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Sociodemographic and geophysical determinants of household vulnerability to coastal hazards in the Volta Delta, Ghana

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ABSTRACT

Theoretical emphasis on combining geophysical and socioeconomic characteristics in assessing vulnerability is growing but with little empirical support. Similarly, there is increasing consideration of cumulative vulnerability to multiple stressors, yet empirical studies are scant. This study seeks to assess the geophysical and socioeconomic determinants of households' vulnerability to the cumulative impacts of three coastal hazards – flooding, erosion and salinity – using evidence from the Volta Delta in Ghana. The study employed multiple linear regression and binary logistic regression functions to assess cumulative vulnerability and exposure to individual hazards, respectively. Results indicate that while exposure to hazards is determined largely by geophysical factors, the socioeconomic and demographic characteristics of households determine the extent of vulnerability to their impacts. In addition, socioeconomic and demographic characteristics of households, particularly higher wealth levels, non-agricultural occupation, and improved drinking water source, are associated with lower levels of vulnerability to the cumulative impacts of coastal hazards. In developing contexts, resilience to coastal hazards requires improved access to social amenities as well as alternative livelihood options.

1. Introduction

Coastal systems are synchronously exposed to shoreline erosion, saline intrusion, and inundation of wetlands and estuaries, among other hazards, due to the effects of sea level rise, ocean acidification and rising ocean temperatures. These exacerbate the poor state of livelihoods, infrastructural, cultural and historic coastal resources [1–6]. Deltaic ecosystems, in particular, are fragile and submit to the impacts of climatic change [7], which are likely to increase exposure to exogenous hazards. Coastal actions reinforce the exceptional fragility of deltas. Land subsidence and geology expose delta populations to flooding, erosion and salinity from both sea level rise and overflowing rivers and lagoons [7].

Furthermore, different population sub-groups are exposed to different hazards and may respond to the same hazards differently [8, 9]. Some studies find that socially marginalised populations are concentrated in areas that have high exposure to the hazards in deltas [10]. Therefore, it is recommended that assessments of risks in delta systems include both physical and anthropogenic factors in order to prescribe strategies for sustainable resilient practices [11].

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Moreover, several studies acknowledge the importance of integrating livelihood vulnerabilities to multiple hazards, yet the cumulative effect of hazards has not been much explored (Bacon et al., 2017; [12]. To account for the co-occurrence of multiple coastal hazards and the interactive effects of their simultaneous impacts, recent studies employ cumulative vulnerability or cumulative risk assessments, including the use of the Cumulative Vulnerability Index (Bukvic et al., 2020; [13]. These measures of cumulative vulnerability attempt to assess holistically the concurrent experience of the impacts of multiple hazards. This study aims to determine cumulative vulnerability to the impacts of erosion, flooding and salinity in the Volta Delta and to assess the geophysical and sociodemographic determinants of vulnerability.

2. Assessing vulnerability to hazards

Vulnerability comprises exposure, sensitivity and lack of adaptive capacity [5]. The Fifth Assessment Report of the IPCC (5AR) defines vulnerability as "the propensity or predisposition to be adversely affected" [5]. Exposure in this study refers to the extent (magnitude and frequency) to which households experience coastal hazards. Sensitivity covers the extent to which a household is adversely affected by the hazards to which it is exposed. Adaptive capacity reflects the ability to reduce damages and cope with the consequences. In this study, a lack of adaptive capacity is reflected by the extent of damage caused by the coastal hazards.

Studies estimate vulnerability using indicators based on population characteristics [10,14] but do not adequately assess household-level vulnerability due to the absence of explicit data on exposure and vulnerability to hazards at that level [13]. Studies of vulnerability have employed indirect quantitative methods which included proxies or estimates for vulnerability [7,14]. Several indicators, including poverty measures, gross domestic/national products and governance estimates, have been used as proxy for vulnerability indicators [7,14]. While such measures may be useful for country-level and regional assessment of vulnerability they have some fundamental theoretical and internal inconsistencies and may have modest utility for higher resolution vulnerability assessments at local community, household and individual levels and may be used to provide context [15,16]; Spielman et al., 2019).

Furthermore, empirical assessments of vulnerability tend to focus on only one hazard [11,17,18] whereas populations, particularly those living in coastal areas, are concurrently vulnerable to multiple hazards [9]. The convergence and interaction of the impacts of multiple hazards create areas of compound risk in delta areas [5]. Though studies measure vulnerability as a single epistemic theme they underscore the importance of analysing the varying individual components [19,20]. More so, even though the concept of cumulative vulnerability or risk assessment has gained prominence in environment and public health research and policy [12,21], assessment of the cumulative vulnerability of populations to environmental hazards is scant. Direct measurements of population vulnerability to hazards are rare. Majority of studies focus narrowly on individual hazards and individual livelihood dimensions. However, households are concurrently affected by the combined ecological, human and economic impacts of multiple hazards in deltas differently, resulting in different levels of vulnerability.

A few studies measure the exposure component of vulnerability of coastal areas [22]; 2014 [23]; focusing on geophysical interactions along coasts. These seek to inductively project impacts on coastal populations as homogeneous groups. Analysis of exposure, though useful for regional or national level analysis may not suffice in reaching socially vulnerable groups. Environmental hazards impact specific environmental, social and economic capital assets of exposed households [24]. For example, local populations perceive their vulnerability to erosion to include the impacts on their housing structures [25] while vulnerability to flooding may include impacts on human health [26]. Thus, aggregated estimates at the macro or national levels may lose details of the impacts of hazards at the micro or household levels. The propensity and willingness of people to act in response to hazards are dependent upon the perceptions or actual experiences of risks triggered by the hazard [15,25,27]. Imputing risks and imposing actions, without engaging stakeholders, may be incongruent to the desired effect of reducing vulnerability [25]. An integration of stakeholders' perceptions and experience of vulnerability and technical knowledge engenders a holistic appraisal of risks associated with coastal hazards and appropriate future actions.

It is important to note that sensitivity and adaptive capacity of population vary with sociodemographic and economic characteristics of populations at the micro level. Other studies that attempt to include population characteristics employ proxies that do not actually capture the direct impacts of hazards on particular capital assets [18,28,29] but rather focus on just population structure and characteristics [3].

3. Factors influencing vulnerability

The 5AR highlights the synergistic rise in vulnerability due to exposure to multiple hazards and the sensitivity of critical infrastructure [5]; p. 1048). It identifies key socioeconomic and demographic factors that determine exposure and vulnerability to climate-related risk [5].

Vulnerability is a "human value judgement" [29]; p. 496). It is a political-ecological concept which has biophysical, social and political economic risk components [30]. Mathematical representations of vulnerability based on broad conceptualisations [31] may shroud the complexity underlying the dynamic process of vulnerability. They may also be inadequate to assess the gamut of cumulative impacts of the real-world experiences of co-occurrence of coastal hazards. Quantitative estimates may fail to account for interactions among environmental stressors and exclude important population experiences such as the impact of flooding on housing or household food security or water quality. Thus, we utilise subjective household experiences of the impacts of flooding, salinity and erosion as our measure of vulnerability to coastal hazards. In their study assessing both geophysical and socioeconomic determinants, Codjoe & Afuduo [15] identify that the former have dominant impacts on people's perceptions. They however, stress the importance of examining sociodemographic variables in vulnerability assessments. This study seeks to improve this assessment by moving beyond perceptions of vulnerability to reports of prior experience of actual impacts on particular capital assets by three coastal hazards. This

study uses survey data to evaluate the geophysical and sociodemographic determinants of households' cumulative vulnerability to floods, salinity and erosion along the coast of the Volta Delta. Prior studies have assessed perceptions of and self-rated vulnerability to hazards [15,32], but not actual experiences of vulnerability to coastal hazards. We seek to ascertain which factors determine the extent of cumulative vulnerability of households' different livelihood spheres to different hazards in deltaic coasts.

4. Study area

The coastal Volta Delta is located in the south-eastern part of Ghana between longitudes 0°04′E and 1°13′E and latitudes 5°25′N and 6°00′N. It traverses the Greater Accra Region and Volta Region (Fig. 1). The delta is mainly drained by the Volta River, to its east is the Keta Lagoon Complex (KLC) and to its west the Songhor Lagoon [33,34]. The KLC has in its basin, small lagoons including the Avu and Angor Lagoons which join it during the rainy season, wetlands, dugouts and freshwater reservoirs. The coast of the delta is relatively the most vulnerable to the effects of sea level rise and coastal action in Ghana due to its geophysical characteristics including low elevation, geology, geomorphology and erosion/accretion rates [3]. The geology of the area is characterised mainly by "sandy barriers with confining lagoons at the backshore" [3]. Rapid erosion rates of about 4–8 m/year [33] prompted the Government of Ghana to construct two sea defense structures, in Keta and Ada East from 1997 to 2016. In Keta, for instance, entire communities have been resettled in government resettlement programmes due to the impacts of coastal erosion and inundation.

Sediment supply to the Volta Delta has been greatly interfered with by the construction of the Akosombo Dam in the 1960s [35], reducing supply by over 70% contributing to increased erosion. Without intervention, sea levels across Ghana are expected to rise by about 3 m over a century and have dire consequences for coastal populations [3]. Previous global estimates of populations and settlements within coastal regions assume a 100 km distance off the coastline as the "near-coastal" zone [36]. We note that many coastal hazards may not directly impact places as far as 100 km from the coastline, but the utility of this estimate lies in the global level of analysis and lack of higher resolution data. In this study, the coastal area is defined using administrative districts along the coastline of Ghana.

5. Data and methods

Data were sourced from Phase 1 of the DEltas, vulnerability to Climate Change: Migration and Adaptation (DECCMA) Ghana Survey, conducted April–June 2016 across fifty enumeration areas in nine administrative areas of the Volta Delta. The DECCMA Sending Area Survey was conducted to investigate vulnerability to climate change, migration and adaptation in river deltas in Bangladesh, Ghana and India. The survey collected data on household socio-demographics, geolocation, subjective and material wellbeing, migration, adaptation, environmental stress, income thresholds and expenditure. Though the survey collected data on drought and its impacts this study focuses on hazards related mainly to coastal action. In Ghana, the survey collected complete data on

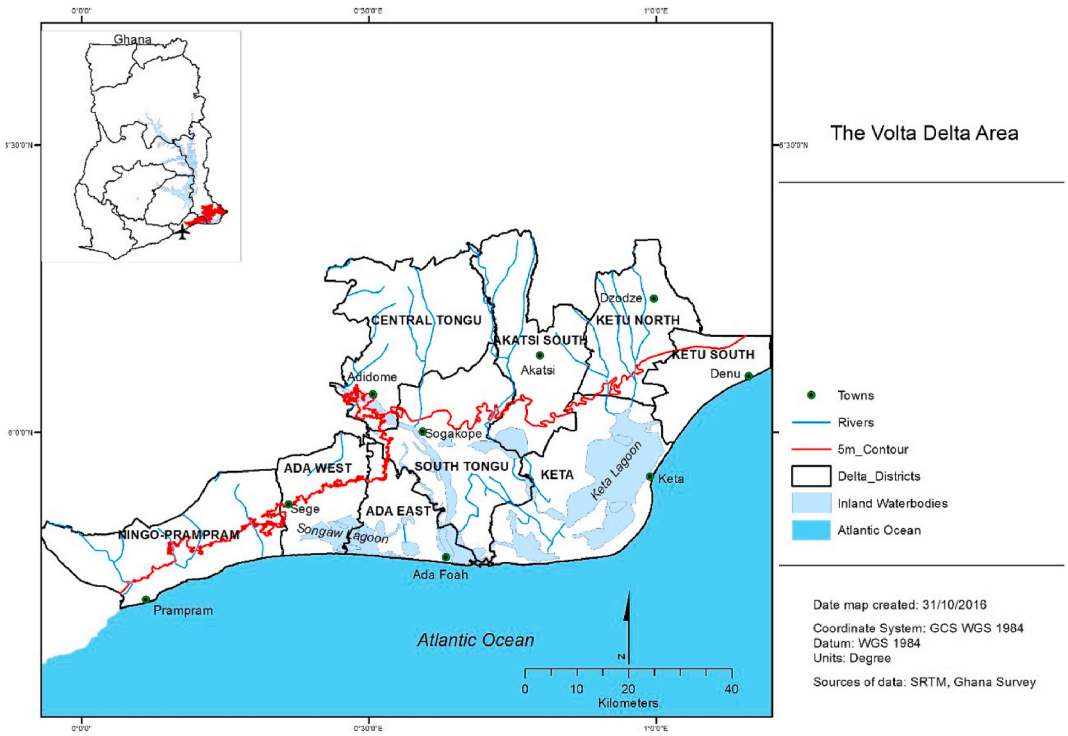

Fig. 1. Map of the Volta Delta showing the coastal districts and the 5-m contour.

1346 out of a targeted 1500 households across 9 districts [37]. Households were selected through a stratified random sampling approach. Strata were based on levels of geophysical vulnerability, which were measured by exposure to hazards. Geophysical vulnerability was determined by flooding, drought and erosion risks based on geographic information systems data on temperature, rainfall, and elevation. Enumeration areas for the survey were based on demarcations for the 2010 Population and Housing Census by the Ghana Statistical Service. This study utilises data on 933 households from only 5 coastal districts: Ningo-Prampram, Ada West and Ada East and Keta and Ketu South in the Volta Delta area.

5.1. Variables

The main dependent variable in the study is vulnerability to coastal hazards. The first dependent variable measures experience of any coastal hazards. There are 3 different hazards of interest to this study: flooding, salinity and erosion. Three dependent variables are based on vulnerability to each of these three hazards: Vulnerability to flooding; vulnerability to salinity and vulnerability to erosion.

Vulnerability is derived from two sets of retrospective questions relating to experiencing a particular hazard and the perceived severity of its impacts on seven types of household capital assets. This can be represented as

Table 1
Measurement and definition of variables.

Variable	**Definition**	**Measurement (±)**
Dependent variables		
Exposure to coastal hazard (flooding, salinity, erosion)	Having experienced a hazard	No exposure Exposure (low, medium, high)
Vulnerability to hazard (flooding, salinity, erosion)	Extent of impact of experienced hazard on household economic security, housing, drinking water, food security, health, crop/livestock disease, loss of human life	Continuous
Cumulative Coastal Hazard Vulnerability	Summation of all three vulnerability scores for all 3 coastal hazards	Continuous
Independent variables		
Distance to coastline (km)	Distance as the crow flies, in kilometre, from the location of a household to the nearest point on the coastline	Continuous (−)
Distance to lagoon (km)	Distance as the crow flies from the location of a household to the nearest point on the lagoon (in kilometres)	Continuous (−)
Distance to river (km)	Distance as the crow flies from the location of a household to the nearest point on the river (in kilometres)	Continuous (−)
Altitude (m)	Height above sea level (in metres)	Continuous (−)
Household dependency	Proportion of economically dependent household members (i.e. Below 15 years and all over 15 who are not working because they may be aged, retired, disabled or unemployed)	Continuous (+)
Household sex ratio	Proportion of male household members with 0 indicating an absence of males in a household and 1 signifying an all-male household	Continuous (−)
Mean household age	Average age of all household members	Continuous (+)
Household size	Total number of persons in a household	Continuous (+)
Mean years of education	Mean years of schooling of household	Continuous (−)
Sex of household head	Sex of the head of household	Male (ref) Female (+)
District of residence	Administrative area of residence	Ningo-Prampram (ref) Ada West (−) Ada East (+) Keta (+) Ketu South (+)
Drinking water source	Main source of household drinking water	Open unimproved source (ref) Pipe/Borehole (−) Other improved (−)
Type of toilet facility	Type of main toilet facility used by household	No facility (bush/beach/field) (ref) Pit latrine (−) KVIP (−) Flush toilet (−)
Tenancy	Household tenancy arrangement	Owner (ref) Non-owner (+)
Subjective wealth	Subjective measure of household's level of income stress	Income stressed - food insecure (ref) Income stressed - food secure (−) Not income stressed (−)
Access to mobile phone	Mobile phone ownership of any household member	No (ref) Yes (−)
Head's main occupation	Main occupation of household head	Agricultural (ref) Non-agricultural (−) No occupation (−)

ref: reference category km: kilometre; m: metre; + increases vulnerability; - decreases vulnerability.

$$V = E_h^c * \sum S_h^{cd} \tag{1}$$

where E_h^c is the level of exposure of a household h to a coastal hazard c applied as a weight.

S_h^{cd} is the sensitivity of a household h to the destructive impacts d of coastal hazard c.

The magnitude of impacts was also ranked and weighted as no negative impacts/unsure/don't know – 0, a few/moderate negative impacts – 1, and a lot of negative impacts – 2.

A cumulative coastal vulnerability index was derived from the summation of all three vulnerability indices into one variable. This measure of vulnerability as an outcome of the impacts of hazards on livelihood dimensions is based on an antecedent approach where vulnerability occurs when there is an absence of entitlements, hence lower adaptive capacity [38].

Table 1 presents a detailed description of the variables in the study while Table 2 and Table 3 provide summary statistics of the dependent variables and independent variables, respectively.

5.2. Analysis

Univariate analyses include the use of frequency distributions and number summaries to describe the spread of all variables in the study. Bivariate analyses include the use of cross-tabulations and chi-square tests of association between individual independent variables and the dependent variable. Where the independent variable is non-categorical, one-way ANOVA tests are conducted at the bivariate level. The final stage of analysis involves two levels of analysis. The first is the use of binary logistic regression models to test the independent effect of the predictor variables on the exposure of households to coastal hazards.

The equation for the logistic regression model to determine the odds of a household's exposure to a hazard is given as:

$$P(Y=1) = \left[\frac{1}{1+e^{(-(\alpha+\beta 1X1+\ldots+\beta kXk))}}\right] \tag{2}$$

where α is a constant, β is the regression coefficients, Y is the dichotomous outcome variable where Y = 1 if the household is vulnerable to coastal hazards and Y = 0 if not, X1, …Xk are all predictor variables.

The second level of multivariate analysis involved the use of multiple linear regression to determine which factors were associated with households' vulnerability to each hazard and finally to the overall cumulative coastal hazard vulnerability. Only households that had experienced at least one hazard were included in the analyses at this stage (n = 572).

The formula for deriving the multiple linear regression was

$$\mathrm{Y} = \alpha + \beta 1X1 + \ldots + \beta kXk \tag{3}$$

where Y is the cumulative coastal hazard vulnerability index, α is a constant; β refers to the regression coefficients; X1, …Xk are all predictor variables.

Predictor variables were included in the multivariate analyses based on their association with the dependent variables in the bivariate tests of association. All the geophysical variables had non-normal distributions; hence they were natural log-transformed before being included in the regression analyses.

6. Results

6.1. Distribution of households by their vulnerability and geophysical, socioeconomic and demographic characteristics

Of the 933 households that were studied, about 39% were not vulnerable to any of the three coastal hazards - flooding, salinity or erosion. Vulnerability levels differed for the three hazards. As shown in Table 2, the mean score was highest for salinity but lowest for erosion. The high standard deviations reflect a non-normal distribution which is to be expected considering patterns of settlement and boundary delineation in the Volta Delta.

As defined by the study population and shown in Table 3, distance to the coastline is lower than distance to river. While it is expected in a delta that distance to river will be shorter on the average it is higher than distance to lagoon and sea. This is primarily due to the demarcation of the Volta Delta area by the DECCMA Project. Generally, households that are vulnerable to at least one coastal hazard tend to have lower mean values for proximity to sea, lagoon and river, and also have lower mean elevation than all households together.

Households tend to have as many dependents as non-dependent members. Also, there are about as many males as there are females in households generally. Households have a mean education of less than 6 years. The mean household size is about 4 persons per households, slightly lower than the national average of 4.2 from the 2010 Population and Housing Census. The mean household age is

Table 2
Distribution of households by their vulnerability to coastal hazards and background characteristics (n = 572).

Vulnerability to Hazard	Range	Mean statistic	Standard deviation
Flooding	0–21	4.330	4.774
Salinity	0–31	5.290	5.345
Erosion	0–18	1.341	2.699
Cumulative coastal vulnerability	1–51	10.962	8.389

Table 3
Distribution of households by their geophysical, socioeconomic and demographic characteristics.

Household characteristic	Mean statistic (SD) – All n = 933	Mean statistic (SD) – Only vulnerable n = 572
Distance to coastline (km)	4.464 (6.763)	3.610 (6.391)
Distance to lagoon (km)	11.078 (10.907)	8.848 (9.538)
Distance to river (km)	34.050 (18.086)	31.703 (17.310)
Altitude (m)	45.822 (35.361)	42.957 (33.614)
Proportion dependent	.483 (.309)	.489 (.303)
Proportion male	.493 (.298)	.493 (.290)
Mean years of education	5.643 (3.528)	5.490 (3.436)
Household size	3.960 (2.536)	4.120 (2.554)
Mean household age	29.939 (14.222)	29.933 (14.463)
	Proportion (n = 933)	**Proportion (n = 572)**
Vulnerability to coastal hazard		
No	38.7	–
Yes	61.3	100.0
District of residence		
Ningo-Prampram	15.2	13.6
Ada West	17.9	19.1
Ada East	19.0	19.4
Keta	23.4	25.3
Ketu South	24.5	22.6
Drinking water source		
Open unimproved source	17.0	16.6
Pipe/Borehole	63.5	66.3
Other improved	19.5	17.1
Type of toilet facility		
No facility (bush/beach/field)	46.3	51.7
Pit latrine	20.9	20.1
KVIP	22.1	19.2
Flush toilet	10.7	8.9
Tenancy		
Owner	83.1	87.2
Non-owner	16.9	12.8
Subjective wealth		
Income stressed - food insecure	42.1	44.4
Income stressed - food secure	45.6	46.5
Not income stressed	12.3	9.1
Access to mobile phone		
No	4.5	5.7
Yes	95.5	94.3
Sex of household head		
Female	42.3	42.3
Male	57.7	57.7
Head's main occupation		
Agricultural	28.3	29.9
Non-agricultural	59.6	57.7
No occupation	12.1	12.4

about 30 years.

The highest proportion of households were from the Keta Municipality while the lowest proportion were from Ningo-Prampram District. The main source of drinking water for majority of households in the Volta Delta was the pipe or borehole, while about 17% sourced theirs from open sources including ponds, dugouts, streams, river etc. A high proportion of households did not have a toilet facility and resorted to the use of the bush, beach or field. These households constituted the majority of those vulnerable to coastal hazards. The use of flush toilets was the least common among households and about a fifth of households used the KVIP.

A large majority of households owned the structures they lived in. More than two-fifths of households were identified as income stressed - food insecure and about a tenth were classified as not income stressed. Just about 5% of households did not have access to a mobile phone. Over 40% of households were headed by a female; this proportion is higher than the national estimate of about 35% female-headed households [39]. A little under a third of households had their heads engaged in agricultural occupations. This is evident of the occupational transition and livelihood diversification that has occurred in Ghanaian households due to the combined effects of urbanisation, the structural adjustment programme, globalisation and environmental change.

6.2. Vulnerability of Volta Delta households by their geophysical, socioeconomic and demographic characteristics

As depicted in Table 4, non-vulnerable households differ significantly from vulnerable households in their distance to coastline, lagoon and river ($p < .001$) and also by elevation above sea level ($p < .01$). Similarly, mean household sizes generally differ between vulnerable and non-vulnerable households.

Contrary to expectation, households whose main source of water is the pipe/borehole have the highest proportion of vulnerable

Table 4
Geophysical, socioeconomic and demographic characteristics of households by their vulnerability to hazards.

Household characteristic		f-statistic
Distance to coastline (km)		23.332***
Distance to lagoon (km)		66.365***
Distance to river (km)		25.697***
Altitude (m)		9.626**
Proportion dependent		.544
Proportion male		.000
Mean educational attainment		2.537
Household size		5.887*
Mean household age		.001
	Proportion vulnerable % (n = 933)	**Chi square value**
District of residence		*8.861*
Ningo-Prampram	54.9	
Ada West	65.3	
Ada East	62.7	
Keta	66.8	
Ketu South	56.3	
Drinking water source		*6.419**
Open unimproved source	59.7	
Pipe/Borehole	64.1	
Other improved	53.8	
Type of toilet facility		*19.463****
No facility (bush/beach/field)	68.5	
Pit latrine	59.0	
KVIP	53.7	
Flush toilet	51.0	
Tenancy		*17.626****
Owner	64.4	
Non-owner	46.5	
Subjective wealth		*14.863***
Income stressed - food insecure	64.8	
Income stressed - food secure	62.6	
Not income stressed	45.2	
Access to mobile phone		*3.596*
No	49.1	
Yes	62.1	
Sex of household head		*0.003*
Female	61.3	
Male	61.5	
Head's main occupation		*2.246*
Agricultural	64.8	
Non-agricultural	59.5	
No occupation	62.8	

*p < .05 **p < .01 ***p < .001.

households. As expected, households without toilet facilities have the highest proportion of vulnerable households while those with flush toilets have the lowest proportion of vulnerable households. Households who own their occupied structures have more vulnerable households than their tenant counterparts. Proportion of vulnerable households negatively correlates with household wealth level.

6.3. Multivariate results

Exposure to coastal hazards: Table 5 shows that when only geophysical characteristics are taken into consideration, both proximity to coastline and to lagoon are associated with lower likelihood of exposure to coastal hazards. When socioeconomic and demographic characteristics of households are controlled for (Table 4, Model 2), the geophysical factors are still significantly associated with exposure to hazards. The further a household is from a river the less likely it is to be exposed to any coastal hazard in the Volta Delta. In particular, the natural log of a kilometre increase in distance from lagoon is associated with about less likelihood of exposure to coastal hazards. Similarly, the natural log (*ln*) of a kilometre increase in distance from shoreline is associated with about 20% reduction in the odds of being exposed to coastal hazards.

A unit increase in household size is associated with about 11% higher likelihood of household exposure to coastal hazards. Non-owner occupant households are about 40% less likely than structure owners to be exposed to hazards.

Wealthy households are about 60% as likely as than income stressed - food insecure households to be exposed to coastal hazards.

From Table 6, different geophysical characteristics are differently associated with vulnerability to different hazards and the cumulative vulnerability measure. Result for the second models which include all variables are discussed for each of the hazards and then for the cumulative vulnerability score.

Flooding: About 21% of the variation in vulnerability to flooding is explained by the sociodemographic and geophysical

Table 5
Geophysical, socioeconomic and demographic characteristics of households by their exposure to coastal hazards (n = 933).

	Model 1
Nagelkerke R^2	**.205**
Household characteristic	**Odds ratios (CI 95%)**
Constant	5050 ***
Distance to river (ln)	.727 (.593,.892)**
Distance to lagoon (ln)	.718 (.585,.880)**
Distance to coastline (ln)	.795 (.708,.894)***
Altitude (ln)	.883 (.773,1.064)
Proportion dependent	.539 (.267,1.090)
Proportion male	.963 (.572,1.622)
Mean educational attainment	1.012 (.963,1.064)
Household size	1.102 (1.015,1.197)*
Mean household age	.994 (.982,1.007)
District of residence	
Ningo-Prampram (ref)	
Ada West	.764 (.449,1.290)
Ada East	.434 (.197,.944)*
Keta	.995 (.454,2.182)
Ketu South	1.134 (.634,2.034)
Drinking water source	
Open unimproved source (ref)	
Pipe/Borehole	1.170 (.743,1.844)
Other improved	.782 (.475,1.287)
Type of toilet facility	
No facility (bush/beach/field) (ref)	
Pit latrine	.765 (.499,1.176)
KVIP	.658 (.428,1.016)
Flush toilet	.740 (.418,1.308)
Tenancy	
Owner (ref)	
Non-owner	.585 (.392,.875)**
Subjective wealth	
Income stressed - food insecure (ref)	
Income stressed - food secure	.953 (.976,.710)
Not income stressed	.627 (.388,1.020)*
Access to mobile phone	
No (ref)	
Yes	1.614 (.851,3.060)
Sex of household head	
Female (ref)	
Male	1.038 (.713,1.511)
Head's main occupation	
Agricultural (ref)	
Non-agricultural	1.219 (.848,1.751)
No occupation	1.654 (.880,3.109)

*p < .05 **p < .01 ***p < .001, CI: confidence interval.

characteristics in the model ($R^2 = 0.216$). A one percent kilometre increase in distance from coastline is associated with about a 0.4% increase in a household's vulnerability to flooding while a one percent kilometre increase in distance from lagoon is associated with about 0.70% reduction in a household's vulnerability to flooding. Furthermore, a percentage increase in the distance from a household to the river is associated with a 0.67% decrease in vulnerable to flooding.

A unit increase in household's mean years of education is associated with about 18% reduction in coastal households' vulnerability to flooding. Households in Ada West are more than twice as vulnerable to flooding as households in Keta whereas households in Ada East are about twice less likely. Households that are not income-stressed are less vulnerable to the impacts of flooding than households that are income stressed and food insecure. Agricultural households are significantly more vulnerable to the impacts of flooding than non-agricultural households.

Salinity: While distance from coastline and lagoon negatively correlate with households' vulnerability to salinity, the distance from river positively correlates with it. All other variables controlled for, one percent of a kilometre away from the coastline is associated with 0.80% decrease while a percentage kilometre from the river is associated with 0.60% decrease in household vulnerability to the impacts of salinity.

Households residing in Ada West are more than twice less vulnerable to salinity than those in Keta. Interestingly, households whose main drinking water source is from open, unimproved or other sources are less vulnerable to the impacts of salinity than those who use the pipe or borehole. Households whose main toilet facility is the KVIP are less vulnerable to salinity than those without toilet facilities.

Erosion: Only distance from coastline and district of residence are significantly associated with vulnerability to erosion. However, the results indicate that a *ln* kilometre away from the coastline is associated with greater vulnerability to the impacts of erosion while residence in Ketu South is associated with lower vulnerability to erosion than residence in Keta.

Table 6
Multiple regression results of the determinants of vulnerability to flooding, salinity, erosion and cumulative coastal vulnerability (n = 572).

Household characteristic	Flooding	Salinity	Erosion	Cumulative
R square	.216	.201	.090	.164
F statistic	5.898***	5.381***	2.115**	4.208***
Distance to river (ln)	−.666 (.218)**	.593 (.246)*	.212 (.132)**	.138 (.395)
Distance to lagoon (ln)	−.702 (.230)**	−.349 (.260)	.053 (.140)	−.998 (.417)*
Distance to coastline (ln)	.426 (.142)**	−.803 (.160)***	.145 (.068)	−.232 (.258)
Altitude (m)	−.084 (.206)	.187 (.232)	.129 (.125)	.231 (.373)
Proportion dependent	−.289 (.916)	1.356 (1.034)	−1.059 (.556)	−.008 (1.660)
Proportion male	1.185 (.770)	−1.204 (.870)	−891 (.468)	−.910 (1.396)
Mean educational attainment	−.179 (.066)**	.091 (.074)	−.007 (.057)	−.094 (.120)
Household size	−.057 (.093)	.017 (.105)	.077 (.057)	.038 (.169)
Mean household age	−.012 (.017)	.024 (.019)	−.012 (.010)	.000 (.030)
District of residence				
Ningo-Prampram	−.639 (1.007)	−2.152 (1.137)	−.288 (612)	−3.079 (1.826)
Ada West	2.382 (.879)**	−2.578 (.992)*	−.044 (.534)	−.240 (1.348)
Ada East	−1.904 (.688)***	−.853 (.777)	.098 (.418)	−2.659 (1.247)*
Keta (ref)				
Ketu South	.659 (1.012)	1.051 (1.143)**	−1.232 (.615)*	.478 (1.835)
Drinking water source				
Open unimproved source	−.170 (556)	−1.493 (.628)*	−.065 (.366)	−1.728 (1.008)
Pipe/Borehole (ref)				
Other improved	−.959 (.602)	−1.790 (.679)**	−.406 (.366)	−3.155 (1.091)**
Type of toilet facility				
No facility (bush/beach/field) (ref)				
Pit latrine	.237 (.547)	−.964 (.618)	.246 (.333)	−.481 (.992)
KVIP	.762 (.561)	−2.472 (.633)***	−.287 (.341)	−1.997 (1.017)
Flush toilet	−.220 (.791)	−.339 (.893)	−.437 (.481)	−.995 (1.434)
Tenancy				
Owner (ref)				
Non-owner	−1.073 (.574)	−.611 (.648)	.058 (.349)	−1.742 (1.041)
Subjective wealth				
Income stressed - food insecure (ref)				
Income stressed - food secure	−.720 (.402)	.143 (.453)	−.051 (.244)	−.527 (.728)
Not income stressed	−1.756 (.695)*	−1.238 (.785)	−.528 (.423)	−3.522 (1.260)**
Access to mobile phone				
No (ref)				
Yes	2.264 (.955)*	1.751 (1.078)	.101 (.580)	4.116 (1.731)*
Sex of household head				
Female				
Male	−.408 (.481)	.619 (.543)	.216 (.292)	.427 (.872)
Head's main occupation				
Agricultural	1.692 (.478)***	−.414 (.539)	−.159 (.290)	1.947 (.866)*
Non-agricultural (ref)				
No occupation	.502 (.701)	−1.089 (.792)	−.093 (.426)	−.681 (1.271)
Constant	14.537 (3.379)***	6.257 (3.814)	−1.232 (2.054)	19.562 (6.125)**

Cumulative vulnerability: Interestingly, the correlates of cumulative vulnerability to coastal hazards present a somewhat different picture. When only geophysical variables are considered, only distance from river and lagoon are significantly associated with the level of cumulative vulnerability. All other variables considered, a kilometre away from the lagoon is associated with a 28% decrease in vulnerability to all coastal hazards. The other geophysical characteristics do not show any significant variation in vulnerability. Households whose main source of water includes the 'other' sources are more than twice less vulnerable than those who use open unimproved sources. Households with no income stress are more than twice less vulnerable than income stressed - food insecure households while access to mobile phones is rather associated with higher vulnerability. Non-agricultural households are also more than twice less vulnerable than agricultural households to the cumulative impacts of coastal hazards.

7. Discussion and conclusion

All things being equal, households are most vulnerable to the impacts of salinity and least vulnerable to the impacts of erosion in the Volta Delta. However, proximity to either the coastline or lagoon is associated with higher vulnerability to salinity.

It seems counterintuitive that the further a household is from the coastline, the more likely it is to be vulnerable to the impacts of flooding. However, the opposite direction of this relationship with proximity to lagoon and river indicates that in the Volta Delta, coastal communities closest to the lagoons and river are more likely to be vulnerable to the impacts of flooding. The further away a household is located from the river, the more vulnerable it is to salinity. The households closest to the river will have more access to its freshwater than households further away from it. Overall, proximity to the sea is associated with exposure and impact of coastal hazards. However, among those households impacted, proximity to the lagoon is positively correlated with vulnerability, especially to flooding and salinity. We find that in the Volta Delta, proximity to a lagoon, rather than the coastline, is positively correlated with

higher vulnerability of households to coastal hazards. It is important for further studies to explore the impacts of lagoons on people's experiences of coastal hazards. However, it is anecdotal that some of the most vulnerable coastal settlements in Ghana lie between the lagoon and the sea. In the Volta Delta, these include Totope and Akplabanya, south of the Songhor Lagoon.

Residence in a district may be strongly linked with higher risk of vulnerability to a particular hazard but reduced risk to another. In Ada West, large portions of the land are covered by the Songhor lagoon and other smaller intermittent lagoons and water bodies, leading to flooding, particularly during the rainy season [40]. The fact that salt mining is a major economic activity which can be affected by flooding can also make households in the district more sensitive to the impacts of flooding. In Ada East, on the other hand, tourism and hospitality potentials exist, thus insulating households from the impacts of flooding on major economic activity [41]. Furthermore, for a district where salt mining is an important and the main economic activity, it is plausible that households in Ada West will be better suited to adapt to salinity and use it to their economic advantage. With regards to erosion, Ketu South lies to the east of Keta and, according to Anthony [42]; beyond Keta there is a more stable shoreline towards Togo and Benin, which includes the Ketu South district.

Even though the geophysical characteristics may determine, to a large extent, households' exposure to coastal hazards, their socioeconomic and demographic characteristics may attenuate the extent to which they are impacted by these hazards. While erosion and flooding may have major physical impacts, it may also be very important to begin to incorporate the socioeconomic and environmental impacts of salinity on households in the Volta Delta. When exposure to individual hazards is assessed, the geophysical characteristics of households tend to be very important determinants of vulnerability. However, when the cumulative impacts of hazards are considered, socioeconomic and demographic characteristics tend to significantly influence households' vulnerability.

In this regard, even though all districts along the coast of the Volta Delta face significant challenges with coastal hazards, the sociodemographic characteristics of different population subgroups make them vulnerable to specific hazards. There is the need, therefore, for improved stakeholder and community engagement to improve their capacities to enhance their resilience to the impacts of coastal hazards [43].

To conclude, geophysical characteristics largely influence exposure to coastal hazards while the socioeconomic and demographic characteristics of households drive the extent to which hazards impact livelihoods in the Volta Delta of Ghana. Additionally, using a cumulative vulnerability index should help to incorporate the synergistic effects of the hazards to which households are exposed in coastal delta areas.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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