Asia-Pacific Regional Framework for **NATECH (Natural Hazards Triggering Technological Disasters)** Risk Management

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AP-STAAG
Asia-Pacific Science, Technology and Academia Advisory Group
SENDAI FRAMEWORK
FOR DISASTER RISK REDUCTION 2015-2030

About this Publication

This publication is developed by a group of individuals from the Working Group on NATECH Risks in the Asia-Pacific with support from researchers, scientists and practitioners from different countries, under the aegis of the UNDRR Asia-Pacific Science, Technology and Academia Advisory Group (APSTAAG). A call for sub-mission of NATECH cases studies was made and 19 examples were submitted. These cases were subsequent analysed leading to the development of guiding principles and a framework for NATECH risk management in Asia Pacific.

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Asia-Pacific Science, Technology and Academia Advisory Group
Working Group on NATECH Risk Management

Foreword

As the world has become more complex, so has risk. In a connected word, with inter-dependent systems, disasters emanating from distant corners are more likely to cause cascading disruptions down the line to countries vast and far.

At the same time, within countries, in the quest to power cities, mine resources, build industries, and feed growing populations, humans have left a strong mark on the environment around them, often creating new risks along the way. Moreover, the need to expand cities and infrastructure means humans are increasingly encroaching on new areas that have traditionally been uninhabited, usually for good reason, thus exposing people and economic assets to new hazards.

This global interconnectedness, and the increased interaction between the built environment and the natural environment, means our development gains are increasingly at risk of natural hazards, notwithstanding the increasing intensity and frequency of climate-related hazards.

Resource-intensive investments such as power plants, factories and public utility infrastructure are not only uniquely vulnerable to these hazards, but also hold the potential to trigger larger disasters if they fail. Such events are known as "natural hazards triggering technological disasters" or NATECH.

The Global Assessment Report (GAR) 2019 was the first GAR to cover NATECH due to their relevance to managing systemic risk and minimizing the cascading impact of disasters. The Asia-Pacific Regional Framework for NATECH Risk Management takes the discussion even further through a closer examination of specific cases and a focus on the Asia-Pacific region.

There is no stopping the pace of human development and growth, but for this growth to be sustainable, it must be risk-informed. This calls for an expanded understanding of new types of complex risk such as NATECH, which is what this report hopes to accomplish.

Loretta Hieber Girardet
Chief, Regional Office for Asia and the Pacific
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Message from AP-STAAG

The Asia-Pacific region has emerged as a hotspot of natural hazards ranging from earthquakes, floods to tsunamis and volcanic eruptions among others. The Sendai Framework for Disaster Risk Reduction has expanded the scope of disaster risk reduction by adding a range of other hazards (including man-made hazards and related environmental, technological and biological hazards and risks).

The NATECH (Natural hazards triggering Technological disasters) risks provide a good basis to demonstrate the expanded scope of the Sendai Framework. In particular, the NATECH risks faced by the Asia-Pacific region is of significant importance due to two specific reasons: first, the potential of NATECH events to compound the impact of a natural hazard and second, very little is known about the past and potential NATECH events.

NATECH events are mostly low impact events aside from the large-scale 2011 East Japan Earthquake and Tsunami that triggered the Fukushima nuclear disaster and brought the global attention to NATECH. However, there is no baseline available to compare NATECH risk trends in the Asia-Pacific region. Furthermore, tools and initiatives for reducing technological risks often overlook specific drivers of NATECH events. This necessitates a study of NATECH risks and relevant risk management principles.

The interest in NATECH risks has grown in recent years across disciplines. In addition, several international organisations have provided sector specific guidelines for NATECH risk management. This study is another step towards creating a shared understanding of the NATECH risk in the Asia-Pacific region by documenting and subsequently analyzing various NATECH events with known impact in the last three decades.

The study has been steered by the UNDRR Asia-Pacific Science, Technology and Academia Advisory Group (AP-STAAG) that established a working group of experts on NATECH risk. The experts have reported and compiled a total of 19 cases studies on NATECH risks in the region. Based on the analysis of the case studies, ten guiding principles are proposed to aid national governments to take up NATECH risk management.

The study has also benefited from a series of consultations to draw lessons from the case studies. A regional action-oriented framework has been proposed as a part of this report. We hope that this report will add momentum to the activities directed towards managing NATECH risk in the Asia Pacific region and help in making the societies sustainable and disaster resilient.

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Executive Summary

NATECH (Natural hazards triggering Technological disasters) is an emerging theme in the field of disaster risk reduction globally. The Sendai Framework for Disaster Risk Reduction 2015-2030 and the Global Assessment Report (GAR 2019) have stressed the need for engaging in NATECH risk assessments, policy formulation and local actions. In 2017, UNDRR developed a guideline on national disaster risk assessment that included NATECH risks and urged countries to undertake risk assessment, preparedness planning and build capacity for effective response.

The Asia-Pacific region faces a varied continuum of natural hazards creating greater complexity and deep uncertainty in the face of changing climate and rapid industrialization. Considering the number of chemical industries and units handling hazardous materials has increased, the NATECH risk is growing in the region. This necessitates advancing the present understanding of the NATECH risk based on past incidents and potential future events for informed decision-making.

The report, through a series of consultations and drawing lessons from the past NATECH disasters proposes ten guiding principles for NATECH risk management in the Asia-Pacific region:

1. **Conduct Multi-Hazard, Systematic Risk and Ecological Impact Assessment**
   A holistic and systematic risk assessment for multiple hazards should form the basis of all future actions for NATECH risk management.

2. **Enable Coordinated Policy and Planning among Local Government and Industrial Clusters**
   Effective planning for NATECH risk management should involve active engagement of institutions at all levels with time-bound roles and responsibilities for all stakeholders including the private sector.

3. **Develop and Implement Safety Codes**
   Safety codes and regulations for land use, construction, design, materials and usage for ensuring sustainable and resilient infrastructure tailor-made to national and local needs incorporating global and regional experiences. Further mechanisms for implementing and monitoring should be set up by the regulatory authorities.

4. **Enhance Offsite and Onsite Risk Communication**
   The findings from the risk assessment and development of codes need to be effectively communicated to all stakeholders for informed decision making for effective risk management. This should be complemented by enhanced risk

communication between the scientific, community, and the policy makers; amongst the personnel of industrial and hazardous installations; between such installations and the nearby exposed communities.

5. **Strengthen Internal Capacities**
   Building capacities by means of skills development for resource mapping, response and scaling up of required resources (human, equipment and financial). National and local governments need to work closely to strengthen the capacities at national, sub-national and local level for providing timely early warning and specialized response to NATECH incidents.

6. **Build and Reinforce Critical Infrastructure**
   Critical infrastructure needs to be designed to minimize service disruptions in case of a NATECH disaster. At the same time, existing infrastructure needs to be retrofitted based on NATECH risk assessments and national codes.

7. **Enhance Response Capacities**
   Capacities to respond effectively need to be strengthened at regional, national and local levels. Countries need to share, cooperate and establish joint NATECH response centers for transboundary NATECH response based on risk assessments.

8. **Promote Business Resilience**
   Industries and corporate houses need to be aware of NATECH risk and factor in for investment decisions and integration into business continuity plans.

9. **Plan for Recovery**
   Planning for early recovery needs to be aligned to principles of sustainable development and should be guided by the "Build Back Better" approach to prevent creation of future risks.

10. **Foster Multi-Stakeholder Partnerships**
    NATECH risk management needs a multidisciplinary approach bringing together academics, practitioners and policy makers at various levels. The ARISE regional and country chapters, a disaster risk reduction platform for the private sector, and other business networks should be leveraged to spearhead and foster NATECH partnership in Asia Pacific region.

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1. The Context

Natural hazards triggering technological disasters (NATECH) are complex events that were first studied at the end of 1970s and have regained importance in the recent past, particularly after the 2011 Great East Japan Earthquake and Tsunami. The occurrence of NATECH events was estimated to be approximately 5 percent of the total records reported in industrial accident database up to about 20 years ago. The NATECH events at present are under reported. In addition, it is presumed that the increasing frequency of climate change linked natural hazards will lead to a spike in the number of NATECH cases in future (Alessio Misuri, 2020).

Traditionally, NATECH has been studied with focus on adverse impacts of disasters on industrial facilities leading to release of hazardous materials (hazmat). The size of the global chemical industry exceeded $5 trillion in 2017 and is projected to double by 2030 (UN Environment, 2019). The production and consumption of manufactured chemicals continues to spread worldwide, with an increasing share now located in developing countries and economies in transition, many of which may have limited regulatory capacity. Considering these, it is certain that the industrial sector and installations will continue to be a primary focus for NATECH

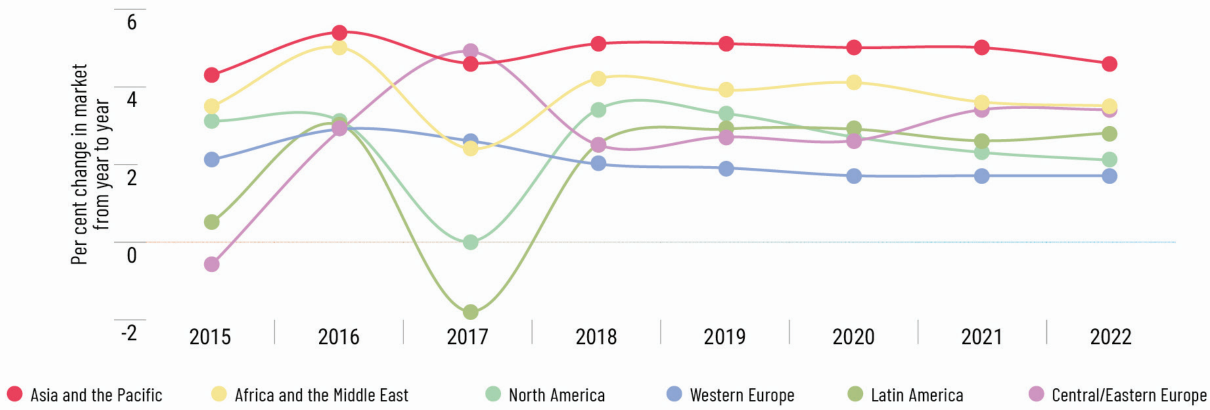
Addressing cascading and complex hazards and risks

There is an urgent need to investigate further the direct and indirect linkages and effects of natural, biological, technological and other human-induced hazards to identify better and understand cascading and complex hazards and risks in a systematic way.

The shift towards a broader view and a more context-dependent definition of hazards requires a systematic approach to risk that considers hazard, vulnerability, exposure and capacity together and better understands their complex interactions. The hazard list and associated HIPs may assist the activities of the GRAF, informing efforts to develop an enhanced understanding of the systemic nature of risk, including the management of systemic risks.

UNDRR and ISC (2020) Hazard Definition and Classification Review

Figure 1: Projection of annual production growth in chemical industry by region



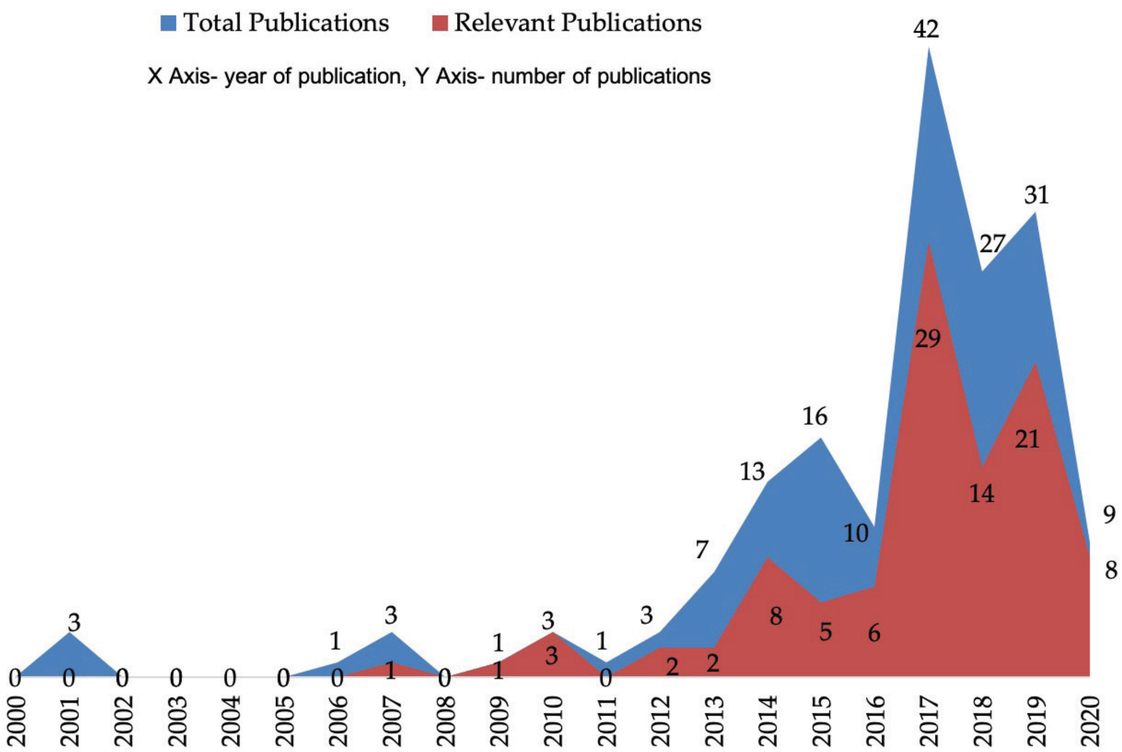
risk management. Nevertheless, over the years, various other infrastructure sectors like water reservoirs, power stations, barges, etc. have faced NATECH disasters, thereby highlighting the changed and advanced nature and complexities of these events. This demands for an inter-disciplinary approach and a comprehensive framework for efficient management of NATECH risk.

Over the past 25 years, presence and growth of chemical industries has increased tremendously in countries like Indonesia, Thailand, Vietnam and the Philippines and is expected to continue this growth path further in the coming years (ASEAN, 2014). This information must be examined closely with the fact that the Asia-Pacific Region has also witnessed the highest number of disasters in the past decade. Thus, the growing threat of NATECH in the region must be studied from all possible dimensions of exposure and vulnerabilities in order to lay down a holistic regional framework for NATECH risk management in the Asia-Pacific.

2. Background

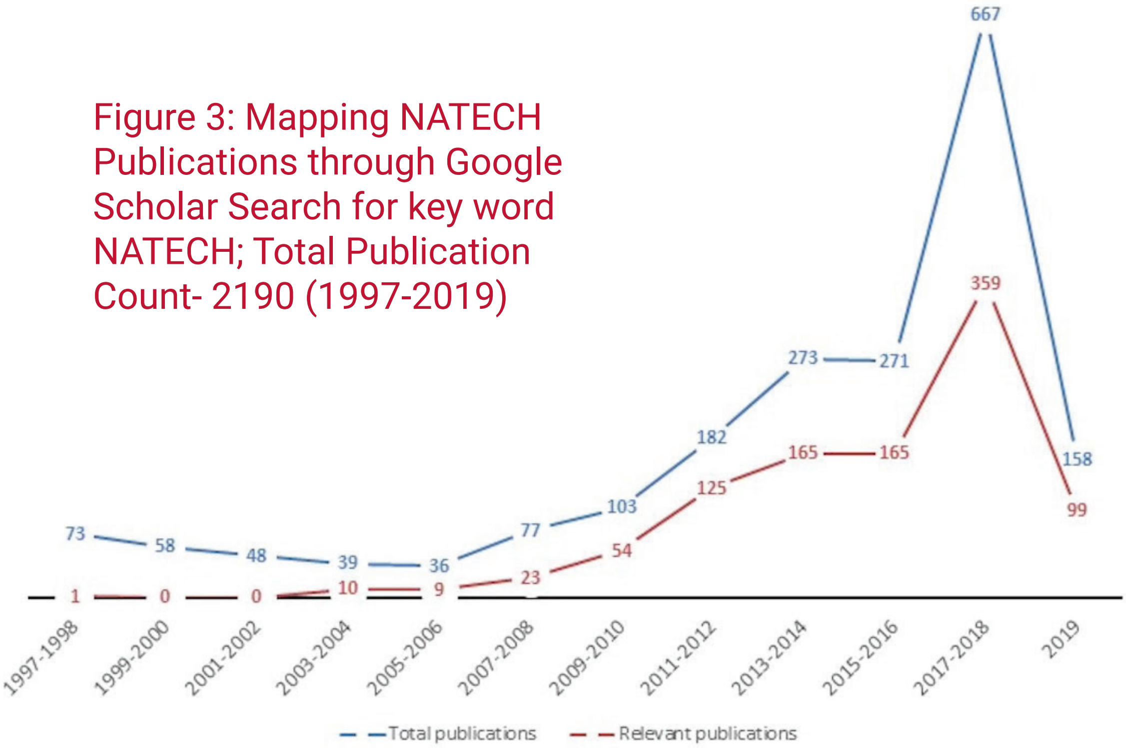
The academic interest in NATECH has increased over the past two decades. As per a review of Science Direct , out of 170 publications (2000-2020), 100 were found to be relevant. Figure 2, 4 and 5 map these publications on basis of year of publications, type of publications and publication titles of relevant ones respectively.

Figure 2: Mapping Academic Interest in NATECH through Science Direct Search for keyword NATECH (2000-2020) as on 07.01.2020



A higher number of publications is found through other search methods like the Google Search using the keyword NATECH (Figure 3) vis-à-vis that done on Science Direct using the same keyword.

Figure 3: Mapping NATECH Publications through Google Scholar Search for key word NATECH; Total Publication Count- 2190 (1997-2019)



The difference could indicate more discussions happening on the topic in workshops and conferences (compared to academic publications) whose proceedings are included in Google search but are not included in Science Direct search which included five key types of academic publications (Figure 4).

Figure 4: Relevant Publications during 2000-2020 as per type of publications based on search on Science Direct for keyword NATECH on 07.01.2020

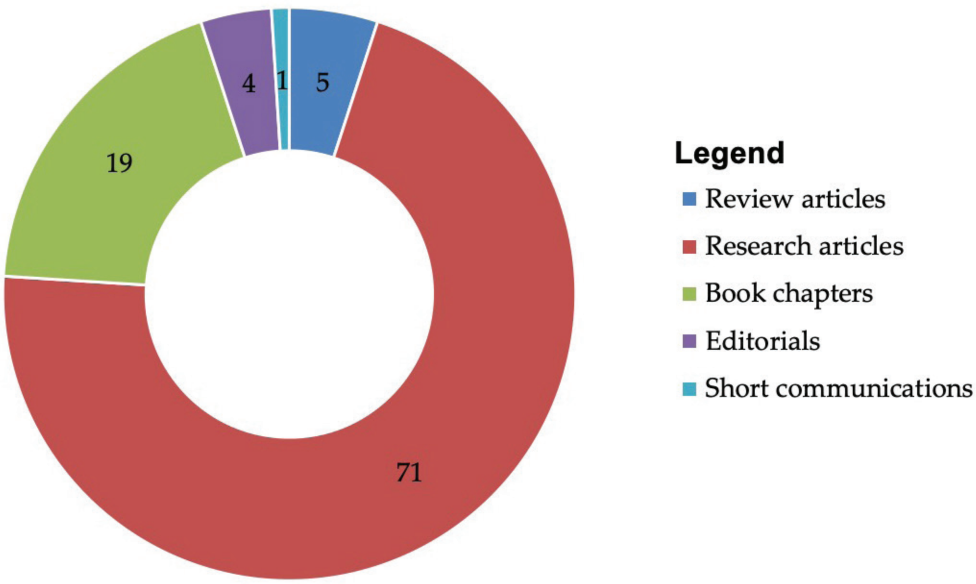
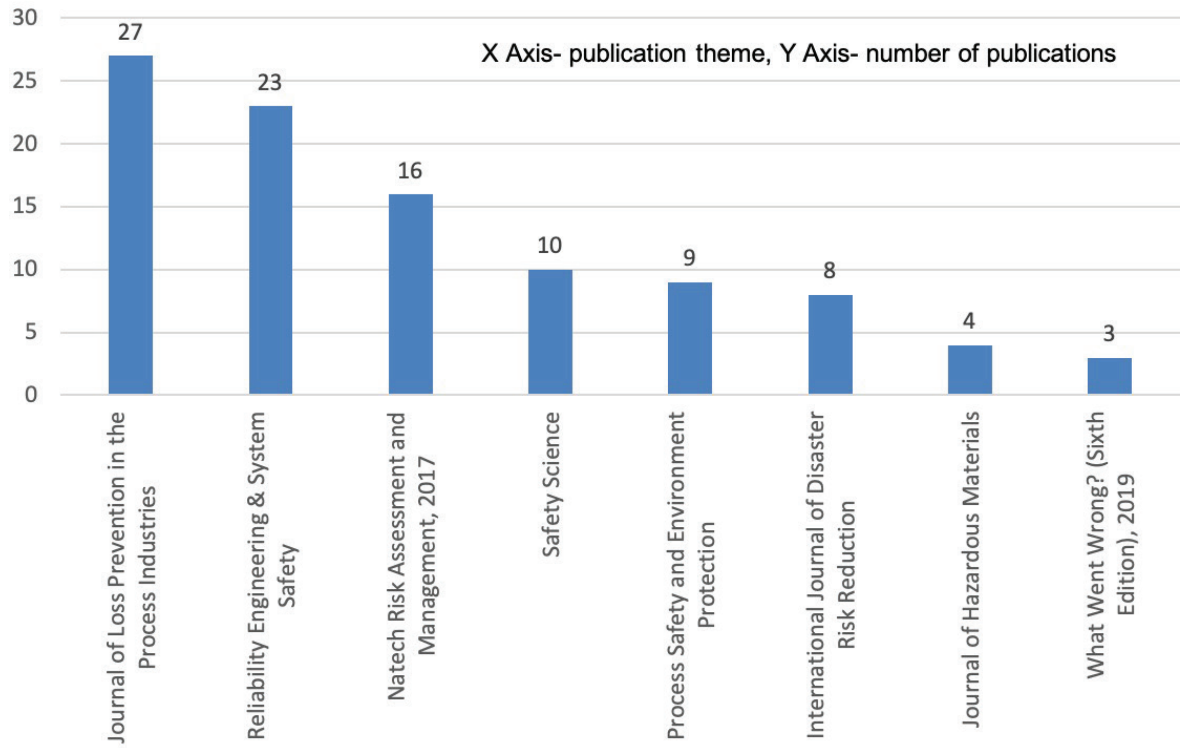


Figure 5: Relevant Publications during 2000-2020 as per Publication Title based on search on Science Direct for keyword NATECH as on 07.01.2020



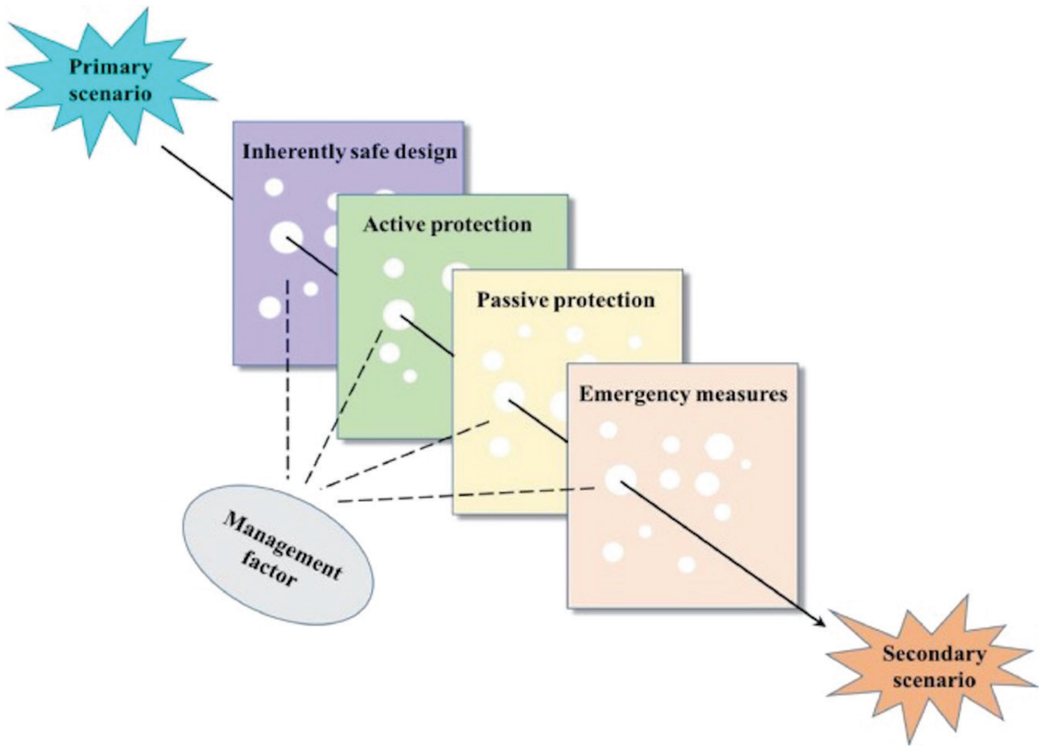
Among others, NATECH risk management has been highlighted in context of design and safety standards of ageing factories and contaminated environments (Rongshi Qin, 2020; Hangnan Yu, 2020). Some studies emphasise the importance of conducting regular risk assessment with the help of various tools including GIS, remote sensing and other statistical models.

Sano et al. propose an index for translating risk assessment results for production process safety to costs, thus aiding in appropriate prioritization and allocation of management resources to safety investments. The index also accounts for indirect costs including that of lost opportunity, business interruption, loss of raw materials and products, lost profits, etc. for expressing damages incurred. A key highlight of the paper is inclusion of natural hazards as one of the four considerations for risk identification at industrial level. This marks an important shift in the approach of compartmentalizing the natural and technological hazards for risk assessment.

The domino effect in the field of risk analysis was first documented in 1947, while the earliest systematic study began in 1991. Domino effect can be understood as "An accident in which a primary unwanted event propagates within an equipment ("temporally"), or/and to nearby equipment ("spatially"), sequentially or simultaneously, triggering one or more secondary unwanted events, in turn possibly triggering further (higher order) unwanted events, resulting in overall consequences more severe than those of the primary event" (Lei Hou, 2020). Conventional domino effects are cascading accidents caused by a primary event like fires, blast waves, etc. inside the boundaries of the plant and NATECH can be considered as an external domino effect caused by natural events. NATECH events in an industrial or process installation are likely to escalate the internal domino effect involving surrounding equipment, thus further exacerbating the already catastrophic consequences of the initial scenario (Alessio Misuri, 2020).

Hou et al. highlight four management factors for preventing and mitigating escalation accidents (Figure 6). While inherently safe designs can mitigate the risk of domino effect to certain extent but often the pre-designs have limitations of not taking into account the cost and land use planning. Active protective barriers automatically or manually trigger the protection action and include fire-fighting systems, etc. Passive protective devices tend to delay the time of triggering domino effect by constructing physical barriers between primary scenario and the secondary target. For e.g. fireproofing. Emergency measures are related to personnel performance and emergency procedures (Lei Hou, 2020)

Figure 6: Safety Barriers for Preventing and Mitigating Escalation Accidents Source: (Lei Hou, 2020)



Misuri et al. flag that despite the growing interest in the analysis of NATECH scenarios, systematic approaches for the analysis of the performance of safety barriers in NATECH scenarios are lacking (Alessio Misuri, 2020).

Nishino et al. (2020) raises a significant aspect of safety of pre-identified shelters in case of NATECH. For e.g., the study highlights how that tsunami vertical evacuation buildings would be exposed to high thermal radiation in event of tsunami-triggered oil spill fire. So, it brings forth a critical aspect that identification of safe evacuation shelters should be done in due consideration of the potential consequences of NATECH events, which is not a practice currently.

2.1 Trends in Definition

The first use of the term "natech" is traced back to a journal paper by Showalter and Myers in 1994, analysing the release of oil, chemicals, and radiological materials due to natural hazard-induced disasters. This section traces the etymological evolution of the term from natech to more recent usage of the term NATECH. GAR 2019 notes that natural hazards have the potential to surpass safeguards, triggering negative impacts that may entail hazardous substance release, fire, explosion or indirect effects with wider repercussions than those felt in the immediate proximity. The cascading technological side effects of natural hazards are called NATECH accidents. NATECH event consequences can range from health impacts and environmental degradation to major economic losses at local or regional levels due to damage to assets and business interruption.

As per Joint Research Centre, European Commission, accidents initiated by a natural hazard or disaster which result in the release of hazardous materials is commonly referred to as Natech or na-tech accidents. This includes releases from fixed chemical installations and spills from oil and gas pipelines.

As per OECD, a natech accident is a chemical accident caused by a natural hazard or a natural hazard-induced disaster. Chemical accidents include accidental oil and chemical spills, gas releases, and fires or explosions involving hazardous substances from fixed installations (e.g. petrochemical, pharmaceuticals, pesticides, storage depot) and from oil and gas pipelines.

ASEAN Risk Monitor and Disaster Management Review describes that technological accidents triggered by natural hazards, known as Natech, are typically more devastating in terms of human casualties, economic loss, and environmental damage than either a natural or technological disaster on its own. When a natural hazard occurs in an industrial area where hazardous materials (hazmat) are used, handled, generated, or stored, there is a high risk of the release of contained hazmats. Hazmats include certain liquids, gases, and pressurized gases with hazardous properties, such as toxic, flammable, and/or explosive materials. Hazmat releases – depending on their properties, processes, and confinement – can result in contamination, toxic vapor, fire, or explosion that can impact surrounding communities and industries.

Natural hazards, such as earthquakes, floods, storms, or extreme temperatures etc., can cause the release of dangerous substances from hazardous installations resulting in fires, explosions or toxic or radioactive releases. These are called Natech accidents. They are frequent in the wake of natural-hazard induced disasters and have often had severe and long-term consequences on the population, the environment and the economy. Any kind and size of natural hazard can trigger a Natech accident. It does not necessarily require a major natural hazard event, like a strong earthquake or a major hurricane, to cause a Natech accident. With increasing industrialisation and urbanisation coupled with climate change, Natech risk is expected to increase in the future.

WHO mentions that a Natech event is a technological accident triggered by a natural hazard. These can include floods, earthquakes, lightning, cyclones and extreme temperatures. A technological accident can include damage to, and release of chemicals from, fixed chemical installations, oil and gas pipelines, storage sites, transportation links, waste sites and mines.

Apart from the above, various journal papers, workshop proceedings and NATECH related literature were referred to better understand the diverse definition and description of the term in use. A summary of the same is listed below in annexure 1.

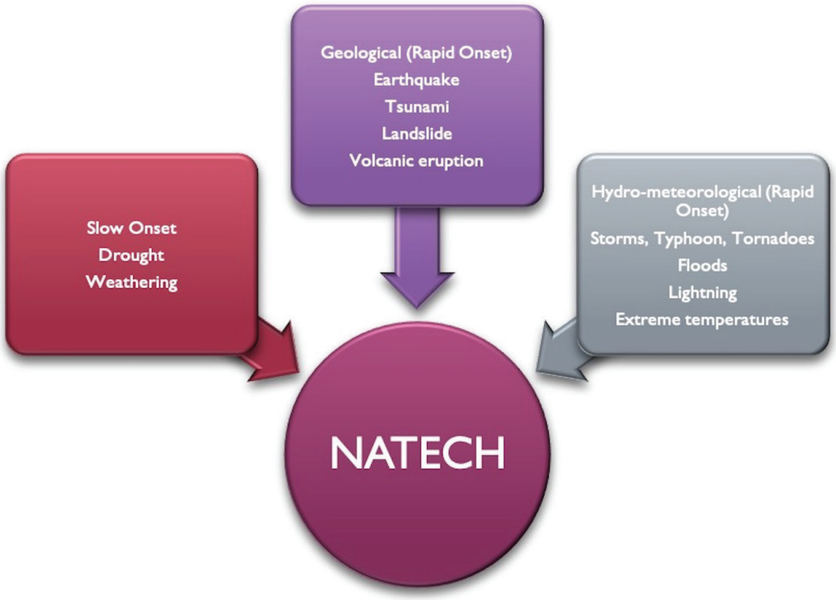
2.2 Clarification on the Terminology

Existing literature use varied terminology for NATECH and there is a need to clarify and standardize the terminology. Various terminology currently in use include NATECH, Natech, na-tech, Na-tech, etc. Henceforth, this document will use the terminology NATECH (NAtural hazards triggering TECHnological disasters) as mentioned in GAR 2019.

2.3 Areas of Focus

The natural hazards triggering NATECH can be broadly divided into slow onset hazards like drought and weathering and rapid onset hazards of geological and hydro-meteorological nature (Figure 7). Thus, the area of focus for NATECH risk management should include understanding the nature of cascading risk these natural hazards can pose to different infrastructure and services and thereby having a potential to become technological disaster.

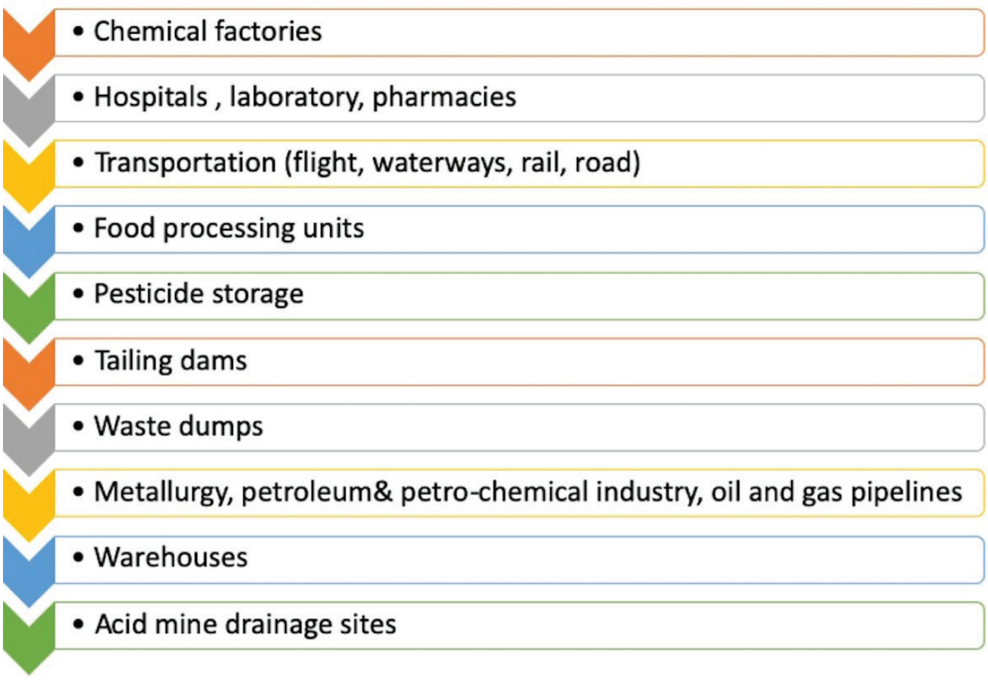
Figure 7: Types of Natural Hazards Triggering NATECH



Majority of the publications and case studies exiting on NATECH are focused on NATECH risk on fixed installations like industrial setup, warehouses, hospitals, etc. However, there are possibilities of NATECH risk to assets which are of mobile/ non-fixed nature or even while in transit. Thus, areas of focus include studying and understanding the nature of NATECH risk to both kinds of infrastructure and the identifying the challenges therein. Some of these infrastructures is listed in Figure 8.

Figure 8: Types of Infrastructure at NATECH Risk

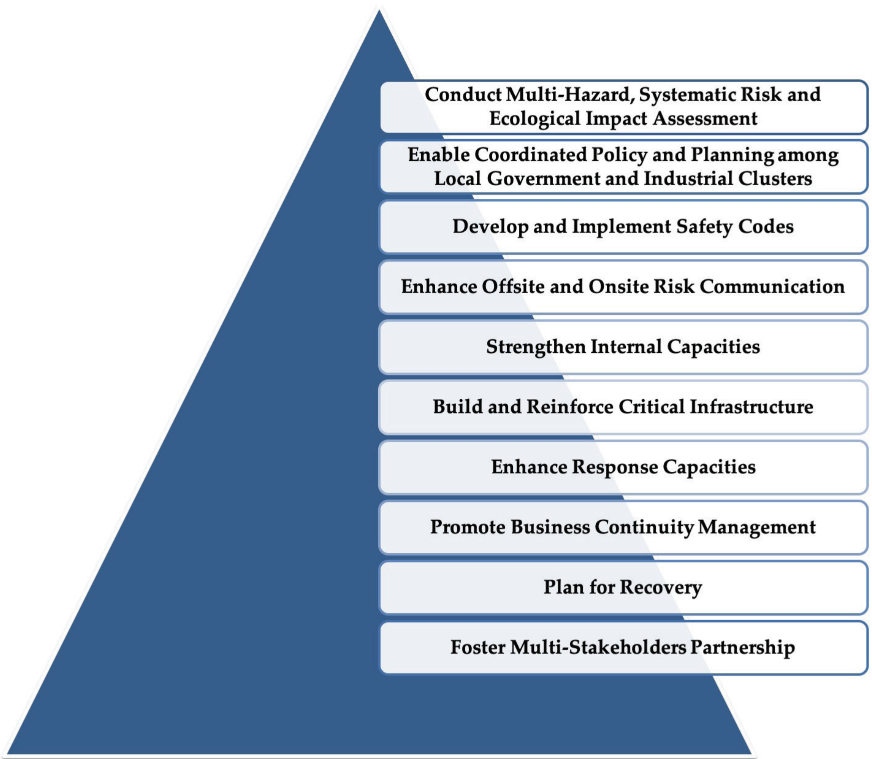
(Source: WHO, 2018)



3. Ten Basic Principles of NATECH Risk Management

The implementation of the Asia-Pacific Regional Framework for NATECH Risk Management can be guided by the following principles (Figure 9), with due considerations of national circumstances, consistency with domestic laws as well as international obligations and commitments.

Figure 9: Ten Basic Principles of NATECH Risk Management



1. Conduct Multi-Hazard, Systematic Risk and Ecological Impact Assessment

NATECH risk management calls for a holistic risk assessment in all its dimensions of vulnerability, capacity and exposure of community, assets and environment to multiple hazards. It should include assessing the systemic interdependencies between natural hazards and technological hazards in a built environment and evaluating the effectiveness of existing capacities with respect to likely risk scenarios.

2. Enable Coordinated Policy and Planning among Local Government and Industrial Clusters

Each State has the primary responsibility to establish and put in place a systems of risk governance comprising of institutions, mechanisms and policies for implementation of the present framework at national, sub-national and on-site level. Effective planning for NATECH risk management should involve active engagement of institutions of legislation and execution at all levels; thereby clearly voicing out of time-bound roles and responsibilities across all stakeholders including private businesses and academia. The sources of funding for implementation of the plan should be specified in the plan. Linkages to existing disaster risk management plans sustainable development and climate change adaptation plans should be made where possible.

3. Develop and Implement Safety Codes

Safety codes and regulations should be developed at national and sub-national levels catering to various aspects of structural and non-structural safety with an all-hazards approach. These include norms for land use, construction, design, materials and usage for ensuring sustainable and resilient infrastructure. Codes, tailor-made to national and local needs, should incorporate global and regional experiences.

4. Enhance Offsite and Onsite Risk Communication

Comprehensive risk assessment is a pre-cursor to efficient risk communication. Risk communication provides a ground for informed decision making for effective risk management and includes understanding and building the risk perception of the stakeholders. Effective risk communication should take place between the scientific & academic community and the policy makers; amongst the personnel of industrial and hazardous installations; between such installations and the nearby exposed community.

5. Strengthen Internal Capacities

Capacity development includes skill development, resource mapping and scaling up of required resources (both human, equipment and financial). In-charge of each hazardous and industrial installations are responsible for developing on-site capacity for mitigation, prompt response and rapid recovery commensurable to the nature and quantum of risks assessed They are also responsible for enhancing the coping capacity of the off-site community. Each State is responsible for strengthening the internal capacities at national and sub-national level for providing timely early warning of and specialized response to NATECH.

6. Build and Reinforce Critical Infrastructure

The critical infrastructure at national and sub-national levels needs to be strengthened and made resilient by respective authorities for ensuring continued social and economic functioning of the community even during times of disasters. The resilient lifeline infrastructure of health, fire and emergency response aids in substantial reduction of life loss & injuries and in prompt containment of damage and losses to assets.

7. Enhance Response Capacities

The litmus test for response mechanism is the number of lives saved and quantum of damage & destruction prevented. It relies on NATECH risk-informed preparedness measures, readiness and response capacities of on-site and off-site responders including the communities. It is the responsibility of authorities at national, sub-national and on-site level to put in place a set of specialized agencies and mutual-aid groups to save lives, contain health and other cascading impacts, ensure public safety and meet the immediate basic needs of the affected community.

8. Promote Business Continuity Management

Each industry and business should analyze the NATECH risk and put in place arrangements including processes, robust supply chains, financial mechanism for ensuring continued functioning of business, commercial activities and services in aftermath of NATECH.

9. Plan for Recovery

The sub-national and on-site authorities are responsible for safe disposal and management of hazmat, if any, released during the NATECH. This is followed by prompt restoration of services, livelihood and normalcy in the affected community. The process of recovery should be aligned with principles of sustainable development and should be guided by the building back better approach so as to prevent creation of future risks.

10. Foster Multi-Stakeholders Partnerships

NATECH risk management is an inter- and trans-disciplinary field and seeks coming together of academicians, practitioners and policy makers at multiple levels. Depending on the nature of technological disaster, NATECH sometimes calls for trans-boundary cooperation for its management. It is the responsibility of authorities at relevant levels to nurture such partnerships.

4. Policy Integration

Cases studies were used to understand the existing policies, if any, on NATECH and related issues. In most of the cases, a specific policy on NATECH is missing. There are policies existing on safety, preparedness and response measures concerning industrial, chemical, nuclear and other infrastructure including dam, power plants, etc. but the possibilities of them getting impacted due to natural hazards and leading to NATECH have not been fully explored and addressed. Thus, in most of the cases, these policies fail to link the cause (natural hazard) and effect (triggered technological disaster) relationship and in some cases, where they do, proper implementation and its monitoring is a key challenge and gap.

Japan

Legislation exist on **specific sector safety** requirements, such as Petroleum Complex Disaster Prevention Law (Policy and legislation related to the safety measures in the petroleum industry in Japan: https://www.paj.gr.jp/english/data/paj2011.pdf

With regard to the nuclear disaster, Japan has an Act on Special Measures Concerning Nuclear Emergency Preparedness (1999) which aims to strengthen nuclear disaster control measures, under which there is a Guideline for Earthquake Resistant Design of Nuclear Power Plant (2006) dedicated to the regulations on the nuclear power plant design against earthquake. An Interim Report of the Special Committee on Safety Goals for Nuclear Installations (2003) indicates the importance of performing probabilistic risk assessment which cover all hazards including natural-hazard induced disaster, though the assessment was not mandated until after the 1FNPP accident. Although NATECH was not included as a keyword in these documents, the nuclear community has been aware of the nuclear disaster induced by earthquakes. **However, combination of natural hazards, e.g. an earthquake followed by a tsunami, was not considered, and the risk assessment was on voluntary basis.**

Overall, a comprehensive policy addressing technological hazards in general and NATECH in particular is mostly missing at sub-national, national and regional level. Absence of a targeted policy on NATECH risk management results in operational gaps in understanding and management of the NATECH whereby the triggering natural hazards and the triggered technological disasters are often compartmentalized.

Malaysia

Given the low frequency of NATECH events in Malaysia in the past, there is still no official platform that engages and informs communities about NATECH. Although authorities such as BOMBA and Department of Occupational Safety and Health (DOSH) are usually well informed about industrial disaster risks, communication to communities and other stakeholders such hospitals and CBOs are very limited. **As of now, if a NATECH event would occur in Malaysia, the authorities will respond to it as two separate events; natural hazard event (flood / lightning) and industrial incident.**

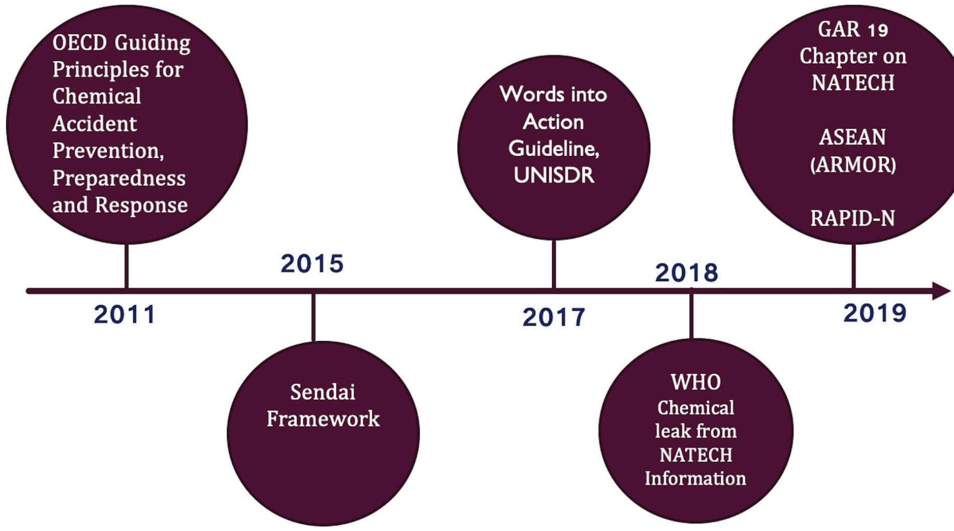
Nonetheless, an Internal Emergency Response Team (ERT) is established based on relevant regulations. The industry players conduct their annual emergency drills according to legislation and guidance such as, Control of Industry Major Accident Hazard (CIMAH) Regulation under Occupational Safety and Health Act 1994 (OSHA) and ERP (Emergency Response Planning), CMP (Crisis Management Planning) program of individual companies.

In Pasir Gudang, major industries like oil and gas companies are required to register in **a mutual aid membership** called PAGEMA (Pasir Gudang Emergency Mutual Aid). PAGEMA was established in 1988 and the main objective of the establishment is to improve **coordination during emergencies between private sector and government stakeholders.**

The year 2011 onwards, there has been an increasing focus on evolving nature of NATECH risk resulting in development of various framework and guidelines on/including the subject of NATECH (Figure 10). These includes the OECD Guiding Principles for Chemical Accident Prevention, Preparedness and Response (2011), Sendai Framework 2nd Addendum for NATECH, OECD (2015), Words into Action Guideline, UNDRR (2017), WHO Chemical Leak from NATECH Information (2018) and GAR 2019 Chapter on NATECH, ARMOR, ASEAN and RAPID-N in 2019, among others. The recently released Sendai Framework-aligned hazard definitions and classification lists NATECH hazard under technological hazards and "industrial failure/non-compiance" hazard cluster (UNDRR and ISC, 2020).

The Sendai Framework acknowledges the need to focus on technological hazards and disasters and has stressed for sectoral approach while building coherence among various related stakeholders to manage risk.

Figure 10: Recent Guidelines and Framework on NATECH Risk Management



Thailand

The National Disaster Management Policy focuses on disasters resulting from natural hazards, and more emphasis is placed on mitigation and response measures rather than protective measures. No policy on NATECH is confirmed. **Only large enterprises had a business continuity plan (BCP).**

APRU (Association of Pacific Rim Universities)

APRU, consisting of 50 universities in the Pacific Rim, initiated the **Campus Safety Program under its Multi-Hazards Program**. Under the campus safety program, a workshop to discuss the issue and challenges related to disaster preparedness on campus is organized every two years since 2016. The 3rd workshop to be held in 2020 includes the aspect of man-made hazards as well as natural hazards. It is because the risks of the NATECH is acknowledged through various natural hazards experience and it is important for universities to expand their preparedness capacity to man-made hazards considering the huge impact to the communities if it happens.

The Global Assessment Report (GAR) of 2019 included NATECH along with hazards like environment, radiological, nuclear among others. The very first guidelines on chemical accidents was prepared by OECD in 2011. The guiding principles revolve around four pillars of prevention, preparation, response and follow up.

- Preventing the occurrence of incidents involving hazardous materials
- Preparing for accidents, and mitigating adverse effects of accidents through effective planning
- Responding to accidents that do occur in order to minimize impact
- Follow-up to accidents, reporting and analysis

In 2015, OECD came up with Addendum 2 to address NATECH adding to the earlier OECD guiding principles for chemical accident prevention, preparedness prepared in 2003. A new chapter was added to NATECH risk to support better management and preparedness. The guidelines focus inclusion of NATECH risk in hazard mapping, adequate training of human resources, regulations and planning, transboundary cooperation, and bettering of warning systems among others.
The UNDRR Word into Action guidelines (2017) emphasizes on NATECH as an emerging hazard risk and is inter-reliant on human, natural and technological systems. Acknowledging the lack of comprehensive NATECH assessment tools, the guidelines lists out quantitative, semi quantitative and qualitative tools (ARIPAR, RAPID-N, PANR) available at present for conducting regional and national risk assessments.

Japan

Since 2005 there has been a requirement for municipalities in Japan to **develop and publicize hazard maps** and by 2013, 95 % of municipalities had produced flood hazard maps and 81 % for landslides. Nonetheless, a number of houses, built before the 2005 requirement, were erected on areas of higher risk (WEF, 2018).

Global Assessment Report (2019) was first to include various hazards for the first time including NATECH linking its impact to social, environment, health and economy. The GAR 19 proposes ways to map the NATECH risk in relation to not only critical infrastructure and industrial sites but overall socio-economic and governance issues.

The World Health Organisation (2018) guidelines principally for health impacts of NATECH events focus on earthquakes, cyclones and floods. The guideline is inclusive of immobile and mobile sites which includes hazardous material transportation through rail, road, air and sea.

Philippines

In recognition of the need to mitigate potential effects of disasters on energy supply due to damaged facilities, and subsequent impacts such as disruption to vital public services, associated risks to public health and safety, and economic and financial losses to communities and businesses, the Department of Energy issued a department circular on, **"Adoption of Energy Resiliency in the Planning and Programming of the Energy Sector"** in January 2018. Citing laws on power sector reform, deregulation of the downstream oil industry, and the Philippine Disaster Risk Reduction and Management Act of 2010, the policy defines **resilient energy infrastructure** as, "…the ability to restore and sustain availability and accessibility of energy in the most timely and efficient manner in the aftermath of natural and man-made disaster" with particular focus on developing standards and strengthening infrastructure, and improving operational and maintenance standards and practices to expeditiously restore energy supply. It also requires energy sector actors to formulate Resiliency Compliance Plans (RCP) to constitute the Energy Resiliency Plan, which, in turn, will form part of the Philippine Energy Plan (Department of Energy, 2018). **The risk posed by the exposure of ecosystems and communities to the energy infrastructure is not addressed in the policy document.**

Malaysia

Control of Industry Major Accident Hazard (CIMAH) Regulation was adopted in 1996 with aim to enhance control of major accidents at high-risk places (e.g. office, factories, warehouses). Although this regulation requires **establishments with HAZMAT to provide information to the nearby communities on the possible risks** and consequences of emergency incidents, some companies are found to be reluctant on giving such information.

Singapore

The Fire Code of Singapore requires oil storage tanks to have **lightning protection systems**. The Singapore Civil Defence Force (SCDF) has been officially tasked with mitigating and response to hazmat incidents. Since 2002 fire stations in Singapore have been going through major capability upgrades in order to be able to respond to emergencies involving releases of hazardous materials. All responders from regular fire stations receive training on response measures to hazmat-related incidents. A second tier of **specialized respondents** is established – the hazmat Incident Team (HIT) who are responsible for mitigation and decontamination operations (Hwa et al., 2016). A Hazmat Emergency Assessment and Response Team (HEART) is also established to provide specialist advice to respondents on the ground in time of incidents. The team utilized a unique vehicle – the Hazmat Control Vehicle (HCV), which is deployed during incidents to identify the type of hazard and to assess the level of contamination. The vehicle has an integrated functional laboratory for analysis of hazardous materials and can be deployed in monitoring operations. The SCDF has also established a social media monitoring function in its operation centre to monitor social media platforms in case citizens post information on new incidents (Hwa et al., 2016).

Another aspect missing in the existing legislations, guidelines, etc. is holistic coverage of all components of disaster management cycle. While some only lays down preventive and mitigation measures for safety, others only focus on the response component, thus leaving operational gaps.

New Zealand

After the September 2010 Earthquake, the Government created the Canterbury Earthquake Response and Recovery Act (2010), appointed a dedicated Minister for Canterbury Earthquake Recovery and established the Canterbury Earthquake Recovery Commission. However, the Commission was not considered to be effective. For example, the CCC had not **produced a recovery plan** by the time of the February 2011 earthquake (CGC, DPM&C, 2017).

At the time of the February 2011 Earthquake, there were three primary documents in effect that outlined the roles and responsibilities of key government agencies that were involved in the **response**. These are:

a. The Civil Defence Emergency Management Act (2002);
b. National Civil Defence Emergency Management Plan (2005); and
c. The Guide to the National Civil Defence Emergency Management Plan of 2006 (revised 2009) (CGC, DPM&C, 2017; McLean et al., 2012)

Together with improving regulatory enforcement, it is recommended that the existing and future policies should incorporate measures for management of risks related to natural hazards that could multiply the effects of conventional industrial incidents. They should also include aspects of disclosure of information and risk communication to public describing worst case scenarios, alternative evacuation routes and relevant emergency contact details.

Further, national and regional legislations and guidelines should include the evaluation of community-based and traditional knowledge and cultural practices in the design of prevention, remediation and resilience plans for natural-technological disasters. This process should include the utilization of locally available natural materials and appropriate technologies.

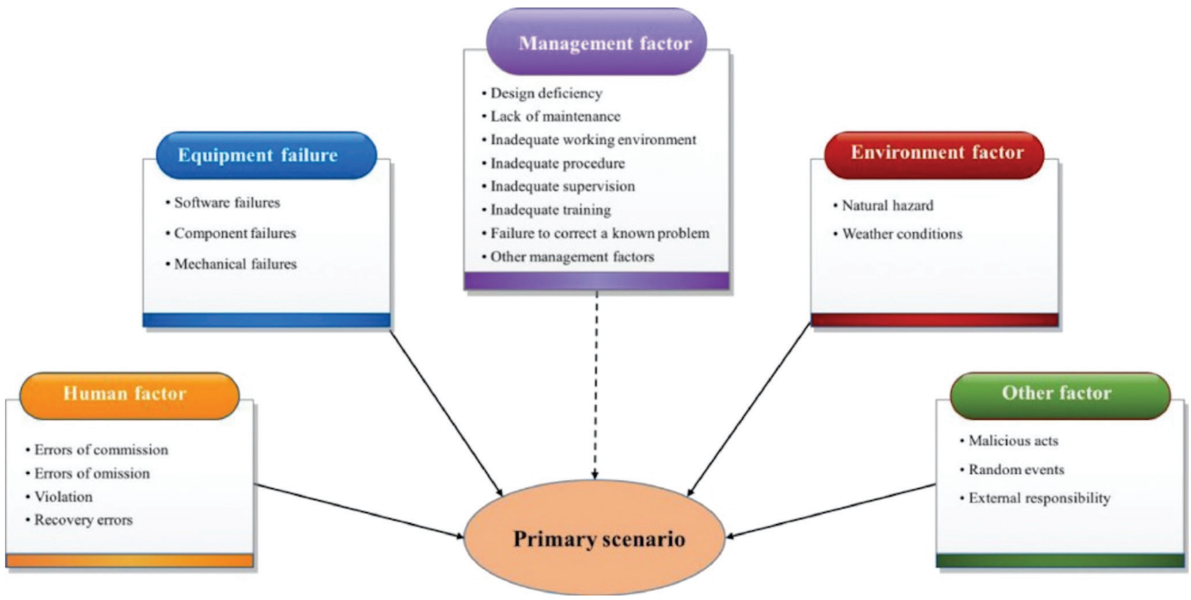
5. Operational and Knowledge Management

5.1 Operational Management

Major causes of NATECH include high population density, increased frequency of severe weather related events, more industries and infrastructure at risk. With growing industrialization (notably in emerging economies), rising vulnerability (e.g. due to encroachment and often unplanned urban development), as well as changing hazard frequency and occurrence (including as a result of a changing climate), NATECH risk is expected to trend upwards.

Despite presence of some existing policies on safety and management of various infrastructure including dams, industries and other technological assets, gap in efficient and effective implementation of these existing policies and the inability of these policies to fully explore, understand and address NATECH related complexities. During onset of any natural hazard, these operational gaps are aggravated further, often resulting in technological disasters.

Figure 11: Potential Contributors to the Primary Scenario
Source: (Lei Hou, 2020)



Hou et al. have suggested potential contributors to the primary scenario (Figure 10). If the listed factors/ failures other than the environment factor (which in our case is the natural hazard triggering the disaster) are considered, potential operational issues could be worked out.

5.2 Knowledge Management

The Sendai Framework recognizes that disaster risk reduction requires a multi-hazard approach and inclusive risk-informed decision-making based on the open exchange and dissemination of disaggregated data and easily accessible, up-to-date, comprehensible, science-based, non-sensitive risk information, complemented by traditional knowledge.

The risk and challenges faced during NATECH events have been evolving over the years and have become more frequent and unpredictable due to climate-induced hazards. Comprehending the degree of cascading risk and developing ways to isolate, measure and manage or prevent them is challenging. To have better risk perception and to address these cascading nature of challenges faced during NATECH, the key is creation and sustenance of knowledge at all levels. Lack or gaps in knowledge limits the ability of government and other stakeholders to act and effectively communicate the risk to all concerned. Thus, knowledge management is inevitable to support informed decision-making for effective management of NATECH risk.

Further, GAR 2019 flags the importance and need to assemble new combinations of tools that can help the world think and act at a pace, as well as at the scale commensurate with the complex problems we face. In too many fields, the most important data and knowledge remain flawed, fragmented or closed, lacking the context and organization required for them to be accessible and useful for decisions.

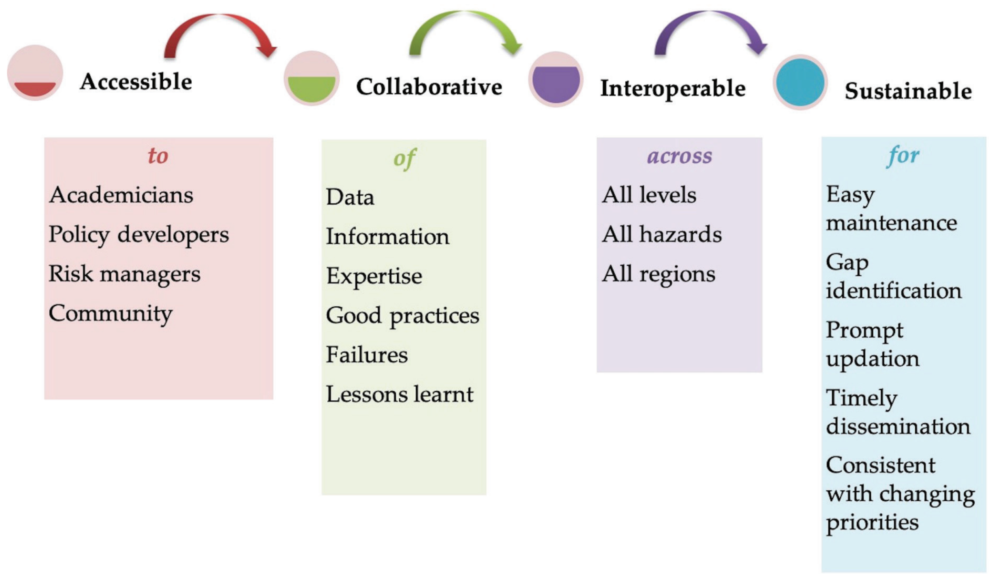
The following gaps have been observed in the knowledge management of NATECH:

a. Absence of single registry of the location of industrial facilities in natural hazard zones
b. Absence of baseline to compare NATECH risk trends
c. Absence of information on natural hazard in industrial accident databases and that on NATECH events in disaster loss databases
d. Instruments for reducing technological risks often tend to overlook the specific drivers of NATECH, leaving an important gap in managing this type of risk
e. Inadequate interaction amongst the various stakeholder communities involved in NATECH risk management including the experts of technological risks, natural risks, industrial risks, civil safety and protection, etc.
f. Low risk perception of NATECH events triggered by certain hazards like lightning and low/ high temperatures

g. Absence of composite indicators for measuring progress in NATECH risk management

In the context of NATECH, knowledge management must take into account the interactive nature of the drivers of risk; their interrelationships and interdependencies. Tools of knowledge management for NATECH include IT-based tools and non-IT tools. While the former include databases or application for collection and generation of baseline information, risks maps, assessment tools, etc., the latter include policies, research studies and platforms like conferences, workshops for knowledge-sharing and dissemination, etc. These tools should be easy to access, easy to disseminate, easy to use, easy to update and should be relevant to all-hazards and all stakeholders (Figure 12) to ensure better coverage of stakeholders and hence effective risk communication. Apart from the creation, application and updation of the NATECH knowledge, another critical aspect of its management is acknowledging the gaps in existing knowledge and prioritizing ways to understand them.

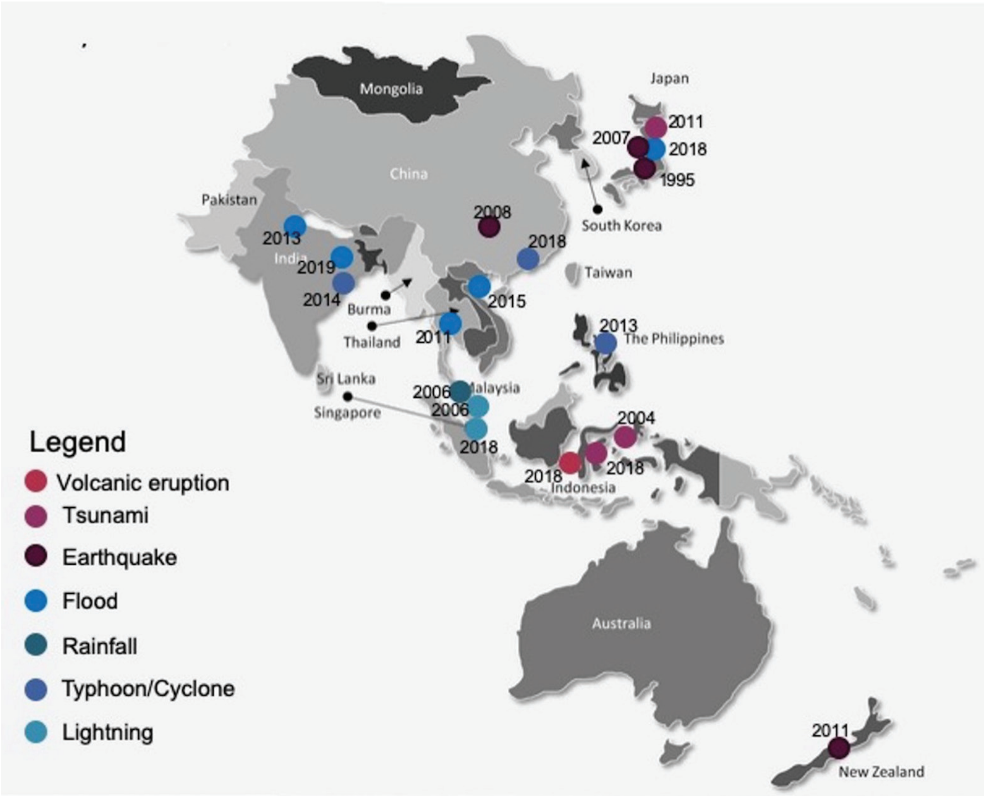
Figure 12: Attributes of NATECH Knowledge Management Tools



While an essential step is to strengthen technical and scientific capacity to capitalize on and consolidate existing knowledge, focus should also be on concerted international, regional and local cooperation to stimulate and contribute towards the same at all the levels. GAR 2019 notes that regional cooperation mechanisms can provide key support to knowledge-sharing and capacity-building among countries with similar risk profiles and regional concerns. Nevertheless, contextual understanding and the use of appropriate traditional, indigenous and local knowledge and practices must complement the scientific knowledge for NATECH for having a holistic understanding of under-lying systems and challenges therein.

6. NATECH Events in Asia-Pacific

Figure 13: Distribution of Case Studies



6.1 Details of Referred Case Studies

Various cases of NATECH in the Asia-Pacific region have been studied for the purpose of identifying the nature of failure, gaps and best practices and for understanding the lessons learnt and recommendations put forth in aftermath of each case. These case studies have been analysed in Table 1.

S. No	Disaster	Impact	Failure/Gaps/ Good Practices	Lesson Learnt/ Recommendations
1.	Earthquake, Kobe Japan (1995)	• Minor leaks and fire at many hazmat facilities • Damage to gasoline stations leading to release of LPG • Damage to storage containers • Mixing of chemicals in government laboratory leading to fire	• No major releases despite the proximity of industrial facilities to the epicenter and severe ground shaking • Industries better prepared due to existing codes and practices • Improved foundation construction, flexible pipes, concrete block firewalls around gasoline stations • Lack of preparation & coordination amongst civil protection agencies	• All indoor storage facilities, especially warehouses are extremely vulnerable to ground shaking, so develop a broad-based widely applicable solution • Review earthquake design criteria for plants, tanks, pipelines, containment walls, equipment, etc. • Include social, systemic and organisational vulnerabilities in NATECH preparedness and management
2.	Earthquake, Tsunami, Aceh, Indonesia (2004)	• Damage to oil, gasoline and jet fuel tanks leading to spill • Damage to cement plant leading to high chances of chemical spill • Damage to ship, tugboat and barge leading to spill	• Poor early warning for earthquake and tsunami • Lack of adequate awareness in the community for tsunami risks • Poor mitigation practices for earthquake and tsunami	• Develop and improve early warning system for earthquake & tsunami • Improve knowledge and enhance awareness of local community • Improve disaster response planning • Put in place business continuity plan

S. No	Disaster	Impact	Failure/Gaps/ Good Practices	Lesson Learnt/ Recommendations
3.	Heavy rainfall, Selangor, Malaysia (2006)	• Disruption of landfills and water treatment plants leading to severe pollution of water sources	• Prompt action by authorities in shutting down affected water supply	• Equip landfills with modern and environment-friendly systems • Undertake EIA before establishing waste disposal sites • Human technical blunder plays a role in contributing to the NATECH • Implement structural and non-structural measures of DRR • Investigate landfills exposure to climatic hazards
4.	Lightning, Johor Port, Pasir Gudang, Malaysia (20 06)	• Fire and explosion at petroleum tank • Spread of fire to nearby tanks and installed pipelines	• Situation was easily controlled with help of government and private fire-fighters • Local authorities didn't have required equipment ready • Only single route for evacuation was available that became congested due to mass evacuation • Because NATECH is a new emerging risk, information regarding NATECH risks have hardly been shared outside of industrial players, hence, others stakeholders are unaware of the lessons and knowledge gained through these incidents	• Pre-disaster agreement between local authorities and industry players helped make disaster response more efficient during crisis • Rumours based on unconfirmed information could be disseminated quickly through social media and may create panic • Relevant authorities may develop a proper monitoring/ checking system for industries to manage supplies for better emergency response.

S. No	Disaster	Impact	Failure/Gaps/ Good Practices	Lesson Learnt/ Recommendations
5.	Earthquake, Niigata, Japan (2007)	• Fire broke out at nuclear power plant • A very small amount of radioactive material flowed into the sea	• Vulnerability of crisis response system such fire-fighting system at the nuclear plant, lack of required equipment, etc. was highlighted • With support of employees and business partners in clean up and restoration, the affected factories were fully restored in just two weeks • There was a delay in providing correct information to local residents	• Importance of BCP and supply chain management • Need for diversifying suppliers or multiple purchasing is highlighted • Importance of cooperation of business partners was highlighted • The importance of proper information sharing within the crisis management
6.	Earthquake, Chengdu, China (2008)	• Collapse of phosphate mines • Spill of hazardous materials from multiple chemical industries • Leakage of sulphuric acid and ammonia from plants and fertilizers producing facilities • Fire and explosion in sulphur plant	• Failure of safety measures • Building codes to withstand lesser seismic intensity were in place • Safety barriers had largely failed in the older buildings • Failure of non-structural elements like pipes and storage tanks	• Seismic designs of buildings and codes are of prime importance and should be regularly updated to address higher seismicity • Realistic and continuous risk assessments are recommended • Buildings with poor reinforcement, non-reinforced brick structures, stiff-frame design, heavy topsides and thin columns were much more vulnerable to collapse.

S. No	Disaster	Impact	Failure/Gaps/ Good Practices	Lesson Learnt/ Recommendations
7	Heavy rainfalls and tropical storms causing floods, Thailand (2011)	• Excess water levels in waterways, dams, reservoirs • Submergence of the industrial estates • Washing out of toxic materials by the flood like the waste or mud which severely contaminated the water during the flood	• Lack of explicit roles & responsibilities of stakeholders relating water management • No policy on NATECH • Only large enterprises have BCP	• Industrial estate level and SMEs should develop BCP • Decentralise planning and decision making • As factories in industrial estates contain significant amount of hazardous materials, measures for prevention and mitigation of NATECH risk must be discussed in the aforementioned BCPs. • Measures to prevent electrocution and mitigate deterioration of water quality must be discussed at both local and national levels.
8.	Earthquake and Tsunami, Honshu Island, Tohoku, Japan (2011)	• Station blackout in the Fukushima Daiichi Nuclear Power Plant (1FNPP) leading to reactor core meltdown in Unit 1 – 3 and contamination of about 800 km2 of land around power plant • Damage to many hazardous installations leading to release of hazmat in air and flood waters	• The accident at the LPG storage tank farm might have been manageable had the safety valve not been locked open. (Human error) • Laws existed focusing on petrochemical, oil and gas industries along with earthquake structural safety measures	• Undertake realistic and continuous risk assessments • Adhere to and monitor safety systems and measures at installations with major accidents potential • Ensure that all personnel are aware of applicable laws and regulations • Reinforce LPG tank braces to increase resistance to tank to future earthquakes • Minimize human errors • Nuclear power plant or other facilities with hazardous materials

S. No	Disaster	Impact	Failure/Gaps/ Good Practices	Lesson Learnt/ Recommendations
8.		• Damage to LPG storage tank farm leading to BLEVE		must design preparedness and response strategy to natural hazards, including combination of hazards. • Local disaster management center should establish cooperation with related organizations and effective communication means with public at daily basis in order to ensure its functionality during the disaster • The 1FNPP accident demonstrated that the conventional nuclear safety regulations which emphasizes on the protection of the power plant from designed natural hazards are not sufficient. The regulatory framework must be able to holistically cover various

S. No	Disaster	Impact	Failure/Gaps/ Good Practices	Lesson Learnt/ Recommendations
.				types of natural hazards including their combinations, and also to design response measures once the nuclear disaster happened. The accident has also revealed the importance of the local disaster management center (so called off-site center) which has to be trained and maintained to be able to function during the disaster
		• Fire in Dept. of Chemistry, Tohoku University • In Dept. of Engineering, Tohoku University, some chemicals splashed and a few high pressure gas cylinder fell	• Failure of non-structural elements like high book shelves	• Not many staff and faculty members understood the response manual thoroughly • Seismic reinforcement was extremely effective to reduce the damage of the strong earthquake • Need for further comprehensive disaster preparedness on campus considering the fact that universities keep various types of dangerous chemicals and risks of discharge of gas, experiment waste liquid, high pressure gas, explosives, radiation, poisonous substance, etc.

S. No	Disaster	Impact	Failure/Gaps/ Good Practices	Lesson Learnt/ Recommendations
9.	Earthquake leading to liquefaction, flooding and lateral spreading, Christchurch, New Zealand (2011)	• Damage to wastewater treatment plant • Uncontrolled release of untreated sewage	• Water and wastewater infrastructure was not well designed/ prepared to continue functioning with minimum disruption due to earthquakes. It was already weakened by the September 2010 earthquake • Post-earthquake, Christchurch was divided into four zones based on varying stability of land for further land use planning • Shut-down and containment procedures for sites with dangerous chemicals had not been considered in detail prior to the event	• Pre-established, functional relationships with external agencies allowed for more rapid response than formal communication channels would have provided • Better understanding of distribution and use of alternate waste disposal systems • Management and coordination of information to the public • Evaluation and planning for the use of temporary toilets in an emergency would be appropriate • To prevent contamination of drinking water supplies from broken sewage pipes, drinking water pipes and sewage pipes should be installed at a greater depth from each other. Drinking water pipes could also be laid aboveground to allow for faster repair of broken pipes

S. No	Disaster	Impact	Failure/Gaps/ Good Practices	Lesson Learnt/ Recommendations
10.	Typhoon Haiyan, Estancia, Iloilo Province, Panay Island, The Philippines (2013)	• Damage to power barge which broke loose and ran ashore • Oil spill leading to contamination of fishing grounds and coastal waters	• Power barge crew implemented emergency measures post-disaster but failed to contain heavy fuel oil spill • Challenges to contain the spilt fuel were compounded by the need to manage, collect and treat this mixed and contaminated debris	• Review safety protocols in power sector against natural hazards • Continuously monitor key contaminant levels to understand temporal trend of the pollution • Enhance equipment and infrastructure for prevention, emergency and hazardous waste management • Incorporate impacts of multiple hazards on interdependent socio-ecological and technological systems in disaster management planning at local level • Enhance occupational health and safety procedures • Mandate minimum investment for private companies for multi-hazard risk assessment and strengthen risk and resilience research • Promote inter-agency coordination and risk communication program • Promote use of renewable energy in island sites

S. No	Disaster	Impact	Failure/Gaps/ Good Practices	Lesson Learnt/ Recommendations
				• Increase regional cooperation on resilience to natural-technological hazards • For mega cities, consideration of the complexities of urban systems in terms of continuity in space of functions, networks, flows, etc., and varying exposures and vulnerabilities should be strengthened in emergency planning regardless of administrative boundaries • Reference must also be made to International Good Practice of policies and guidelines that require investment projects to have an emergency preparedness and response plan that is commensurate with the risks of the facility • Ensure that the potentially affected communities are informed of significant potential hazards and the emergency preparedness and response plan

S. No	Disaster	Impact	Failure/Gaps/ Good Practices	Lesson Learnt/ Recommendations
11.	Floods, Uttarakhand (2013)	• Dam failure and destruction of seven hydroelectricity projects • Damage to power house	• Realizing the full • extent of floods, all the dam gates were opened at once to avoid structural damage to the Dam. This sudden release of • water was done without a concern for the downstream people, leading to large scale damage. • If the Dams were properly managed the • impact of the flood could have been reduced to a great extent.	• Development and enforcement of guidelines, regulations and codes for floods and landslides is critical • Environmental Impact Assessment (EIA) and Disaster Impact Assessment (DIA) should be made compulsory for kinds of projects in eco-sensitive regions • Blasting for developmental activities be avoided as it may destabilize the weak rocks in mountainous regions. A special central programme be undertaken for construction of new roads and renovation of existing roads in a scientific manner • Develop Disaster Risk Management plans which should be regularly reviewed and updated to ensure a functional structure and accountability for all actions initiated by the State Government to enhance the resilience of the region • The community-based disaster management system at the local level must be given

S. No	Disaster	Impact	Failure/Gaps/ Good Practices	Lesson Learnt/ Recommendations
				utmost importance and strengthened through appropriate training and awareness programmes • Tourism related development should not be allowed along the river banks • An effective pilgrim control and regulatory body should be constituted for control and management of pilgrims/ tourists • Need of planned and sustainable development
12.	Hudhud Cyclone, Andhra Pradesh, India (2014)	• It doesn't mention any NATECH event which happened or was prevented!	• Timely early warning by IMD • Pre-positioning of alternate communication system, response forces and relief material • Mandatory evacuation	• Need for integrated DM plan among all stakeholders and equip response teams • Develop multi-hazard resistant housing and infrastructure including power, communication • Establish cyclone resistant agriculture • Need of disaster insurance for infrastructure and assets • Develop cyclone building codes and cyclone zonation • Rigorous implementation of coastal zone management plan should be ensured • Eco-based resilience mechanism like mangrove forest protection, conservation and plantations should be a priority area for mitigation

S. No	Disaster	Impact	Failure/Gaps/ Good Practices	Lesson Learnt/ Recommendations
13.	Heavy rainfall leading to floods, Quang Nihn province and Ha Long Bay area, Vietnam (2015)	• Flooding of coal mines leading to release of toxic waste water • Dam and dyke failure • Damage to coal port facilities	• Area was suffering from deforestation and occasional landslides	• Retrofit coal plants • Increase dependence on renewable energy • Take measures against deforestation • Legislation on environment protection • Monitor and manage waste water • Role of local organisations and communities
14.	Lightning, Pulau Busing Island, Singapore (2018)	• Fire at oil storage tank	• NATECH was prevented by prompt response by specialised forces and equipment • Establishing two levels of respondents – providing trainings for general respondents and setting up a specialized team - is a good practice in securing immediate and adequate response	• Importance of specialised response and equipment • Social media monitoring proved useful in detecting the disaster and analyzing public opinion, level of awareness and preparedness of citizens
15.	Anak Krakatau Volcanic Eruption, Landslide, Tsunami, Banten and Lampung Provinces, Indonesia (2018)	• It doesn't mention any NATECH event which happened or was prevented!!	• Limited early warning system/ lack of technology to detect tsunami due to volcanic eruption • Inadequate shelters & poor community preparedness • Poor disaster planning & mitigation system	• Develop and maintain early warning system • Develop technology to detect tsunami due to volcanic eruption • Improve knowledge and awareness of local community • Build appropriate number of shelters • Improve disaster response planning • Conduct comprehensive financial impact analysis of disaster

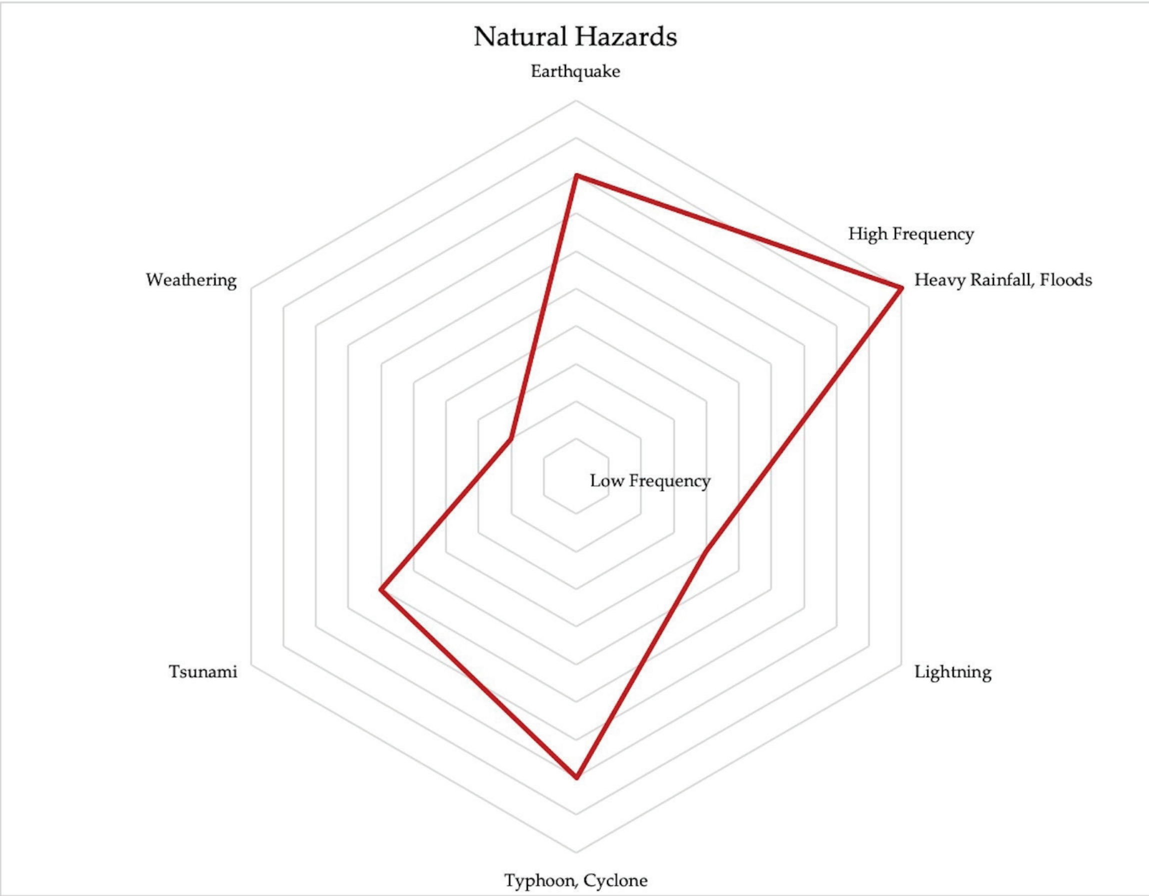
S. No	Disaster	Impact	Failure/Gaps/ Good Practices	Lesson Learnt/ Recommendations
			• Lack of financial impact analysis on disaster • Lack of allocated funds for disaster planning	• Provide sufficient funding for disaster mitigation and planning
16.	Earthquake, Tsunami and Liquefaction Phenomenon, Central Sulawesi, Indonesia (2018)	• It doesn't mention any NATECH event which happened or was prevented!	• The tsunami early warning system created a false sense of security	• Explore limitations of tsunami early warning system technology • Self-evacuation is the key to safety • Ensure unimpeded evacuation routes from beachfronts • Use experience and local knowledge • Contextualise preparedness education to characteristics of local threats
17.	Typhoon, Heavy rains, Floods and Landslides, West Japan (2018)	• Fire and explosion at aluminium factory	• Social media was used to allocate victims and people in need and re-connect family members • The government started several loan schemes with special interest rates for businesses to support recovery of operations • Volunteers undertook a number of activities to rebuild and restore the city after the explosion	• Train communities on different types of disasters as well as on complex disasters • Need for improved communication on preparedness and safety • Properly communicate the severity of possible risks and mitigation measures to be taken to those who live in high risk areas

S. No	Disaster	Impact	Failure/Gaps/ Good Practices	Lesson Learnt/ Recommendations
18.	Typhoon/ extreme wind events, Hong Kong (2019)	• No documented impact	• Better prepared community • Existing institutional mechanism for response • The Philippines reported over 100 deaths; while in Hong Kong, there were no fatalities	• Identify transportation and risk communication channels that will work during disasters • Lay down inter-department SOPs • Fund preparedness and mitigation measures • Identify occupational risks • Mobilise social capital and volunteers • Establish evaluation mechanism • Conceptualise health-emergency and disaster risk management
19.	Muri, Jharkhand, India (2019)	• Breach of retaining wall of bauxite residues storage pond leading to spillage of bauxite residues (BRs)	-	• Study soil strata and probability of liquefaction at each stage of dumping/ storage of BRs • Develop guidelines for utilization of BRs for various conventional and new applications • Policies related to storage/ management/ transportation/ utilization should be brainstormed, created and implemented • Use online instruments for studying the micro-motions in embankments and retention walls

6.2 Case study Analysis

A total of 19 cases were collected representing countries in the Asia Pacific region. Out of 19 cases 14 cases reported a NATECH event while other 5 cases reported a possibility of a NATECH event. From the reported cases flooding and heavy rainfall is the most potential natural hazard to trigger a NATECH event. This is followed by earthquake and Typhoon/cyclone as the second most potential trigger. Along with these cases of slow onset hazards like weathering has been reported as a trigger for NATECH event (Figure 14).

Figure 14: Type of Natural Hazards Triggering Technological Disasters



Analysing the various trigger points for the reported case studies, physical damage to plant and equipment is the most common cause for triggering a NATECH event. From the other case studies, apparently it is evident that physical damage is the major causal factor leading to a NATECH event (Figure 15). Need for safety of storage and warehouse facilities comes out strongly in the case studies. A possible contributing factor which has not been reported in the case studies is human error and lack of training and expertise to contain a crisis situation.

Based on the cases studies, a set of recommendations (Figure 16) were proposed by the experts which is customized to the regional and national context in Asia Pacific region. Most of experts recommend preparation on business continuity plans, occupation safety guidelines and standard operation procedures are the most crucial for NATECH risk management. This is followed by emphasis on research, development of risk assessment tools customized to the local context. The experts also stress on community participation in NATECH decision making process, strengthen coordination among various stakeholders and focus on resilience infrastructure. Other recommendations include need for early warning mechanism, awareness and training as important activities for NATECH risk management.

Figure 15: Type of Triggered Technological Failure

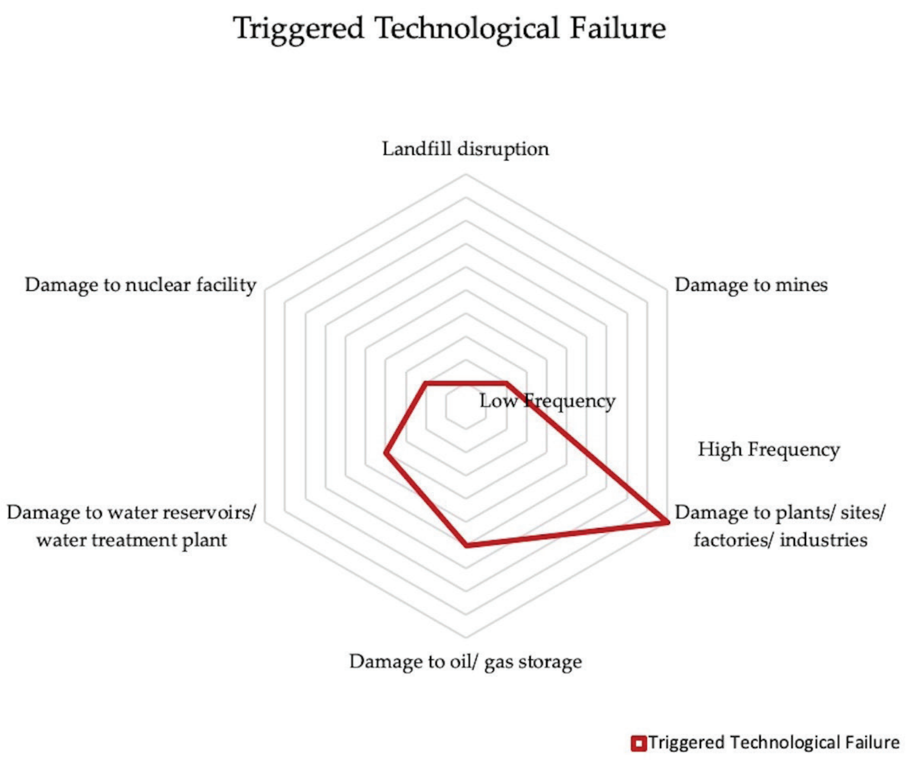
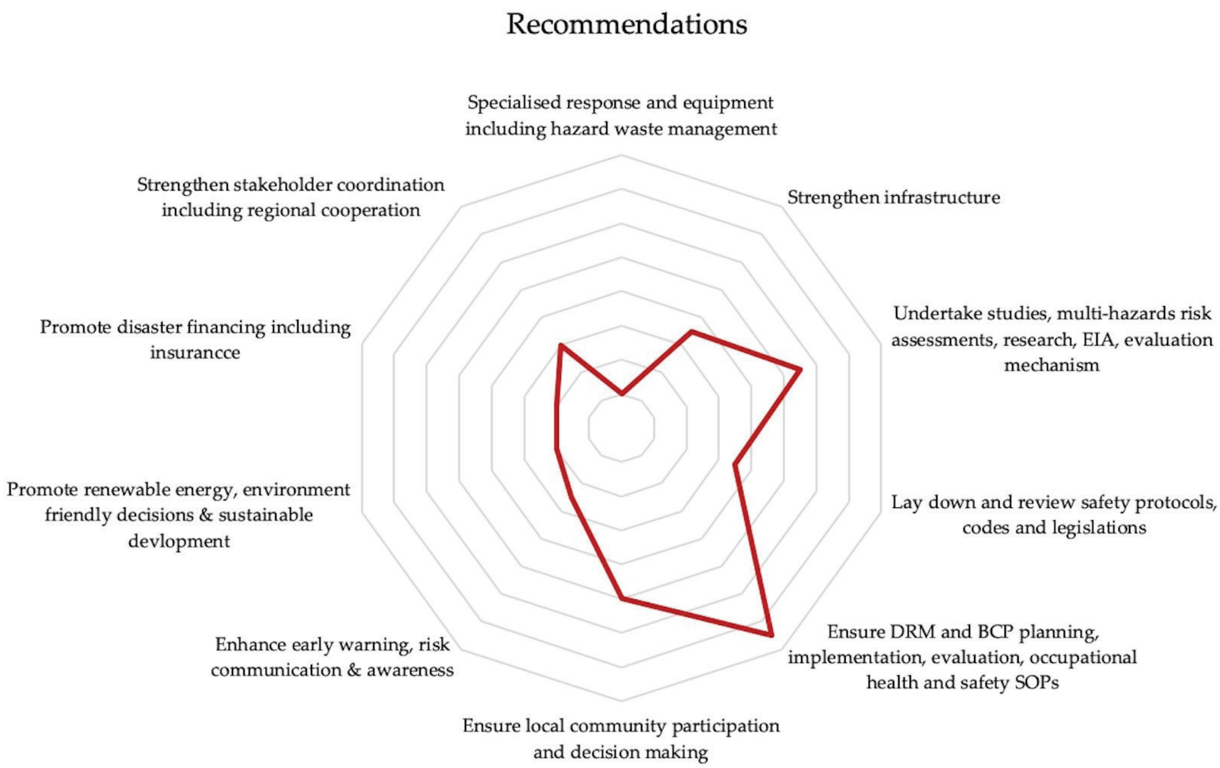


Figure 16: Recommendations for NATECH risk management



6.3 Gaps

Based on the case studies and secondary data including various research papers, reports, case studies and databases from across the globe on the NATECH management, the following gaps have been identified through different phases of disaster management cycle.

1. To holistically understand the **inter-linkages of natural and technological hazards**, definition and scope of NATECH may be expanded to include the cases where technological hazards have triggered disasters. Currently studies on NATECH are focusing only on one aspect of this linkage that is natural hazards triggering technological disasters. Some of the cases to highlight the significance of studying the other aspect of the linkage include the Chasnalla (Jharkhand, India) mine disaster (1975) killing 375 persons due to flooding in the mine, the 2009 oil depot's fire explosion triggering an earthquake of 2.3 Richter in Jaipur, India.

2. Further, there is a need to better **define what a technological disaster constitutes**. Currently most of the research papers deal with release of chemicals

or hazardous material as technological disasters. As per UNDRR, technological hazards 'originate from technological or industrial conditions, dangerous procedures, infrastructure failures or specific human activities. Examples include industrial pollution, nuclear radiation, toxic wastes, dam failures, transport accidents, factory explosions, fires and chemical spills. Technological hazards also may arise directly as a result of the impacts of a natural hazard event.' By better defining the technological hazards, one would be better able to gauze all aspects of NATECH which currently mainly focuses on fixed installations like chemical industries.

3. **Risk perception and tolerance** of the society shapes our decisions on protection against and management of certain risks. It is pertinent to note here that only after Fukushima Daiichi disaster of 2011 public in general and stakeholders in particular started noticing possible consequences of nuclear and radiological disasters as NATECH. Learning from this event, it is necessary to work on NATECH risk perception and tolerance of different stakeholders even for the biological hazards which have not yet attracted the required attention from the stakeholders and operators.

4. Many papers advocate plant/ factory specific assessment and audits as a tool for NATECH risk prevention and mitigation measures. Though it is a step in right direction but at ground level, these measures are often not implemented effectively because of either inadequate risk perception or due to lack of financial, human and technical resources. The latter issue is often faced by small and medium enterprises with limited resources. Thus, suitable mechanism for **capacity development** should be explored so as to ensure better management of NATECH risk across different sectors

5. Case of Singapore Lighting Incident of 2018 underscores the importance of having **specialised response** for NATECH management. A huge fire took over on oil storage tank on Pulau Busing island as a result of a lightning. However, due to existing response mechanism (including Singapore Civil Defence Force (SCDF), the Hazmat Incident Team (HIT), Hazmat Emergency Assessment and Response Team (HEART), the Hazmat Control Vehicle(HCV) and Company Emergency Response Team (CERT)), NATECH was prevented and no domino effects were reported. Thus, as part of NATECH management, specialized and well-equipped teams should be put in place for containing and responding to NATECH events

6. **Proper containment and disposal of hazardous materials** in aftermath of NATECH in installations dealing with hazmat is of prime importance to limit the adverse impacts of the disaster. For this, trained, specialized and well-equipped teams need to be put in place. Besides, the nearby community, all stakeholders should be duly made aware about possible cascading events along with actions to be taken. This can be taken care of if capacity development is made an integral part of NATECH management.

7. **Psycho-social support** is very crucial in aftermath of any major disaster; the same is the case for NATECH as the adverse impacts are further aggravated due to the triggered technological disaster. Further, in case the disaster involves hazmat release and contamination having long term health and environmental impacts, the need for psychological first aid and care is all the more needed. Previous studies suggest that the prevalence of post-traumatic stress disorder (PTSD) of natural hazard-induced disasters is often lower than the rates of human-made or technological disasters, and that the prevalence of PTSD following technological disasters ranged from 15 to 75 percent (Neria et al, 2008). In the aftermath of the 2011 Great East Japan Earthquake and Tsunami which had triggered Fukushima Nuclear Disaster, the affected population including the plant workers exhibited high levels of post trauma stress disorder. In a study examining the distress in survivors of the GEJE disaster, they found that 406 deaths in Minamisona City, in Fukushima Prefecture, were officially attributed to disaster related distress (Hori et al, 2014). Hence, psychological support should be made an integral part of NATECH risk management.

8. The Sendai Framework emphasizes that risk is everyone's business. "While the enabling, guiding and coordinating role of national and federal State Governments remain essential, it is necessary to empower local authorities and local communities to reduce disaster risk, including through resources, incentives and decision-making responsibilities, as appropriate. The same holds true for NATECH risk management. Thus, management of NATECH risk of a specific infrastructure/ installation should not be done in isolation from its surrounding and should consider all possible interactions of the same with the surrounding community, other installations, critical infrastructure, etc. for identifying potential cascading events. It is of paramount importance to **identify and map the stakeholders** and lay down **engagement mechanism and inclusive action plan** for NATECH risk management.

9. **Trans-boundary cooperation** is crucial in the prevention of all hazards and disasters as these do not stop at borders. The Sendai Framework recognizes that it is important that states consider the potential impacts of man-made/ technological hazards on other States – whether neighbouring or riparian – in particular as the effects of accidental water pollution can be far-reaching. Thus, such a cooperation is also crucial while planning, developing and institutionalizing NATECH risk management mechanism.

10. GAR 2019 identifies that natural hazard information is often absent in industrial accident databases; vice versa, information on NATECH events is often missing in **disaster loss databases**.

11. Due to climate change, one can expect non-linear changes in the frequency and intensity of natural hazards and such effects should be considered while planning NATECH management. GAR 2019 calls for urgent action to deal with

simultaneous systemic change around land, ecosystems, energy, industrial and urban systems, and the social and economic transformations that these infer.

12. In European Union, gaps in NATECH risk reduction were recognised and are mostly due to **budget** constraints and a lack of adequate resources which lead to the prioritisation of tasks deemed more important, a lack of training and insufficient knowledge of the dynamics of NATECH accidents. This has resulted in a lack of specific NATECH risk-assessment methodologies and tools.

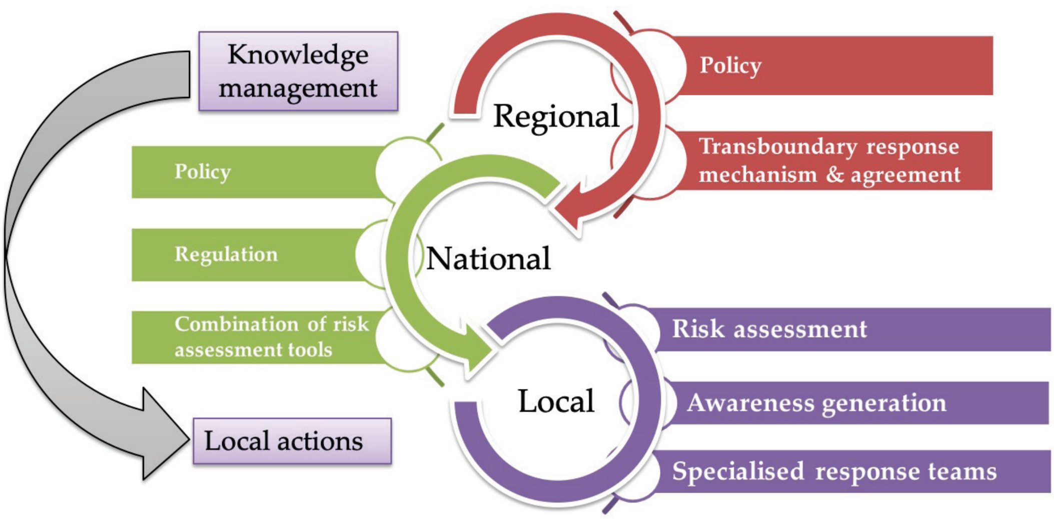
13. GAR 2019 flags that **existing disaster risk reduction frameworks** have not fully addressed the issue of technological hazards in general, and NATECH hazards in particular, although they usually highlight it as an example of a cascading multi-hazard risk. The Tohoku disaster showed that even countries with high levels of disaster preparedness are at risk of major NATECH accidents.

7. Proposed Framework for NATECH Risk Management

NATECH risk provides a practical demonstration of the increasingly interconnected and cascading nature of risk – disaster risk cannot be managed unless risk in its totality is addressed. The era of hazard-by-hazard risk reduction is over; present and future approaches to managing risk require an understanding of the systemic nature of risk (GAR 2019). Hazards interact with each other in increasingly complex ways; making NATECH risk a multi-hazard risk cutting across different fields and stakeholder communities that traditionally have not interacted much with each other. For managing and governing such a cascading nature of NATECH risk, a paradigm shift is required that takes into account diverse and interdisciplinary dimensions of the risk and challenges associated therein. It calls for substantial improvements in our understanding of anthropogenic systems in nature to identify precursor signals and correlations to better prepare, anticipate and adapt.

The proposed NATECH framework is envisioned at three levels namely regional, national and local level. At the regional level, developing regional NATECH risk management policies and development of standards is essential. In addition,

Figure 17: Proposed Framework for NATECH Risk Management



development of response capacities for transboundary response and agreement among various nations in the Asia Pacific region is important.

At the national level, the regional policies can be customized leading to development of national NATECH policies and Acts. The available NATECH risk assessment tools can be contextualized to the national and sub national conditions. The knowledge generated through research and documentation of past NATECH cases needs to be transform into local actions. At the local level, the focus should on implementing risk assessment, creating awareness among various stakeholders and raising specialized response teams to handle NATECH cases. Various NATECH assessment tools as mentioned in Annex 2 can be used for the customization at the national and local level. The existing Natech RateME Framework for Performance Rating System of Colombia focuses on four key aspects of infrastructure, organization and management, external environment and risk governance & risk communication. This can be customized for national and subnational conditions and integrated at local level for holistic risk assessment and effective NATECH risk management.

Figure 18: Key Aspects of Capacity Development for NATECH Risk Management

As a way forward for NATECH risk management the following points may be considered;

- Studying the long term social and health effects of a NATECH event.
- Integration of NATECH risk management policies and risk assessment methodologies with land use policies & real time risk analysis
- Integration of climate change adaptation and slow onset hazards implication for NATECH risk management and policy making.
- Strengthening of early warning systems, hazard mitigation, for building resilience in critical infrastructure
- Undertaking domino effects assessment of possible hazards, event tree analysis for all-inclusive understanding of NATECH events.
- Understanding liability of plant operator in case of NATECH management
- Critical aspects for capacity building for NATECH management

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Annexure

Annex 1: Summary of Existing Definition/ Description of NATECH

S. No	Literature Details		Definition/ Description
1	Journal Paper	Advances in NATECH research: An overview	Natural hazard triggered technological accidents involving the release of hazardous materials are known as NATECHs
2	NEIDIES Workshop Proceedings, JRC	The Black-Out of 28 September 2003 (Italy), Marta Di Gennaro	Natural Hazard Triggering Technological Disasters
3		Cascading events and hazardous materials releases during the Kocaeli Earthquake in Turkey, Ana Maria Cruz	Earthquake-triggered hazardous materials releases, hazmat releases, hazmat problems, earthquake triggered cascading event
4		Observation on the Recent Earthquake Damage in Japan Tetsushi kurita	No specific definition or description used
5		NATECHs in the United States: Experience, Safeguards, and Gaps, Laura J. Steinberg	Natural hazard-triggered technological disasters
6		Information System for the Mitigation and Reduction of the Consequences of Accidental Events, Loretta Floridi	Overlapping of natural risk on industrial areas
7		NATECH disaster risk management on the territory of Bulgaria, Dimitar Donkov	• Natural hazard-triggering factors • Triggered technological disasters • Domino effects" triggered by the natural hazard

S. No	Literature Details		Definition/ Description
8		NATECH disasters risk management in France, Agnes Vallee	• Industrial accident triggered by a natural event • Technological disaster triggered by any type of natural-hazard induced disaster
9		NATECH Disaster Risk Management in Bavaria, Bernd Zaayenga	No specific definition or description used
10		NATECH Risk Management in Portugal, Catarina Venâncio, Patrícia Pires, Carlos Mendes	No specific definition. Hazards triggering industrial accidents, pipeline collapse, dam breaks, fire in chemical plants or storage, collapse
11		Lessons Learnt from the Baia Mare Cyanide Spill (January 30, 2000, North-Western Romania) Septimius Mara	Technical accidents triggered by natural events
12		Swedish NATECH Activities Mattias Strömgren	No specific definition. train derailment, leakage
13	Journal Paper	Industrial accidents triggered by natural hazards: an emerging risk issue E. Krausmann, V. Cozzani, E. Salzano, and E. Renni	Chemical accidents triggered by natural events
14	Study	NATECH Disasters: A Review of Practices, Lessons Learned and Future Research Needs, Ana Maria Cruz	Technological disasters triggered by a natural-hazard induced disaster, like toxic air releases, spill of hazardous materials, fires or explosions, release from containment vessels, damage to lifeline systems that are needed to contain the releases

S. No	Literature Details		Definition/ Description
15	Proceeding	Joint Natural and Technological Disasters: An Emerging Risk Issue, Ana Maria Cruz	Natural hazard–triggered technological hazards or disasters
16	Report	State of the Art in NATECH Risk Management, JRC	Natural Hazard Triggering a Technological Disaster
17	DPRI Annuals	Stakeholder Input for a Common, Global, Comprehensive Risk Management Framework for Industrial Parks to Manage Risks from Natural Hazards	Natural hazard triggered technological accidents Industrial installations, concurrent damage to lifeline systems
18	Journal Paper	Systematic literature review and qualitative meta-analysis of NATECH research in the past four decades, Suarez-Paba Maria Camilaa, Perreur Mathisb, Munoz Felipec, Cruz Ana Mariad	Industrial accidents caused by natural hazards and involving hazardous materials (hazmat) release

Annex 2: List of Key Reference Materials

A. NATECH Guidelines and Legislations

1. OECD Guiding Principles for Chemical Accident Prevention, Preparedness and Response (2015, 2nd Ed.) to Address Natural Hazards Triggering Technological Accidents (Natechs) "Addendum Number 2 to the." OECD Environment Directorate, 2015
2. Words into Action guidelines: National disaster risk assessment, UNDRR, 2017.
3. Chemical releases caused by natural hazard events and disasters – information for public health authorities. Geneva: World Health Organization (WHO); 2018.
4. Global Assessment Report 2019 (GAR 19)
5. ASEAN risk monitor and disaster management review (ARMOR), The AHA center, ASEAN, 2019

B. NATECH Risk Assessment Tools

1. RAPID-N: Rapid NATECH risk assessment and mapping framework
2. Natech-RateME - Comprehensive Natech Performance Rating System
3. ARIPAR-GIS
4. RISKCURVES
5. PANR

Annex 3: Case study Template

Name of the disaster	
Location:	**Natural hazard:**
Description:	
Domino effects:	
Consequences	
Fatalities/injuries:	**Structural damage:**
Financial Loss:	**Hazmat Release (amount and type):**
Preparedness measures:	
Response:	
Lessons learned:	
Map:	

1. General Information:

2. Incident:

3. Impact:

- **Impact on human life:**
- **Economic impact:**
- **Environmental and linked health and other impacts:**

4. Level of preparedness, measures taken:

- **Level of preparedness:**
- **Response measures:**

5. Lessons learnt and recommendations:

6. Sources: