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General Morphological Analysis in Public Health Emergency Management: An Environmental Scan

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ABSTRACT

Background

Uncertainty is inherent in public health emergency management (PHEM) due to the unpredictable nature of some emergencies and interplay of public health threats and their drivers. PHEM practitioners must continuously develop and adapt methods to manage this uncertainty. General morphological analysis (GMA) is a computer-aided scenario modelling method that can address complex, uncertain problems. GMA examines components of a complex problem and allows practitioners to consider potential connections and outcomes. Through iterative steps, GMA can generate new knowledge and insights in the development of scenarios to aid in decision-making and planning within PHEM.

Method

An environmental scan was designed to identify articles that applied GMA as one of the primary methodologies to support natural hazards management with potential extrapolation to PHEM. Academic databases included PubMed and ResearchGate. A broad search strategy was applied to scan grey literature, including Google Scholar.

Results

This environmental scan identified ten examples of GMA with PHEM relevance across multiple countries and organizations. Examples in the literature targeted either a specific natural hazard or more broadly all known natural hazards. The findings can be divided into three interconnected categories: (a) scenario modelling for managing natural disasters, (b) strategy development and prioritization tools, and (c) decision-making support tools for emergency management teams.

Conclusion

GMA can support the development of scenarios and strategies to inform decision-making on which course of action should be selected to address uncertainties. This modelling method leverages subject matter experts to uncover unforeseen connections and outcomes when navigating complex problems like those observed within PHEM. Future research can involve applying GMA to PHEM in a Canadian context. Currently, the Public Health Agency of Canada is applying GMA to cyclical events (e.g., wildfires, floods, extreme heat events, and extreme weather events) to create scenarios using a PHEM lens. Future practice should involve integrating GMA with other PHEM methodologies to enhance strategies to prevent, prepare, respond, and recover from future public health emergencies.

Keywords: GMA, public health, emergency management, natural hazards

1.0 Introduction

Effective Public Health Emergency Management (PHEM) is essential for mitigating the impacts of natural hazards, such as wildfires, which can lead to significant public health consequences, including increased demand for health services and risk of chronic diseases (Giorgadze et al., 2011; Rose et al., 2017). Specifically, PHEM can be defined as the integration of knowledge, techniques, and principles of public health (PH) and emergency management (EM) to address complex emergencies affecting the health system and population health (Rose et al., 2017). In addition, the COVID-19 pandemic has highlighted gaps within the PH system due to inadequate resources and tools, leading to critical challenges and vulnerability when dealing with new and emerging threats (Public Health Agency of Canada, 2021). Thus, a need has been identified specifically for EM organizations to promote continuous enhancement and innovation to increase resilience and better respond to new threats (Public Safety Canada, 2025).

In Canada, PHEM is a shared responsibility among federal, provincial, and territorial governments, who are mandated to coordinate responses to mitigate, prepare, respond, and recover from a wide range of public health threats (Public Safety Canada, 2017). As part of this coordinated effort, scenario planning serves as a critical organizational framework, supporting activities such as capability-based planning, resource allocation, and other preparedness activities (Hales & Chouinard, 2011; Hoerger et al., 2022; Neiner et al., 2004). Scenario planning offers a forward-looking approach by developing and analyzing possible future scenarios to inform decision-making in the face of uncertainty (Bin Nafisah, 2021).

Uncertainty is an inherent aspect of PHEM due to the unpredictable nature of emergencies and the complex interplay of various factors involved (United Nations High Commissioner for Refugees, 2023). It arises when attempting to predict the likelihood, impact, exposure, and vulnerability of a PH threat due to the multitude and complexity of risk drivers, thereby complicating decision-making and planning processes (Handmer, 2008; Reisinger et al., 2020). These challenges make it essential for PH agencies to continually adopt robust methods that can effectively help manage such uncertainties (Handmer, 2008; Reisinger et al., 2020). However, current scenario planning practices within PHEM often rely on narrative-based formats which are less exploratory and rely on storytelling to develop a limited number of scenarios (Beach, 2021; Gaßner & Steinmüller, 2018; Kosow & Gaßner, 2008). This restricts the ability to systematically explore key elements and diverse outcomes. Introducing biases and restricting the consideration of alternative scenarios, can hinder the effectiveness of emergency responses (Beach, 2021; Gaßner & Steinmüller, 2018; Kosow & Gaßner, 2008).

General Morphological Analysis (GMA) offers a structured and adaptable method and can be used as a tool for scenario development within PHEM (Lantada et al., 2020; Ritchey, 2022). GMA facilitates the deconstruction of complex problems into their core components, allowing for the exploration of various possible scenarios and their interconnections (Lantada et al., 2020; Ritchey, 2022). Unlike traditional narrative approaches which focus on limited scenarios and key elements, GMA leads to numerous scenarios that can be compared to one another and considers a wide range of core elements. Thus, as an innovative scenario planning tool, GMA can potentially support PH agencies to better manage uncertainties and enhance strategic planning efforts for various emergencies (Garvey, 2017; Lantada et al., 2020; Neiner et al., 2004; Ritchey, 2022).

This environmental scan will explore the application of GMA as a forward-looking tool through scenario development to aid in decision-making and planning in PHEM. This paper examines natural hazards, recognizing Canada's exposure to diverse natural hazards that are associated with complex PH consequences (Giorgadze et al., 2011). Furthermore, since the practice and principles of EM are grounded in an all-hazards approach, the findings of this paper—while focused on natural hazards—are broadly applicable across sectors. This cross-applicability implies that tools used in managing natural disasters can be adapted to address a range of other PHEM threats. The findings of this paper will be highlighted by examples of GMA's contributions through case studies from different countries and organizations. These case studies are provided later in this paper to illustrate the practical impact and adaptability of GMA across diverse contexts with relevance to PHEM. By examining the relevance of GMA for PH, this study aims to adapt these insights to strengthen scenario planning in the Canadian context.

2.0 Methods

An environmental scan is a method of searching, collecting, interpreting, and utilizing information from numerous sources (e.g., grey literature and journal articles) to provide evidence-based data to support strategic decision-making (Charlton et al., 2019; Graham et al., 2008). A primary benefit of an environmental scan is that information can be leveraged from various social, cultural, political, and technological *fields*, which provides the author the ability to address limitations and identify biases (Charlton et al., 2019; Graham et al., 2008). While there is no formal methodology to conduct an environmental scan, the primary purpose of this approach is to acquire new insights that inform the establishment of actionable objectives for an organization (Rowel et al., 2005).

An environmental scan was chosen for this paper as the information on how GMA has been applied in PHEM is not just limited to academic literature but also substantially discussed in grey literature. Furthermore, environmental scans allow for rapid collection of data on trends within a targeted population from multiple data sources such as key informant interviews (Rowel et al., 2005). In our initial search, we found that GMA is an already established best practice for scenario development in sectors outside PH (Álvarez & Ritchey, 2015; Ritchey, 2009b, 2022). Provided, our objective to enhance scenario development methods, we selected an environmental scan as the most suitable approach, as it can reveal the method's applicability in similar fields. We anticipate that insights from these applications can inform scenario development within PHEM.

To determine relevant papers for this environmental scan, the following inclusion and exclusion criteria were applied:

- Inclusion:
  - Reports on using GMA as one of the primary methodologies across different natural hazards.
  - Has PHEM relevance, i.e., explicitly considers potential health impacts of hazards on human health or considers health systems, which in the context of an emergency, could affect or influence population health outcomes.
- Exclusion:
  - Reports not published in English.
  - No mention of GMA as one of the primary methods.
  - Study scope outside natural hazards.
  - Not of PHEM relevance.

The following databases and sources were utilized for this environmental scan.

- Key Databases and Search Engines:
  - PubMed/NCBI, ResearchGate, and Google Scholar.
- Key Terms:
  - GMA, Morphological analysis, Natural hazards, Decision-making support tool, Risk reduction, Disaster preparedness, Emergency Management, Scenario analysis/development/planning/modelling, and Disaster risk management/strategies.
- Sources:
  - Peer-reviewed academic papers, government reports, internet/grey literature, and the Swedish Morphological Society.

3.0 General Morphological Analysis

3.1 Definition

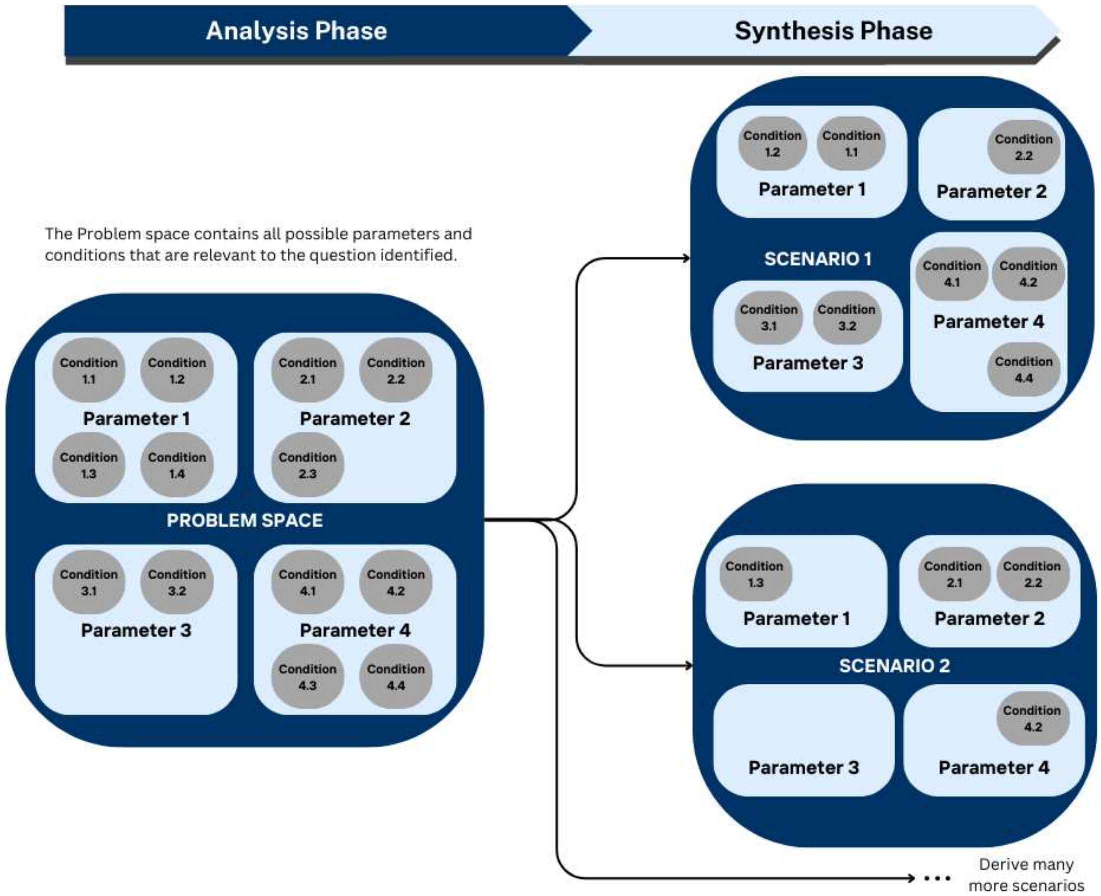
GMA is a computer-aided tool that supports the exploration of different connections between various components of a complex problem (Ritchey, 2022). These components are represented by parameters, which are further broken down into conditions. These conditions can then be combined in multiple ways to identify connections and solutions. The identification and investigation of these components involve engaging with subject matter experts (SMEs). For instance, when developing scenarios for a pandemic in the context of PHEM, the process of GMA can help identify parameters, such as infection transmission rates and health system capacity. Each parameter can have multiple conditions, such as high, medium, or low. These conditions can then be combined in various ways where connections and outcomes are examined, leading to a model with various applications (e.g., scenario development tool). GMA can provide PH agencies with a tool to support scenario development by comprehensively analyzing and integrating numerous key variables to create scenarios (Ritchey, 2022).

The process of GMA consists of two iterative steps, represented by cycles of analysis and synthesis phases (Ritchey, 2022). Figure 1 illustrates an overview of the GMA process. First, the problem is broken down into its components (i.e., parameters and conditions) and those components are then combined in various ways using GMA. As shown in Figure 1, within the GMA software, a model will be created that demonstrates several combinations of each component, allowing practitioners to consider different connections, resulting in multiple outcomes (e.g., various scenarios) of a complex problem (Ritchey, 2022).

For example, if GMA is applied to plan for a pandemic scenario, we can include multiple variables to consider what might happen if the disease spreads at a high rate and whether hospitals and current infrastructure have the capability to respond or not. Thus, GMA's ability to facilitate a comprehensive understanding of complex scenarios demonstrates GMA as a versatile tool that can be applied across various sectors to address complex challenges (Ritchey, 2022).

Figure 1

Overview of General Morphological Analysis



Note. A schematic representation of GMA, with the problem space containing the parameters and conditions resulting in multiple scenarios.

3.2 Principles and Concepts of GMA

The basic principle of GMA involves taking a complex problem and breaking it down into its basic components (Ritchey, 2022). For example, an infectious disease scenario can be deconstructed into key components such as virulence and transmission mode. These components can then be systematically recombined in a structured manner, allowing for the exploration of new connections and solutions that may not be initially apparent (Ritchey, 2022). Since GMA provides a structured approach to identify the critical components that define a problem and systematically explores all possible configurations, it ensures that no essential aspects of a problem are overlooked, allowing for a comprehensive process in developing complex scenarios (Ritchey, 2022). Thus, GMA would be suitable as a scenario planning tool to tackle the multifaceted challenges found within PHEM.

3.3 GMA Process

GMA is an iterative process that consists of two phases and is typically conducted by a group of SMEs with relevant expertise (e.g., an epidemiologist for an infectious disease scenario) to the identified problem (Lantada et al., 2020):

1. Problem definition and analysis phase
2. Synthesis phase

Step 1: Problem definition and Analysis phase

The problem definition stage is where a question is identified that is intended to be addressed through GMA (Lantada et al., 2020). There is no specific way to define a problem, but it can involve working with relevant SMEs. It can begin by determining a specific issue with an understanding of the broader context of the topic. For example, a topic of interest could be a natural hazard such as floods and then further narrowing down the focus to a key challenge or uncertainty within that context to create a question. This process is often driven by predefined goals, such as improving emergency response or mitigating public health risks, which helps to ensure that the issue chosen aligns with the desired outcomes of the analysis. This step serves as a roadmap for SMEs in subsequent phases, where they will identify and explore the various components related to a problem (Lantada et al., 2020).

Once the problem has been defined, a facilitated discussion with SMEs will guide the analysis phase by breaking down the problem into parameters and assigning conditions (Lantada et al., 2020). In the analysis phase, a structured table or a morphological field is created to represent the different components of the problem through parameters and conditions (Figure 2) (Lantada et al., 2020). For example, to elaborate on the infectious disease scenario mentioned above, virulence and transmission parameters can be further broken down. Virulence can include conditions such as high infectivity, medium infectivity, and low infectivity. Transmission can include conditions such as airborne, droplet, contact, and vector-borne. This table facilitates a comprehensive analysis by providing a structured approach to identifying and understanding how these conditions interact with each other (Lantada et al., 2020). These conditional pairs can showcase potential connections and solutions within the table that will be further examined by SMEs in the next phase (Lantada et al., 2020).

Figure 2

Infectious Disease Scenario Morphological Field

Parameter A	Parameter B	Parameter C	Parameter D
Condition A1	Condition B1	Condition C1	Condition D1
Condition A2	Condition B2	Condition C2	Condition D2
Condition A3		Condition C3	Condition D3
Condition A4		Condition C4	
Condition A5			

Transmission	Virulence	At risk Populations	Direct Health Impacts
Airborne	High infectivity	Young children	Fever
Droplet	Medium infectivity	Older adults (65+)	Muscle pain
Contact	Low infectivity	Indigenous people	Dehydration
Vector Borne		Immunocompromised individuals	

Note. Five-Parameters Structured Table or Morphological Field for an infectious disease scenario.

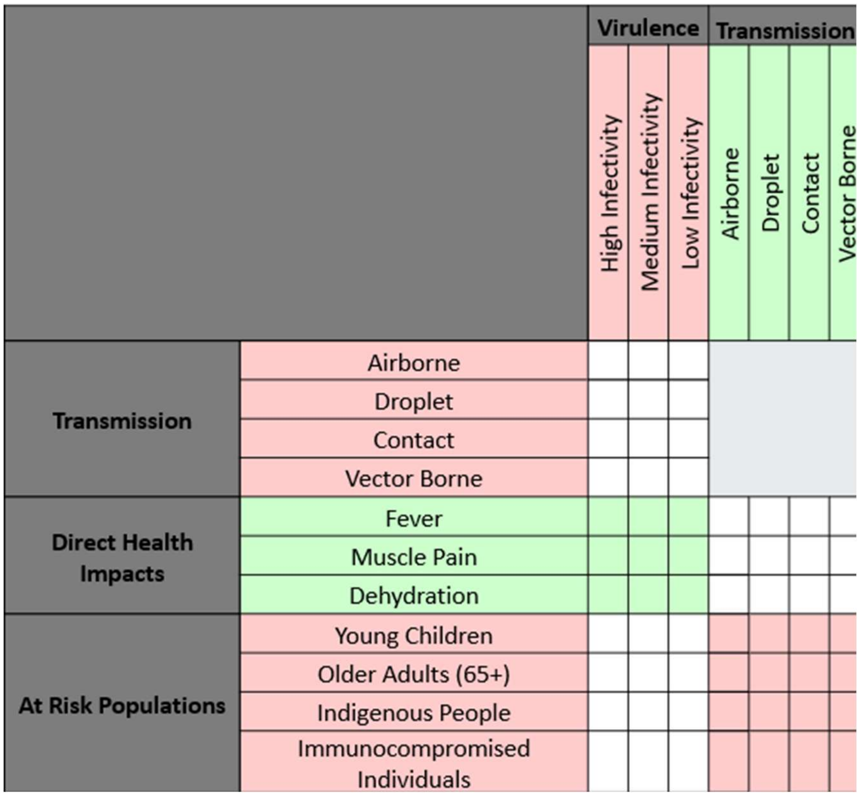
Step 2: Synthesis phase

The synthesis phase involves inputting parameters and conditions identified in the structured table from the analysis phase into the GMA software (Lantada et al., 2020; Ritchey, 2022). After these components have been entered, the software transforms the table into a cross-consistency matrix (Figure 3). This matrix supports discussions by enabling SMEs to systematically compare pairs of conditions to see if the elements in each conditional pair work together. Through these discussions, SMEs identify and remove conditions that contradict one another. SMEs are prompted to contemplate whether the conditional pairs can occur at the same time and fit together within the context of the problem. To do so, SMEs use one of three assessment keys (X, –, or K) and criteria to mark each pair of conditions. These assessment keys will be entered for each pair into the GMA software (Lantada et al., 2020; Ritchey, 2022):

- **X** = Contradictory or impossible/incompatible pair.
- "**–**" (hyphen) = Fully consistent; good or optimal pair.
- K = Uncertain or conditionally possible, with specific criteria, for example:
  - Possible but far-fetched or uninteresting relationships.
  - Need more information to make a grounded assessment.

Figure 3

Cross-consistency matrix



Note. A section of a cross-consistency matrix for a five-parameter morphological field.

For example, in a PHEM pandemic scenario (Figure 3), SMEs can consider if fever *(under direct health impacts)* and high infectivity *(under virulence)* can co-exist during an emergency. Since a fever is a common symptom for an infection with high infectivity, this pair of conditions would be marked as a fully consistent pair and given a "---" in the software.

Once this process is complete, the software will analyze all possible assessment keys, removing any pairs marked with an "X" (Lantada et al., 2020; Ritchey, 2022). This creates an inference model or "what if" model, where one or more conditions can be selected as inputs, and an output is provided with multiple outcomes and connections, as indicated in the dark blue boxes (Figure 4). GMA consists of iterative steps allowing for continuous scrutinization of the inference model to adjust previously established parameters and conditions to further refine the model (Lantada et al., 2020; Ritchey, 2022).

3.4 Applications of General Morphological Analysis

GMA has been applied in various fields within emergency management. Some applications include decision-making tools to support national crisis management, disaster risk management for natural disasters, and scenario development in an earthquake crisis (Hosseinikhah & Zarrabi, 2021; Lantada et al., 2020; Ritchey et al., 2004). The three examples presented below highlight how GMA has been implemented in various countries and contexts.

Figure 4

Morphological field or 'What-If' Model

Parameter A	Parameter B	Parameter C	Parameter D	Parameter E
Condition A1	Condition B1	Condition C1	Condition D1	Condition E1
Condition A2	Condition B2	Condition C2	Condition D2	Condition E2
Condition A3	Condition B3	Condition C3		Condition E3
Condition A4		Condition C4		Condition E4
		Condition C5		Condition E5

Note. Five-Parameters morphological field or 'what-if' inference model, with multiple configurations (Ritchey, 2009b).

Example 1: Sweden– Generic Design Basis Model for National Crisis Management

The Swedish Emergency Management Agency and the Swedish Defence Research Agency created a Generic Design Basis (GBD) model prototype using GMA (Figure 5) (Ritchey et al., 2004). The GBD model can support strategic decision-making and scenario planning for three hypothetical causes including natural, technological, and antagonistic, leading to adverse outcomes to society. Specifically, the GBD model can detect extraordinary societal events, determine the best crisis management measures, and create a national security strategy. Although still a prototype, this model has been tested at both local and regional government levels. It has shown value in enhancing risk and vulnerability assessments across various agencies, providing a framework for crisis management, and improving communication among different sectors (Ritchey et al., 2004).

Figure 5

Scenario Model

Generic Analytical Examples: expressed as threat levels	Where taking place	Number of fatalities	Number of seriously injured	Consequences for environment	Consequences for capital and property	Number of persons needing social assistance
Threat to society's existence	Far from Sweden	> 1 million deaths	Millions	Large geographical scope/ permanent damage	> 1000 billion $	Millions
Threat of permanent major damage	Close to Sweden	100, 000 - 1 million deaths	Hundreds of thousands	Limited geographical scope/ permanent damage	> 100 billion $	Hundreds of thousands
Major societal damage Only partial recovery	Partially in Sweden	> 10,000 - 100,000 deaths	Ten of thousands	Large geographical scope/ slow recovery	> 10 billion $	Tens of thousands
Major societal damage Full recovery possible	Only in Sweden	> 1000 - 10,000 deaths	Thousands	Limited geographical scope/ slow recovery	> 1 billion $	Thousands
Major accident		100 - 1000 deaths	Hundreds	Quick recovery	> 100 million $	Hundreds
Everyday accident		10 - 100 deaths Thousands injured	10 - 100	No substantial damage	< 10 million $	Less than one hundred
		< 10 deaths	< 10 seriously injured			

Note. A seven-parameter morphological field where scenarios can be generated. The conditions highlighted in blue are a scenario of a dam bursting in Sweden (Ritchey et al., 2004).

Example 2: Venezuela – Disaster Risk Mitigation Tool

Utilizing two models of GMA, the authors created a decision-making support tool for disaster risk management for natural hazards in urban areas (Figure 6) (Lantada et al., 2020). This tool prioritizes the most effective risk-reduction strategies to support urban areas during an emergency. GMA was utilized to examine strategies that reduce physical damage and improve vulnerability and resilience. Some strategies involve risk identification, risk reduction, and governance. Each strategy was ranked according to influence, ranging from favourable to no influence. The authors highlighted that this tool supported the prioritization of the most effective strategy during an emergency, thereby improving their decision-making process (Lantada et al., 2020).

Figure 6

Strategic Model

DESCRIPTORS of PHYSICAL DAMAGE		STRATEGIES							
		Risk identification		Risk reduction		Disaster management		Governance and financial protection	
X_{RPh1}	Percentage of destroyed area	*RI1*	Systematic disaster and loss inventory	*RR1*	Risk consideration in land use and urban planning	*DM1*	Organization and coordination of emergency operations	*FP1*	Inter-institutional, multi-sectoral and decentralizing organization
X_{RPh2}	Dead people	*RI2*	Hazard monitoring and forecasting	*RR2*	Hydrographical basin intervention and environmental protection	*DM2*	Emergency response planning and implementation of warning systems	*FP2*	Reserve funds for institutional strengthening
X_{RPh3}	Injured people	*RI3*	Hazard evaluation and mapping	*RR3*	Implementation of hazard-event control and protection techniques	*DM3*	Endowment of equipment, tool, and infrastructure	*FP3*	Budget allocation and mobilization
X_{RPh4}	Homeless	*RI4*	Vulnerability and risk assessment	*RR4*	Housing improvement and human settlement relocation from prone-areas	*DM4*	Simulation, updating, and test of inter-institutional response	*FP4*	Implementation of social safety nets and funds response
X_{RPh5}	Potential damage in the system of potable water	*RI5*	Public information and community participation	*RR5*	Updating and enforcement of safety standards and construction codes	*DM5*	Community preparedness and training	*FP5*	Insurance coverage and loss transfer strategies of public assets
X_{RPh6}	Damage for the road system	*RI6*	Training and education on risk management	*RR6*	Reinforcement and retrofitting of public and private assets	*DM6*	Rehabilitation and reconstruction planning	*FP6*	Housing and private sector insurance and reinsurance coverage

Note. A five-parameter morphological field that analyzes strategies to reduce physical damage in urban areas (Lantada et al., 2020).

Example 3: Iran – Scenario Development in an Earthquake Crisis

Scenario planning through GMA was used in earthquake disaster management to identify factors influencing the severity and financial impact of an earthquake in rural and urban settlements (Figure 7) (Hosseinikhah & Zarrabi, 2021). Multiple scenarios were developed based on the most effective and probable parameters identified. Each relationship was scored on a scale from 0% (no impact) to 100% (high impact), facilitating the identification of ideal scenarios. The most influential factors that decreased casualty and financial loss included city-level crisis documents, improved warning systems, and earthquake-resistant building codes. Additionally, specific cities and villages were identified as vulnerable to earthquakes through GMA. The authors emphasized that the model assisted in pinpointing mitigation strategies essential for enhancing the resilience of cities and villages vulnerable to earthquakes (Hosseinikhah & Zarrabi, 2021).

Figure 7

Scenario and decision-making tool model

Factors	Hypothesis			
	H1	H2	H3	H4
Comprehensive document of earthquake crisis	Compilation of comprehensive document for earthquake crisis (76%)	Injection of earthquake crisis management principles in all projects (15%)	Failure to formulate a comprehensive earthquake crisis document (5%)	Keeping up with the current trend (4%)
Earthquake alert systems	Design and construction of earthquake alert systems (40%)	Purchase of earthquake warning systems (50%)	Lack of attention to purchasing and designing earthquake warning systems (5%)	Keeping the earthquake alert strategy current (5%)
Strengthening the buildings	Increasing the retrofitting of buildings (63%)	Demolition of unstable buildings (17%)	Lack of attention to retrofitting buildings (10%)	Persistence of the status quo (10%)
Construction in the vicinity of faults	Preventing construction at fault (80%)	Prevention of the construction at seismic zones (14%)	Relocation and integration of earthquake-prone population centres (6%)	Continuation of the existing status of building construction (0%)
Telecommunications	Development of modern telecommunications infrastructure between people and government (60%)	Development of telecommunication infrastructure among the people (16%)	Development of telecommunications infrastructure among government agencies (20%)	Persistence of the status quo (4%)

Note. A portion of a five-parameter morphological field where scenarios were generated and analyzed for earthquake disaster management (Hosseinikhah & Zarrabi, 2021).

The examples provided above, drawn from literature within emergency management, use different versions of specialized GMA computer software. The examples above do not encompass the full range of GMA's diverse applications, which extend across numerous fields of study (Álvarez & Ritchey, 2015). While applications of GMA within PHEM have been rare, the application of GMA in other fields can be adapted to develop this methodology within PHEM. Specifically, scenario development through GMA is a valuable tool that could support addressing the pervasive uncertainty surrounding numerous PH issues today (Neiner et al., 2004).

3.5 Benefits and Limitations of GMA

Benefits

The environmental scan observed that GMA has successfully been applied with other modelling techniques, demonstrating its compatibility with other methods (Ritchey, 2009b). GMA can be integrated with other methods as a first step or a follow-up to other modelling techniques. For example, mind mapping can identify parameters and conditions which can then be examined and linked through GMA to identify scenarios or strategies (Ritchey, 2009b). In addition, GMA can inter-link two models (e.g., scenario and strategy models) where one model is used as input conditions, and the other as set of output conditions (Ritchey, 2011). This is considered a duplex model where two models are concurrently assessed to see how they inform one another (e.g., establishing the most effective strategies for different types of scenarios) (Ritchey, 2011).

GMA also enables decision-makers to discover novel solutions by considering multiple connections and outcomes of conditional pairs, especially when addressing complex issues dependent on interconnectivity with other sectors (Garvey, 2017; Swanich, 2014). Another advantage of GMA includes enhancing knowledge translation of scientific information through visual models and in promoting partner and stakeholder engagement through collaborative efforts to determine concepts and assess internal consistency (Ritchey, 2009b). Finally, GMA leaves an audit trail. The conclusions drawn from GMA are documented within the software, thus, increasing the traceability and reproducibility of data (Ritchey, 2009b).

Limitations

While advantages exist, challenges in applying GMA in PHEM have been identified in the literature. GMA is time-consuming, primarily as the quality of results heavily relies on the inputs of SMEs (Johansen, 2018; Ritchey, 2009b; Swanich, 2014). This process may require multiple sessions to work through the problem, thus, participants must be highly committed and adequately knowledgeable to provide quality data. This is especially true at the beginning of the process, considering the likelihood that the model may not yield valuable results. Additionally, dedicated software (e.g., MA/CARMA) is necessary to properly conduct GMA, which requires the commitment of financial resources.

Furthermore, GMA lacks a universal way to assess the effectiveness of the results (i.e., utilizing a specific tool) as it heavily relies on SMEs throughout the entire process. Given the complexity of PHEM, the number of configurations can grow exponentially. This leads to challenges including the inability to analyze all feasible connections and outcomes due to resource constraints. Finally, while GMA is a comprehensive method, the inputs from SMEs may not be exhaustive, as it is inherently challenging for SMEs to identify all possible parameters and conditions during facilitated discussion. Thus, all possible components may not all be identified within the model (Johansen, 2018; Ritchey, 2009b; Swanich, 2014). With that said, artificial intelligence (AI) may help alleviate most of these limitations and how in a time where AI is undergoing significant expansion due to the broad adoption of Large Language Models, there is an opportunity to integrate standard approaches like GMA with new AI powered tools.

4.0 Key Findings from the Environmental Scan

4.1 Notable contributions and advancements in the use of GMA

GMA is ultimately a flexible generic emergency management tool that supports decision-making processes by organizing complex information in a structured way. GMA's strength lies in gathering various inputs, organizing them systematically, and allowing users to consider all options and possibilities before making decisions. As GMA simply facilitates structured thinking, it can be adapted to other EM sectors beyond natural disaster management, including PHEM. Although most applied examples come from natural disaster management, GMA’s role remains the same: to bring structure, clarity, and thoroughness to decision-making by ensuring every relevant factor is considered and all potential strategies are explored. Findings from this research are shown in Table 1 are relevant to PHEM due to their broader applicability to EM. If GMA is effective within other sectors of EM, it can reasonably be inferred that these findings are equally applicable to PHEM. The examples below identified applications of GMA organized into the following categories:

1. Scenario modelling tool for the management of natural disasters
2. Decision-making tool for EM teams
3. Strategy development and prioritization tools (e.g., risk mitigation strategies)

5.0 Discussion and Implications

5.1 Discussion

This environmental scan is not a critical appraisal; therefore, we will not be assessing the suitability and applicability of GMA as a method compared to current scenario development methods. With that said, this paper identified ten examples of GMA that have PHEM relevance from across seven countries and five organizations. While the findings were targeted at natural hazards, the principles and techniques employed by GMA in other sectors demonstrate its potential for adaptability and effectiveness within other PHEM activities. For example, the processes for scenario building and strategy development are consistent across different types of hazards. GMA can support these activities through its structured yet flexible analytic approach. Secondly, as a computational tool, GMA has been designed to support EM processes across multiple emergencies, making it applicable across a diverse range of PHEM challenges. Furthermore, the integrative nature of GMA encourages a comprehensive consideration of various factors and SMEs, promoting a holistic approach to EM. These aspects illustrate how GMA findings from natural hazards applications are transferable and valuable to the broader field of PHEM. Despite its underutilization in PHEM to date, GMA's proven effectiveness in other complex fields positions it as a critically adaptable tool for enhancing decision-making processes in PHEM.

The prevalence of scenario modelling as a primary application of GMA in four of the ten reviewed studies highlighted its applicability and relevance in comprehensive EM (Fernandez et al., 2006; Hosseinikhah & Zarrabi, 2021; Navrátil et al., 2019; Schneider et al., 2022). Scenario modelling enabled the users to incorporate several factors concerning natural hazards into the model (e.g., number of fatalities), providing a broader picture of an emergency and an organization's response capacity to address it. These scenarios helped identify gaps in current EM plans, thereby strengthening the most effective approaches across various sectors, including government agencies and private organizations. The use of GMA as a tool provided the basis for decision-makers to prioritize ideal scenarios that support and strategize improvements in current EM plans (Fernandez et al., 2006; Hosseinikhah & Zarrabi, 2021; Navrátil et al., 2019; Schneider et al., 2022).

The identification of strategy development and prioritization in five of the ten articles underscores GMA's role in risk reduction and disaster preparedness (Fernandez et al., 2006; Lantada et al., 2020; Ritchey, 2006; Ritchey et al., 2004; Roy & Garg, 2014). These articles examined risk reduction strategies and compared disaster preparedness and mitigation plans. Through the comparisons of these plans, organizations developed new strategies aligned with best practices in disaster risk management. This highlights the adaptability of GMA as a tool in evolving EM strategies to meet changing needs and contexts of an emergency (Fernandez et al., 2006; Lantada et al., 2020; Ritchey, 2006; Ritchey et al., 2004; Roy & Garg, 2014).

Finally, six articles utilized GMA to create a decision-making support tool for emergencies (Fernandez et al., 2006; Lantada et al., 2020; Ritchey et al., 2004; Roy

& Garg, 2014; Savchenko, 2018; Watson et al., 2015). GMA provided a framework that presents an organization's emergency plans and mitigation strategies. For instance, it was used to develop effective mitigation strategies for natural hazards and assist in mitigation programs and funding (Lantada et al., 2020; Roy & Garg, 2014). These frameworks were used by EM stakeholders to make decisions during an emergency to plan, manage, and react effectively. These of GMA as a decision-making support tool highlights its applicability to support an organization's emergency preparedness and response activities (Fernandez et al., 2006; Lantada et al., 2020; Ritchey et al., 2004; Roy & Garg, 2014; Savchenko, 2018; Watson et al., 2015).

5.2 Identification of gaps or areas requiring further research or development

Table 1 references examples of how GMA was applied to the development of scenarios that may have PH relevance in a Canadian context. Based on these examples, GMA is broadly applicable to scenarios developed specifically for PHEM. However, literature has revealed areas requiring further research and development, for example, examining the integration of GMA and its impact with other methodologies in EM (Ritchey, 2009b). It has been found that GMA can be an initial step that provides input for other modelling methods such as Multi Criteria Decision Analysis (MCDA). Specifically, GMA can complement Analytic Hierarchy Process (AHP), a specific MCDA method. AHP requires synthesizing internally consistent solutions (e.g., scenarios) through a hierarchy of goals and criteria, which can be facilitated through GMA. GMA can provide a variety of solutions which AHP can then systematically compare to determine the best solutions for complex problems (Ritchey, 2009b). While GMA effectively explores complex problems, MCDA enhances decision-making by allowing the evaluation and prioritization of key criteria such as health impact and feasibility (Zhao et al., 2022). The integration improves the clarity and practical applicability of the model's outputs, making GMA more user-friendly and actionable (Ritchey, 2009b; Zhao et al., 2022).

5.3 Implications of GMA in PHEM for Decision-Makers and Practitioners

In PHEM decision-making, the available data, tools, and priorities often involve a high level of uncertainty (Larsson et al., 2010). Thus, choosing a suitable method to manage this uncertainty is essential (Larsson et al., 2010). GMA supports decision-makers and practitioners within PHEM. As illustrated in Table 1, GMA supports scenario and strategy development, which can serve as a decision-making support tool for PH issues. For instance, the diverse set of scenarios that GMA provides can be used to support EM exercises and training to increase preparedness for emerging threats (Public Safety Canada, 2025). Furthermore, capacity issues have prompted PH systems at multiple levels of government to look for methods that make the best possible use of limited resources (Canadian Institutes of Health Research, 2021; Public Safety Canada, 2025). GMA is one such method that is not too intensive while allowing public health units to handle a diverse risk environment with limited resources. In summary, GMA has demonstrated effectiveness in decision-making by identifying various connections and outcomes for proposed problems, thereby fostering a more holistic, efficient, and multi-sectoral approach to addressing issues in PHEM.

GMA supports a multidisciplinary group of decision-makers in assessing the importance and significance of numerous conditional pairs and the compatibility of each pair in relation to their impact (Ritchey, 2009a). GMA fosters organizations to uncover innovative solutions by leveraging the diverse insights of SMEs, particularly when navigating complex problems that interconnect with other sectors (Garvey, 2017). In closing, SMEs engagement within GMA mitigates the risk of erroneous decisions by comprehensively filtering out inconsistent relationships within the models, thereby enhancing the reliability of the decision-making process (Garvey, 2017).

6.0 Conclusion

6.1 Conclusion

PHEM protects the health systems and population health by managing complex emergencies through various knowledge, techniques, and principles (Rose et al., 2017). GMA can support PHEM through scenario modelling, strategy development and prioritization, and decision-making. Furthermore, GMA, informed by SMEs, can support PH agencies through a comprehensive process to examine complex problems that guide decisions and strengthen PHEM. Given the increased frequency, intensity, and impacts of PH emergencies, there is a need to continually adapt current tools to mitigate the negative impacts of disasters, improve outcomes, and boost national resilience. Thus, the capability of GMA to support PH agencies in enhancing EM planning, fostering collaboration among partners and stakeholders, and incorporating innovative solutions into practice is instrumental in tackling challenges within PHEM.

6.2 Closing remarks and recommendations for future inquiry and practice

Modular scenario development using GMA is compatible with modelling approaches and could serve as a first step in advanced scenario generation. GMA can support PHEM by bolstering the decision-making and planning processes within the intricate landscape. GMA is a modelling method employed by various countries and organizations to analyze and structure complex problems within the realm of EM.

GMA features can be extended beyond scenario modelling to support decision-making and planning in PHEM. In times of crisis when numerous components demand consideration, GMA can provide valuable insights integral to EM. While this is contingent on the GMA model being pre-built as a PHEM tool, the model can be quickly deployed during an emergency to

Table 1

Contributions and Advancements of GMA

Author(s)	Country or Organization(s)	Study Purpose	Contributions and Advancements
Scenario development tool			
Navrátil et al., 2019	Slovakia	• Create a scenario model in a participatory manner. • Identify new sustainable forest management models incorporating multiple natural, social, or economic uncertainties.	• Increased participation (e.g., forest owners and other stakeholders) and scope in forest management levels. • Created scenarios that may occur within 30 years, allowing stakeholders to set plans for further development and identify patterns of effective strategies. • Model allows for new methodological possibilities in dealing with the increasing demands of environmental health risks like climate change and other extreme weather events on forest management.
Hosseinikhah & Zarrabi, 2021	Iran	• To create a comprehensive earthquake management plan to reduce human and financial loss.	• Identified earthquake crisis management scenarios to assist in decision-making and effectively implement strategies (e.g., earthquake warning systems). • Preventive scenario model identified the importance of city-level approaches and areas of improvement to help increase resilience in the affected areas.
Schneider et al., 2022	German Aerospace Center	• Examine current knowledge to identify emerging risk scenarios within emergency management.	• Model accommodated any novel observations such as damage type and cause, occurring in real-time. • GMA, in combination with the Bayesian Network (BN) model, enabled the estimation of the probability of the overall scenario that enhanced situational awareness in an emergency. • Model provided a broader picture of an emergency through information gathering from various scenario factors.
Decision-making support tool			
Savchenko, 2018	Ukraine	• Generate models for preventing and mitigating social disasters (e.g., floods and typhoons).	• Used for evaluating preparedness (e.g., testing the effectiveness of current measures for disasters), monitoring (e.g., activation of early warning systems), and response towards a disaster (e.g., best practice for mitigation during a crisis). • Aided in control and management during a crisis as a decision-making support tool.
Watson et al., 2015	Foresight Tools for Responding to cascading effects in a crisis – European Commission project	• Create a conceptual model to understand the interdependencies of cascading crises (e.g., Japanese Nuclear Power Plant failure due to previous earthquake and tsunami events).	• Used as a decision- support tool to aid crisis managers in planning and reacting to cascading events. • Discovered disparities between vulnerability and resiliency factors using case studies. • Assisted in determining which systems are connected to various crisis and disaster responses and are affected by cascading effects in an emergency.

Strategy development and prioritization tool			
Ritchey, 2006	Japan	• Create a prototype of a multi-hazard disaster risk reduction model.	• Enabled comparison and identification between multiple disaster risk reduction strategies, and mitigation and preparedness measures for hazards (e.g., hurricanes).
Strategy development/prioritization tool and Scenario development tool			
Fernandez et al., 2006	United Nations Office for Disaster Risk Reduction Earthquake Disaster Mitigation Research Center Swedish National Defence Research Agency	• Build a prototype of a Disaster Risk Management (DRM) model for earthquake management.	• Developed realistic strategies and tools for decreasing disaster risk and determining best practices in DRM for various cities. • While the model was focused on earthquake management, the design includes a multi-hazard approach and thus can apply to other natural hazards. • Scenario development included risk reduction strategies, mitigation, preparedness, planning measures, as well as unsafe physical conditions and practices.
Strategy development/prioritization tool and decision support tool			
Ritchey et al., 2004	Sweden	• Aid in crisis management for extreme societal events.	• Designed as a strategic decision support tool for municipal, regional, and national government levels. • Enabled ability to identify extreme societal events, management capacities to handle those events, and set crisis management priorities. • Discovered strategies for improvements concerning a national security strategy.
Lantada et al., 2020	Venezuela	• Strategy development and prioritization for high seismic regions. • Decision-making tool for public stakeholders at the local level.	• Used as a decision-making tool to implement effective risk mitigation strategies for urban areas dealing with natural hazards. • Determined the need to adjust public administration priority, including a higher focus on risk reduction strategies, specifically for earthquakes, and some focus on financial protection and governance strategies.
Roy & Garg, 2014	India	• Identify elements of risk and create multiple risk reduction strategies.	• Created a multi-hazard risk reduction model that identified and compared risk reduction strategies and disaster preparedness and mitigation plans. • Identified gaps in disaster reduction methods. • Assisted in decision-making for the allocation of mitigation programs and funding.

Note. This table provides a summary of each study and how GMA has been applied in natural hazard(s) for a country or organization (e.g., scenario development). While this paper primarily focuses on GMA's role in scenario development, its utility extends beyond this application. GMA has demonstrated broader value in strategy development and decision-making, including supporting the prioritization of risk mitigation efforts and guiding decision-making processes during crises. These applications allow stakeholders to make informed decisions and adjust strategies to address threats.

support decision-making. Moreover, GMA can also enhance other methodologies, such as MCDA, thereby reinforcing the evaluation and robustness of various PHEM tools.

Future research and practice can involve applying GMA within a PHEM lens (e.g., health-centric scenarios). Ongoing research, spearheaded by the Public Health Agency of Canada, is focusing on cyclical events such as wildfires, floods, extreme heat events, and extreme weather events through the lens of PHEM within the Canadian context. Other research studies could also look at building scenarios for PH emergencies triggered by infectious and non-infectious agents. Furthermore, future applications will involve the use of artificial intelligence (e.g., GPT-4) to decompose scenarios by producing the morphological field. In conclusion, integrating GMA with other PHEM methodologies can significantly enhance the robustness and effectiveness of EM methodologies, ensuring that GMA is not only interoperable but also a cornerstone in the broader PHEM framework.

7.0 References

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