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From Early Warning to Early Action: Household Responses to Flood Early-Warning Information in Northwestern Bangladesh

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ABSTRACT

Flood early-warning systems can be used to minimize losses that can be avoided, only when the households change the warning messages into prompt protective behavior. This paper analyses the behavioural process that occurs between flood early-warning message and household early action in northwestern Bangladesh. A survey conducted cross-sectionally produced 460 valid household responses. The model that is suggested combines the perceived quality of warning information, trust in warning sources, perceived risk of the flood, perceived response capacity, early-action intention, and household early-action. Partial least squares structural equation modelling was used to assess the measurement and structural models. All measurement scales showed good reliability, convergent validity and discriminant validity. The structural findings demonstrate that quality of warning information and trust can be a significant predictor of perceived flood risk, and early-action intention. The perception of flood risk and perception of response capacity also have a positive impact on early-action intention. Early-action intention ranks highest with direct impact on early action by a household. Important indirect effects point to the fact that warning quality, trust and response capacity to action have their impact on risk perception and behavioural intention. The results indicate that correct warnings that appear technically accurate are not enough unless they are credible, comprehensible, actionable, and in parity with the household response potential. The research offers an empirical model of enhancing warning communication, preparedness, and community-based flood risk mitigation in at-risk environments within vulnerable communities.

INTRODUCTION

Household safety, livelihoods, mobility, food security and other vital assets in much of Bangladesh have continued to be threatened by floods. Physical magnitude of an event is not the determining factor of the human impacts of flooding. They also hinge on the availability of credible information to exposed households at the appropriate time, the interpretation of potential outcomes, and the ability to act on the intention, and the ability of the credible information to translate intention into actual protective behaviour. This is why flood early-warning systems should not be judged merely on the basis of the generation of the forecasts but on whether they can prompt households to take timely measures (Potutan & Suzuki, 2023).

A key environment to study this behavioural process is in Northwestern Bangladesh. The warnings to households living in flood vulnerable areas can be channeled through government announcements, local authority, mobile phone, broadcast media, community volunteers, social network, and community volunteers among others. These channels may vary in timeliness, consistency, specificity and perceived credibility (Shi *et al.*, 2020). Although a warning should be received in a home, the response may be postponed due to the inability to understand it, uncertain expected severity, lack of trust in the sender,

lack of funds, transportation, access to shelter, and coordination, or lack of belief in preparedness capability. Early warning is thus, an information-to-action chain and not a single communication event.

Among the main research issues, there is a gap between a warning and before the arrival of floodwater. Current methods of disaster preparedness tend to believe that better information leads to safer behaviour by default. Practically, perception of risk, trust, resources, past experience, and ability to act is applied in interpreting the warning information (Chaves-Gonzalez *et al.*, 2022). The technically right message might not make much practical impact when it fails to produce enough concern or households feel that they cannot do anything to protect them. On the other hand, believable and practical information may stimulate instant preparation, asset preservation, evacuation, aid to the vulnerable members of the household, and arrangements with neighbours. The current study handles such an issue by exploring the role of perceived information quality of warning on perceived flood risk and early-action intention in relation to trust in source of flood-warning messages (Mallick *et al.*, 2022). It takes perceived response capacity as a direct antecedent of intention also. Observed household early action is then related to early-action intention. This model thus relates communication quality, institutional

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credibility, risk appraisal, perceived capability, behavioural intention, and actual protective behaviour together in one empirical model.

Three contributions are made in the study. Firstly, it puts an emphasis on the warning receipt into the behavioural processes that elaborate on whether warning will result in action. Second, it can compare both direct and indirect relationships, which enables the research to determine the transmission of effect of upstream warning factors via perceived flood risk and early-action intention (Bernard *et al.*, 2022). Third, it provides evidence derived based on 460 valid household responses and analyzes the proposed relationships based on partial least squares structural equation modelling. The results are to be used in argumenting people-centred flood early-warning practice by indicating the aspects of the warning communications and home preparedness that are the most strongly correlated with taking early action. The main purpose is thus to describe the ways in which households change their awareness to preparedness and action to preparedness (Lopez *et al.*, 2020). The discussion is centered on household perceptions since the success of a warning will, ultimately, hinge on how the recipients will understand its meaning, credibility, urgency and applicability.

LITERATURE REVIEW

Warning Information Quality and Household Response

Early-warning information comes into play when it is perceived by the households as timely, clear, specific, consistent, and adequately updated as the conditions vary. Technical forecast accuracy is thus narrower than information quality (Forsyth *et al.*, 2023). It encompasses the state of learning severity to come, awareness of sites that might be subjected to it and practical advice regarding protection measures. With these qualities in place, the households can interpret the warning as personally relevant information as opposed to the general background information (Samansiri *et al.*, 2023). Good warning messages may also be used to minimize ambiguity in the quickly evolving flood situations.

The perceived quality of the information will have an effect on the risk appraisal. An early warning with a clear message of severity can reinforce the notion that there is a high risk of flooding and that the effects of flooding can be severe (Mondal *et al.*, 2020). It may also directly affect behavioural intention since when particular guidance is involved, uncertainty will be reduced with regards to what is to be done. In line with this, the framework hypothesizes that perceived warning information quality enhances perceived flood risk and intention to take action early. H1 and H3 represent these relationships (Alam *et al.*, 2023).

Trust in Flood-Warning Sources

Trust defines how households perceive warning information as credible to accept and take consequential

decisions. Response to floods can be in the form of relocation of assets, halt livestock, preparing medication, or relocating family members. Such practices come at a price (Panapitiya *et al.*, 2022). Any information perceived by the households as exaggerated, inconsistent, politicized, and unreliable is hence not likely to induce a strong household response. Development of trust may also be reinforced by recognised sources being honest, giving accurate information, and advice that is consistent with what is observed (Perera *et al.*, 2020).

Perceived flood risk can be influenced by trusted sources of warnings since believable information is more apt to be paid attention to. Trust can also have an influence on intention regardless of risk perception (Huq *et al.*, 2022). A family can learn not to expect mud up to their hips but they remain skeptical until they have trust in the authority giving them the advice (Mehta *et al.*, 2022). The conceptual model thus anticipates the perceived flood risk and early-action intention to be enhanced by trust in warning sources. Propositions H2 and H4 are these.

Perceived Flood Risk

The perceived flood risk demonstrates the perception of the household of the probability, susceptibility and the possible extent of the damage following an alert of severe risk. Risk perception provides meaning of behaviour to warning information (Nofal *et al.*, 2021). When a household deems flooding to be unlikely or the consequences to be minor the household can delay in preparing even when a technically correct warning is provided. Conversely, more intense perceptions of threat would generate a sense of urgency and tend to increase the perceived need of protective actions (Giaro *et al.*, 2023).

The model considers perceived flood risk both as a mediator and a direct predictor of intention. The quality of warnings and trust can affect the way households perceive the threat, and the risk appraisal may stimulate preparations (Ibrahim *et al.*, 2020). H5 thus suggests that perceived flood risk is positively related to early-action intention. The mediating role of risk perception also acknowledges that communication affects behaviour partially based on the perception of danger (Noll *et al.*, 2022).

Perceived Response Capacity

Risk awareness in itself does not mean action. This also requires households to be confident that they are capable of undertaking viable protective measures (Nauman *et al.*, 2021). Perceived response capacity consists of understanding what to do, capability to obtain food and water, keeping documents and valuables safe, access to transport or evacuation aid, knowledge of safe places, and ability to network with neighbours or local organisations (Fatemi *et al.*, 2020). The practical aspect of preparedness is embodied in this construct.

A family might experience high flood risk but will be inactive where the respond is no longer seen possible due

to financial, logistical and social barriers (Lee *et al.*, 2021). This gap can be narrowed by developing the perceived ability to act early by building confidence. The model thus hypothesizes that perceived capacity to respond positively influences early-action intention, as modeled by H6.

Early-Action Intention and Household Early Action

Early-action intention demonstrates the willingness of the household to initiate preparation, adhere to protective measures, obtain necessary supplies, protect the vulnerable population, want to get more information and collaborate with others. Intention comes right before the behaviour since it encompasses readiness to react upon one perceiving a valid threat. Household early action, on the other hand, indicates impeded protective actions actually taken following the most recent serious warning (Ahsan *et al.*, 2020).

It is significant to differentiate between intention and action (Saha & Pittock, 2021). Families can be willing to cook but are not able due to lack of resources, transportation issues, space and shelter, property or family conflict of the family. Having said that, the more intense the intention, the more likely it is that preparation will take place (Samansiri *et al.*, 2022). H7, therefore, hypothesizes that there is a positive impact of early-action intention in house-early action.

Conceptual Framework and Hypotheses

The six constructs are incorporated in the conceptual framework. The perceived information quality of warning, trust in warning sources, and perceived response capacity are exogenous variables (Hossain, 2020). The perceived flood risk and early-action intention are mediating variables. The last endogenous outcome is household early action. The model has seven direct hypotheses: H1, PWIQ has a positive relationship with PFR; H2, TWS has a positive relationship with PFR; H3, PWIQ has a positive relationship with EAI; H4, TWS has a positive relationship with EAI; H5, PFR has a positive relationship with EAI; H6, PRC has a positive relationship with EAI; and H7, EAI has a positive relationship with HEA. The framework also allows analysis of particular indirect effects with risk perception and behavioural intention and thus gives a more comprehensive account of how warning communication is communicated to action in households (Suroso *et al.*, 2022). This combined framework considers early warning to be a behaviour system as opposed to a unilateral message. It acknowledges that the information, credibility, threat appraisal, capability and intention follow a chain of reactions and at the same time each of the constructs continues to play a unique role in the overall response chain.

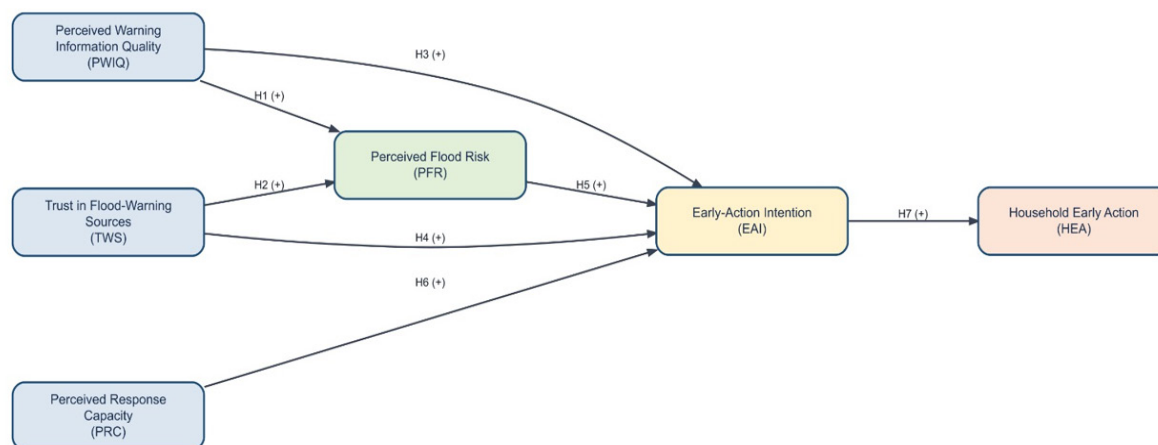


Figure 1: Conceptual framework of the flood early-warning-to-action process

METARIALS AND METHODS

Research Design and Study Population

It was a quantitative and cross-sectional survey study design that was used to explore the response of the households to the early-warning information about floods in northwestern Bangladesh. Household was the unit of analysis and this was represented by an adult respondent who took part in decisions regarding flood preparation or response. Six screening questions were the eligibility criteria (Adaikkalam Zabihi *et al.*, 2025). The respondents had to be aged 18 years or older and live in the northwestern part of Bangladesh, had an experience of a flood or a threat of a flood in the last five years, had received a flood warning in the last five years, and voluntarily gave their consent. The last dataset

was 460 valid cases.

There were four sections in the questionnaire. The screening criteria were used in the first section. The second respondent and household categories captured comprised of gender, age, marital status, education, occupation, income, and household size, vulnerable household, residence, housing ownership, flood experience, primary source of warning, lead time of warning and distance to a river or major water body. The six latent constructs were measured in the third part (Mellenbergh *et al.*, 2003). The fourth section measured barriers that may inhibit or delay early action and welcomed respondents to specify circumstances that would facilitate earlier action.

Measurement of Constructs

Each of the latent constructs was assessed in a reflective manner with the five-point Likert scale with emphasis from 1, strongly disagree, to 5, strongly agree. The respondents were directed to think about the latest serious flood warning that their household had received. Perceived quality of warning information was established using six items that described the timeliness, severity information, areas impacted, consistency, action guidance, and updates. Reliability, accuracy, confidence in local authorities, honesty, and confidence to act on recognised information were all in five items in trust in warning sources.

Perceived flood risk was assessed using five items that included perceived likelihood, potential household damage, vulnerability, severity, and perceived household safety concern. Perceived response capacity utilized 6 items concerning preparedness knowledge, necessary supplies, documents and valuables protection, transportation or evacuation, safe location knowledge and coordination capacity (Andiappan & Wan, 2020). Early-action intention comprised six items that indicated immediate preparation, adherence to instructions, essential assets, protection of vulnerable members, seeking of information and cooperation. Household early action had seven items that talk of actual protective behaviour which occurred after the last severe warning.

Data Screening and Descriptive Analysis

Data quality has been determined and then PLS-SEM model estimated. The completeness of the measurement variables, duplicate response identifiers, allowable Likert-scale values, and possible multivariate outliers were screened. The demographic variables and all the measurement items were then analyzed descriptively. The distributions of the responses were analyzed in terms of item-level means, standard deviations, minimum and maximum values, skewness, and kurtosis to figure out the abnormal patterns (Mimansha Patel & Nitin Patel, 2019).

PLS-SEM Assessment

The type of structural equation modelling partial least squares was taken, as the analysis is aimed at prediction, and simultaneous estimation of more than two direct and indirect relations. The analysis was done in two steps. The measurement model was first evaluated using outer loadings, variance inflation factor of indicators, Cronbachs

alpha, rho A, composite reliability, average variance extracted, Fornell/Larcker criterion and the heterotrait/monotrait ratio. The reliability of indicators, internal consistency, discriminant validity, convergent validity and possible collinearity were assessed using these statistics.

Second, the structural model was assessed by the inner VIF measures, the path coefficients, the bootstrap standard errors, t values, p values, confidence intervals, the coefficient of determination, predictive relevance, and effect sizes. Specific indirect effects were the estimated values to mediate perceived flood risk and early-action intention (Chen, 2023). Combined direct and indirect effects of each predictor were also computed to demonstrate the total effect. The criterion of model fit was the standardised root mean square residual alongside discrepancy-based measures of the residuals. The direction, magnitude, significance, and confidence intervals of the estimated relationships were used to arrive at statistical conclusions instead of using a single fit statistic.

Ethical and Analytical Considerations

Participation was optional and the respondents were told that the information would be utilised solely in academic purposes and that it would be analysed at the aggregate level. The questionnaire did not ask the respondents to give an objectively correct answer; it touched upon their experience in the household and the perception of the last serious warning (Earley, 2023). The methodology was suitable as structural model is related to the perceived quality of information, trust, risk, capability, intention and self-reported action.

The analytical sequence was tailored to prevent interpretation of structural paths before assuring the quality of measurement. The direct hypotheses, mediation relationships, predictive indicators, and model-level residual statistics were only interpreted after determining reliability and validity (Moura & Neves, 2025). This sequencing assists in a transparent evaluation of whether or not the empirical relations can be reasonably ascribed to the suggested latent constructs.

RESULTS AND DISCUSSION

Data Quality and Sample Profile

Interpretation

Table 1 confirms that the dataset could be used to continue with the analysis. The all-valid measurement

Table 1: Data Screening Results

Indicator	Result
Total imported responses	460
Valid measurement cases	460
Total missing measurement values	0
Duplicate Response ID values	0
Minimum Likert-scale value	1
Maximum Likert-scale value	5
Mahalanobis cutoff	66.619
Potential multivariate outliers	0

cases were kept to 460 imported responses. None of the missing measurements or similar response identifiers were found. The Likert responses that were observed were within the desired range of 1-5. Any potential outliers

were not found in the multivariate screening process as the Mahalanobis of 66.619 was not exceeded. The above outcomes show that there are no missing or internally inconsistent analytical data.

Table 2: Respondent and Household Characteristics

Variable	Category	Frequency	Percentage
Gender	Female	193	41.96
Gender	Male	261	56.74
Gender	Other / Prefer not to say	6	1.30
Age Group	18-25	74	16.09
Age Group	26-35	107	23.26
Age Group	36-45	115	25
Age Group	46-55	57	12.39
Age Group	56-65	68	14.78
Age Group	Above 65	39	8.48
Marital Status	Divorced / Separated	18	3.91
Marital Status	Married	343	74.57
Marital Status	Unmarried	64	13.91
Marital Status	Widowed	35	7.61
Education	Higher secondary	88	19.13
Education	No formal education	50	10.87
Education	Postgraduate or above	22	4.78
Education	Primary	119	25.87
Education	Secondary	132	28.70
Education	Undergraduate	49	10.65
Main Occupation	Agriculture	143	31.09
Main Occupation	Business	51	11.09
Main Occupation	Day labour	74	16.09
Main Occupation	Fishing	33	7.17
Main Occupation	Homemaking	61	13.26
Main Occupation	Other	17	3.70
Main Occupation	Salaried employment	44	9.57
Main Occupation	Student	14	3.04
Main Occupation	Unemployed	23	5
Monthly Household Income BDT	15,000-29,999	182	39.57
Monthly Household Income BDT	30,000-49,999	106	23.04
Monthly Household Income BDT	50,000-69,999	49	10.65
Monthly Household Income BDT	70,000 or above	16	3.48
Monthly Household Income BDT	Below 15,000	107	23.26
Household Size	1-3	90	19.57
Household Size	4-5	213	46.30
Household Size	6-7	111	24.13
Household Size	8 or more	46	10
Children Under 5	None	185	40.22
Children Under 5	One	168	36.52
Children Under 5	Three or more	24	5.22
Children Under 5	Two	83	18.04
Adults 65 Plus	None	275	59.78

Adults 65 Plus	One	142	30.87
Adults 65 Plus	Two or more	43	9.35
Disability or Chronic Illness	No	358	77.83
Disability or Chronic Illness	Yes	102	22.17
Residence Type	Char / river island	121	26.30
Residence Type	Other	4	0.87
Residence Type	Rural village	259	56.30
Residence Type	Small town / municipality	76	16.52
Housing Ownership	Informally occupied	27	5.87
Housing Ownership	Other	12	2.61
Housing Ownership	Owned	369	80.22
Housing Ownership	Rented	52	11.30
Serious Floods 5Y	Four or more	77	16.74
Serious Floods 5Y	One	126	27.39
Serious Floods 5Y	Three	117	25.43
Serious Floods 5Y	Two	140	30.43
Primary Warning Source	Community volunteer	73	15.87
Primary Warning Source	Government announcement	52	11.30
Primary Warning Source	Local administration	63	13.70
Primary Warning Source	Mobile SMS	64	13.91
Primary Warning Source	NGO	27	5.87
Primary Warning Source	Neighbours / relatives	80	17.39
Primary Warning Source	Other	8	1.74
Primary Warning Source	Radio	27	5.87
Primary Warning Source	Social media	32	6.96
Primary Warning Source	Television	34	7.39
Warning Lead Time	13-24 hours	103	22.39
Warning Lead Time	3-6 hours	75	16.30
Warning Lead Time	7-12 hours	114	24.78
Warning Lead Time	Less than 3 hours	60	13.04
Warning Lead Time	More than 24 hours	76	16.52
Warning Lead Time	Uncertain	32	6.96
Distance From River	1-3 km	203	44.13
Distance From River	Do not know	14	3.04
Distance From River	Less than 1 km	150	32.61
Distance From River	More than 3 km	93	20.22

Interpretation

Table 2 shows a heterogeneous household sample. The percentage of male respondents was 56.74% and female respondents 41.96%. The age bracket of 36-45 years was the largest. The majority of the respondents were married and secondary education was the most widespread level of education. The most common occupation was agriculture. Income was concentrated in the household income by category of BDT 15,000-29,999. The percentage of residence in rural villages was

56.30% and owned houses was 80.22%. The sources of warnings were various, but the most significant ones were the neighbours or relatives. The majority of households said that they gave warning lead times of 7-24 hours.

Descriptive and Measurement Model Results Interpretation

Table 3 on the item-level descriptive statistics shows a moderate agreement in all constructs of the warning,

Table 3: Descriptive Statistics of Measurement Items

Construct	Item	N	Mean	Standard Deviation	Minimum	Maximum	Skewness	Kurtosis
PWIQ	PWIQ1	460	3.176	1.22	1	5	-0.065	-0.977
PWIQ	PWIQ2	460	3.226	1.196	1	5	-0.228	-0.751
PWIQ	PWIQ3	460	3.122	1.148	1	5	-0.032	-0.774
PWIQ	PWIQ4	460	3.25	1.232	1	5	-0.197	-0.93
PWIQ	PWIQ5	460	3.246	1.197	1	5	-0.184	-0.876
PWIQ	PWIQ6	460	3.167	1.203	1	5	-0.22	-0.833
TWS	TWS1	460	3.196	1.207	1	5	-0.127	-0.884
TWS	TWS2	460	3.185	1.182	1	5	-0.132	-0.864
TWS	TWS3	460	3.248	1.173	1	5	-0.117	-0.802
TWS	TWS4	460	3.176	1.212	1	5	-0.142	-0.878
TWS	TWS5	460	3.146	1.24	1	5	-0.12	-0.931
PFR	PFR1	460	3.287	1.164	1	5	-0.259	-0.728
PFR	PFR2	460	3.246	1.24	1	5	-0.172	-0.956
PFR	PFR3	460	3.257	1.208	1	5	-0.272	-0.757
PFR	PFR4	460	3.313	1.193	1	5	-0.236	-0.861
PFR	PFR5	460	3.283	1.16	1	5	-0.255	-0.71
PRC	PRC1	460	3.237	1.222	1	5	-0.209	-0.896
PRC	PRC2	460	3.241	1.223	1	5	-0.175	-0.886
PRC	PRC3	460	3.265	1.186	1	5	-0.226	-0.813
PRC	PRC4	460	3.315	1.218	1	5	-0.288	-0.816
PRC	PRC5	460	3.235	1.203	1	5	-0.211	-0.831
PRC	PRC6	460	3.304	1.211	1	5	-0.32	-0.798
EAI	EAI1	460	3.261	1.144	1	5	-0.217	-0.732
EAI	EAI2	460	3.25	1.157	1	5	-0.168	-0.814
EAI	EAI3	460	3.246	1.146	1	5	-0.221	-0.754
EAI	EAI4	460	3.278	1.187	1	5	-0.198	-0.848
EAI	EAI5	460	3.237	1.198	1	5	-0.175	-0.922
EAI	EAI6	460	3.241	1.187	1	5	-0.161	-0.841
HEA	HEA1	460	2.978	1.24	1	5	-0.034	-0.942
HEA	HEA2	460	2.957	1.173	1	5	0.028	-0.871
HEA	HEA3	460	2.92	1.175	1	5	0.035	-0.788
HEA	HEA4	460	2.935	1.219	1	5	0.038	-0.882
HEA	HEA5	460	2.928	1.172	1	5	-0.023	-0.821
HEA	HEA6	460	2.97	1.197	1	5	0.02	-0.907
HEA	HEA7	460	2.926	1.236	1	5	0.044	-0.914

trust, risk, capacity, and intention. They have a general means slightly higher than the scale midpoint. Household early-action items are lesser, with means ranging between 2.920 and 2.978 indicating that reported behaviour was not so strong compared to perceptions and intentions.

Most items have standard deviations of around 1.2. The values of skewness and kurtosis are not excessive and it implies that there is no extreme distributional anomaly (Potutan & Suzuki, 2023)

Table 4: Outer Loadings and Indicator VIF

Construct	Item	Outer Loading	Indicator VIF	Loading Decision
PWIQ	PWIQ1	0.816	2.139	Retain
PWIQ	PWIQ2	0.824	2.228	Retain
PWIQ	PWIQ3	0.819	2.044	Retain
PWIQ	PWIQ4	0.798	2.061	Retain

PWIQ	PWIQ5	0.829	2.265	Retain
PWIQ	PWIQ6	0.828	2.239	Retain
TWS	TWS1	0.807	2.046	Retain
TWS	TWS2	0.826	2.004	Retain
TWS	TWS3	0.786	1.821	Retain
TWS	TWS4	0.782	1.794	Retain
TWS	TWS5	0.859	2.362	Retain
PFR	PFR1	0.845	2.14	Retain
PFR	PFR2	0.817	1.983	Retain
PFR	PFR3	0.792	1.87	Retain
PFR	PFR4	0.783	1.825	Retain
PFR	PFR5	0.838	2.273	Retain
PRC	PRC1	0.803	2.125	Retain
PRC	PRC2	0.779	1.89	Retain
PRC	PRC3	0.792	1.871	Retain
PRC	PRC4	0.768	1.775	Retain
PRC	PRC5	0.807	1.946	Retain
PRC	PRC6	0.786	1.87	Retain
EAI	EAI1	0.795	1.967	Retain
EAI	EAI2	0.791	1.87	Retain
EAI	EAI3	0.769	1.816	Retain
EAI	EAI4	0.749	1.761	Retain
EAI	EAI5	0.788	1.833	Retain
EAI	EAI6	0.781	1.832	Retain
HEA	HEA1	0.834	2.341	Retain
HEA	HEA2	0.768	1.886	Retain
HEA	HEA3	0.764	1.86	Retain
HEA	HEA4	0.76	1.824	Retain
HEA	HEA5	0.803	2.05	Retain
HEA	HEA6	0.762	1.909	Retain
HEA	HEA7	0.802	2.052	Retain

Interpretation

Table 4 shows satisfactory performance of the indicators. All outer loadings are greater than 0.70 and they vary between 0.749 and 0.859 with all being retained. The values of Indicator VIF are low (between 1.761 and

2.362), which means that there is no problematic collinearity among the measurement items. The trend is similar in all the six constructs. The findings thus uphold indicator reliability and give a good foundation in gauging construct-level reliability and validity.

Table 5: Construct Reliability and Convergent Validity

Construct	Number of Items	Cronbach Alpha	rho A	Composite Reliability	AVE	Reliability Decision	Convergent Validity
PWIQ	6	0.902	0.924	0.924	0.671	Reliable	Established
TWS	5	0.871	0.907	0.907	0.66	Reliable	Established
PFR	5	0.873	0.908	0.908	0.664	Reliable	Established
PRC	6	0.879	0.908	0.908	0.623	Reliable	Established
EAI	6	0.87	0.903	0.903	0.607	Reliable	Established
HEA	7	0.896	0.918	0.918	0.617	Reliable	Established

Interpretation

Strong internal consistency is also verified in table 5, as well as convergent validity. The alpha values of Cronbach are between 0.870 and 0.902, and composite reliability are between 0.903 and 0.924. The rho A values are also satisfactory. Each of the constructs has an average

variance extracted exceeding 0.50 with the highest values of 0.607 (early-action intention) and 0.671 (perceived warning information quality). Based on this, it was found that all constructs were reliable and convergent validity was achieved.

Table 6: Fornell-Larcker Criterion

Construct	PWIQ	TWS	PFR	PRC	EAI	HEA
PWIQ	0.819	0.178	0.3	0.12	0.388	0.197
TWS	0.178	0.812	0.302	0.055	0.39	0.197
PFR	0.3	0.302	0.815	0.004	0.369	0.242
PRC	0.12	0.055	0.004	0.789	0.314	0.28
EAI	0.388	0.39	0.369	0.314	0.779	0.482
HEA	0.197	0.197	0.242	0.28	0.482	0.785

Interpretation

Table 6, the Fornell-Larcker matrix, validates the discriminant validity. The square roots of AVE illustrated on the diagonal lie between 0.779 and 0.819. The diagonals are greater than the inter-construct correlations

in the row and column. Even though the early-action intention has a moderate correlation with the household early-action, i.e., at 0.482, it is less than the corresponding diagonal values. The constructs thus do not lose sufficient empirical uniqueness.

Table 7: Heterotrait-Monotrait Ratio (HTMT)

Construct	PWIQ	TWS	PFR	PRC	EAI	HEA
PWIQ	1	0.202	0.332	0.133	0.436	0.219
TWS	0.202	1	0.339	0.07	0.443	0.224
PFR	0.332	0.339	1	0.045	0.421	0.272
PRC	0.133	0.07	0.045	1	0.352	0.315
EAI	0.436	0.443	0.421	0.352	1	0.54
HEA	0.219	0.224	0.272	0.315	0.54	1

Interpretation

Table 7 offers a second evaluation of the discriminant validity based on HTMT. All the inter-construct HTMT ratios are significantly lower than traditional critical values. The largest ratio is 0.540 between early-action intention and household early action, with the other ratios being 0.045 to 0.443. This data validates the idea that the constructs

that are conceptually related are not statistically redundant and the model of measurement differentiates the use of warning, trust, risk, capacity, intention, and action.

Structural Model Assessment

Interpretation

It was also acceptable to have structural collinearity. The

Table 8: Structural Collinearity Assessment

Predictor	Endogenous Construct	Structural Relationship	Inner VIF	Decision
PWIQ	PFR	PWIQ -> PFR	1.033	No critical collinearity
TWS	PFR	TWS -> PFR	1.033	No critical collinearity
PWIQ	EAI	PWIQ -> EAI	1.125	No critical collinearity
TWS	EAI	TWS -> EAI	1.113	No critical collinearity
PFR	EAI	PFR -> EAI	1.184	No critical collinearity
PRC	EAI	PRC -> EAI	1.018	No critical collinearity
EAI	HEA	EAI -> HEA	1	No critical collinearity

inner VIF values have an interval of 1.000 to 1.184 as shown in Table 8. These values are well below the levels that would signify problematic overlap among predictors. The quality of perceived warning information and trust

can thus be jointly modeled in predicting perceived flood risk and warning quality, trust, flood risk and response capacity may be modeled jointly as predictors of early-action intention without critical multicollinearity.

Table 9: Coefficient of Determination and Predictive Relevance

Endogenous Construct	R Squared	Adjusted R Squared	Q Squared	R2 Interpretation	Q2 Interpretation
PFR	0.153	0.15	0.145	Very weak	Small predictive relevance
EAI	0.363	0.357	0.346	Weak	Medium predictive relevance
HEA	0.232	0.231	0.226	Very weak	Small predictive relevance

Interpretation

Table 9 presents various amounts of explanatory and predictive results with respect to the endogenous constructs. The model accounts 15.3% variation in perceived flood risk, 36.3% in early-action intention and 23.2% in household early action. All the three outcomes

are positively predicted. The Q-squared of perceived flood risk is 0.145, early-action intention 0.346 and household early action 0.226. The model is thus especially informative on elucidation of intention, although it maintains a positive prediction applicability on risk perception and action.

Table 10: Effect Size Assessment

Predictor	Outcome	Structural Path	F Squared	Interpretation
PWIQ	PFR	PWIQ -> PFR	0.074	Small
TWS	PFR	TWS -> PFR	0.075	Small
PWIQ	EAI	PWIQ -> EAI	0.083	Small
TWS	EAI	TWS -> EAI	0.101	Small
PFR	EAI	PFR -> EAI	0.061	Small
PRC	EAI	PRC -> EAI	0.112	Small
EAI	HEA	EAI -> HEA	0.303	Medium

Interpretation

The results of the effect-size in Table 10 indicate that most of the individual antecedents have small incremental effects. The perceived quality of warning information and trust have negligible impacts on perceived risk of a flood. They also have small effects on their direct effects on early-action intention as do the perceived flood risk and perceived response capacity. Conversely, the f-squared of the path between the independent variable (early-action

intention) and the dependent variable (household early action) is equal to 0.303, which is a medium effect. This brings out intention as the central proximal motivating force behind protective behaviour reported.

Hypothesis Testing, Mediation, and Total Effects Interpretation

The direct hypothesis tests are in table 11. Each of the seven hypothesised paths has a positive and significant

Table 11: Direct Path Coefficients and Hypothesis Testing

Hypothesis	Predictor	Outcome	Structural Path	Path Coefficient	Bootstrap Mean	Bootstrap SD	T Value	P Value	CI 2.5 Percent	CI 97.5 Percent	Significance	Decision
H1	PWIQ	PFR	PWIQ -> PFR	0.2541	0.2542	0.0435	5.8397	0	0.1698	0.3395	***	Supported
H2	TWS	PFR	TWS -> PFR	0.2564	0.2565	0.0442	5.7989	0	0.1659	0.3418	***	Supported
H3	PWIQ	EAI	PWIQ -> EAI	0.2444	0.2434	0.0404	6.0457	0	0.1635	0.3229	***	Supported
H4	TWS	EAI	TWS -> EAI	0.2676	0.267	0.0389	6.8744	0	0.1931	0.3433	***	Supported
H5	PFR	EAI	PFR -> EAI	0.2138	0.2139	0.0403	5.299	0	0.135	0.2918	***	Supported
H6	PRC	EAI	PRC -> EAI	0.2696	0.269	0.037	7.2942	0	0.1963	0.34	***	Supported
H7	EAI	HEA	EAI -> HEA	0.482	0.4813	0.0401	12.0342	0	0.4016	0.5587	***	Supported

value, thus rejecting H1-H7. Perceived flood risk and early-action intention are positively influenced by warning information quality. Trust exhibits the same positive impact on the two outcomes. Perceived flood risk and response capacity are significant boosters of early-action

intention. The direct relationship between early-action intention and household early action is the strongest one (beta = 0.482, $t = 12.0342$). The bootstrap confidence intervals are all non-parametric, which supports the consistency of the results.

Table 12: Specific Indirect Effects

Indirect Relation ship	Indirect Effect	Boots trap Mean	Bootstrap SD	T Value	P Value	CI 2.5 Percent	CI 97.5 Percent	Significance	Mediation Decision
PWIQ -> PFR -> EAI	0.0543	0.0543	0.0137	3.9629	0.0001	0.03	0.0838	***	Significant indirect effect
TWS -> PFR -> EAI	0.0548	0.055	0.0147	3.717	0.0002	0.0286	0.0857	***	Significant indirect effect
PWIQ -> EAI -> HEA	0.1178	0.1171	0.0214	5.5168	0	0.0767	0.1602	***	Significant indirect effect
TWS -> EAI -> HEA	0.129	0.1286	0.0222	5.7988	0	0.0865	0.1745	***	Significant indirect effect
PFR -> EAI -> HEA	0.103	0.103	0.0216	4.7761	0	0.0621	0.1458	***	Significant indirect effect
PRC -> EAI -> HEA	0.13	0.1297	0.0225	5.7657	0	0.0872	0.1773	***	Significant indirect effect
PWIQ -> PFR -> EAI -> HEA	0.0262	0.0262	0.0072	3.6504	0.0003	0.0138	0.0417	***	Significant indirect effect
TWS -> PFR -> EAI -> HEA	0.0264	0.0265	0.0074	3.5617	0.0004	0.0134	0.0424	***	Significant indirect effect

Interpretation

Table 12 suggests that all of the estimated indirect effects are statistically significant. Information quality and trust as a warning affect early-action intention based on perceived risk of floods. They also influence household early action by influencing the early-action intention. Household action is also affected by intention via

perceived flood risk and response capacity. The pathways PWIQ -> PFR -> EAI -> HEA and TWS -> PFR -> EAI -> HEA are noteworthy as well. These findings indicate that risk appraisal and behavioural intention are significant mechanisms of transmissions in the warning-to-action process.

Table 13: Total Effects

Pred ictor	Out come	Direct Effect	Indirect Effect	Tot al Effect	Bootstr ap Mean	Bootst rap SD	T Value	P Value	CI 2.5 Per cent	CI 97.5 Per cent	Signif icance
PWIQ	PFR	0.2541	0	0.2541	0.2542	0.0435	5.8397	0	0.1698	0.3395	***
TWS	PFR	0.2564	0	0.2564	0.2565	0.0442	5.7989	0	0.1659	0.3418	***
PWIQ	EAI	0.2444	0.0543	0.2988	0.2977	0.0397	7.5176	0	0.2191	0.3759	***

TWS	EAI	0.2676	0.0548	0.3224	0.322	0.0386	8.34 37	0	0.2461	0.3962	***
PFR	EAI	0.2138	0	0.2138	0.2139	0.0403	5.29 9	0	0.135	0.2918	***
PRC	EAI	0.2696	0	0.2696	0.269	0.037	7.29 42	0	0.1963	0.34	***
EAI	HEA	0.482	0	0.482	0.4813	0.0401	12.03 42	0	0.4016	0.5587	***
PWIQ	HEA	0	0.144	0.144	0.1433	0.0224	6.43 89	0	0.1005	0.1884	***
TWS	HEA	0	0.1554	0.1554	0.1551	0.0234	6.64 05	0	0.1117	0.2025	***
PFR	HEA	0	0.103	0.103	0.103	0.0216	4.77 61	0	0.0621	0.1458	***
PRC	HEA	0	0.13	0.13	0.1297	0.0225	5.76 57	0	0.0872	0.1773	***

Interpretation

Table 13 shows the cumulative significance of the predictors in the total-effect estimates. The strongest total effect of trust on early-action intention is 0.3224, with warning information quality, and perceived response capacity coming next at 0.2988 and 0.2696 respectively. Early-action intention has the greatest total impact on household early action of 0.482. Out of the upstream

predictors, the total effect of trust on household action is 0.1554, warning quality 0.1440, response capacity 0.1300, and perceived flood risk 0.1030. All of the reported total effects are significant.

Model Fit

Interpretation

Table 14 shows good model fit with respect to residuals.

Table 14: Model Fit Indices

Fit Index	Estimated Value	Recommended Criterion	Interpretation
SRMR	0.0446	Below 0.080	Acceptable model fit
d_ULS	1.1817	Lower values indicate better fit	Exact discrepancy measure
RMS residual	0.0439	Lower values indicate better fit	Residual discrepancy measure

The value of the SRMR stands at 0.0446, which is lower than the suggested level of 0.080. The d_ULS value is 1.1817 and the RMS residual is 0.0439. These statistics show that there is a comparatively minor difference between the model-implied and the observed relationships. The model fit is addressed along with the measurement quality, predictive indicators, effect sizes, and path significance as opposed to being a standalone basis to evaluate the model.

Discussion

The results give a logical description of the transformation of flood-warning information into household action. The first significant finding is that the quality of perceived warning information influences perceived potential risks of a flood as well as early-action intention. This indicates that useful warning messages perform two functions (Shi *et al.*, 2020). They assist families in understanding the gravity of the threat, and they simplify protective behaviour to plan. Timeliness, clarity, consistency, relevancy of location, practical guidance and updates thus seem to be behavioural aspects of warning effectiveness

and not communication characteristics.

Reliance on sources of warning is also a key component. Its direct influence on early-action intention is a little greater than the maximum influence of the quality of the warning information, and its overall influence on intention is the biggest of the upstream predictors (Chaves-Gonzalez *et al.*, 2022). This implies that households do not solely respond to the content of messages. They also judge the source of information, and whether the source is reliable. In situations where warnings involve homes facing direct expenses or inconvenience, credibility can be particularly significant since they will have to decide whether the threat is worth responding to before the result can be entirely measurable.

Perceived flood risk is a significant predictor of early-action intention as well as mediates the impact of information quality and trust. This finding lends credence to the assumption that warning communication has an effect on behaviour by modifying the endangering perception of the household. But the perception of risk is not the predominant predictor of intention (Mallick *et al.*, 2022). There is a direct coefficient of perceived response

capacity that is stronger as compared to perceived flood risk. This is a substantively important difference. During the lack of trust in the possibility to get supplies, to secure assets, to organize transportation, to find safe locations, or to organize help, households could still realise that they are in serious danger but fail to take that step.

The best correlation among the variables in the model is that of early-action intention and household early action. The path has a medium effect size, which further differentiates it with the other smaller effects in the model. The outcome indicates that intent is the direct behavioural mediator between the perceptions of warning and actual protective behavior. Simultaneously, the mean scores of the household action items are low in comparison with most perception and intention items (Bernard *et al.*, 2022). This trend indicates there is an intention-action gap. The households will be able to identify risk and declare readiness to prepare and face practical obstacles that will limit the implementation.

This interpretation is supported by the considerable indirect and sequential impacts. There is no single path in which the quality of the warning and trust impact household action. Their influences are by way of perception of risk, intention, or both. Action is indirectly influenced by response capacity through intention (Lopez *et al.*, 2020). The process of warning-to-action is thus stratified. Making credible information, meaningful threat appraisal, responsive options that are feasible and sufficient behavioural commitment are key to effective flood preparedness. Enhancing a single aspect is not likely to optimise the household protection in case of vulnerabilities in other areas of the chain. The moderate explanatory power of the model in explaining early-action intention, in contrast to the lower R-squared values of the perceived risk and actual action, also suggests that there are other contextual constraints which the six latent constructs do not fully capture the effect of on household behaviour. This aligns with some of the practical barriers that are part of the questionnaire including transport, access to shelter, financial limitations, property issues, and household coordination (Forsyth *et al.*, 2023).

Implications

There is a definite theoretical implication of the study. It demonstrates that a more effective way to conceptualize household flood response is as a staged behavioural process, rather than merely being linked to receipt of warning. The quality of information and the trustworthiness of the source influence the interpretation of risks and intention, whereas the response capacity plays a independent role in intention (Samansiri *et al.*, 2023). The intention to take early action is then the nearest predictor of reported action. The considerable chain indirect impact also proves that communication and behaviour are interrelated via various psychological processes.

To practice, message should be prioritised by warning agencies to be early and focused locally, consistent across

channels, updated as conditions changed and explicit about what households are advised to do. The credibility is to be enhanced by the use of recognised sources and coordination between the official agencies and the local administration, community volunteers and trusted local networks. Measures that enhance capacity to respond should also be accompanied by warning programmes (Mondal *et al.*, 2020). They can include evacuation assistance, available shelter details, transportation, preparedness advice, document and asset security, and specific care of households with children, elderly individuals, individuals with disabilities, or individuals with chronic ailments. The comparatively less reported level of household action implies that the enhancement of communication should be complemented by viable assistance. The aim must not be to simply raise consciousness of the risk of flood in households, but to ensure early protective action is a possibility.

Limitations and Future Research

The interpretation should be limited by a few factors. The cross-sectional design indicates statistically significant relationships, but does not demonstrate temporal causality. The scales are based on self-reporting of the household and can hence be biased in recollection or response (Perera *et al.*, 2020). The model also embodies the chosen perceptual and behavioural processes as opposed to the structural constraints that have to influence flood response. Longitudinal studies, comparisons of warning episodes in different flood seasons, and integration of household surveys and administrative or behavioural data can be employed in future studies. Further analyses may investigate how the occurrence of past floods, income, vulnerability, and access to shelters precondition the intention-action gap. It is also possible that future research can investigate whether the same pathway of actions works differently in the villages, char communities, and municipalities. Multi-group analysis could indicate whether vulnerable household composition or distance to rivers alters the strength of relationships among key warning-to-action. Replication in other prone areas would also assist to ascertain whether the framework will be stable across various institutional and environmental settings outside and within Bangladesh.

CONCLUSION

This article looked at the process of transition in the households of the northwestern region of Bangladesh, between receiving flood early-warning information and protective action. The PLS-SEM findings confirm all the seven initial hypotheses and demonstrate that warning information quality, trust, perceived flood risk, perceived response capacity have an impact on early-action intention. In its turn, intention is directly correlated with household early action the most. There are important indirect effects showing that quality of warnings and trust can affect behaviour via risk appraisal and intention, and response capacity can affect action via intention.

The results indicate that successful early warning does not occur whenever a message has been conveyed. To be understandable, credible, relevant and actionable, a warning should have the capability of response by the households. The gap in the comparatively positive intention scores and lower action scores observed also indicates that willingness might not be sufficient to balance practical constraints. Communication quality and trust building, preparedness capability and operational support then should be incorporated as part of flood risk reduction strategies. This strategy has the potential to support the last connection between early warning and early action and enhance resilience of households prior to increasing impacts of floods.

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