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Spatial and Temporal Variability of weekday Urban Heat Island in Port Harcourt and Environs

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Abstract:
The study examined weekday variability of urban heat island in Port Harcourt and Environs. The data used for this study were generated from field observation and complemented with airport meteorological data. Analysis of Variance was used to determine the differences in UHI in the land use areas across the weekdays. The findings revealed that UHI effects were high on Sunday, Monday and Tuesday which Monday was the hottest daywith6.9^{o}C and Saturday was the lowest in both seasons.UHI was relatively intense during the wet season with 5.3^{o}Cand lower in the dry season with 5.0^{0}C at 0.3^{o}C seasonal variation. The study area had mean UHI of 5.2^{0}C per annum and seasonal temperature variation of 1.1^{0}C within the urban canopy across different land use types. The result indicated that increase in temperature does not show proportional increase in UHI across the different land use types. The city surpassed the heat comfort threshold of 27^{o}C temperature and +0.5^{o}C-2.5^{o}C UHI values with annual mean temperature of 30.1^{o}C and 5.2^{o}C UHI respectively, indicating that human comfort has been compromised in the city. Commercial and high residential areas had the highest urban heat effect across the weekdays. The study therefore, recommends proper urban planning and management, environmental and health as well as urban greening as intervention strategies.

Keywords: *Port Harcourt, Urbanization, Urban Heat Island, temperature, weekday*

1. Introduction

As a whole, 50% of the world population is leaving in the urban area and 70% is expected to leave in the cities in the year 2050 [1].Urbanization as a product of concentration of people and pavement materials to a particular geographical space has resulted to the phenomenon of Urban Heat Island (UHI). Urban heat island occurs when the temperature of the city is higher when compared to that of the rural fringes [2]. Urban heat island is accelerated by the level of industrialization of the city area [3].Also, the heat island effects within urban centers of fast growing metropolitan regions may double within 50 years [4]. When the city UHI is compromised, there will be increased energy consumption, raised emissions of air pollutants and greenhouse gases, compromised human health and comfort as well as impaired water quality[5][6].

Many factors have caused the effects of urban heat islands such as greenhouse gas emission, loss of urban tree cover, increased pavement surfaces and low albedo of materials; others are thermal properties of materials, urban morphology, city size and generated anthropogenic heat [7] [8].

Urban heat island is known to occur in the three key layers of the city: the boundary, canopy and the surface layer respectively[9]. Boundary layer urban heat island starts from the rooftop and treetop level up to the point where urban landscape no longer influences the atmosphere. The canopy layer is immediately above the surface up to the average height of the buildings and trees. And the surface layer is the heat generated around the city ground surface[10].

In a coastal environment like Port Harcourt Metropolis and Environs, the urban climate irregularity has increased with the changes from low-single storey buildings to multi storey buildings [8]. Anthropogenic heats are released into the atmosphere by vehicles exhaust fume and urban pavement materials stores heat in the day and gradually release it in the night [11].The general pattern of the urban structure and function are altered on regular bases such as the urban geometry, sky view, and greenhouse gas emission, gradual loss of urban tree cover, impermeability of surfaces and low albedo of materials[12]. Other alterations are thermal properties of materials, urban morphology and the size of cities as well as generated anthropogenic heatetc. [10].Port Harcourt metropolis and environs has experienced a lot of changes in its structure and geometry, caused by erected buildings and street spacing over the years [7].These areas involve the Port Harcourt Township, Government Residential Area (GRA), Trans-Amadi, Muscow area as well as Mile 1-3 (Diobu) area, Woji, Rumudara, Rumuokoro, Rumuola, Eligbam, Orazi, Rumuokwuta, Trans-amadi, D-line, etc. have close building space average distanceranging from 1000 mm - 10,000 mm in the traditional settlements and 30m - 50m in the planned areas [13].However, in tropical humid African cities much is not known about the extreme conditions of urban climate and the concept of urban heat island has been hardly associated to the other climatic parameters that have some relations with temperature [14].In this vein, the operations of UHI are generally understudied in Africa. The aim of this study therefore, is to assess the spatial and temporal variability of urban heat island across the weekdays in Port Harcourt metropolis and environs.

2. Materials and Method

2.1. Description of Study Location

Port Harcourt is positioned in the Niger Delta area of Nigeria within Latitudes 4°05’30’’N and 5°14’25’’N and Longitudes 5°40’30’’E and 7°11’01’’E of the Greenwich Meridian. The two central local government areas are Obio/Akpor and Port Harcourt City; its environs extend to Etche, Okirika, Degema Ikwere, Eleme, Emohua and Oyibo, LGAs respectively. (Figures 1 and 2). The area is located within the Niger Delta coastal zone made up of sedimentary formations [15]. As a coastal city, the equatorial monsoon climate influences its atmospheric characteristics due to its nearness to the Atlantic Ocean. Both the maritime and continental air masses control the rainfall and temperature pattern of the city [16]. As a city located within the Inter-Tropical Convergence Zone (ITCZ), it is affected with the warm humid maritime Tropical air mass with its south-western winds and the hot and dry continental air mass from the north-easterly winds. The moist south-west wind in the area generates heavy rainfall amount ranging from 2000 to 2500 mm with the peak period from April to September and in some years extends to October [17]. From April, relative humidity increases, peaking in July to September and dropping steadily and continuously till March with the lowest trough in January [16]. In a year cycle, temperature peaks in January to March and relative humidity drops continuously within the months. The urban heat island that affects human comfort is a function of air temperature during dry season, relative humidity during the rainy season and wind flow systems in the dry season [18]. Average peak temperature is 32°C and the lowest 26°C are usually observed in January and July respectively [17]. The humidity is high with mean annual figure at 85% with high and low peaks during the wet and dry seasons respectively [8].Cloud cover pattern in the area is constantly being improved with monthly average of over 6 okt as [16]due to the massive water vapour that rises to the atmosphere as a result of adjacent water bodies. Cloud cover is highest during the wet season and lowest during the dry months respectively. The average daily sunshine was less than 3 hours as observed in July and about 4-5 hours in January and December respectively [13].For the wind speed pattern, mean monthly range is between 0-3m/s [14][15] with high and low trends observed during the nocturnal hours. Urban heat island is influenced by these climatic parameters operating in Port Harcourt and Environs, Rivers State, Nigeria.

Figure 1: Port Harcourt Metropolis and Environs

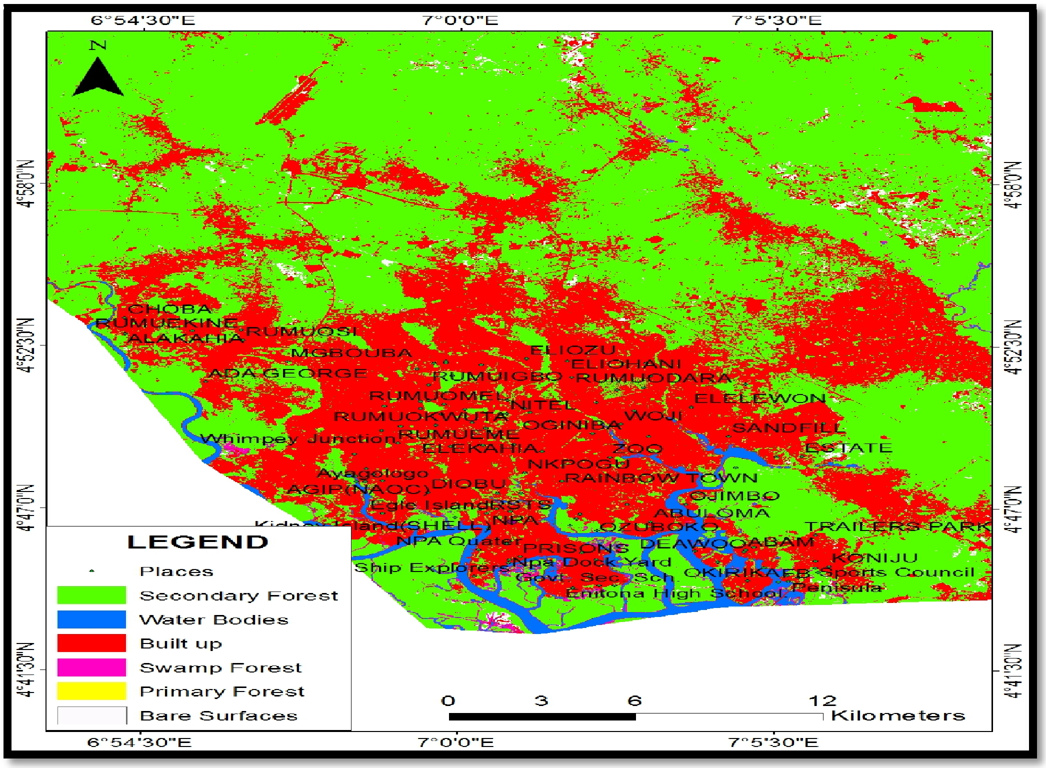

Figure 2: Land Cover of Port Harcourt Metropolis and Environs

2.2. Methods of Data Collection

Data used for this study were collected from direct field observation and from the archives of Nigerian Meteorological Agency (NIMET), Port Harcourt International Airport covering a period of 12 months (January – December, 2017).Direct field measurement of temperature was carried out during the 0600, 1200 and 1800 GMT hours. Port Harcourt and Environs was stratified into 10 zones based on land use types, with the Tent zones serving as control (Table 1). The temperature data were collected simultaneously from the various land use types in Port Harcourt and Environs as adopted by [19][20]. Temperature from ground observation and recording was carried out at the various land use types in pre-determined land use locations (35 points)across the weekdays (Sunday, Monday, Tuesday, Wednesday, Thursday, Friday and Saturday) in both wet and rainy seasons. The Multi-thermometers were HI/LO/AL UP model manufactured by MEXTECH. The thermometers have temperature resolution of 0.1^{0}C with measuring range of -50^{0}C to 300^{0}C and -50^{0}C to 200^{0}C respectively. The temperature accuracy was ±1^{0}C at the range of -50^{0}C to 150^{0}C. And the equipment was properly protected to avoid error reading. This was carried out with the help of field assistants at various data sample points in Port Harcourt and Environs. Temperature data from rural sites were collected from plots of land covered with low plants and grasses with the thermometer mounted on wooden pole. Rural areas used were Elibrada, Obeta,Dankiri, Aleto and Omuagwa which acted as control points. Temperature data from urban area were collected from areas with low and high buildings, some with few or no trees collected 3 meters above head height in the canopy layer. The urban land cover was made up of stone, brick urban, pavement materials, concrete and other materials for construction.

Urban heat island pattern across the weekdays (Sunday-Monday) was derived from hourly and daily temperature readings and converted to mean values in wet seasons of April, May and June (early wet season); July, August and September (late wet season) and dry season of October, November and December (early dry season) as well as January, February and March (late dry season). Wet season in Port Harcourt metropolis and environs begins from April - September and dry season from October – March [10] [13]. Descriptive statistics of mean, range, tables, charts and plates were used to analyze the data generated. Also, The analysis of variance (ANOVA) was used to ascertain the variation in UHI across the weekdays (Sunday - Monday) in both wet and dry seasons respectively. Additionally, remote sensing satellite imageries from Enhance Thematic Mapper (ETM+) of2017were adopted to detect changes and delineate land use types of Port Harcourt and Environs. The Normalized Difference Vegetation Index (NDVI) was used to differentiate the greenness of the city area and the Normalized Difference Built-up Index (NDBI) was used to separate the built-up of the area in terms of infrastructure and urban pavement material variation.

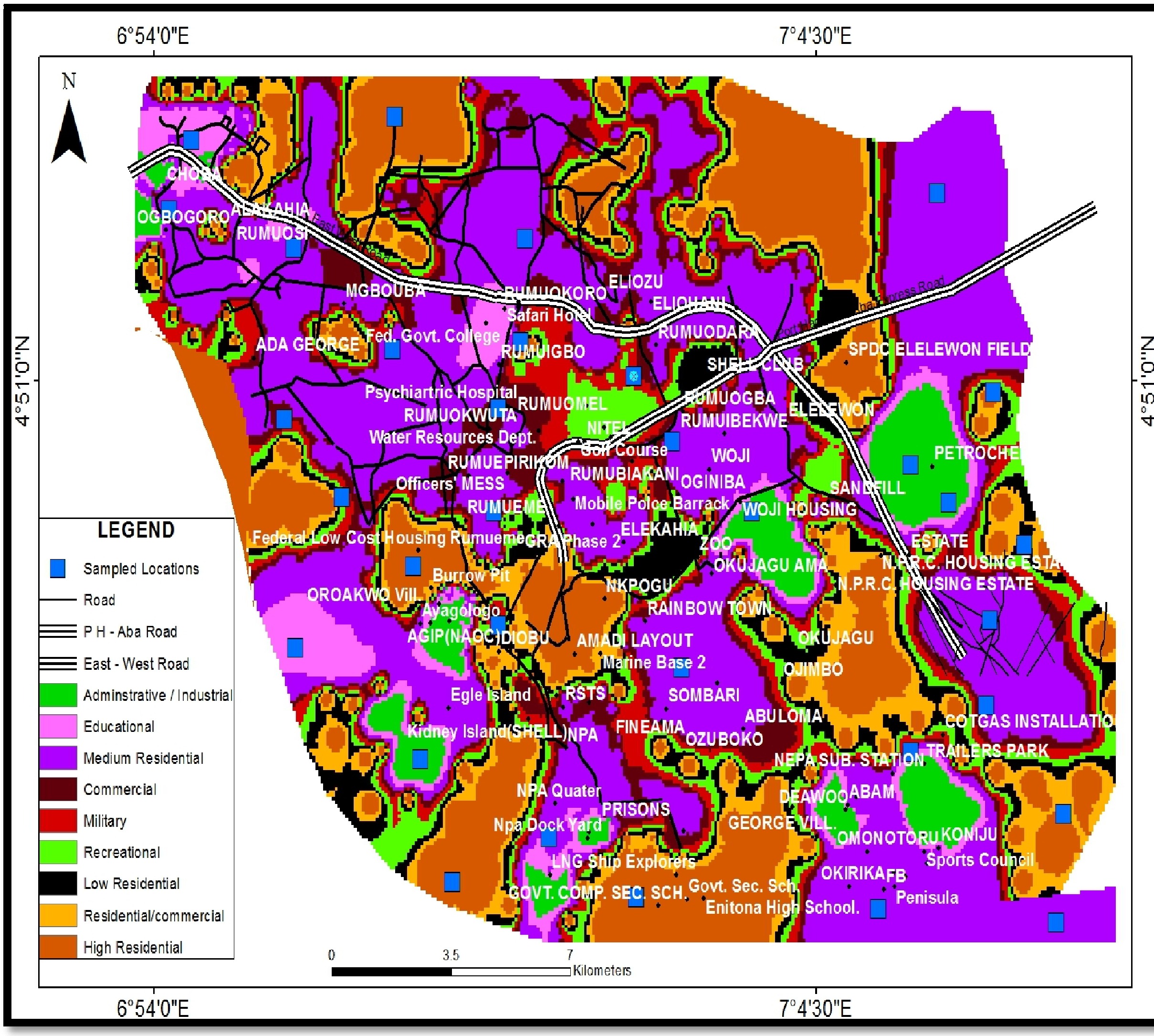

Figure 3: Land Use Types and Observation Sites

Zone	Land Use Type	Location
1	Low Residential	GRA, Shell estate, Total estate, Intel zone, Oyibo, Eleme, Igwuruta, Gbolokiri, Etche, Choba, Iwofe, Jetty, Elelenwo, Okirika, Eagle Island, Rumosi, Elekahia, Mgbuoba.
2	High Residential	Diobu, Enitona School Area, D-Line
3	Medium Residential	Ada-George, Abloma, Rumuigbo, Port Harcourt Township, Rumuola, Choba, Mgbuoba, Woji, Okirika, Rumuodara
4	Educational	University of Port Harcourt, University of Science and Technology, Port Harcourt Poly Technique, Ignatious Ajuru University
5	Commercial	Mile One market, Mile 3 Market, Rumuokoro Market, Slaughter, Oil Mill Market, Ikoku market
6	Military	Bori Camp, Airforce, Navy barracks
7	Recreational	Port Harcourt Tourist, Rainbow Zoo, Boro Park, Port Harcourt Pleasure Park, Woji Housing
8	Residential/Commercial	Rumuaghorlu, Rumuokwuta, Rumukrushi, Rumuodomaya, Rumuibekwe, Rukpoku, Orazi, Ogbunabali,
9	Admin/Industrial	Rivers State Secretariat, BMH, UPTH, Transamadi, Agip, Marine Base, NPA, Eleme petrochemical area.
10	Rural	Elibrada, Aleto, Dankiri, Obeta, Omuagwa as control sites

Table 1: Zone, Land Use Type and Location

3. Results and Discussion

The data collected were presented in Tables 2-4 and Figures 6-11; and discussed below.

3.1. UHI Pattern across the Weekdays during the Wet season

Temperature distribution and urban heat island at various land use types across the weekdays during the wet season was summarized in Table 2. Monday recorded the highest UHI of 7.2°C and Saturday had the lowest UHI intensity of 3.9°C. Thursday had UHI of 5.0°C; Tuesday was 6.2°C and Sunday 5.9°C. Wednesday value was 4.3°Cand Friday 4.8°C. UHI variation of 3.3°C across the weekdays and mean UHI of 5.3°C were recorded during the period. Also, there was noticeable temperature difference (Figure 6) between the rural site and the city center made up of high residential and commercial structures.

Temperature varied at the range of 4.7°C and mean temperature value of 29.5°C was recorded across different land use types (Table 2). This finding is similar to [21]in Benin City which had mean temperature value of 28.8°C across various land use types during the wet season.

The interaction between temperature and UHI (Figure 7) indicated that increase in UHI is not directly proportional to increase in temperature due to the variation in human activities and climatic parameters across the weekdays. Monday had the highest UHI of 7.2°C with relatively low temperature of 29.4°C compared to Saturday that had UHI of 3.9°C and temperature level of 29.5°C. Friday had the highest temperature value of 30.2°C but maintained UHI value of 4.8°C. It is obvious that the city UHI was high in the early weekdays as against the low UHI in the middle of the week. The low temperature during the wet season was influenced by thick cloud cover and the high UHI was favored by low wind velocity prevalent during the wet season.

Mean Temperature and UHI in Degree Celcius											
	Rural	Military	Admn /Indust.	High Res.	Res/ Comer.	Med Res.	Commer.	Low Res.	Educt.	Recreat.	UHI= (∆Tu-r)
Mon	28.7	28.8	30	29.1	33.7	30.3	29.9	29.5	27.9	26.5	7.2
Tues	28.7	30.5	31.3	30.8	33.1	30.7	30.5	28.3	30.4	27.1	6.2
Wed	28.8	28.3	31.6	30.8	32.4	30	30.2	29.1	30.9	29.2	4.3
Thurs	29.2	30	26.5	27.8	31.2	28.1	27.7	28.2	27.5	26.1	5
Fri	28.7	31.5	30	30	33.2	30.5	30.6	29.3	30	28.3	4.8
Sat	28.8	28.5	29.4	29.8	31.7	28.2	30.6	28.8	31.4	28.2	3.9
Sun	28.9	28.4	28.5	29.9	32.8	30.7	28.2	28.1	27.1	27	5.9
Mean	28.8	29.1	29.6	29.7	32.6	29.8	29.6	28.7	29.3	27.9	5.3

Table 2: Temperature and UHI across Weekdays and Land Use Types during the Wet Season

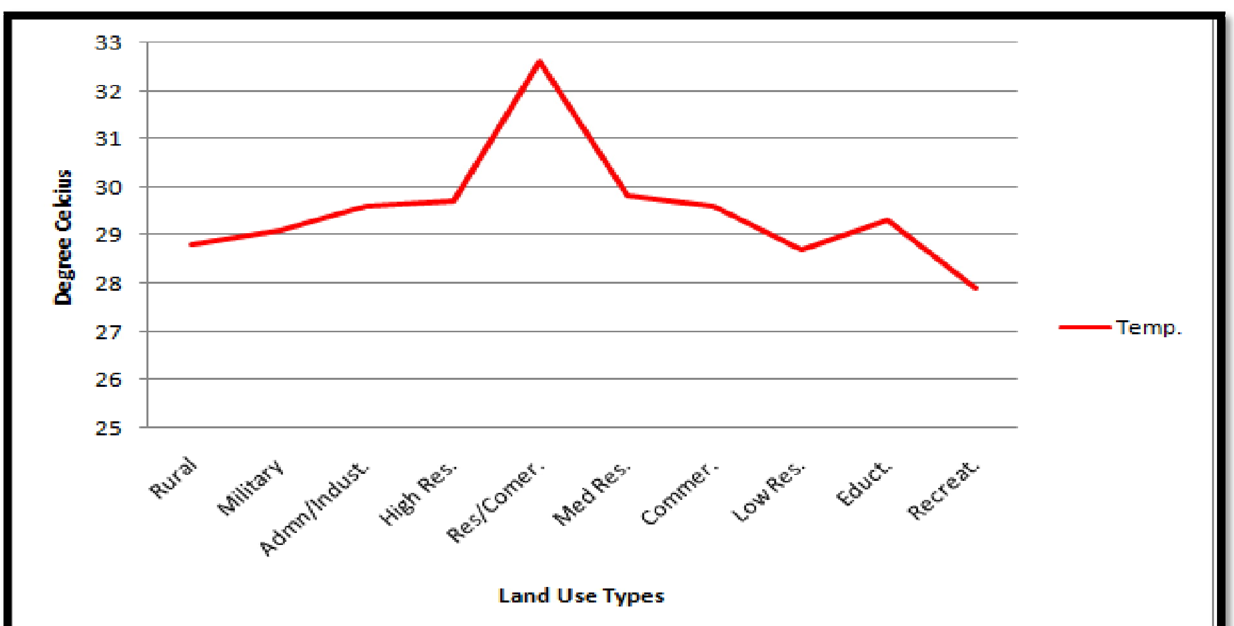

Figure 4: Temperature Spread across Land Use Types during the Wet Season

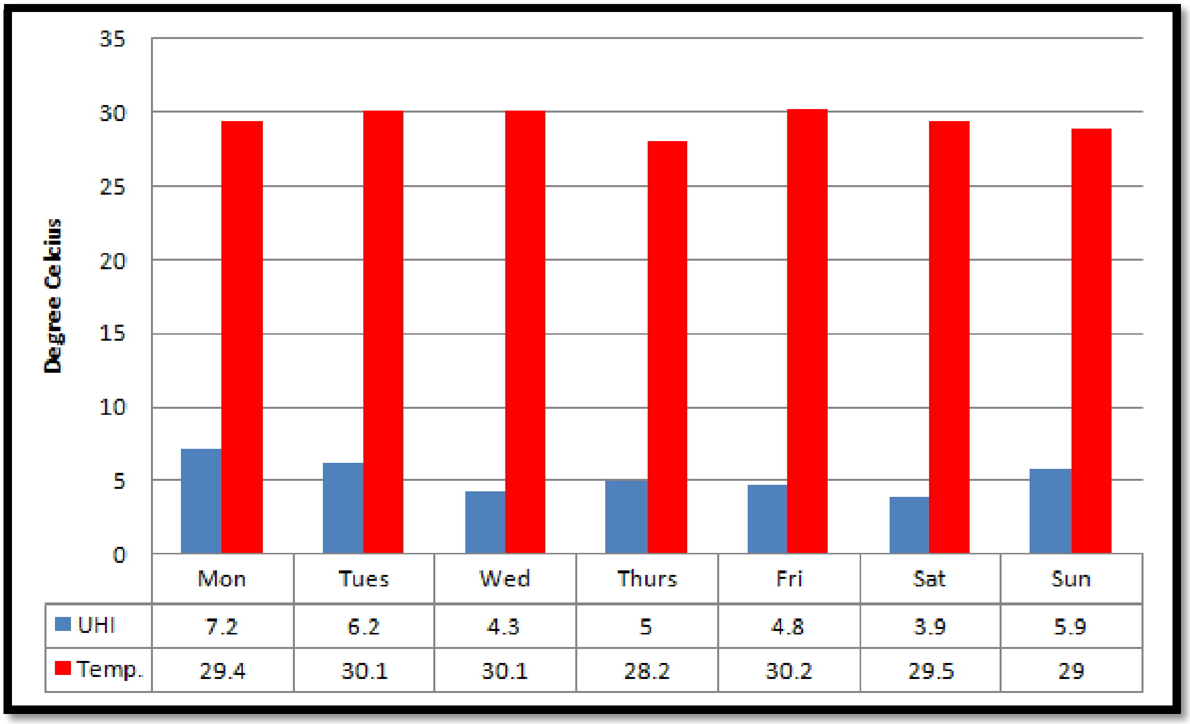

Figure 5: UHI and Temperature Interaction across the Weekdays during the Wet Season

3.2. UHI Pattern across the Weekdays during the Dry Season

During the dry season (Table 3) Monday recorded UHI of 6.6^{o}C as the highest and the lowest UHI was recorded on Thursday and Saturday with equal value of 4^{0}C and weekly variation of 2.6^{0}C respectively. Sunday had UHI of 5.5^{o}C, Tuesday was 6.1^{0}C, Wednesday 4.5^{0}C and Friday 4.7^{0}C. The season had mean UHI of 5^{o}C across the weekdays. Mean temperature variation during this period was 4.7^{o}C. There was temperature rise at the center of the city made of commercial and high residential buildings.

The relationship between temperature and UHI (Figure 9) showed the role of anthropogenic activities and climatic parameters as they influence the interaction between temperature and UHI during the dry season. Monday had the highest UHI of 6.6^{o}C with temperature value of 30.1^{o}C compared to Friday that had UHI of 4.7^{o}C and highest temperature level of 31.5^{o}C. Sunday, Monday and Tuesday had the highest UHI across the weekdays. [22] in their studies in Paris suggested UHI values of +0.5^{o}C-2.5^{o}C as comfortable threshold for city dwellers. This indicates that human comfort was compromised in the city. [23]noted that these anthropogenic activities are on the high side during the beginning of the weekdays. The dry season experiences clear cloud cover that favors insolation and intense wind velocity that reduces UHI due to the harmattan north-easterly wind that blows across the gulf of Guinea down to the coast of Nigeria which Port Harcourt and its environs are affected [24].

Mean Temperature and UHI in Degree Celcius											
	Rural	Military	Admn /Indust.	High Res.	Res/ Comer.	Med Res.	Commer.	Low Res.	Educt.	Recreat.	UHI= (△Tu-r)
Mon	29.5	29.8	31.2	29.7	34.1	30.8	30.2	30.4	28	27.5	6.6
Tues	29.3	32.4	31.9	31.8	33.8	31.3	31.3	29.7	30.3	28.6	6.1
Wed	29.4	29	32	31	33.4	30.4	30.5	29.3	30.5	29.2	4.5
Thurs	30.8	30.4	30	32	33.6	31	30	29.7	30.4	29.4	4
Fri	30	32.2	32.2	31.5	34	32.2	32.5	30.5	30.7	29.4	4.7
Sat	30.2	28.4	30	30.6	32.4	28.6	31.8	29.5	32.32	29.3	4
Sun	30.1	29.1	29	31	33.6	31.3	30	29	28.6	28.1	5.5
Mean	29.9	30.2	30.8	31.1	33.5	30.8	30.8	29.6	30.1	28.8	5

Table 3: Temperature and UHI across Weekdays and Land Use Types during the Dry Season

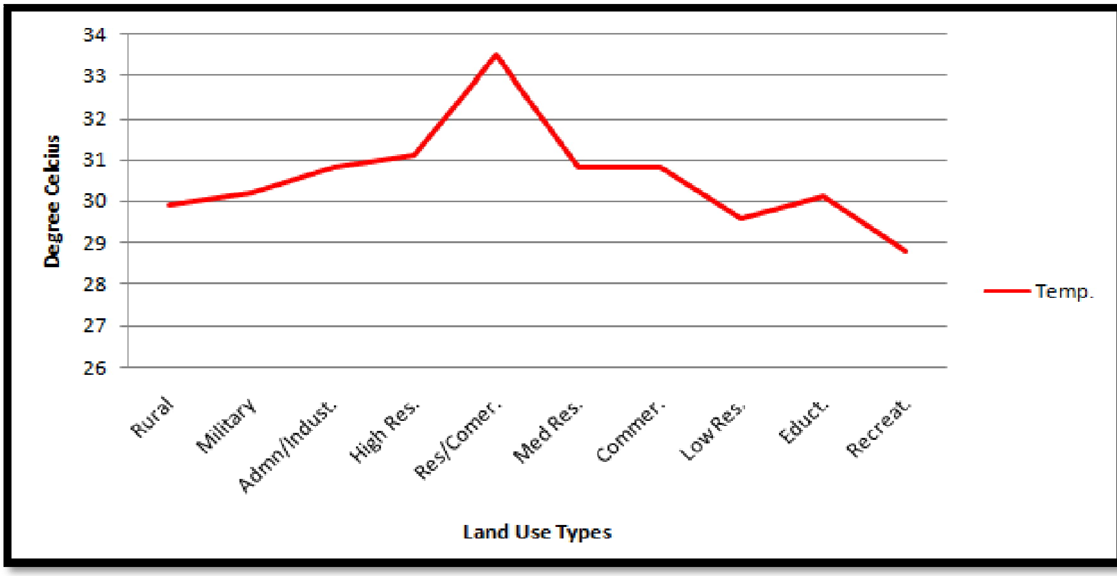

Figure 6: Temperature Spread across Land Use Types during the Dry Season

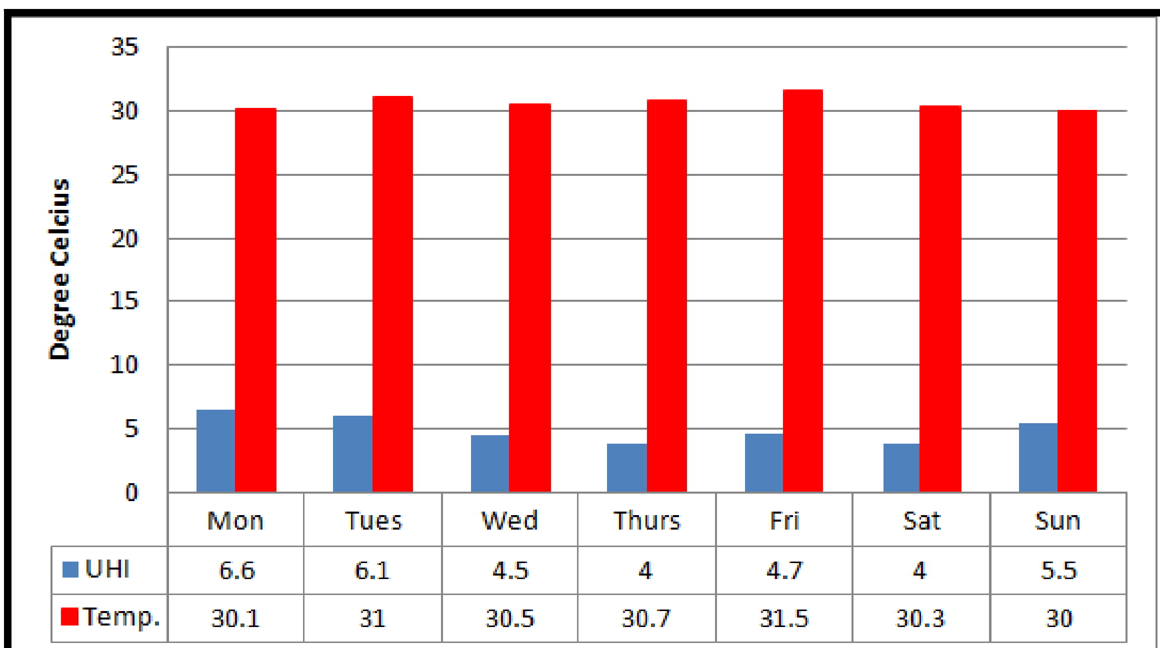

Figure 7: UHI and Temperature Interaction across the Weekdays during the Dry Season

3.3. Evaluation of Weekday Uhiunder Wet and Dry Season Conditions

A comparison of UHI in both wet and dry seasons is expressed in Figure 10. UHI in both seasons had similar pattern such that Sunday had UHI of 5.9^{0}C wet and 5.5^{0}C dry, Monday 7.2^{0}C wet and 6.6^{0}C dry and Tuesday 6.2^{0}C wet and 6.1^{0}C dry indicating that UHI was highest in the beginning of the week. This view is similar to the findings of [25]that the urban heat island in Seoul was stronger in the beginning of the week. [26] Noticed that the flow of vehicular traffic across the weekdays was intense during the beginning of the weekdays such as Sunday, Monday and later Friday suggesting the contribution of vehicular contribution to UHI performance in the city. Thus, Saturday had the least UHI of 3.9^{o}C during the wet season and 4.^{0}C during the dry season. Saturday and Wednesday had the least UHI regime in both seasons showing days of relative comfort in the city during the survey period. The mean UHI value during the wet season was 5.3^{0}C and 5.1^{0}C during the dry season showing that dry season offered relative comfort to Port Harcourt city dwellers.

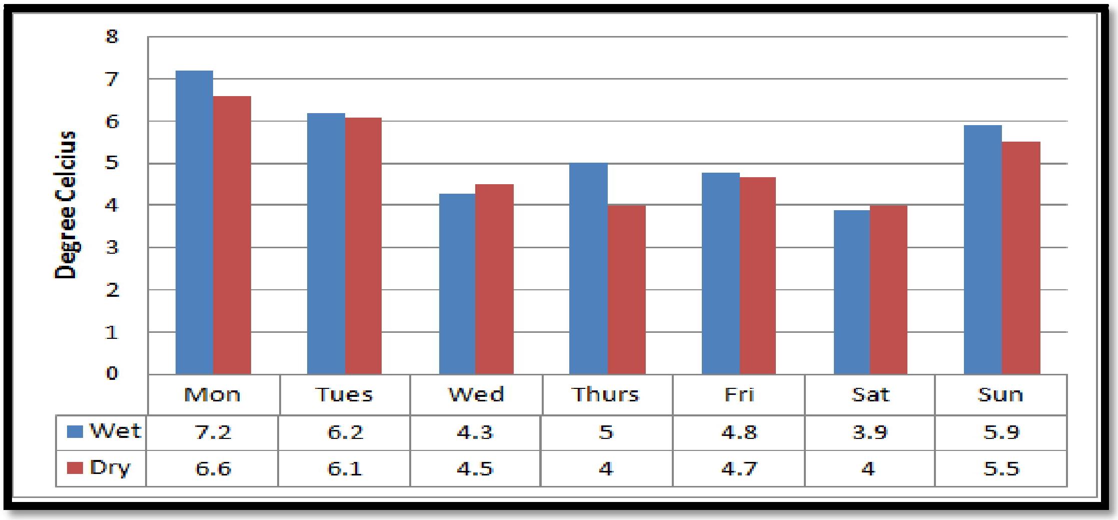

Figure 8: Weekday Urban Heat Island during Wet and Dry Seasons

As observed in Figure 11, temperature in Port Harcourt and Environs was highest during the dry season due to clear cloud cover that permitted high insolation during the dry season. Friday had the highest temperature in the seasons with the values of 30.2^{0}C wet and 31.5^{0}C dry while Sunday had the least temperature of 29^{0}C wet and 30^{0}C dry. Similarly, [21]observed Benin City to be cooler on Sundayswith mean temperature of 29.4˚C and 27.1˚C within the urban canopy. Tuesday ranked the second highest temperature day with the values of 30.1^{0}C and 31.0^{0}C in both seasons respectively. The midweek days had the highest temperature beginning from Wednesday to Friday in both seasons. The mean temperature values 30.1^{0}C for both seasons were 29.5^{0}C during wet season and 30.6^{0}C in the dry season respectively. A study undertaken by [27]observed that UHI effects were found to be severe in areas of dense built-up infrastructure and at commercial centers with dry months having high temperature variability than cool months.Both seasons have exceeded the comfort threshold of 27^{0}C according to [28]indicating that human comfort is compromised.

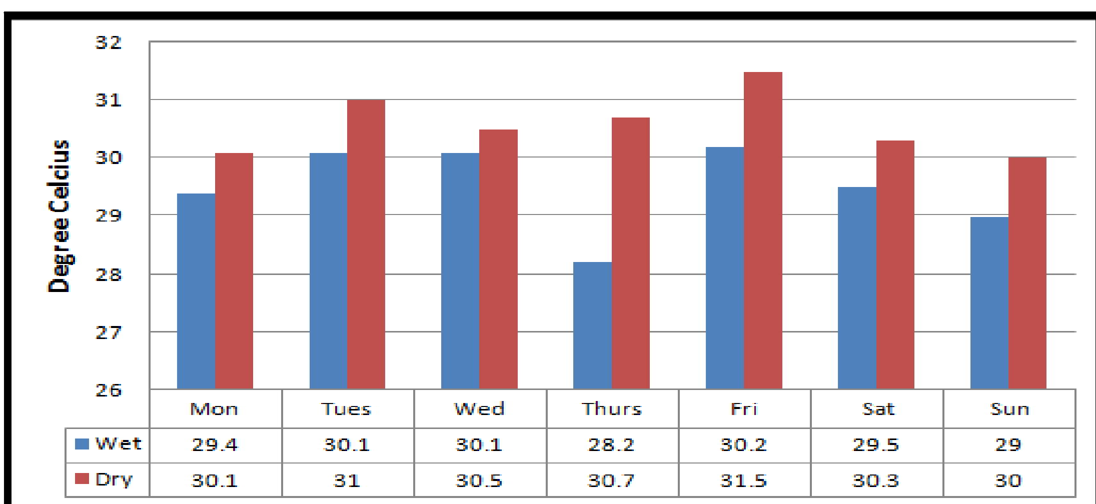

Figure 9: Weekday Temperature in Both Wet and Dry Seasons

In order to ascertain if there is significant variation in urban heat island across the weekdays in Port Harcourt and Environs, the analysis of variance (ANOVA) was employed (Table 4).When the calculated F-value is greater than the critical F-value, it means there is a significant variation [29].

The urban heat island across the weekdays has the calculated F value of 7.8325 and the critical f-value of 2.77629 with 4 degrees of freedom for a two-tailed test at 0.05 significant levels. This showed that the calculated value (7.8325) is greater than the critical f-value of 2.77629. This indicates that UHI across the weekdays (Monday, Tuesday, Wednesday, Thursday, Friday, Saturday and Sunday) differ significantly. This confirms the earlier view that UHI was intensive on the Sunday, Monday and Tuesday skewing toward the beginning of the week days. Also, the midweek UHI level dropped from Wednesday through Friday and a severe decrease on Saturday. This is similar to the UHI variation in the City of Kuala Lumpur in Malaysia as noted by [3] where the weekday UHI varied with Monday (4.7°C), Tuesday (3.9°C) Wednesday (4.2°C) and 5.1°C, 5.4°C, 4.3°C and 5.5°C on Thursday, Friday Saturday and Sunday respectively showing variation of 1.6°C UHI across the weekdays.

Source of Variation	SS	df	MS	F	P-Value	Critical-f	Remark
Daily UHI	6.85829	4	1.71457	7.8325	0.00035	2.77629	Rejected
Seasonal UHI	34.072	6	5.67867	25.9413	2.3E-09	2.50819	Rejected
Error	5.25371	24	0.2189				
Total	46.184	34					

Table 4: ANOVA Test Explaining the Difference in UHI across the Weekdays and Seasons

4. Conclusion

Urbanization as a product of people and materials on a particular geographical space has altered the temperature of the city center different from the rural fringes thereby propagating urban heat island effect such as consumption of more energy, raise air pollutants and greenhouse gas, compromise human health as well as impaired water quality.Urban heat island effect is intensive in the beginning of the week (Sunday, Monday and Tuesday). Monday was the hottest day of the weekand the lowest UHI was noticed on Saturday. Intensity of UHI is severe during the wet season when compared withthe dry season. Both wet and dry seasons have mean UHI of 5.2°C per annum with temperature variation of 1.1°C. It was observed that increase in temperature does not imply proportional increase in UHI in Port Harcourt and Environs. Temperature in the area has exceeded the heat comfort threshold of 27°C temperature and +0.5°C-2.5°C UHI value when compared with annual mean temperature of 30.1°C and 5.2°C UHI respectively. Commercial and high residential areas have the highest urban heat effect in the city with temperature rise of 32.6°C in wet season and 33.5°C in dry season respectively. Thus the study concludes that the weekday urban heat island of Port Harcourt and Environs has exceeded the comfort threshold which is severe in the beginning of the week.It is therefore pertinent for policy makers to urgently implement land use planning and green-city projects without further delay in order to make Port Harcourt and Environs a livable place free from heat disaster.

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