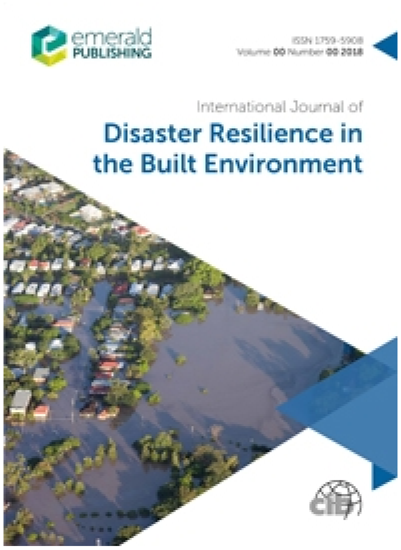

Living with Water: Quantitative Assessment of Property-Level Resilience to Urban Flooding

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Table 1: Resilience Measurement Constructs and Indicators

S/No	**Proxy**	**Resilience Indicator**	**Literature Source**
Inherent Resilience (Structural Adaptation)	Landscape design	Properties with green landscape	Oladokun et al. (2017); Adebimpe et al. (2018); Adegun (2021)
	Building Type	Households occupying more than one floor or in multi-storey buildings	Oladokun et al. (2017); Adebimpe et al. (2021)
	Elevation	Households living in elevated houses/elevated land	Attems et al., (2020); (Adegun, (2021)
	Floor Type	Households living in houses with concrete floors	Oladokun et al. (2017); Adebimpe et al. (2021)
	Floor Finishes	Households living in houses with screeded/ceramic tiled floors	Oladokun et al. (2017); Adebimpe et al. (2021)
	Wall Type	Households living in houses with block walls.	Oladokun et al. (2017); Adebimpe (2018) Adebimpe et al. (2021)
	Wall finishes	Households living in houses with water-repellant wall finishes (plastered and painted with matt or silk/tiled).	Oladokun et al. (2017); Adebimpe et al. (2021)
	Electrical Installation	Households living in houses with electrical sockets raised at a higher level.	Oladokun et al. (2017); Adebimpe et al. (2021)
Supportive Attributes (Semi-Structural Adaptation)	Additional Barriers to water entry	Households with additional water barriers such as window seals, door guards, and using sandbags/demountable barriers/embankments	Attems et al., (2020); Adegun (2021)
	Backup storage	Households with backup space for storing water-sensitive items.	Oladokun et al. (2017); Adebimpe et al. (2021)
	Flood Adapted interior	Households that repositioned water-sensitive furniture/appliances, removed wallpapers, and rugs	Koerth et al., (2014; Attems et al., (2020);
	Backup power/ energy Source	Households with backup power (Generators, solar batteries, inverters, solar panels)	Oladokun et al. (2017); Adebimpe et al. (2021)
	Flood water removing Systems	Households with pumps, dryers, or other rapid water removal mechanisms.	Oladokun et al. (2017); Attems et al., (2020); Adebimpe et al. (2021)
Residents' Capacity (Non-Structural Adaptation)	Economic Capacity	Households with savings/funds reserve/insurance policy	Koerth et al., (2014); Oladokun et al. (2017);
	Flood Awareness behavior	Households with pre-flood awareness behavior-Listening to/keeping up with weather reports, collective effort, storing phone numbers, storing important documents, clearing gutters, having a plan of where to temporarily evacuate to.	Koerth et al., (2014); Isunju (2016) Adegun, (2021)
	Technical Capacity	Households with technical knowledge/free access to technicians, having technical tools/emergency kits, knowledge about how to switch off electricity supply	Oladokun et al. (2017); Adebimpe et al. (2021)
	Social capacity	Households with membership in supportive social networks	Oladokun et al. (2017); Adebimpe et al. (2021); Adegun, (2021)

Table 2: Flood Prone Areas in Port Harcourt

S/No	Street/Area	Northings	Eastings	Flooding Classification
1	Abanna Street, Old GRA	4.785583	7.022028	Low
2	Hon. Attah Close, Peter Odili Road	4.793833	7.05075	Low
3	L.K. Anga Road, Off Peter Odili Road	4.801917	7.047389	Low
4	Hilltop Road, Amadi-Kalagbo	4.823806	7.023444	Low
5	Uyo Street, Rumumasi	4.838444	7.017583	Low
6	Omerelu Street, GRA Phase 11	4.839583	7.005639	Low
7	Akwaka Street, Rumuodomaya	4.880281	6.994285	Low
8	Peter Odili Road	4.804861	7.045556	Low
9	Omachi Road, Rumuodomaya	4.875247	6.999777	Moderate
10	Salem Close, Off Ada George Road	4.855444	6.979556	Moderate
11	Obiwali Road, Rumuigbo	4.858639	6.986944	Moderate
12	Diamond Valley Estate	4.796222	7.046083	Moderate
13	Zion Street, Rumuodomaya	4.881607	6.993837	Moderate
14	Odani Road, Elelenwo	4.840208	7.073506	Moderate
15	Evelyn‘s Close, GRA Phase 11	4.8195	7.006917	Moderate
16	Horsefall Street, Old GRA	4.786017	7.001000	Moderate
17	Alalibo Road, Old GRA	4.794083	7.019917	Moderate
18	Nkpolu Road 1, Rumuigbo	4.853346	6.986527	High
19	Eneka Town	4.878167	7.029514	High
20	NTA/Apara Link Road	4.854637	6.983774	High
21	Rotimi Amaechi Drive, GRA Phase 11	4.821278	6.000972	High
22	Kenka Road, Off Mgbuoba Road	4.856194	6.980361	High
23	Abacha Road, GRA Phase 11	4.823778	7.003361	High
24	Orubo Close, Peter Odili Road	4.797111	7.052361	High
25	BuePearl Street, Peter Odili Road	4.794083	7.019917	High

Table 3: Principal Component Analysis

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.887	45.507	45.507	7.887	45.507	45.507	4.853	37.973	37.973
2	3.159	11.924	57.431	3.759	11.924	57.431	3.707	13.729	51.702
3	2.902	8.750	66.181	2.902	8.750	66.181	3.393	8.568	60.270
4	2.295	6.499	72.679	2.295	6.499	72.679	2.346	7.688	67.958
5	1.901	5.040	77.720	1.901	5.040	77.720	2.103	6.790	74.748
6	1.747	4.471	82.191	1.747	4.471	82.191	2.065	5.146	79.895
7	1.438	3.325	85.516	1.438	3.325	85.516	2.044	5.071	84.966
8	1.034	2.831	88.347	1.034	2.831	88.347	1.453	3.381	88.347
9	.934	1.961	90.308						
10	.919	1.905	92.213						
11	.667	1.469	93.682						
12	.643	1.381	95.064						
13	.456	1.070	96.133						
14	.367	0.980	97.113						
15	.263	.975	98.088						
16	.217	.604	98.692						
17	.160	.511	99.203						
18	.136	.505	99.708						
19	.111	.211	99.899						
20	.071	.163	99.962						
21	.053	.197	99.899						
22	.025	.094	99.954						
23	.010	.038	99.992						
24	.002	.008	100.000						
25	3.931E-16	1.456E-15	100.000						
26	3.421E-16	1.267E-15	100.000						
27	1.287E-16	4.768E-16	100.000						

Table 4: Component Scores Extracted from PCA Analysis

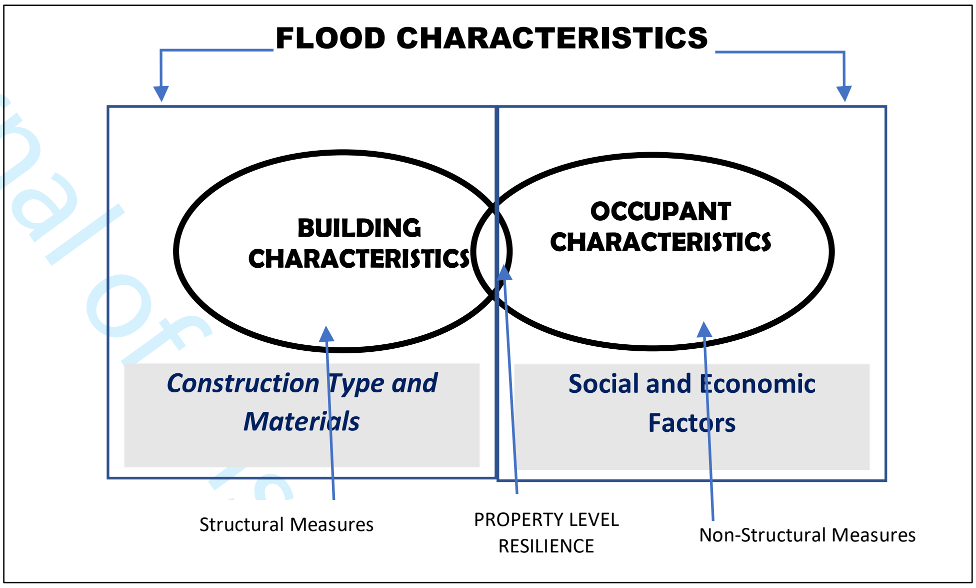
Indicators	Component-1 scores
Landscape (%greened)	.069
Building Type (%Duplex/Multi)	.042
Elevated Land (%)	.173
Elevated Building (%)	.152
Floor Type (% Concrete)	.066
Floor Finish (% screeded/tiled)	.028
Wall type (% Block)	.017
Wall Finish	.081
Raised Electricals	.241
Barriers-Doors/Windows	.034
Barriers-External	.205
Back-up Space	.050
Back-up Power	.091
Flood Water Removal	.167
Reposition Furniture/appliances	.032
Remove Rugs/Wallpaper	.222
Savings/Funds Reserve	.037
Insurance	.049
Keeping up with Weather	.166
Collective Effort	.029
Desilt/clear Gutters	.018
Store Phone Numbers	.143
Knowledge about repair	.027
Free Access to Technicians	.052
Technical tools/emergency kit	.011
Knowledge to switch off electricity supply	.021
Membership in social network	.034

Table 5: Computed Resilience Indices

Flooding LEVEL					
LOW		MODERATE		HIGH	
Area	RI	Area	RI	Area	RI
1	0.35	9	0.45	18	0.38
2	0.45	10	0.50	19	0.57
3	0.53	11	0.31	20	0.67
4	0.55	12	0.43	21	0.63
5	0.45	13	0.59	22	0.34
6	0.51	14	0.54	23	0.57
7	0.59	15	0.64	24	0.48
8	0.38	16	0.43	25	0.54
		17	0.61		

Table 6: ANOVA Descriptives

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
LOW	8	.4775	.08285	.02929	.4083	.5468	.35	.59
MODERATE	9	.5066	.09350	.03117	.4347	.5785	.31	.64
HIGH	8	.5137	.12106	.04280	.4125	.6150	.34	.67
Total	25	.4996	.09715	.01943	.4595	.5397	.31	.67


FLOOD CHARACTERISTICS
BUILDING CHARACTERISTICS
OCCUPANT CHARACTERISTICS
Construction Type and Materials
Social and Economic Factors
Structural Measures
PROPERTY LEVEL RESILIENCE
Non-Structural Measures

Living with Water: Quantitative Assessment of Property-Level Resilience to Urban Flooding

Abstract

Purpose: This study is carried out to quantitively assess the resilience of residential properties to urban flooding in Port Harcourt, Nigeria, and whether they vary at spatially aggregated scales relative to the level of flood exposure.

Design/Methodology/Approach: The study synthesizes theoretical constructs/indicators for quantifying property level resilience, as a basis for measuring resilience. Using a two-stage purposive/stratified randomized sampling approach, 407 questionnaires were sent out to residents of 25 flood-prone areas, to solicit information on the resilience constructs as indicated by the adaptation behaviors of individual households and their property attributes. A Principal Component Analysis approach is used as a mechanism for weighting the indicators, based on which aggregated spatial-scale resilience indices were computed for the 25 sampled areas relative to their levels of flood exposure.

Findings: Area-11 located in the moderate flood zone has the lowest resilience index, while Area-20 located in the high flood zone, has the highest resilience index. The Resilience Indices for the low, moderate, and high flood zone, show only minimal and statistically insignificant differences indicating maladaptation even with incremental levels of flood exposure.

Practical Implications: The approach to resilience measurement exemplifies a reproducible lens through which the concept of ‘living with floods’ can be holistically assessed at the property level while highlighting the nexus of the social and technical dimensions.

Originality/Value: The study moves beyond theoretical conceptualization, to empirically quantify the complex concept of property-level flood resilience.

Keywords: Flood resilience, property-level adaptation, Resilience Measurement, Urban Flooding

1.0 Introduction

The occurrence of various types of floods depends on the hydrogeological and anthropogenic conditions of a locality. Flooding can be a result of rivers or other inland water bodies overflowing their banks and spilling onto their floodplains, normally after heavy rainfall. This is a common form of flooding in riverine communities (Ali et al., 2016). Typically, in the UK, the River Thames has a history of flooding, and relevant institutional support is provided to residents (DEFRA, 2008). Coastal floods are experienced along the coastal shore, on low-lying land as a result of intense offshore winds, tides, and sea level rise which causes abrupt and sudden inundation (Chattopadhay, 2006). Urban floods however are a type of flooding unique to urban areas, triggered as a consequence of the built environment (Andjelkovic, 2001). Pilgrim and Cordery (1993) attribute urban floods to inadequate drainage networks relative to flood run-off on built-up surfaces. Urban floods are thus mostly caused by flash floods, which often occur after a prolonged period of intense rainfall, causing a rapid rise and fall in water levels within urban areas, and are characterized by high flow velocities (Ologunorisa and Diagi, 2005; Pratomo, 2016).

Urban floods are a common occurrence in Nigeria, where recurring flood events have been experienced, with catastrophic human and property losses (Kofo, 2012). Other than hydro-meteorological factors, inadequate/blocked drainage network, lack of land-use planning. and urbanization have been identified as the key factors inducing urban flooding in Nigerian cities (Akinyemi, 1990; Akukwe, 2014). Urbanisation has led to population increases whereby the demand for land has led to building on swamplands and floodplains, without due consideration of the implications (Akintola, 1978, Abam 2001).

Port Harcourt is a metropolitan city in the coastal lowlands of southern Nigeria and lies within the flood plain of the river Niger. Flooding, particularly during heavy rainfall is a predominant cause of temporary human displacement and property loss in Port Harcourt (Gerald-Ugwu et al., 2019; Johnson et al., 2021). The flooding pattern has recurred over the years and the consequences follow a repetitive spatial scale of impact on buildings. Extensive local research has thus been carried out to demarcate flood-prone areas and spatially assess the levels of vulnerability to flooding for various locations.

Yet, several studies including Oladokun and Proverbs (2016) as well as Adebimpe et al. (2018) report the lack of an adequate flood risk management framework in Nigeria. Typically, unlike in developed countries such as the UK, there are mostly no flood warning systems and institutional support is weak (Amangabra and Obenade, 2015). This shifts the bulk of the technical and financial burden for managing flood risk to the property level. All these inherent shortcomings reinforce the need for property-level resilience in Port Harcourt, Nigeria.

Given the weak institutional structure for flood preparedness in Nigeria, the study is framed from the viewpoint that measuring in-situ flood resilience is core to making a business case for property-level adaptation. This view is compatible with the concept of ‘living with water’, which resonates globally. Living with water entails building more resilient communities that are flood-aware and adapted to flood risks (Adedeji et al., 2022). This requires that the pattern of adaptive measures which define the flood resilience status of different areas/locations are systematically understood.

The objectives of this paper are to quantitively assess the resilience of residential properties in Port Harcourt and whether they vary at spatially aggregated scales relative to the level of flood exposure. The rest of the paper is structured to theoretically outline constructs and indicators for quantifying property level resilience that incorporates both the technical and socio-economic dimensions. This theoretical backdrop forms the basis on which a quantitative research approach is adopted and rationalized from a positivist philosophical viewpoint.

2.0 Literature Review

Resilience is a transdisciplinary and complex concept, which is diverse in its applicability. Measuring resilience is fraught with ambiguities, due to its multidimensional inclinations. Resilience has technical and social dimensions, and as such measures adopted within the built environment are a mix of socio-technical adaptations, as no one measure is considered adequate (Heinkel et al., 2022). From this viewpoint, an eclectic range of studies have been carried out, in an attempt to quantify resilience.

Much of the research efforts that have been made in the direction of quantifying resilience within the built environment have mostly been carried out utilizing urban function indicators that emphasize the biophysical feature, economic, social, and institutional dimensions. Typically, Rajib (2009) developed a methodology for computing Climate Disaster Resilience Index, which was empirically extended and utilized by Batica (2015) for mapping urban flood resilience. Batica (2015) utilized rated indicators such as availability of water, waste disposal mechanisms, food availability transportation, etc. to compute a composite resilience index of urban cities. Chen and Leandro (2019) conceptualized a resilience index relative to time, to visualize how urban systems react before and after flooding, using an inundation modelling of the urban landscape of Munich. De Bruijn (2005) utilized a set of flood resilience indicators to reflect the reaction amplitude, reaction graduality in response to flood wave severity, and the recovery rate. Mugume et al. (2014) quantified urban resilience in the UK as a function of drainage systems, via a combination of utility performance indicators and depth-damage data. Similarly, lee and Kim (2017) generated a Resilience Index assessment tool utilizing multi-dimensional flood damage criteria. Narjiss (2021) quantified urban resilience using indicators to reflect the social, physical, and natural dimensions of urban cities. Kutty et al (2022) presented a novel two-stage data-driven framework combining a multivariate metric-distance analysis with machine learning techniques for resilience and livability assessment of smart cities. This framework leveraged these advanced techniques to provide a thorough examination of community resilience and other critical components of resilience including the social, economic, infrastructure and built environment and, institutional resilience. An underlying theme in these studies is that emphasis was placed primarily on the urban character as well as the interrelatedness of city elements and functions at a macro level.

From a more micro-level perspective such as at the property level, there is a discernible lack of empirical investigation, with the initial attempts primarily conceptual in nature (Oladokun et al., 2017; Proverbs et al., 2018; Adedeji *et al*., 2018). Aligning with Adedeji et al. (2018), this study conceptualizes property level resilience as a function of the nature of flooding, building structure, and the occupants' characteristics, which interlace to determine the nature of structural and non-structural adaptation measures (Figure 1). This is underpinned by the empirical literature which shows that differences in residents/occupier characteristics can significantly affect the capacity of individuals to proactively undertake property-level adaptive measures in response to disaster risk. (Koerth, et al., 2014; Adedeji et al., 2022; Heinkel et al., 2022; Skouloudis et al. 2023). Typically, Skouloudis et al. (2023) showed that flood resilience responses and efforts at the property level even for non-residential entities such as micro, small, and medium-sized enterprises are associated with a typology of adaptation strategies that are linked to the occupier characteristics. Heinkel et al., 2022 studied how disaster preparedness and resilience at the property level in Yangon, were impacted by household characteristics.

INSERT FIGURE 1 HERE

The approaches proposed for measuring property resilience by Oladokun et al. (2017) and Proverbs et al. (2018) demonstrate the complexity of quantifying resilience and the difficulty in assessing/operationalizing it. The most comprehensively conceptualized approach to measuring property level resilience identified in the literature is by Oladokun et al. (2017). Oladokun et al. (2017) developed a conceptual outline to quantify flood resilience, by identifying resilient input factors, grouping the factors into dimensions, and weighting the factors using a Fuzzy logic approach. The primary ideology in Oladokun et al. (2017) methodology is that input factors which are used for measuring resilience, should be observable and the output is an abstraction of the interactions between the factors. A checklist of input factors was identified, while the subjective judgment of experts was incorporated via fuzzy logic for the assignment of weights.

Oladokun et al. (2017) derived input parameters to represent the inherent attributes of the property, the supportive attributes, and the resident capacity. The inherent attributes were described as variables that define the architectural and material specification of the building such as the surrounding landscape, wall type, wall finish, floor finish, floor type, and electrical installations. They are the fixed structural features of a building that affect water entry or exclusion and mostly cannot be altered without extensive retrofitting. Empirical studies such as Adegun (2023) reported that extensive retrofitting of structural features to cope with floods, entailing raising the building's foundation, sand-filling the surrounding, and re-roofing were carried out at an informal coastal settlement in Nigeria, as part of self-help individual and community efforts to minimise flood impact. Supportive attributes are other ancillaries/backup features or facilities in a building that affects the extent of water intrusion or ease of recovery after a flood event. These range from attributes such as the availability of backup space for storing water-sensitive items, backup power sources, additional barriers to water entry, etc. Resident capacity variables essentially describe the occupants' capacity to cope with flood events. They range from attributes that define the economic, technical, social, and behavioral status of the building inhabitants.

More recent studies such as Adebimpe et al. (2021) and Adedeji et al. (2022) have attempted to quantify flood resilience at the property level. Adebimpe et al. (2021) conceptualized attributes and sub-attributes, categorized according to inherent resilience, supportive resilience, human resilience, and socioeconomic resilience. An analytical hierarchy process was then proposed as a statistical mechanism for assigning weights to each of the defined attributes/sub-attributes. Adedeji et al. (2022) developed a predictive multiple regression model to measure the resilience of a property as perceived by homeowners in the UK. The findings revealed that the key structural variables which impacted the level of property-level flood resilience were the property type, wall type, presence of cellar/basement, kitchen unit type, and ground floor type.

Whilst these proposed approaches for property-level resilience measurement are remarkable, they are limited in their operationalizability. They are mostly conceptual, with the exception of Adedeji et al. (2022). This is because although the input resilience parameters were adequately described, there was no clear-cut proxy for quantifying them. Numerous qualitative indicators were used as proxies for a single parameter, which makes the application of the methodology highly subjective. They rely on the subjectivity of individual experts or homeowners to assess the configuration of the listed, and sometimes conflicting property attributes to assign weights to the resilience parameters. Furthermore, the parametrization of indicators at spatial scales is limited. The limitations identified in these conceptual methodologies however form the foundation upon which a Principal Component Analysis (PCA) approach is used at a spatial scale in this study. PCA is justified on the basis that the resilience indicators identified will be analysed with respect to how much variance they account for. The underlying ideology in using PCA, therefore, is that resilience indicators that do not substantially contribute to the total variance will have lower explanatory power in accounting for resilience. PCA thus provides a statistically robust basis for identifying the degree of contribution of variables to the resilience status of properties without subjectivity. PCA is a common technique for constructing spatial scale indices in disaster vulnerability studies (Cutter et al. 2003; Wirehn et al., 2015; Akukwe and Ogbodo, 2015; Žurovec et al., 2017). PCA thus enables the weighting of clear-cut proxies that can be used as indicators for property level resilience at spatial scales without the need for expert judgment. This approach enhances the operationalizability of measuring resilience while building on the conceptual approach proposed in the literature.

Table 1 presents the resilience measurement constructs, as synthesized from the literature, listing, and grouping structural and non-structural indicators which affect the resilience of households/properties.

INSERT TABLE 1 HERE

3.0 Study Methodology

3.1 Approach

For this study, the positivist philosophical position is adopted as a worldview for investigating the uptake of flood risk adaptation measures at the property level. A reductionist empiricist view is thus taken to investigate property-level adaptation measures as entities that may vary relative to flood exposure levels. Aligning with the positivist philosophical orientation of the study, a quantitative method is adopted, (Creswell and Clark, 2013). Data collection on property-level adaptation characteristics was thus primarily geared toward generating numerical measures that are susceptible to statistical analysis.

To achieve the study objectives, and in alignment with the study's methodological and philosophical posture, the survey research strategy is used and guides the more practical elements of data collection as a basis for quantitative analysis. The survey strategy was deemed adequate for collecting information on the property-level flood adaptation measures adopted in Port Harcourt metropolis, due to its inherently wide and inclusive coverage. Although it may be argued the range of coverage offered by surveys limits the depth of information obtained, the survey strategy is considered adequate due to its unintrusive and structured nature (Saunders et al., 2019). Previous research further attests to the viability of surveys as a strategy for carrying out studies on flood disaster resilience (Isunju et al., 2016; Ahmad and Afzal, 2020; Jumbo and Wizor, 2020). Typically, Ahmad and Afzal (2020) deployed the survey research strategy to investigate flood mitigation measures in Pakistan.

3.2 Sampling Framework and Data Collection

Residential properties are the unit of analysis, and the geographic spread of Port Harcourt metropolis, Nigeria defines the spatial extent/boundary of investigation. Therefore, all data collection efforts were directed to the households which occupy residential buildings in Port Harcourt, Nigeria. Port Harcourt metropolis comprises the current Port Harcourt LGA as well as Obio-Akpor LGA.

However, the target of the analysis is to investigate property-level adaptation strategies relative to the levels of exposure to flood hazards. As such, for this purpose, flood-prone areas must be identified and spatially disaggregated relative to the level of flood exposure. The sampling approach adopted is thus partly purposive in the first phase and stratified randomized in the second phase. This approach was necessary to adequately represent properties facing varying degrees of flood exposure. To identify areas prone to flooding, the study relied on previous research on flooding patterns in Port Harcourt. This is because there was no readily available flood map of Port Harcourt, from institutional sources. Previous research has delineated Port Harcourt according to the risk, exposure, and vulnerability to flooding (Akukwe and Obodo, 2015; Wizor and Mpigi, 2020; Johnson et al., 2021). Wizor and Mpigi (2020) identified 25 spatially dispersed areas in Port Harcourt that are prone to flooding. The vulnerability to flooding in these areas was similarly corroborated by Jonhson et al. (2021). The identified areas mostly have high property concentrations (Eyenghe et al., 2019). Households situated in these areas were thus purposively sampled, in line with the study objectives. This study further adopts Wizor and Mpigi (2020) classification as a basis for the sampling framework, and for achieving stratification. Wizor and Mpigi (2020) delineated Port Harcourt metropolis into 3 three zones: low (20 -40cm; 200 – 400 m), moderate (41-80cm; 401 – 600 m), and high (above 80cm; Above 600 m), based on the depth of inundation and extent of floodwater. The GPS coordinates of the flood-prone areas identified in Wizor and Mpigi (2020) study and their classification is shown in Table 2.

INSERT TABLE 2 HERE

Based on Table 2 and given the resource constraints and time available for the study, for each of the 25 areas, the study set out to sample 20 residential properties, with only one household respondent per property.

To spatially aggregate the indicators of property level adaptation for each of the sampled areas, Principal Component Analysis (PCA) is used. PCA is a factor reduction/classification technique that is used to analyse dimensionality in data. This allows for more concise summary indices of the factors, that can be easily analysed and visualized. However, in the context of this study, PCA is primarily used as a mechanism for weighting the indicators, based on which aggregated spatial resilience indices are computed for the different sampled areas/locations. A number of methods exist for determining the number of principal components to be retained. The commonly used methods are the Kaiser criterion and the scree test. The Kaiser criterion drops the components, for which the eigenvalues are less than 1. Eigenvalues that are greater than 1 suggests that the corresponding component explains more variance, while components with eigenvalues less than 1 have negligible effect in explaining the variability of the data. Unlike the exact rule, determined by the Kaiser criterion, the scree test is more subjective and relies on visual interpretation of the eigenvalues curve on the scree plot. The scree plot method of component selection relies on identifying the point at which the curve changes its slope and retaining only factors with corresponding eigenvalues that lay above this elbow on the plot. When there is more than one rapid change in the curve's slope, the subjectivity and imprecision associated with the scree plot method are further amplified. To minimize subjectivity in determining the number of principal components, the Kaiser criterion is adopted in this study. As proposed by Kaiser (1960), the "eigenvalue-greater-than-one" rule is used, as a cut-off point for factor extraction for optimizing the number of principal components. The first principal component accounts for the maximum amount of variation, and in the coordinate system, it is determined by a vector, which has the direction of the greatest variability in the data (Sheytanova, 2015). Factor scores for the first principal component are used as weights and the algebraic sums of the weighted indicators are computed as resilience indices (RI) for the 25 areas sampled areas (Equation 1).

$$RI = W_1X_1 + W_2X_2 + \ldots\ldots WnX_n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{Equation 1}$$

Where w = Weight of indicator

X = Indicator (level of uptake per Area)

n = Number of Indicators

This methodological approach has been similarly used by Cutter et al. (2003), Wirehn et al. (2015), Akukwe and Ogbodo (2015) as well as Zurovec et al. (2017) to generate composite spatial indices. To test the overall study hypothesis, the computed composite resilience indices for the sampled areas were further analysed using a one-way Analysis of Variance (ANOVA). This is based on the following hypothesis:

H_0: Resilience Indices do not significantly vary relative to the flooding levels.

H_1: Resilience Indices significantly vary relative to the flooding levels.

ANOVA is thus deployed to test for statistically significant differences in the spatially aggregated property level resilience relative to the level of flood vulnerability.

4.0 Results and Discussion of Findings

4.1 Resilience Quantification

Principal Component Analysis was carried out to assess the spatial scale of property level resilience at the sampled flood-prone locations in Port Harcourt (Table 3). As earlier explained in the research methods section, PCA in this study is not used for dimensionality detection but is primarily used as a mechanism for weighting the indicators, based on which aggregated spatial-scale resilience indices are computed for the different sampled areas/locations. From the PCA analysis, eight principal components were extracted. However, only the component scores/loadings of the resilience indicators for the first principal component, which accounted for 45.51% and 37.97% of the variation before and after varimax rotation, are used as a mechanism for weighting.

INSERT TABLE 3 HERE

The component scores for the first principal components, which were normalized and used as weights for the resilience indicators are shown in Table 4.

INSERT TABLE 4 HERE

Table 5 shows the composite Resilience Indices (RI) computed for the 25 sampled areas, grouped according to the flooding level.

INSERT TABLE 5 HERE

Area-11 located in the moderate flood zone has the lowest resilience index (0.31), while Area-20 located in the high flood zone, has the highest resilience index (0.67). Buildings located in Area 11 are thus the least resilient to flooding and are likely to suffer higher damage in the event of flooding. This creates a clearer picture of the resilience status of properties located within various zones in Port Harcourt, particularly where property-level flood hotspots exist.

Although this study primarily focuses on property level characteristics, the spatial scale adopted creates a locational relativity context for residential properties in Port Harcourt, with respect to their flood resilience, similar to the outcome of Akukwe and Obodo (2015) who computed flood vulnerability indices for 13 locations in Port Harcourt. The study resonates with previous studies that have sought to quantify the complex concept of resilience including Lee and Kim (2017), Narjiss (2021), and Kutty et al (2022), as the computed flood resilience indices provide an aggregated quantitative mechanism for placing different locations within the relative spectrum of the multi-dimensions of resilience. The indices generated further amplifies the usefulness of the PCA methodological approach to composite index building, which has hitherto only been used in disaster vulnerability studies such as Wirehn et al. (2015) and Zurovec et al. (2017). This study aggregated 27 indicators of structural and non-structural resilience measures using PCA, compared to Zurovec et al. (2017) study where 20 indicators, were quantitatively assessed and aggregated.

4.2 Resilience Variation Relative to the Level of Flood Exposure

Analysis of Variance was carried out to test the overall study hypothesis as to whether the computed spatial scale property resilience indices significantly vary relative to the flood vulnerability of the areas. Table 6 shows the descriptive statistics for the analysis. As indicated, the mean Resilience Index is 0.48 for the low flood zone, 0.51 for the moderate flood zone, and 0.51 for the high flood zone. This shows only minimal incremental differences in mean resilience levels relative to flooding levels.

INSERT TABLE 6 HERE

The ANOVA output further showed that the minimal differences in the mean resilience levels between the different flood zones are not significant. Based on the ANOVA outcome, it is inferred that although there are differences in the spatial scale resilience of properties in the sampled areas of Port Harcourt, they do not significantly vary relative to the level of flood exposure. This indicates that the differences in the level of exposure to flooding in the areas do not induce corresponding differences in the uptake of adaptation measures.

The non-significance of the differences in the computed indices even with increasing flood exposure show maladaptation. This is indicative of poor risk perception by residents in the low, medium, and high flood-prone areas identified by Wizor and Mpigi (2021). This is further magnified in view of the property density reported by Eyenghe et al. (2019) since these areas are completely built up with high population concentration. This outcome also corroborates the view of earlier studies, such as Akintola (1978) and Abam (2001), that with increasing demand for land, property developers have resorted to building in flood-prone areas without taking adequate protective measures. This brings to the fore, the need for effective urban physical planning, and makes a case for developing locally defined institutional guidelines for property owners in Port Harcourt, to technically assist them in undertaking property-level flood risk adaptation measures. This stance is compatible with the precedence set by DEFRA (2008) in the UK, as well as Oladokun and Proverbs (2016), Adebimpe et al. (2018), and Gerald-Ugwu (2019) assertions, that flood risk management at the property level in Nigeria should receive institutional support, even though the primary responsibility lies with property owners.

5.0 Conclusion

The quantification of property level resilience as an aggregated measure is a useful component of flood risk management, which is central to the theme of 'living with water'. The study has quantitively assessed the resilience of residential properties in Port Harcourt, and the level of variation at spatially aggregated scales. This study has thus manifested a move from theoretical conceptualisation to practical exemplification, adding to the discourse on adaptation and resilience to flooding at the household/property level and how this varies with estimated exposure to hazards. Although the study specifically provides quantitative spatial insights on the resilience status of residential properties across Port Harcourt, the analytical approach adopted portends generalizable methodological applicability. Via this quantitative medium, institutional response requiring comparative cross-sectional studies on the resilience status of residential properties in flood-prone communities can be planned. This can be achieved by systematically collecting data to build up an evidence-based measure of community resilience at the property level.

The study has shown that the resilience status of residential properties in Port Harcourt does not significantly vary even with increasing levels of flood exposure. This maladaptation is indicative of poor risk perception by residents of flood-prone areas in Port Harcourt, reiterating literature assertions that property developers have resorted to building in flood-prone areas without duly incorporating protective measures. Considering the differential weighting of factors in the composite Resilience Index, priority should be given to the most important measures that account for a higher level of resilience. Some of the measures may however require a considerable amount of funds which may not be readily affordable to residential homeowners. Government intervention via the provision of subsidies may thus be required to catalyse a more positive response to the uptake of property-level adaptation measures.

The study outcome provides a business case for decision-making and can serve as a foundation for policy advocacy, guidelines, and intervention bespoke to the flood-prone landscape of Port Harcourt metropolis, Nigeria. This is because the traditional flood risk management philosophy in Nigeria is based on institutional responses without the required engagement of property owners/residents. It is thus imperative that property owners/residents are included as stakeholders in decision-making processes at institutional levels, if the Resilience Index as a tool, is to have any meaningful impact. Typically, the Niger Delta Development Commission (NDDC) flood intervention efforts and plans should make provisions for the retrofitting of residential properties in areas where resilience is low, in addition to rebuilding damaged infrastructure in urban areas.

As the study indicates, a wide range of technical and social factors can affect the spatial patterns of resilience to floods. The range of factors accounted for is however not exhaustive, thus constituting a limitation to the study, while creating room for further studies. Further studies can thus build on the study approach as a basis for developing more comprehensive Resilience Index frameworks. Additional case studies can also be carried out to operationalize the composite resilience index methodology across other flood-prone locations within and outside Nigeria.

References

Abam (2001). Regional hydrological research perspectives in the Niger Delta Hydrological Sciences Journal Volume 46, Issue 1, pp. 35-43.

Adebimpe, O. A., Proverbs, D.G. and Oladokun, V.O. (2021). A fuzzy-analytic hierarchy process approach for measuring flood resilience at the individual property level. *International Journal of Building Pathology and Adaptation* Vol. 39 No. 2, pp. 197-217. DOI 10.1108/IJBPA-10-2019-0094

Adebimpe, O. A., Oladokun, Y. O. M., Odedairo, B. O., and Oladokun, V. O. (2018). Developing flood resilient building in Nigeria: A guide. *Journal of Environment and Earth Science,* Vol. 8 No. 3, pp. 143-150. https://www.iiste.org

Adedeji, T.J., Proverbs, D.G., Oladokun, V.O. and Xiao, H. (2019). Making Homes More Resilient to Flooding: A New Hybrid Approach. *Resilient Structures and Infrastructure*, Springer, Singapore, pp. 159-176.

Adedeji, T.J., Proverbs, D.G., Xiao, H and Oladokun, V.O. (2018). Towards a conceptual framework for property level flood resilience. *Int. J. of Safety and Security Eng.,* Vol. 8, No. 4, pp. 493–504.

Adedeji, T., Proverbs, D.G., Xiao, H. and Oladokun, V.O. (2022), Measuring property flood resilience (PFR) in UK homes, International Journal of Building Pathology and Adaptation, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/IJBPA-06-2022-0092

Adegun, O.B. (2021). Climatic disasters within a flood-prone coastal slum in Lagos: coping capacities and adaptation prospects. *International Journal of Disaster Resilience in the Built Environment.* DOI 10.1108/IJDRBE-11-2021-0154

Adegun, O.B. (2023), Climatic disasters within a flood-prone coastal slum in Lagos: coping capacities and adaptation prospects, International Journal of Disaster Resilience in the Built Environment, Vol. 14 No. 2, pp. 212-228. https://doi.org/10.1108/IJDRBE-11-2021-0154

Ahmad, D and Afzal, M. (2020). Flood hazards and factors influencing household flood perception and mitigation strategies in Pakistan. *Environmental Science and Pollution Research*. Vol. 27 pp. 15375–15387.

Akintola, F.O. (1978). The Hydrological Consequences of Urbanization: A Case of Ibadan City in Sada and Oguntoyinbo (eds). Urbanization processes and problems in Nigeria. Ibadan, Ibadan University Press.

Akinyemi, T. (1990). Stemming the tide of Lagos floods, in: *The Guardian*. Friday, July 1989.

Akukwe, T.I. (2014). *Determinants of flooding in Port Harcourt metropolis, Nigeria*.

Akukwe, T. I and Ogbodo, C. (2015). Spatial Analysis of Vulnerability to Flooding in Port Harcourt Metropolis, Nigeria. *SAGE Open*, pp. 1-19. DOI: 10.1177/2158244015575558

Ali, K., Bajracharya, R.M. and Koirala, R.L. (2016). A Review of Flood Risk Assessment. *International Journal of Environment, Agriculture and Biotechnology*, 1: 2456 – 1878.

Amangabra, G.T and Obenade, M. (2015). Flood vulnerability assessment of Niger Delta states relative to 2012 flood disaster in Nigeria. *American Journal of Environmental Protection,* Vol. 3 No. 3, pp. 76–83.

Andjelkovic, I. (2001). Guidelines on non-Structural Measures in Urban Flood Management. IHRV Technical Documents in Hydrology No 50. Paris, UNESCO.

Attems M.S., Thaler, T., Genovese E and Fuchs S. (2020). Implementation of property-level flood risk adaptation (PLFRA) measures: Choices and decisions. *WIREs Water*. https://doi.org/10.1002/wat2.1404

Batica, J. (2015). Methodology for flood resilience assessment in urban environments and mitigation strategy development. *International Conference on Flood Resilience Experiences in Asia and Europe*, Exeter, United Kingdom.

Chen, K and Leandro, J. (2019). A Conceptual Time-Varying Flood Resilience Index for Urban Areas: Munich City. *Water* Vol 11, pp. 830-841. doi:10.3390/w11040830

Chattopadhay, S. (2006). Integrated coastal Zone Management Action Plan of Mararikulam Area. A Discussion note Centre for Earth Science Studies, Trivandrum 695031, Mararikulam.

Cutter, S.L.; Boruff, B.J.; Shirley, W.L. (2003). Social vulnerability to environmental hazards. *Social Science Quaterly* Vol. 84, pp. 242–261.

De Bruijn, K. M (2005). *Resilience and Flood Risk Management: A Systems Approach Applied to Lowland Rivers*. A PhD Thesis submitted to Delft University of Technology. Netherlands.

DEFRA. (2008). Consultation on Policy Options for Promoting Property-Level Flood Protection and Resilience. *Flood Resilience Consultation*, Department for Environment, Food and Rural Affairs, London.

Eyenghe, Tari, Ibama B and Oviebor, P. (2019). Dynamics of gentrification: experiences from selected neighbourhoods in Port Harcourt municipality. *MOJ Civil Eng.*. 5(4):107–113. DOI: 10.15406/mojce.2019.05.00163

Gerald-Ugwu, G.C., Egolum, C.C and Emoh, F.I (2019). Investigating the adoption of Property-Level Flood Protection (Plfp) By Homeowners In Obio/Akpor Port-Harcourt. *International Journal of Thesis Projects and Dissertations*. Vol. 7, No. 3, pp. 48-57.

Heinkel, S. Benni T., Zin M, T., Toe A., Tin T, K., Win L, M., Saw S, O., Christian, M., Marlene W., Win M., Zin N, M., KhinK. S., Regine S and Frauke, K. (2022). Disaster preparedness and resilience at household level in Yangon, Myanmar. *Natural Hazards.* Vol. 112, pp. 1273–1294.

Isunju, J.B., Orach, C.G and Kemp, J. (2016). Community-level adaptation to minimize vulnerability and exploit opportunities in Kampala's wetlands. *Environment and Urbanization*, Vol. 28 No. 2, pp. 475–494. DOI: 10.1177/0956247816647342

Johnson, D.V., Gobo, A.E., Ngerebara, O.D and Ekaka-a, E.N. (2021). Assessment and Modelling of Flash Flood Risk from Extreme Rainfall and Soil Permeability in Port Harcourt Metropolis, Nigeria. *African Scholar Journal of African Sustainable Development (JASD-2)* Vol. 21 No. 2 pp.1 -19.

Jumbo, S. E and Wizor, C. H. (2020). Critical Assessment of Urban Residents' Perception of Disaster Risk Management in Obio/Akpor Local Government Area of Rivers State, Nigeria. *International Journal of Research and Scientific Innovation*.Vol 7, Issue 2, pp. 1-12.

Kaiser, H.F. (1960). The application of electronic computers to factor analysis. *Educational Psychology and. Measurment*. Vol. 20, pp. 141–151.

Koerth, J., Vafeidis, A.T., Carretero, S, Sterr, H and Hinkel, J. (2014). A typology of household-level adaptation to coastal flooding and its spatio-temporal patterns. *Springer Plus* 3:466 http://www.springerplus.com/content/3/1/466

Kofo, A.A. (2012). Global warming and challenges of floods in Lagos metropolis, Nigeria. *Academic Research International*. ISSN-L: 2223 – 9553.

Kutty, A. A., G. Wakjira, T. G , Kucukvar, M, . Abdella, M.G and Onat, N. C. (2022). Urban resilience and livability performance of European smart cities: A novel machine learning approach. *Journal of Cleaner Production* 378 (10). DOI: https://doi.org/10.1016/j.jclepro.2022.134203

Lee, E.H. and Kim, J.H. (2017). Development of Resilience Index Based on Flooding Damage in Urban Areas. *Water,* Vol 9, pp. 428-2442.

Mugume, S., Gomez, D and Butler, D. (2014). Quantifying the resilience of urban drainage systems using a hydraulic performance assessment approach. In Proceedings of the 13th *International Conference on Urban Drainage*, Sarawak, Malaysia, 7–12 September.

Narjiss, S., Otmane, R., Nabil, E. l, M., Ilias, K and Nadia, K. (2021). Spatialized flood resilience measurement in rapidly urbanized coastal areas with a complex semi-arid environment in northern Morocco. *Natural Hazards and Earth System Sciences*, Vol. 21, pp. 1101–1118. https://doi.org/10.5194/nhess-21-1101-2021

Oladokun V.O. and Proverbs, D. (2016*).* Flood risk management in Nigeria: A review of the challenges and opportunities. *International Journal of Safety and Security Engineering.* Vol. 6, No. 3 pp 485-497

Oladokun, V. and Proverbs, D and Lamond, J. (2017). Measuring flood resilience: A fuzzy logic approach. *International Journal of building Pathology and Adaptation.* Vol 35. Issue 5, pp. 470-487.

Ologunorisa, E.T and Diagi, P.N. (2005). Extreme rainfall and its implication for flood frequency in the Western Niger Delta. A case study of Warri. *Nigerian Journal* of *Tropical Geography*, 1.

Pilgrim, D.H and Cordery, F.S. (1993). Flood Runoff in D.R. Maidment (Ed.). *Handbook of hydrolog*y. New York: McGraw -hill Inc. 9 (1) 9-42.

Pratomo, R.A. (2016). Sensitivity analysis of Flash flood modelling in Grenada, as a small island Caribbean states. The 5th International Symposium on Earth hazard and Disaster Mitigation. AIP conf. Proc. 1730.

Proverbs D., Oladokun V.O., Xiao H and Adedeji T.J. (2018). A Conceptual Model For Measuring Flood Resilience at the Individual Property Level. *The Construction, Building and Real Estate Research Conference of the Royal Institution of Chartered Surveyors*, London, UK.

Rajib, S. (2009). Climate Disaster Resilience: Focus on Coastal Urban Cities in Asia. Available at http://www.unescap.org/idd/events/2009_EGM-DRR/Japan-Rajib-Shaw-climate-disaster-resilience.pdf. [Accessed 27 May 2022].

Saunders, M., Lewis, P and Thornhill, A. (2019). *Research Methods for Business Students* 8th edition. Pearson Education Limited; Prentice Hall.

Sheytanova, T. (2015). A Monte Carlo Study Comparing Three Methods for Determining the Number of Principal Components and Factors. An unpublished Masters Dissertation submitted to School of Business, Örebro University.

Skouloudis, A., Leal Filho, W., Deligiannakis, G., Vouros, P., Nikolaou, I. and Evangelinos, K. (2023). Coping with floods: impacts, preparedness and resilience capacity of Greek micro-, small- and medium-sized enterprises in flood-affected areas. International Journal of Climate Change Strategies and Management, Vol. 15 No. 1, pp. 81-103. https://doi.org/10.1108/IJCCSM-09-2022-0122

Wirehn, L., Danielsson, Å and Neset, T.S.S. (2015). Assessment of composite index methods for agricultural vulnerability to climate change. *Journal of Environmental Management*. Vol. 156, pp. 70–80.

Zurovec, O., Sabrija C and Bishal, K.S. (2017). Quantitative Assessment of Vulnerability to Climate Change in Rural Municipalities of Bosnia and Herzegovina, *Sustainability* Vol. 9, 1208- 1219. doi:10.3390/su9071208