Overview of the Environmental Emergency Management Studies in National Institute for Environmental Studies (NIES)

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Abstract

Despite its significance in achieving sustainability in an era of frequent disasters, environmental emergency management (EEM) is a field that has not attracted enough attention from policy makers. This article provides an overview of and outlook for EEM studies at the National Institute for Environmental Studies (NIES). For this, a framework is presented for EEM based on recent international literature, and representative works undertaken by NIES are presented in line with this framework to examine research gaps and outlook. Our analysis shows good coverage of research topics aimed at enhancing understanding of the impact of environmental emergencies and advancing both pre- and post-disaster actions for disaster waste management (DWM). Some research gaps are also identified: namely, research on post-disaster assessment of environmental impacts and decision making under emergency circumstances, research on responses and recovery actions against impacts from hazardous substances released in the course of natural hazard events, and research collaboration within the EEM discipline and between natural hazard experts (especially regarding physical countermeasures).

Key words : disaster waste, environmental emergency, management, toxic release, Natech

1. Introduction

Environmental emergencies are a serious concern for both developed and developing countries (Liao et al., 2012; Srinivas & Nakagawa, 2008). They are defined as sudden-onset disasters or accidents resulting from natural, technological or human-induced factors, or a combination of these, that cause or threaten to cause severe environmental damage as well as harm to human health and/or livelihoods (UNEP, 2002). They may occur in the form of a discharge of pollutants such as oil, hydrocarbons, hazardous chemicals or radioactive substances, or the generation of disaster waste that could result in public sanitation issues and environmental pollution (Srinivas & Nakagawa, 2008). Compared with general environmental pollution in normal times, environmental emergencies are characterized by sudden onset, typically a large volume of pollutant discharge in a short period of time, and the need for urgent decisions to be made under stressful circumstances (French & Geldermann, 2005; Liao et al., 2012). The aim of environmental emergency management (EEM) is to mitigate these environmental impacts by taking systematic pre-and post- disaster actions.

Despite its significance in achieving sustainability in an era of frequent disasters, EEM is a field that has not attracted enough attention from policy makers. The Joint UNEP/OCHA Environment Unit points out the policy gap and highlights the need for a new (or improved) preparedness framework that integrates environmental emergencies into disaster preparedness planning and emergency response (JEU, 2013a). In terms of research, a quick search in a scientific database (Web of Science Core Collection) shows an increasing trend in the number of studies related to EEM especially in the last ten years. Some focus on specific types of environmental emergencies, such as oil spills (e.g., Peterson et al., 2003; Kujawinski et al., 2011) or "Natechs," i.e., natural-hazard triggered technological accidents (e.g., Young et al., 2004; Krausmann et al., 2011); and others focus on specific aspects of EEM such as decision making on initial responses (e.g., Hernandez & Serrano, 2001; Liao et al., 2012; Wang et al., 2020). There has been no attempt, however, to construct an integrated theory on EEM.

The aim of this article is to present an overview of recent EEM studies as a first step toward constructing a comprehensive EEM theory, with a special focus on the works undertaken at the National Institute for Environmental Studies (NIES), where EEM research has been conducted extensively and most comprehensively in Japan, mainly since the 2011 Tohoku Earthquake. The

EEM framework is presented in Chapter 2 based on recent international literature, and the representative works undertaken at NIES are presented in line with the framework in Chapter 3 to discuss research gaps and outlooks. Details on issues and research related to radioactive substances are dealt with in other articles in this special issue.

2. Environmental Emergency Management Framework

2.1 Object of Environmental Emergency Management

The environmental impacts of disasters can be categorized by being triggered by natural hazard events (e.g., earthquakes, flooding, tsunamis) or technological hazards (e.g., chemical factory accidents). Another aspect is whether the impact is caused directly by the disaster or from response and recovery from the disaster. Based on these two aspects, at least four types of disaster-induced environmental impacts can be indicated (Table 1). The first is disturbances in the natural environment. An example is the damage caused by the 2004 Indian Ocean Tsunami to coral reefs, sea grass beds and other elements of coastal ecosystems (Srinivas & Nakagawa, 2008). This type of impact may have both negative and positive impacts on local sustainability.

The second is disaster waste generated through the destruction of the built environment. Disaster wastes are different from wastes disposed of in normal times as they include both household waste and industrial waste and are often mixed at source. They pose short-term sanitation risks (e.g., odor, pests) and public health risks (e.g., infection), and over the longer term, environmental risks from inappropriate treatment and disposal (Brown et al., 2011; JEU, 2013b). Serious environmental impacts may occur when disaster wastes are contaminated with hazardous substances such as asbestos.

The third is release of hazardous substances. The cause of such releases may be industrial accidents triggered by human/ system errors, or Natechs triggered by natural hazard events, such as power plant explosions triggered by tsunamis (e.g., Young et al., 2004; Krausmann et al., 2011). Releases of hazardous substances may result in acute environmental and health impacts. In addition, recent studies highlight chronic environmental and health impacts. For example, the 1989 Exxon Valdez oil spill had delayed, chronic and indirect effects from petroleum contamination in the marine environment, including, e.g., decreased sea otter survival due to chronic exposure to residual petroleum hydrocarbons from sediment contact and ingestion of bivalve prey (Peterson et al., 2003).

The fourth is impacts caused by disaster recovery and reconstruction, from both natural and technological hazards. As disaster recovery is a resource intense project, environmental concerns from intensified resource depletion can have detrimental effects on the long-term sustainability of disaster-impacted countries (UNEP & SKAT, 2007; Chang et al., 2010). Reconstruction projects may also have direct and long-term environmental impacts, e.g., impacts on water quality caused by land-clearing projects to develop new housing sites (Spaling & Vroom, 2007).

Among the environmental impacts listed in Table 1, "(1) Disturbances in the natural environment" and "(4) Environmental impacts of disaster recovery" are different from "(2) Generation of disaster wastes" and "(3) Release of hazardous substances" in that the impact on human society does not appear in the immediate aftermath of the disasters, and thus their management does not share the common characteristics of EEM, i.e., urgent need and stressful circumstances of decision making (French & Geldermann, 2005). In this manuscript we focus on (2) and (3) in Table 1 as the target of EEM. However, this does not mean ecosystem disturbances and environmental impacts of reconstruction are less important. They can have a significant impact on sustainability of the stricken area after reconstruction and rehabilitation and should be managed under different management theories and tools.

2.2 Process of Environmental Emergency Management

Similar to the disaster management cycle (Collins, 2009), which embraces both pre-disaster activities (mitigation, preparedness, early warning) and post-disaster activities (relief, recovery, rehabilitation), EEM also has both pre- and post-disaster dimensions as illustrated in Fig. 1.

2.2.1 Post-disaster EEM Actions

The first two steps of post-disaster EEM are identification and assessment of potential environmental

Table 1 Environmental impacts of disasters and target of environmental emergency management (EEM).

	Direct result of the hazard	Result of disaster response
Triggered by natural hazard	(1) Disturbance on natural environment (2) Generation of disaster waste	(4) Environmental impact of disaster recovery
Triggered by technological hazard (including Natech)	(3) Release of hazardous substance Object of EEM	(4) Environmental impact of disaster recovery

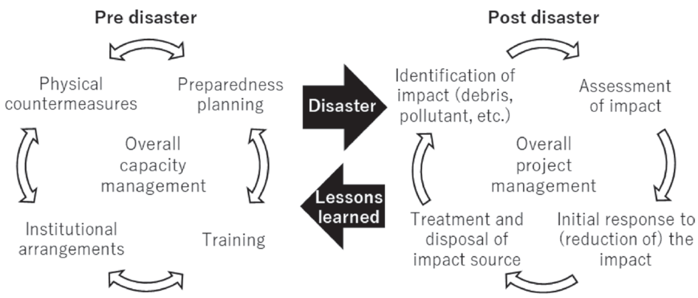

Fig. 1 Environmental emergency management framework.

impacts. This can be done at two different levels of concreteness. At a relatively abstract level, the type of environmental impact (disaster wastes, hazardous substances, etc.) and its urgency is identified, to guide common-sense response actions. Rapid Environmental Impact Assessment (REA) is a tool for this, in which potential environmental impacts in disaster situations can be defined and prioritized shortly after the disaster occurrence (Hauer & Kelly, 2018). At a more concrete level, actions to identify potential impacts differ according to the type of environmental impact. The impact of disaster wastes is identified by estimating the amount and composition of disaster wastes. Here, identification of impact (=estimation) is undertaken for different purposes at different phases of the disaster waste management (DWM) process. In the early response phase, a very rough estimation is made to decide the scale of DWM and necessary resources and external assistance. In later phases, after undertaking the initial response actions and initiating disaster waste treatment, more certain numbers can be acquired through measurement and calculation to facilitate decisions on the selection of treatment and disposal options (Tajima et al., 2018). To assess the potential impact of disaster wastes and the urgency and scale of DWM, the amount of disaster wastes is compared with the waste disposal capacity of the stricken area, the existence of putrefactive and hazardous wastes is ascertained, and the degree of separation (or mixture) of accumulated disaster wastes is evaluated (JEU, 2013b). In terms of hazardous substances, it is important to identify the released substances quickly through emergency monitoring and assess their impact in terms of toxicity, concentration and quantity (Young et al., 2004). Simulation of the transportation and dispersion of hazardous substances is typically undertaken. Identification and assessment of impacts may become problematic when the released substance is unknown, especially in the case of large-scale Natechs that involve multiple industrial accidents. In these cases, there are risks from released chemicals and their side products (e.g., from fires) that are not anticipated in normal times. The Flash Environmental Assessment Tool (FEAT) can help responders prioritize measures to reduce impacts from chemicals through decision trees and lookup tables (Posthuma et al., 2014).

The next two steps of post-disaster EEM are initial response to the impact (impact reduction) and treatment/disposal of the impact sources. For disaster wastes, collection and treatment of hazardous and putrefactive disaster wastes are the highest priority (JEU, 2013b). Following this is the collection of other non-hazardous disaster wastes (e.g., concrete from demolition) to reduce sanitation risks. Recycling and reuse of materials and appropriate treatment and disposal are then undertaken, considering the balance between the conflicting environmental (recycling rate, carbon footprint) and economic (direct cost) benefits and impacts (Amato et al., 2019). Mathematical models to support decisions on disaster waste processing systems under high uncertainty are being widely studied (e.g., Habib et al., 2019; Cheng et al., 2018). To implement collection, treatment and disposal, DWM requires specific management tasks including procurement, financing, and planning (Tajima, 2020). For hazardous substances, measures to reduce impact, including emission reduction (limiting the sources), dispersion (limiting the pathways) and evacuation (removal of impact receptors) are implemented (Posthuma et al., 2014). In some occasions, prophylactic drugs and antidote agents are used to reduce health impacts (Georgiadou et al., 2010). Such decisions are based on the characteristics of the site (e.g., location, surrounding environment) and the environmental and health standards to follow. Studies on methods and models to support decisions on initial response, based for instance on a case-based reasoning approach, have been widely studied (e.g., Hernandez & Serrano, 2001; Liao et al., 2012; Wang et al., 2020). After these response actions, the released substances and contaminated water/soils are collected using adsorbent materials or by physical removal to a reasonable extent and disposed of through the usual hazardous waste management stream.

Another important element of post-disaster EEM is overall management of the response and recovery process. The entire post-disaster EEM process needs to be monitored and evaluated because situations surrounding environmental emergencies become clear and new issues and needs arise over time. Overall management is also important because environmental impacts at the intersection of disaster wastes and hazardous substances can occur, such as contamination of disaster wastes by hazardous substances.

2.2.2 Pre-disaster EEM Actions

The aim of pre-disaster actions is to effectively reduce and respond to the impact of a foreseeable disaster. The lessons learnt through post-disaster EEM should guide pre-disaster EEM. Based on theoretical grounds in capacity development for disaster risk reduction (Hagelsteen & Becker, 2013), we considered four key elements of pre-disaster EEM actions: preparedness planning, training, institutional arrangements and physical countermeasures (Fig. 1). Pre-disaster EEM should be dynamic and continuous, and to enhance synergistic effects, these actions should not be undertaken in isolation (Karunasena & Amaratunga, 2016).

The first element is preparedness planning, the core of preparedness (USEPA, 2008; JEU, 2013b). Scholars in emergency management state that preparedness planning is a process of generating emergency response measures and protocols, and the written plan represents a snapshot of that process (Perry & Lindell, 2003). Another important implication of preparedness planning in EEM is that considering the large uncertainties of the emergency context, the fundamental principles of response and priorities should be specified whereas the amount of operational details should be minimized (Perry & Lindell, 2003). For DWM this means identification of different waste management approaches and required resources including personnel, vehicles, staging and disposal sites, and recycling technology/facilities (Brown & Milke, 2016). The same principle applies to hazardous substances, but current research and practice seem more inclined to use detailed quantitative risk assessments for planning. One example is the procedure for Natech risk assessment which consists of (1) characterization of the natural event, (2) identification of target equipment, (3) identification of damage states and reference scenarios, (4) estimation of damage probability, (5) evaluation of consequences in reference scenarios, (6) identification of credible combinations of events, (7) frequency/probability calculations for each combination, (8) consequence calculations for each combination, and (10) calculation of risk indices (Antonioni et al., 2009). Mapping of those risks is also an effective practice (Girgin & Krausmann, 2013). Another important component of preparedness planning is to establish a coordination framework and personal relationships between organizations that will be required to coordinate in post-disaster EEM (Perry & Lindell, 2003). Unlike waste management and chemical accident management in normal times, EEM requires involvement of natural hazard experts and other disaster respondents such as military, civil engineers and social welfare staff.

The second element is training, which increases the effectiveness of preparedness plans. Preparedness plans are only effective when knowledge, skills and attitude (KSA) are transferred to emergency responders, and that KSA is applied effectively to real world performance (Ford & Schmidt, 2000). Typical training methods include lectures, workshops, drills, tabletop exercises and functional exercises, the latter being a more active type of learning. Training courses are also effective venues for developing inter-organizational coordination (Perry & Lindell, 2003).

The third element is institutional arrangements such as enactment and revision of laws and regulations. Legislation on waste management (e.g., mandatory recycling targets) can either enhance or compromise recycling of disaster wastes (Brown & Milke, 2016). Restricting industrial development in disaster-prone areas through land-use planning, building codes and safety regulations may reduce the risk of toxic releases after natural hazard events (Krausmann & Cruz, 2013). Regarding hazardous substances, standards for emergency exposure play a critical role because environmental standards developed for environmental management in normal times may not be applicable to acute and short-term exposures.

The final element, physical countermeasures, reduces the impact of natural hazard events and ensures the availability of resources and functions needed for response actions. Regarding disaster wastes, flood prevention facilities and anti-seismic reinforcement of housing can decrease the amount of disaster wastes, which in turn facilitates environmentally friendly disposal in terms of pollutant emissions (Hirayama et. al., 2013; Wakabayashi et al., 2017). Reinforcement of installations and equipment in various ways such as by anchoring and using safe equipment design can also help reduce the impact of disasters (Krausmann et al., 2011).

Just as with post-disaster EEM, it is important to get an overview of the capacity development process and actions for preparedness. As environmental emergencies are dependent on local situations, analysis of the existing risks and capacity of the responding organizations is necessary for effective preparedness capacity development (Hagelsteen & Becker, 2013).

3. Environmental Emergency Management Studies at NIES

3.1 Understanding Impacts of Environmental Emergencies

NIES has conducted research aimed at elucidating the impact of environmental emergencies, focusing mainly on the 2011 Tohoku earthquake and tsunami, as little was known about the environmental impact of tsunamis and tsunami-induced industrial accidents. Regarding disaster wastes, the characteristics of disaster wastes from the 2011 Tohoku earthquake and their disposal process were summarized by Osako and Tajima (2014). A large concern regarding these disaster wastes, apart from those radioactively contaminated, was impact of tsunami sediments, amounting to ca. 10 million tons. Oguchi et al. (2013) summarized the state of chemical pollution and concluded that although some reports indicated levels in excess of environmental standards for lead, arsenic, fluorine and oil, the overall level of pollution was low. In terms of hazardous substances, Kanaya et al. (2016) investigated the ecological consequences of the fuel spills and subsequent conflagrations that resulted from the tsunamis following the 2011 Tohoku earthquake. The results indicated that although sediment in the bay still contained high levels of polycyclic aromatic hydrocarbons (PAHs) four years after the disaster, no negative impacts of the PAHs were detected in the dominant macrozoobenthos. A series of environmental emergency monitoring actions were also conducted to clarify the release and impact of some inorganic elements, persistent organic pollutants (POPs), microorganisms and pests, mainly near the evacuation centers and temporary storage/treatment sites for disaster wastes (Nakajima et al., 2019). Hashimoto et al. (2019) investigated the health and sanitation risks of debris stored at a temporary storage site on its surroundings and found higher outdoor concentrations of certain microorganisms known to be respiratory allergens compared to in a normal environment. The effects of particulate matter (PM) derived from tsunami sediments on human health were studied and it was concluded that the overall concentration of PM was low but that vulnerable people may need special care (Suzuki et al., 2019). The impact of the 2011 Tohoku tsunami on the local ecology and population were also evaluated. It was found that a large-scale tsunami caused mass mortality of intertidal organisms over a broad spatial scale but did not significantly affect the genetic diversity of the local populations (Miura et al., 2017; Miura et al., 2019). Kanaya et al. (2019) reached a similar conclusion from studies in Fukushima and Ibaraki prefectures, but they also pointed out the detrimental impact of restoration work after 2016 on faunal diversity and mortalities of some marine taxa.

Comparing among the four types of environmental impacts of disasters indicated in Table 1, the research at NIES seemed to cover (1) ~ (4) relatively well, and some work has been done at the intersection of (2) and (3). Studies on other disasters could enhance generalization of their findings, as most of the work solely concerns the 2011 Tohoku earthquake.

3.2 Development of Post-disaster EEM Theory and Technology

Studies on post-disaster EEM at NIES are summarized in Table 2. Regarding identification of impacts, methods to estimate the amount of disaster wastes were developed, implemented and reviewed to enhance their accuracy (e.g., Hirayama et al., 2013; Tajima et al., 2018). A rapid screening method for asbestos was developed to help enhance disaster waste treatment while controlling health risks (Yamamoto et al., 2018). For hazardous substances, works related to developing and applying a technology that could quickly identify and quantify substances existing in post disaster environments, namely AIQS-GC (Automated Identification and Quantification System using gas chromatograph-mass spectrometry), were undertaken (e.g., Nakajima et al., 2019). On the other hand, there has been no particular research regarding assessment of the impact that could facilitate decision-making in the initial response.

Regarding the response and treatment/disposal step, research efforts have focused mainly on disaster wastes. For example, based on practical experience in providing technical assistance to management of temporary storage sites, management methods to prevent spontaneous fires, a potential risk during the initial response phase of DWM, were clarified (Endo & Yamada, 2012). Regarding disposal of disaster wastes, work has been done to confirm the risk of generating dioxins from incineration of wooden disaster wastes saturated with sea water, and ergonomic studies have been done on factors related to efficient hand separation. To enhance recycling of tsunami deposits, their properties were investigated and methods and standards for environmentally and physically safe recycling as geomaterials were clarified (e.g., Katsumi et. al., 2017). These research activities contributed to production of guidelines for effective utilization of reconstruction materials recycled from disaster wastes (Japanese Geotechnical Society, 2014). Research on overall management was intensely undertaken regarding disaster wastes. Tasks and functions necessary for a DWM project were clarified from in depth research on various DWM cases in Japan, and differences related to the scale of the responding local government were analyzed (e.g., Tajima, 2020)

The first research gap indicated in Table 2 is research on assessing impacts, a missing link between results of impact identification and response actions. The research outputs mentioned above could contribute more to EEM by linking the results of impact identification to existing assessment tools such as REA, or by developing tools or systems to aid post-disaster EEM decision making. Another research gap in EEM worth noting is research on response methods and processes and their overall management, specifically for toxic releases under emergency circumstances. The current response methods and procedures summarized in the Japanese guidelines do not anticipate Natechs (Ministry of the Environment, 2009), which could hinder effective responses to toxic releases after large-scale natural hazard events and Natechs under stringent resource restrictions.

3.3 Development of Pre-disaster EEM Theory and Technology

Research on pre-disaster EEM at NIES is summarized in Table 3. With regard to preparedness planning, DWM planning principles have been summarized (e.g., Tajima et al., 2013a), extensively

Table 2 Main research items of post-disaster EEM (environmental emergency management) research at NIES.

	Disaster wastes	Hazardous substances
Identification of impacts (debris, pollutants, etc.)	Estimation of disaster waste Rapid screening for asbestos	Environmental monitoring system
Assessment of impacts	No particular research output	No particular research output
Initial response to (reduction of) the impacts	Methods of managing temporary storage sites	No particular research output
Treatment and disposal of impact sources	Methods and strategies for recycling tsunami sediments	No particular research output
Overall management	Tasks and functions of DWM (disaster waste management)	No particular research output

Table 3 Main items studied in pre-disaster EEM (environmental emergency management) research at NIES.

	Disaster wastes	Hazardous substances
Preparedness planning	Principles of DWM (disaster waste management) planning	No particular research output
Training	Development of training methods and theories	Implementation of training to familiarize people with AIQS-GC
Institutional arrangements	Impact of institutional arrangements on the DWM process	Development of priority lists of chemicals in emergencies
Physical countermeasures	No particular research output	No particular research output
Overall capacity management	Online tools to evaluate resilience of local waste management systems	No particular research output

guided by principles of preparedness planning for emergency management (Perry & Lindell, 2003). Other works related to overall management in post disaster DWM also help inform the planning process by pointing out the necessary tasks, functions and resources. No particular work has been done to develop preparedness planning for hazardous substances, including research related to development of quantitative planning models and tools using linear programming and its applied methods, which have been rather well studied internationally (see 2.2.2 above). Training has gained special attention and works have been undertaken with regard to both disaster wastes and toxic releases. Notably, theories and methods for DWM training have been developed, including workshops (Tajima et. al, 2015) and functional exercises for local government officers (Tajima et al., 2019), with workshops applied to enhance civic action among residents (Mori et al., 2020). These methods were developed based on understanding of the necessary KSAs for DWM personnel (Tajima et al., 2014). Research has been undertaken in collaboration with several prefectural governments and citizen groups in Japan, referring to the theory of action research (Stringer, 2014). Training to gain technical skills needed to use AIQS-GM has also been undertaken (Nakajima et al., 2019).

Another item that has received attention regarding both disaster wastes and hazardous substances is institutional arrangements. For disaster wastes, the effects of definitive and provisional institutional arrangements for DWM on actual management processes in the 2011 Tohoku earthquake have been analyzed, and suggestions have been made for future development (Tajima et al., 2013b). For hazardous substances, domestic and overseas efforts in response to accidents and disasters with release of chemical substances have been investigated, mainly from the viewpoint of exposure levels, and a list of substances deserving high-priority management has been developed (Koyama & Suzuki, 2019). In addition, NIES researchers have been extensively involved in the development of various EEM guidelines, including, e.g., the DWM guidelines of Japan’s Ministry of the Environment (Ministry of the Environment, 2018). No particular research has been conducted so far regarding physical countermeasures for disaster wastes and hazardous substances. For overall capacity management, online tools to evaluate the resilience of local waste management systems from various viewpoints have been developed (e.g., Tajima & Osako, 2017). They are intended to help local governments plan for capacity development, by recognizing the risks in their waste management system and their current capacity to respond, adapt to and cope with disaster wastes. This is associated with an online information platform for disaster waste management developed by NIES, in which technical and administrative guidance, reports on DWM experience, a database of local DWM plans and other materials for individual and organizational learning are consolidated.

One gap obvious from Table 3 is research on physical countermeasures. This is usually studied by structural dynamics experts. Collaboration with external natural hazard experts on physical countermeasures would have important implications in preparedness planning (e.g., the role of treatment facilities, post-disaster functionality of disposal facilities) and institutional arrangements (e.g., provision of incentives). Another issue regarding collaboration is inadequate interaction between disaster waste and hazardous substance researchers on preparedness planning, training and capacity management. For example, methods and theories on training for EEM could be developed and implemented more efficiently by integrating the findings from works undertaken for disaster wastes and toxic releases. A tool to evaluate the capacity to manage hazardous substance releases similar to the tool developed for disaster wastes could benefit from integration to enhance awareness of both issues by local governments.

4. Conclusions

Since 2011, research on EEM has been undertaken extensively by NIES, mainly driven by the needs and issues recognized in EEM practice. This article has attempted to clarify the overall framework of EEM, and give an overview of associated research conducted at NIES. Our analysis shows good coverage of research topics aimed at enhancing understanding of the impact of environmental emergencies and at advancing both pre- and post-disaster actions for DWM. Some research gaps have also been identified, namely, research on post-disaster assessment of environmental impacts and decision making under emergency circumstances, research on response and recovery actions against impacts from hazardous substances released by natural hazard events, and research collaboration within the EEM discipline and among natural hazard experts (especially regarding physical countermeasures) . Finally, we should note that to enhance EEM in an age of limited public resources (budgetary and staff), future research should focus on synergetic benefits for development in normal times and response in emergencies. Innovations in technologies and governance structures of normal-time environmental management are required in a way that mainstreams EEM.

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