Adolescent Flood Exposure and Life-Course Cognitive Adaptation: Implications for Climate Resilience in China

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Abstract (274 words)

Objective: As climate-related disasters become more frequent and severe, understanding their long-term implications for adaptive capacity is increasingly important. This study examines whether adolescent exposure to flood events is associated with life-course cognitive adaptation in later adulthood and considers the broader implications for climate resilience in China, where flood risks are spatially uneven and regionally concentrated.

Methods: We used five waves (2011–2020) of the China Health and Retirement Longitudinal Study (N = 10,321; age 45+). Retrospective reports of adolescent flood exposure were linked to subsequent cognitive performance. Group-based trajectory modeling identified heterogeneous cognitive trajectories over time. Multinomial logistic regression estimated associations between flood exposure and trajectory membership, adjusting for sociodemographic and baseline health characteristics. Inverse probability weighting addressed potential bias from differential survival and attrition. Mediation analyses assessed adult social participation, health behaviors, and intergenerational ties.

Results: Three cognitive trajectories were identified: low-stable (22.6%), moderate-decline (43.0%), and high-stable (34.4%). Light and moderate adolescent flood exposure were associated with a higher likelihood of membership in the moderate-decline and high-stable trajectories relative to the low-stable group. Inverse probability–weighted estimates were consistent. Adult social participation accounted for a modest share of the association (approximately 5–8%), whereas health behaviors and intergenerational ties showed no significant mediation.

Conclusions: Findings suggest that manageable early-life environmental adversity may be associated with stronger long-term cognitive adaptation. Given the geographically concentrated nature of flood exposure in China, these results underscore how spatially differentiated climate risks may contribute to uneven distributions of adaptive human capacities across regions. Understanding such life-course consequences is essential for informing place-based climate resilience strategies.

Keywords: flood exposure; cognitive adaptation; life-course trajectories; climate resilience; regional heterogeneity; China

1. Background and Contribution

Climate change is increasing the frequency and severity of floods, raising concerns not only about short-term health impacts but also about long-term adaptive capacity in aging societies (Field et al., 2012; Watts et al., 2019). In countries such as China—where flood risks are geographically concentrated and population aging is rapid—understanding how early-life exposure to climate-related disasters shapes life-course outcomes is essential for climate resilience planning.

Life-course research offers competing perspectives on early adversity. The stress sensitization hypothesis posits that early exposure increases vulnerability to later stressors (Maclean et al., 2016). In contrast, resilience frameworks suggest that successfully coping with manageable adversity may strengthen adaptive resources (Rutter, 1985). Trauma research further proposes that post-adversity adaptation may involve strengthened social engagement and behavioral change (Tedeschi & Calhoun, 1996). While these perspectives are often examined at the individual level, their implications extend to regional science: cognitive capacity and social participation constitute durable human resources that underpin territorial resilience.

This study contributes in three ways. First, it links adolescent flood exposure to heterogeneous cognitive trajectories rather than single-point cognitive outcomes. Second, it tests robustness to selective survival and attrition using inverse probability weighting (IPW). Third, it examines adult social participation, health behaviors, and intergenerational ties as potential mediators aligned with post-adversity adaptation mechanisms. We interpret results through a climate resilience lens, highlighting how spatially uneven flood risks may contribute to territorially differentiated adaptive capacities.

2. Data and Measures

We use five waves (2011–2020) of the China Health and Retirement Longitudinal Study (CHARLS), a nationally representative survey covering 28 provinces. After applying inclusion criteria, the analytic sample includes 10,321 adults aged 45–90 at baseline (2011).

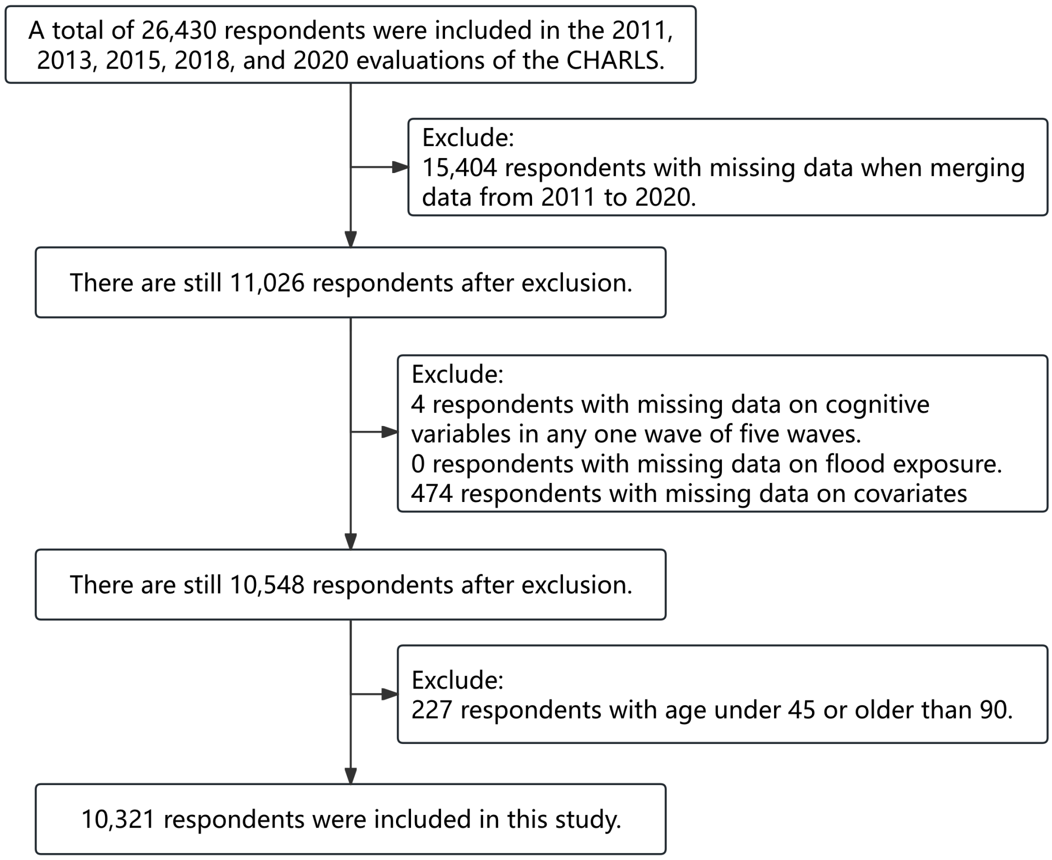

Figure 1. Flow chart of the respondent sample selection process.

Cognitive function (2011–2020). Cognitive scores range from 0–19, combining mental intactness (orientation, serial subtraction, figure drawing; 0–9) and memory (immediate and delayed recall; 0–10).

Adolescent flood exposure. Using the 2011 community questionnaire, we classify respondents as exposed if a recorded flood occurred when they were ages 10–24. Exposure intensity is categorized as no exposure (reference), light (0 deaths), moderate (1–3 deaths), and severe (≥5 deaths), based on recorded flood-related mortality.

Mediators (adulthood). Three binary indicators are examined: (1) social activity participation (any activity in past month), (2) sustained health-promoting behavior (≥1 year), and (3) intergenerational ties (frequent contact/co-residence or grandchild care).

Covariates. Baseline controls include age, gender, residence, marital status, employment, smoking, drinking, self-rated health, log per-capita household expenditure, and household fixed assets.

3. Methods

We proceed in five steps. Analyses were conducted in R 4.5.1 and Stata 17.0. Statistical significance was defined as $p < 0.05$.

First, baseline characteristics are summarized and attrition patterns assessed.

Second, group-based trajectory modeling (GBTM) is used to identify cognitive trajectories from 2011–2020, with age as the time scale. Model selection is based on BIC/AIC, posterior probabilities, entropy, and group size.

Third, multinomial logistic regression models estimate associations between adolescent flood exposure (binary and intensity) and trajectory membership, adjusting for covariates. Results are reported as relative risk ratios (RRRs).

Fourth, to address potential survival bias, we estimate inverse probability weighted (IPW) average treatment effects (ATEs).

Fifth, mediation is assessed using Karlson–Holm–Breen (KHB) decomposition.

Table 1. Descriptive statistics of main variables from the 2011 baseline data.

Main Variable	Successfully followed-up samples (N=10,321)	Censored samples (N=6,787)	*p*-Value
Cognitive function, mean (SD)	8.58 (4.41)	7.80 (5.00)	***
Adolescent flood exposure, *n* (%)			
No	9,699 (93.97)	6,409 (94.43)	> *0.05*
Yes	622 (6.03)	378 (5.57)	
Flood exposure intensity, *n* (%)			
No exposure	9,699 (93.97)	6,409 (94.43)	*
Light exposure	502 (4.86)	320 (4.71)	
Moderate exposure	67 (0.65)	22 (0.32)	
High exposure	53 (0.51)	36 (0.53)	
Age, mean (SD)	58.02 (8.58)	60.51 (11.89)	***
Gender, *n* (%)			
Female	5,511 (53.40)	3,392 (49.98)	***
Male	4,810 (46.60)	3,395 (50.02)	
Residence, *n* (%)			
Rural	8,616 (83.48)	4,731 (69.71)	***
Urban	1,705 (16.52)	2,056 (30.29)	
Marital status, *n* (%)			
Unmarried	1,012 (9.81)	1,148 (16.91)	***
Married	9,309 (90.19)	5,639 (83.09)	
Employment, *n* (%)			
No	8,516 (82.51)	5,474 (80.65)	**
Yes	1,805 (17.49)	1,313 (19.35)	
Smoking, *n* (%)			
No	6,351 (61.53)	3,970 (58.49)	***
Yes	3,970 (38.47)	2,817 (41.51)	
Drinking, *n* (%)			
No	6,877 (66.63)	4,605 (67.85)	> *0.05*
Yes	3,444 (33.37)	2,182 (32.15)	
Self-reported health, *n* (%)			
Fair/bad	7,827 (75.84)	5,221 (76.93)	> *0.05*
Good	2,494 (24.16)	1,566 (23.07)	
Household expenditure, mean (SD)	3.99 (0.92)	4.12 (1.06)	***

Household fixed assets, mean (SD)	4.20 (2.18)	4.11 (2.31)	**

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; p-value was based on the chi-square test, or Welch's t-test where appropriate; Household expenditure is the abbreviation for "the logarithmic value of Household per capita monthly expenditure"; Censored samples are retained only for those that existed during the 2011 baseline survey and have no missing values in the Main Variable.

4. Results

GBTM identifies three trajectories: low-stable (22.6%), moderate-decline (43.0%), and high-stable (34.4%). Approximately 6% of respondents experienced adolescent flood exposure.

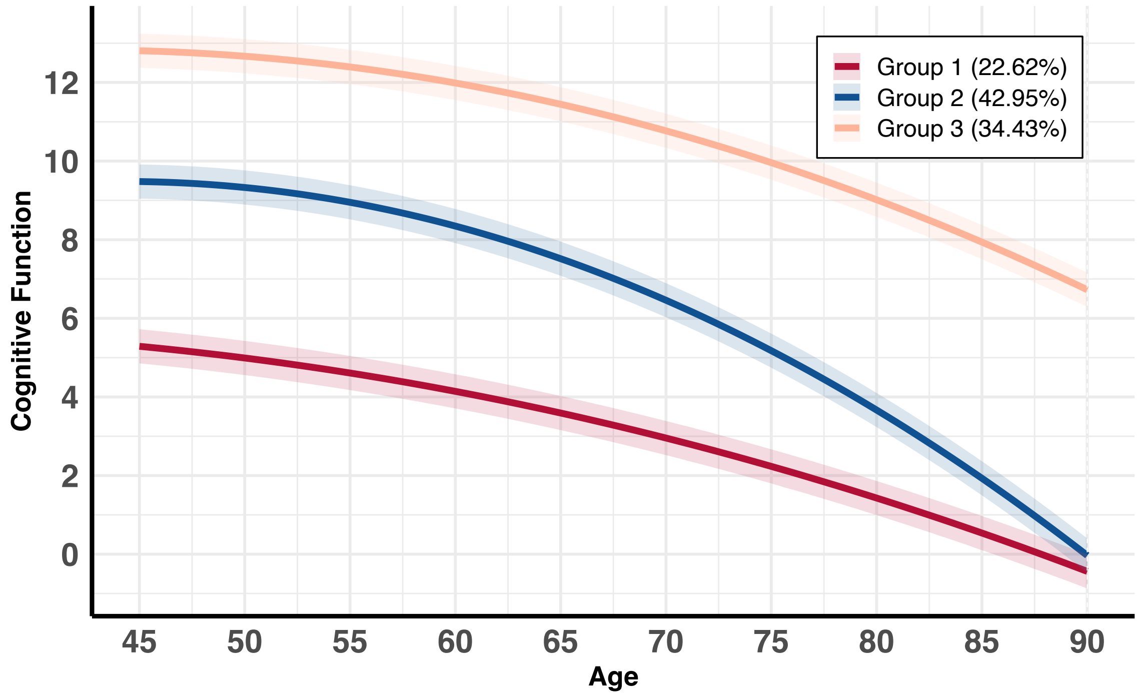

Figure 2. Trajectories of cognitive function among middle-aged and older adults.

Table 2. Baseline characteristics of the sample for cognitive function trajectories among middle-aged and older adults.

Characteristic	Trajectory of Cognitive Function			*p*-Value
	Low-stable (Group 1)	Moderate-decline (Group 2)	High-stable (Group 3)	
Adolescent flood exposure, *n* (%)				
No	2,227 (95.42)	4,167 (93.98)	3,305 (93.02)	**
Yes	107 (4.58)	267 (6.02)	248 (6.98)	
Flood exposure intensity, *n* (%)				
No exposure	2,227 (95.42)	4,167 (93.98)	3,305 (93.02)	**
Light exposure	89 (3.81)	207 (4.67)	206 (5.80)	
Moderate exposure	8 (0.34)	33 (0.74)	26 (0.73)	
High exposure	10 (0.43)	27 (0.61)	16 (0.45)	
Gender, *n* (%)				
Female	1,674 (71.72)	2,395 (54.01)	1,442 (40.59)	***
Male	660 (28.28)	2,039 (45.99)	2,111 (59.41)	
Residence, *n* (%)				
Rural	2,219 (95.07)	3,918 (88.36)	2,479 (69.77)	***
Urban	115 (4.93)	516 (11.64)	1,074 (30.23)	
Marital status, *n* (%)				
Unmarried	313 (13.41)	442 (9.97)	257 (7.23)	***
Married	2,021 (86.59)	3,992 (90.03)	3,296 (92.77)	
Employment, *n* (%)				
No	2,072 (88.77)	3,723 (83.96)	2,721 (76.58)	***
Yes	262 (11.23)	711 (16.04)	832 (23.42)	
Smoking, *n* (%)				
No	1,697 (72.71)	2,719 (61.32)	1,935 (54.46)	***
Yes	637 (27.29)	1,715 (38.68)	1,618 (45.54)	
Drinking, *n* (%)				
No	1,724 (73.86)	2,998 (67.61)	2,155 (60.65)	***
Yes	610 (26.14)	1,436 (32.39)	1,398 (39.35)	
Self-reported health, *n* (%)				
Fair/bad	1,893 (81.11)	3,390 (76.45)	2,544 (71.60)	***
Good	441 (18.89)	1,044 (23.55)	1,009 (28.40)	
Household expenditure, mean (SD)	3.71(0.94)	3.95 (0.91)	4.23 (0.84)	***
Household fixed assets, mean (SD)	3.49 (2.06)	4.12 (2.15)	4.77 (2.15)	***
N	2,334	4,434	3,553	

Notes: * p < 0.05, ** p < 0.01, *** p < 0.001; p-value was based on the chi-square test, or ANOVA where appropriate; Household expenditure is the abbreviation for "the logarithmic value of Household per capita monthly expenditure".

In covariate-adjusted models, adolescent flood exposure is associated with higher likelihood of membership in more favorable trajectories relative to the low-stable group. Exposure predicts increased likelihood of belonging to the moderate-decline (RRR ≈ 1.48) and high-stable (RRR ≈ 2.03) groups compared with the low-stable group. Intensity analyses indicate positive associations for light and moderate exposure, while severe exposure shows no statistically significant association.

Table 3. Estimates of multinomial logistic regression on cognitive function trajectories.

	Model1			Model2		
	G3vsG1	G3vsG2	G2vsG1	G3vsG1	G3vsG2	G2vsG1
Adolescent flood exposure	2.025*** (1.580-2.595)	1.371** (1.139-1.650)	1.477** (1.169-1.868)	— —	— —	— —
Flood exposure intensity						
Light exposure	— —	— —	— —	1.991*** (1.518-2.611)	1.458*** (1.187-1.791)	1.366* (1.055-1.769)
Moderate exposure	— —	— —	— —	3.196** (1.402-7.282)	1.308 (0.772-2.215)	2.443* (1.115-5.353)
Severe exposure	— —	— —	— —	1.359 (0.578-3.196)	0.797 (0.417-1.523)	1.706 (0.810-3.593)
Control variable		YES			YES	
N		10321			10321	
Pseudo R2		0.081			0.082	

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; G1 = “Low-stable (Group 1)” subgroup, G2 = “Moderate-decline (Group 2)” subgroup, G3 = “High-stable (Group 3)” subgroup; Values in parentheses indicate the 95% confidence interval for the Relative Risk Ratio (RRR); In all group comparisons formatted as "Gm vs. Gn", the second group (Gn) serves as the reference category (e.g., "G3 vs. G1" compares the Relative Risk Ratio of belonging to Group 3 relative to Group 1); Other variables were controlled for, including gender, residence, marital status, employment, smoking, drinking, self-reported health, household expenditure, household fixed assets; Flood exposure intensity uses no exposure as the reference.

IPW estimates confirm robustness: overall exposure increases the probability of moderate-decline and high-stable membership by approximately 7.7 and 11.0 percentage points, respectively, with the most consistent effects observed for light exposure.

Table 4. Average Treatment Effects of Adolescent Flood Exposure on Cognitive Trajectory (IPW Estimates)

Treatment Variable	G2vsG1	G3vsG1
Adolescent flood exposure	0.077** (0.030, 0.123)	0.110*** (0.064, 0.156)
Flood exposure intensity		
Light exposure	0.061* (0.008, 0.114)	0.107*** (0.057, 0.156)
Moderate exposure	0.079 (-0.107, 0.264)	0.042 (-0.193, 0.276)
Severe exposure	0.088 (-0.041, 0.218)	-0.023 (-0.268, 0.222)

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; G1 = "Low-stable (Group 1)" subgroup, G2 = "Moderate-decline (Group 2)" subgroup, G3 = "High-stable (Group 3)" subgroup; Values are Average Treatment Effects (ATE) with 95% confidence intervals in parentheses; In all comparisons "Gm vs. Gn", group Gn is the reference category; A positive ATE indicates that the treatment increases the probability of belonging to group Gm relative to group Gn; Other variables were controlled for, including gender, residence, marital status, employment, smoking, drinking, self-reported health, household expenditure, and household fixed assets; For the 'severe exposure' model, the variable "household expenditure" was omitted due to violations of the overlap assumption necessary for IPW estimation; Flood exposure intensity uses no exposure as the reference.

Mediation analysis indicates that adult social participation accounts for a modest share (approximately 5–8%) of the association, whereas health behaviors and intergenerational ties show no significant mediation. These findings suggest that social engagement may partially link early-life adversity to later-life cognitive adaptation.

Table 5. Mediators in the association between adolescent flood exposure and cognitive function trajectories

		Adolescent flood exposure				Flood exposure intensity			
		G3vsG1		G2vsG1		G3vsG1		G2vsG1	
Mediators	Effect	Coefficient	Mediation (%)	Coefficient	Mediation (%)	Coefficient	Mediation (%)	Coefficient	Mediation (%)
Social activity participation	Total	0.710*** (0.460, 0.959)		0.393** (0.158, 0.628)		0.446*** (0.265, 0.628)		0.298** (0.127, 0.468)	
	Direct	0.657*** (0.407, 0.906)		0.369** (0.134, 0.604)		0.416*** (0.234, 0.597)		0.284** (0.113, 0.454)	
	Indirect	0.053*** (0.026, 0.080)	7.46	0.024** (0.009, 0.039)	6.11	0.031** (0.012, 0.050)	6.93	0.014** (0.004, 0.024)	4.70
Health behaviors	Total	0.710*** (0.461, 0.959)		0.390** (0.156, 0.625)		0.448*** (0.266, 0.630)		0.298** (0.127, 0.470)	
	Direct	0.697*** (0.448, 0.946)		0.384** (0.150, 0.619)		0.436*** (0.255, 0.618)		0.293** (0.122, 0.465)	
	Indirect	0.013 (-0.008, 0.034)	NA	0.006 (-0.004, 0.016)	NA	0.011 (-0.004, 0.026)	NA	0.005 (-0.002, 0.012)	NA

Intergenerational ties	Total	0.705*** (0.457, 0.953)		0.390** (0.155, 0.624)		0.445*** (0.264, 0.626)		0.298** (0.127, 0.469)	
	Direct	0.706*** (0.458, 0.954)		0.392** (0.157, 0.626)		0.446*** (0.265, 0.627)		0.301** (0.130, 0.472)	
	Indirect	-0.001 (-0.004, 0.002)	NA	-0.002 (-0.008, 0.004)	NA	-0.001 (-0.004, 0.002)	NA	-0.003 (-0.008, 0.002)	NA

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; G1 = “Low-stable (Group 1)” subgroup, G2 = “Moderate-decline (Group 2)” subgroup, G3 = “High-stable (Group 3)” subgroup; In all comparisons “Gm vs. Gn”, group Gn is the reference category; Other variables were controlled for, including gender, residence, marital status, employment, smoking, drinking, self-reported health, household expenditure, household fixed assets. Mediation (%) was only calculated when the indirect effect was significant ($p < 0.05$); NA = Not applicable.

5. Discussion and Climate Resilience Implications

Results suggest that manageable early-life flood exposure may be associated with stronger long-term cognitive adaptation. The absence of consistent benefits for severe exposure aligns with resilience frameworks emphasizing the role of adversity intensity: overwhelming shocks may undermine adaptive gains.

From a regional science perspective, flood risks in China are geographically concentrated. Early-life exposure to climate shocks may therefore contribute to spatial variation in adaptive human capacities across regions. These findings underscore the importance of place-based climate resilience strategies that protect educational continuity and support social infrastructure in disaster-prone areas. Policies that sustain community engagement and mitigate long-term human-capital loss may strengthen resilience in aging regions facing increasing climate hazards.

6. Limitations and Future Directions

Several limitations warrant consideration. First, adolescent flood exposure was measured at the community level using historical disaster records rather than individual-level experience. While this approach reduces recall bias, it may not fully capture variation in personal loss, displacement, or exposure duration. Second, exposure intensity was proxied by recorded flood-related mortality, which reflects severity but does not incorporate economic damage or infrastructure disruption. Future research should integrate higher-resolution hazard data, multilevel or spatial models, and contextual indicators of institutional capacity to better understand how regional conditions shape life-course adaptation following climate shocks.

7. Conclusion

Using nationally representative longitudinal data, this study shows that adolescent flood exposure is associated with heterogeneous cognitive trajectories in later adulthood, with the most consistent evidence for light exposure and results robust to survival adjustments. A modest indirect pathway through adult social participation suggests that social integration may contribute to life-course cognitive adaptation. By linking early-life climate shocks to durable human capacities, this study provides life-course evidence relevant for place-based climate resilience strategies in aging societies.

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