

Exploring the moderating role of climate services on flood resilience: Insights from Chinese SMEs

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ABSTRACT

Small and medium enterprises (SMEs) play a vital role in world economic growth and employment creation, but climate hazards especially floods have become a core risk compromising their production systems, and derailing supply chains. Flood resilience is essential to cater negative effects on SMEs as it protects business assets, minimizes operational disruptions, and ensure quicker recovery. Climate services can assist SMEs in their effort to become flood resilient, as long as services are planned and are according to SME needs. Therefore, this study investigated the moderating effect of climate services on the relationships between six key determinants financial capacity, awareness and risk perception, government support and policy environment, technological capability and innovation, location and exposure, social networks and partnerships, and the flood-resilience of SMEs. The data were collected from 250 SMEs using multistage stratified random sampling technique from three Chinese provinces through face-to-face surveys. The collected data were analyzed using partial least squares structural equation model. The findings showed that more financial capacity, greater awareness and perceived risk associated with floods, innovative and technological capability, and strong social networks and partnerships may facilitate flood resilience of SMEs. The findings revealed that climate services significantly moderate the relationship between awareness and risk perception, government support and policy environment, technological capability and innovation, location and exposure, social networks and partnerships and flood resilience outcomes of SMEs. These findings underscore the critical role of climate services in strengthening SMEs flood resilience and provide a robust framework for integrating climate information into SME disaster-risk management.

Practical implications

The empirical findings demonstrate that climate services function as a critical enabling mechanism that strengthens how internal capacities and external support translate into flood resilience among SMEs. Building on the significant interaction effects identified in the analysis, an integrated policy framework is proposed to operationalize climate services as a core component of SME flood-risk management. First, the significant moderating effect of CLS on the relationship between awareness and risk perception and flood resilience highlights the need for climate-service-driven preparedness. Risk awareness alone is insufficient unless SMEs

receive timely, credible, and actionable information. Governments and meteorological agencies should therefore institutionalize SME-targeted flood early warning systems that translate probabilistic forecasts into clear operational guidance, such as asset protection, inventory relocation, and production rescheduling. To ensure effectiveness and accountability, at least 90% of SMEs located in flood-prone areas should receive warning messages via SMS or digital platforms within 30 min of issuance, while at least 70% of SMEs should demonstrate an adequate understanding of warning content and recommended actions, as measured through periodic surveys.

Second, the significant interaction between climate services and the government support and policy environment underscores that public support mechanisms are most effective when aligned with

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climate information. Financial incentives, emergency grants, tax rebates, and recovery packages should be explicitly linked to real-time and seasonal flood risk information, enabling SMEs to time their investment and preparedness decisions accurately. Climate advisories should be embedded within public SME support portals and concessional loan schemes to reduce informational asymmetries and improve uptake. As a monitoring benchmark, at least 80% of flood-related SME support programs should integrate climate risk triggers or seasonal forecasts, and no less than 60% of beneficiary SMEs should receive climate advisory support alongside financial assistance. These measures would allow governments to assess whether policy instruments are being used proactively rather than reactively.

Third, the moderating role of climate services on the relationship between technological capability and innovation and flood resilience indicates that digital and technological investments generate higher resilience returns when combined with climate information. Policymakers should therefore promote climate-enabled digital tools, including mobile warning applications, real-time monitoring dashboards, and low-cost sensor technologies tailored to SME operations. Public-private partnerships and innovation hubs can play a central role in facilitating access to these technologies. To track progress, at least 50% of SMEs in high-risk flood zones should adopt at least one climate-enabled digital tool within five years, and SMEs using such tools should experience at least a 40% reduction in reported operational downtime following flood events, compared to non-adopters.

Fourth, the significant interaction between climate services and location and exposure confirms that climate services convert geographic vulnerability into proactive adaptation when information is localized and frequent. SMEs operating in low-lying or flood-exposed areas require hyper-local forecasts, impact-based warnings, and regularly updated flood risk maps to make timely decisions. Meteorological agencies, in collaboration with local governments, should prioritize industrial clusters and SME dense floodplains in the provision of location-specific climate services. In terms of measurable outcomes, at least 95% of SMEs in designated high-risk zones should be covered by localized flood forecasting and early warning systems, and flood risk maps for these zones should be updated annually. Over the medium term, these measures should contribute to a minimum 30% reduction in asset losses among SMEs located in highly exposed areas.

Finally, the significant moderating effect of climate services on the relationship between social networks and partnerships and flood resilience highlights the importance of collective and trusted dissemination channels. Business associations, chambers of commerce, and SME networks should be formally integrated into national and local climate service delivery systems, serving as intermediaries that translate warnings into sector-specific guidance and coordinate collective preparedness actions. Governments should support these networks through training and certification programs. As a monitoring target, at least 70% of SME associations in flood-prone regions should be trained as authorized climate service dissemination partners, and at least 60% of SMEs should receive climate warnings and advisories through both official and network-based channels. Increased collaboration within these networks should also lead to a measurable rise in joint preparedness initiatives, such as shared storage or pooled logistics arrangements.

Overall, this consolidated policy framework positions climate services as a systemic enabler that strengthens the effectiveness of awareness, policy support, technology, spatial planning, and social collaboration in enhancing SME flood resilience. The inclusion of clear, quantifiable targets allows policymakers and implementing agencies to monitor coverage, responsiveness, adoption, and impact, thereby ensuring that climate-service-based interventions deliver measurable and sustained resilience outcomes.

Introduction

Climate change has become a core economic risk, compromising production systems, and derailing supply chains. Climate hazards have both direct and indirect effects on production systems. The direct effect includes damage to physical infrastructure and indirect effects includes loss due to supply-chain disruptions and decreased labor productivity (IPCC, 2022). The frequency and intensity of climate hazards is increasing every year (WMO, 2024). Climate hazards can also significantly slow down GDP growth, and worsen inequality without adaptation (UNEP, 2024; Abbass, 2022).

Climate change adaptation includes the adjustments in practice, processes, and structures to minimize vulnerability (IPCC, 2022). Adaptation can range from hard infrastructural development (e.g., flood resilient facilities) to soft procedural measures (e.g. contingency planning, information systems, organizational change). Nevertheless, adaptation can be costly and situation-specific: it needs actionable, timely, and relevant information regarding climate risks, exposure, and vulnerability at spatial and temporal scales in line with decision intervals (Bremer et al., 2019). Climate services refer to the generation, translation, and value addition of climate and weather information into specific applications to address the demands of particular users (Vincent et al., 2018). The literature is rapidly emphasizing the importance of the user-driven design and co-production processes. This makes the value of climate services meaningful to users in terms of the decisions they need to make keeping in view their capacity, and timing (SEI, 2024; Jacob, 2025).

The small and medium enterprise (SMEs) are the backbone of the world economy. They play central role in world economy, value chains and innovations (Alam et al., 2022; Tautiva et al., 2025). The SMEs support industrial clusters and local labor markets (Gao et al., 2024). However, due to limited liquidity, lower managerial capacity and access to technical advisory services, SMEs are generally prone to climate vulnerabilities (ASAP, 2023). These limitations imply that SMEs can more frequently encounter problems to adaptation actions than larger firms. Moreover, their ability to absorb climate shocks is an essential factor that can determine economic resilience.

Therefore, climate change and SMEs are a nexus of vulnerability and opportunity. Climate hazards can be both a stressor and an innovation stimulus. SMEs predicting climate risk can reorganize resources, invest in green technologies, or change their operations (Zhang and Bao, 2025; Wang and Liu, 2024). The success of SMEs heavily relies on two factors: (1) access to timely and relevant information, and (2) the establishment of enabling support mechanisms. Thus, climate services can assist SMEs in their effort to climate change adaptation, as long as services are planned and are according to the needs of SMEs (Opitz-Stapleton et al. 2021; SEI, 2024).

Climate services can benefit SMEs in several ways. First, short-term weather predictions and early warnings allow changing operations and protecting assets to prevent instant disruptions (Fejes and Katits, 2025; Pescaroli et al. 2025). Secondly, the inventory management, and input-procurement can use the seasonal and sub-seasonal forecasts. Third, longer-term weather forecasts and risk analysis are used to assist firms in making investment choices (Goddard et al., 2010). Fourth, climate-related financial instruments can help lower the cost of capital on investments and improve the access of SMEs to risk transfer tools (UNEP, 2024; Tautiva et al., 2025) leading to their higher flood resilience capacity (FRC).

Despite the fact that climate hazards, such as floods, are a huge challenge to SMEs business continuity. The current literature extensively focuses on how SMEs handle flood risk and build resilience, considering structural and non-structural strategies. For example, Ingirige and Wedawatta (2018) adopted a structural and organizational approach to examine SMEs flood resilience. They highlighted the importance of preparedness for tackling flood impacts to maintain their operational activities. Moreover, the review on flash floods and SMEs

indicates that resource constraints and preparedness affect the flood resilience capacity of SMEs and exhibit the need to explore other factors affecting the flood resilience of small businesses (Skouloudis et al., 2020). Similarly, Skouloudis et al. (2023) investigated the flooding experiences of micro and SMEs and examined their adoption of coping strategies; however, they did not model the other factors affecting their resilience.

Although earlier studies present the basics for understanding the resilience mechanism and flood impact of SMEs, they do not present how climate services interact with the capabilities of SMEs to improve flood resilience capacity. Therefore, there is little empirical literature on how the internal capacity of firms and external support are transformed into successful flood resilience (Pham et al., 2025; UNFCCC, 2022). Majority of the literature has focused on the direct effects of financial ability, technological advancement, government assistance, and social networks on flood resilience (Imran et al., 2019; CSIS, 2023). However, the moderating role of climate services in enhancing SMEs flood resilience remains underexplored (IDB, 2021). Moreover, the current literature on flood resilience predominantly focuses on large listed and agricultural enterprises, ignoring SMEs. In addition, awareness, risk perception, and location exposure have been influential factors in the flood resilience of SMEs (Kang et al., 2021). No study has guided policymakers on how access to and use of credible climate services moderate such perceptions and capacities into tangible flood-resilient measures (Climate Adaptation Platform, 2022).

Hence, this study intends to fill this literature gap regarding the moderating effects of climate services on the relationship between financial capacity, awareness and risk perception, government support and policy environment, technological capability and innovation, location and exposure, social networks and partnerships, and flood resilience in Chinese SMEs. Therefore, this study is novel in examining the moderating role of climate services in the relationship between all these crucial determinants of SMEs flood resilience. Moreover, this study integrates the in a single framework, which provides important insights into understanding SMEs internal and external aspects to improve their resilience.

Addressing this gap will advance the existing body of research on SME flood resilience. Moreover, it will show how climate services can be used as an intermediary between internal capacities and climate-resilient behaviors to help vulnerable economies develop more inclusive business strategies. Addressing this research gap, this study clearly conceptualizes the moderating role of climate services, which highlights the conditions of SMEs and how they effectively translate their capacity into more effective flood resilience.

SMEs importance in Chinese economy

SMEs are the cornerstone of the Chinese economic system and one of the primary forces which made it the 2nd largest world economy. SMEs are critical in ensuring the economic growth, provision of employment, stimulating innovations, and advancement of regional equilibrium in China (Xuelei and Bhaumik, 2024). This input is deeply rooted in China long-term development policies which emphasize on sustainable growth (UNDP China, 2024; World Bank, 2025). SMEs represent approximately 98 percent of the total number of registered businesses in China. They also account for approximately 60 percent national GDP. They control more than 70 percent of technological innovation and supply approximately 80 percent of urban jobs (Yang, 2025; ESCAP, 2025). This depicts that they are indispensable in sustaining the socio-economic stability of the country (OECD, 2024; UNDP China, 2024). SMEs are involved in all leading sectors: manufacturing, services, trade, ICT and agriculture. However, they are significantly important in industrial clusters of the regions, as they constitute the main part of local economies. In such regions, large enterprises rely on SMEs as suppliers and service providers (EU SME Centre, 2025).

One of the most evident and effective contributions of the SMEs is

their employment role in the country. It is estimated that SMEs offer 4 out of 5 employment opportunities in urban regions (National Bureau of Statistics of China, 2024). This is particularly relevant in the light of the ongoing economic change in China. Where traditional heavy industries are becoming stagnant in growth, while growth of the service sector, the digital economy, and the green industries is expanding (Ding and Ouyang, 2025; Min et al. 2020). Thus, SMEs are critical to maintain employment and stabilize the levels of income in the country (Algan, 2019). Besides the creation of employment, SMEs play a significant role in financial wellbeing and productivity of the country. They also produce almost 50 percent of the total tax revenue and approximately two-thirds of industrial production (EU SME Centre, 2025). Their operations provoke local consumption, supply chain interconnection and diffusion of innovation (OECD, 2024). The further feature of the Chinese SMEs is the increase in their involvement into technological advancement and upgrading of industry. These are small but highly technical firms that are at the center of strategic sectors. There are over 12,000 recognized small firms in China and they are projected to reach more than 15,000 by 2026 (MIIT, 2024). The SMEs are also becoming the important agents of the digital and green transitions in China (ACE Vision, 2023). SMEs are implementing digital tools and greener business models in order to stay competitive (Putri et al. 2025; Huang et al. 2024).

Hypotheses development

Flood resilience indicates how a firm can prepare for floods, absorb and recover from their impacts, and adapt to flood events (Endendijk et al., 2024). In the context of SMEs, this indicates how well a firm anticipates, withstands, and recovers from flood impacts. Financial capacity plays fundamental role in flood resilience of SMEs (Skouloudis et al. 2023). Moreover, SMEs can improve their capacity to counter future flood risks. Majority of SMEs are not in a position to adapt to the structure such as strengthening of their physical infrastructure (Skouloudis et al. 2020). Firms with fewer financial means lose significantly more revenue after flooding showing that preparedness and recovery are hindered by the lack of liquidity (World Bank, 2024). Such financial limitations are further exacerbated by the reality that the flood resilience finance rarely flows to SMEs. The large enterprises get the majority of the national and international adaptation funds than SMEs (Schaer and Kuruppu, 2018; Hankinson and Surminski, 2018). Musah-Surugu et al. (2024) showed that greater climate resilience finance significantly reduces climate vulnerability. Lipper et al. (2021) also stated that adaptation investments are crucial for climate resilience and significantly contribute flood resilience capacity. They also highlight the importance of aligning finance with adaptive capacity.

Local seasonal forecasts, flood hazard maps, and real-time early warning systems that form part of climate services can be critical moderating factors between financial capacity and flood resilience. Climate services prevent the perceived risk and de-risk flood resilience investment (Fernández-Nóvoa et al. 2024). Having more accurate data on forecasts, SMEs and financiers will be able to make more prudent decisions. Financial institutions can also use such information to tailor specific programs to the SMEs that are vulnerable to flood risks (Skouloudis et al. 2020). By doing so, climate services decrease the informational asymmetries between lenders and SMEs. Therefore, we hypothesize that:

H1: There is a positive relationship between SMEs financial capacity and flood resilience and this relationship is moderated by climate services.

The knowledge about the flood risk is important factor in climate change resilience (Linh and Bleys, 2024). The enterprises that view flooding as a critical risk tend to take preparedness measures more than those which do not consider it risk for their business (Skouloudis et al. 2020). Nevertheless, perception itself is not sufficient to act: research has also indicated that in the absence of trustworthy, actionable information, high-risk perception may be held abstractly and will not result

in flood resilience (Sawada et al. 2021). Ferdushi et al. (2019) stated knowledge and perception of climate change is an influential factor in flood residence of enterprises. Similarly, Kabir et al. (2016) found that knowledge and perception of climate change increase flood resilience.

Perceived risk can be transformed into practical and timely decisions by use of early warning systems, probabilistic forecasts, and sector-specific advice (Hammood et al., 2021). Risk of high floods is forecasted via a hydrometeorological system that enables the managers of enterprises to take precautionary measures (Fernandez-Novoa et al. 2024). The systematic reviews of flood early-warning and response systems underline the importance of co-production of warnings and stakeholders to increase flood resilience (Hammood et al., 2021). In addition, it is demonstrated in social models of trust that false alarms can impair long-term responsiveness. Similarly, credible and true warnings consistent with the experience of the users reinforce resilient behavior (Sawada et al., 2021). Thus, climate services are not just information but they make risk perceptions operative. We assume that:

H2: The awareness and risk perception has a positive impact on SMEs flood resilience and climate services moderate this relationship.

This institutional and governmental support, in the form of subsidies, grants and regulation and technical assistance is necessary for flood resilience of SMEs (Crick et al. 2018). The success of these policy tools mostly relies on their correlation with the scientific and forecast-based information on climate. The incentives provided by the government cannot correspond to the current state of hazards without the inclusion of climate information (Skouloudis et al. 2020). The risk perception is constrained by the unavailability of locally relevant climate information, which limits the impact of the policy measures (Darlington et al. 2024). Pu et al. (2021) stated that government support plays a vital role SMEs climate change resilience.

Governments can use climate data and seasonal predictions to create financial incentive programs for enterprises (Fernández-Novoa et al., 2024). In addition, timely alerts built into policy structures may improve the outreach efficiency. Therefore, climate services can serve as an important conduit and we hypothesize that.

H3: There is significant positive relationship between SMEs flood resilience and government support and policy environment and this relationship is moderated by climate services.

SME resilience revolves around technological capability such as the application of early warning applications, real-time surveillance systems, and resilient physical assets. It has been found that SMEs with digital tools may continue functioning throughout and even after floods (Carayannis et al., 2025; Koporcic et al. 2025). In the meantime, innovation helps enterprises to rearrange logistics, storage, or supply chains to shorten recovery time (Siagian et al., 2021). Government supports can assist in technology adoption, and SMEs' economic sustainability. Zella et al. (2023) found that innovation helps entrepreneurs to tackle climate risk. They further argued that ICT-based innovations improve decision-making and reduce flood vulnerability.

Climate services may facilitate the usefulness of technology by providing the information that is acted upon by these tools. The digital platforms (IoT, dashboards, mobile warnings) are fed with forecasts, risk maps, and real-time hydrometeorological information, allowing the SMEs to enable operational decisions based on climate data (Fernández-Nóvoa et al., 2024). Even with warnings, firms must be technologically prepared to be able to receive and respond to them (Hammood et al., 2021). We suppose that:

H4: Technological capability and innovation have a positive effect on flood resilience and climate services moderate this relationship.

The geographic location of SMEs and its susceptibility to floods is one of the core contributors to climate change resilience (Tabasi et al., 2025). Firms that are situated in the low-lying areas, and close to rivers experience more frequent and severe floods (Shrestha et al. 2023; Mashwama and Phesa, 2025). Exposure does not always necessarily lead to flood resilience. Even highly exposed firms fail to invest in flood resilience properly because of a poor risk awareness, and resource

limitations (Zhao et al. 2025). Munyai et al. (2021) stated that settlements in low-lying, and river-proximate face higher exposure. They link this exposure with the communities' resilience strategies. Climate services bridge the gap between exposure and FRC by transforming fixed risk into dynamic and practical intelligence. We hypothesize that:

H5: Location and flood exposure has a positive effect on flood resilience and this relationship is moderated by climate services.

The social networks such as business associations, relationships with suppliers, the community partnership, and peer firms are vital in SMEs flood resilience (Asamoah et al., 2020). These networks enable firms to share knowledge and pool resources, as well as organize flood resilient strategies (Nikolaou et al., 2020). SMEs that are integrated into robust local business network are likely to have greater flood resilience ability (Revilla Diez et al. 2024). Braunschweiger et al. (2022) argued that cross collaboration is necessary for enhancing climate change resilience.

Climate services are not just a source of information in this regard: it acts as a bridge to network-based SME resilience. In a situation where forecasts are spread with the help of credible networks, the benefits will be greater than top-down dissemination (Hammood et al., 2021). Trade and business associations are able to turn a flood warning into industry-specific guidelines (Sawada et al., 2021). Therefore, we assume that:

H6: Social networks and partnerships have a positive effect on flood resilience and this association is moderated by climate services.

Grounded in the Theory of Planned Behavior (TPB), climate services have the ability to facilitate the resilience of SMEs to flooding by improving their perceived behavioral control and influencing positive attitudes toward adaptive behavior. Through timely, credible and localized flood predictions, CLS may reduce uncertainty and increase confidence in decision-making. Thus, allowing SMEs to transform awareness, government support, technological capacity, location exposure and social networks into resilience practices. In this respect, climate services are seen as a contextual facilitator, which can moderate the behavioral influence of internal and external support on flood resilience outcomes.

Materials and methods

Study area selection and data collection procedure

This study used a multistage stratified random sampling technique to select SMEs from three Chinese provinces (Guangdong, Jiangsu, and Shandong). These provinces have a substantial share in national SMEs output, employment, and industrial activity. Stratified sampling was used to select samples to enhance representativeness because of the existence of heterogeneity in SMEs across sectors and firm sizes. Stratification was implemented at two levels in each province: (1) industry sector, and (2) firm size. In industrial-level stratification, SMEs were stratified based on manufacturing, services, trade/wholesale, ICT, and agriculture-related SMEs. Firm size stratification was based on China's SME classification criteria (micro, small, and medium enterprises). Thus, 100 SMEs from Guangdong, 80 from Jiangsu, and 70 from Shandong were chosen for data collection based on each province's SME population share. The sample reflected the relative size and economic weight of SMEs in all provinces. Furthermore, proportional allocation across industry sectors was performed to obtain a representative sample of SMEs in all sectors.

Data were collected through a semi-structured face-to-face survey with the owners or senior representatives of the selected SMEs. Before beginning the final survey, the research team coordinated with local chambers of commerce, industrial park administrations and municipal SME services. Enumerators, consisting of both male and female members, visited each enterprise at its registered business location. They explained the purpose of the study and obtained informed verbal consent before beginning the survey. A two-day training program was arranged for the enumerators for data collection to ensure consistency and accuracy in data collection. Each interview lasted approximately 20–25

min. Wherever owners/senior managers were unavailable, a revisit was planned within the same week to avoid replacement of the respondents. Non-response bias was analyzed using the early late respondent comparison method. According to this method, the respondents were grouped into two categories, early and late respondents, according to the timing of the survey responses (Armstrong and Overton, 1977). The mean difference was measured for key constructs and then compared between the two groups. The findings of this comparison of early and late respondents indicated no significant difference in the mean of the constructs. Therefore, this implies that non-response bias is not a serious concern in the current study. Thus, data from 250 SMEs were collected for further analysis.

The guidelines for partial least squares structural equation modeling (PLS-SEM) were used to assess sample size adequacy. The 10-time rule was used to ensure the adequacy of sample size. According to this rule, the sample size must be ten times the number of structural paths from all constructs. Therefore, there are six constructs directly affecting SMEs FLC, one moderator CLS, and six interaction path arrows. A total of 13 path arrows required a minimum sample size of 130. The sample size of the current study, 250 SMEs exceeds 130, which confirms sample size adequacy. Moreover, there is not a single construct with fewer than three, which also fulfills the minimum measurement requirement of indicators to measure a construct. This confirms the reliability and validity of the constructs in the PLS-SEM.

Survey questionnaire design

Data were collected using a semi-structured questionnaire developed for SMEs prone to flood-related risks in China. The survey questionnaire consisted of multiple sections that measured both independent and dependent variables. The independent variables consisted of seven constructs: (1) financial capacity, (2) awareness and risk perception, (3) government support and policy environment, (4) technological capability and innovation, (5) location and exposure, (6) social networks and partnerships, and (7) access to and use of climate services. Each of these constructs was assessed using three to five items measured on 5-point Likert scale questions. The CLS is a multidimensional concept that generally focuses on forecasting, advisory services, early warning, and information sharing. These CLS elements are frequently operationalized as a single composite construct. This indicates how users integrate climate information to make effective decisions rather than considering its sub-dimensions separately. Moreover, users of CLS generally consider early guidance, warning, forecasting, and trust in climate information as an integrated information environment rather than as separate services. This study considers CLS as a unidimensional variable that reflects timely forecasts and warnings, clear and actionable guidance, access to and understanding of climate information, and trust in the early warning system. Therefore, this approach is appropriate for investigating CLS as a moderator in improving SMEs FLC rather than focusing on individual components of CLS. The detail of each construct and their indicators is provided in [supplementary material S1](#) prepared by taking insights from the previous relevant literature.

The survey questionnaire was validated using a two-step process. First, the survey questionnaire was validated by subject specialists to accurately convey the intended meaning of each statement. Second, the questionnaire was validated through pre-testing with 20 SMEs to ensure the reliability and validity of the final survey questionnaire. The data collected during pre-testing were not used in the final analysis because of changes in the survey questionnaire.

Methods

Partial least square structural equation model (PLS-SEM) was used to analyze the collected data. This method has the advantage of performing factor analysis and path analysis together. Moreover, SEM is very suitable when various latent variables (constructs) are analyzed

simultaneously. SEM also uses different econometric techniques, such as analysis of variance and regression, along with factor and path analysis (Byrne and Stewart, 2006). Moreover, in social science, SEM is widely recognized for its suitability in examining the complex relationships among various latent variables (Kline, 2023).

Before proceeding to the PLS-SEM, the common method bias was assessed. For this purpose, Harman's single-factor test was used by conducting an unrotated exploratory factor analysis considering all items. The findings indicate that the first factor accounted for only 39.52% of the total variance, which is substantially lower than the threshold level (=50%), implying that there is no single factor dominating the data. The other method used to assess common method bias was the collinearity VIF for all the constructs of the study. The estimated scores of VIF for all constructs were in the range of 1.371 to 2.368, which also confirms that there is no problem of collinearity or method bias. Moreover, we applied the unmeasured latent method construct (Latent CMV approach), after adding a latent method factor to the analysis and estimating the path coefficients. The changes in the path coefficients were calculated with and without the latent method factor. The findings do not depict the change in the beta coefficients of all latent variables and their significance levels. This confirms that CMB is not an issue.

After ensuring that there were no issues with common method bias, the final analysis was conducted. This study applied the reflective specification method to measure all constructs. According to this method, it was assumed that all items or indicators reflected the underlying latent variables. Therefore, this method is more suitable for measuring perceptual constructs (Hair et al., 2019; Hair et al., 2021). Moreover, the SMEs FRC is measured based on perception, because the respondents respond to all items according to their self-assessment of their firm's ability to cope with floods. FLC considers structural, financial, organizational, and technological measures, and all these items are considered perceptual rather than externally verified outcomes. Moreover, this approach is more acceptable in the case of non-availability of data on the performance of SMEs after floods.

Four items were considered to measure the CLS construct. These four items capture the perception of SMEs of early warning services and the accessibility, clarity, timeliness, and trustworthiness of information regarding floods. These four items included the following: 1) Timely climate and hydro meteorological forecasts/warnings helped us prepare for recent flood events; 2) Local authorities shared clear, actionable flood guidance (what to do) based on climate information before or during the flood; 3) Climate services (forecasts, warnings, advisories) were accessible and understandable in the affected area; and 4) Climate services (forecasts, warnings, advisories) were accessible and understandable in the affected area, combined by using a single, first-order reflective construct. The second-order factor structure is not necessary for measuring the CLS construct because no separate subdimensions were considered in this study. Moreover, all validity measurements, such as factor loading, average variance explained, and composite reliability, confirm the construct validity and reliability of the CLS.

Before proceeding to the path analysis, the validity of the measurement model was assessed. Convergent and discriminant validity must be confirmed. Convergent validity (CV) shows that the items in each construct are highly correlated with each other. Factor loadings (FL) were used to assess the magnitude of the relationship between each item and its construct. The value of FL remains in the range of 0 and 1. A high FL indicates a reliable and strong relationship between a construct and its items. Moreover, the FL values for each item under a specific construct must surpass the threshold level of 0.70 (Cheung and Rensvold, 2002; Su et al., 2023).

Cronbach's alpha was used to assess internal consistency of each item. Cronbach's alpha indicates the strength of correlation among items within a specific construct. Cronbach's alpha's value greater than 0.70 depicts the internal consistency a construct. Composite reliability (CR) is also widely used to assess the internal consistency of each construct. A value greater than 0.60 shows CR of a construct (Zhang

et al. 2024). The threshold level of average variance explained (AVE) must surpass 0.50. All the findings show CV of each construct.

Discriminant validity (DV) of each construct was estimated after confirming CV. DV indicates that the measured construct is unique from all other constructs. Two different methods were used to test the independence of each construct. First, the Fornell-Larcker criteria (FLC) and the square root of the AVE value for each construct was measured. The FLC requires that the correlation scores of a particular construct with all other constructs be lower than the square root value of the AVE. The second approach was the heterotrait-monotrait ratio (HTMT), and requires its value lower than 0.90 for DV (Rouf and Akhtaruddin, 2018). Both approaches indicated DV of each construct. The bootstrapping procedure was completed with 500 subsamples, and bias-corrected 95% confidence intervals were used to analyze the significance of all paths.

Measurement model

The measurement model shows that the items under constructs belong to that specific construct. Fig. 1 shows the factor loadings of all items. The red line shows the threshold level (0.70) that each item under a specific construct must surpass to be included in a specific construct. The findings revealed that all items significantly exceeded the threshold level. This also shows the reliability of each construct.

Cronbach’s alpha, shows the internal consistency of the items used to measure a particular construct. Fig. 2a presents the Cronbach’s alpha scores. These scores regarding all constructs exceeded the threshold line (0.70) (Pan et al., 2024), indicating a high correlation between items within a particular construct. Therefore, higher Cronbach’s alpha values confirmed the internal consistency of each construct.

CR is an alternative to Cronbach’s alpha for assessing the internal consistency of each construct. The CR scores must exceed a threshold level of 0.60 (Zhang et al., 2024). The values greater than 0.80 in Fig. 2b indicate that all constructs are internally consistent.

To assess the shared variance of items explained in a particular construct, the AVE scores must exceed the threshold level (=0.50). Fig. 2c shows that the AVE scores for all constructs are greater than 0.50, which indicates that all items explain the variance in a particular construct by more than 50%. It is imperative from these findings that measurement model has a high CV (Fig. 2).

Table 1 shows the HTMT scores in red in the upper diagonal, and the

values in the lower diagonal are the correlation scores. In the diagonal line, bold values indicate the square root of the AVE scores. Based on the findings in, the correlation scores of a particular construct with all other constructs were lower than the square root values of that particular construct. According to the FLC, this confirms that all constructs are unique and independent of each other (Rahman et al., 2021). Red-colored HTMT scores lower than 0.90 (Rouf and Akhtaruddin, 2018) along with FLC confirm the DV of the constructs.

Goodness of fit

The SRMR value was 0.068, which is lower than 0.08, indicating a good model fit. Similarly, the NFI was equal to 0.911, which also surpassed the threshold level of 0.90. This also confirmed that the current study model fit better than the baseline model. The findings of PLS-predict indicate that the items under the flood resilience capacity (FRC) construct secured Q2 (=0.596) greater than 0, which confirmed the strong predictive relevance. Similarly, the PLS-RMSE scores for all items were lower than the LM-RMSE, which also confirmed that the PLS model was more predictive than the linear benchmark model.

Path analysis

The R2 for FRC was 0.695 in Table 2, which was substantially greater than 0.26, indicating the strong predictive capacity of the structural model for FRC. It implies that structural model explains the 69.5% variation in SMEs FRC. The findings revealed that ARP, FNC, LE, SNP, and TCI significantly affected FRC at 5% level of significance, while GSPE influenced FRC at 1% level of significance. This implies that more financial capacity, high awareness and perceived risk associated with floods, innovative and technological capability, and strong social networks and partnerships may facilitate FRC of SMEs. Similarly, the outcomes of the study indicate that government support and effective policies strongly matter in enhancing the FRC of SMEs. The significant coefficient of LE implies that SMEs with a high risk of flooding are more likely to may facilitate their FRC. Therefore, ARP, FNC, GSPE, LE, SNP, and TCI are the most important factors of the flood resilience capacity of SMEs. Considering the f2 values, FNC, GSPE, and LE had medium effect sizes on FRC. TCI had a medium-sized effect on FRC, while ARP and SNP had small-sized effects on the FRC of SEMs. Fig. 3 presents a visual

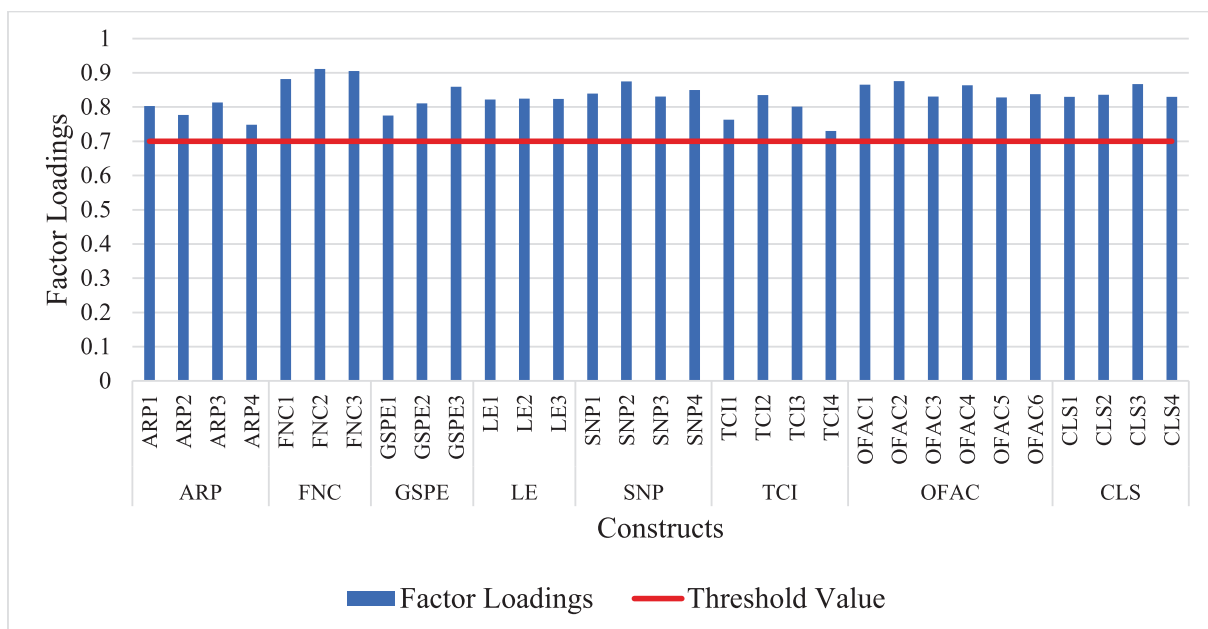


Fig. 1. Factor loadings.

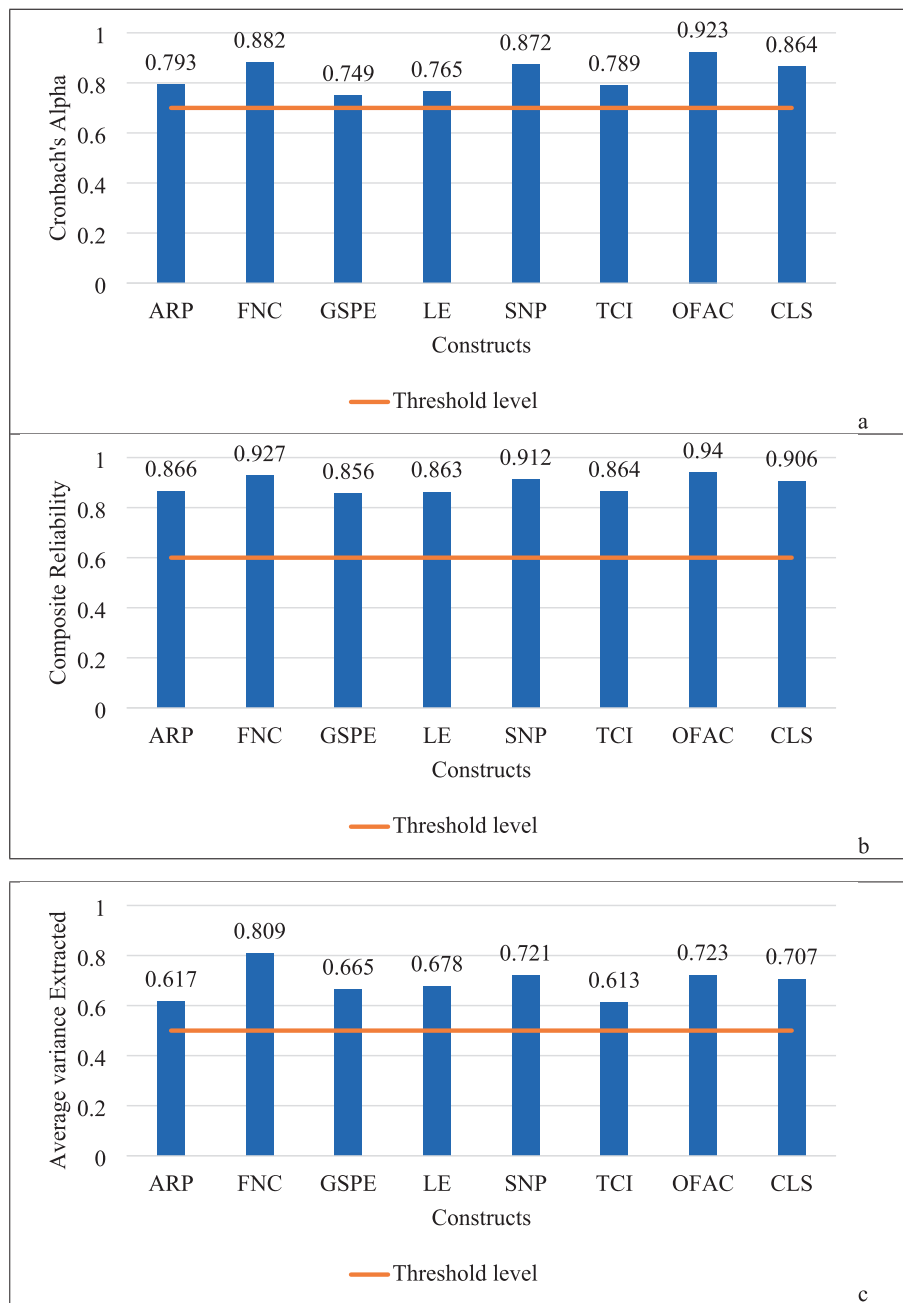


Fig. 2. Cronbach's alpha, composite reliability, and average variance extracted.

Table 1
FLC and HTMT scores.

Constructs	ARP	FNC	GSPE	LE	SNP	TCI	FRC	CLS
ARP	0.786	0.334	0.52	0.232	0.28	0.515	0.529	0.17
FNC	0.282	0.899	0.386	0.31	0.308	0.304	0.424	0.175
GSPE	0.406	0.315	0.816	0.55	0.575	0.67	0.71	0.417
LE	0.183	0.254	0.425	0.823	0.69	0.296	0.538	0.605
SNP	0.232	0.275	0.476	0.836	0.849	0.323	0.546	0.9
TCI	0.41	0.253	0.732	0.231	0.272	0.783	0.733	0.192
FRC	0.455	0.383	0.765	0.46	0.502	0.625	0.85	0.396
CLS	0.138	0.161	0.352	0.84	0.786	0.166	0.366	0.841

representation of the direct path analysis.

Table 3 presents the moderating role of CLS in the relationships between ARP, FNS, GSPE, LE, SNP, TCI, and FRC. The findings reveal that CLS significantly moderates the impact of all variables on FRC,

except for FNC. The positive sign indicates that CLS substantially may facilitate the influence of ARP, GSPE, LE, SNP, and TCI on FRC.

Fig. 4 presents a simple slope analysis of CLS's moderating effect. The upward slope of the simple slope analysis of CLS × ARP shows that

Table 2
Direct path analysis.

Paths	Coefficients	Standard deviation	T statistics	f2
ARP → FRC	0.129**	0.058	2.224	0.157
FNC → FRC	0.108**	0.053	2.038	0.414
GSPE → FRC	0.497*	0.087	5.713	0.436
LE → FRC	0.083**	0.037	2.243	0.365
SNP → FRC	0.100**	0.048	2.083	0.038
TCI → FRC	0.135**	0.058	2.328	0.270

R-square (FRC) = 0.652; R-square adjusted (FRC) = 0.636.
*, ** indicates significance level at 1% and 5% respectively.

ARP’s positive impact on SMEs FRC is stronger at a high CLS level. Similarly, the slope analysis of the moderating impact of CLS on the relationship between LE, SNP, and TCI with FRC indicates an upward slope in Fig. 4c, 4d, and 4e, respectively. This implies that CLS substantially increases the impact of the variables on SMEs FRC. Fig. 4b indicates that GSPE is highly linked to CLS. The downward slope of CLS at -1 SD and the mean indicate that the exposure of SMEs to government support and policy environment at low CLS levels makes SMEs indifferent in improving their FRC. Therefore, the upward slope at +1SD shows that the high level of CLS assists SMEs in understanding the government support and policy environment to build their FRC.

Discussion

Climate change alters weather patterns, which further increases the number of challenges for the business community. Floods are one of the major outcomes of climate change, which majorly influences SMEs owing to the differences in proper resources, policy environment, managerial skills, business location, social involvement, climate services, and technology and innovation. Therefore, these factors determine how strongly internal and external factors support SMEs in enhancing their flood resilience capacity. Therefore, it is crucial to understand how these internal and external factors contribute to the FRC of SMEs. This study aimed to determine how the FRC of SMEs would increase if ARP, FNC, GSPE, LE, SNP, and TCI were favorable. Moreover,

Table 3
Moderating effect of climate services.

Paths	Coefficients	Standard deviation	T statistics
CLS x ARP → FRC	0.098**	0.043	2.28
CLS x FNC → FRC	0.079 ^{NS}	0.048	1.65
CLS x GSPE → FRC	0.169**	0.071	2.38
CLS x LE → FRC	0.074**	0.033	2.24
CLS x SNP → FRC	0.140**	0.060	2.33
CLS x TCI → FRC	0.087**	0.038	2.29

** indicate significant at 5%. NS shows non-significant effect.

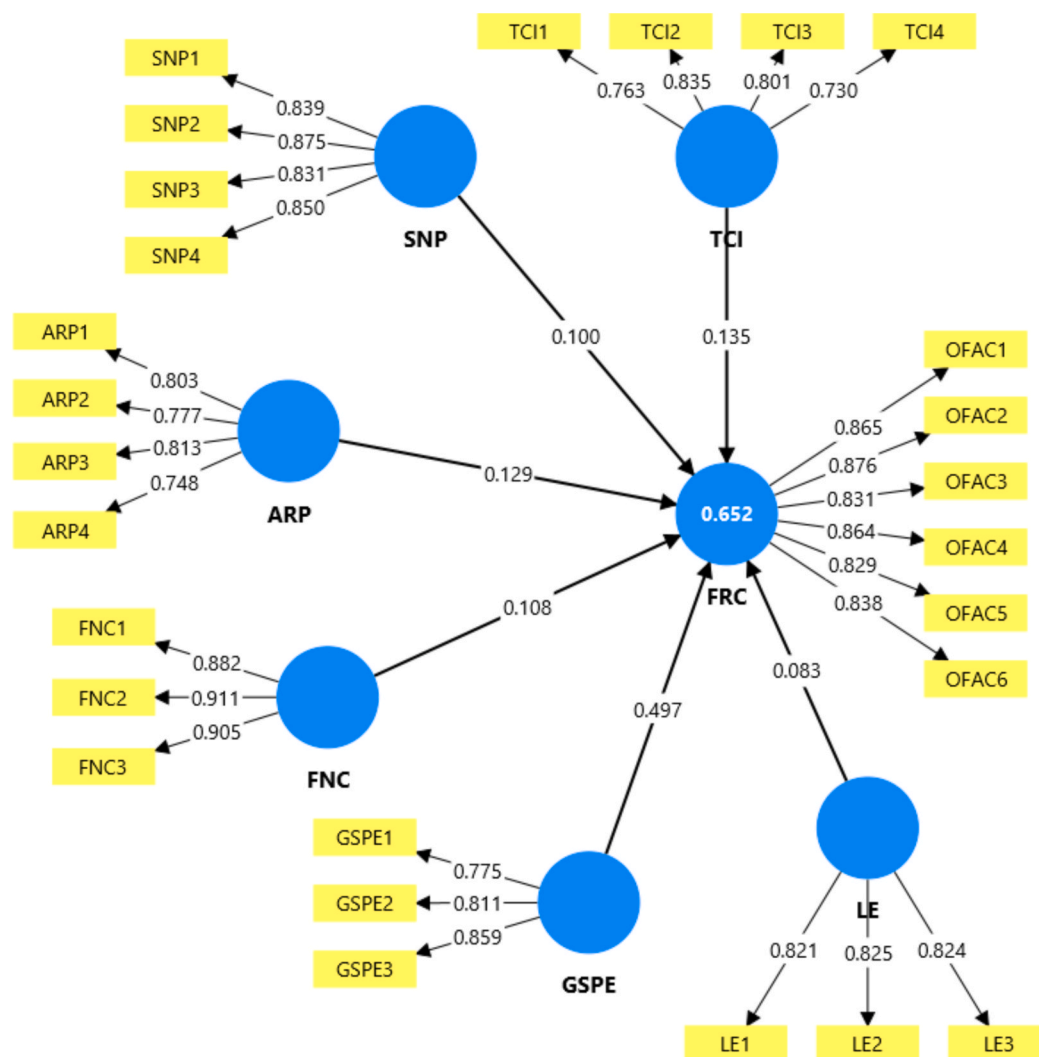


Fig. 3. Graphical visual of path analysis.

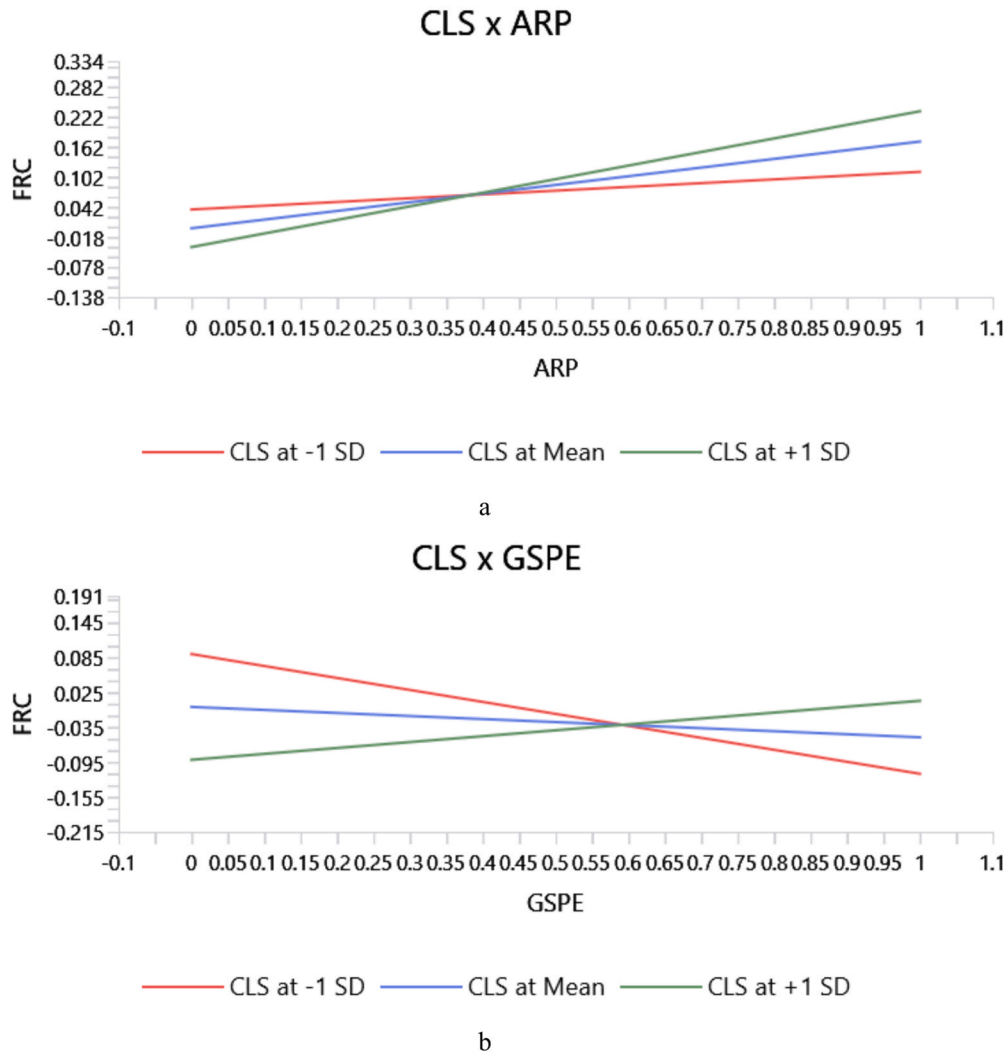


Fig. 4. Simple slope analysis.

this study also focuses on the question of whether CLS significantly moderates the impact of all these variables on SMEs FRC.

The fact that ARP has a significant influence on the FRC of SMEs implies that risk perception and awareness of entrepreneurs are crucial in flood resilience. This means that SMEs with high ARP experience are likely to take proactive initiatives. In situations where businesses face high risks, they use resilience strategies and recover quickly after floods (Didier and Tsan, 2024). Agrawal et al. (2020) showed that risk perception is essential for enhancing community resilience to such disasters. Webb et al. (2002) found that SMEs recovery after extreme external shocks is dependent on the entrepreneurs ARP. These findings are in line with those of Skouloudis et al. (2022), who also found that entrepreneurs ARP is an influential factor in the flood resilience of SMEs. Entrepreneurs ARP assists in contingency plans and mitigation measures, which may facilitate their flood resilience. Asgary et al. (2012) indicated that lack of risk perception negatively affects evacuation plans. Hashim et al. (2021) stated that risk perception is the most critical factor that directly affects a community’s flood preparedness.

The findings demonstrate how FNC has a huge positive impact on flood resilience in SMEs. This indicates that FNC is an important variable in the flood resilience of SMEs. Limited FNC makes organizations to focus on short-term solutions rather than long term flood resilient measures. The funding usually favors bigger firms by the governments at

the expense of the SMEs hence generating inequality in the resilience based on the financial support (UNDP, 2013). Skouloudis et al. (2022) also found similar results on the impact of FNC on the FRC of SMEs. They found out that low FNC extremely diminishes the resilience capacity of SMEs in the flood prone areas. High FNC allows firms to quickly recover and become more resilient to the future floods (Merry and Calderón, 2024).

GSPE also has a significant impact on SMEs flood resilience. This demonstrates that GSPE is vital in increasing the ability of SMEs to cope with disasters of climate change. Pathaka and Ahmad (2018) also established that the government plays a very crucial role in managing natural disasters. They claimed that the bad government policies lead to higher losses because of climate susceptibility. The findings are associated with those of Wen et al. (2025), who found government policies to be comprehensive and efficient to assist SMEs in conquering floods. Taneo et al. (2022) addressed the issue of government in enhancing the strength of the SMEs. They concluded that resilience to floods among SMEs is significantly increased by the assistance of local governments. Moreover, recent studies by Hadi and Supardi (2020) and Ipinnaiye et al. (2017) also stated the role of government policies in stabilizing SMEs in disasters.

The beneficial impact of LE means that location and exposure are key components used in the flood resilience of SMEs. The issues of SMEs in

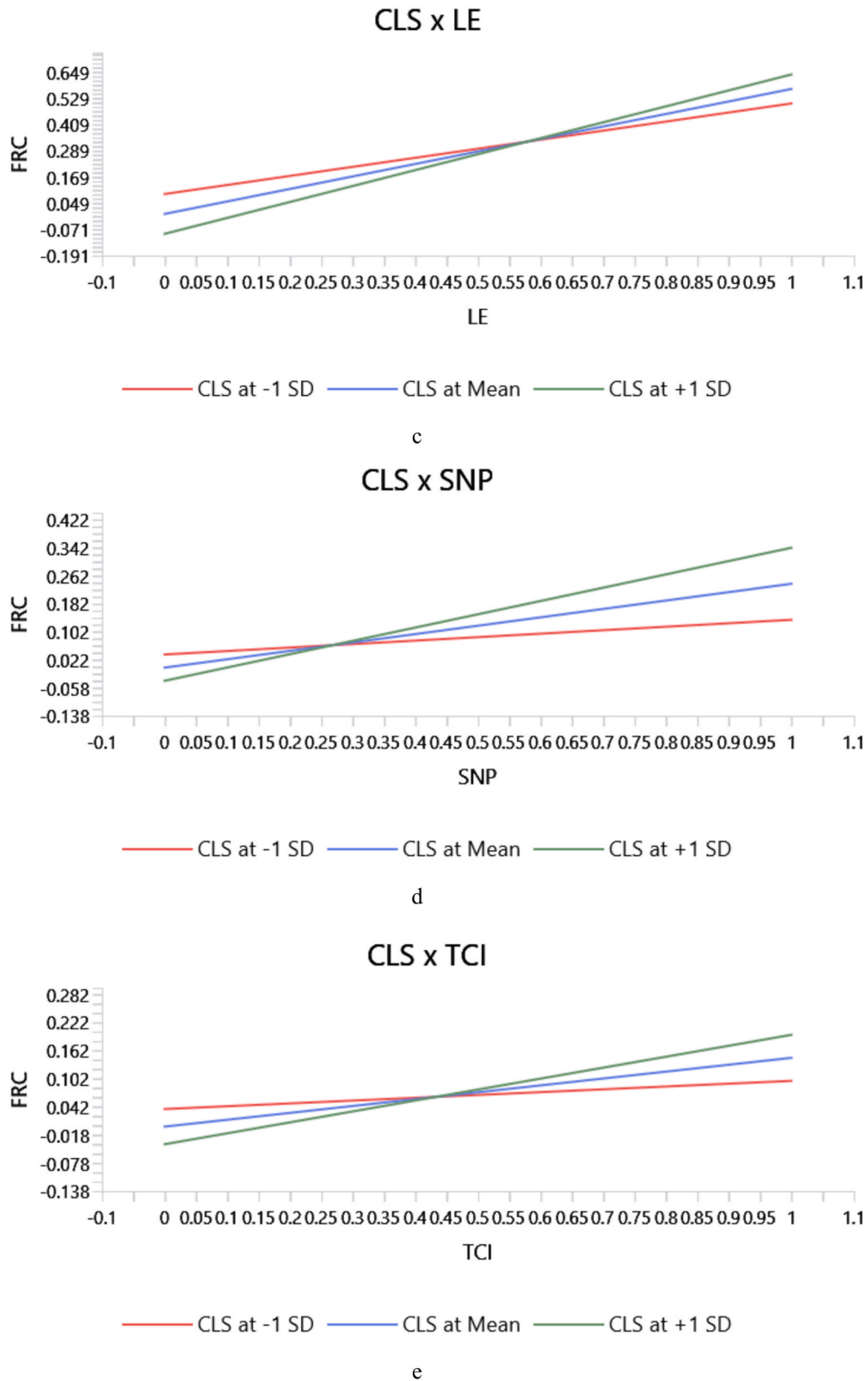


Fig. 4. (continued).

the flood prone areas are unique and they have impact on their flood resilience and recovery capacity. This result is in line with Orhan (2016), who argued that historical exposure to disasters is essential in improving the resilience of businesses. Gilinsky et al. (2020) opined that firms located in the most susceptible areas of calamities are likely to develop

strategic resilience measures. The large exposure to natural disasters makes firms understand their needs and strengthen their operations. According to Ntim-Amo et al. (2022), the firms that experience have higher chances of the floods are likely to take more measures to mitigate the risks of the floods.

The existence of the positive correlation between the SNP and flood resilience is a testament that SMEs social networking improves their flood resilience. The SNP offers a chance to share the resources and expertise and possesses a support network to increase the capacity of resilience. Skouloudis et al. (2022) believed that the best practices and exchange of these practices would enable SMEs to prepare against flood through the pooling in of resources. Therefore, the SNP will make SME collaborate to achieve successful disaster management (Ortiz et al., 2025). Other research results also confirm the validity of these findings by stating that SNP can help improve the resilience capacity of SMEs (Ingirige et al., 2008; Ingirige and Wedawatta, 2018).

The results indicate that technological abilities and innovation are crucial elements in flood-resistance of SMEs. TCI assists in the improvement of infrastructure and creation of information resulting to proactive approach to the management of disasters. As such, TCI does not only help in countering the impacts of floods but also helps SMEs to change their strategies. Ramani et al. (2023) stated that green roofs among infrastructural innovations have a great influence on flood resilience of SMEs. Flood preparedness and responses are also facilitated by the use of TCI. TCI enables the location of safe places and emergency services during floods in SMEs, as well as stated by Saputra et al. (2025) and Ramani et al. (2023).

The CLS helps SMEs to comprehend and adjust to climate risks in flooding. The high degree of CLS moderation between the ARP and FRC of SMEs justifies the intensity of the effect of ARP on the resilience capacity of SMEs propounded by CLS. These climate services help SMEs obtain pertinent information that can help them embrace more robust practices. Consequently, CLS creates awareness of the possible effects of flooding that can affect SMEs to embrace flood resilience. These services supplement the optimization of mitigation methods by providing farmers with viable information (Carr et al., 2020; Fikadu et al., 2024). Hence, CLS facilitates valuable information and resources to may facilitate SMEs resilience competence. The findings of this study also ensure that CLS is a moderator in relation to all other factors, including GSPE, LE, SNP, and TCI, to SMEs FRC. Thus, SMEs can receive timely forecasts, warning updates, and government support via the CLS. Access to this information in good time on the risk of flooding, government provisions, and policy initiatives will ensure that SMEs make proper decisions regarding FRC. Similarly, the association between LE and the FRC of SMEs is facilitated by clear information regarding the climate. When CLS alerts about the danger of floods, SMEs in high-prone regions will be in a position to respond sooner. This enables SMEs to change their strategies at the right time to prevent huge losses. In addition, CLS may facilitate the effect of SNP on SMEs' FRC. Through CLS, climate data are provided to relevant SME stakeholders in a timely manner and with increased speed. They will have access to resources and reduce possible losses with the help of timely warnings. The impact of TCI is also facilitated by CLS, as SMEs with well-developed technology and innovations can incorporate climate data to offer real-time and automatic warnings. In this way, SMEs regulate their production to avoid huge losses. This makes the TCI of SMEs a resilient tool for CLS. Thus, CLS will significantly increase managers' awareness of their daily operations and enable them to make thorough decisions to mitigate the effects of climate change (Van Huynh et al., 2020; Yona et al., 2025).

Conclusion

Floods pose a severe threat to the growth of SMEs, and climate services may assist in building their resilience. Therefore, the current study analyzed data collected from 250 Chinese SMEs. The analysis included various internal and external factors, such as ARP, FNC, GSPE, TCI, LE, and SNP. The findings show that all these factors significantly affect the flood resilience of SMEs. The results related to the moderating effect showed that climate services significantly moderated the relationship between all variables, except FNC, and flood resilience of SMEs. This confirms that high access to and use of climate services may facilitate the

favorable impact of ARP, GSPE, TCI, LE, and SNP on SMEs' flood resilience capacity.

Theoretical implications

This study also contributes theoretically to the existing studies on the flood resilience of SMEs by advancing a contingency based perspective. The behavioral theories support the study findings. For example, protection motivation theory describes how individuals and firms respond to risk according to threat and coping appraisal. In this case, the CLS is a source of information that enhances threat awareness and enables them to operationalize effective coping strategies. This intensifies the effects of FNC, ARP, and TCI. The second theory, which also supports the findings of this study, is the theory of planned behavior. According to this theory, perceived behavioral control and attitude shape actions through intentions. Therefore, CLS strengthens the perceived control over flood risks by providing timely forecasts and guidance in an understandable manner. Moreover, the information-cognitive-action framework also supports the findings of this study. This framework describes that the timely and understandable information provided by CLS enables cognitive processing and informed decision-making. This further improves the resilience actions of SMEs. In particular, it describes how CLS assists SMEs in translating their internal capacity and external support to build their FRC. Therefore, the findings highlight that the flood resilience of SMEs is subject to the availability and use of CLS, thereby presenting theoretical insights for understanding, what leads to strengthen FRC of SMEs. Moreover, this study also contributes to the literature by providing a marginal analysis of CLS as a moderator, which offers important insights into how CLS contributes to promoting the FRC of SMEs to face flood risk.

Policy implications

Based on the findings of this study, climate services must be promoted because they may substantially improve the association of all key determinants with flood resilience capacity of SMEs. For this purpose, the government must provide these services in a simple way, such as alerts should reach SMEs via SMS, digital apps, or local communication sources in regional languages. Similarly, grants and support by the government and any policy initiatives must be linked with climate information, enabling SMEs to act accurately and at the right time. Similarly, flood risk prone locations must be disclosed, and exposure reports must be openly available for SMEs to take timely initiatives. The connection between SMEs, local disaster agencies, and chambers of commerce should be strengthened to ensure the smooth and quick dissemination of climate data. The policymakers should establish integrated flood resilience frameworks that integrate the climate information departments, SME support institutions, and the local governments.

Short-term measures must consider targeted early warning to SMEs in the form of early forecasting and practical guidance. For these measurements, the government, climate service providers, and local business associations must be active in countering flood risk or damages. Therefore, these stakeholders must ensure that more than 90% of SMEs in flood-prone areas receive alert messages within 30 min. In medium-term measures, government bodies and local business associations may focus on improving the capacity of SMEs by offering emergency funds and insurance, launching awareness and training programs, and promoting the adoption of technologies such as backup systems and monitoring applications. Therefore, capacity-building programs must consider more than 80 percent of SMEs from high-flood-risk areas. Long-term measures require institutional integration. Policies regarding SMEs must also focus on flood risk management measures and climate services. The government must try to register 95% of SMEs in the early warning systems as soon as possible and monitor the use of CLS. Moreover, collaboration among stakeholders must be strengthened. Through this measurement, SMEs can improve their FRC in the short and

long terms.

Study limitations

Although this study provides insightful outcomes, it has some limitations. The current study considered cross-sectional data, which cannot examine cause-effect relationships among variables. Future studies should consider longitudinal data to observe the time variation in the internal and external factors that impact on flood resilience. The size diversity, sector differences, and ownership structure were not considered in this study, which may exhibit different responses to floods. Moreover, this study has another limitation regarding endogeneity and reverse causality, which can bias the estimated upward moderation effects. The cross-sectional data allowed us to examine the association but did not fully allow us to assess the causal directions. Therefore, future studies may address the concerns of the current study by adopting the instrumental variable approach with two-stage least squares to segregate the exogenous variation in CLS exposure. The FNC \times CLS interaction had an insignificant impact on FRC in this study. A post-hoc explanation, such as “money is a hard constraint” may describe these findings. Future studies should consider a more rigorous assessment to explain the threshold and diminishing-return effects. Therefore, future studies could consider the Johnson-Neyman technique or other moderation tools to examine the region of significance, which is currently not provided by Smart-PLS for insignificant moderating impact of factors. Furthermore, the unidimensional specification of CLS in analytical model may simplify its potentially multidimensional structure. Future research should validate CLS moderating role using a higher-order framework to capture its distinct functional dimensions more rigorously.

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Ethical approval

The study was approved by Leshan Normal University, Sichuan, China.

CRedit authorship contribution statement

Hualin Xu: Writing – review & editing, Writing – original draft, Visualization, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Pomi Shahbaz:** Writing – review & editing, Writing – original draft, Software, Resources, Project administration. **Aybike Bayraktar:** Writing – review & editing, Writing – original draft, Visualization, Supervision.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.cliser.2026.100652>.

Data availability

Data will be made available on request.

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