Fig. 3.6. Efficacy of strategy**

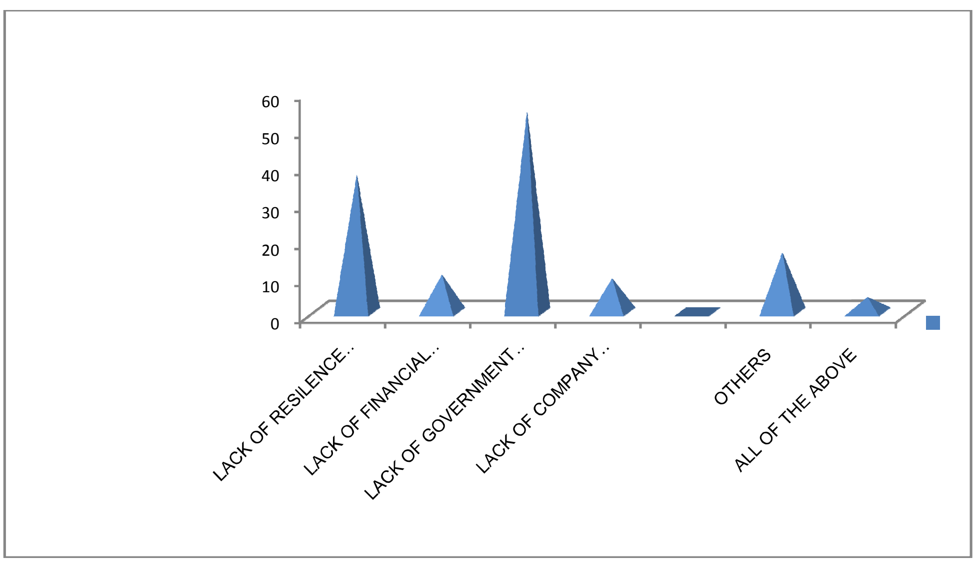


**Fig. 3.7. Constraints to climate change resilience strategy**

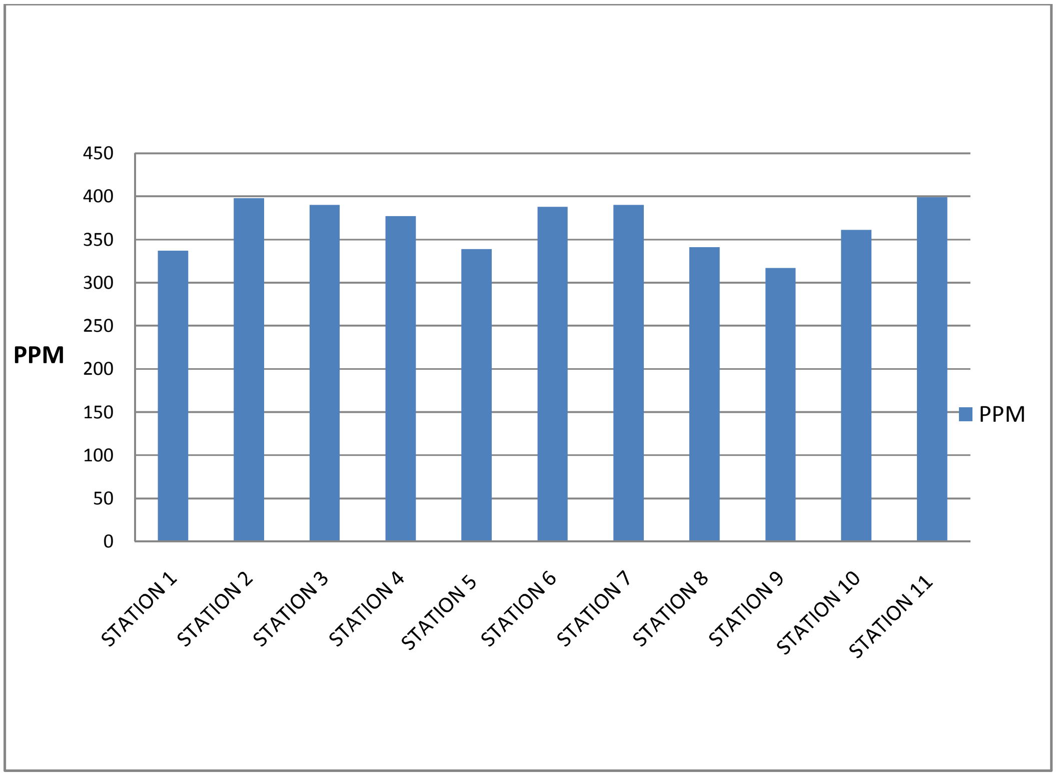


**Fig. 3.8. $CO_2$ concentration within study area (Air stations = x axis and concentration = y axis)**

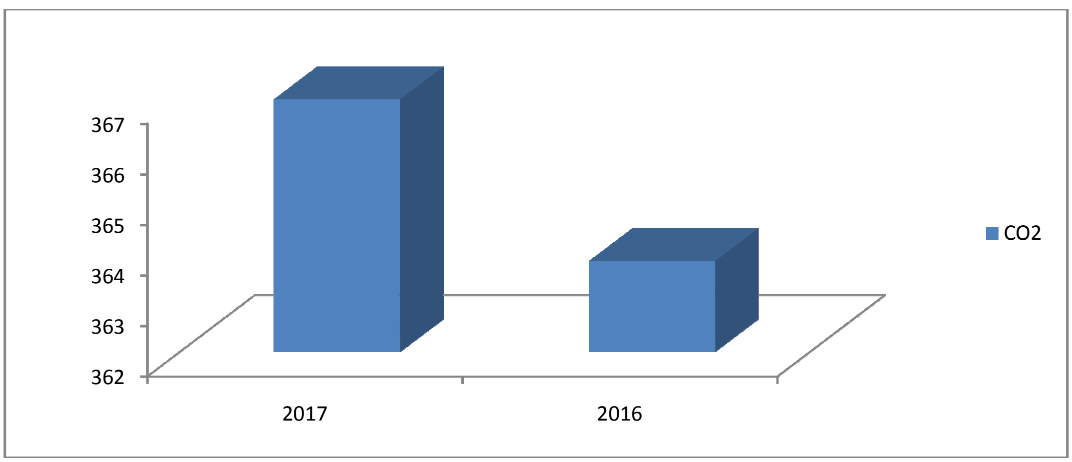


**Fig. 3.9. $CO_2$ comparison**

## 4. CONCLUSION AND RECOMMENDATIONS

### 4.1 Conclusion

Resilient companies will have a less negative impact on the environment due to reduced emissions, increased energy efficiency, and improved waste management. This will contribute to the development and environment sustainability. To become resilient, the identified constraints must be overcome and resilience strategies developed. Urban greening involving green spaces, parks, gardens and the creation of green infrastructure is relevant to mitigating climate change. For a developing country, tree planting is one of the most cost-effective strategies for climate change resilience.

### 4.2 Recommendation

Resilience strategies do not stop climate change but they reduce its impacts. The following recommendations are made from the results of this study.

1. Urban greening should be used to mitigate the impact of climate change. Companies and individuals should plant and maintain trees around and within their locales.
2. Low maintenance, fast growing and woody trees with large biomass should be preferred in urban greening programmes by city authorities.
   State and non state actors should take urgent steps to implement adequate and efficient climate change resilience strategies in Trans Amadi.
3. Companies should intensify efforts at closing the gap between the knowledge and the practice of resilience strategies in order to reduce the impacts to their business.
4. Government should drive economic growth to reduce poverty as a means reducing vulnerability and building resilience to climate change.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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