MITIGATION STRATEGIES FOR THE EFFECTS OF CLIMATE CHANGE ON ROAD INFRASTRUTURE IN LAGOS STATE

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Abstract

Global climate change-induced effects form part of the principal challenges confronting mankind in the recent years. The world is becoming more conscious of the fact that our ecosystem is not adapting naturally to the stresses caused by excessive and uncontrollable human activities. Many known effects of climate change on some sectors of the economy are already receiving appropriate evaluations with mitigation strategies being proffered. Some other areas of the economy, especially in the developing nations are scarcely considered. One of such area is the road infrastructure sector. In spite of the importance of transportation as a key driver and enabler of the economy, little research has been conducted around the world on how vulnerable it will be to climate change. Any unforeseen damage caused by climate change on the few and insufficient road infrastructure of developing nations will negatively impact the economy and severely retard economic growth.

For these reasons, this research focuses on the consequences of global climate change on the road infrastructure network in Lagos State (Nigeria) and its mitigation strategies. Data from the Nigeria Meterological Agency (NIMET) such as rainfall, temperature, relative humidity and pressure were analysed. Regression analysis was applied for predictions. However, the results obtained confirm that the road infrastructure in Lagos State is experiencing the basic features of climate change which urges for urgent mitigation and adaptive measures.

Keywords: Climate change, roads infrastructure, mitigation approach, regression analysis

Introduction

Climate change is one of the contrary environmental phenomenons generating great concern around the world in the recent time. The civil built infrastructure is one of the systems most exposed to the ever changing climate and environmental conditions [1]. The global climate change is caused by the depleting of the ozone layer as our ecosystem is not adapting naturally to the stresses caused by excessive population growth and the consequent increase in human activities [2]. As the effects of the climate change are being made manifest around the world, it is now known that no nation including Nigeria is immune from its effects [3]. The climate change increases the rate and intensity of extreme weather events and the effects are already evidenced in different parts of Nigeria. They include but not limited to desert encroachment in the northern part of Nigeria, drying up of rivers, gully erosion in the south eastern part of the country, rising sea level and flooding in various parts of the coastal areas of the country. Within the Gulf of Benin in which Nigerian coastal boundaries lies, it has been estimated that the 50-year mean sea level rise is about 3 mm/year, which will translate to about 50 m coastline retreat in the next 50 years. The people living in the low lying coastal areas of Southern Nigeria, particularly in Lagos are under severe risk as a good percentage of the inhabitants of Lagos living mainly in slums are exposed to this danger. All these will lead to damages to the few existing infrastructures and threats to the safety and health of the populace. As the key climate change indicators (increasing temperature, changes in amount, intensity, and pattern of rainfall, sea surge, drought and sea level rise) are being verified in Nigeria, the related challenges will most likely manifest themselves in Nigeria sooner or later. In fact, the terrible flood of July 2011 will not easily be forgotten by Lagosians, just as the July/August 2012 mass flood that submerged many parts of Nigeria will remain in the minds of Nigerians for a while. As these extreme weather events occur more frequently with greater intensity, the socioeconomic costs will be overwhelming [4]. Therefore, for these frightening facts, efforts need to be made to drastically reduce the risks of the unpredictable challenges which might emerge from the climate change.

The transportation network system is globally recognized as the cornerstone of civilization as the growth of every nation’s economy is measured by the growth of the transport infrastructure. No wonder the beauty of the advanced nations’ economies can be swiftly measured by the beauty of their transport facilities, while the stunted economy of the under-developed nations like Nigeria is easily visible in their pot-holed road infrastructural system [5]. The safety of this very important index of development is at a great risk as numerous developing nations lack the coping capacity for normal emergencies talk less of the unpredictable impacts of climate change.

Faced with this scenario, the transport system of the mega-city of Lagos is highly predisposed to the impacts of climate change. Imparts of climate change on Lagos transportation facilities can come in the form of rising sea-level submerging low-lying road networks and sea ports, devastating effects of increased hurricane and flooding on all civil built facilities, strong wind and higher storm surges that will put more land and transportation facilities at great risk. When the transport system is affected by any form of disaster, all the diverse sectors of the economy will suffer. Unless an adequate attention is paid to the impacts of climate change and adaptive resilience and cope mechanisms formulated, the vulnerability of Lagos State, the economic hub of Nigeria can endanger the long-term development of the country and retard the economic emancipation of the West African sub region.

For these reasons, this research focuses on the consequences of global climate change on the road infrastructure network in Lagos State and mitigation strategies. Data from the Nigeria Meterological Agency (NIMET) such as rainfall, temperature, relative humidity and pressure were analysed. Regression analysis was applied for predictions and the results obtained confirmed that Lagos State is experiencing the basic features of climate change which urges for urgent mitigation and adaptive measures.

Climate Change

Climate is the weather conditions prevailing in an area over a long period and encompasses the statistics of temperature, humidity, atmospheric pressure, wind and precipitation. Climate change is the variation in global and regional climates over time. It reflects changes of the average state of the atmosphere over a long period from decades to millions of years. Climate change is an interdisciplinary topic, and so it draws on the work of people in widely divergent fields of study such as physical and environmental sciences, engineering and social sciences. Leading thinkers from various scientific fields all have a role to play in unraveling the uncertainties that surround the climate change phenomenon. These changes could be caused by processes internal to the earth such as human activities and external forces such as variation in sunlight intensity. According to [6], climate change is caused by two basic factors: natural or bio-geographical processes and human activities or anthropogenic processes. The natural processes have to do with astronomical and extraterrestrial factors. The astronomical factors include the changes in the eccentricity of the earth’s orbit, changes in the obliquity of the plane of ecliptic and changes in orbital procession, while the extra-terrestrial factors are solar radiation quantity and quality among others. The human activities have to do with the emission of greenhouse gases into the atmosphere that depletes the ozone layer or activities that reduce the amount of carbons absorbed from the atmosphere.

Greenhouse Gases

A greenhouse gas (GHG) is a gas in the atmosphere that absorbs and emits radiation within the thermal infrared range in a process known as the greenhouse effect. The most abundant greenhouse gases in the Earth's atmosphere are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). In the Solar System, other planets contain gases that cause greenhouse effects. Greenhouse gases greatly affect the temperature of the Earth.

Since the advent of industrialization, the burning of fossil fuels has contributed to about 40% increase in the concentration of carbon dioxide in the atmosphere from about 280 ppm to 397 ppm, despite the absorption of a large portion of the emissions by various natural "sinks" involved in the carbon cycle. The carbon dioxide (CO_2) emissions from human activities come basically from combustion of carbon based fuels such as wood, coal, oil and natural gas. The atmospheric concentrations of greenhouse gases are determined by the equilibrium between sources of emission of the gas (bio-geographical processes and anthropogenic processes) and sinks (process of removal of the gas from the atmosphere by conversion to a different chemical compound). The portion of an emission remaining in the atmosphere after a specified time is the airborne fraction (AF). In particular, the annual AF is the ratio of the atmospheric increase in a given year to that year's total emissions. However, CO_2 AF has been on the increase over the past 50 years.

Effects Of Increased Temperature And Intensity Of Rainfall On Road Infrastructure

In spite of the importance of transportation as a key driver and enabler of the economy, little research has been conducted around the world into how vulnerable it will be to climate change. This is surprising as lack of efficient and reliable transportation can severely impact on economic growth given that the influence of meteorological effects on accidents and traffic disruption will negatively impact any economy. Changes in climate will cause both negative and positive impacts on the operation and maintenance costs of transportation systems. Higher temperatures will result in lower maintenance costs in the northern climates due to fewer freeze-thaw cycles and less snow, while increased pavement buckling will occur due to intense heat. Typical effects of climate change to infrastructure ([7], [8], [9] and [10]) can be found in table 1.

Temperature changes affect the stresses and deformations of every component of road infrastructural system, because the materials will experience contraction and expansion in response to temperature changes. Structural temperature fluctuations are often separated into two major components: a uniform change and a gradient change which generates strains on structural materials. In the long-term, ambient temperature changes will have adverse effects on the materials used for infrastructure design. Studies by Changnon's research group [11] showed that highways and railroads were damaged as a result of heat-induced heaving and buckling of joints during the 1995 heat wave in Chicago. They also noted that a train wreck was linked to heat-induced movement of the rails. The Cambridge Systematics Report [12] posited that the range in temperatures to be verified by 2100 would make today's pavement design approach ineffective. We therefore expect that research in materials science would provide solutions to pavement design in higher temperature conditions.

Transportation structures are constructed from materials chosen for their performance under design loads and environmental conditions. The performance of pavements can change dramatically given changing conditions, such as increasing temperature and changing sub-grade soil dynamics due to saturation and erosion.

Higher temperatures can cause pavement to soften and expand. This can create rutting and potholes, particularly in high-traffic areas and can place stress on bridge joints. Heat waves can also limit construction activities, particularly in areas with high humidity. With these changes, it could become more costly to build and maintain roads and highways. On the other hand, certain areas may experience cost savings.

Changes in precipitation and water levels forms part of the consequences of global climate change which affect most infrastructure components in existence today. Thus, climate change is projected to concentrate rainfall into more intense storms

Water is one of the most difficult aspects to design for in transportation engineering. Saturated soils can be a critical concern in the design of a facility's substructure and foundations. Additionally, runoff from impermeable surfaces such as bridge decks or road surfaces should be handled in a way that redirects water flows away from the structure and does not harm the surrounding environment. Heavy rains may result in flooding, which could disrupt traffic, delay construction activities, and weaken or wash out the soil and culverts that support roads, tunnels, and bridges ([13], [14]). More moisture in the soil and also the hydrostatic pressure buildup behind retaining walls and abutments would possibly cause a change of the design method, types of materials and construction procedures for bridges and the other dependent substructures. Increased intensity of precipitation and the consequent flooding will have devastating impacts on drainage designs. The design water discharge for culvert design and drainage systems must be increased to accommodate larger capacity flow. Faster velocity flows becomes necessary to cope with the speed of the water flow entering the drainage. Standard designs for drainage systems, open channels, pipes, and culverts [15] reflect the expected runoff or water flow that may occur at a given assumed magnitudes of storms. Exposure to flooding also shortens the life expectancy of highways and roads. The stress of water may cause damage, requiring more frequent maintenance, repairs, and rebuilding. Road infrastructure in coastal areas is particularly sensitive to more frequent and permanent flooding from sea level rise and storm surges [16].

With the increasing intensity of rain storms, increasing wind loads will possibly be an event that will affect future engineering designs since increase in storm intensities is always accompanied by high wind speeds. Increased wind speeds will definitely affect all built structures above ground level including transportation signage and signal installations, long-span bridges, and in particular, suspension and cable-stayed bridges. Storm surges are going to be of great concern to engineers designing for coastal environments as the storm forces produced on the transportation facilities will be accompanied with the debris of all the other structures that have been destroyed in its path. In this way, the impacts will be devastating and difficult to predict. In fact, the worst damage caused on highway bridges during Hurricane Katrina was traceable to the buoyancy force on the bridge decks resulting from the storm surge and wave action. This force effectively elevated the decks off of their supports as against the design criteria of the weight of the bridge deck being adequate to maintain the deck in place. Wave forces on bridge piers, columns, and abutments will affect their design criteria. Therefore, an increased wave load on the structures will necessitate new design concept that will affect the dimension, and materials protective mechanisms.

TABLE 1: Impacts of climate change on road infrastructure in temperate regions and adaptation strategies

CLIMATE IMPACT	POTENTIAL INFRASTRUCTURAL IMPACT	POTENTIAL OPERATIONS IMPACT	ADAPTATION
Increased Temperature	Highway asphalt rutting Rail buckling Thermal expansion of bridges Overheating of diesel engines Increased vegetation – leaf fall	Potential for derailment and malfunction of track sensors and signal sensors, Increased travel time due to speed restrictions, Increased risk of hazardous material spill Frequent detours, traffic disruptions Reduced efficiency of engines Ineffective braking of rail cars, visual obstruction	Proper design/construction, Milling out rut pavements, Overlay with more resistant asphalt, Speed restrictions, Improved inspection, maintenance and repairs, Improve sensing and warning systems, Better updates of the weather situation and track conditions Improved cooling systems Improved Vegetation management
Increased Precipitation - Rain	Frequent and increased flooding of roads/rails /airport runways /bikeways and walkways Highway, rail, and pipeline embankments at risk of subsidence/heave Flooding of underground transit systems	Infrastructure deterioration (quicker with acid rain), impacts on water quality, Service disruption, Travel and schedule delays and Stranded motorists. Increased accidents, Loss of life and property, Increased safety risks, Increased risks of hazardous cargo accidents and spills Landslides and wash-outs, Increased malfunctions of track and signal sensors, Power outages.	Seek alternative routes, Improve flood protection, Risk assessment for new roads, Emergency contingency planning, Culverts sufficient to deal with flooding, Improve drainage systems, Improved asphalt/concrete mixtures, And minimize repair backlogs Improved inspection, maintenance and repairs. Improved engineering solutions, Increase advisories, warnings and updates to dispatch centres, crews, and stations. Improved operations plan
Sea Level Rise Storm Surges	Erosion of coastal highways Coastal road flooding Damage to infrastructure: roads, railways, pipelines, seaports, airports	Increased accidents, Evacuation route delays, Stranded motorists. Closures or major disruptions of roads, railways, airports, transit systems, pipelines, marine systems and ports; emergency evacuations; Travel delays Safety risks to personnel and equipment (risks of injury or death from accidents); Damages to roads, rails and runaways;	Construction of sea walls Build more redundancy into the system, Support land use policies that discourage development on shoreline, Adoption of improved design and materials
Increased Wind Speeds	Bridges, signs, overhead cables, railroad signals, tall structures at risk	Increased accidents, Roadways: loss of visibility from drifting Loss of stability /manoeuvrability, Lane obstruction (debris), Railways: Rail car blow over; schedule delays; Safety risks to personnel and equipment (risks of injury or death from accidents);	Design structures for more turbulent wind conditions, build with better material, Use “smart” technologies to detect abnormal events, Improved engineering solutions.
Lightning	Disruption to transportation electronic infrastructure, signalling, /Electrical disturbance etc.	Risk to personnel from lightning, Operations/Maintenance activity delays, Track signal sensor malfunction resulting in possible train delays and stops, threats to barge tow equipment, communications and data transfer may fail	Adopting all preventive measures against lightening and electric shock

Material And Method

This research analyses the effect of temperature, rainfall, relative humidity, and atmospheric pressure on transportation network in Lagos State over a period of 20 years (1991-2010). The data used were the monthly rainfall, temperature, relative humidity and pressure for 20 years compiled by the Nigerian Metrology Agency (NIMET). Temperature data collected from NIMET were the monthly temperature (^{o}C) for two stations (Ikeja and Lagos Island) which was transformed to mean annual temperature using Microsoft Excel. In like manner, monthly relative humidity (%), monthly pressure (mb) and monthly rainfall (mm) of the two stations and for the same period of 20years were collected and transformed to mean annual values. Statistical analyses were performed on the data. The study period of 20 years were subdivided into two climatic periods of 10 years each, i.e. (1991-2000) period and (2001-2010) period. For the analysis of the data collected, the average values for each year were calculated and then the mean values of the first climatic period was subtracted from the mean value of the second climatic period according to equation (1) to stabilize the trend of the data.

$$x = \sum C_2 / n - \sum C_1 / n \qquad (1)$$

Where:
x = Change in data (temperature, rainfall, relative humidity, and atmospheric pressure).
$\sum C_2$ = sum of data 2nd climatic period

$\sum C_1$ = sum of data 1st climatic period
n = number of years (10 years)

Simple linear regression analysis was used for the analysis of the data as to hypothesize a probabilistic relationship between the mean values within the interval of the years considered. This calculation was done with Microsoft excel using equation (2)

$$y = mx + c \qquad (2)$$

Where:
y = variable (temperature, rainfall, relative humidity, and atmospheric pressure).
m = the slope of the line and
c = the y-axis interception.

Findings And Discussion Of Results

The result of the analyses was hereby presented. The average rainfall in the first climatic period (1991-2000) was 132.5mm while the value for the second climatic period (2001-2010) was 134.1mm. Thus, this shows an increase of 1.6mm in the rainfall of the study area for the 20 years period indicating the existence of climate change. Figure 1 shows the mean annual rainfall for Lagos State.

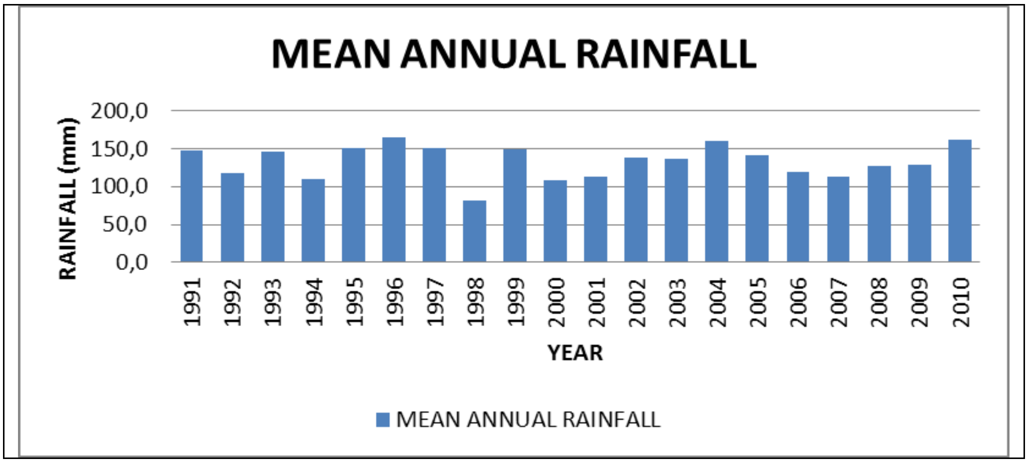

Figure 1: Mean Annual Rainfall for Lagos State. (Source: NIMET)

The analysis of the temperature considered mean annual maximum temperature and the mean annual minimum temperature. The average maximum temperature in the first climatic period (1991-2000) was 30.8^{o}C while the second climatic period (2001-2010) measured 31.0^{o}C. Therefore, this shows an increase of 0.2^{o}C in the maximum temperature of the study between the 20 years period indicating the existence of climate change. The average minimum temperature showed also an increase of 0.5^{o}C in the minimum temperature of the study between the 20 years period confirming the existence of climate change. Figure 2 shows the mean annual maximum temperature for Lagos State. The trend of temperature rise is further confirmed in figure 3.

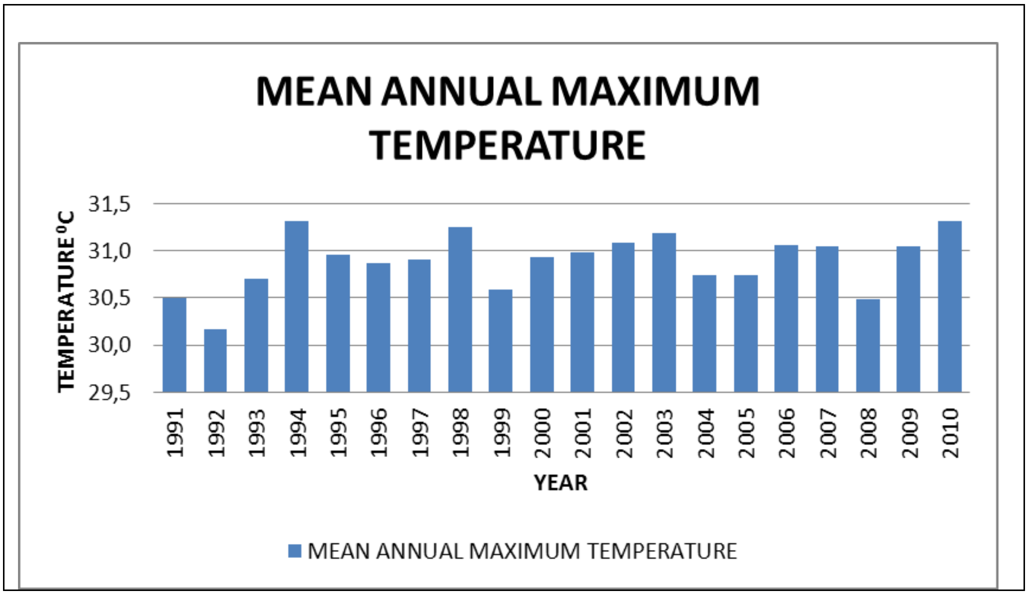

Figure 2: Mean Annual Maximum Temperature for Lagos State (Source: NIMET)

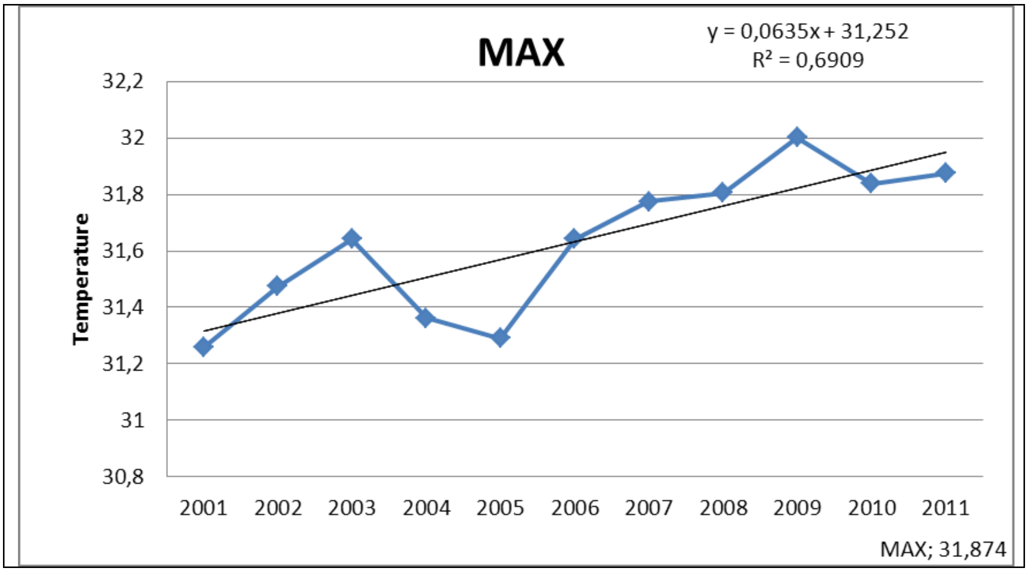

Figure 3: Trend of max temperature in Lagos between 2001-2011

The analysis of the relative humidity considered mean annual relative humidity at 10am and mean annual relative humidity at 4pm. The average relative humidity at 4pm in the first climatic period (1991-2000) was 70.4% while for the second climatic period (2001-2010), it was 71.1%. This showed an increase of 0.7% in the relative humidity at 4pm for the 20 years study period, thereby indicating the existence of climate change. The average relative humidity at 10am showed an increase of 1.4% in 20 years study period, thereby confirming the existence of climate change. Figure 4 shows the mean annual relative humidity at 4pm for Lagos State.

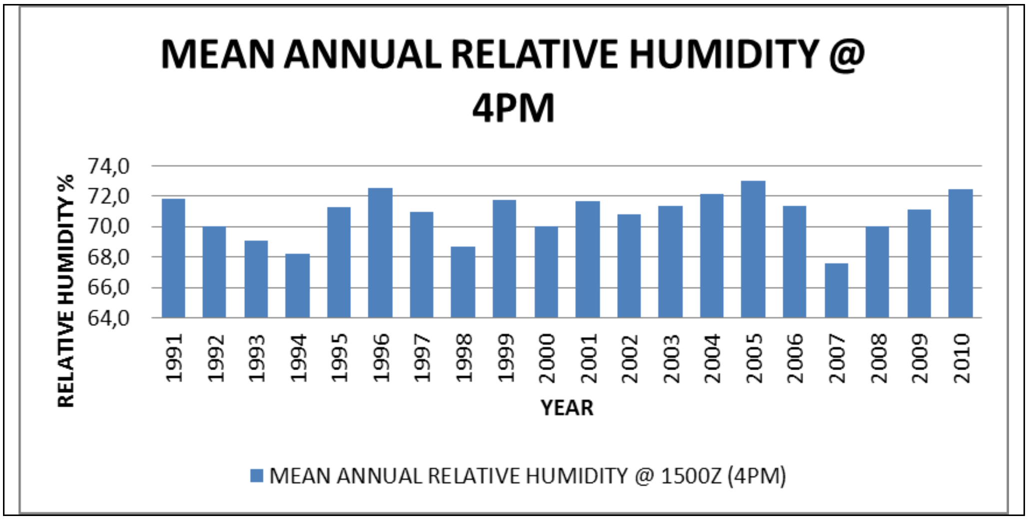

Figure 4: Mean Annual Relative Humidity at 4pm for Lagos State (Source: NIMET)

The analysis of the pressure considered mean annual pressure at 10 am and mean annual pressure at 4pm. The average pressure at 4pm in the first climatic period (1991-2000) was 9.3 millibars while for the second climatic period (2001-2010), it was 10.3 millibars. Hence, this shows an increase of 1 millibar in the pressure at 4pm of the study of the 20 years period indicating the existence of climate change. The average pressure at 10am showed an increase of 0.8 millibars in the pressure at 10am of the study for the 20 years period confirming the existence of climate change. Figure 5 shows the mean annual pressure at 4 pm for Lagos State.

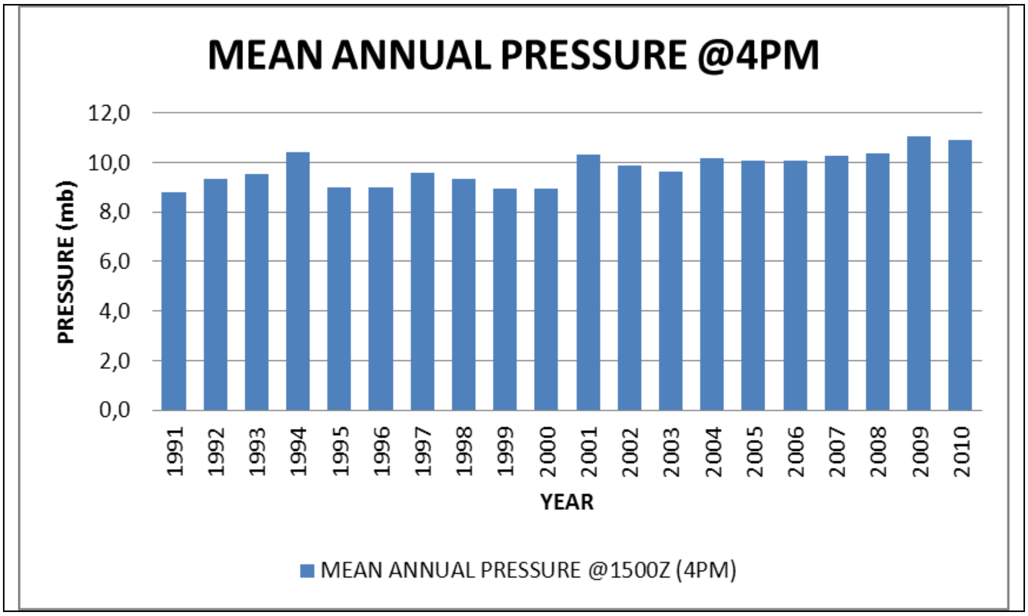

Figure 5: Mean Annual Pressure at 4pm for Lagos State (Source: NIMET)

Conclusion And Recommendations

This study examined the effect of climate change on transportation network in Lagos state. The analyzed data (rainfall, temperature, relative humidity, and pressure) confirmed that the road infrastructure in Lagos State is under the siege of the effects of climate change as the basic features were confirmed.

It is evident from this study that the intensity of rainfall, temperature, relative humidity, and pressure are all increasing, thereby confirming the existence of the phenomenon of climate warming in Lagos State. This goes to confirm that some of the challenges traceable to climate change as listed on table 1 that are certifiable for road infrastructures in Lagos State are due to global climate warming. Figure 6 shows a classic flooding on a major highway in Lagos State; and this confirms how climate change (flooding in particular) has disrupted socio economic activities, inflicted physical and economic damages and impacted negatively on the environmental harmony of Lagos State.

Figure 6: Apapa/Oshodi Expressway under Flood (Source: Nairaland Forum, 2011)

Since the result of this research confirms the increasing trend of the basic features of climate change, it will be necessary that all stake holders should adopt innovative approaches towards tackling the unpredictable consequences of climate change in the Nigerian coastal areas of which Lagos State was singled out as a case study. This will include revisiting the existing town planning laws; and the government must be more proactive in designating new areas for development, based on the projection that such areas will be safe in the advent of worsening environmental changes. Applicable urbanization laws must be strictly adhered to in any future developments while all the developed areas must be compelled to conform accordingly. Drainage systems in all the low lying areas of the State and all the areas at risk need to be revisited and upgraded to cope with the high intensity of rains that are becoming more frequent in recent times. Stake holders (Government, professional bodies, NGOs etc.) are obliged to invest maximally in human resources development, innovative researches and technologies capable of predicting and handling accurately future climate change-induced events as they emerge. Therefore, with a good policy in place and the collaborative support of the citizens, the long range consequences of climate change can be reduced to a supportable level.

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