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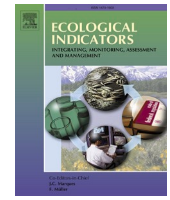

Original Articles

Development and validation of an index to measure progress in adaptation to climate change at the municipal level

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A R T I C L E I N F O

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A B S T R A C T

Background: Given the important role that municipalities must play in adapting to climate change, it is more than ever essential to measure their progress in this area. However, measuring municipalities' adaptation progress presents its share of difficulties especially when it comes to comparing (on similar dimensions and over time) the situation of different municipal entities and to linking adaptation impacts to local actions. Longitudinal studies with recurring indicators could capture changes occurring over time, but the development of such indicators requires great emphasis on methodological and psychometric aspects, such as measurement validity. Therefore, this study aimed to develop and validate an index of adaptation to heatwaves and flooding at the level of municipal urbanists and urban planners.

Methods: A sample of 139 officers working in urbanism and urban planning for municipal entities in the province of Quebec (Canada) completed an online questionnaire. Developed based on a literature review and consultation of representatives from the municipal sector, the questionnaire measured whether the respondent's municipal entity did or did not adopt the behaviors that are recommended in the scientific and gray literature to adapt to heatwaves and flooding.

Results: Results of the various metrological analyses (indicator reliability analysis, first order confirmatory factor analysis, concurrent validity analysis, and nomological validity assessment analysis) confirmed the validity of the index developed to measure progress in climate change adaptation at the municipal level. The first dimension of the index corresponds to preliminary measures that inform and prepare stakeholders for action (i.e., groundwork adaptation initiatives), whereas the second refers to measures that aim to concretely reduce vulnerability to climate change, to improve the adaptive capacity or the resilience of human and natural systems (i.e., adaptation actions).

Conclusion: The results of a series of psychometric analyses showed that the index has good validity and could properly measure the adoption of actions to prepare for adaptation as well as adaptation actions per se. Municipal and government officials can therefore consider using it to monitor and evaluate adaptation efforts at the municipal level.

1. Introduction

With climate change, the frequency and intensity of certain climate hazards, such as heatwaves and floods, will increase, leading to greater impacts at several levels, particularly global health, built environment, public safety, and food security. As manifestations of climate change multiply, the need for some adaptation, along with mitigation measures, to reduce adverse impacts (IPCC, 2018; IPCC, 2014a) has been recognized. Increasingly, initiatives to address global issues like climate change are being taken by local governments, even in the absence of national- or international-level mechanisms. As municipalities represent the level of government closest to the populations that are vulnerable to the impacts of climate disruptions, they are expected to play an important role in the necessary efforts to adapt to climate change (Bulkeley et al., 2012; Ebi and Semenza, 2008; Gore and Robinson, 2009; Henstra, 2012).

Identifying indicators to assess governments' progress in meeting their adaptation commitments is critical to achieving adaptation and reducing vulnerability to climate change (Berrang-Ford et al., 2019). The proliferation of frameworks, approaches, guides, policies, and

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resources for developing indicators and tracking adaptation progress, at the national, regional, and sectorial levels shows the breadth and dynamism of this field of research and practice (Ayers and Faulkner, 2012; Brooks et al., 2011; Dinshaw et al., 2014; Faulkner et al., 2015). Considering the important role that municipalities must play in adapting to climate change (Bulkeley et al., 2012; Ebi and Semenza, 2008; Henstra, 2012), it is more than ever essential to develop capacities to measure their progress in this area (Berrang-Ford et al., 2019). Indeed, the identification of adaptation indicators is critical to helping decision-making and to ensuring that funding is directed toward interventions that successfully produce certain adaptation results (Lesnikowski et al., 2017). Work on adaptation indicators and evaluation methods is also necessary to assess the effectiveness of the measures planned and implemented by municipalities, and to then determine the extent to which such actions increase municipalities' levels of adaptation or, conversely, are harmful in this respect, or even lead to maladaptation (Smit and Wandel, 2006).

Measuring adaptation progress by municipalities presents its share of difficulties. One of the main issues concerns the various conceptualizations of adaptation that lead to a multiplicity of actions, practices, and adaptive behaviors that the various actors can adopt (Ford and Berrang-Ford, 2016; Kuhlicke et al., 2020; Wilson et al., 2020). Adaptation is not achieved through one specific action but rather through the adoption and continued exercise over time of a diverse range of behaviors associated with broader categories of adaptation actions. This diversity of action complicates not only the identification of indicators but also the establishment of common comparison bases (Ford et al., 2015; Dupuis and Biesbroek, 2013; Berrang-Ford et al., 2011). It is indeed difficult to establish whether a municipality is on the right track without comparing its level of adaptation with its past level of adaptation or with the average level of adaptation associated with similar municipalities. Therefore, establishing thresholds for what constitutes success or a good level of adaptation proves to be difficult at best (Dilling et al., 2019).

An important literature is devoted to adaptation tracking, which refers to the development and application of systematic approaches to assessing progress on adaptation efforts over time and across space, and between and across populations and sectors (Berrang-Ford et al., 2019; Araos et al., 2016). Research on adaptation tracking has, however, shown that making such comparisons between different contexts is complicated because of: i) the lack of data based on a coherent and operational conceptualization of adaptation, ii) the absence of comparable units of analysis, iii) the scarcity of comprehensive data sources presenting adaptation actions, and iv) the difficulty identifying indicators that reflect substantial adaptation, for example, based on deeper and more critical aspects of successful adaptation (Ford and Berrang-Ford, 2016). Because of these difficulties, any conclusions drawn from comparisons between the adaptation carried out by municipalities in different geographical or temporal contexts will be limited by a problem of equivalence between the indicators selected.

Linking adaptation impacts to local actions requires indicators whose validity would have been proven to compare (on similar dimensions and over time) municipalities that adopt adaptation actions in varying degrees. However, the lack of recurrent indicators impedes the conduct of longitudinal studies (i.e. involving the repeated measurement of the same indicators over an extended period of time) that can capture changes occurring over time. Using indicators in recurring surveys or monitoring and evaluation efforts requires great emphasis on methodological and psychometric aspects, such as measurement validity. Validity refers to the degree to which evidence and theory support the interpretations of test scores for proposed uses of tests (Messick, 1989). The validation process consists in accumulating relevant evidence to provide a sound scientific basis for the proposed score interpretations (American Educational Research Association et al., 2014). This point about validity is critical and, to our knowledge, is not stressed enough in the climate change adaptation literature. Sound adaptation measurement practices are imperative because, from a metric standpoint, the quality of the answers given to a question like "are we adapting more over time?" will depend on the quality of the indicators used. There is a need to improve the precision of social science methodologies for measuring climate change adaptation at the municipal level, specifically when evaluating the validity of the construct being measured.

Given the various adaptation actions linked to urbanism and urban planning that municipalities can adopt (e.g., reducing the area of asphalt surfaces, promoting the installation of green roofs or light-colored and reflective roofs, using permeable and porous paving materials for roads, parking lots, and sidewalks), the development and refinement of an adaptation index is a preferred way to allow temporal monitoring of the progress made at the municipal level. Using common sets of specific indicators for such tasks raises the issue of the validity of the metrics used. Fortunately, there are methods for evaluating the construct validity of a measure of climate change adaptation (e.g., an index). It is the accumulation of evidence derived from these methods that strengthens confidence in the construct validity of the measurement, thereby contributing to the use of similar indicators and indices representing adaptation behaviors or practices in different settings and contexts. The development and use of composite indicators have become more widespread, whereas several indices have been developed to assess the vulnerability (El-Zein et al., 2021; Delaney et al., 2021; Edmonds et al., 2020) or resilience (Feldmeyer et al., 2020; Ferrier et al., 2020; Wu et al., 2020) of human systems or ecosystems to natural hazards. The use of composite indicators has numerous benefits (e.g. helping to summarize complex, multi-dimensional realities) but also several caveats. Indeed, in the absence of a rigorous and transparent construction process, the use of composite indicators can have important negative policy implications, such as sending misleading messages, inviting simplistic conclusions, being misused to support a desired policy (OECD, 2008). Furthermore, while several indices have been developed to measure adaptive capacity (Siders, 2018), this work is often criticized because of the absence of standardization in the choice of the dimensions and indicators included in these indices, as well as insufficient validation of the created indices (Brooks et al., 2005; Eriksen and Kelly, 2007; Hinkel, 2011; Klein, 2009). To the best of our knowledge, no study has ever focused on demonstrating the construct validity of composite indicators for measuring municipalities' adaptation progress.

In this article, we present the application of a general methodology for developing and validating an adaptation index and illustrate how it could help measure adaptation progress at the municipal level. The purpose of our study was twofold. First, the aim was to develop an index of climate change adaptation at the municipal level. For that purpose, we identified a preliminary list of municipal adaptation efforts to include in a survey sent to urbanists and urban planners working for municipalities in the province of Quebec (Canada). Then, we created a parsimonious index by using empirical item analysis to identify which behaviors, among all those measured in our survey, best represent the concept of adaptation at the level of urbanists and urban planners. The second aim of this study was to verify whether the created index is a valid representation of the construct we are trying to measure, by evaluating its construct validity. To do so, we performed three specific analyses: first order confirmatory factor analysis, concurrent validity analysis, and nomological validity analysis.

There are two main benefits to this study. First, it enabled us to offer solutions to some of the most prominent problems in the monitoring and evaluation of adaptation, by outlining a method to develop valid recurrent indicators for longitudinal studies that can capture changes occurring over time. Second, it produced indicators that municipal and government officials will be able to use to monitor and evaluate their adaptation efforts.

2. Conceptual and theoretical frameworks

2.1. Typologies of adaptation actions

The Intergovernmental Panel on Climate Change (IPCC, 2014b) defines adaptation as "the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects." Adaptation should not be defined only as a process aimed at producing a palliative response. It also refers to dimensions of transformation or adjustment of political and economic systems at the origin of vulnerability to climatic hazards (Simonet, 2015), hence the attention paid to the concept of vulnerability and its dimensions.

Vulnerability represents "the propensity or predisposition to be adversely affected [and] encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC, 2014b). The IPCC distinguishes between "outcome vulnerability" and "contextual vulnerability." Whereas the first is associated mainly with exposure or sensitivity to disasters, the second leads to consideration of non-climatic factors of vulnerability by specifying the socio-ecological vectors on which to intervene to reduce vulnerability. In this latter view of vulnerability, the exposure to climate variability and change, as well as potential responses, can be influenced by contextual conditions linked to elements from political, institutional, economic and social contexts. Thus, adaptation measures could target the projected biophysical or social impacts of climate change linked to a particular exposure unit (outcome vulnerability). Adaptation actions could also seek to alter "the context in which climate change occurs, so that individuals and groups can better respond to changing conditions" (contextual vulnerability) (O'Brien et al., 2007, pp. 75-76). A successful adaptation project will therefore have reduced the vulnerability of a system by reducing its exposure to climate change impacts (outcome vulnerability), or by strengthening the resilience and capacity of threatened social and ecological structures to absorb shocks and thus face future threats (contextual vulnerability) (Ensor and Berger, 2009).

Given these elements, and in line with Adger et al. (2005), we consider that adaptation refers to "a continuous stream of research, activities, actions, decisions and attitudes that informs decisions about all aspects of life, and that reflects existing social norms and processes" (Adger et al., 2005). Furthermore:

> Adaptation can involve both building adaptive capacity thereby increasing the ability of individuals, groups, or organizations to adapt to changes, and implementing adaptation decisions, i.e., transforming that capacity into action. Both dimensions of adaptation can be implemented in preparation for or in response to impacts generated by a changing climate (Adger et al., 2005, p. 78).

In other words, some adaptation efforts could aim to develop capacity building or to reduce the negative influence of social factors of vulnerability, whereas others could target the effects of climate stimuli and the resulting vulnerability, that is, natural variability and impacts of climate change (Dupuis and Biesbroek, 2013). Depending on the climatic hazard to which individuals, groups, or organizations need to adapt (e.g., heatwaves, floods), the nature of the implemented actions will be different.

To operationalize how adaptation might occur at the municipal level, different typologies are outlined in the adaptation literature. For instance, Lesnikowski et al. (2016) opposed groundwork initiatives to adaptation actions. Groundwork actions refer to preliminary measures that inform and prepare stakeholders for action, but do not bring changes in policies, programs, or services. Impact and vulnerability assessments, adaptation research, conceptual tools and strategic plans, climate change scenarios, and stakeholders networking are examples of such measures.

Adaptation actions refer to measures that aim to concretely reduce vulnerability to climate change and improve the adaptive capacity or the resilience of human and natural systems. Such actions include modifications to legislation and creation or organization of public structures (working groups, ministries, services), public awareness and outreach activities, surveillance and monitoring, infrastructure, innovation and technologies, program or policy evaluations, resource transfers, and financial support for autonomous adaptation (Lesnikowski et al., 2016).

Building on Biagini et al.'s (2014) typology, Araos et al. (2016) used an adaptation policy typology to classify adaptation initiatives regarding the policy tool used by governments. Such policy tools include capacity building, management, planning and policy, practice and behaviors, information, and financing. Araos et al. (2016) also outlined the different, not necessarily sequential, phases in the planning and implementation of adaptation actions by public organizations (policy process). This dimension refers to actions taken at the various stages of the adaptation decision-making and implementation process: analysis of climate projections, preparation of vulnerability assessments, consideration of multiple sectors, reassessment of development priorities in the face of climate change, creation of climate change planning documents, use of consultative tools and stakeholder engagement, management of barriers and uncertainty, and monitoring and evaluation of adaptation activities. Finally, another typology used by Araos et al. (2016) refers to the nature of the impacts that cities are trying to address (heat spells, drought, coastal exposure, inland flooding, and human health issues) and the affected sectors or human systems exposed to climate impacts that cities are prioritizing (water supply, energy supply, transportation and telecommunications, built environment, green infrastructure and ecosystem services, and human and social services).

2.2. Theoretical models to validate the index

2.2.1. Risk perception

In the present study, concurrent validity was used to verify whether the index created is a valid representation of the concept of adaptation at the municipal level. The main function of this analysis is to define the relationship between index results (here, the newly created adaptation index score) and another criterion considered to be an indicator of the construct to study (Hogan, 2007).

In this study, the criterion used corresponded to the perceived risk associated with climate change for the municipality. A growing literature has shown that psychosocial factors, such as perception of climate risk, and cognitive and motivational factors (Carman and Zint, 2020; Kuhlicke et al., 2020; Grothmann and Patt, 2005), can lead individuals to adopt specific behaviors that might protect them from the consequences of a climatic hazard. Indeed, risk perception is an important psychological dimension of climate change adaptation, some studies having established that it is positively linked to adaptation behaviors (Akompab et al., 2013; Liu et al., 2013; Semenza et al., 2011). This is also true at the organizational level, where the extent to which an organization adopts adaptive actions will be influenced by such factors as perceptions and framing of risks (Berkhout, 2012; Berkhout et al., 2006; Zhang et al., 2018).

2.2.2. Theory of planned behavior

In this study, we also used nomological validity assessment analysis as one of the strategies to verify whether the index created is a valid representation of the concept of adaptation at the municipal level. The nomological validity of an index is assessed by testing whether it fits into a network of related constructs and measures derived from a proven theoretical model. The nomological validity of the index will be confirmed if all the relationships proposed in the theoretical model are supported statistically (Hagger et al., 2017).

Specifications to assess the nomological validity of the index were derived from the relationships among the variables of the theory of planned behavior (TPB) (Ajzen, 1991; Fishbein and Ajzen, 2010). This model has been frequently used to explain and predict adaptation (Deng et al., 2017; Doran et al., 2020; Hengst-Ehrhart, 2019; Masud et al., 2016; Meinel and Höferl, 2017) and mitigation actions (Obaidellah et al., 2019; Afroz et al., 2015; Li et al., 2021) as well as other pro-environmental behaviors (Chan et al., 2020; Kim et al., 2013; Papagiannakis and Lioukas, 2012; Savari and Gharechaee, 2020; Sharma and Sharma, 2011; Taghikhah et al., 2020; Yaghoubi Farani et al., 2019; Zhang et al., 2017; Wang et al., 2019).

This theory (see Fig. 1) postulates that:

1) Intentions to implement an action (in this case, a groundwork adaptation initiative or adaptation action) and perceived control over an action (in this case, people's perceptions of their ability to implement groundwork or adaptation actions and/or the presence of factors that may facilitate their implementation) are the immediate antecedents of such behavior. Perceived behavioral control can have a direct effect on behavior but can also influence the behavior indirectly via its effect on the intention to implement said action.
2) Perceived behavioral control, to the extent that it faithfully reflects actual control, like actual control, can moderate the effect of intention on behavior. In Fig. 1, this moderating effect is illustrated by the dotted arrow. According to Fishbein and Ajzen (2010), the effect of intention on behavior should be stronger when actual control is high rather than low. When people really control the exercise of a behavior, they are more likely to act according to their intentions.
3) People's intentions to implement groundwork or adaptation actions should increase to the extent that they show a favorable attitude toward said actions, think that significant people support these actions (i.e., perceived social norms), and perceive that they have control over the implementation of these actions.

3. Materials and methods

3.1. Participants

The target population of this study included 1,218 municipal entities located in the province of Quebec (Canada). There are two levels of municipal organization in this province of 8.6 million inhabitants: local and supralocal. Municipalities constituted under general municipal regimes (N = 1,110) and Montreal boroughs (N = 19) represent an important part of the local level. At the supralocal level, regional county municipalities, or RCMs (municipalités regionales de comtés [MRC]; N = 87), represent all local municipalities within an RCM's territory. Whereas municipalities have several levers at their disposal to implement climate actions (Jacob et al., 2021), RCMs can also act via their power in terms of land use planning as well as in terms of risk coverage. Two metropolitan communities in the province complete the supralocal level: Montreal (population: 3.8 million) and Quebec City (population: 0.79 million). These two metropolitan communities represent respectively 82 and 28 municipalities located within their territories. Because they also exercise powers in several areas, including land use planning (MAMOT, 2016), they were included in the target population of this study.

An invitation to complete an online questionnaire was sent to officers working in urbanism and urban planning in the municipal entities. A total of 139 municipal entities (including 84 municipalities, five Montreal boroughs, and 50 RCMs and metropolitan communities) participated in this study (response rate of 11.41%). The respondents were responsible for development and land use planning (71.22%), urban planning (68.35%), the environment (56.83%), or municipal inspection

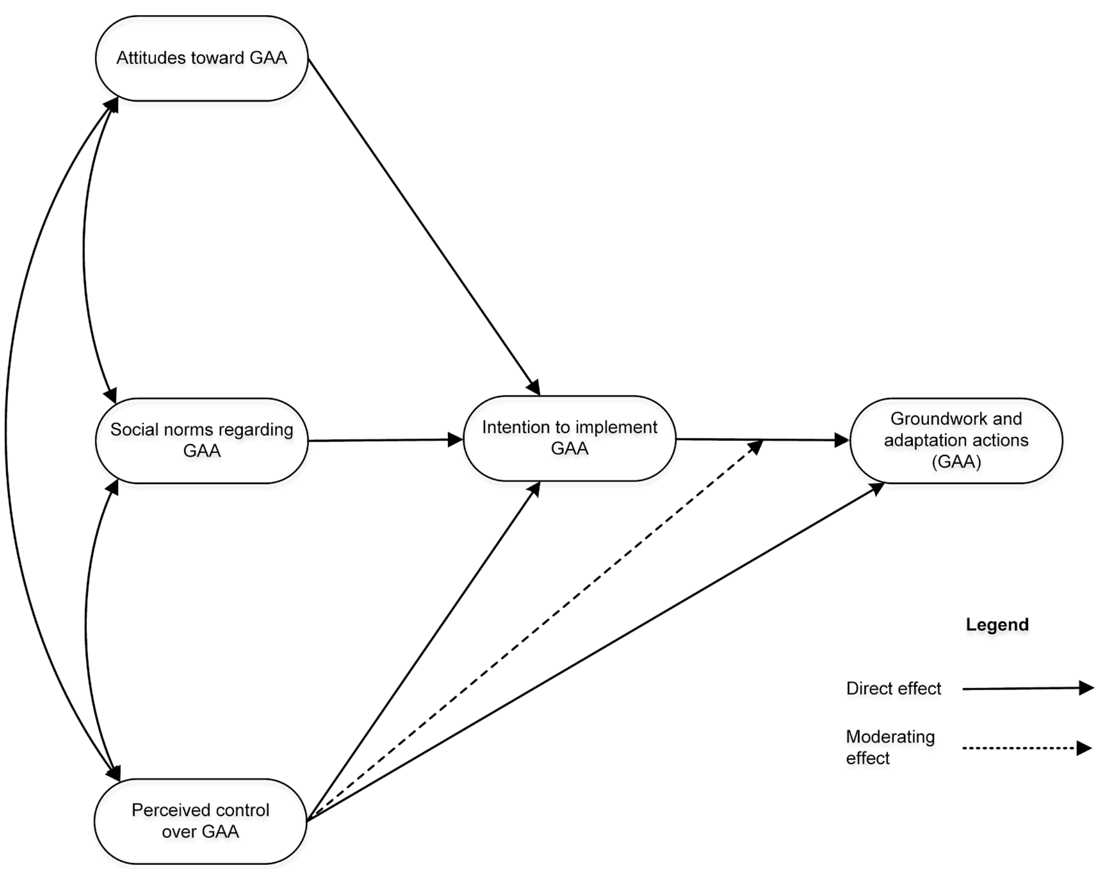

Fig. 1. The theory of planned behavior model.

(46.76%). For 73.39% of the participants, the highest educational level obtained was a university degree (undergraduate: 38.14%; graduate: 35.25%). The participants were also asked their age bracket: 8.63% were aged 30 years or under, 30.22% were 30–39 years old, 20.86% were 40–49 years old, 20.14% were 50–59 years old, and 6.47% were over 60 (13.67% did not respond). Finally, our sample included participants who had been employed by their current municipality for different lengths of time: 25.18% for <3 years, 27.34% for 3–10 years, 17.99% for 11–20 years, and 15.11% for >20 years (14.39% did not respond).

3.2. Measures

The questionnaire administered to the municipal officers was developed based on a literature review on adaptation preparation behaviors or actions and adaptation interventions that are recommended in the scientific and gray literature. It had been previously submitted for comment to representatives of Quebec City, the *Association des aménagistes régionaux du Québec* (AARQ), the *Ministère des Affaires municipales et de l'Occupation du territoire* (MAMOT), the *Fédération québécoise des municipalités* (FQM) and the *Union des municipalités du Québec* (UMQ). The purpose was to review the relevance, completeness, and wording of the indicators selected.

3.2.1. The adaptation index

First, to develop the Adaptation Index, the questionnaire asked which actions the municipalities and their staff were implementing to adapt to climate change. The index created included two main dimensions: groundwork adaptation and adaptation actions.

3.2.1.1. Dimension 1 of the adaptation index: Groundwork adaptation initiatives. For the groundwork adaptation initiatives (GAI) dimension, we created four groups of behaviors, inspired by the dimensions presented in Araos et al. (2016): i) capacity building, ii) climate and vulnerability assessment, iii) review of development plans with climate change lens and consultation process and inclusion of stakeholders, and iv) management of barriers and uncertainties. Apart from the first dimension, which was linked to a policy typology, most of our dimensions referred to the policy process typology. Furthermore, the relatively small number of respondents somewhat limited the metrological analysis that could be performed. This is why "reassessment of development priorities in the face of climate change" and "use of consultative tools and stakeholder engagement" were regrouped into a single dimension (i.e., review of development plans with climate change lens and consultation process and inclusion of stakeholders). For a similar reason, we had to regroup "analysis of climate projections" and "preparation of vulnerability assessments" into "climate and vulnerability assessment."

The development of composite indicators to measure macro-dimensions of adaptation was motivated by the fact that there were simply too many particular adaptation behaviors for the size of the sample analyzed, which would have made it impossible to carry out metrological analyses. Therefore, these four groups of behaviors referred to several particular behaviors (see Table 1 below).

3.2.1.2. Dimension 2 of the adaptation index: Adaptation actions. As with the groundwork adaptation dimension, the large number of possible adaptation actions for the available sample size required each item to be combined into adaptation action sub-dimensions. Once again, these sub-dimensions were informed by typologies presented in Araos et al. (2016). We thus created three groups of adaptation actions (AA): i) urban temperature variation; ii) inland flooding and hydrological and geo-hydrological hazards at urban level; and iii) monitoring and evaluation (see Table 2 below).

Once again, these three groups of behaviors referred to several particular behaviors. For instance, the group of behaviors on the "urban temperature variation" dimension was associated with such indicators as measures to control heat islands (adaptation action) embedded in the transportation and telecommunications sector (sub-dimension). Each adaptation action was further broken down into specific actions or interventions. For example, the adaptation action called "measure to control heat island" included such interventions as i) reducing the area of asphalt surfaces; ii) increasing the use of permeable and porous materials for roads, parking lots, and sidewalks; and iii) increasing the use of clear and reflective coating materials for roads, parking lots, and sidewalks. Another example, the group of behaviors on the "monitoring and evaluation" dimension was associated with indicators linked to monitoring the implementation of adaptation actions (e.g., site visits, scorecard, indicators) and evaluation of their effectiveness (Nilsson et al., 2012; Rydin et al., 2012).

Tables 1 and 2 also present a summary of the method used to compute the scores for each groundwork initiative and adaptation action. All the scores obtained were dichotomous, the first modality (0) meaning that initiatives were performed insufficiently or not at all and the second modality (1) indicating that initiatives were more frequently implemented. Even when scales other than dichotomous responses were used in the survey, the scores were dichotomized. Although binary variables are less sensitive to differences between municipalities, preliminary analyses, as well as previous studies (Bélanger et al., 2015; Valois et al., 2017), showed that it was better to dichotomize, as the low variance in the responses produced outliers. In some cases, cut-off points were based on the nature of the questions, whereas, in other cases, the pattern of observed frequencies guided their definition. Also, the pattern of observed frequencies varied from one group of initiatives to another, which explains why the cut-off points chosen for ranking adaptation scores differed between initiative groups. All patterns are detailed in Tables 1 and 2. The two dimensions were computed as follow:

$$GAI = (1^{*}GAI1 + 1^{*}GAI2 + 1^{*}GAI3 + 1^{*}GAI4) \ / \ 4$$

$$AA = (1^{*}AA1 + 1^{*}AA2 + 1^{*}M\&E) \ / \ 3$$

3.2.2. Perceived risk

In addition to the questions relating to municipalities' groundwork initiatives and adaptation actions, the questionnaire administered to municipal officers assessed the perceived risk associated with climate change for the municipality, according to municipal officers, to assess the concurrent validity of the index.

Prevalence of perceived exposure to flood events (past or future). (i) In your municipality's territory, are there any inhabited sectors, infrastructures, or buildings (commercial, institutional, industrial) that have already been affected by a flood?; (ii) In your municipality's territory, are there any inhabited sectors, infrastructures, or buildings (commercial, institutional, industrial) that could be affected by a flood? If the answer was "yes" to either of these items, the score for this variable was "1." Otherwise, it was "0."

Prevalence of perceived future exposure to heatwaves and flood. (i) In your opinion, in the next 10 years, what is the probability that heatwaves will occur more often than before in your municipality's territory?; (ii) In your opinion, in the next 10 years, what is the probability that floods will occur more often than before in your municipality's territory? This question was rated on a 5-point ordinal scale: "Very low" (+1), "Low" (+2), "Medium" (+3), "High" (+4), and "Very high" (+5). If any of the items was above (+3), the score for this variable was "1." Otherwise, it was "0."

Prevalence of perceived anticipated impacts. (i) In the event that heatwaves occur in your municipality's territory, what would be the approximate extent of the damage caused to property and infrastructure?; (ii) In the event that floods occur in your municipality's territory, what would be the approximate extent of the damage caused to property and infrastructure?; (iii) In the event that heatwaves occur in your

Table 1
Groundwork adaptation initiatives (GAI) indicators.

Dimension	Groundwork initiatives	Scale	Criteria used to distinguish adaptation from non-adaptation	Frequency of adaptation (%)
GAI1_Capacity building	Availability of specific budget for adaptation	• Yes • No	**Adaptation:** • Existence of a budget **Non-adaptation:** • Non-existence of a budget	6/139 (4.32%)
	Proportion of staff having received training linked to adaptation	• 0% • 1 to 25% • 26 to 50% • 51 to 75% • 76% and more	**Adaptation:** • At least one staff member of the urban planning department has received training linked to adaptation **Non-adaptation:** • No staff member of the urban planning department has received training linked to adaptation	105/139 (75.54%)
	Identification of a municipal adaptation officer	• Yes • No	**Adaptation:** • Appointment of an officer **Non-adaptation:** • No officer responsible	16/139 (11.51%)
	Use of available information on climate change issues	• I don't know this source • I know this source, but I've never consulted it • I've used this source	**Adaptation: Consultation of at least one of the following sources** • Good practices' guides on territorial planning and sustainable development published by Quebec's Ministry of Municipal Affairs and Land Occupancy (66/139; 47.48%) • Publications of professional or municipal associations related to climate change (49/139; 35.25%) • Other official publications from the Government of Canada and the Government of Quebec on climate change adaptation (34/139; 24.46%) • Academic publications on climate change, such as scientific articles, books (25/139; 17.99%) • Guide for the Quebec municipal sector produced by the Ouranos Consortium (24/139; 17.27%) • Publications from international organizations specializing in climate change (13/139; 9.35%) **Non-adaptation:** • No consultation of these sources	88/139 (63.31%)
GAI2_Climate and vulnerability assessment	Use of mapping tools and production of studies on climate change issues	• Yes • No	**Adaptation: Have used two of the following four tools:** • Map / database of flood risk areas (109/139; 78.42%) • Map / database of areas at risk of erosion and / or landslide (83/139; 59.71%) • Map / database of the distribution of heat islands (20/139; 14.39%) • Map / database of the distribution of the population that is vulnerable to heat / flood according to their sociodemographic characteristics (10/139; 7.19%) • Technical analysis or advice on vulnerabilities to climate change, such as climate impact assessment, risk assessment, and studies on vulnerabilities (5/139; 3.60%) **Non-adaptation:** • Have used less than two of these tools	86/139 (61.87%)
GAI3_Review of development plans with climate change lens, consultation process and inclusion of stakeholders	Mainstreaming of adaptation	1. Never 2. Rarely (i.e., less than once a year) 3. Occasionally (i.e., once or twice a year)	**Adaptation: Mean score > 2** • Address a heat wave or flood preparation issue in communication with supervisors (meeting, written note, informal discussion, etc.)	55/139 (39.57%)

(continued on next page)

Table 1 (*continued*)

Dimension	Groundwork initiatives	Scale	Criteria used to distinguish adaptation from non-adaptation	Frequency of adaptation (%)
		4. Regularly (i.e., three times or more per year) Mean score of the 5 items	• Recommendation to supervisors to adopt a heat wave or flood preparedness measure (written or verbal recommendation) • Address heat wave or flood preparedness issues in communication with the department's staff members • Have the department's staff members consider the consequences of heatwaves or floods in the course of a mandate • Address heat wave or flood preparedness issues in communication with other organizations (regional partner, private company, developer, etc.) • Get personally involved in a heatwave or flood preparedness project **Non-adaptation: Mean score ≤ 2**	
GAI4_Management of barriers and uncertainties	Technical analysis or advice on measures to adapt to climate change (e.g., feasibility study, cost-benefit analysis, evaluation of the results of a pilot project, etc.)	• Yes • No	**Adaptation:** • Yes **Non-adaptation:** • No	16/139 (11.51%)
	Pilot projects or demonstration projects to adapt to climate change	• Yes • No	**Adaptation:** • Yes **Non-adaptation:** • No	17/139 (12.23%)

municipality's territory, what would be the approximate magnitude of the negative impacts on the physical and mental health of the population?; (iv) In the event that floods occur in your municipality's territory, what would be the approximate magnitude of the negative impacts on the physical and mental health of the population? This question was rated on a 5-point ordinal scale: "Very low" (+1), "Low" (+2), "Medium" (+3), "High" (+4), and "Very high" (+5). If item (i) or item (ii) was above (+3) OR if item (iii) or item (iv) was above (+3), the score for this variable was "1." Otherwise, it was "0."

3.2.3. TPB variables

Finally, the questionnaire also assessed TPB constructs, to assess the nomological validity of the index.

Intentions to implement adaptation behaviors. We assessed intentions by computing the mean response to the following three items (reliability according to Cronbach's alpha = 0.905). The Cronbach's alpha coefficient provides an estimate (ranging from 0 to 1) of the homogeneity (internal consistency) of a measurement instrument or latent variable composed of a set of items that all putatively measure the same construct or concept. A Cronbach's alpha value close to 1 indicates a high level of internal consistency among the items measuring the construct (i.e., its reliability). As part of my duties: (INT-1) I intend to prioritize the preparation for heat waves or flooding over the next three years, (INT-2) I am determined to take action to prioritize the preparation for heat waves or flooding over the next three years, and (INT-3) I plan to regularly propose measures to prioritize preparation for heat waves or flooding over the next three years. Responses were provided on 4-point scales ranging from "strongly disagree" (+1) to "strongly agree" (+4).

Attitudes toward the implementation of adaptation behaviors. Responses to two items were used as reflective indicators of municipal officers' attitudes toward the implementation of adaptation behaviors (Cronbach's alpha = 0.684). Participants rated each of the following items on a 4-point scale ranging from "strongly disagree" (+1) to "strongly agree" (+4). In general, the majority of elected officials in our municipality believe that: (ATT-1) municipalities have an important role to play in planning for heat waves and flooding and (ATT-2) reducing the population's vulnerability to heat waves and its territory's vulnerability to flooding should be among our municipality's priorities. The higher the score for this variable, the more the respondents had a positive attitude towards adopting the behaviors.

Perceived social norms regarding adaptation behaviors. Responses to four questions were used to assess municipal officers' perceptions of social norms related to the adoption of adaptation behaviors (Cronbach's alpha = 0.748). Participants rated each of the following items on a 4-point scale ranging from "strongly disagree" (+1) to "strongly agree" (+4): (N-1) Some Quebec municipalities that are comparable to ours prioritize preparation for heat waves or flooding, (N-2) Regional bodies to which this municipality belongs have strict requirements regarding our municipality's actions to prepare for heat waves or flooding, (N-3) Provincial and federal governmental authorities have strict requirements regarding our municipality's actions to prepare for heat waves or flooding, and (N-4) The population of our municipality has high expectations regarding our actions to prepare for heat waves or flooding. The higher the score for this variable, the more the respondents believed that significant others thought they should adopt the behaviors.

Perceived control over the implementation of adaptation behaviors. The questionnaire addressed seven control factors (Cronbach's alpha = 0.724). Participants rated each of the following eight items on a 4-point scale ranging from "strongly disagree" (+1) to "strongly agree" (+4): (B-1) The role of municipalities in preparing for heat waves or for flooding is unclear, (B-2) There is no consensus among specialists on the methods and techniques to implement to prepare for heat waves or flooding, (B-3) There is little concrete or useful information available on preparing for heat waves or flooding in the official documentation, (B-4) Employees in our municipality are too overburdened with their basic responsibilities to spend time preparing for heat waves or flooding, (B-5) Actions to prepare for heat waves or flooding are in areas beyond the scope of the municipalities, (B-6) It is difficult to achieve joint action with the other actors in our region in terms of preparing for heat waves or flooding, (B-7) It is difficult to have an internal budget in place to fund measures to prepare for heat waves or flooding. The higher the score for this variable, the more the respondents believed they had control over the adoption of the behaviors.

Table 2
Adaptation actions (AA) indicators.

Dimension	Sub-dimension	Adaptation actions	Scale	Criteria used to distinguish adaptation from non-adaptation	Frequency of adaptation (%)
AA1_Urban temperature variation	Sector_Transportation and Telecommunications	Measures to control heat islands	• Yes • No	**Adaptation: Implementation of at least one of the following interventions** • Reducing the area of asphalt surfaces (43/139; 30.94%) • Increasing the use of permeable and porous materials for roads, parking lots, and sidewalks (21/139; 15.11%) • Increasing the use of clear and reflective coating materials for roads, parking lots, and sidewalks (12/139; 8.63%) **Non-adaptation:** • No implementation of any of these interventions	50/139 (35.97%)
	Sector_Built Environment, and Recreational and Heritage Sites	Measures to control heat islands	• Yes • No	**Adaptation: Implementation of at least one of the following interventions** • Promoting the proximity of essential services (66/139; 47.48%) • Promoting the installation of green roofs or light-colored and reflective roofs (26/139; 18.71%) • Optimizing the orientation of new buildings and traffic lanes (8/139; 5.76%) **Non-adaptation:** • No implementation of any of these interventions	70/139 (50.36%)
	Sector_Green Infrastructure and Ecosystem Services	Measures to control heat islands	• Yes • No	**Adaptation: Implementation of at least one of the following interventions** • Planting, conserving, and protecting trees in urban areas (97/139; 69.78%) • Increasing the presence of green spaces, parks and water features (88/139; 63.31%) • Promoting the installation of rainwater management systems (68/139; 48.92%) **Non-adaptation:** • No implementation of any of these interventions	109/139 (78.42%)
AA2_Inland Flooding, Hydrological and Geo-Hydrological Hazards at Urban Level	Sector_Transportation and Telecommunications	Immunization measures for floodplain construction	• Yes • No	**Adaptation: Implementation of at least one of the following interventions** • Use permeable and porous paving materials for roads, parking lots, and sidewalks (19/139; 13.67%) **Non-adaptation:** • No implementation of any of these interventions	19/139 (13.67%)
	Sector_Built Environment, and Recreational and Heritage Sites	Immunization measures for floodplain construction	• Yes • No	**Adaptation: Implementation of at least one of the following interventions** • Mechanically stabilize the banks of a watercourse or lake (rock, concrete, steel, wood) (50/139; 35.97%) • Implement means of controlling / prohibiting the discharge of gutter water into the storm sewer system (39/139; 28.06%) • Rectify the route, dig or widen a stream (30/139; 21.58%) • Build a flood protection dyke (7/139; 5.04%) • Construct a floodway for a watercourse (4/139; 2.88%) **Non-adaptation:** • No implementation of any of these interventions	73/139 (52.52%)
	Sector_Green Infrastructure and Ecosystem Services	Immunization measures for floodplain construction	• Yes • No	**Adaptation: Implementation of at least one of the following interventions** • Stabilize the banks of a stream or lake with plants (63/139; 45.32%) • Build retention basins (41/139; 29.50%) • Dig grassed ditches or vegetated valleys (28/139; 20.14%) • Install strips of filter vegetation (19/139; 13.67%) • Develop rain gardens (16/139; 11.51%)	79/139 (56.83%)

(*continued on next page*)

Table 2 (*continued*)

Dimension	Sub-dimension	Adaptation actions	Scale	Criteria used to distinguish adaptation from non-adaptation	Frequency of adaptation (%)
				• Voluntarily build a floodplain in rural areas to reduce urban spillover (7/139; 5.04%) • Construct a reservoir or a water dam (7/139; 5.04%) **Non-adaptation:** • No implementation of any of these interventions	
	Policy tool _Management, Planning, and Policy	Decisions linked to floodplain construction projects	• Yes • No	**Adaptation: Implementation of at least one of the following interventions** • Revise the regulations for the protection of shorelines, coastlines, and flood plains to ensure that they are consistent with the regional authority land use and development plan (86/139; 61.87%) • Request modifications to a construction project deemed too flood-prone (45/139; 32.37%) • Refuse construction project deemed too flood-prone (33/139; 23.74%) • Adopt immunization measures applicable to construction in flood zones more stringent than those provided for in the regional authority land use and development plan (5/139; 3.60%) **Non-adaptation:** • No implementation of any of these interventions	98/139 (70.50%)
	Policy tool_Financing	Decisions linked to floodplain construction projects	• Yes • No	**Adaptation: Implementation of at least one of the following interventions** • Acquire riparian properties to protect them from real estate development (25/139; 17.99%) **Non-adaptation:** • No implementation of any of these interventions	25/139 (17.99%)
M&E_Monitoring and evaluation	Monitoring of the implementation of adaptation actions (e.g., site visits, scorecard, indicators) and evaluation of their effectiveness		• 2 for carrying • out a or b AND • c or d • 1 for carrying • out either a or b • OR either • c or d, but not • both • 0 for no M&E • activity	**Adaptation: Have carried out at least one of the following activities:** • a) Monitoring of the implementation of actions against heat islands (51/139; 36.69%) • b) Monitoring of the implementation of actions against flooding (61/139; 43.88%) • c) Evaluation of the effectiveness of actions against heat islands (33/139; 23.74%) • d) Evaluation of the effectiveness of actions against flooding (57/139; 41.01%) **Non-adaptation:** • No monitoring or evaluation activity	2: 58/139 (41.73%) 1: 24/139 (17.27%)

3.3. Statistical analysis

Four different analyses were performed: i) indicator reliability analysis, ii) first order confirmatory factor analysis, iii) concurrent validity analysis, and iv) nomological validity assessment analysis.

3.3.1. Indicator reliability analysis

First, we assessed the psychometric qualities of the adaptation index by performing an item analysis, using Samejima's graded response model (Samejima, 1969). The purpose was to assess the performance of each indicator according to a certain number of psychometric parameters (e.g., the power to distinguish between municipalities that are proactive on the adaptation front and those that are not as proactive) and to determine which indicators should be retained in the final index. The discriminant parameter thus represents a description of the association between an item and the construct to be measured (i.e., the level of adoption of groundwork adaptation initiatives or adaptation actions by a municipality). The higher the discrimination index for an item, the better that item can distinguish between proactive and less proactive municipalities. Baker (2001) proposed the following classification to interpret the discrimination parameter of each indicator: (a) very poor: 0.34 or less, (b) poor: 0.35–0.64, (c) moderate: 0.65–1.34, (d) good: 1.35–1.69, and (e) very good: 1.70 or higher.

3.3.2. First order confirmatory factor analysis

Second, confirmatory factor analyses were conducted to assess the dimensionality of the index. We first tested a parsimonious bi-dimensional model (i.e., adoption of groundwork adaptation initiatives and adaptation actions) that included all the initiatives and actions within a single construct. Then, the compatibility of the empirical data with the hypothetical measurement model was assessed using various indexes as operationalized in Mplus 8.0 (Muthén and Muthén, 2017) in conjunction with the maximum likelihood estimation with robust standard errors (MLR) estimator. This estimator was used because it is robust with respect to low numbers of subjects (Muthén et al., 2015).

3.3.3. Concurrent validity analysis

After the assessment of the psychometric qualities of the index, concurrent validity was the first method used to assess its validity. As indicated in Section 2.2.1, the criterion used corresponded to the perceived risk associated with climate change for the municipality. The respondents were asked eight questions (see Section 3.2.2). The municipalities where their officers perceived a very low, low, or medium probability and potential impacts comprised a group of municipalities where the perceived risk was considered lower, whereas those where they perceived a high or very high probability and potential impacts comprised a group of municipalities where the perceived risk was considered higher. To test the concurrent validity of the index, we first calculated the tetrachoric correlation between the index and perceived risk. Then, we calculated the prevalence of risk perception (low perceived risk, high perceived risk) according to the adaptation level as measured by a dichotomized index, using a nominal-type polytomous logistic analysis (Hosmer and Lemeshow, 1989). For this last analysis, we dichotomized the adaptation scores by performing a multiple correspondence analysis (Greenacre, 1984) following the method outlined in Valois et al. (2017).

It is plausible that municipalities whose officers perceived a higher risk of being exposed to climatic hazards or anticipated greater damage because of these exposures were the ones who adapted the most. This would imply a positive correlation between each index and the perceived risk criterion, as well as a stronger prevalence of perceived risk for municipalities that are more active on the adaptation front.

3.3.4. Nomological validity assessment analysis

A final analysis was carried out to assess the nomological validity of the index created. Specifications to assess the nomological validity of the index were derived from the relationships among the variables of the theory of planned behavior (Ajzen, 1991; Fishbein and Ajzen, 2010). In line with the theoretical specifications of this theory, the adaptation index created would show nomological validity if one or more of the statements derived from this theory was confirmed by a statistical analysis.

Structural equation modeling (SEM) with Mplus 8.0 (Muthén and Muthén, 2017) was used to test the specifications derived from the nomological network. Much like a combination of factor analysis and regression or path analysis (Hox and Bechger, 1998), SEM entails representing the relationships between the constructs of the theory that are being measured with appropriate observed variables or indicators (Hayduk et al., 2007). The theory is then tested by verifying the compatibility of the observed associations with the theory-implied associations.

To produce more reliable and valid scores, SEM should be carried out with multiple rather than simple indicators that measure each theoretical construct (Kline, 2015). However, due to the relatively small number of observations for the number of parameters to estimate in our model, each item used to measure a given theoretical construct could not be considered as an individual indicator of that construct. This problem was solved by defining the constructs using parcels that consisted of the sum or mean of the responses to several questions designed to measure the same construct (see Jacob et al. [2021] for the method used to create each parcel). Once again, maximum likelihood estimation with robust standard error (MLR) was used because of its robustness with respect to non-normal distribution of scores and a low number of subjects (Muthén et al., 2015).

The following fit indices were used to assess model fit for the confirmatory factor analysis and SEM: comparative fit index (CFI), Tucker–Lewis Index (TLI), and root mean squared error of approximation (RMSEA). Contrary to the chi-square test, these tests are sample-size-independent and therefore not oversensitive to the size of the available sample. CFI and TLI values greater than or equal to 0.95 indicate an excellent fit of the data to the model, whereas values ranging from 0.90 to 0.94 indicate an acceptable model fit. RMSEA values less than or equal to 0.06 indicate an excellent fit, whereas values between 0.08 and 0.061 indicate an acceptable fit (Kline, 2015; Hu and Bentler, 1999).

4. Results

4.1. Item analysis

The first series of analyses consisted in item analyses and were performed using the Excel add-in EIRT (Valois et al., 2011). The results indicated that the group of behaviors seemed to measure the uptake of groundwork adaptation initiatives (Table 3) and adaptation action constructs (Table 4). Regarding the adoption of groundwork adaptation initiatives, the discrimination power of each indicator was either very good (management of barriers and uncertainties, capacity building, review of current and future development plans with climate change lens, consultation process and inclusion of multiple stakeholders) or moderate (climate and vulnerability assessment). As indicated in Table 1, the most adopted groundwork adaptation initiatives were “offering training linked to adaptation” (75.54%) and “using available information on climate change issues” (63.31%), whereas the least adopted initiatives were “availability of specific budget for adaptation” (4.32%), “identification of an officer responsible for adaptation” (11.51%), and “obtaining technical analysis or advice on measures to adapt to climate change” (11.51%).

Regarding the adoption of adaptation actions (Table 4), the discrimination power of each indicator was either very good (inland flooding, and hydrological and geo-hydrological hazards at urban level), good (monitoring and evaluation), or moderate (urban temperature variation). The results in Table 2 show that the most adopted adaptation actions were “planting, conserving, and protecting trees in urban areas” (69.78%) and “increasing the presence of green spaces, parks, and water features” (63.31%). Conversely, the least adopted adaptation action was “construction of a floodway for a watercourse” (2.88%), and the second least adopted was “adoption of immunization measures applicable to construction in flood zones more stringent than those provided for in the regional authority land use and development plan” (3.60%).

4.2. Confirmatory factor analysis

A confirmatory factor analysis was performed on the seven behaviors that were retained following the item analysis to verify whether they corresponded to the two dimensions of the theoretical construct, namely groundwork adaptation initiatives (for the first four groups of behaviors) and adaptation actions (for the latter three groups). The results showed that our model had an excellent level of fit to the data (CFI = 1.000, TLI = 1.000, and RMSEA = 0.000; see Fig. 2).

4.3. Concurrent validity of the index

We assessed the concurrent validity of the adaptation index by examining the relationship between the two dimensions or factors and three theoretically related variables linked to the perceived risk

Table 3
Discrimination indices for each adaptation groundwork initiative.

Adaptation Groundwork Initiative	Indicator Discrimination Value	99% Confidence Interval
1) Management of barriers and uncertainties	2.465	[1.334, 3.596]
2) Capacity building	2.156	[1.440, 2.872]
3) Review of current and future development plans with climate change lens, consultation process and inclusion of multiple stakeholders	1.957	[1.053, 2.861]
4) Climate and vulnerability assessment	0.799	[0.248, 1.350]

Table 4
Discrimination indices for each adaptation action.

Adaptation Action	Indicator Discrimination Values	99% Confidence Interval
1) Inland flooding, and hydrological and geo-hydrological hazards at urban level	3,131	[2.308, 3.954]
2) Monitoring and evaluation	1.677	[1.036, 2.318]
3) Urban temperature variation	1.118	[0.663, 1.574]

associated with climate change for the municipality, according to individuals working for the municipality: prevalence of perceived exposure to flood events (past or future), prevalence of perceived future exposure to heatwaves and floods, and prevalence of perceived anticipated impacts.

A global adaptation score was computed using the responses to the actions and initiatives included in the index. It was dichotomized as follows: municipalities that are more active in adaptation (score > 0) and those that are less active (score < 0).

The validity of the two dimensions of the index was first tested using a series of tetrachoric correlations with the measurement of flood events (that have occurred or are likely to occur) in the territory of the respondents' municipality (see supplementary material, Tables 1 and 4), the measurement of perceived risk for the respondent's municipality of being more exposed in the future to heatwaves and floods (see supplementary material, Tables 2 and 5), and the perceived anticipated damage resulting from this exposure (see supplementary material, Tables 3 and 6). Then, the prevalence of risk perception (low perceived risk, high perceived risk) according to the adaptation level as measured by the dichotomized index was also calculated using a nominal-type polytomous logistic analysis (Hosmer and Lemeshow, 1989).

The results of the tetrachoric correlations (see supplementary material, Tables 1 to 6) suggested that the index created had a good validity. The groundwork adaptation initiatives dimension was significantly and positively correlated with 2 out of 3 of its related variables (ρ = 0.430 with occurrence or likely occurrence of flood events and ρ = 0.504 with the perceived risk for the respondent's municipality of being more exposed in the future to heatwaves and floods; see supplementary material, Tables 1 and 2). Furthermore, 2 out of 3 significant correlations were found between the adaptation actions dimension and its related variables (ρ = 0.689 with occurrence or likely occurrence of flood events and ρ = 0.274 with the perceived risk for the respondent's municipality of being more exposed in the future to heatwaves and floods; see supplementary material, Tables 4 and 5).

The results of the odds ratio analyses (nominal-type polytomous logistic analysis) were consistent with the correlation results. According to the index, the prevalence of each dimension of risk perception was higher in the group of municipalities that were more active in adaptation than in the group that was less active. For instance, the prevalence of the perception that heatwaves and floods would occur more often than before in the municipal territory was 92.9% in the more active group versus 75.3% in the less active group: odds ratio = 4.274, p = 0.0240 (see supplementary material, Table 2).

Due to the lack of significant differences for some variables, we used the value of the odds ratio (OR), which can be interpreted as an effect size according to Chen et al. (2016). As indicated by these authors, an OR < 1.68 indicates a "very small" effect size, an OR > 1.68 but < 3.47 indicates a "small" effect size, an OR > 3.47 but < 6.71 indicates a "medium" effect size, and an OR > 6.71 indicates a "large" effect size. Therefore, results regarding the magnitude or practical significance of the differences between municipalities that were more and less active in adaptation showed that the effect size for the dimensions of risk perception could be qualified as large for one dimension (perceived risk for the respondent's municipality of being more exposed in the future to heatwaves and floods, regarding adaptation actions), medium for two variables (occurrence or likely occurrence of flood events, regarding groundwork adaptation initiatives; perceived risk for the respondent's municipality of being more exposed in the future to heatwaves and floods, regarding groundwork adaptation initiatives), small for one variable (occurrence or likely occurrence of flood events, regarding adaptation actions), and very small for the other two variables (perceived anticipated impacts, regarding groundwork adaptation initiatives; perceived anticipated impacts, regarding adaptation actions).

4.4. Nomological validity

Finally, an SEM analysis was performed to assess the nomological

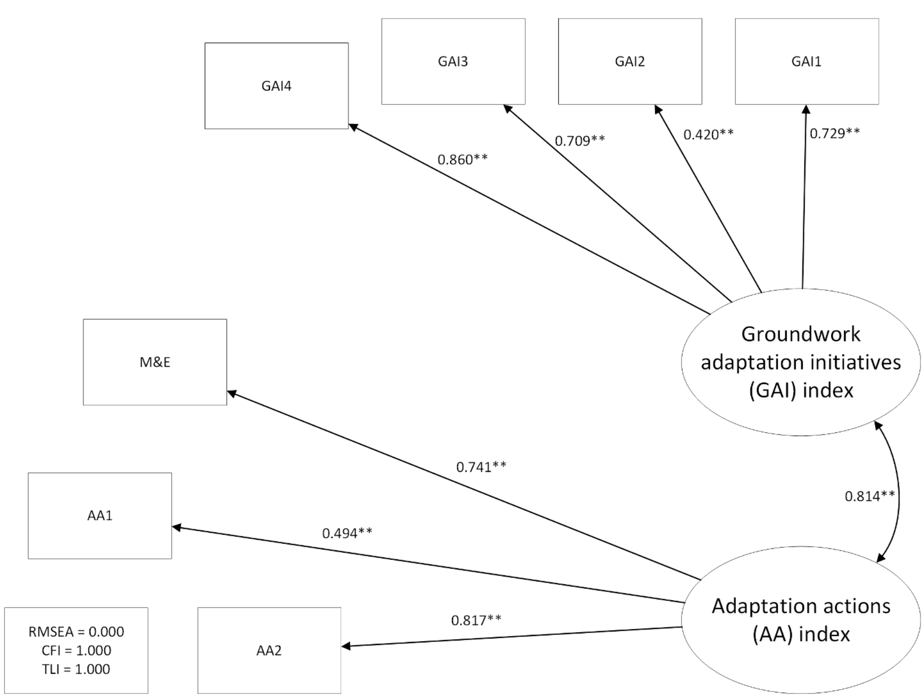

Fig. 2. Results for the final model tested with confirmatory factor analysis (Groundwork Adaptation Initiatives dimension and Adaptation Actions dimension). Legend: GAI1. Capacity building; GAI2. Climate and vulnerability assessment; GAI3. Review of current and future development plans with climate change lens, consultation process and inclusion of multiple stakeholders; GAI4. Management of barriers and uncertainties; AA1. Urban temperature variation actions; AA2. Inland flooding, and hydrogeological and geo-hydrological hazards at urban-level actions; M&E. Monitoring and evaluation.

validity of the index created. The results showed that the TPB-derived model accounted for 34.9% of the variance in intentions to adopt groundwork and adaptation actions and 32.4% of the variance in the adoption groundwork and adaptation actions (see Fig. 3). They also showed that among the determinants of the TPB, municipal officers' perceived control over the adoption of GAA (standardized beta, $\beta = 0.321$, $p < 0.021$) was significantly associated with their intentions to adopt GAI and AA, whereas their attitudes toward the adoption of GAA and their perception of the opinions of significant others (municipality's population, regional bodies, governmental authorities, other municipalities) were not significantly associated with the intention to adopt such actions.

The association of intentions ($\beta = 0.569$, $p < 0.001$) with the adoption of groundwork and adaptation actions was significant. The fit of the model to the data was excellent: CFI = 0.998, TLI = 0.998, and RMSEA = 0.019. The results also revealed that municipal officers who had the intention to adopt GAA had indeed taken action.

Because no specific weighting was attributed in the measurement of GAI and AA, we also verified whether the SEM results would be similar if we weighted our indicators with the factor loadings obtained from the CFA (see Fig. 2). More specifically, the weighted indices were computed like this:

$$GAI = (0.729*GAI1 + 0.420*GAI2 + 0.709*GAI3 + 0.860*GAI4) / (0.729 + 0.420 + 0.709 + 0.860)$$

$$AA = (0.494*AA1 + 0.817*AA2 + 0.741*M\&E) / (0.494 + 0.817 + 0.741)$$

Results obtained from this SEM analysis with weighted indicators are almost identical to the results obtained from this SEM analysis with unweighted indicators. The fit of the model to the data was also excellent: CFI = 0.998, TLI = 0.997, and RMSEA = 0.023 (compared to CFI = 0.998, TLI = 0.998, and RMSEA = 0.019). Results obtained from this SEM analysis with weighted indicators were included in supplementary material (see supplementary material, Fig. 1).

5. Discussion

The aim of this paper was to develop and validate a bi-factor adaptation index at the level of urbanists and urban planners working for municipalities that could be used to monitor municipalities' adaptation progress. As the validation of the index is a continuous process over time, other studies will have to be conducted to confirm and enrich the present results. We will discuss this later in this section.

Through a series of analyses with a focus on factor structure, reliability, as well as concurrent and nomological validities, this study led to the development of an adaptation index formed by two main dimensions: groundwork adaptation initiatives and adaptation actions. Unfortunately, the relatively small number of observations for the number of parameters to estimate in our models prevented us from creating an index with a global dimension, which would have included both groundwork adaptation and adaptation action dimensions. This is why we developed a correlated first-order factor index. Nevertheless, the results of psychometric analyses indicated that the index created is a valid measure of these two theoretical constructs.

A key contribution of this research relates to the development of a valid and parsimonious index, based on simple actions that municipal staff can adopt. Municipal and government officials can therefore consider using the created indices to monitor and evaluate adaptation efforts at the municipal level. While the indicators included in the index could be used by municipal entities to monitor their adaptation efforts, these metrics could also become part of the information these organizations normally share with public agencies aiming to evaluate adaptation efforts at an aggregated level. However, future studies will be necessary to confirm the validity of the index created. A greater participation of urbanists and urban planners in similar studies would likely enrich the validity of the index developed, as larger sample sizes would make it possible to perform measurement invariance analyses. Such analyses are important because several factors (e.g., cultural differences, different cognitive processes, different interpretations of the wording of items or questions in a questionnaire, language specificities) could bias the results obtained on a test or scale and hence make the results from these indicators unsuitable for comparisons. In other words, in some cases, factors that are completely unrelated to a certain municipality's propensity to adapt can affect the probability of the municipality obtaining a given score to a question measuring the adoption of a specific adaptation action (e.g., reducing the area of asphalt surfaces). Consequently, such an indicator could be a reliable adaptation indicator in one context (in the sense that it does indeed capture a latent dimension of the construct to be measured), but not in another context. Therefore, it is important, in addition to ensuring that the actions chosen in an index are a valid measure of adaptation (in the sense that the selected behaviors are a valid representation of the construct to be measured), to also assume that the same indicators will be relevant in different contexts. Authors of future research could aim to verify the equivalence of the adaptation index with municipalities presenting different socioeconomic profiles (e.g., advantaged compared to disadvantaged neighborhoods).

The results of our study have important methodological implications for the monitoring and evaluation of adaptation. In the event that measurement invariance for a given index is confirmed (i.e., that the index works the same way for each group compared), the same indicators could be used at different moments in time, and at different levels (city, regional, provincial, etc.). This would open the possibility of assessing, in a given context, whether municipalities are adapting more than before (and therefore ruling out measurement errors), or of comparing municipalities' propensity to adapt between different places, such as cities, regions or countries. Furthermore, the development and validation of valid and parsimonious adaptation indices, and their recurring measurement, would make it possible to identify baselines that would serve as benchmarks to assess progress, the first measurement being a standard against which future progress would be assessed. Such development would help to define adaptation success, which is an important recurring issue in adaptation monitoring and evaluation (Dilling et al., 2019).

At the moment, the absence of indicators with a certain level of uniformity and aggregation limits the possibility of designing studies where different contexts are compared, and therefore prevents causal inferences from being made between the measures planned and implemented by municipalities and their possible consequences (Kuhlicke et al., 2020; Berkhout, 2012). Having valid indicators that allow comparisons over time and between different contexts could help link impacts to local adaptation actions. For instance, by capturing changes occurring over time or by using similar dimensions to compare municipalities that adopt adaptation actions to varying degrees, longitudinal studies with recurring valid indicators could reduce threats to internal validity (i.e., that an unmeasured process or confounding factors or variables might be responsible for the observed result). This would help to establish an attribution or contribution link between incremental

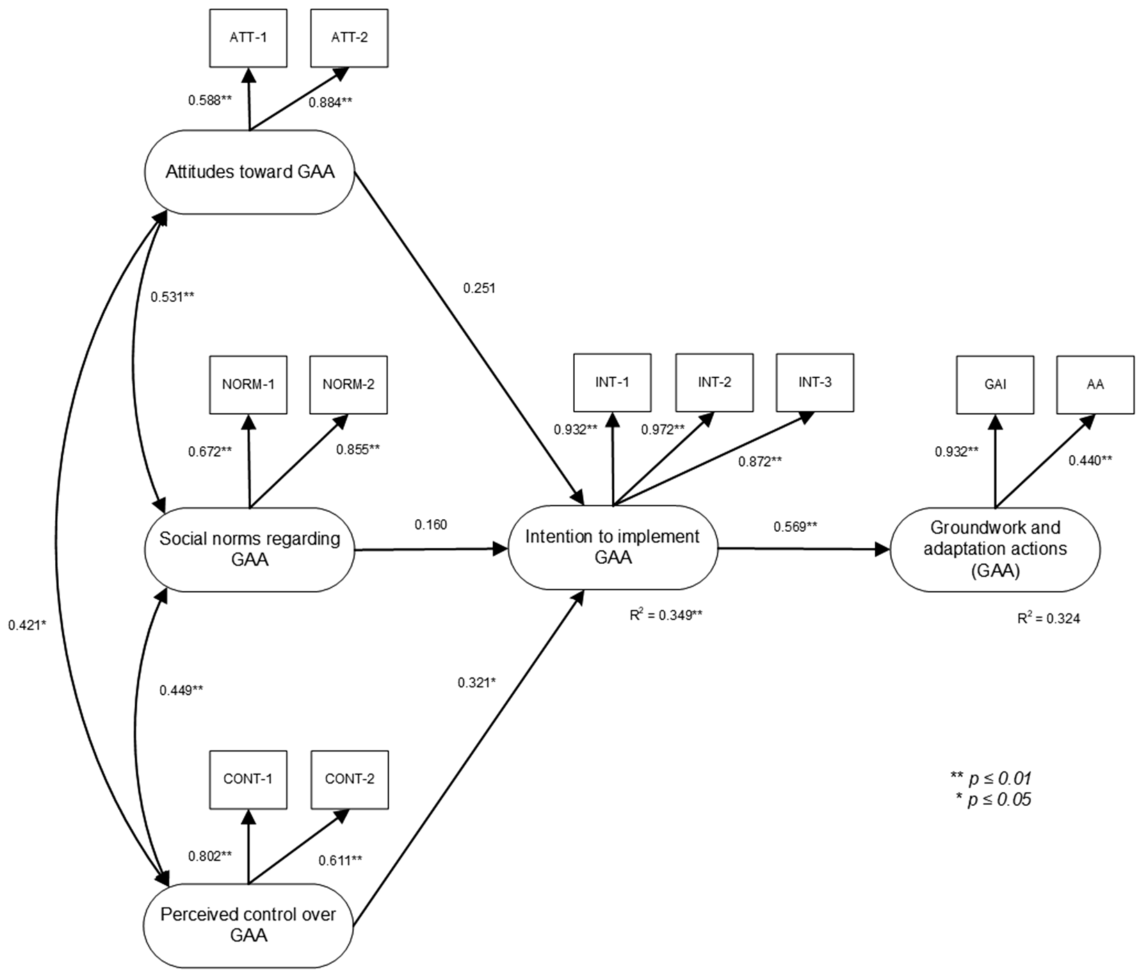

Fig. 3. TPB variables predicting the adoption of groundwork and adaptation actions.

adaptation actions and possible repercussions on a larger scale. Such repercussions could be, for example, a reduction of the losses associated with avoided impacts of climatic hazards, a decrease in elements of vulnerability following a municipality's adaptation efforts, or a strengthening of elements of resilience at the regional or group level, for example.

The actions included in the created index can be taken by municipalities to adapt to climate change. However, the results indicate that climate change management by Quebec municipalities is still limited. Our results also show that, overall, municipal entities whose staff members perceive risks associated with climate change for the municipality tend to adopt more groundwork adaptation initiatives and adaptation actions than those who perceive little or no risk at all. Dimensions of risk perception were always higher in the group of municipalities that were more active in adaptation than in the less active group. For this reason, the absence of significant differences for some variables (mostly regarding perceived risk and adoption of adaptation actions) coupled with small effect size is not worrisome, as this situation could be attributed to the size of the study sample, which was also relatively small.

This study has a few limitations. First, the low response rate obtained (11.41%) prevents us from claiming a representative portrait of the reality of municipal entities in Quebec. Therefore, we cannot rule out the possibility that our sample consisted mainly of municipal entities that were more proactive in terms of climate change adaptation. In addition, the low variance in the responses constitutes a second limitation. This situation led us to dichotomize the scores associated with the various adaptation actions measured in the questionnaire to avoid aberrant results in the construction of the index. For instance, the first modality (0) meant that the actions were adopted insufficiently or not at all and the second modality (1) indicated that the actions had been adopted at an acceptable level. Although this dichotomization theoretically reduced the variance in the responses, the reality of current adaptation in Quebec municipal entities (visible in the low frequency of adoption of certain actions) made this data transformation necessary. In this regard, our method was similar to the one used in Bélanger et al. (2015).

As a third limitation, it is possible that, since the index was based on its power of differentiation between municipal entities, certain adaptation actions could have been erroneously excluded. It could be argued that an action not retained in the index because it has a weak discriminating power (e.g., because it is not widely adopted by municipal entities) is still important to consider when monitoring and evaluating adaptation. However, it is important to keep in mind that the adaptation index developed in this study does not seek to determine dichotomously which municipalities adapt and which do not. Its objective is rather to measure adaptation at an aggregated level, which requires the identification of actions or behaviors that allow differentiation of municipal entities that adapt the most from those that adapt the least. As shown by our results, in the context of Quebec's municipal entities, only certain adaptation actions have the psychometric characteristics to do this.

As a fourth limitation, it could be argued that the index fails to consider the quality of the adaptation measures implemented, and that this dimension should be at the heart of determining the threshold separating municipalities that adapt the most from those that adapt the least. Once again, the cut-off points established for each of the groups of adaptation actions tested were intended to differentiate municipal entities that adapt the most and those that adapt less. The objective was not to create a dichotomy between "good" and "bad" municipal entities and to pass a normative judgment on their adaptation efforts. Of course, an adaptation measure, like any program or policy, can be a good idea on paper, but if its implementation fails, this would inevitably affect its quality. That said, considering the quality of the adaptation interventions implemented by municipalities would require a detailed portrait of their implementation, which is beyond the aim of the methodology used in this paper. It is nonetheless a recurring problem with the monitoring and evaluation of adaptation (Jacob et al., 2021).

Finally, the choice was made not to use a method where experts would have examined the retained items to determine a threshold or passing mark for each. This choice was motivated primarily by the difficulties of applying such a method for indices measuring more abstract traits (such as climate change adaptation). Indeed, an expert would have great difficulty estimating the probability that a municipality with just the desired degree of propensity to adapt would obtain the correct "answer" to an item that would put this municipality in the group considered to be adapting. Furthermore, because the type of judgment requested from experts is difficult, hypothetical, and often subjective (Clauser, 2013), this method is cumbersome and would also require empirical testing of the identified thresholds (Zieky and Perie, 2006).

6. Conclusion

This study led to the creation and validation of an index of climate change adaptation with sound factor structure, good reliability, and construct validity. The index is composed of indicators representing actions that are carried out by the staff of municipal entities within their usual mandates. Whereas further testing is necessary (for instance, to confirm the unidimensionality of the actions included in the index developed or the invariance of the index across different contexts), our results already suggest that the index presented has good validity. Municipal and government officials can therefore consider using it to monitor and evaluate adaptation efforts at the municipal level.

7. Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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CRediT authorship contribution statement

Johann Jacob: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Pierre Valois:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – review & editing. **Maxime Tessier:** Data curation, Formal analysis, Visualization, Writing – review & editing.

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.ecolind.2022.108537.

References

Adger, W.N., Arnell, N.W., Tompkins, E.L., 2005. Successful adaptation to climate change across scales. Global Environ. Change 15 (2), 77–86. https://doi.org/10.1016/j.gloenvcha.2004.12.005.

Afroz, R., Masud, M.M., Akhtar, R., Islam, M.A., Duasa, J.B., 2015. Consumer purchase intention towards environmentally friendly vehicles : An empirical investigation in Kuala Lumpur, Malaysia. Environ. Sci. Pollut. Res. 22 (20), 16153–16163. https://doi.org/10.1007/s11356-015-4841-8.

Ajzen, I., 1991. The theory of planned behavior. Organ. Behav. Hum. Decis. Process. 50 (2), 179–211. https://doi.org/10.1016/0749-5978(91)90020-T.

Akompab, D.A., Bi, P., Williams, S., Grant, J., Walker, I.A., Augoustinos, M., 2013. Heat waves and climate change : Applying the health belief model to identify predictors of risk perception and adaptive behaviours in Adelaide, Australia. Int. J. Environ. Res. Public Health 10 (6), 2164–2184. https://doi.org/10.3390/ijerph10062164.

American Educational Research Association, American Psychological Association, National Council on Measurement in Education, 2014. Standards for educational and psychological testing. Washington, DC: American Psychological Association.

Araos, M., Berrang-Ford, L., Ford, J.D., Austin, S.E., Biesbroek, R., Lesnikowski, A., 2016. Climate change adaptation planning in large cities : A systematic global assessment. Environ. Sci. Policy 66, 375–382. https://doi.org/10.1016/j.envsci.2016.06.009.

Ayers, J., Faulkner, L., 2012. Action research for community-based adaptation (CBA) in Bangladesh (ARCAB): M&E and baseline strategy for CBA (Final report). International Centre for Climate Change and Development (ICCCAD), Dhaka, Bangladesh.

Baker, F.B., 2001. The basics of item response theory. ERIC Clearinghouse on Assessment and Evaluation, College Park, MD.

Bélanger, D., Abdous, B., Gosselin, P., Valois, P., 2015. An adaptation index to high summer heat associated with adverse health impacts in deprived neighborhoods. Clim. Change 132 (2), 279–293. https://doi.org/10.1007/s10584-015-1420-4.

Berkhout, F., 2012. Adaptation to climate change by organizations. Wiley Interdiscip. Rev. Clim. Change 3 (1), 91–106. https://doi.org/10.1002/wcc.154.

Berkhout, F., Hertin, J., Gann, D.M., 2006. Learning to adapt : Organisational adaptation to climate change impacts. Clim. Change 78 (1), 135–156. https://doi.org/10.1007/s10584-006-9089-3.

Berrang-Ford, L., Biesbroek, R., Ford, J.D., Lesnikowski, A., Tanabe, A., Wang, F.M., Chen, C., Hsu, A., Hellmann, J.J., Pringle, P., Grecequet, M., Amado, J.-C., Huq, S., Lwasa, S., Heymann, S.J., 2019. Tracking global climate change adaptation among governments. Nat. Clim. Change 9 (6), 440–449. https://doi.org/10.1038/s41558-019-0490-0.

Berrang-Ford, L., Ford, J.D., Paterson, J., 2011. Are we adapting to climate change? Global Environ. Change 21 (1), 25–33. https://doi.org/10.1016/j.gloenvcha.2010.09.012.

Biagini, B., Bierbaum, R., Stults, M., Dobardzic, S., McNeeley, S.M., 2014. A typology of adaptation actions : A global look at climate adaptation actions financed through the Global Environment Facility. Global Environ. Change 25, 97–108. https://doi.org/10.1016/j.gloenvcha.2014.01.003.

Brooks, N., Anderson, S., Ayers, J., Burton, I., Tellam, I., 2011, November. Tracking adaptation and measuring development. [Working paper]. Retrieved from International Institute for Environment and Development website: https://pubs.iied.org/pdfs/10031IIED.pdf.

Brooks, N., Adger, N., Kelly, M., 2005. The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Global Environ. Change 15 (2), 151–163. https://doi.org/10.1016/j.gloenvcha.2004.12.006.

Bulkeley, H., Broto, V.C., Edwards, G., 2012. Bringing climate change to the city : Towards low carbon urbanism? Local Environ. 17 (5), 545–551. https://doi.org/10.1080/13549839.2012.681464.

Carman, J.P., Zint, M.T., 2020. Defining and classifying personal and household climate change adaptation behaviors. Global Environ. Change 61, 102062. https://doi.org/10.1016/j.gloenvcha.2020.102062.

Chan, H.-W., Pong, V., Tam, K.-P., 2020. Explaining participation in Earth Hour : The identity perspective and the theory of planned behavior. Clim. Change 158 (3), 309–325. https://doi.org/10.1007/s10584-019-02554-y.

Clauser, J.C., 2013. Examination of the application of item response theory to the Angoff standard setting procedure (Doctoral dissertation, University of Massachusetts Amherst). Retrieved from ProQuest Dissertations and Theses (UMI No. 3603067).

Delaney, J.T., Bouska, K.L., Eash, J.D., Heglund, P.J., Allstadt, A.J., 2021. Mapping climate change vulnerability of aquatic-riparian ecosystems using decision-relevant indicators. Ecol. Ind. 125, 107581. https://doi.org/10.1016/j.ecolind.2021.107581.

Deng, Y., Wang, M., Yousefpour, R., 2017. How do people's perceptions and climatic disaster experiences influence their daily behaviors regarding adaptation to climate change? — A case study among young generations. Sci. Total Environ. 581–582, 840–847. https://doi.org/10.1016/j.scitotenv.2017.01.022.

Dilling, L., Prakash, A., Zommers, Z., Ahmad, F., Singh, N., de Wit, S., Nalau, J., Daly, M., Bowman, K., 2019. Is adaptation success a flawed concept? Nat. Clim. Change 9 (8), 572–574. https://doi.org/10.1038/s41558-019-0539-0.

Dinshaw, A., Fisher, S., McGray, H., Rai, N., Schaar, J., 2014, December. Monitoring and Evaluation of Climate Change Adaptation. [Working paper]. Retrieved from OECD iLibrary website: https://www.oecd-ilibrary.org/fr/environment/monitoring-and-evaluation-of-climate-change-adaptation_5jxrclr0ntjd-en.

Doran, E.M.B., Zia, A., Hurley, S.E., Tsai, Y., Koliba, C., Adair, C., Schattman, R.E., Rizzo, D.M., Méndez, V.E., 2020. Social-psychological determinants of farmer intention to adopt nutrient best management practices : Implications for resilient adaptation to climate change. J. Environ. Manage. 276, 111304. https://doi.org/10.1016/j.jenvman.2020.111304.

Dupuis, J., Biesbroek, R., 2013. Comparing apples and oranges : The dependent variable problem in comparing and evaluating climate change adaptation policies. Global Environ. Change 23 (6), 1476–1487. https://doi.org/10.1016/j.gloenvcha.2013.07.022.

Ebi, K.L., Semenza, J.C., 2008. Community-based adaptation to the health impacts of climate change. Am. J. Prev. Med. 35 (5), 501–507. https://doi.org/10.1016/j.amepre.2008.08.018.

Edmonds, H.K., Lovell, J.E., Lovell, C.A.K., 2020. A new composite climate change vulnerability index. Ecol. Ind. 117, 106529. https://doi.org/10.1016/j.ecolind.2020.106529.

El-Zein, A., Ahmed, T., Tonmoy, F., 2021. Geophysical and social vulnerability to floods at municipal scale under climate change : The case of an inner-city suburb of Sydney. Ecol. Ind. 121, 106988 https://doi.org/10.1016/j.ecolind.2020.106988.

Ensor, J., Berger, R., 2009. Community-based adaptation and culture in theory and practice. Cambridge University Press, New York, NY.

Eriksen, S.H., Kelly, P.M., 2007. Developing Credible Vulnerability Indicators for Climate Adaptation Policy Assessment. Mitig. Adapt. Strat. Glob. Change 12 (4), 495–524.

Faulkner, L., Ayers, J., Huq, S., 2015. Meaningful Measurement for Community-Based Adaptation. New Directions for Evaluation 2015 (147), 89–104. https://doi-org.acces.bibl.ulaval.ca/10.1002/ev.20133.

Feldmeyer, D., Wilden, D., Jamshed, A., Birkmann, J., 2020. Regional climate resilience index : A novel multimethod comparative approach for indicator development, empirical validation and implementation. Ecol. Ind. 119, 106861. https://doi.org/10.1016/j.ecolind.2020.106861.

Ferrier, S., Harwood, T.D., Ware, C., Hoskins, A.J., 2020. A globally applicable indicator of the capacity of terrestrial ecosystems to retain biological diversity under climate change : The bioclimatic ecosystem resilience index. Ecol. Ind. 117, 106554. https://doi.org/10.1016/j.ecolind.2020.106554.

Fishbein, M., Ajzen, I., 2010. Predicting and changing behavior : The reasoned action approach. Psychology Press, New York, NY.

Ford, J., Berrang-Ford, L., 2016. The 4Cs of adaptation tracking : Consistency, comparability, comprehensiveness, coherency. Mitig. Adapt. Strat. Glob. Change 21 (6), 839–859. https://doi.org/10.1007/s11027-014-9627-7.

Ford, J.D., Berrang-Ford, L., Biesbroek, R., Araos, M., Austin, S.E., Lesnikowski, A., 2015. Adaptation tracking for a post-2015 climate agreement. Nat. Clim. Change 5 (11), 967–969. https://doi.org/10.1038/nclimate2744.

Gore, C., Robinson, P., 2009. Local Government Response to Climate Change : Our Last, Best Hope? In: Selin, H., VanDeveer, S.D. (Eds.), Changing Climates in North American Politics : Institutions, Policymaking and Multilevel Governance. MIT Press, Cambridge, MA, pp. 137–158.

Greenacre, M.J., 1984. Theory and applications of correspondence analysis. Academic Press, London, UK.

Grothmann, T., Patt, A., 2005. Adaptive capacity and human cognition : The process of individual adaptation to climate change. Global Environ. Change 15 (3), 199–213. https://doi.org/10.1016/j.gloenvcha.2005.01.002.

Hagger, M.S., Gucciardi, D.F., Chatzisarantis, N.L.D., 2017. On Nomological Validity and Auxiliary Assumptions : The Importance of Simultaneously Testing Effects in Social Cognitive Theories Applied to Health Behavior and Some Guidelines. Front. Psychol. 8, 1933. https://doi.org/10.3389/fpsyg.2017.01933.

Hayduk, L., Cummings, G., Boadu, K., Pazderka-Robinson, H., Boulianne, S., 2007. Testing ! Testing ! One, two, three – Testing the theory in structural equation models! Personality Individ. Differ. 42 (5), 841–850. https://doi.org/10.1016/j.paid.2006.10.001.

Hengst-Ehrhart, Y., 2019. Knowing is not enough : Exploring the missing link between climate change knowledge and action of German forest owners and managers. Ann. For. Sci. 76 (4), 94. https://doi.org/10.1007/s13595-019-0878-z.

Henstra, D., 2012. Toward the climate-resilient city : Extreme weather and urban climate adaptation policies in two Canadian provinces. J. Comp. Policy Anal. Res. Pract. 14 (2), 175–194. https://doi.org/10.1080/13876988.2012.665215.

Hinkel, J., 2011. Indicators of vulnerability and adaptive capacity : Towards a clarification of the science–policy interface. Global Environ. Change 21 (1), 198–208. https://doi.org/10.1016/j.gloenvcha.2010.08.002.

Hogan, T.P., 2007. Psychological testing : A practical introduction, 2nd ed. John Wiley & Sons, Hoboken, NJ.

Hosmer, D.W., Lemeshow, S., 1989. Applied logistic regression, 1rst ed. Wiley, Hoboken, NJ.

Hox, J.J., Bechger, T.M., 1998. An introduction to structural equation modeling. Family Sci. Rev. 11, 354–373.

Hu, L., Bentler, P.M., 1999. Cutoff criteria for fit indexes in covariance structure analysis : Conventional criteria versus new alternatives. Struct. Eq. Model. Multidiscip. J. 6 (1), 1–55. https://doi.org/10.1080/10705519909540118.

IPCC, 2018. Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Retrieved from Intergovernmental Panel on Climate Change (IPCC) website: https://www.ipcc.ch/sr15/.

IPCC, 2014a. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects (Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change). Retrieved from Intergovernmental Panel on Climate Change (IPCC) website: https://www.ipcc.ch/report/ar5/wg2/.

IPCC, 2014b. Annex II: Glossary [Agard, J., E.L.F. Schipper, J. Birkmann, M. Campos, C. Dubeux, Y. Nojiri, L. Olsson, B. Osman-Elasha, M. Pelling, M.J. Prather, M.G. Rivera-Ferre, O.C. Ruppel, A. Sallenger, K.R. Smith, A.L. St. Clair, K.J. Mach, M.D. Mastrandrea, and T.E. Bilir (Eds.)]. In V. R. Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, & L.L. White (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY: Cambridge University Press. Retrieved from Intergovernmental Panel on Climate Change (IPCC) website: https://www.ipcc.ch/report/ar5/wg2/.

Jacob, J., Valois, P., Tessier, M., 2021. Using the theory of planned behavior to predict the adoption of heat and flood adaptation behaviors by municipal authorities in the province of Quebec, Canada. Sustainability 13 (5), 2420. https://doi.org/10.3390/su13052420.

Kim, S., Jeong, S.-H., Hwang, Y., 2013. Predictors of pro-environmental behaviors of american and korean students : The application of the Theory of reasoned action and protection motivation Theory. Sci. Commun. 35 (2), 168–188. https://doi.org/10.1177/1075547012441692.

Klein, R.J.T., 2009. Identifying countries that are particularly vulnerable to the adverse effects of climate change : An academic or a political challenge? Carbon Clim. Law Rev. 3 (3), 284–291.

Kline, R.B., 2015. Principles and practice of structural equation modeling, 4th ed. Guilford Press, New York, NY.

Kuhlicke, C., Seebauer, S., Hudson, P., Begg, C., Bubeck, P., Dittmer, C., Grothmann, T., Heidenreich, A., Kreibich, H., Lorenz, D.F., Masson, T., Reiter, J., Thaler, T., Thieken, A.H., Bamberg, S., 2020. The behavioral turn in flood risk management, its assumptions and potential implications. WIREs Water 7 (3), e1418. https://doi.org/10.1002/wat2.1418.

Lesnikowski, A., Ford, J., Berrang-Ford, L., Biesbroek, R., 2017. Assessing adaptation progress at the global level : Conceptual and methodological issues. [Technical report]. Retrieved from the United Nations Environment Program (UNEP).

Lesnikowski, A., Ford, J., Biesbroek, R., Berrang-Ford, L., Heymann, S.J., 2016. National-level progress on adaptation. Nat. Clim. Change 6 (3), 261–264. https://doi.org/10.1038/nclimate2863.

Li, W., Ruiz-Menjivar, J., Zhang, L., Zhang, J., 2021. Climate change perceptions and the adoption of low-carbon agricultural technologies : Evidence from rice production systems in the Yangtze River Basin. Sci. Total Environ. 759, 143554. https://doi.org/10.1016/j.scitotenv.2020.143554.

Liu, T., Xu, Y.J., Zhang, Y.H., Yan, Q.H., Song, X.L., Xie, H.Y., Luo, Y., Rutherford, S., Chu, C., Lin, H.L., Ma, W.J., 2013. Associations between risk perception, spontaneous adaptation behavior to heat waves and heatstroke in Guangdong province, China. BMC Public Health 13 (1), 913. https://doi.org/10.1186/1471-2458-13-913.

MAMOT, 2016. L'organisation municipale au Québec en 2016. Retrieved from. https://www.mamh.gouv.qc.ca/fileadmin/publications/organisation_municipale/organisation_territoriale/organisation_municipale_2016.pdf.

Masud, M.M., Al-Amin, A.Q., Junsheng, H., Ahmed, F., Yahaya, S.R., Akhtar, R., Banna, H., 2016. Climate change issue and theory of planned behaviour : Relationship by empirical evidence. J. Cleaner Prod. 113, 613–623. https://doi.org/10.1016/j.jclepro.2015.11.080.

Meinel, U., Höferl, K.-M., 2017. Non-adaptive behavior in the face of climate change : First insights from a behavioral perspective based on a case study among firm managers in alpine Austria. Sustainability 9 (7), 1132. https://doi.org/10.3390/su9071132.

Messick, S., 1989. Validity. In: Linn, R.L. (Ed.), Educational measurement, 3th ed. American Council on Education/Macmillan, New York, NY, pp. 13–103.

Muthén, B.O., Muthén, L.K., Asparouhov, T., 2015. Estimator choices with categorical outcomes. Retrieved from. http://www.statmodel.com/download/EstimatorChoices.pdf.

Muthén, L.K., Muthén, B.O., 2017. Mplus User's Guide, 8th ed. Retrieved from. https://www.statmodel.com/download/usersguide/MplusUserGuideVer_8.pdf.

Nilsson, A.E., Gerger Swartling, Å., Eckerberg, K., 2012. Knowledge for local climate change adaptation in Sweden : Challenges of multilevel governance. Local Environ. 17 (6–7), 751–767. https://doi.org/10.1080/13549839.2012.678316.

Obaidellah, U.H., Danaee, M., Mamun, M.A.A., Hasanuzzaman, M., Rahim, N.A., 2019. An application of TPB constructs on energy-saving behavioural intention among university office building occupants : A pilot study in Malaysian tropical climate. J. Hous. Built Environ. 34 (2), 533–569. https://doi.org/10.1007/s10901-018-9637-y.

O'Brien, K., Eriksen, S., Nygaard, L.P., Schjolden, A., 2007. Why different interpretations of vulnerability matter in climate change discourses. Clim. Policy 7 (1), 73–88. https://doi.org/10.1080/14693062.2007.9685639.

OECD, 2008. Handbook on constructing composite indicators. Methodology and user guide. [Technical report]. Retrieved from OECD website: http:oecd.org/std/42495745.pdf.

Papagiannakis, G., Lioukas, S., 2012. Values, attitudes and perceptions of managers as predictors of corporate environmental responsiveness. J. Environ. Manage. 100, 41–51. https://doi.org/10.1016/j.jenvman.2012.01.023.

Rydin, Y., Bleahu, A., Davies, M., Dávila, J.D., Friel, S., De Grandis, G., Groce, N., Hallal, P.C., Hamilton, I., Howden-Chapman, P., 2012. Shaping cities for health : Complexity and the planning of urban environments in the 21st century. Lancet

Commissions 379 (9831), 2079–2108. https://doi.org/10.1016/S0140-6736(12)60435-8.
Samejima, F., 1969. Estimation of Latent Ability Using a Response Pattern of Graded Scores (Psychometric Monograph No. 17). Richmond, VA: Psychometric Society. Retrieved from http://www.psychometrika.org/journal/online/MN17.pdf.
Savari, M., Gharechaee, H., 2020. Application of the extended theory of planned behavior to predict Iranian farmers' intention for safe use of chemical fertilizers. J. Cleaner Prod. 263, 121512. https://doi.org/10.1016/j.jclepro.2020.121512.
Semenza, J.C., Ploubidis, G.B., George, L.A., 2011. Climate change and climate variability: Personal motivation for adaptation and mitigation. Environ. Health 10 (1), 46. https://doi.org/10.1186/1476-069X-10-46.
Sharma, P., Sharma, S., 2011. Drivers of proactive environmental strategy in family firms. Bus. Ethics Q. 21 (2), 309–334. https://doi.org/10.5840/beq201121218.
Siders, A.R., 2018. Adaptive capacity to climate change : A synthesis of concepts, methods, and findings in a fragmented field. Wiley Interdiscip. Rev. Clim. Change e573. https://doi.org/10.1002/wcc.573.
Simonet, G., 2015. Une brève histoire de l'adaptation : L'évolution conceptuelle au fil des rapports du GIEC (1990–2014). Nat. Sci. Sociétés 23, S52–S64. https://doi.org/10.1051/nss/2015018.
Smit, B., Wandel, J., 2006. Adaptation, adaptive capacity and vulnerability. Global Environ. Change 16 (3), 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008.
Taghikhah, F., Voinov, A., Shukla, N., Filatova, T., 2020. Exploring consumer behavior and policy options in organic food adoption : Insights from the Australian wine sector. Environ. Sci. Policy 109, 116–124. https://doi.org/10.1016/j.envsci.2020.04.001.
Valois, P., Houssemand, C., Germain, S., Abdous, B., 2011. An open source tool to verify the psychometric properties of an evaluation instrument. Procedia - Social Behav. Sci. 15, 552–556. https://doi.org/10.1016/j.sbspro.2011.03.140.
Valois, P., Talbot, D., Caron, M., Carrier, M.-P., Morin, A.J.S., Renaud, J.-S., Jacob, J., Gosselin, P., 2017. Development and validation of a behavioural index for adaptation to high summer temperatures among urban dwellers. Int. J. Environ. Res. Public Health 14 (7), 820. https://doi.org/10.3390/ijerph14070820.
Wang, Y., Liang, J., Yang, J., Ma, X., Li, X., Wu, J., Yang, G., Ren, G., Feng, Y., 2019. Analysis of the environmental behavior of farmers for non-point source pollution control and management : An integration of the theory of planned behavior and the protection motivation theory. J. Environ. Manage. 237, 15–23. https://doi.org/10.1016/j.jenvman.2019.02.070.
Wilson, R.S., Herziger, A., Hamilton, M., Brooks, J.S., 2020. From incremental to transformative adaptation in individual responses to climate-exacerbated hazards. Nat. Clim. Change 10 (3), 200–208. https://doi.org/10.1038/s41558-020-0691-6.
Wu, Y.i., Que, W., Liu, Y.-G., Cao, L.i., Liu, S.-b., Zhang, J., 2020. Is resilience capacity index of Chinese region performing well? Evidence from 26 provinces. Ecol. Ind. 112, 106088. https://doi.org/10.1016/j.ecolind.2020.106088.
Yaghoubi Farani, A., Mohammadi, Y., Ghahremani, F., 2019. Modeling farmers' responsible environmental attitude and behaviour : A case from Iran. Environ. Sci. Pollut. Res. 26 (27), 28146–28161. https://doi.org/10.1007/s11356-019-06040-x.
Zhang, F., Welch, E.W., Miao, Q., 2018. Public organization adaptation to extreme events : Mediating role of risk perception. J. Public Administration Res. Theory 28 (3), 371–387. https://doi.org/10.1093/jopart/muy004.
Zhang, X., Geng, G., Sun, P., 2017. Determinants and implications of citizens' environmental complaint in China: Integrating theory of planned behavior and norm activation model. J. Cleaner Prod. 166, 148–156. https://doi.org/10.1016/j.jclepro.2017.08.020.
Zieky, M., Perie, M., 2006. A Primer on Setting Cut Scores on Tests of Educational Achievement. Retrieved from https://www.ets.org/research/policy_research_reports/publications/publication/2006/dbkw.