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Analysis of the perceptions of flood and effect of adoption of adaptation strategies on income of informal settlements of Mamelodi in South Africa

Y.S. Nyam^{a,*}, N.T.S. Modiba^a, T.O. Ojo^{a,b}, A.A. Ogundeji^a, C.C. Okolie^a, O.T. Selelo^c

^a Disaster Management Training and Education Centre for Africa at the University of the Free State, Bloemfontein 9300, South Africa

^b Department of Agricultural Economics, Obafemi Awolowo University, Nigeria

^c The University of the Free State, Bloemfontein 9300, South Africa

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ABSTRACT

Extreme weather events are being experienced all over the world because of climate change, posing challenges for individuals and households who rely on agricultural operations as their major source of livelihood. Household-level adaptation is an efficient way of dealing with global climate change. As such, this study aims to examine the perception of informal settlers to flood risk and their adoption of adaptation strategies to flood. This study applied the seemingly unrelated regression (SUR) to identify factors influencing the perception of flooding on community members and probit regression to identify the factors influencing the adoption of adaptation strategies to floods and examined the impact of the adoption of adaptation strategies on income in Eerste Fabriek informal settlement in Mamelodi using two-step quasi-maximum likelihood estimates of fractional response model. Our results show that community members are perceptive of floods and their impact on the environment and their livelihoods, and on average, they believe flood impact is significant. Age, marital status, education, employment status, income, and household size are demographic factors that tend to influence their perception of the impact of flood events. Access to institutional facilities such as health and recreational facilities was also a significant factor in how community members adapt to the impact of floods. Timely healthcare access services are a significant precursor for people to form their perception, which is intended to help them adapt appropriately to situations as health is wealth. Community members' perceptions and adaptive capacity can be improved through policies that foster the adoption of effective adaptation strategies. Community-based adaptation strategies are necessary for involving all stakeholders and necessary for mitigating the effects of flooding.

Practical implications

The world is experiencing an increase in the frequency and intensity of flood events due in part to extreme weather events and changing rainfall patterns (Gori et al., 2022). This has been made worse by factors such as population growth, urbanization, poor urban planning, and poor solid management among others. The impact of these flood events has both direct and indirect socio-economic and environmental consequences on the economy (Echendu, 2020). Though flood is experienced by both developed and less developed countries around the world, the impacts are more pronounced in less developed countries and communities that lack the capacity to adequately prepare, respond, and

mitigate the impacts of these flood events (Leal Filho et al., 2019). One of the factors exacerbating the impact of floods in less developed countries is the growth of informal settlements because of poor urban planning. As population increases in urban cities, the formation of informal settlements increases especially in flood-prone areas (Williams et al., 2019). The growth of urban populations and informal settlements combined have amplified flood events which is greatly endangering the well-being of households (Baklanov et al., 2018; Dalu et al., 2018). Flooding is a disaster that has been frequently occurring in the 21st century and is expected to increase in the near future (Dube et al., 2021; Rosenzweig et al., 2018). According to Munyai et al. (2021), flooding events especially in countries like South Africa can be attributed to various factors such as heavy rainfall, blocked drainage systems, and other various factors. These flooding events often impact

* Corresponding author.

E-mail address: yongsebastian04@gmail.com (Y.S. Nyam).

¹ ORCID: 0000-0001-7175-2873.

households in various negative ways such as the loss of property, displacement, illness, and death especially affecting households in informal settlements (Bell et al., 2018; Cianconi et al., 2020). As such, measures are needed to help communities build adaptive capacity and resilience to flooding. Perception, awareness, and training have been identified as a strong tool for communities to build resilience to flood events. Therefore, policy formulation and local governance must help boost the perceptions of communities in informal settlements of floods, their impact, and adaptation measures. Policy formulation must take on a participatory approach towards members of the public regardless of their age, marital status, employment status, income, and household size to help boost their perception of flooding in their areas. Policy formulation on improved education, training, and awareness of flooding can also help to boost the perception, resilience, and adaptation by members of the community, as well as encourage communities to adopt available strategies to protect themselves against flooding events in the future. The proper strengthening of institutional health facilities especially for the urban poor can help circumvent the transmission of diseases, especially during such events. Empowering disadvantaged groups can help boost the adaptation to such events by all members of the community. Policy formulation must also consider the use of advanced techniques such as early warning systems and flood mapping across various municipalities to identify areas that are highly susceptible to floods as a way of increasing perception and encouraging adaptation against flooding, especially in informal settlements.

1. Introduction

Flooding remains one of the world's most dangerous hazards, disproportionately affecting vulnerable groups in low-income areas (Deria et al., 2020; Tasantab et al., 2022). In recent decades, the intensity and frequency have increased due in part to climate change. Between 2010 and 2020, flood damage was estimated to be approximately 250 billion US dollars globally (Tembata and Takeuchi, 2019). Population growth, urbanization, and poor solid waste management have further increased the occurrence of flood events and exacerbated the impacts on vulnerable households (Echendu, 2020; Poku-Boansi et al., 2020; Sakijege and Dakyaga, 2023). Research has established a relationship between flooding events, extreme climatic conditions, and anthropogenic activities (Birkholz et al., 2014). Understanding and preparing for flood events is quite challenging, as such it is important to develop strategies for mitigating and adapting to the impact of flooding (Pour et al., 2020). These mitigation and adaptation strategies are especially important in low-income areas such as informal settlements that are vulnerable to the impacts of flood events (Bloemen et al., 2018). Informal settlements are low-income areas mostly in urban settings and are greatly impacted by flood events (Roy et al., 2018; Serdeczny et al., 2017).

According to Giri et al. (2021), informal settlements are those developed outside the formal system where the impoverished are regularly found and are generally situated in ecologically fragile and marginal areas (Ming et al., 2021; Liang et al., 2020). People residing in such areas are highly susceptible to extreme events such as floods, and a much deeper understanding of urban poverty is needed to enhance their resilience (Satterthwaite et al., 2020). Projected to grow by 10 % annually, informal settlements have received increased attention from policymakers and other stakeholders (Tasantab et al., 2022). Due to their location and socio-economic status, informal settlements are exposed and vulnerable to the impacts of floods. It is widely acknowledged that Sub-Saharan Africa has a significant and growing population living in informal settlements. (Silvestri et al., 2018; Baye et al., 2020).

The frequency and impact of floods have increased greatly impact Sub-Saharan Africa affecting the livelihoods of households in low-income communities (Mangey, 2021; Sono et al., 2021). The region has been experiencing increased occurrences of flood events and

communities have shown an inability to cope with the impacts of floods (Codjoe and Atiglo, 2020). Floods are considered the most devastating, especially in communities and ecosystems that are found in vulnerable areas such as informal settlements (Rentschler et al., 2022; Mashi et al., 2020). Flood events have resulted in the loss of life and property (Waghwalwa and Agnihotri, 2019; Tellman et al., 2021), and there is an increased risk to human health due to the transmission of waterborne diseases (Suhr and Steinert, 2022; Wright et al., 2021). Like many countries in Sub-Saharan Africa, the frequency and intensity of flood events have increased significantly in South Africa. South Africa is a semi-arid country with below-average rainfall, but the country has experienced increasing flood events as a result of changing climate patterns, the settlement of people on flood plains and riverbanks, and the mismanagement of solid waste (Kunene et al., 2021).

South Africa experienced severe flooding and landslides in April 2022 in Durban caused by heavy rainfall resulting in deaths, displacement of people, and destruction of infrastructure in the eastern part of the country (World Health Organization, 2022). The flood destroyed homes in informal settlements, schools, bridges, and roads in the eThekweni Metropolitan Municipality. According to Dalu and Shackleton (2018), 33 towns were considered disaster areas in South Africa during recent flood events. Thus, a greater understanding of the impact of floods on those who are vulnerable is needed. The Tshwane Metropolitan Municipality is one of the areas in South Africa facing the significant impacts of flooding, with most of those affected located in informal settlements (Loots and Smithers, 2020). Factors such as climate change, population growth, and urbanization have increased the worth of informal settlements and exacerbated the impact of flooding in the municipality. Due to the lack of capacity, the impact of floods in these informal settlements in Tshwane is loss of livelihood, food insecurity, poverty, and inequality (De Silva and Kawasaki, 2020). Eerste Fabriek informal settlement in the Mamelodi township of Tshwane is one of the most severely affected communities by flood. Located along the banks of the Pienaarsrivier, Eerste Fabriek is a low-lying area prone to flooding during heavy rains. Flooding is a major problem in the area with the severe floods of December 2019 and February 2022 a case in point. This makes it necessary to enhance the understanding of the impact of floods on this vulnerable community. Despite the recurrent flood events in the community, their impact and perception of adaptation strategies have not been empirically researched in the region. Hence there is an urgent need to assess the state of flooding conditions and the factors influencing the choice of adaptation strategies toward developing an integrated flood risk management plan for enhancing flood resilience in the community.

This study assesses the perceptions of flood and the effect of adoption of adaptation strategies on the income of informal settlements Eerste Fabriek in the township of Mamelodi, Gauteng Province of South Africa. The study examines the socioeconomic impact of flood events among community members in the Eerste Fabriek informal settlement. This study is divided into 5 sections. The next section examines the conceptual framework, followed by the methodology, the results, and the conclusion and recommendation in the final section.

2. Assessment of the impact of flooding

Economic development enhances urban development, urbanization, and growth in informal settlements. A study conducted in the informal districts in Burundi concluded that zones where towns/cities expand are the most exposed to flooding (Kubwarugira et al., 2019). Uncontrolled urbanization is a concern that leads to the formation of informal settlements because of the poor settling on vulnerable ecosystems and marginal areas, thus leaving people susceptible to the effects of floods (Chilinde and Mamiwa, 2022; Williams et al., 2019; Kikwasi and Mbuya, 2019; Dalu et al., 2018). Therefore, it is necessary to integrate the vulnerability of communities in the urban planning process to attain safer communities (Seddiky et al., 2020). Furthermore, understanding

the exposure to water, energy, and urban infrastructure is pivotal to achieving better resilience against extreme weather events like floods (Salimi and Al-Ghamdi, 2020; Baklanov et al., 2018).

Dube et al. (2021) stated that flooding in areas surrounding cities of the Western Cape results from both biotic and abiotic factors like extreme rainfall. Increased occurrences of flooding have led to the loss of life, especially in cities that are situated by the coast (Atanga and Tichaawa, 2020; Bell et al., 2018; Ma et al., 2018). The obstruction of waterways and drainage structures also aggravates the incidence of floods occurring across different cities (Yin et al., 2021; Douglas, 2017). As posited by Floodlist (2019), certain areas of South Africa experienced flooding encompassing various provinces including Gauteng that led to the death of about 32 people. In the Gauteng City- Region of South Africa, there has been evidence of rapid urbanization that poses challenges to land use management, service delivery, and social cohesion which exacerbates the impacts of events such as flooding around these areas (Nhamo et al., 2021). For sustainable and resilient regions, rational adaptation strategies must be put in place against the effects of floods (Rayan et al., 2022; Li et al., 2020; Haer et al., 2020). Busayo et al. (2022), indicated that ecosystem-based adaptation strategies are encouraged to be put in place because of their cost-efficiency and multifunctionality in flood disaster risk reduction. It is paramount to integrate biodiversity and ecosystem services as an adaptation by different households especially those in flood-prone areas of South Africa (Leal Filho et al., 2021).

As opined by Kom et al. (2020), households utilize both on-farm and off-farm adaptation strategies to deal with the impact of climate change. Changing cropping plans, urban migration, and involvement in off-farm businesses are some of the adaptation strategies households utilize (Gebru et al., 2020). Talanow et al., (2021) indicated that communities in the Western Cape have noticed the increased rates of flooding. The ability of households to adapt is greatly motivated by having previously

encountered floods and other extreme events (Jellason et al., 2019). The perception of the community to flood risk is crucial to investing in effective adaptation strategies to mitigate the impacts of flood events (Shikwambana et al., 2020; Meyiwa, 2019).

Assessing the perception of informal settlements to flood risk in Ghana, Tasantab et al., (2023) found that factors such as fear, flood experience, and coping experience were the major factors influencing residents' flood risk perceptions with fear being the most significant. Furthermore, Okaka and Odhiambo (2019) found that residents in informal settlements in Mombasa perceived future flooding as high risk but chose not to vacate the area. They however invested in short-term adaptation measures mainly due to financial constraints, lack of knowledge, and government support. Moreover, Owusu et al. (2023) revealed that residents in Accra Ghana use local coping and adaptation strategies such as digging trenches around houses before and during floods, constructing temporary barriers, and using rocks, sandbags, and concrete to divert floodwaters away from homes to mitigate the effects of flooding.

3. Materials and method

3.1. Study area, sampling, and method of data collection

This study was conducted in the Eerste Fabriek informal settlement, which is located in the township of Mamelodi, City of Tshwane (CoT), Gauteng Province of South Africa. The Tshwane Metropolitan Municipality (TTM) (Fig. 1) is the largest of the three metropolitan municipalities in the Gauteng Province, which also includes Johannesburg and Ekurhuleni, and is the third-largest metropolis in the world by land mass with a total area of about 6 345 km² (CoTIDP, 2014). Given that Tshwane is the nation's capital, there is an issue with increasing urbanization that leads to the development of illegal informal settlements,

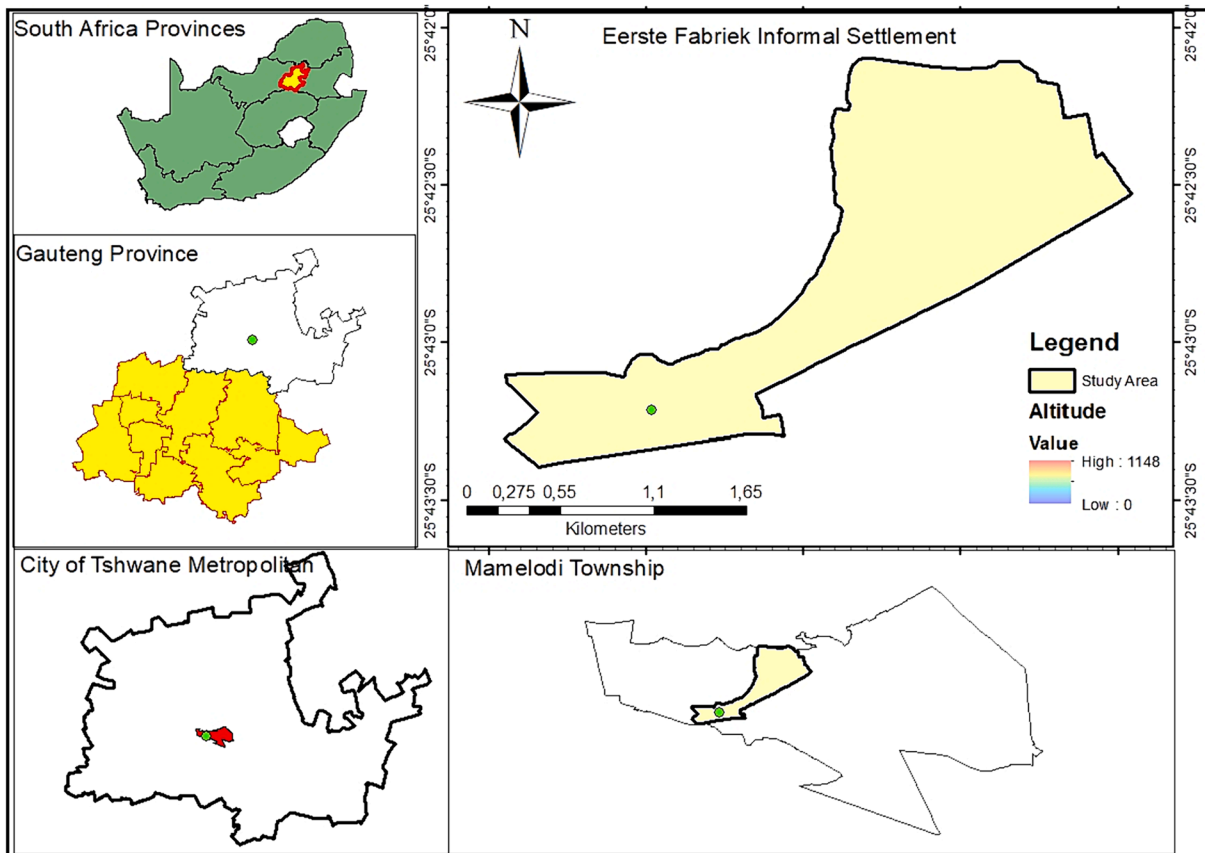


Fig. 1. Map of South Africa and the City of Tshwane.

which is a problem when it comes to disaster exacerbation (Khanna, 2020). According to StatsSA (2016), slightly more than 2.9 million people are living in the CoT.

Mamelodi township has a population of approximately 337, 577 people, according to StatsSA (2016) community survey. Ninety percent of the people in Mamelodi are black Africans, 2.2 % are whites, 2.1 % are Asian/Indian, and 6.6 % are coloured (mixed race). Of this population, 79 % are of working age, and 21 percent are dependents (StatsSA, 2016). Due to a lack of economic activity, inequality is widespread in townships and informal settlements in Mamelodi, where the unemployment rate is 24.2 %. There has been an increase in informal settlements in the Mamelodi township as people migrate from largely rural areas to seek economic opportunities in the big cities. This has led to problems of inequality particularly evident in the lower-income areas of the township such as the Eerste Fabriek informal settlement. Eerste Fabriek is located along the banks of the Pienaarsrivier, which is a seasonal river that flows through the area (CoTIDP, 2014) and has an estimated population of 1,700 people. Eerste Fabriek is a major flood-prone area since it is located in a low-lying area and is at risk of flooding during heavy rains. Floods in Eerste Fabriek in December 2019 damaged approximately 700 shacks and displaced about 1,300 people (Modiba, 2021). In February 2022, the area experienced another major flood event which disrupted major infrastructure such as education and healthcare services.

Data for this study was collected in August 2021 through the administration of a structured questionnaire with open and close-ended questions. Since then, one major flood event has been recorded in the area (February 2022). Five trained enumerators with good knowledge of the study area assisted in the administration of the questionnaires. The questionnaires were administered in English and translated to the local language for respondents who had a limited understanding of English language. The questionnaires were designed to capture relevant input-output data of community members' perception of flood, their socio-economic status, losses and damages from floods, and adaptation and resilience indicators in the community.

Given that the population of the area is estimated to be 1,700 people, a multi-stage sampling method was used for this study. A purposive sampling technique was used in the first stage to identify individuals who were more than 18 years old and had lived in the area for more than two years. Individuals and households with more than two years in the area were purposively targeted for this study because they have good experience of the area, have experienced at least one flooding event in the area, and can explain the impact of these flood events on their socio-economic livelihoods. As such, 384 individuals were purposely sampled based on these criteria. Questionnaires were administered and 100 questionnaires were correctly completed. Incomplete questionnaires were discarded. The final sample of this study is 100 which is representative of the study area.

3.2. Conceptual framework

3.2.1. Factors influencing the perception of flooding among the informal settlement-seemingly unrelated regression (SUR) model

To estimate factors influencing the perception of flooding in the informal settlement, a seemingly unrelated regression (SUR) model was employed. This approach has been used in similar studies (Nilakantan et al., 2013; Ojo and Baiyegunhi, 2020). Thus, when analyzing factors affecting the perception of flooding among the informal settlements where the dependent variables are considered as a group but do not have a direct interaction, seemingly unrelated regression (SUR) modeling—first discussed by Zellner (1962)—is appropriate. In general, an SUR system is an extension of a linear regression model. It consists of multiple regression equations, each of which can have a different set of exogenous regressors and its own dependent variable. The main characteristic of the SUR model is that the errors of these equations are probably going to be correlated when they pertain to responses from the

same set of observational units. From this perspective, the SUR model can be understood as a generalization of the general linear model in which the right-hand side explanatory variables are permitted to vary across equations, or as a condensed version of the general linear model in which some of the coefficients in matrix are restricted to equal zero. Furthermore, as posited by Rentziou et al. (2012), contemporaneous correlation of error terms exists even though the equations appear to be unrelated. Consequently, the coefficients are consistent but typically inefficient if interlinked equations are estimated using OLS separately as opposed to the SUR model, which amounts to workable generalized least squares (FGLS) with a specification of the variance-covariance matrix.

Bearing in mind the likelihood of informal settlement's socio-economic characteristics will undoubtedly influence their adoption status, simply put, the variables that affect their perception of climate change such as flood causing homelessness, could also affect floods leading to environmental degradation and as well causing reduction in expenditure, meanwhile, the impact would be diverse. The SUR model was thus specified by cross-equation correlation among the error terms. In line with the study of Asfaw et al., (2016) and Ojo and Baiyegunhi (2020), a correlation coefficient with a positive sign is consistent with the unobservable heterogeneity in the tendency to discriminate the respondents. On the other hand, a coefficient with a negative sign is in line with the interpretation of factors influencing community members' likelihood of not adopting the climate change adaptation strategies. As specified in Equation (1), the degree to which a farmer adopts is indicated by an index $PERCEPTION_i^*$, which is a latent variable (Foltz, 2004).

$$PERCEPTION_i^* = L_i^* \beta_i + \varepsilon_i \quad i = 1 \dots N \quad (1)$$

Where, $PERCEPTION_i^*$ is the observed variable equals 1 if $PERCEPTION_i^* > 0$, when a farmer perceives climate change (flood causing homelessness, environmental degradation and reduction in expenditure) and 0 if $PERCEPTION_i^* \leq 0$; L_i is a vector of covariates; β_i , parameters to be estimated; while ε_i is the error term. The three highest loadings from PCA are modelled in the analysis, namely, flood causes homelessness, environmental degradation, and reduction in expenditure. The equations for the three perception conditions are specified as follows:

$$PERCEPTION_{1i} = \delta_i L_i + \lambda_i \quad (2)$$

$$PERCEPTION_{2i} = \varpi_i L_i + \psi_i \quad (3)$$

$$PERCEPTION_{3i} = \theta_i L_i + \chi_i \quad (4)$$

where $PERCEPTION_{1i}$ is a binary variable which takes a value of 1 for a flood causing homelessness for the settlement i and 0 if otherwise; $PERCEPTION_{2i}$ has a value of 1 for environmental degradation perception i and 0 if otherwise; $PERCEPTION_{3i}$ has a value of 1 for reduction in expenditure i and 0 if otherwise; L_i represents a vector of explanatory variables; δ_i ϖ_i and θ_i are coefficients to be estimated; and λ_i ψ_i and χ_i are random error terms.

The climate change perceptions of the community members in the study area were numerous. Hence, the use of principal component analysis (PCA) as employed by (Ojo and Baiyegunhi, 2020) was employed to reduce the multi-dimensionality into an array of case-specific scores defining the strength and shapes of belief in the perception of climate change (Jolliffe, 2022). For this study, the first PCs with the highest loadings of 68 % were chosen and subsequently used as outcome variables in the SUR model.

Impact of adoption of adaptation strategies on income share- two-part quasi-maximum likelihood estimates of the fractional response model

The decision of community members to adopt climate change adaptation strategies or not is a binary choice, and this decision is controlled by various factors, for example, socio-economic, availability

of resources, and information. To implement this model, it is expected to estimate the decision of households to adopt climate change adaptation strategies or otherwise. The behaviour can be explained by a criteria function and expressed as a function of exogenous factors and community members' socioeconomic factors (Q). Q is a set of exogenous variables influencing households' decision to adopt climate change adaptation strategies. The set of exogenous variables in Q are gender, age, household size, education, land ownership, farm size, access to extension, and access to credit. There is an endogeneity issue that needs to be addressed in Eq. (6) to obtain consistent and unbiased estimates. Community members' access to credit facilities can be potentially facilitated through the adoption of climate change adaptation strategies. The underlying latent variable that captures the true socio-economic characteristics is hypothesized to determine the probability of $COPART_i$ by a smallholder farmer. The regression equation (1) defines the latent variable $COPART_i^*$:

$$ADOPTCCAS_i^* = Q_i\beta + e_i \quad e_i \approx N(0, 1) \text{ (First Part)} \quad (5)$$

$$\text{and } ADOPTCCAS_i^* = 1 \text{ if } ADOPTCCAS_i^* > 0$$

$$ADOPTCCAS_i^* = 0 \text{ if } ADOPTCCAS_i^* \leq 0$$

where $ADOPTCCAS_i^*$ is a categorical variable that takes the value of 1 if a smallholder farmer adopts climate change adaptation strategies and 0 otherwise; and β is a vector of parameters to be estimated.

In the second part of the model, the study employs the method of Papke and Wooldridge (1996), using a fractional response model to estimate the impact of the adoption of climate change adaptation strategies on the income share of community members while taking into account the type of dependent variable. The predicted residual from the probit model is plugged into the second part model to account for potential endogeneity in the fractional response model (Lin and Wooldridge, 2017). The second part (impact of the adoption of climate change adaptation strategies on income share) equation is expressed as:

$$E(INCSHARE_i / ADOPTCCAS_i = 1) = f(W_i, \beta) + \alpha\Phi \text{ (Second Part)} \quad (6)$$

$$E(INCSHARE_i / W_i ADOPTCCAS_i = 1) = f(W_i, \beta) + \alpha\Phi$$

where $INCSHARE_i$ is the observed response of income share ($INCSHARE_i$), E is the expectation operator; W is a vector of the household characteristics; β is a vector of parameters to be estimated; Φ is the residual which accounts for the endogeneity issue from the probit model; and α is the associated parameter to be estimated. Based on the literature of Quasi-MLE (White, 1982; Wooldridge, 2011), the findings above carry through if $INCSHARE_i$ is a fractional response with a conditional mean that happens to have a probit form. The key insight from quasi-likelihood estimation is that we do not need to know the true distribution of the entire model to obtain consistent parameter estimates. This likelihood function could also be applied to the case where $INCSHARE_i$ is a fractional response, as long as we model the conditional mean of $INCSHARE_i$ to have a probit form. Interesting questions of functional form and inference arise because of the bounded nature of the income shares variable and the potential to observe values at the boundaries.

In order to create reliable methods for estimation and inference with fractional response variables, we have synthesized the quasi-likelihood method, which we describe in this paper. The main reason is that since income shares are bounded between 0 and 1, no single explanatory variable can have a constant effect across the entire range of variables (unless the explanatory variables have a very narrow range). Although non-linear functions of the explanatory variable can partially mitigate this issue, the predicted values from an OLS regression are never guaranteed to fall inside the unit interval. As a result, the disadvantages of the linear probability model for binary data are comparable to those of linear models for fractional data. Given the explanatory variables, one

can always estimate the model by assuming a specific distribution for the outcome variable and estimating the conditional distribution's parameters using maximum likelihood.

Mullahy (1990) proposed the beta distribution as a possible distribution for fractional outcome variable (income shares); however, estimates of the parameters obtained are known to be not robust to distributional failure (Gourieroux et al., 1984). It is obvious that in some situations, standard distributional assumptions can be incorrect. The beta distribution implies that every value in $[0, 1]$, for instance, is taken on with probability zero, which is a significant limitation. Because of this, it is challenging to defend the beta distribution in situations where a significant percentage of the sample falls between zero and one. As a result, the fractional response model with quasi-MLE was selected to estimate the impact of the adoption of climate change adaptation strategy on income shares of the community members in the study area. With the Bernoulli distribution being in the linear exponential family, quasi-LIML can identify parameters in a correctly specified conditional mean regardless of misspecification in other aspects of the distribution.

6. Results and discussion

4.1. Descriptive statistics

Table 1 presents descriptive statistics for the data used in the estimation. The average age of the respondents was approximately 44 years with a maximum and minimum of 60 and 22 years, respectively. The average years of education was 8 years of formal education. Most of them (68 %) are married and more than half (52 %) are males. The result shows that the average family size is 3 with a monthly income of above R3000. These results show that the combination of educational attainment, married status, and income offers information on the respondents' socioeconomic standing. These findings can be used to generate tailored policies and programmes that address the specific requirements of Eerste Fabriek community.

4.2. Factors influencing the perception of flooding

To devise effective and efficient policy alternatives for flood management, we examine the community members' perceptions of flood from three aspects: environmental degradation, homelessness, and reduced expenditure. The coefficient estimates of the factors influencing community members' perceptions of environmental degradation, homelessness, and reduced spending impact of flood from the Seemingly unrelated regression (SUR) model are presented in Table 2. Using the Breush-Pagan test, we performed correlation analysis on the SUR model to test the hypothesis that the error components of the three perceived impact equations are not correlated. The test indicates the null hypothesis of environmental degradation flood, homelessness flood, and reduced expenditure flood. At a 1 % level of significance, the test shows

Table 1
Descriptive Statistics.

Variable	Mean	Std. Dev.	Min	Max
Share of income	0.234	0.194	0	0.811
Affected by flood	0.74	0.431	0	1
Gender	0.52	0.544	0	1
Age	43.82	8.67	22	60
Marital status	0.68	0.614	0	1
House structure	0.76	0.431	0	1
Education level	3.08	1.226	1	5
Year spent in school	8.304	4.511	0	15
Employment status	2.44	1.264	1	4
Source of income	2.816	1.764	1	5
Monthly household income	3038.776	1928.278	350	10,000
Household size	3.2	1.278	1	6
Access to recreational facility	0.65	0.141	0	1
Do you receive flood information	0.64	0.485	0	1

Table 2
Factors influencing the perception of flooding. Seemingly unrelated regression model.

Perception of Flooding	Environmental Degradation_Flood			Homelessness_Flood			Reduced Expenditure_Flood		
	Coeff	Std. err.	P-value	Coeff	Std. err.	P-value	Coeff	Std. err.	P-value
Gender	0.248	0.674	0.713	-0.333	0.602	0.580	1.064	0.671	0.113
Age	-0.110	0.064	0.085*	-0.130	0.057	0.023**	-0.136	0.064	0.032**
Marital_status	1.382	0.601	0.021**	0.549	0.537	0.306	0.444	0.598	0.458
House_structure	-0.006	0.749	0.993	-0.070	0.669	0.917	0.881	0.746	0.238
Education_level	0.481	0.550	0.383	0.820	0.492	0.095*	1.007	0.548	0.066*
Year_of_education	-0.237	0.147	0.107	-0.361	0.131	0.006***	-0.350	0.146	0.017**
Employment_status	-0.349	0.482	0.469	-0.710	0.431	0.099*	-0.460	0.480	0.338
Source_of_income	0.540	0.310	0.082*	0.228	0.277	0.411	0.716	0.309	0.021**
Monthly_Household_Income	0.000	0.000	0.589	0.000	0.000	0.542	0.001	0.000	0.060*
Household_size	0.574	0.332	0.084*	0.386	0.297	0.194	0.669	0.331	0.043**
Years_Lived_in_Eerste_Fabriek	0.067	0.120	0.576	0.142	0.107	0.183	0.066	0.119	0.580
Access_health_facility	4.396	3.114	0.158	1.860	2.783	0.504	5.527	3.102	0.075*
Access_religious_facility	-1.373	3.598	0.703	1.000	3.215	0.756	2.624	3.584	0.464
Access_recreational_facility	-7.534	3.759	0.045**	-5.054	3.359	0.132	-7.921	3.744	0.034**
Do_you_live_with_elderly_physi	-1.059	0.992	0.286	-0.166	0.886	0.851	-0.690	0.988	0.485
Constant	11.163	7.214	0.122	9.430	6.446	0.143	-0.248	7.185	0.973
R-squared	0.32			0.30			0.37		
Prob > chi2	0.043			0.023			0.03		

that the null hypothesis of economic, environmental, and social effect independence should be rejected. As a result, the SUR model is acceptable for fitting the three perceived impact equations.

Fifteen explanatory variables were included in the SUR model to identify the separate and underlying factors influencing the perception of flooding: gender, age, marital status, house structure, education level, years of education, employment status, sources of income, monthly house income, household size, years lived in Eerste Fabriek, access to a health facility, access to a religious facility, access to a recreational facility, and living with elderly physically challenged person. The regression result identifies ten factors that are found to be significant with various degrees of influence. Of the total reduced expenditure flood variables, education level, sources of income, monthly household income, household size, and access to a health facility showed a significant and positive association with the perception of the impact of flooding while age, years of education, and access to recreational facility exhibited a significant and negative correlation with factors influencing the perception of the impact of flooding. Similarly in environmental degradation flood variables, marital status, sources of income and household size showed significant and positive associations with the perception of the impact of flooding while age and access to a recreational facility exhibited significant and negative correlations with factors influencing the perception of flooding. More so, for homelessness, flood variables education level has a significant and positive association with the perception of the impact of flooding while age, year of education, and employment exhibited significant and negative correlation with factors influencing the perception of flooding.

In this study, there was a significant negative correlation between age and flood risk perception. The coefficient for respondents' age is negative for all three impacts (environmental degradation flood, homelessness flood, and reduced expenditure flood). This suggests that younger respondents tend to better perceive the impact of flooding than older respondents. This is consistent with the findings of Botzen et al., (2009) although some studies found a positive relationship between age and flood risk perception (Bessie et al., 2014; Mallick et al., 2021) while in some studies, age was found to have no influence flood risk perception (Rana et al., 2020; Diakakis et al., 2018). Similarly, marital status tends to have a positive influence on the perceived impact of flood events. Thus, a respondent who is married will have a better perception of the environmental degrading impact of flood events than their counterparts.

Floods can be perceived more effectively by educated household heads, and they were proven to be more risk-averse. Education status has a positive and significant correlation with homelessness flood and reduced expenditure flood for the perception of flooding. Literate

respondents perceive homelessness and reduced expenditure as flood impacts than illiterate respondents do. This finding is consistent with some previous studies (Saqib et al., 2016; Landry and Turner, 2020; Mallick et al., 2021) where respondents with a school degree have a higher flood risk perception than respondents without education. The perceived impact of flood also varies depending on whether respondents are employed or not. Respondents who are employed are less likely to perceive homelessness as a flood impact than respondents who are unemployed due to income differentials. The respondent's source of income leads to a positive perception of the environmental degradation, and reduced expenditure impact of flood, but has no significant impact on the perception of the homelessness impact of flood by the respondents. As a result, sources of income are more in agreement with the devastating environmental degradation and reduced expenditure on the impact of flood events. Likewise, the monthly house income of the respondents was found to be statistically significant at 10 % and has a positive coefficient of (0.001) in the reduced expenditure perception of flood. Similarly, a respondent with many household members has a significant positive perception of the environmental degradation, and reduced expenditure impact of flood, but has no significant impact on the perception of the homelessness impact of flood by the respondents.

The implications of the presented regression results on the factors influencing the perception of flooding are crucial for understanding the intricate relationship between various socio-demographic factors and individuals' viewpoints. The positive and significant association between education level and the factors influencing the perception of flooding across homelessness and reduced expenditure suggests that higher educational attainment might contribute to increased awareness and understanding of the consequences of flooding. This highlights the importance of education in shaping individuals' perceptions of certain disasters like floods. The respondents' sources of income are positive and have a significant association with environmental degradation and reduced expenditure indicating that individuals who rely on diverse sources of income may be more susceptible to recognizing the repercussions of flooding. This emphasizes the economic vulnerability of certain groups and underscores the need for targeted financial support and resilience-building programs. The positive and significant association between monthly household income and the perception of flooding for reduced expenditure suggests that those with higher incomes are more likely to perceive and acknowledge the consequences of flooding. Policymakers may consider income-based interventions to enhance economic resilience and preparedness for flood-related events. The positive correlation between household size and perception of flood indicates that larger households may be more vulnerable to the effects of

flooding. This emphasizes the need for community-level strategies and support systems to address the unique challenges faced by larger households during and after flooding events.

Table 2 also shows that access to healthcare facilities has a significant positive impact on their perception of the reduced expenditure impact of flood events. Community members' access to healthcare facilities will continue to dwindle as the floods spread. People's access to key services and resources, such as pharmacies, grocery stores, and hospitals will be significantly hampered by flooding. People will be unable to receive timely medical treatment if a community's access to a healthcare institution is disrupted, putting their safety and health at risk (Dong et al., 2020). Reduced access to healthcare is thought to be a risk factor for the worsening or emergence of various noncommunicable diseases following floods (Saulnier et al., 2018). Similarly, Access to recreational facilities has a significant negative relationship with the perceived impact of flood events on environmental degradation and the reduced expenditure on flood but has no significant impact on the perception of the homelessness impact of flood by the respondents. This study supports Shen and Kim's (2020) conclusions that tidal flooding causes disturbance and delays, as well as a loss of accessibility. More also in Jacksonville Florida, flooding during full-moon tides decreases access to services such as the use of parks and malls, reducing mobility within neighborhoods and to other locations and in less developed places, tidal flooding decreases household access to important public services, food, and work (Shen and Kim, 2020).

The positive association between access to health facilities and the perception of flooding underscores the importance of healthcare infrastructure in disaster-prone areas. Conversely, the negative correlation between access to recreational facilities and perception of impact suggests that individuals with fewer recreational options may have a more acute awareness of flood-related challenges. The negative correlation between age and perception of flooding, along with years of education, indicates that younger individuals and those with more years of education tend to have a more acute awareness of the consequences of flooding. This insight is valuable for tailoring awareness campaigns and educational programs to different age groups. The positive correlation between marital status and perception of flooding in environmental degradation suggests that married individuals may be more attuned to the environmental consequences of flooding. The negative correlation between employment and perception of flooding in homelessness implies that employed individuals may have a less acute awareness of

homelessness-related challenges. Understanding these associations is essential for policymakers and disaster management authorities to develop targeted and effective strategies for community resilience, risk mitigation, and public awareness campaigns. By addressing the specific needs of different demographic groups, interventions can be more precisely tailored to enhance overall community preparedness and response to the impacts of flooding.

Table 3 presents coefficient estimates of the probit regression for factors influencing the adoption and adaptation strategies to floods in Eerste Fabriek. In terms of household factors that influence flood adoption and adaptation strategies, the study's empirical findings revealed a significant negative relationship between gender (female respondents) and flood adoption and adaptation strategies. Thus, female household heads are more likely to adopt adaptation strategies than their male counterparts. Because women are more exposed to the impacts of extreme weather than men, they are more concerned about the implications of climate change, such as flooding, than men (Semenza et al., 2008; Soetanto et al., 2017). The facts about women's vulnerability during extreme events support this line of thought as well. Women and children are 14 times more likely than males to die in disasters (Soetanto et al., 2017). Females are more exposed to risk, frustration, and violence connected with the upheaval during and after an intense event, according to Bartlett (2008). However, other studies found that women were less likely to adopt adaptation strategies to flood events (Ahmad and Afzal, 2020; Shah et al., 2017). Similarly, Harvatt et al. (2011) found little evidence of gender differences in householder responses to flooding and sea level rise in three high-risk locations in England. Despite these contrasting findings, this suggests that, given the difference in responses and social reactions to flooding, there may also be gender influences in the adoption and adaptation strategies to floods, which may then affect decision-making and behaviour.

The result also shows a negative and significant relationship between the age of the household head and the adoption of flood adaptation strategies. At the margin, a 1 % increase in age will result in the decline of the probability of the adoption and adaptation strategies to flood by 0.045 units. This outcome could be explained in a variety of ways. To begin with, it is tied to natural conditions in that when the household head's age increases, their motivation to invest in adaptation strategies reduces. As a result, older community members are more likely to focus on on-farm agricultural activities only to meet their subsistence consumption needs (Kassie et al., 2017). Younger community members are

Table 3
Factors influencing the adoption of adaptation strategies to floods-Probit regression.

Strategies_to_reduce flooding	Coef.	St.Err.	p-value	dy/dx	std. error	p-value
Gender	-1.962	1.158	0.090*	-0.410	0.211	0.053
Age	-0.216	0.094	0.022**	-0.045	0.014	0.002
Marital_status	0.365	0.537	0.496	0.076	0.109	0.485
House_structure	-1.811	0.866	0.036**	-0.378	0.139	0.007
Education_level	-0.367	0.724	0.612	-0.077	0.150	0.610
Year_of_education	-0.255	0.191	0.181	-0.053	0.036	0.138
Employment_status	-0.162	0.544	0.766	-0.034	0.113	0.765
Source_of_income	0.228	0.356	0.522	0.048	0.073	0.516
Monthly_Household_~	0.000	0.000	0.435	0.000	0.000	0.426
Household_size	-0.376	0.372	0.312	-0.078	0.075	0.293
Years_Lived_in_Eer ~ k	0.369	0.162	0.022**	0.077	0.024	0.002
Do_you_live_with_e ~ a	1.210	1.147	0.291	0.253	0.231	0.274
Communication_F&F	-1.610	1.157	0.164	-0.336	0.224	0.134
Communication_TV	1.130	1.005	0.261	0.236	0.198	0.234
Constant	11.157	5.226	0.033**			
Mean dependent var	0.475					
Pseudo r-squared	0.456					
Chi-square	25.264					
Akaike crit. (AIC)	60.087					
Bayesian crit. (BIC)	85.421					
Prob > chi2	0.032					
Mean VIF	3.88					

*** p < 0.01, ** p < 0.05, * p < 0.1.

more likely to be exposed to new technology and innovative ideas, and they are less risk-averse when it comes to adopting current farm technologies. This study aligns with the findings of [Alhassan, 2020](#) who found that younger community members are more innovative and eager to test new technology to improve flood adaptation through on-farm practices and non-farm activities, allowing farm households to recover faster from flood shocks.

Another aspect we discovered to have a significant impact on a household's ability to deal with the effects of flooding in their home is house structure. The house structure is negative and significant at the 5 % level of significance. The structure of a house is important during floods because well-built dwellings can absorb the shocks induced by flooding. As a result of this finding, housing structures made of light and inexpensive materials are less likely to withstand the shock of flooding, which will have a detrimental impact on the household. Eerste Fabriek is an informal settlement where houses are fashioned of light and inexpensive materials, exposing them to the impacts of flooding. The home constructions in these informal settlements are not robust enough to withstand the shock, and as a result, whenever there is flooding, it has a detrimental impact on their livelihood. This finding is in line with the findings of other scholars ([Immaculata and Emmanuel, 2018](#); [Chung and Adeyeye, 2018](#); [Brisibe et al., 2021](#)). Another factor influencing the adoption and adaptation strategies to flood at the household level is the years lived in Eerste Fabriek. Year lived in the community which was one of the main criteria for inclusion in this study has a significant positive effect on the adoption and adaptation strategies to flood. Flooding incidents were not particularly favorable, according to respondents. A respondent's years of living in the area facilitate the establishment of an economic endeavor specific to that place. For instance, an individual may not have been born in that town, but has built the required networks and abilities to adopt certain economically profitable adaption techniques, and finally, to construct a respectable living structure, due to his or her year of living in the area ([Heryanti and Kingma, 2012](#)). Our analysis shows that a unit increase in the years lived in Eerste Fabriek will increase the probability of the adoption and adaptation strategies to reduce the impact of flooding by 7.7 % units. Their knowledge and experience of the area are crucial to understanding adequate adaptation strategies to mitigate the impact of flood events.

Regarding household factors that impact the adoption and adaptation strategies on the income share of flood, age is positive and significant ([Table 4](#)). This implies that at the margin, a unit increase in age will result in the increase of their share of income by 0.023 % units. The positive relationship between age and the adoption of adaptation strategies on the income share of flood suggests that older household heads choose to apply flood adoption and adaptation strategies over younger

ones. This result is consistent with the findings of [Ahmad and Afzal, 2020](#). Age is an important social indicator, particularly when it comes to people's potential and capabilities for natural disasters like floods, which need to be improved in rural regions ([Shah et al., 2017](#)). The employment status of the household head was also found to have a significant and negative impact on flood adoption and adaption techniques on income share. Due to frequent social and communal interactions, an unemployed household head would focus on measures to enhance their livelihoods and less on adaptation strategies. Unemployed community members are more sensitive to the impacts of severe weather phenomena than employed community members, but their lack of income reduces their ability to develop adaptative capacity. With respect to extreme weather events like floods, people in rural communities are particularly vulnerable. "It has been reported that unemployed people in rural and remote areas were 12 times as likely to experience distress as employed people of the same age" ([Austin et al., 2018](#)).

People with greater income levels are generally less vulnerable to negative events and are better able to deal with them ([Cvetković et al., 2018](#)). The economic status of a household is a significant predictor of that household's ability to adjust to flood hazards and in deciding which adaptation methods to apply. Households with a large income or savings can quickly assist themselves in the case of a flood, making them less vulnerable to flood disasters ([Shah et al., 2017](#)). In this study, we found that income is significant and negatively associated with the share of income allocated to adaptation, which implies that as the value of household monthly income increased by 1 %, their share of income allocated to flood adaptation decreased by 0.00 % units. We also found household size to be positive and significant ([Table 4](#)). This indicates that household size significantly influences the share of income allocated to flood adaptation in the study area. The size of a household can play a role in determining whether particular measures are implemented, as it can alter the household's adaptive ability in either a positive or negative way ([Shah et al., 2017](#)). A larger family usually has more working people, which means more labor availability for adoption and adaptation strategies that enhance the income share of the household. As a result, if all other factors remain constant, larger households may have a better likelihood of allocating a better share of their income to adaptation ([Kabir, et al., 2013](#)). A positive coefficient of household size for adoption and adaptation strategies in our scenario indicates that larger families are more likely to adopt more adaptation strategies. At the margin, a unit increase in the household size will result in the increase of their adaptation share of income by 0.068 % units. These findings are consistent with [Abebe and Sewnet \(2014\)](#). However, this finding is in contrast with the findings of [Shah et al. \(2017\)](#).

The years lived in Eerste Fabriek have a negative and significant

Table 4

Impact of adoption of adaptation strategies on income share of flood - two-step quasi-maximum likelihood estimates of fractional response model.

Share of income	Coefficient	Robust std. err.	P-value	dy/dx	std. err.	P-value
Gender	0.334	0.321	0.298	0.092	0.086	0.285
Age	0.084	0.031	0.006***	0.023	0.008	0.003***
House_structure	-0.173	0.344	0.614	-0.048	0.095	0.614
Education_level	0.075	0.107	0.484	0.021	0.030	0.489
Year_of_education	0.061	0.047	0.202	0.017	0.013	0.185
Employment_status	-0.257	0.120	0.031**	-0.071	0.033	0.032**
Source_of_income	-0.011	0.068	0.871	-0.003	0.019	0.871
Monthly_Household_Income	-0.000	0.000	0.004***	-0.000	0.000	0.005***
Household_size	0.245	0.128	0.056**	0.068	0.034	0.046**
Years_Lived_in_Eerste_Fabriek	-0.172	0.066	0.009***	-0.047	0.017	0.005***
Do_you_live_with_elderly_physica	0.683	0.277	0.014**	0.188	0.073	0.010**
Communication_F&F	0.560	0.355	0.115	0.154	0.095	0.103
Communication_TV	-0.292	0.292	0.317	-0.080	0.080	0.318
Type_of_mitigation_provided_muni	-0.030	0.303	0.920	-0.008	0.083	0.920
Predicted_score_Residual	0.660	0.677	0.329	0.182	0.182	0.317
Constant	-4.587	2.408	0.057*			
Log_pseudolikelihood	-18.660					
Wald_chi2(15)	89.58					
Prob > chi2	0.0000					

association with household income share allocated to adaptation. Thus, at the margin, a unit increase in the number of years lived in Eerste Fabriek will result in a decrease of their share of income allocated to flood adaptation by 0.047 % units. This result is consistent with the findings of Mabuku et al. (2019) who found that those who had lived in the flood plain for less than 10 years were more likely to adopt food production strategies than those who had lived in the flood plain for more than 10 years. The explanation for this is that people who have stayed longer in an area have more experience and can cope better with the impacts of flooding when living on the riverbank (Anacio et al., 2016). Generally, elderly people typically have more control over resources and the power to make decisions than younger ones, which increases their capabilities to adapt and cope faster with flood shocks. In our findings, living with an elderly person has a significant positive impact on the share of income allocated to flood events in Eerste Fabriek. At the margin, a unit increase in the number of elderly people in the household will result in an increase in the share of income allocated to adaptation by 0.188 units.

7. Conclusions and recommendations

Extreme weather events are being experienced all over the world as a result of climate change, posing challenges for individuals and households who rely on agricultural operations as their major source of livelihood. Extreme weather conditions such as floods are one of the major contributors to poverty, malnutrition, food insecurity, and a degraded environment. The factors influencing the perception of flooding on environmental degradation, homelessness, and reduced expenditure, together with the factors influencing the adoption of adaptation strategies to floods, and the impact of the adoption of adaptation strategies on the income share of flood on community members, are necessary to advise effective and efficient policy implementation for practitioners and policymakers to develop sustainable adaptation interventions to improve resilience. In this respect, this article provided a substantial contribution to empirical climate change studies: (1) identified factors influencing the perception of flooding on community members in the study area through the use of SUR, (2) identified the factors influencing the adoption of adaptation strategies to floods using Probit regression, and (3) examined the impact of adoption of adaptation strategies on income share of flood by community members in the Eerste Fabriek informal settlement using two-step quasi-maximum likelihood estimates of fractional response model. It should be noted that the disadvantages of the linear probability model for binary data used in this study are comparable to those of linear models for fractional data.

Community members in Eerste Fabriek understand how changing climate, particularly flooding affects the environment and their livelihoods, according to SUR findings, and on average, community members believe flood impact is significant. Age, marital status, education, employment status, income, and household size are demographic factors that tend to influence their perception of the impact of flooding. Access to institutional facilities such as health and recreational facilities was also a significant factor in how community members perceived the impact of floods. Timely access to healthcare services are a significant precursor for people to form their perception, which is intended to help them adapt appropriately to situations as health. In the event of a flood, community members with access to health facilities may be less vulnerable to the emergence of several communicable diseases following floods as the community will get adequate and timely medical care to prepare themselves during and after the flood event. It is therefore important to strengthen timely medical services in the communities in order to reduce their vulnerability to flood.

According to the empirical findings, the response variables that have a significant effect on the factors influencing the adoption of adaptation strategies to floods include gender, age, house structure and years lived in Eerste Fabriek. Female gender according to the result shows favourable adoption and adaptation strategies for flood risk events possibly

because they are more exposed to the vagaries of nature. Empowering women in the community will go a long way to fostering sustainable adaptation strategies that will help mitigate the impact of flood events. Women are nation builders and as such should be given significant attention in terms of policy formulation and application. Household structure is very important in the face of flooding as good construction has the capacity to withstand the impact of flood. Building floodproof structures such as the elevation of the house, floodwalls, dry flood-proofing, and wet floodproofing are some good examples of household structures that can aid in flooding in Eerste Fabriek. Thus, to lessen the impact of floods on individual homes or large catchments, good physical house structures are erected. Moreover, as a person continues to stay in a flood-prone region, he or she will adopt more of the adaptation techniques to enhance resilience to the impact of flood.

Compliance with ethical standards

Ethical clearance: This study received ethical clearance from the ethics committee of the University of the Free State (Reference: UFS-HSD2021/1139/21).

Consent to participate: This study obtained written informed consent from the participants before data collection.

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Y.S. Nyam: Conceptualization, Validation, Writing – original draft, Writing – review & editing. **N.T.S. Modiba:** Conceptualization, Project administration, Visualization. **T.O. Ojo:** Data curation, Formal analysis, Methodology. **A.A. Ogundeji:** Supervision, Validation. **C.C. Okolie:** Writing – original draft. **O.T. Selelo:** Writing – original draft.

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.

Data availability

Data will be made available on request.

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