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Following up on flood adaptation in Québec households four years later: A prospective exploratory study

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ABSTRACT

The frequency and severity of flooding events are expected to increase with climate change in Canada's province of Québec. Highly publicized flooding events ravaged the province's waterfront communities in 2017 and 2019, with dire health and economic impacts. A recognized component of integrated flood risk management is the adoption of adaptive behaviors that reduce the vulnerability of exposed households to flooding. A previous study established an index of pre-flood adaptation based on 15 behaviors, using responses of 1951 participants residing within or less than 150 m from officially designated high flood risk zones. 325 of these respondents were successfully recontacted in 2019 for a follow-up survey on their adaptive behaviors, constituting the longitudinal sample used in this study. The new database tracks changes in pre-flood adaptation of Quebecers over a span of 4 years and seeks to establish experiential, socio-demographic, and psychosocial variables that predict the preventive behavior adoption rates four years on. Results suggest that there has been no significant increase in the level of adaptive behavior between 2015 and 2019, though households that have experienced a flood or a flood alert in the past are more likely to adapt than those who have not. Furthermore, the most important measures reported in 2015 for predicting adoption of behaviors four years on are income, the experience of a flood, and the belief that one lives in a flood-prone zone. Finally, a second stepwise regression indicates that a change in flood experience, an increase in perception of the severity of flood impacts on one's residence, and adaptation in 2015 are the strongest predictors of adaptation in 2019. Results from this exploratory longitudinal study provide critical information regarding flood adaptive behavior over a long period of time, and its predictors.

1. Introduction

Worldwide, more people are affected by flooding than by any other natural disaster [1]. In 2019, 1,586 people lost their lives to floods, while the economic toll of floods amounted to 33.7 billion USD in the first half of 2019 alone [2]. In addition to their devastating human and economic costs, floods expose populations to a variety of direct and indirect mental and physical health issues [3–6]. Flooding is caused by extreme weather conditions such as storms and tropical cyclones, convective rainfall, sustained snowmelt, or a

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combination of them (compound flood events). There is a strong scientific consensus that climate change is intensifying extreme weather conditions in many parts of the world [7], thus increasing flood risks.

Much like elsewhere, flooding is of high concern in Québec, Canada. In this province, which covers 1,667,441 km^2 (643,802 mile^2) and has a population of 8.3 million, climate change is estimated to occur twice as fast as the world average [8]. Increases in rainfall intensity and frequency are anticipated [9], as well as the risk of compound and flash floods [10]. In recent years, a series of severe floods hit the province, stressing the necessity for better flood risk mitigation. In 2017, floods on the Ottawa and St. Lawrence rivers affected 146 communities in Québec, inundating more than 2,400 homes [11]. The economic toll stood at approximately 220 million CAD in insured damages [12]. Only two years later, the 2019 floods ravaged the same region once more, with water exceeding the record levels set in 2017 and inundating more than 6,000 residences. The 2019 floods exposed important weaknesses in Québec's flood barriers. For example, the dike protecting the town of Sainte-Marthe-sur-le-Lac breached, forcing the municipality's 6,500 residents to evacuate. Elevated levels of post-traumatic stress and psychological distress were reported [13] as is often the case in the short and long term after flooding events [14,15]. In response to the major flood events of recent decades, local governments throughout Québec have endeavored to delineate zones that are at high-risk of flooding (henceforth referred to as "designated flood zones") to increase the resilience, preparedness and risk awareness of households residing therein. Unfortunately, climate change increasingly jeopardizes the reliability of these designations, as they are generally based on past flood limits of 20- and 100-year flood events [16], which are expected to be exceeded in coming decades [17]. Therefore, it is important that people living near to officially designated flood zones prepare appropriately for potential future flood risks too.

The adoption of household behaviors, which prevent the entry of water into homes or minimize its consequences, is an increasingly recognized measure to strengthen the resilience of at-risk populations. They are fundamental to modern flood risk management, as reported by a significant body of literature that evaluated their effectiveness and level of adoption [18–22], as well the determinants leading to their adoption. These include socio-demographic (annual household income, household composition, homeownership [23]), psychosocial (risk perception, vulnerability perception) and experiential (experience of flooding or lack thereof) factors which are regularly incorporated into study designs in flood adaptation research [24–28] and theoretical frameworks commonly used to understand health- or disaster preparedness-related behaviors. Frequently employed frameworks include the health belief model and the theory of planned behavior [22], which contend that human behavior results from the beliefs held by individuals. As such, the health belief model includes variables such as perceived vulnerability and perceived severity, and both models relate background factors such as household composition and income to beliefs and subsequent behavior.

The present study brings together three elements that allow us to explore household flood adaptation in a unique way. First, we investigate the adaptive behaviors adopted by residents living not only in designated flood zones, but also near them, that is, those living within a 150 m buffer thereof. Second, this study considers both people with different levels of disruption resulting from floods, as well as persons that have never been flooded before but live in or near flood-prone areas, thus constituting a potential pool of future flood victims. It is just as important for these individuals to adopt mitigation behaviours, but previous studies demonstrate that they adapt less than their previously flooded counterparts [28–30]. We therefore seek to understand whether and why this disparity might exist in our pool of respondents. Third, the study focusses on the evolution of adaptive behaviors using a longitudinal design that spanned four years (with two measurement periods). This is noteworthy given the paucity of longitudinal data related to flood adaptation [31]. Furthermore, it means that the study can address questions regarding the effect of recency of flood experience and change in flood experience on adaptation.

The goal of this prospective exploratory study is thus to assess the change in adoption of flood adaptive behavior among Quebecers living in or near a flood-prone area over a four-year period, and having varying experiences of flooding over that time. Second, it aims to explore the relationship between potential determinants of the adoption of flood adaptive behavior four years on, among different types of variables: socio-demographic (e.g., income, homeownership, presence of children in the house), psychological (e.g., perceived life stress), psychosocial (e.g., perceived adverse effects on physical or mental health), and experiential (e.g., flood alert experiences).

2. Methods

2.1. Sampling design and procedure

This research relies on responses of two surveys, one performed in 2015 and the other in 2019, wherein participants residing within or near designated flood zones responded to questions about their adoption (or lack thereof) of expert-recommended actions to be taken at different chronological periods throughout a flooding event, as well as various other questions such as their flood risk perception, health and socio-demographic background. The target population for this research consists of the 136,505 Québec households whose main residence is in or near a designated 20- to 100-year flood zone, as per the maps of the Centre d'expertise hydrique du Québec [Quebec Water Expertise Center] [16]. To sample this population in the initial 2015 study, a stratified approach was employed, with quotas of participants recruited from each of Québec's administrative regions according to their total flood-prone population. A total of 1,951 individuals (women, 44.54%; men, 55.46%) were surveyed by a polling firm; 1,450 lived in a designated flood zone, while 501 lived less than 150 m therefrom. To define an appropriate sample size, we used Cochran's formula [32] with a 95% confidence level, a maximal variance for a five-point scale (i.e., 4), and a precision level of 0.12. For the purposes of the current study, in 2019, we re-contacted a subset of 1288 people from the original 2015 cohort who had given their consent and contact information for follow-up questionnaires. Out of this subset, 325 participants were successfully reached by telephone, and 274 responded to all the questions pertinent to the objectives of this study. This represents an attrition rate of 86%. Those who did not respond to our follow-up survey either were unreachable due to changes in their phone numbers or main email address, didn't answer or simply refused to participate in the second survey. Therefore, the sampling strategy for this longitudinal sample is arbitrary and outside of the control of the authors. The spatial distribution of the respondents in our longitudinal sample in the province of Québec is shown in Fig. 1 and the characteristics of our longitudinal sample in comparison to the full sample surveyed in 2015 can be found in Table 1.

2.2. Measures

The sampled participants in 2015 and 2019 responded to a questionnaire with 29 questions (Supplementary Materials), and from these, we were able to derive a binary index of adaptation used as the response variable for both objectives, as well as several explanatory variables, which we describe below.

2.2.1. Dependent variable

Flood adaptation. To assess flood adaptation, we used the index of precautionary adaptive behaviors developed by Valois et al. (2019) [18] (Table 1) based on the 2015 study of 1951 flood-prone residents mentioned above. This index includes 15 items (9 structural flood protection measures and 6 non-structural flood protection measures) selected from a review of literature on property-level

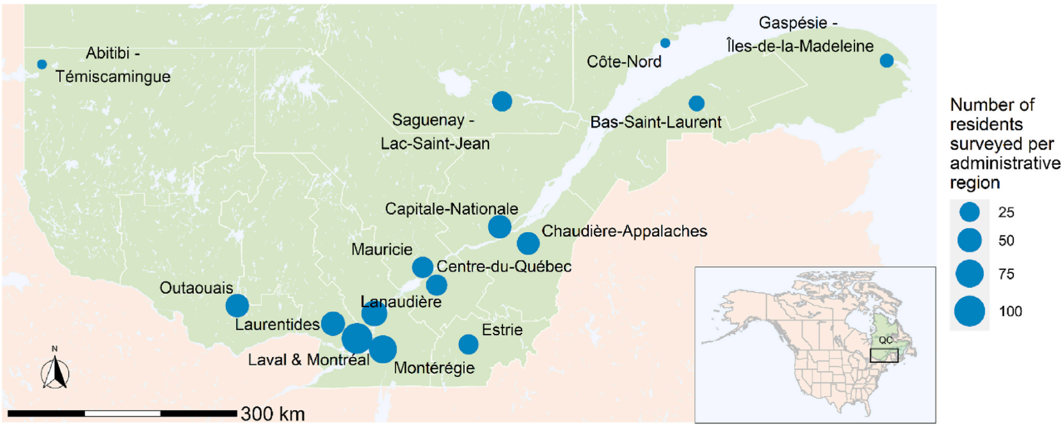

Fig. 1. Map of Southern Québec with centroids of longitudinal sample respondents grouped by administrative region.

Table 1
Characteristics of our longitudinal sample in comparison to the full sample surveyed in 2015.

Variable		Percentage of respondents surveyed in 2015 study (n = 1951)	Percentage of respondents followed up in 2019 study (n = 274)
Administrative region	Abitibi Témiscamingue, Côte-Nord et Gaspésie - Îles-de-la-Madeleine	1.5% (29)	1.8% (5)
	Bas-Saint-Laurent	2.3% (45)	1.8% (5)
	Capitale-Nationale	5.5% (108)	8.0% (22)
	Centre-du-Québec	5.4% (107)	5.8% (16)
	Chaudière-Appalaches	11.6% (226)	7.3% (20)
	Estrie	3.9% (77)	4.7% (13)
	Lanaudière	12.0% (240)	11.0% (30)
	Laurentides	8.0% (157)	8.8% (24)
	Laval	13.3% (259)	11.7% (32)
	Mauricie	5.0% (98)	5.8% (16)
	Montérégie	15.8% (309)	13.8% (38)
	Montréal	5.5% (107)	6.6% (18)
	Outaouais	5.8% (114)	8.0% (22)
	Saguenay – Lac-St-Jean	3.8% (75)	4.7% (13)
Age	18–34	7.1% (139)	4.7% (13)
	35–49	20.8% (405)	19.3% (53)
	50–64	38.9% (759)	45.6% (125)
	65 +	32.8% (640)	30.3% (83)
	No answer	0.4% (8)	0% (0)
Gender	Male	44.5% (869)	41.6% (114)
	Female	55.5% (1082)	58.4% (160)
Flood zone	Inside designated flood zone	74.3% (1450)	65.7% (180)
	Within 150 m of a designated flood zone	25.7% (501)	34.3% (94)
Household annual income	Less than CAD$50 000	30% (587)	33.6% (92)
	CAD$50 000 – CAD$100 000	29.2% (570)	31.4% (86)
	CAD$100 000 +	26.7% (521)	24.4% (67)
	No answer	14% (273)	10.6% (29)

Table 2
List of precautionary adaptive behaviors.

Structural flood protection measures	
1	Waterproofing the foundations
2	Raising the baseboard heaters and electrical outlets on the walls
3	Replacing water-sensitive flooring (e.g., carpeting) with a waterproof finish (e.g., ceramic)
4	Installing a backwater valve
5	Moving the dwelling elsewhere on the property (e.g., onto higher ground)
6	Modifying the dwelling in ways other than those mentioned (e.g., modifying the windows, the insulation, the walls, or the ceiling, sealing the cracks)
7	Changing the landscape to help water runoff
8	Checking to ensure that the foundation drain is not blocked
9	Modifying the landscape in ways other than those mentioned (e.g., planting trees, making a dam, developing the banks)
Non-structural flood protection measures	
10	Making a list of belongings that could be used for a claim in case of flooding
11	Preparing an evacuation plan to leave the neighborhood in case of emergency
12	Inquiring about better ways to prepare for a flood or to make the dwelling more flood-resistant
13	Inquiring about the consequences that a flood can have on physical and mental health
14	Owning a water pump that could be used to remove water from the home in case of a flood
15	Knowing how to cut off the electricity or water

flood protection measures and recommendations from public health agencies [22–24]. In the original validation study [18], results indicated that the factorial validity of this index provided a good data fit: Comparative Fit Index (CFI) = 0.92; Tucker-Lewis Index (TLI) = 0.91; Root Mean Square Error of Approximation (RMSEA) = 0.04. The measurement invariance of this index was then verified in 2019 using an independent sample of 974 flood-prone residents [31]. This variable was dichotomized to profile respondents into two categories reflecting different levels of adoption of adaptive behaviors, which is useful for downstream targeting of interventions [33]. These categories are: (0) less adapted individuals, and (1) more adapted individuals. This binary index was computed using the coordinates of each respondent obtained through a multiple correspondence analysis of their adoption of the 15 recommended preventive behaviors (Table 1), undertaken in Valois et al. (2019) [21]. These coordinates, ranging between −5 and +5 with a quasi-normal distribution, were then added up. Individuals with a negative total score are assigned to the "less adapted" group, and those with a positive score are considered part of the "more adapted" group. To provide additional empirical validity to the index, Valois et al. (2019) [21] detected a significant tetrachoric correlation between this binary index of pre-flood adaptation and the respondents' risk perception of being flooded in the next five years.

2.2.2. Independent variables

Flooding experience recency group. The longitudinal structure of the data allowed us to classify participants according to their exposure to flooding over time. The three categories are: "never affected" (NA: never flooded or experienced an alert), "less recently affected" (LRA: flooded or experienced an alert before 2015 but not between 2015 and 2019) or "more recently affected" (MRA: flooded or experienced an alert within the last four years).

Flooding experience. Flooding experience was assessed using the following question: How many times have you been flooded in your current home? Responses were dichotomized: 0 = Never; 1 = once or more.

Presence of children. The participants indicated which type of household best describes their current situation (e.g., You lived as a couple, but with no children). Based on their response, we created a dichotomous variable: 0 = no children; 1 = one or more children).

Believing that one lives in an at-risk area. Participants were asked if, to their knowledge, they live in a flood-risk area: 0 = No; 1 = Yes.

Homeownership. Participants also reported whether they were the owner of the house (1) or not (0).

Perceived risk. Participants were asked "What is the risk of your current home being flooded in the next five years?" This question was rated on a five-point ordinal scale: "very high", "high", "moderate", "low", "very low", or "nil". People who reported that the risk was "very high", "high", or "moderate" formed the group feeling the most at risk (1) and those who answered "low", "very low", or "nil" formed the group feeling the least at risk (0).

Perceived adverse physical health impacts. The participants were asked the following question: "If you have been a victim of flooding, would you say that the negative consequences for your physical health would be … ?". Those who reported "quite severe" or "very severe" were defined as the group that perceived more adverse physical impacts (1) in opposition to those who reported "not very severe" or "no negative consequence" (0).

Perceived adverse mental health impacts. The perceived adverse impacts were assessed by asking the participants the following question: "If you were to experience a flood, would you say that the negative consequences for your mental health would be … ?". Those who reported "quite severe" or "very severe" were defined as the group that perceived more adverse health impacts (1) in opposition to those who reported "not very severe" or "no negative consequence" (0).

Perceived adverse impacts on one's residence. Similarly, to the two last questions, the participants were asked: "If you have been a victim of flooding, would you say that the damage caused to your home and your personal effects would be … ?". Those who reported "quite severe" or "very severe" were defined as the group that perceived more adverse impacts on their housing (1) in opposition to those who reported "not very severe" or "no damages" (0).

Alert experience. The participants also reported yes (1) or no (0) on whether their municipality ever issued a flood alert that concerned them, while living in their current home.

Stress experienced. The participants also reported on a 5-point scale whether most of the time they would describe their life with regards to stress as amount of stress in their life was: 1 = not stressful at all, 2 = not very stressful, 3 = slightly stressful, 4 = quite stressful, 5 = extremely stressful. Those who reported "quite stressful" or "extremely stressful" were defined as the group that experienced more stress in their life (1) in opposition to those who reported "slightly stressful", "not very stressful" or "not stressful at all" (0).

Annual income. Finally, participants were asked to indicate their net annual income. Responses were categorized as follows: 1 = [CAD$1–50,000[, 2 = [CAD$50,000–100,000[, 3 = [more than CAD$100,000].

Administrative region. Participants were recruited from all 16 administrative regions dividing the province of Québec in Canada. However, some regions had a very small population pool for data collection. In order to have a minimal group size for each region some administrative regions were pooled together in the same group. Thus, 14 different groups make it in the final analysis, with Abitibi-Témiscamingue, Côte-Nord and Gaspésie - Îles-de-la-Madeleine composing a single group of less populated regions.

2.3. Statistical analyses

To evaluate the attrition bias inherent in our longitudinal sample, we performed Chi-square tests on contingency tables comparing the frequency of different sociodemographic (age, sex, income) and geographic (within or 150 m from a designated flood zone, administrative region of residence) characteristics in our 2015 respondents who were successfully re-contacted in 2019 ("successfully recalled", n = 274) with those of our respondents who were not ("not successfully recalled", n = 1951–274 = 1677). In the case of a significant result (p-value < 0.05), we also examined the residuals to see which levels of the different characteristics differed between the two samples. Then, we performed a descriptive analysis of the longitudinal sample (n = 274) to present the number of participants in each of the flooding experience groups (MRA, LRA, NA) and verified whether there are significant differences between these groups in terms of the type of residence they lived in (e.g., condo, townhouse).

Next, we propose an analysis of covariance and two stepwise regression analyses to explore patterns in our unique longitudinal dataset and uncover some variables which might predict adaptation over a four year period. These were all undertaken in SAS version 9.4, and include one ANCOVA with repeated measures, and two stepwise logistic regressions. More specifically, we computed an ANCOVA with repeated measures using the PROC GLM function to evaluate the effect of time on the level of adaptive behavior performed by residents living in or near a designated flood zone, according to three levels of flood experience recency (objective 1): those who have never experienced a flood or flood alert (never affected, NA), those who experienced a flood or flood alert more than four years ago (less recently affected, LRA), and those who experienced a flood or a flood alert within the past four years (more recently affected, MRA). The response variable consists of the binary flood adaptation index. Covariates were also added to the analysis to control for various sociodemographic and psychosocial factors. Covariates used were the annual gross income of the household, the administrative region of residence and the zone in which the residence is located (within vs less than 150 m from a designated flood zone).

Finally, a stepwise logistic regression approach was used in two exploratory analyses to probe which variables might significantly predict adaptation or lack thereof in 2019 (objective 2). Our stepwise approach was based on the Chi-square residual statistic with a 5% threshold for both backward and forward selection. This analysis was undertaken using the PROC LOGISTIC function. The dependent variable for both analyses is the participants' binary adaptive behavior score observed in 2019. Meanwhile, the independent variables in these two stepwise regression models both include the responses to the questions on sociodemographic, psychosocial, and experiential explanatory variables described above (flooding experience, presence of children in the household, belief regarding one's flood risk status, homeownership, risk, adverse mental and physical impacts and property damage perceived, alert experience, self-reported stress levels and annual income). The first stepwise logistic regression uses only the 2015 responses to these questions. In contrast, the second regression model uses the change in the responses to these questions over the four years, computed by simply subtracting the 2015 response values from those of 2019. For instance, the flood experience variable divides our respondents into two groups: those whose flood experience status did not change between the two survey timepoints (i.e. never flooded/alerted at both timepoints or flooded/alerted at both timepoints), and those whose flood status changed between the two timepoints (i.e. never flooded/alerted before 2015, flooded/alerted between 2015 and 2019). To control for prior adaptation, the binary adaptation score in 2015 was included as an additional explanatory variable in this second stepwise regression model.

3. Results

The Chi-squared tests comparing the successfully recalled and not successfully recalled groups indicate that age, sex, and administrative region of residence do not vary significantly between the groups. However, income and position of one's residence within or less than 150 m from a designated flood zone did change between the two samples. Our longitudinal sample contains fewer than expected respondents from low-income households (earning less than a total of CAD50,000), and more than expected from middle- and high-income households (earning CAD50,000 to CAD100,000 and over CAD100,000). Likewise, those residing within designated flood zones are underrepresented in our sample, while those residing within 150 m thereof are overrepresented in our sample.

Descriptive analyses show that among the 274 individuals in our sample, 92 are classified as never affected (NA: never flooded or experienced an alert), 95 as less recently affected (LRA: flooded or experienced an alert before 2015 but not between 2015 and 2019), and 87 as more recently affected (MRA: flooded or experienced an alert within the last four years). There are no statistically significant differences between these three groups with respect to the type of residence they lived in (two-tailed Fisher exact test: $p = 0.71$). The groups are not compared on other variables because they are included in the subsequent stepwise regression analyses.

Regarding the first objective, results indicate that overall, adaptation levels have not changed between 2015 and 2019 ($F(1, 244) = 0.49$, $p = 0.48$)). In fact, all within-subject fixed effects are non-significant. However, the three flood experience recency groups differ in regard to flood adaptation: $F(2, 244) = 4.29$, $p = 0.02$ (Table 3), controlling for region, zone, and income. In addition, Tukey comparison tests indicate that the NA participants are less likely to adopt adaptive behaviors (20.65% in 2015 and 21.74% in 2019) than the LRA (58.95% in 2015 and 54.74% in 2019) and MRA (48.28% in 2015 and 55.17% in 2019) participants ($p < 0.001$) (Table 4). Furthermore, results also indicate that differences in adaptation between groups do not vary over time (i.e., no interaction effect): $F(2, 271) = 1.38$, $p = 0.50$.

Regarding the second objective (identify the key predictors of the adaptive behavior 4 years later), results of the first stepwise logistic regression indicate that three variables measured in 2015 are significant predictors of the adaptive behavior in 2019 (see Table 5): 1) participants' belief that they live in a flood-risk area (Wald $\chi^2_{(1)} = 13.43$, $p < 0.001$), 2) their income (Wald $\chi^2_{(2)} = 8.33$, $p = 0.015$), and 3) having experienced a flood (Wald test: $\chi^2_{(1)} = 7.61$, $p = 0.006$). More specifically, the odds ratios (OR, Table 2) of probable adoption of flood adaptive behavior are higher for participants who believed they lived in flood-prone areas than for those who did not believe they lived in flood-prone areas, with OR 3.23 (95% CI 1.73–6.04). Participants who were flooded have increased odds ratios of probable adoption of flood adaptive behavior (OR 2.28, 95% CI: 1.27–4.01). Finally, the OR of probable adoption of flood adaptive behavior are significantly higher among people earning $100,000 or more than those earning between $50,000 and $100,000 (OR 2.56, 95% CI: 1.25–5.23) or less than $50,000 (OR 2.48, 95% CI: 1.23–5.00). Additional exploratory analyses reveal that people earning $100,000 or more are not different than people earning less than 100,000 regarding the adoption of structural adaptation to flooding behaviors: $t(205) = 0.38$, $p = 0.71$.

For the second regression, using the change in responses for each predictive variable listed for the previous regression as potential predictors of adaptation in 2019, three variables were retained in the final model obtained through the stepwise variable selection process (Table 6): 1) the flood adaptation from 2015 (Wald $\chi^2_{(1)} = 8.94$, $p < 0.001$), 2) the change in perceived impact on residence

Table 3
Analysis of covariance for flood adaption by group and time with sociodemographic and psychosocial variables as covariates.

Variables	df	Sum of squares	Mean squares	F	p-value
Between subjects					
Group	2	87.68	43.84	4.29	0.02
Region	13	178.67	13.74	1.35	0.19
Income	2	7.15	3.58	0.35	0.71
Zone	1	32.03	32.03	3.14	0.08
Error	226	2308.32	10.21		
Within subjects					
Time	1	1.38	1.38	0.49	0.48
Time x Group	2	3.91	1.95	0.70	0.50
Time x Region	13	61.40	4.72	1.68	0.07
Time x Income	2	1.48	0.74	0.26	0.77
Time x Zone	1	0.72	0.72	0.26	0.61
Error(Time)	226	634.31	2.81		

Eta-squared = 0.17 and 0.16 for adaptation in 2015 and 2019, respectively.

Table 4
Percentages of participants adopting flood adaptive behavior per group, in 2015 and in 2019.

Groups compared	Year	
	2015	2019
Never Affected (NA)	20.65%	21.74%
More Recently Affected (MRA)	48.28%	55.17%
Less Recently Affected (LRA)	58.95%	54.74%

Table 5
Results of the stepwise logistic regression predicting flood adaptation in 2019 from 2015 predictor variables.

Variables	Reference Group	Estimate	SE	Odds ratio[a]	95% CI	Wald statistic	p-value
Intercept		0.31	0.16			3.73	0.05
Flood experience	Not flooded	0.41	0.15	2.28	[1.27, 4.09]	7.61	0.01
Belief regarding one's flood risk status	Does not believe	0.59	0.16	3.23	[1.73, 6.04]	13.43	0.001
Income	[CAD$1–50,000]	0.29	0.20	2.48	[1.23, 5.00]	2.24	0.14
Income	[CAD$50,000–100,000]	0.32	0.20	2.56	[1.25, 5.23]	2.59	0.11

[a] The global Wald statistic for income is 8.33 with a p-value of 0.015.

Table 6
Stepwise logistic regression results for prediction of adaptation score in 2019 with adaptation score from 2015 and the relative change in the other predictor variables.

Variable	Reference Group	Estimate	SE	Odds ratio[a]	95% CI	Wald statistic	p-value
Intercept		−0.86	0.29			8.56	0.01
Adaptation in 2015	Not adapted	1.10	0.18	8.94	[4.48, 17.84]	38.58	0.001
Change in flood experience	No change	0.66	0.25	3.72	[1.39, 9.99]	6.81	0.01
Change in perceived impact on residence	Lowered	0.80	0.31	7.84	[2.25, 27.29]	6.67[a]	0.01
Change in perceived impact on residence	No change	0.46	0.25	5.56	[1.89, 16.34]	3.36[a]	0.07

[a] The global Wald statistic for change in perceived impact on residence is 11.52 with a p-value of 0.003.

of a flood (Wald $\chi^2_{(1)} = 11.52$, $p = 0.003$), and 3) the change in flood experience (Wald $\chi^2_{(1)} = 6.81$, $p = 0.009$). Regarding the odds ratios, people who were more adapted at the first time of measurement are 8.94 times more likely to adapt at the second time of measure than those who were less adapted at the first time of measurement. People who had not experienced a flood at the first time of measurement and experienced one within the 4 years span between both studies are 3.72 times more likely to be adapting in 2019 than those who saw no change in their flood experience. People who had an increase in their perceived flood impact on their residence are 6.67 times more likely to adapt in 2019 than those whose perceived severity of flood impact on their residence decreased and 3.36 times more likely to adapt than those who showed no change in perceived flood impact between the two times of measure.

4. Discussion

Results of this prospective exploratory study provide some possible innovative insights into the persistence of the adoption of flood adaptation behaviors by Quebecers living in or near designated flood-prone areas as well as factors that may explain this adaptation over a four-year period. Its findings need to be interpreted under a critical lens, as it faces challenges common to longitudinal research in the flood risk domain [34] such as a relatively high attrition rate and some forms of retention bias, which make it difficult to assert whether our findings apply to the general population of flood-prone residents in Québec. The longitudinal sample contains 274 respondents out of an original 1951 surveyed in 2015, representing an attrition rate of 86%. According to our Chi-square tests comparing our “successfully recalled” and “unsuccessfully recalled” respondents, this longitudinal sample may be biased toward higher-income households located close to but not within designated flood zones. The implications of these biases will be raised throughout the following discussion as caveats to our findings.

1. Flood experience increases adaptation over time

The results from all three of our analyses suggest that flood experience has an effect on flood adaptation behavior. Overall, the proportion of adapted individuals in our longitudinal sample does not rise over the 4-year period studied, which is somewhat alarming given that the media has extensively reported on the two severe floods that took place in Quebec between 2015 and 2019. Moreover, the proportion of people living in flood-prone areas that adapt to floods is not very high and this proportion is much lower among people who have never been flooded (around 20%). This result is in line with studies carried out earlier and in other countries [23,35,36]. Our repeated-measures ANCOVA also demonstrates that the proportion of participants who have adapted to flooding is higher in the groups who have been affected (more or less recently) than in the group who has never been affected. Other studies have also found that adaptation levels are insufficient in households who have never experienced flooding [23,35,36], and that being flooded can motivate people to better protect themselves [37–41]. The repeated-measures ANCOVA also demonstrates that the effect of flooding or alert experience on the adoption of adaptive behaviors seems to last over time; indeed, people who have been flooded or have experienced an alert to flooding less recently (LRA) do not adapt less than those having experienced disruption within the last four years (MRA).

Our stepwise regression model using predictive variables from 2015 to predict adaptation in 2019 finds that the experience of flooding in one's home before 2015 is a strong predictor of households' adaptive behavior four years in the future - flooded or alerted respondents are over twice as likely to adapt as those who were not flooded or alerted before 2015. This result corroborates the findings of our repeated measures ANCOVA, and is in line with previous studies [28,42,43] indicating that flood experiences and adaptive behaviors are positively related. It also aligns with previous findings suggesting that those residing within designated flood zones do not adapt more than those residing within 150 m of them, unless they have experienced a flood [44].

The second stepwise regression results add another level of interest to these findings. The model suggests that a change in flood experience between 2015 and 2019 has an incidence on adaptation – indeed, those whose flood status changed between the two timepoints (i.e. never flooded/alerted before 2015, flooded/alerted between 2015 and 2019) are over three times more likely to adapt than those whose flood experience status did not change between the two survey timepoints (i.e. never flooded/alerted at both timepoints or flooded/alerted at both timepoints). This finding is supported by those of other panel studies [43]. However, an important caveat here is the relatively small number of respondents who changed in flood experience status between our two survey time points, 34 respondents. This is a common problem to panel surveys in the flood risk domain [34], as only a small proportion of at-risk households will actually be flooded in a given time period. Fortunately, other variables can also be relatively good predictors of adaptation over time, such as perceptions of risk and severity.

2. Belief that one lives in a flood-prone area and that the impacts of flooding on one's home would be severe increases adaptation

According to our first stepwise regression analysis using 2015 variables to predict 2019 adaptation, the belief of living in a flood-prone area is the foremost factor influencing someone to adapt at the end of a 4-year period out of the explanatory variables selected. The reasonable explanation for this result is that believing that one lives in a flood-prone area increases residents' perception of the likelihood that they will be flooded in the next years. This is interesting because, as suggested by Ajzen et al. (2011) [45], it demonstrates that people's beliefs guide their actions, whether these beliefs are true or false. The fact that the belief of living in a flood-prone area exceeds the effect of having experienced a flood on adaptation behavior, as suggested by this analysis, is an encouraging finding, but it is also alarming. It is encouraging as it suggests that alerting citizens of their flood-prone status is a feasible and long-term strategy to increase their mitigation behaviors and does not involve all the negative consequences of actually being victimized by a flood. It is also alarming however, because a cross-sectional study by Valois et al. (2020) [31] revealed that the proportion of Quebecers living in designated flood zones who were unaware of the fact was approximately 1 in 4 and 1 in 3 in 2015 and 2019 respectively. Therefore, residents may not be perceiving the appropriate amount of risk that would encourage them to protect themselves.

In our second stepwise regression using the change in predictive variables and adaptation in 2015 to predict adaptation in 2019, a change in one's perception of the severity of impacts of a flood on one's home is a strong predictor of adaptation in 2019 – those who have increased their perception of severity of the impacts on one's home are almost 8 times and 6 times more likely to adapt than those who whose severity perception decreased or remained unchanged, respectively. The results of Oubennaceur et al., 2022 [46] lend support to this result, as they reveal that in Southern Québec, citizens' perception of the long-term consequences of flooding on property values was of highest concern among questions on flood risk perception. This finding is alarming, as in our sample, more respondents decreased (55 respondents) than increased (35 respondents) their severity perception of flood hazards on their property between 2015 and 2019.

These findings summarily point to the importance of alerting citizens about the flood risk to which they are exposed by living in flood-prone areas in Québec, and the severity of the impacts flooding hazards may pose to their residence.

3. Higher income leads to more adaptation

Income is yet another factor that encourages people in flood-prone areas to adapt more four years down the road, according to our first stepwise regression model. This result is not surprising as Xu et al. (2018) and Soane et al. (2010) [47,48] found that high income has a positive influence on disaster preparedness behavior. As suggested, by Ashenefe et al. (2017) [49], this could be because households with greater financial resources can afford costly adaptive modifications to their properties. However, this explanation has some caveats. First, our results showed that people with higher income did not engage in more structural adaptive behaviors, which tend to cost more than non-structural adaptive behaviors, compared to those with lower incomes. Third, other studies [42,50–52] found that the impact of income on flood adaptation is ambiguous. Finally, our longitudinal sample is biased toward mid- and higher-income residents relative to our 2015 sample, which is problematic as lower-income residents tend to be overrepresented in high flood risk zones in Canada [53].

4. Those who were previously adapted are more likely to be adapted in the future

Our second stepwise regression controls for previous adaptation to measure how changes in explanatory variables between 2015 and 2019 lead to differing levels of adaptation in 2019. However, the result that previous adaptation is very strongly associated with later adaptation – earlier "more adapted" residents are almost 9 times as likely to adapt as their previously "less adapted" counterparts - is interesting in itself. This result could be partly explained by the fact that one or many of the adaptations they made in 2015 could be long-lasting (e.g., insulating the exterior walls). However, for habits that can be adopted repeatedly (e.g. Making a list of belongings that could be used for a claim in case of flooding), this finding makes evident the importance of developing these into regular habits. As indicated by Fishbein and Ajzen [54], if a behavior is regularly repeated, its initiation becomes habitual and automatic without cognitive intervention. Thus, this result indicates that suitable messaging to incite flood-prone residents should be repeatedly communicated to facilitate habit formation. So that for instance, every spring when water levels rise in Southern Québec's rivers, nearby residents will instinctively put in place measures to protect themselves.

5. Conclusion

The scarcity of longitudinal research represents an important research gap in the flood risk and adaptation domain [34]. This study contributes to bridging this gap and engages in an important exploration of different modeling methods that can be used to take advantage of unique panel datasets such as this one. However, it also faces many of the same challenges commonly plaguing panel studies such as its high attrition rate and potential for retention bias. It also lacks an experimental design, which prevents us from inferring cause-and-effect relationships between our variables. Stepwise regression also presents important limitations, as it embraces the endogeneity of different variables, which can limit the interpretability of coefficients. Consequently, more research is required to generalize the above findings. Results from this exploratory longitudinal study provide critical information regarding flood adaptive behavior over a long period of time, and its predictors. Future analyses should examine flood adaptive behaviors in relation with psychosocial factors not included in the current study such as beliefs about the advantages and disadvantages to adopt adaptive behaviors.

Ethics approval and consent to participate

The study was approved by the Human Subject Research Ethics Board, Université Laval, QC, Canada (reference number 100719, file number 2019–209). In the introduction of the study, participants were explicitly asked for their informed oral consent before they could answer the survey, since obtaining a written consent was not feasible over the phone. This method ensured their anonymity and was approved by the ethics committee.

Author contributions

Pierre Valois: Conceptualization, methodology, writing – original draft preparation, funding acquisition. François Anctil: Research design, writing – reviewing and editing. Geneviève Cloutier: Research design, writing – review and editing. Maxime Tessier: Data analysis and interpretation. Naomie Herpin-Saunier: Investigation, writing – original draft preparation, review, and editing.

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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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2023.103782.

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