URBAN POPULATION EXPOSURE TO HEATWAVES AND ADAPTIVE CAPACITY IN THE NIGER DELTA

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Abstract
The study investigates spatial disparities in urban heatwave exposure and varied adaptive capacity in four Niger Delta: cities, namely Port Harcourt, Warri, Yenagoa, and Uyo. The study addresses the need for city specific evidence that guides heat risk planning in a region with rapid urban growth and rising thermal stress. It employs a mixed- methods, ex post facto design with data from meteorological archives from 1995 to 2024, institutional health records, municipal housing registries, and retrospective household surveys. Stratified criteria based on housing type, population density, and past climate patterns guided the selection of 434 households across the four cities. Heat index values were computed with the Rothfusz regression formula. Port Harcourt recorded the highest peak value at 43.7°C, followed by Warri at 39.8°C. Heavy concrete use and limited ventilation produced the highest Heat Retention Index in Port Harcourt with a value of 0.78. The Adaptive Capacity Index showed marked infrastructure gaps in Warri and Yenagoa, which increased their exposure to thermal stress linked to urban form and institutional readiness. The findings support targeted planning for each city in the Niger Delta rather than broad references to sub- Saharan African urban systems.

Keywords: Urban Population; Exposure; Heatwaves; Heat index; Adaptive Capacity; Niger Delta,

1. Introduction

The increasing intensity and frequency of extreme heat events represent a significant and growing threat to urban populations, particularly in low-income and middle-income regions already facing rapid urbanisation, socio-economic inequalities, and weak infrastructural systems. Climate change increases heatwaves in tropical and subtropical regions, making urban centres vulnerable due to urban heat island effect, anthropogenic emissions, and dense built environments (Joshi et al., 2024). The Niger Delta is faced with rapid urbanisation, environmental deterioration, and climate variability; thus, heat stress is increasing (Victor & Ayegbunan, 2025). The need to understand the relationship between exposure to and adaptation to extreme heat is of necessity essential for sustainable urban development as cities expand, particularly without adequate climate-sensitive planning.

Boyitie et al. (2024) reports that Warri, Yenagoa, and Uyo face soil depletion, reduced vegetation cover, biodiversity loss, and environmental damage linked to gas flaring and other oil sector activities. The study adds that weak governance and persistent emissions of CO_2, SO_2, and NO_2 raise local temperatures. These conditions limit thermal control in the built environment and increase heat exposure. Because of the high temperatures and relative humidity, the Niger Delta is disproportionately potentially at risk of heat-related morbidity and mortality. Urban resilience in the Niger Delta is under threat due to rising heatwaves, putting strain on underfunded public health systems (Aweda, 2025). The resilience of individuals, households, and institutions is influenced by factors such as building density, vegetation cover, housing materials, and access to services. The resilience of these systems is crucial in mitigating the effects of stress and promoting urban resilience in the face of climate change. The study clarifies heat related risks in urban areas in the Niger Delta. It defines exposure levels, housing related drivers, and gaps in local capacity. It offers evidence that supports planning and policy decisions that aim to improve climate resilience in these cities. It strengthens current knowledge on heat exposure in Niger Delta cities by providing measured evidence on household conditions, housing materials, and local capacity. It gives researchers and public institutions data they can apply in climate risk assessments and in the design of heat response plans.

2. Conceptual Issues

The study applies urban socio ecological resilience as the framework that guides the assessment of heatwave exposure and adaptive capacity in the Niger Delta. This concept integrates the dynamic interaction between social systems, ecological processes, and urban infrastructure to evaluate how cities respond to climatic stressors such as extreme heat (Chen et al., 2024). Urban socio-ecological resilience highlights the importance of cities being able to create adaptive systems that are flexible, inclusive, and integrated across scales (Herath, 2025). The Urban Socio-Ecological Resilience Framework offers an extensive strategy to assessing and responding to heatwave exposure and ability to adapt in the Niger Delta (Figure 1).

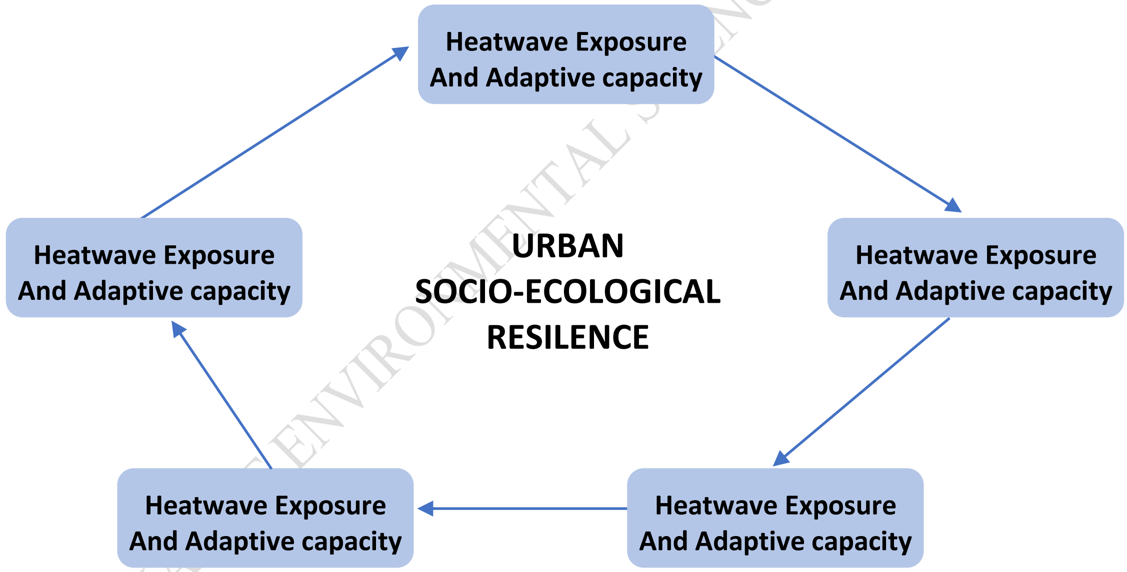

Figure 1: Urban socio-ecological resilience model

The study uses urban socio ecological resilience as its guiding framework because it links social conditions, ecological change, and the built environment in one system. The model in Figure 3 shows a cycle because exposure and capacity influence each other over time. Cities adjust their behaviour, infrastructure, and institutions in repeated cycles as heat conditions intensify. The framework integrated three interdependent components (social systems, ecological processes, and urban infrastructure). Feedback mechanisms are also included, highlighting the socioeconomic constraints influencing adaptation and the need for interventions that are both technically feasible and socially equitable. Urban systems in heat-vulnerable regions exhibit urban socio-ecological resilience, a dynamic concept that requires continuous learning, adaptation, and transformation, promoting long-term resilience across multiple sectors.

Furthermore, the concept of socio-ecological resilience incorporates feedback mechanisms, which are evident in the behavioural adaptations reported in the household survey, such as reliance on traditional cooling methods due to economic limitations (Asibey et al., 2025). Urban systems are transforming to improve resilience against heatwaves, balancing infrastructure with social equity through socio-ecological resilience framework (Courtney-Wolfman, 2024), promoting integrative planning, climate-sensitive building standards, and community-based early warning mechanisms. The framework is suitable for this study because the Niger Delta faces rapid urban growth, weak services, and environmental stress linked to oil activity. These conditions shape how households experience heat and how cities respond. The approach allows you to assess exposure, material conditions in housing, access to services, and local decision making as one connected system. Studies in Accra, Durban, and Kigali have used this framework to assess heat risk by linking household behaviour, vegetation loss, and infrastructure gaps. The approach also exposes challenges. Household surveys show that many families rely on improvised cooling because of low income and unstable power supply. The model accounts for these behavioural constraints. Ecological data show reduced vegetation cover, which increases surface temperatures. Infrastructure assessments show limited ventilation in dense settlements. The study navigated these challenges by collecting data across ecological, social, and infrastructural domains. This produced an integrated picture of how heat exposure develops and how cities in the region can strengthen their response capacity.

3. Materials And Method

The Niger Delta located in southern Nigeria is an ecologically sensitive and commercial regions. The region, positioned between latitude 3˚00'N to 6˚00'N and longitude 5˚00'E to 8˚00'E (Figure 2), spans approximately 70,000 square kilometres and includes nine establishing states, including Rivers, Delta, Bayelsa, and Akwa Ibom (Boyitie et al., 2024).

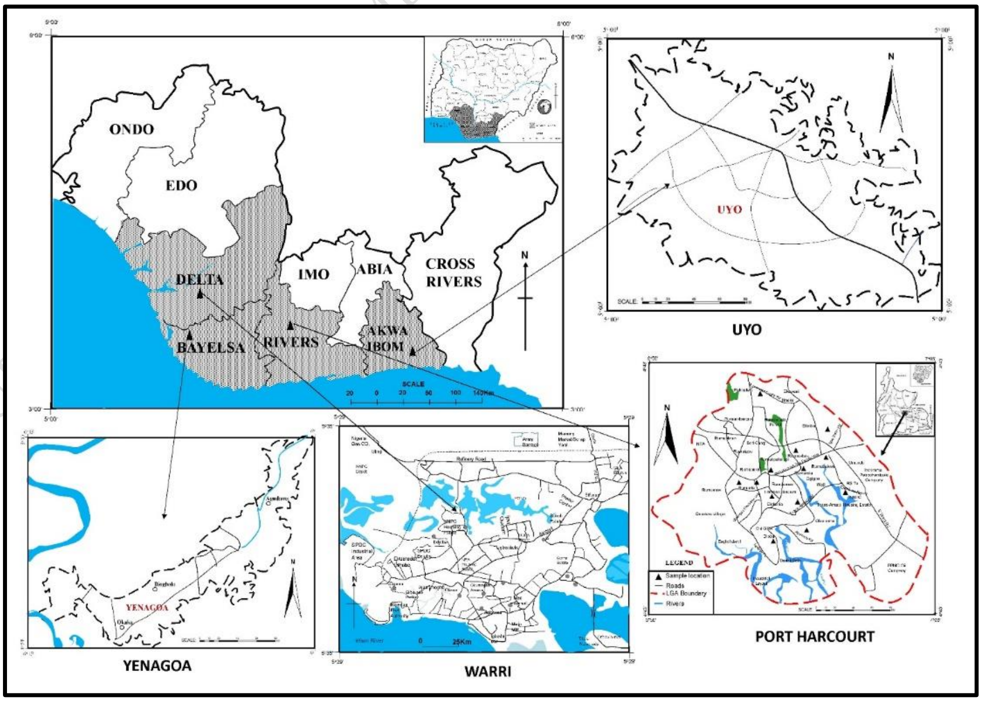

Figure 2: Map of the Niger Delta
Cartographic Unit of the Department Geography, Dennis Osadebay University, Asaba

The Niger Delta, has a population of over 50 million and this makes it a focal point for national development while also making it susceptible to severe environmental stress. The region's ecological landscape, which includes wetlands, and estuaries, supports livelihoods such as fishing, agriculture, and oil production. However, industrial activities have caused widespread environmental degradation. Population growth in urban areas such as Port Harcourt, Warri, Uyo, and Yenagoa has increased environmental pressures due to changes in land use, increased vehicular emissions, and residential development (Victor & Ayegbunan, 2025).

The study used an ex post facto design to measure the link between heatwave exposure and adaptive capacity in Port Harcourt, Warri, Yenagoa, and Uyo. The cities were selected through a comparative assessment of climate vulnerability and urban growth. Historical temperature increases from 1995 to 2024, frequency of days above the 90th percentile heat threshold, and trends in humidity formed the climate vulnerability criteria. Urban growth was differentiated with annual population change from city census records, rate of built-up expansion from Landsat imagery, and documented pressure on housing services. These criteria showed higher thermal stress and faster urban expansion in Port Harcourt and Warri than in Yenagoa and Uyo. The distribution of the 434 sampled households followed the proportion of occupied housing units in each city from municipal housing registries. Port Harcourt had the highest share of occupied units, which informed the selection of 120 households. Warri, Yenagoa, and Uyo had 104, 112, and 98 households respectively, reflecting their smaller housing stock. The aim was to produce proportional representation rather than equal samples.

Neighbourhood density classes followed city master plans and population enumeration area data from state planning offices. High density areas were those with more than 450 persons per hectare. Medium density areas had 200 to 449 persons per hectare. Low density areas had fewer than 200 persons per hectare. These thresholds guided the stratification process. Primary data came from questionnaires and field observations collected during the 2024 dry season. The instrument covered heat stress experiences, cooling practices, and dwelling structure. Field checks validated ventilation features, roofing sheets, wall materials, and cooling devices. Secondary data were from administrative archives including the Nigerian Meteorological Agency, state health departments, housing registries, and planning authorities. Variables included temperature, relative humidity, heat index, morbidity records, building counts, and population distribution. ArcGIS supported spatial mapping of housing type, population density, and access to cooling infrastructure. The heat index was computed with the Rothfusz regression formula. The variables were temperature in degrees Fahrenheit and relative humidity in percent. The model followed the standard expression

$$HI = c1 + c2T + c3RH + c4TRH + c5T^2 + c6RH^2 + c7T^2RH + c8TRH^2 + c9T^2RH^2 \ldots\ldots \text{ (Equ 1)}$$

This produced daily and peak heat index values used for comparison.

The Heat Retention Index measured the thermal load of housing materials. The calculation used weighted thermal coefficients assigned to wall type, roof type, and ventilation score. Port Harcourt had the highest score at 0.78 due to its large use of concrete and limited airflow. Two composite indices assessed adaptive response. The Adaptive Capacity Index was constructed through min to max normalization of health service availability, housing permanence, and access to cooling infrastructure. The indicators used to derive the composite adaptive capacity index and the vulnerability score. The computation followed a structured procedure to ensure replicability. The three adaptive capacity inputs were normalised to a 0 to 1 scale. Access to health facilities drew from WHO service benchmarks. Quality housing reflected structural adequacy, ventilation, and material strength. Public cooling infrastructure represented the availability of shaded transit points, cooling centres, and water points.

Each variable received equal weight. The adaptive capacity index was the arithmetic mean of the three normalised inputs. Vulnerability followed a separate formula. Exposure and sensitivity scores were derived from population density, local temperature anomalies, housing conditions, and health risk patterns. These two elements were summed to produce the impact score. Adaptive capacity was then subtracted from the impact score to generate the final vulnerability value on a 0 to 100 scale. This aligns with established heat risk frameworks that treat adaptive capacity as a moderating factor in thermal stress assessment (Zhang et al., 2024).

The Vulnerability Score was the inverse of the Adaptive Capacity Index and captured the combined effect of exposure and limited response options. Qualitative data from open responses and institutional interviews were coded and grouped into themes that explained the quantitative patterns. The combined approach allowed the study to link climatic records, health burdens, and infrastructure gaps with observed heat exposure in the four cities. The statistical analyses were performed using SPSS version 27. Qualitative data from open-ended survey responses and institutional interviews underwent thematic analysis to contextualise the quantitative findings. The integrated methodology enabled the evaluation of pollutants, health outcomes, and infrastructural capacity influence urban heat exposure. The approach is in line with previous studies on climate adaptation in sub-Saharan African cities (Adenuga et al., 2021; Ibrahim & Mensah, 2022; Allarané et al., 2024).

4. Results and Discussion

Table 1 presents the population density of selected Niger Delta cities in 2024, revealing marked spatial disparities in urban concentration. Port Harcourt exhibits the highest population density at 10,284 persons/km^2, significantly surpassing the other cities, with Uyo displaying the lowest at 4,025 persons/km^2. Warri and Yenagoa reflect intermediate densities of 4,373 and 4,731 persons/km^2, respectively. The substantial density in Port Harcourt corresponds with its position as a regional economic hub, which has historically attracted internal migration and urban expansion. The population growth trends between 2000 and 2025, ranging from 2.9% in Yenagoa to 4.3% in Port Harcourt, further underline ongoing urbanization, which intensifies exposure to urban heat stress.

The population and land area data in Table 1 informed the selection of the four cities by showing clear differences in density and growth. Port Harcourt had the highest density and fastest growth, which indicated higher exposure to heat in built up spaces. Warri, Yenagoa, and Uyo showed moderate but distinct density patterns that allowed comparative analysis across different urban forms. These contrasts provided the basis for selecting the cities as representative cases in the Niger Delta. Higher population densities typically correlate with increased impervious surfaces, reduced vegetation, and elevated land surface temperatures, thereby exacerbating the urban heat island effect (Zhang et al., 2022). Consequently, cities like Port Harcourt, with relatively high population density and growth rate, are likely more susceptible to heatwave-related health and infrastructure challenges. The implications are critical for urban climate resilience planning. These findings substantiate earlier studies that emphasized the intersection of demographic pressures and climatic vulnerability in sub-Saharan African urban contexts (Nyathi et al., 2025), thereby reinforcing the urgency for targeted heat adaptation interventions in the Niger Delta.

Table 1: Estimated Population Density of Selected Niger Delta Cities (2024)

City	2024 Population	City Land Area (km²)	Estimated Population Density (persons/km²)	% Growth (2000–2025)
Port Harcourt	3,794,000	369	10,284	4.3
Warri	1,076,000	246	4,373	4
Yenagoa	880,000	186	4,731	2.9
Uyo	1,457,000	362	4,025	3.4

Source: National Bureau of Statistics (NBS, 2023)

Table 2 illustrates a progressive decadal increase in average annual temperatures across four major cities in the Niger Delta from 1995 to 2024. Port Harcourt recorded the most notable rise, with a 0.7°C increase over the three decades, while Warri and Yenagoa experienced 0.8°C and 0.6°C increases respectively. Uyo showed the least change, yet still recorded a 0.5°C rise. These trends point to a consistent warming trajectory that aligns with broader regional climate change projections and confirms increasing thermal exposure within urban environments. Rising temperatures directly intensify the frequency and severity of heatwaves, especially in high-density urban settings where anthropogenic heat retention and limited vegetative cover compound vulnerability (Marcotullio et al., 2022). The thermal shifts noted here are consistent with findings by Li et al. (2022), which document accelerating warming patterns across West African coastal cities due to global climate forcing and urbanisation. Thermal stress increases risks of heat-related morbidity and mortality, undermines urban health systems (Kassomenos & Begou, 2022). Therefore, these findings underscore the urgency for cities in the Niger Delta to mainstream climate adaptation within urban planning frameworks to protect at-risk populations.

Table 2: Decadal Average Temperatures (°C) for Selected Niger Delta Cities (1995-2024)

	Temperature (^{0}C)			
Decadal	**Port Harcourt**	**Warri**	**Yenagoa**	**Uyo**
1995-2004	26.6	26.4	26.5	26.3
2005-2014	26.9	26.8	26.9	26.7
2015-2024	27.3	27.2	27.1	26.8
Net Tempetrature Change	0.7	0.8	0.6	0.5

Source: Nigerian Meteorological Agency (NiMet, 2024)

Table 3 presents monthly temperature and humidity patterns that shape exposure to heatwaves in the four Niger Delta cities. The data show a consistent cycle of high temperatures and elevated humidity, which produces stressful thermal conditions across the year. Yenagoa reports the highest mean temperature at 38.3°C, followed by Port Harcourt at 36.4°C. Uyo records the highest mean humidity at 75 percent, indicating stronger moisture retention in the lower atmosphere. These combinations increase the heat index and intensify exposure, especially during the late dry season. The higher temperatures in Yenagoa align with findings from Melis et al. (2020), who observed strong thermal accumulation in low elevation coastal settlements. The higher humidity in Uyo supports earlier observations by Akande et al. (2023) on inland cities with dense vegetation and limited airflow. The Table highlights marked seasonal shifts. Temperatures peak between January and March across all cities, while humidity reaches its highest values between May and August. This dual pattern elevates heat stress during two distinct periods, the early dry season and the peak rainy season. These findings indicate that residents experience prolonged thermal pressure, which affects adaptive capacity. Urban form, settlement density, and housing materials influence the degree of exposure, consistent with Olanrewaju and Adegun (2021). The Table offers a clear basis for assessing temporal and spatial variations in heat risk across the region.

Table 3: Monthly Mean Maximum Temperature and Relative Humidity

	Port Harcourt		Warri		Yenagoa		Uyo	
Month	**Temp (^{0}C)**	**Humidity (%)**	Temp (^{0}C)	**Humidity (%)**	**Temp (^{0}C)**	**Humidity (%)**	**Temp (^{0}C)**	Humidity (%)
January	38.0	58.0	36.8	60.0	39.5	58.0	36.2	64.0
February	38.0	60.0	37.0	62.0	39.6	60.0	36.4	66.0
March	37.0	66.0	36.3	68.0	39.1	66.0	35.8	72.0
April	37.0	71.0	35.7	73.0	38.5	71.0	35.2	77.0
May	36.0	75.0	35.2	77.0	37.9	75.0	34.6	80.0
June	35.0	77.5	34.7	79.0	37.4	77.0	34.2	82.0
July	35.0	78.5	34.5	80.0	37.0	78.0	33.9	83.0
August	35.0	78.0	34.6	79.0	37.1	78.0	34.0	82.0
September	36.0	76.0	35.0	78.0	37.5	76.0	34.4	81.0
October	36.0	71.5	35.6	73.0	38.0	71.0	35.0	76.0
November	37.0	66.0	36.2	68.0	38.6	66.0	35.4	70.0
December	37.0	62.0	36.6	64.0	39.0	62.0	35.7	67.0
Mean	36.4	70.0	35.7	71.8	38.3	69.8	35.1	75.0

Source: Nigerian Meteorological Agency (NiMet, 2024)

Table 4 presents monthly variations in the heat index across four major urban centres in the Niger Delta, capturing the composite effects of temperature and humidity on human thermal discomfort. The findings indicate that Yenagoa consistently experiences the highest heat index throughout the year, with a mean of 63.2°C, while Port Harcourt follows at 55.6°C. Warri and Uyo register relatively lower average heat indices at 53.9°C and 53.5°C, respectively. This elevated heat burden in Yenagoa reflects both high ambient temperatures and relative humidity levels, intensifying perceived heat stress. High heat index values in Yenagoa, particularly exceeding 60°C during pre-rainy and rainy seasons, pose a significant threat to human health, productivity, and infrastructure resilience. The implication of these findings is that urban residents in Yenagoa, and to a lesser extent Port Harcourt, face substantial risks of heat-related illnesses. Heat index metrics should be integrated into urban planning to mitigate public health risks and enhance adaptive capacity in response to climate change.

Table 4: Monthly Mean Heat Index (°C)

Month	**Port Harcourt Heat Index (°C)**	**Warri Heat Index (°C)**	**Yenagoa Heat Index (°C)**	**Uyo Heat Index (°C)**
January	53.6	50.8	59	51.1
February	55	52.7	61	53.1
March	55.4	54	64	54.7
April	58.9	54.9	65.6	55.4
May	57.5	55.4	66.3	54.8
June	54.9	54.6	65.5	54.3
July	55.6	54.3	64.4	53.5
August	55.2	54.1	64.9	53.4
September	58.2	55.2	65.2	54.5
October	55.1	54.5	63.3	54
November	55.4	53.6	61.9	51.8
December	52.7	52.6	60.3	51.1
Mean	**55.6**	**53.9**	**63.2**	**53.5**

Source: Authors Computation

Table 5 reveals a strong seasonal pattern in heat-related illnesses across the four Niger Delta cities. All cities show peaks in April-May, when heatstroke, dehydration, and fatigue reach their highest levels. For example, Port Harcourt records its maximum total cases (260) in May, driven by 81 out-patient dehydration and 91 fatigue cases. Yenagoa peaks similarly in May (303 total). By contrast, December consistently shows the lowest totals (Port Harcourt: 141; Warri: 130; Uyo: 105; Yenagoa: 172).

Interestingly, Warri's in-patient heatstroke drops to just 1 in July, which deviates sharply from its other summer months. Fatigue (out-patient) remains a large component of cases throughout the year, but still rises in the hottest months (e.g., 106 in May in Yenagoa). These patterns suggest that urban populations in the Niger Delta are most exposed to harmful heat during the peak of the pre-rainy season. The April-May surge aligns with periods of higher ambient temperatures, reduced precipitation, and possibly greater urban heat island effects. Such exposure likely overburdens local health systems, especially outpatient services, indicating limited capacity for preventive adaptation. The marked drop in December may result from both reduced heat stress and possibly lower healthcare-seeking behaviour when temperatures ease.

The anomalous dip in Warri's in-patient heatstroke in July suggests a data anomaly or a localized adaptive response; further investigation is required to understand whether infrastructure, behaviour, or reporting practices drive this. These findings align with biometeorological studies showing that tropical regions, particularly in Nigeria, experience high thermal stress leading to fatigue, sunstroke, and heatstroke. For instance, thermal stress indices have indicated persistent heat fatigue and exhaustion in Nigerian urban centres during warm months (Towolawi et al., 2025). Heat-health adaptation literature for African cities frequently identifies dehydration, heat stroke, and fatigue as recurring impacts (e.g., in low-income urban settlements) (Laue et al., 2022). The high outpatient cases suggest that many individuals rely on primary health care rather than hospitalization, which may reflect limited access to cooling infrastructure or early-warning systems. In terms of adaptive capacity, the data point to systemic weaknesses: absence of effective heat-health early warning, scarce cooling spaces, and likely low awareness of preventive behaviours. To strengthen resilience, city governments should prioritize heat-health action planning: heatwave forecasting, accessible health outreach during peak months, and community cooling interventions (shade trees, public water stations).

Table 5: Monthly Reported In-Patient and Out-Patient Cases of Heat-Related Illnesses

City	Month	J	F	M	A	M	J	J	A	S	O	N	D
Port Harcourt	Heatstroke (In-patient)	8	9	15	16	21	20	16	14	12	15	19	13
	Heatstroke (Out-patient)	18	23	35	40	42	38	30	25	27	32	38	29
	Dehydration (In-patient)	10	13	20	21	25	21	19	16	13	17	21	15
	Dehydration (Out-patient)	22	26	44	62	81	66	56	50	44	47	62	37
	Fatigue (Out-patient)	30	36	55	80	91	79	66	59	53	60	78	47
	Total Cases	88	107	169	219	260	224	187	164	149	171	218	141
Warri	**Month**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
	Heatstroke (In-patient)	6	8	11	13	17	14	12	1	9	11	14	9
	Heatstroke (Out-patient)	15	21	30	35	38	32	29	26	23	28	37	26
	Dehydration (In-patient)	8	9	16	17	21	22	19	15	16	18	19	16
	Dehydration (Out-patient)	19	22	37	50	72	64	55	47	41	45	58	33
	Fatigue (Out-patient)	26	30	51	67	80	73	61	56	53	57	71	46
	Total Cases	74	90	145	182	228	205	176	145	142	159	199	130
Uyo	**Month**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
	Heatstroke (In-patient)	4	7	8	11	11	9	7	9	7	8	9	7
	Heatstroke (Out-patient)	12	17	28	30	34	29	23	25	21	24	27	19
	Dehydration (In-patient)	9	8	13	15	18	15	13	12	11	13	14	11
	Dehydration (Out-patient)	19	20	35	43	56	50	45	37	35	39	45	29
	Fatigue (Out-patient)	20	25	40	57	66	62	57	57	42	53	60	39
	Total Cases	64	77	124	156	185	165	145	140	116	137	155	105
Yenagoa	**Month**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
	Heatstroke (In-patient)	7	11	7	22	28	24	21	19	15	16	23	15
	Heatstroke (Out-patient)	23	29	39	46	53	48	42	39	35	40	48	34
	Dehydration (In-patient)	10	15	23	27	29	23	25	21	19	21	26	17

Dehydration (Out-patient)	28	32	50	65	87	70	65	60	50	57	71	47
Fatigue (Out-patient)	34	41	60	83	106	91	84	82	89	72	99	59
Total Cases	102	128	179	243	303	256	237	221	208	206	267	172

Source: Medical Records, Central Hospitals of Port Harcourt, Warri, Uyo, and Yenagoa (2024)

Table 6 presents the composition of building materials and corresponding Heat Retention Index (HRI) for four major cities in the Niger Delta. The table 6 reports the proportions of concrete, zinc roofing sheets, and mud walls recorded across the four cities. These three materials formed the basis for the Heat Retention Index because they represent the dominant structural elements in residential buildings in the Niger Delta. Concrete refers to reinforced block walls and floors. Zinc roofing sheets represent the standard roofing cover. Mud refers to earth-based walls common in older low-income housing. The index reflects the weighted thermal performance of these materials derived from their surface temperature response and thermal mass. This approach follows established thermal rating procedures applied in humid tropical settlements where concrete exhibits higher heat storage, zinc roofing produces rapid heat gain, and mud walls show moderate thermal absorption (Yuliani et al., 2021). The distribution in Table 6, therefore, provides a clear summary of the material mix used to compute the index.

The findings reveal that cities with a higher proportion of concrete structures, such as Port Harcourt (71%) and Warri (65%), exhibit significantly elevated HRI values of 0.828 and 0.812, respectively. Equally, Uyo and Yenagoa, with comparatively lower concrete use and higher reliance on zinc roofing and mud, show lower HRI values. The association between building material typology and heat retention reinforces the urban heat island (UHI) effect as a critical factor in heatwave exposure. Concrete and zinc materials absorb and retain more solar radiation, thereby intensifying ambient temperatures within densely built environments (Ziaeemehr et al., 2023; Ogbogo et al., 2025). The high HRI values in Port Harcourt and Warri correspond with their higher recorded heat index and heat-related morbidity figures. These findings suggest that current urban development patterns exacerbate thermal exposure risks in the Niger Delta, particularly for populations residing in poorly ventilated, heat-retaining dwellings. To mitigate rising temperatures, passive cooling strategies, improved building codes, and heat-resilient infrastructure designs are crucial, enhancing the adaptive capacity of built environments.

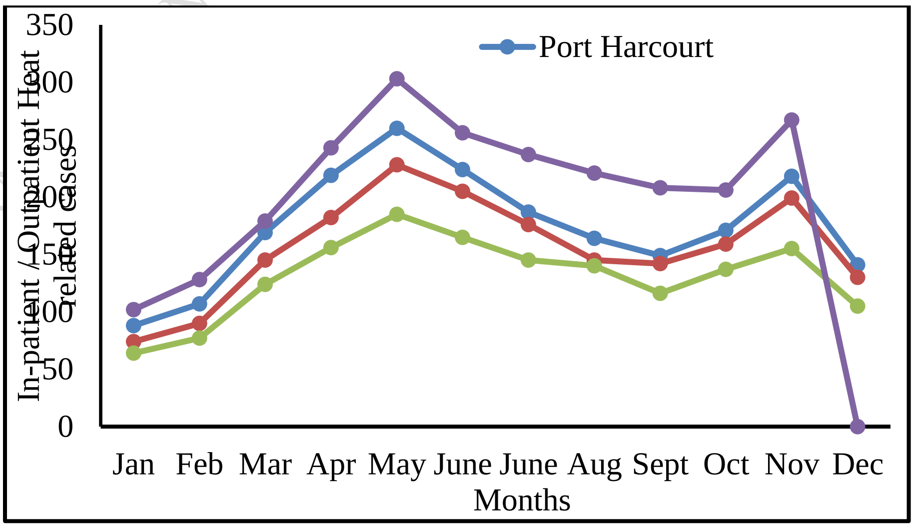

Figure 3: seasonal trends in heat-related illnesses across the Niger Delta cities

Figure 3 highlights clear seasonal trends in heat-related illnesses across the Niger Delta cities. All cities peak between April and May. Yenagoa consistently reports the highest total cases, reaching 303 in May.

Port Harcourt and Warri follow similar mid-year surges, with Uyo remaining lower overall. The mid-year peaks coincide with the hottest pre-rainy months, indicating maximum exposure to heat stress. December shows the lowest totals in all cities, aligning with cooler and wetter conditions. The sharp dip in Warri during July remains evident, signalling either anomalous reporting or local adaptive measures. This visual reinforces the pattern of urban populations facing the greatest physiological burden during peak heat months, stressing the need for targeted adaptive interventions.

Table 6: Distribution of Building Materials and Heat Retention Index

City	Concrete (%)	Zinc Roof (%)	Mud (%)	Heat Retention Index (HRI)
Port Harcourt	71	27	12	0.828
Warri	65	32	11	0.812
Uyo	54	41	9	0.779
Yenagoa	57	37	17	0.782

Source: Field Survey and Housing Inventory Reports (2024)

Table 7 presents the relationship between climatic conditions and household experiences of heat stress, including coping strategies and physiological impacts across four major cities in the Niger Delta. Yenagoa, with the highest mean maximum temperature (38.3°C), also recorded the highest frequency of reported heat stress (86.2%) and sleep disruption (74.6%). Despite its elevated thermal burden, only 60.7% of respondents in Yenagoa relied on fans or air conditioning, reflecting infrastructural and economic constraints. This aligns with findings by Marcotullio et al. (2021), which emphasized the vulnerability of urban populations in tropical regions to thermal extremes, especially in areas with limited access to mechanical cooling. Traditional coping mechanisms, such as shading and the use of wet cloths, remained prevalent, particularly in Yenagoa and Warri, indicating a reliance on adaptive behavioural strategies due to limited technological access. These findings underscore the disproportionate vulnerability of urban residents to extreme heat and point to the necessity for targeted adaptation strategies. Prioritizing equitable access to energy-efficient cooling, expanding urban greening, and improving thermal design in housing are essential for enhancing adaptive capacity in these rapidly urbanizing centres.

Table 7: Household Survey on Heat Stress Experiences and Coping Mechanisms

City	No. of Surveyed Households (n)	% Reporting Frequent Heat Stress	% Using Fans/Air Conditioning	% Using Traditional Cooling (e.g., shading, wet cloth)	% Experiencing Sleep Disruption Due to Heat
Port Harcourt	120	83.5	74.2	55.8	68.3
Warri	104	79.8	68.5	61.3	63.4
Yenagoa	112	86.2	60.7	64.1	74.6
Uyo	98	77.3	71.9	59.2	58.1

Source: Field work (2024)

Table 8 provides critical insights into the spatial inequities in urban adaptive capacity to heatwaves across the Niger Delta. The indicator "Access to Health Facilities (%)" was calculated using the World Health Organization's benchmark of one health facility per 15,000 people. On this basis, Port Harcourt, despite having the highest absolute number of health facilities (n = 86), demonstrates the lowest access rate (2.27%) due to its dense population, exposing a major infrastructural gap. Conversely, Warri exhibits the highest access rate (5.95%), reflecting a better per capita distribution of facilities. This indicator reveals that Port Harcourt has the highest proportion of thermally resilient housing (72.1%), aligning with studies such as that of McNeilly Smith et al. (2024), which highlight the role of built environment quality in reducing heat-related risks. These include public parks, shaded areas, and air-conditioned communal buildings. The Public Cooling Infrastructure Index is low across cities, indicating insufficient public investment in community-level adaptive infrastructure, often overlooked in urban planning.

Table 8: Distribution of Urban Infrastructure Relevant to Heatwave Adaptation

City	Total Health Facilities (n)	2024 Population	Access to Health Facilities (%)	Permanent (Quality) Housing (%)	Public Cooling Points (n)	Public Cooling Infrastructure Index (0–1)
Port Harcourt	86	3,794,000	**2.27**	72.1	45	**0.4**
Warri	64	1,076,000	**5.95**	68.5	39	**0.38**
Uyo	43	1,457,000	**2.95**	62.4	31	**0.33**
Yenagoa	37	880,000	**4.2**	59.8	26	**0.3**

Source: Calculated from WHO Population-to-Health Facility Benchmark (1:15,000); Field Enumeration and Municipal Housing and Infrastructure Records, 2024

Table 9 offers an integrated assessment of adaptive capacity and vulnerability to heatwaves across four urban centres in the Niger Delta. The ranges in Table 9 reflect differences in housing quality, infrastructure distribution, and service coverage across the four cities. The Adaptive Capacity Index, derived from weighted contributions of health facility access, quality housing, and public cooling infrastructure, reveals that Warri holds the highest adaptive capacity score (0.41), correlating with its relatively higher health facility access and moderate housing quality. In contrast, Yenagoa ranks lowest (0.35), reflecting deficits across all three indicators. Despite Port Harcourt's advantage in housing quality (72.1%), its low health access rate (2.27%) and limited public cooling infrastructure (0.4) constrain its overall resilience. The vulnerability scores demonstrate a clear inverse relationship with adaptive capacity. Yenagoa and Uyo, both with lower adaptive capacity indices, register the highest vulnerability scores at 75 and 73, respectively. These findings corroborate earlier work by Smith et al. (2022), who emphasized that structural inequalities in urban infrastructure substantially influence residents' exposure to climate extremes.

Table 9: Composite Adaptive Capacity and Vulnerability Scores to Heatwaves

City	Access to Health Facilities (%)	Quality Housing (%)	Public Cooling Infrastructure Index (0–1)	Adaptive Capacity Index (0–1)	Vulnerability Score (0–100)
Port Harcourt	2.27	72.1	0.4	**0.38**	**71**
Warri	5.95	68.5	0.38	**0.41**	**66**
Uyo	2.95	62.4	0.33	**0.36**	**73**
Yenagoa	4.2	59.8	0.3	**0.35**	**75**

Source: Calculated from WHO Benchmark; Field Enumeration and Municipal Housing and Infrastructure Records, 2024

The regression model in Table 10 reveals a statistically significant model predicting the heat index based on reported cases of dehydration, heatstroke, and fatigue across urban areas in the Niger Delta. With an R Square value of 0.649, approximately 65% of the variance in the heat index is accounted for by these health-related predictors. The adjusted R Square of 0.625 suggests a minimal reduction in explanatory power when adjusting for the number of predictors, affirming the model's robustness. The significance value ($p < 0.001$) supports the reliability of the model.

The derived regression equation is:

Heat Index = 32.487 + 0.121(Heatstroke) + 0.138(Dehydration) + 0.097(Fatigue)

This equation indicates that increases in the incidence of each morbidity type are positively associated with rises in the heat index. These findings corroborate previous studies, such as those by Ugwuanyi et al. (2024), which reported that rising urban temperatures significantly correlate with hospital admissions for heat-related illnesses in Nigerian cities. This model offers a predictive tool for public health planning and early warning interventions, where trends in heat-related illnesses can signal escalating environmental stress before peak thermal thresholds are reached. It reinforces the need for integrating health surveillance with environmental monitoring to strengthen adaptive responses to heatwaves in rapidly urbanizing and vulnerable regions like the Niger Delta.

Table 10: Model Summary of heat index effect on dehydration, heatstroke, and fatigue

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	**.806[a]**	**.649**	**.625**	**2.7061**	**.649**	**27.127**	**3**	**44**	**.000**

a. Predictors: (Constant), Dehydration, Heatstroke, Fatigue
b. Dependent Variable: Heat Index

Source: SPSS Computation

The regression analysis offers important insights into how specific heat-related health conditions relate to rising heat index levels in the Niger Delta. Heatstroke stood out as the most influential variable, showing a strong, positive, and statistically significant association with the heat index (B = 0.528, $p < 0.001$). This means that as heatstroke cases increase, so does the heat index, making it a reliable warning sign of dangerous heat exposure. Remarkably, dehydration was negatively associated with the heat index (B = -0.257, p = 0.005), which might seem counterintuitive. One explanation could be that during periods of extreme heat, people adopt protective behaviours like drinking more fluids or seeking shade, resulting in fewer severe dehydration cases despite higher temperatures. Although fatigue had a positive association with the heat index, its effect was not statistically significant (p = 0.115), likely due to variations in how people experience or report it. Overall, the model shows that among various health symptoms, heatstroke provides the clearest signal of heat stress, reinforcing its importance for real-time monitoring and response strategies in climate-vulnerable urban areas. Port Harcourt records the highest population density among the selected cities, with 10,284 persons per square kilometre, significantly exceeding densities in Yenagoa, Warri, and Uyo, which fall between 4,025 and 4,731 persons per square kilometre. Over the past three decades, Port Harcourt experienced a 0.7°C increase in average annual temperature, while Warri and Yenagoa recorded rises of 0.8°C and 0.6°C, respectively.

Table 11: Coefficients of Predictors in the Regression Model for Heat Index

		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	44.945	1.405		32.000	.000
	Fatigue	.126	.078	.577	1.608	.115
	Heatstroke	.528	.111	1.086	4.748	.000
	Dehydration	-.257	.087	-.957	-2.949	.005

a. Dependent Variable: Heat Index

Source: SPSS Computation

Table 12 presents the results of the ANOVA analysis assessing urban population exposure to heat-related health outcomes in the Niger Delta. The analysis compares in-patient and out-patient cases of heatstroke, dehydration, and fatigue across different groups. The findings show significant differences across groups for heatstroke in-patient cases (F = 10.160, p = 0.000) and out-patient cases (F = 9.836, p

= 0.000). Dehydration also demonstrates statistically significant group differences for in-patient cases (F = 8.321, p = 0.000) and out-patient cases (F = 3.251, p = 0.031). Out-patient fatigue shows significant variation across groups (F = 4.596, p = 0.007). These results indicate that heat-related health outcomes are not uniformly distributed across the population. The patterns suggest that exposure and vulnerability differ across demographic or geographic subgroups, reflecting variable adaptive capacities. Higher F-values for heatstroke and in-patient dehydration indicate stronger group effects, while the lower F-value for out-patient dehydration suggests a weaker, but still significant, difference. The findings imply that hospital records capture real differences in heat stress exposure and its health consequences.

Table 12: ANOVA Results for Heat-Related Health Outcomes in the Niger Delta

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Heatstroke (In-patient)	Between Groups	630.500	3	210.167	10.160	0.000
	Within Groups	910.167	44	20.686		
	Total	1540.667	47			
Heatstroke (Out-patient)	Between Groups	1562.083	3	520.694	9.836	0.000
	Within Groups	2329.167	44	52.936		
	Total	3891.250	47			
Dehydration (In-patient)	Between Groups	460.063	3	153.354	8.321	0.000
	Within Groups	810.917	44	18.430		
	Total	1270.979	47			
Dehydration (Out-patient)	Between Groups	2307.063	3	769.021	3.251	0.031
	Within Groups	10408.417	44	236.555		
	Total	12715.479	47			
Fatigue (Out-patient)	Between Groups	4596.563	3	1532.188	4.596	0.007
	Within Groups	14668.250	44	333.369		
	Total	19264.813	47			

Source: SPSS Computation

Table 13 presents post-hoc comparisons of heat-related health outcomes across urban centres in the Niger Delta using the Scheffe test. The results reveal significant differences in exposure among locations for heatstroke, dehydration, and fatigue. Heatstroke in-patient cases in Uyo were significantly higher than in Port Harcourt and Warri, while Yenagoa recorded lower cases compared with Uyo and Warri. Out-patient heatstroke follows a similar pattern, with Uyo and Warri showing significantly higher incidence than Yenagoa. Dehydration in-patient and out-patient cases are notably elevated in Uyo relative to Yenagoa. Fatigue out-patient cases are also significantly higher in Uyo compared with Yenagoa. These differences indicate uneven vulnerability and adaptive capacity across the urban centres. Uyo consistently records higher cases, suggesting that residents face greater exposure to extreme heat and limited access to mitigating resources. Yenagoa exhibits lower incidence, reflecting better adaptive capacity or lower exposure. The pattern aligns with population density, infrastructure, and local climate variations, emphasizing that urban heat risk is location-specific and mediated by socio-environmental conditions. The findings support targeted interventions, identifying areas where heatwave preparedness and adaptive measures are most critical.

Table 13: Scheffe Multiple Comparisons of Heat-Related Health Outcomes Across Urban Centres

Multiple Comparisons

Scheffe Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Heatstroke In-patient	Port Harcourt	Warri	4.4167	1.8568	0.146	-0.981	9.814
		Uyo	6.7500*	1.8568	0.009	1.353	12.147
	Warri	Yenagoa	-6.9167*	1.8568	0.007	-12.314	-1.519
	Uyo	Yenagoa	-9.2500*	1.8568	0.000	-14.647	-3.853
Heatstroke Out-patient	Warri	Yenagoa	-11.3333*	2.9703	0.005	-19.967	-2.699
	Uyo	Yenagoa	-15.5833*	2.9703	0.000	-24.217	-6.949
Dehydration In-patient	Uyo	Yenagoa	-8.6667*	1.7526	0.000	-13.761	-3.572
Dehydration Out-patient	Uyo	Yenagoa	-19.0833*	6.2790	0.037	-37.335	-0.832
Fatigue Out-patient	Uyo	Yenagoa	-26.8333*	7.4540	0.009	-48.500	-5.166

*. The mean difference is significant at the 0.05 level.

Source: SPSS Computation

Yenagoa records the highest mean heat index at 63.2°C, compared to 55.6°C in Port Harcourt. This indicates stronger combined stress from temperature and humidity. Health records confirm this, as Yenagoa consistently reports the highest heat-related illnesses, peaking at 303 cases in May 2024. The Adaptive Capacity Index is lowest in Yenagoa (0.35), while Port Harcourt is higher at 0.38. Yenagoa also has the highest vulnerability score (75). Housing quality is weaker in Yenagoa, with only 59.8% of dwellings classified as permanent compared to 72.1% in Port Harcourt. Access to cooling infrastructure is also more limited in Yenagoa, with only 60.7% of households reporting fan or AC use against 74.2% in Port Harcourt. These combined conditions explain why Yenagoa residents are more vulnerable despite Port Harcourt's higher density and concrete concentration. Port Harcourt's density is 10,284 persons/km², reflecting extensive impervious land cover and high concrete use (71%), which drives heat retention. Yenagoa, though less dense at 4,731 persons/km², records higher temperatures due to land cover changes that reduce vegetation and increase exposed surfaces. The contrast shows that both density-driven impervious cover (Port Harcourt) and inadequate ecological cover (Yenagoa) intensify heat stress. Integrating land use planning with vegetation restoration is essential. Urban greening, wetlands protection, and reduced concrete surfaces should be prioritized. The regression model explaining 64.9 percent of the variance in heat index ($R^2 = 0.649$) underscores the predictive relevance of heatstroke, dehydration, and fatigue, with heatstroke emerging as the most statistically significant indicator.

5. Conclusion

The study examines the impact of heat stress on human health by analysing hospital records and assessing residents' adaptive capacity using a customized index. It considers local realities like housing quality, healthcare access, and public infrastructure. The findings expose stark inequalities in exposure and resilience across the cities studied. They show that high heat index levels are translating into spikes in heatstroke, dehydration, and fatigue. These symptoms are most severe where infrastructure is weakest. This work expands existing knowledge by demonstrating that heat-related illnesses can serve as early warning indicators for environmental stress. It warns urban planners and policymakers that unless fast and focused actions are implemented, particularly in vulnerable places like Yenagoa and Port Harcourt, heatwaves will continue to undermine public health and overload fragile urban systems. Adaptation must emphasize natural and community-based solutions such as urban greening, shading, improved ventilation, and climate-sensitive land use planning, rather than reliance on mechanical cooling systems. The study offers a grounded and contextual understanding of how heatwaves are affecting urban populations in the Niger Delta. What are the limitations of this study?

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