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Process for integrating local and indigenous knowledge with science for hydro-meteorological disaster risk reduction and climate change adaptation in coastal and small island communities

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ABSTRACT

The important role that local knowledge and practices can play in reducing risk and improving disaster preparedness is now acknowledged by disaster risk reduction specialists, especially since the 2004 Indian Ocean earthquake and tsunami. However, they have yet to be commonly used by communities, scientists, practitioners and policy-makers. We believe that local and indigenous knowledge needs to be integrated with science before it can be used in policies, education, and actions related to disaster risk reduction and climate change. This paper presents a process for integrating local and indigenous knowledge related to hydro-meteorological hazards and climate change with science, developed through a project implemented among coastal and small island communities in Indonesia, the Philippines and Timor-Leste. The process involves observation, documentation, validation, and categorization of local and indigenous knowledge, which can then be selected for integration with science. This process is unique in that it allows communities to (1) identify knowledge that can be integrated with science, which could then be further disseminated for use by scientists, practitioners and policy-makers, and (2) safeguard and valorize those that cannot be scientifically explained. By introducing a process that can be used in other communities and countries, we hope to promote the use of local and indigenous knowledge to enable communities to increase their resilience against the impacts of climate change and disasters.
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1. Introduction

According to the World Risk Index, six out of the world's ten highest disaster risk countries are in Asia and the Pacific [8]. In the first decade of the 21st century, more than 200 million people were affected and more than 70,000 people were killed annually by disasters caused by

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natural hazards in the region, which represent 90% and 65% of the world's total, respectively [50]. Asian communities are thus extremely vulnerable to disasters, which are caused by natural hazards – such as earthquakes, tsunamis, cyclones, droughts, landslides, and floods – in combination with environmental degradation such as deforestation, desertification, biodiversity loss, pollution and soil erosion, as well as social factors such as poverty and inequality. Their vulnerability is also affected by political and economic conditions, and the structure and organization of their societies [40].

Coastal areas in Asia face “an increasing range of stresses and shocks”, which are exacerbated by climate change. The projected sea-level rise would lead to increased frequency and intensity of tropical cyclones, heavier rainfall events, and droughts, and increased damage has already been reported in many parts of Asia ([15]:485). Island (or archipelagic) Southeast Asia – where many poor communities live in coastal areas – is thus extremely vulnerable to the impacts of hydro-meteorological hazards.

Efforts to mitigate the impacts of hazards and climate change tend to focus on infrastructure development such as building high sea walls, or on high-tech solutions such as sophisticated early warning systems based on scientific data and modeling. Although these technical and scientific solutions save lives when hazards strike, they need to be complemented by actions to address the risks surrounding the hazard and the underlying components of vulnerability – the interrelated human, social and cultural factors that influence risk – which can contribute to turning a hazard into a disaster [58]. An important factor that can increase the resilience of communities is their local knowledge, which, in combination with outside knowledge, has helped communities manage crises – be it natural hazards, economic problems, or political conflicts [18].

In the field of disaster risk reduction, evidence that local knowledge and practices can improve preparedness has grown since the 1970s [17]. Although it has been remarked that “indigenous knowledge has been slow to infiltrate the field of disaster management” ([31]:75), a substantial increase in studies on the topic can be noted particularly since mid-2000s, when, in the aftermath of the 2004 Indian Ocean earthquake and tsunami, knowledge that helped indigenous communities survive the disaster was widely publicized. Research that documents traditional knowledge related to geological disaster risk reduction includes those related to tsunamis among Solomon Islanders [19,30,31], among the Mokens on the islands off the coast of Myanmar and Thailand [44], and in Vanuatu, tsunamis [55] and volcanic eruptions [11]. Traditional knowledge related to hydro-meteorological hazards includes knowledge related to flash floods among herders in Pakistan [16], floods and landslides in Mexico [2], floods in Malaysia [10], Bangladesh [41], extreme weather events in Burkina Faso [43]. Shaw et al. [47,48] have published compilations of case studies on traditional knowledge and disaster risk reduction in Asia and the Pacific, and Dekens [17] has reviewed literature on the topic. Globally, the Hyogo Framework for Action (2005–2015) acknowledged “traditional and indigenous knowledge and cultural heritage” as one source of “knowledge, innovation and education to build a culture of safety and resilience at all levels” ([54]:9).

Similarly, in climate change research, social scientists have studied indigenous knowledge and its relevance for our understanding of climate change and adaptation strategies since the 1970s, but recent years have witnessed an explosion of research on the topic. While much of this research focuses on the Arctic [3,4,7,13,14,25,51,56] and the Pacific [1,9,24,26,28,32], other regions of the world are represented in a special issue of the *Global Environmental Change* journal [45], *Climatic Change* journal [21], a compilation of case studies by Galloway McLean [20] and a literature review in Nakashima et al. [38], demonstrating the increasing attention given to the topic.

As seen above, local and indigenous knowledge, observations, and practices related to disaster risk reduction and climate change adaptation have been well documented. It is, however, only in recent years that both scientists and practitioners have paid serious attention to actually using local and indigenous knowledge and practices to increase communities' resilience against the impacts of climate change and disasters, and to fully integrate such knowledge into scientific research, policy-making, and planning.

The resilience of communities facing disasters can increase when new and old techniques and knowledge are combined [18]. Furthermore, it is now generally recognized that integrating indigenous knowledge with scientific knowledge can lead to successful disaster preparedness strategies [35,36] and climate change adaptation strategies [4,23,24,49,57]. In combination with the latest technology and scientific assessment, local and indigenous knowledge can give communities and decision-makers a very good knowledge base to enable them to make decisions about the environmental issues they face. Walshe and Nunn [55] and Lauer [27] describe how indigenous knowledge about tsunami risks and responses, in combination with scientific and other knowledge, played an important role in helping villagers survive the 1999 tsunami in Vanuatu and in the Solomon Islands in 2007, respectively.

The 2004 Indian Ocean tsunami has been credited with sparking interest in integrating indigenous knowledge with science for disaster risk reduction [29], and many such efforts have been undertaken worldwide. In Vanuatu, participatory volcanic hazard awareness and education that incorporates traditional knowledge with volcanology has been developed for disaster-preparedness planning [11,12]. In Washington State, USA, Native American oral history has been incorporated into earthquake and tsunami hazard education [6]. Mercer et al. developed a framework for knowledge integration for a wide range of disasters, based on work in Papua New Guinea [34,36].

We present in this paper a process for integrating local and indigenous knowledge related to hydro-meteorological hazards with science and technology, because we believe this is necessary to promote the use of such knowledge to increase the resilience of communities against the impacts of hazards and to better adapt to climate change. The process was developed through a project led by the United Nations Educational, Scientific and Cultural Organization (UNESCO) Jakarta Office and implemented in Indonesia, the Philippines, and Timor-Leste. In this project, local and indigenous knowledge related to hydro-meteorological hazards was observed, documented and validated, and then integrated with science, through action research. By introducing this process, we hope to promote the use of local and indigenous knowledge to enable communities in other areas and countries to increase their resilience against the impacts of climate change and disasters. The process, as well as the local and indigenous knowledge presented in this paper, are a contribution to the current literature that highlight the role of local and indigenous knowledge in disaster risk reduction and climate change adaptation, and are unique in the focus on hydro-meteorological hazards and in island Southeast Asia.

2. Methods

The research component of the UNESCO project was implemented in two phases, from March 2011 – June 2012 and from August 2012 – April 2013. Indonesia, the Philippines and Timor-Leste were chosen for their particular vulnerability to the impacts of hydro-meteorological hazards and climate change, as well as their rich cultural and biological diversity. The focus is on coastal areas and small islands, where many poor communities live, and which are especially exposed to the impacts of natural hazards and climate change.

Action research was defined by researchers and project advisors at a workshop held to officially launch the project, as a process which entails involving communities and stakeholders in such a way that they are motivated and willing to engage in a process of guided discovery [33,52]. UNESCO engaged non-governmental organizations (NGOs) in each country which selected three coastal and small island communities based on criteria agreed upon at the workshop, and implemented action research. Community leaders and groups (such as youth and women's groups), traditional and religious leaders, local and national governments, local and national NGOs, and local academics and experts were all involved in the action research that included field observations, focus group discussions (FGDs), workshops, semi-structured interviews, participatory mapping, and transect walks. Local and indigenous knowledge and practices related to climate change adaptation and climate-related hazards were thus identified and documented.

According to UNESCO's program on Local and Indigenous Knowledge Systems (LINKS), local and indigenous knowledge refers to the understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings. For rural and indigenous peoples, such knowledge informs decision-making about fundamental aspects of day-to-day life [53]. As this definition implies, local and indigenous knowledge is dynamic and complex, produced and reproduced during social encounters day to day [14]. Researchers involved with the project agreed that the term local and indigenous knowledge is analogous to local knowledge, indigenous knowledge, traditional ecological knowledge, traditional knowledge, indigenous technical knowledge, and endogenous knowledge.

Research in the first phase of the project was undertaken in Indonesia in Sangihe Island, Kendahe (North Sulawesi), Sayung (Central Java), and Pengastulan (Bali) by Bingkai Indonesia. In the Philippines, research was conducted by the Center for Disaster Preparedness (CDP) in Rapu Rapu Island (Albay), Alabat Island (Quezon) and Angono (Rizal). Fig. 1 shows the location of action sites in the first and second phases of the project.[1]

In the second phase of the project, communities and scientists validated the local and indigenous knowledge. FGDs and workshops were organized for community validation and to establish scientific bases for the local and indigenous knowledge. In the Philippines, the results of the scientific explanations were then taken back to the communities, and the communities compared the outcomes of their validation with the explanations provided by the scientists. During this phase, research in Indonesia was undertaken by a different organization, the Tsunami and Disaster Mitigation Research Center (TDMRC), in two different sites: Pulo Breueh and Pulo Nasi Islands, Pulo Aceh (Aceh). TDMRC cooperated with the Indonesian Society for Disaster Management (MPBI) for research in Sayung (Central Java), where research was also implemented in the first phase.[2] In Timor-Leste, the National Center for Scientific Research, at the National University of Timor Leste (UNTL-CNIC) carried out research in Lau-Hata (Liquiça), Maluru-Beaço (Viqueque) and Raimea (Covalima), while in the Philippines activities were implemented by the CDP in the same sites as in the first phase. For more information on the project and researchers involved with the action research, see Hiwasaki et al. [22].

3. Local and indigenous knowledge related to hydro-meteorological hazards and climate change: an overview

Action research in the Filipino sites found that the primary hydro-meteorological hazards facing the communities are typhoons, storms and heavy rainfall, and the resulting floods and landslides. Communities have also observed climatic changes, such as warmer days and nights, changes in rainfall patterns, and more frequent and stronger typhoons. In the Indonesian sites, monsoons, tropical cyclones, coastal erosion, and land subsistence were particularly noticed, with climate change impacts such as sea level rise also being observed, resulting in saltwater intrusion. The primary problems in Timorese sites were tropical cyclones with heavy rainfall, and prolonged dry and extended rainy seasons resulting in floods, landslides and droughts. The country is also affected by El Niño Southern Oscillation (ENSO) climate variability, which changes the timing and volume of rainfall [46]. Hydro-meteorological hazards often lead to food

[1] The first phase research results from Timor-Leste are not included in this paper due to the lack of details provided by the implementing NGO.

[2] The implementing organization in Indonesia and Timor-Leste were changed in the second phase, to ensure high quality research. Local and indigenous knowledge documented in the Philippines was more detailed, and research results and analysis were more thorough due to the continuity of both the implementing NGOs and the sites were research was undertaken. The authors do not feel that these differences in implementation had a negative impact on the project's outcome, but rather strengthened it when research results were shared across countries.

Fig. 1. Map of action research sites, 2011–2013.

shortages in all sites, which are particularly serious for small island communities that become isolated when communication and transportation with the mainland is disrupted. In addition to these hydro-meteorological hazards, all communities are also exposed to a wide range of other hazards, such as earthquakes, tsunamis and volcanic eruptions.

Coastal and small island communities have long histories of observing changes in the environment and have amassed a wealth of knowledge and practices closely related to these changes. A key insight from the action research across the different sites was the ability of local people to closely observe and monitor changes in their environment (seas, clouds, animals, plants, and insects) and celestial bodies (the moon, sun, and stars) to predict hydro-meteorological hazards.

To predict heavy rainfall or strong winds, communities carefully observe clouds, waves, winds, sun, and the stars. For clouds, changes in texture (thin or thick), color (white, dark, yellow or red), location (over mountains or the sea), and movement (to/from the coast), including speed (fast) and direction (vertical or horizontal) are observed; for waves, changes in color (white), direction, and height (high). The direction (usually east or west) and temperature (cold or warm) of winds, the position (high or low) and size (large or small) of the sun, and visibility (many or absent) and constellations of stars are indicators that communities commonly look out for. In both Rapu-Rapu, Philippines and Aceh, Indonesia, it was documented that a foul odor emanating from the sea signified the coming of a storm or typhoon. Observations such as these, in combination with other changes in the environment and the time of the year, were perceived to be extremely effective in predicting hydro-meteorological hazards.

Behavior of animals, insects, and plants also predict hazards. In Raimea and Lau-Hata, Timor-Leste, leaches and caterpillars are noted as appearing before storms. When banana tree leaves and branches of other trees fall to the ground without strong winds, people in Rapu-Rapu, Philippines prepare for storms or typhoons. Birds, usually migratory, are important indicators of changing seasons and their duration, as well as heavy rains, storms, or droughts, in Raimea and Maluru-Beaço, Timor-Leste, and Sayung and Lipang, Indonesia. In Perez and Rapu-Rapu, Philippines, various animals are used to predict hazards: rays jumping consecutively in the sea in summer, the fast movement of sea snakes, and hermit crabs going inland or climbing up trees all forewarn storms or typhoons. These observations are also considered indicators of other hazards such as landslides and flooding, since they often take place after heavy rainfall and strong winds.

Local knowledge has been used to devise traditional seasonal calendars, which were documented in all research sites in Indonesia: the *Sasih* (lunar calendar) in Bali, the

Pranoto Mongso (traditional seasonal calendar) in Central Java, the traditional and fisherfolk's calendar in Lipang, the seasonal calendar in Kendahe, and the *Keuneunong* (traditional Acehnese calendar) in Aceh. Although efforts to document these traditional calendars are increasing, they have yet to be officially adopted by governments.

Communities have also developed ways to prevent or mitigate such hazards, and adapt to and prepare for them, using local materials and methods. In preparation for a storm, for example, local plants are used to strengthen houses, such as *Suhay* (bamboo rods) in the Philippines and *Ai Tatan* (wooden clamp to hold down the roof) in Timor-Leste. Coastal and small island communities across the sites have devised ways to ensure food security, given that they will not have access to obtaining food in the usual way during storms and droughts, and especially for those living on small islands where transportation is disrupted not only during storms, but also for prolonged periods afterwards. Various methods to preserve fish using salt or wind- or smoke-drying were documented. Emergency food includes cassava, yams, and taro in Lipang, Indonesia, while cassava starch and dried taro leaves are eaten in the Philippines. In Timor-Leste, communities eat sago, elephant foot yam, and air potato roots. Special containers used to store food during times of hazards are called *Krong Padee* (community storage) in Aceh, Indonesia, and *Guci* (silo) in Timor-Leste.

Local structures, materials and plants are used to help communities prevent or mitigate the impacts of storms, coastal abrasion and strong winds, such as *Uteun Bangka* (mangrove forest) and *Uteun Pasie* (coastal forest) documented in Aceh, Indonesia. *Uteun Pasie* consists of rows of different species of trees and other vegetation planted along the coast. Together with *Uteun Bangka*, the forest acts as a buffer to protect paddy fields and houses, and is maintained as a conservation area by traditional Acehnese law, with fines imposed for violation. *Panglima Laot*, a traditional fishermen's organization, is responsible for managing these coastal forests.

Communities take part in rituals and ceremonies based on traditional or religious beliefs, which instil respect for nature in all three countries. These annual rituals and festivals commemorate a patron saint or a historical figure, show appreciation for nature and ask for protection from hazards. When hazards do occur, ceremonies held to "apologize" to nature or to stop the hazard were documented in all three sites in Timor-Leste. Religious faith and traditional beliefs play an important role in the recovery process if hazards turn into disasters. Islamic prayers performed in Indonesia during times of hazards or other troubling events include *Qunut Nazilah* (supplication to seek Allah's protection from a particular disaster or tragedy) in Sayung, Pulo Nasi and Pulo Breuh Islands, and *Undango Wanua* (a Muslim ritual performed to strengthen communities in times of trouble) in Kendahe. Similarly, in Rapu-Rapu, Philippines, *Pangangadyi* (special prayers) are performed by elders who ask for God's guidance and the family's safety.

Moreover, customary regulations that prohibit people from cutting trees or taking rocks were documented in Indonesian and Timorese communities. Some of these regulations are voluntary while others are strictly enforced with punishment. The regulations serve to prevent and mitigate hazards such as landslides, floods, and coastal abrasion, and strengthen social relations within communities. Rituals and ceremonies, along with customary laws that govern behavior, engender and reinforce respect for the environment, strengthen social cohesion, and thus enable communities to better face and respond to the impacts of climate change and hydro-meteorological hazards.

4. A process to integrate local and indigenous knowledge with science

In this section, we describe a process that involves identifying, documenting, and validating local and indigenous knowledge and integrating this knowledge with science, which we have termed "**L**ocal and indigenous knowledge and practices **I**nventory, **V**alidation, and **E**stablishing Scientific Knowledge" (LIVE Scientific Knowledge: Fig. 2). The phases in the process are preparation, data gathering, analysis and validation, science integration, and popularization and utilization of local and indigenous knowledge. The process is community-led, with initial support from outside resource organizations such as research agencies or development organizations. These organizations provide the community with an orientation and training so that they can identify, document, assess, and validate their own knowledge. By undertaking this process, communities can categorize local and indigenous knowledge and choose which knowledge to integrate with science, for further research and other activities such as the development of information, education, and communication (IEC) materials, as well as disaster risk and management plans.

The first phase in the process, preparation, is to choose people from the local community to become researchers, and train them on the process, methodology, and key scientific terms.[3] The people chosen should be gender balanced and comfortable using the different research methods. In the Philippines, a module for training and orienting local researchers was prepared and implemented in each study site. Five sets of data-gathering forms were prepared, one for each type of local and indigenous knowledge (i.e., (a) observations of animal behavior, (b) observations of celestial bodies, (c) observations of the environment, (d) material culture, and (e) traditional and faith-based beliefs and practices). Each form consists of a table where the researcher records the local and indigenous knowledge observed, when it was observed, what disaster event or impact happened after the observation, and when the impact occurred. For an example of the form developed in the Philippines, see Fig. 3. Having all local researchers use the same data-gathering form is important to enable both the systematic gathering of data and the standardization of data collected. While different

[3] It is important for researchers to be well aware of, and be able to explain various hydro-meteorological hazards and climate change impacts, the difference between weather and climate, and to distinguish between El Niño Southern Oscillation climate variability and climate change, etc.

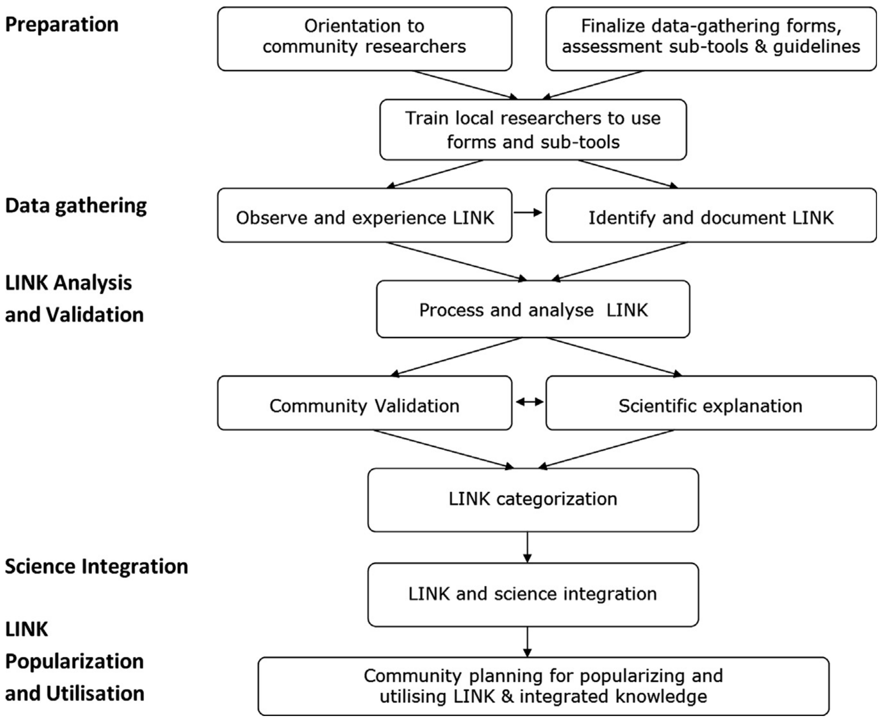

Fig. 2. LIVE scientific knowledge.

Observation of Celestial Bodies (Sun, Moon, Stars, Comets)

Name of Barangay:__________________ Name of Local Researcher:_________

1 Observation Number	2 Date and Time	3 What observations of the sun, moon, stars or other celestial bodies have you seen?	4 What is the meaning or prediction of this observation?	5 What did you do when you observed this celestial body?	6 Did the meaning or prediction actually happen? Yes No	7 When and what time?

Fig. 3. Sample data-gathering form for local and indigenous knowledge for disaster risk reduction.

countries and communities will have their own unique local and indigenous knowledge, the form can still be used and modified for use in other places. For example, regardless of whether an animal is from a tropical region or the temperate zone, animals' behavior can be observed to predict hazards. Similar categories may be used across different contexts, even if the meaning of the local and indigenous knowledge and its impact is unique in a specific setting.

In the data-gathering phase, local researchers fill in data-gathering forms after observing or experiencing local and indigenous knowledge. Each local researcher can focus on a specific type of knowledge. This step entails using the scientific method, which is composed of the following three steps:

1. Identification of informants: hold group discussions or individual interviews to get an overview of relevant

local and indigenous knowledge. It is necessary to ensure that all holders of specialized knowledge are met and interviewed, including religious leaders, fisherfolk, and women.
2. Observation: researchers to observe the local and indigenous knowledge that they have identified in their communities.
3. Recording: document observations in the data-gathering form.

In the analysis and validation phase, each documented local and indigenous knowledge undergoes the following six steps:

1. Analysis and interpretation: give meaning to the observations and confirm that the expected impact actually took place.
2. Data analysis: tabulate frequencies of the observations made, analyze the trends, compare the outcomes, and provide explanations about the outcomes. See Fig. 4 for an example of such a form used in the Philippines.
3. Community validation: present the local and indigenous knowledge documented and analyzed to the community in order to determine which knowledge and practices are most commonly used and considered most effective. This can be done through focus group discussions (FGDs) and key informant interviews. In the Philippines, a one-page FGD guide was used, with different groups such as farmers, the elderly, fisherfolk, and women's groups having separate discussions. During the FGDs, participants could confirm whether the belief, knowledge, or practice:
   – is widely practised in the study area (e.g., by fisherfolk in the village) and not just by one or two individuals;
   – has existed in the community for more than one generation;
   – is still being used and
   – is effective in preventing, mitigating, predicting, or helping communities prepare for or adapt to hydrometeorological hazards and climate change impacts.
4. Scientific explanation: present the outcome of the community validation to scientists and experts. In the Philippines, this was done in a workshop that gathered scientists, with doctorate degrees from both the natural and social sciences, such as marine science, meteorology, biology, anthropology, and development studies. The scientists were given a "LINK Validation Form" to guide their comments. The scientists first gave an

Table 1: LINK Observed or Experienced During Period ___________

Name of LINK Observed or Experienced	Frequency of Observation during the period	Percentage

Table 2 : Time of Occurrence of the Events Predicted by the Observations

LINK Observed	Occurrence of the Predicted Events From the Time of Observation of the LINK to the Occurrence of the Predicted Events					
	Within 12 hours	13 hours to 1day	2 – 4 days	5-7 days	8-10 days	Did not occur

Points for Analysis:

Quantitatively:

If the event predicted by the LINK observed did not occur at all, then the LINK observed is not a good predictor of the event.

The longer the time between the observation of the LINK and the occurrence of the predicted event, the lesser the effectiveness of the LINK.

Qualitatively :

Description of the LINK, the time of observation, the meaning of the LINK or the occurrence of event being predicted by the LINK, the behavioral response of the observer.

Description of the event predicted by the LINK, date and time of occurrence, impact of the event.

Fig. 4. Data Processing Sub-Tool: Frequency Table for local and indigenous knowledge (LINK) observations and Experiences (Sample Quantitative Processing of Aggregated Data).

assessment, stating whether there was the presence, absence or whether they were uncertain of a scientific explanation to the local and indigenous knowledge. They were then asked to provide a detailed scientific explanation or to give empirical evidence (or explain the lack thereof) for the knowledge, and made suggestions on how to deal with the knowledge that could not be explained by science at this point in time. Social scientists were able to provide the social relevance of some of the knowledge for which the natural scientists were not able to explain. Finally, they provided insights on how scientific knowledge can be integrated with local and indigenous knowledge, and how such knowledge can be used for hydro-meteorological hazard risk reduction and climate change adaptation. Because the scientific community has strict protocols in its processes, this step enhanced the credibility of local and indigenous knowledge vis-à-vis scientists. Local and indigenous knowledge with little or no scientific basis needs to be assessed in terms of how it increased the communities' resilience against hazards.

5. Taking back the results of the scientific workshop to the community: this helps the community obtain a better understanding of the scientific explanations to some of their knowledge and practices. At the same time, the knowledge and practices that cannot be explained scientifically at this point should also be presented. In the Philippines, the community validation after the scientific workshop was done in a participatory manner where selected community members were invited to a participatory FGD and workshop, in which they compared the outcomes of community surveys and FGDs, and the scientific explanations.
6. Categorization of local and indigenous knowledge: the last step is to categorize local and indigenous knowledge, depending on the availability of scientific explanations and the relationship and relevance to disaster risk reduction and climate change adaptation, as shown in Fig. 5. The categories are described in detail in the discussion section below.

In the science integration phase, local and indigenous knowledge with a scientific explanation (LINK Category I) is combined with empirical data from the field. This can be done by the community in close cooperation with scientists. In cases where scientists cannot translate the local knowledge into its universal name, there is a need for more in-depth study. Thus, it is important to involve a group of experts from different scientific disciplines in such studies and not scientists specializing in one field. It is also necessary to look for other published studies if available, to add to our understanding of local and indigenous knowledge, locally and internationally.

After local and indigenous knowledge is integrated with science, it can be promoted through information, education and communications (IEC) materials to be used by communities themselves, by scientists for further research, and by practitioners and government entities for disaster risk reduction and management plans, etc. For the UNESCO project, communities themselves were involved in selecting which local and indigenous knowledge would be promoted in the IEC materials. By developing and disseminating IEC materials, which integrate local and indigenous knowledge with science, it is possible to:

– demonstrate the advantages of practising and adopting local and indigenous knowledge for disaster risk reduction and climate change adaptation;
– strengthen the relevance of local and indigenous knowledge for science, and encourage the scientific community to further investigate such knowledge;
– revitalize and strengthen local and indigenous knowledge by demonstrating that it can be used to anticipate and mitigate hazards, and the impacts of climate change;
– transmit local and indigenous knowledge from one generation to the next, and from one community to another.

I LINK which can be scientifically explained/validated, and related to DRR and/or CCA	II LINK which cannot be scientifically explained/validated, but related and relevant to DRR and/or CCA
III LINK which can be scientifically explained/validated, but not related to DRR and/or CCA	IV LINK which cannot be scientifically explained/validated, and not related or relevant to DRR and/or CCA

Fig. 5. Categorization of local and indigenous knowledge (LINK) on disaster risk reduction (DRR) and climate change adaptation (CCA) and its relationship to scientific validation.

The process described above is an integrated process of observing, documenting, analyzing, validating, and integrating local and indigenous knowledge, after which this knowledge can be widely disseminated. Owners of the knowledge can go through the process themselves, with appropriate materials provided by outside resource organizations, as necessary, such as data-gathering forms, assessment sub-tools, and data processing sub-tools.

The process can be easily adapted and implemented by other communities in island Southeast Asia or elsewhere. Participatory and collaborative approaches, which are now predominantly used to facilitate change within a development context, are now being increasingly used as a research methodology within disaster risk reduction [33]. A range of participatory planning methodologies have been used to integrate local and external knowledge for climate change adaptation and/or disaster risk reduction [37]. The process presented here is unique in that it allows communities to categorize local and indigenous knowledge, and thus makes it possible to (1) identify knowledge that can be integrated with science, and at the same time, (2) safeguard and valorize knowledge that cannot be scientifically explained.

5. Results and discussions

Selected examples of local and indigenous knowledge and scientific explanations that emerged from the action research in Indonesia, the Philippines and Timor-Leste are described in Box 1.

As a result of the action research and the process described above, four categories of local and indigenous knowledge emerged, as shown in Fig. 5.

Local and indigenous knowledge (LINK) Category I: the type of local and indigenous knowledge that falls under this category includes (a) observation of celestial bodies which can help communities to predict hazards, e.g., the moon, sun and stars; (b) observation of the environment such as the direction and strength of winds; color, formation and location of clouds; plants; and animal behavior; (c) material culture that people use for mitigation, preparedness, response and recovery, e.g., design and materials used for housing; food eaten during periods of food scarcity, and other protective measures taken during hazards such as storms and droughts; (d) customary regulations concerning the environment, which play a major role in preventing and mitigating hazards such as coastal erosion, landslides and floods.

LINK Category II: these are faith-based beliefs, traditional rituals, legends and songs, which cannot be explained by science at this point, but are practised by communities and help them build their resilience. For example, people are able to have peace despite turmoil, endure difficulties and suffering, and maintain stability through faith and prayer, through processions and acts such as offering flowers and gifts to the divine. These beliefs and rituals provide psychological and inner strength that can make communities more resilient. It is necessary to maintain these practices for the next generation, as long as the communities are still relying on them before a disaster or in times of difficulty. Such local and indigenous knowledge also contributes to increasing a community's awareness of possible hazards which often results in increased preparedness.

LINK category III: there is some local and indigenous knowledge which is considered to be related to climate change and disaster prediction, but its relationship to weather and disaster prediction cannot be scientifically established. For example, fish were often observed acting restless before typhoons, but scientists determined that such behavior is not necessarily related to meteorological elements, but is simply part of the mating or food-searching behaviors of these animals.

LINK category IV: there are some beliefs that have no scientific basis and also cannot be linked to weather prediction or disaster events. For example, it is said that when dogs start to howl, it serves as an omen and then a disaster or something bad will happen. There is no scientific basis for this and the observation is not related at all to actual disaster events.

Categorizing local and indigenous knowledge as above makes it possible for community members to have discussions about, assess, and choose which knowledge they would like to integrate with science for disaster risk reduction and climate change adaptation policy and practices, and then promote, for use by scientists and policy-makers, or through appropriate IEC materials for the public at large. Local and indigenous knowledge that can be explained by science (i.e., LINK category I) can be readily integrated with science and used by scientists, practitioners, and policy-makers to promote further scientific research to enable us to devise the best strategies for disaster risk reduction and climate change adaptation. Such knowledge can also be widely disseminated for educational purposes and integrated in the school curriculum, and used to enhance policies and programs on disaster risk reduction and climate change adaptation.

Among the knowledge in LINK Category I, it is possible to identify transferable indigenous knowledge, i.e., knowledge that is indigenous to specific regions but can be applied to other regions [48]. Some context-specific local and indigenous knowledge can be accessed, documented, taken out of its original context, and adapted for use in other locations. One example is *Tara Bandu*, a customary law practised in Timor-Leste, which governs social relations and places restrictions on the use of natural resources. Originally practised only in some parts of the country, it has now been embraced by various government entities and NGOs as a national tradition, a tool for natural resource conservation and conflict management, and is now implemented country-wide [42]. The validation and categorization process also partially addresses the difficulties scientists face when working with local and indigenous knowledge, in that it makes it possible for scientists to better relate to local and indigenous knowledge and thus more easily understand and accept to work with such knowledge.

Local and indigenous knowledge that falls under LINK Category II, which cannot be explained by science, but can have just as much significance for disaster risk reduction and climate change adaptation, and should not be disregarded. It would, however, be difficult to integrate knowledge in LINK Category II with science. It emerged clearly from the research that folklore, rituals and ceremonies inspire awe of and reinforce respect for nature, provide opportunities to transmit such knowledge to the younger generations, and increase people's awareness of hazards. For example, faith-based beliefs and practices have been cited by many disaster survivors as making communities more resilient, strengthening their inner will and enabling them to move forward. Such comments were heard repeatedly in the aftermath of typhoon Haiyan/Yolanda that hit the Philippines in November 2013 [5,39]. If empiricism is to be applied, it has to be accepted that those who have faith have high resilience to disaster events. Categorizing local and indigenous knowledge as above makes it possible to valorize the local knowledge and practices that cannot be explained by science, and enables us to understand that this knowledge is a body of knowledge in itself, different from scientific knowledge. As such, it should not be judged solely by scientific

Box 1
Scientific explanations of selected local and indigenous knowledge documented in Indonesia, Philippines and Timor-Leste.

Local and indigenous knowledge	Description	Scientific explanation
Observation of the sky and the environment to predict *Angeen Badee* (strong winds and high waves) Documented in Aceh, Indonesia	Observation of dark towering clouds at the horizon, and their upward movement from winds, in combination with position of beehive in a tree, calm sea-weather during transition period (according the traditional calendar) and rancid smell from the sea	The cloud formation and movement is *Cumulus nimbus* (Cb.) cloud type. This cloud is also part of indication of cyclone effects generated around the Indian Ocean and the Andaman Sea. The rancid smell is an indication of over-evaporation process at the sea-surface. This is also an indication of massive clouds formation process that can accumulate large water volume that can later produce high rainfall.
Observation of the environment to predict and prevent landslides Documented in Covalima, Liquiça, and Viqueque, Timor-Leste	When sacred trees (*Ai lulik*: such as teak, bamboo and Beechwood) are cut, and sacred stones (*fatuk lulik*) are destroyed or removed, there will be landslides.	When forests are destroyed or stones are removed, springs will dry up from evaporation because there are no leaves (canopy strata) to cover the spring, and when in rainy season there is no infiltration of water into the land, the physical structure of soil is fragile when there are no stones and tree roots to secure the ground, thus landslides will occur.
Observation of the environment to predict typhoons Documented in Rapu-rapu Island, Philippines	Branches of trees (such as gmelina, talisay, pili, marukbarok, tamarind, santol, narra) and banana leaves fall to the ground even when there is no strong wind. Two days after such observation is made, heavy rains, storm surges or strong winds will hit the community.	The banana is characterized as having the weakest structure. As the temperature decreases, the plants' ability to make chlorophyll stops. Further the synthesis of a plant hormone called auxin also stops. This causes the cells at the junction of the petiole and the twig to weaken and sooner or later the joints break and leafs fall to the ground.
Planting of coastal forest (*Uteun Pasie*) to prevent and mitigate impacts from high waves and strong winds, and coastal erosion Documented in Aceh, Indonesia	Coastal forest around the sandy beach area where several rows of different species of trees, bushes and smaller vegetation grow along the seashore. The coastal forest is managed by coastal community through *Panglima Laot* (traditional fishermen organisation) organisation.	The forest can effectively reduce the wind velocity blown from the coastal area. When the wind comes from the sea, it brings saline vapour that can also create corrosive effects on metal components around the villages. *Uteun Pasie* absorbs the saline vapour.
Food preservation mechanism to prepare for long periods of storms Documented in Rapu-rapu Island, Philippines	Dig a hole in the ground and place root crops such as cassava inside the hole and fill it with soil. The stored root crop is prevented from rotting and can last up to a month, thus providing food security during long periods of storm.	Root crops grow underground and this practice is a natural way of preservation.
Sacred ceremony to apologize to nature after a natural hazard such as landslides Documented in Covalima, Liquiça, and Viqueque, Timor-Leste	*Monu ain ba lulik* held by traditional leader or elder to apologize for taking stones, sand, trees, killing snake, etc. and promise not to do it again. First, an animal (chicken or pig or dog) is killed, and its blood is spread to the affected area with betel nut and betel leaf. Then, trees are replanted in sacred places such as around water sources, river banks, the beach and on upland or hills.	The ceremony reinforces respect for nature and to ensure villagers follow the sacred rules, if not, they will get the nature's curse and disasters will occur. Disasters provide an opportunity for social cohesion, respect for nature, and awe for nature. Such ceremonies contribute to a form of resilience.

parameters, but assessed by another system appropriate to the context and social impact. Local and indigenous knowledge is significant in strengthening communities' resilience.

Having a system of categorizing local and indigenous knowledge in this way makes it easier for everyone involved in this process to deal with knowledge that "cannot be shared because it is too sacred, risky to disclose or weakly protected from appropriation and misuse" ([57]: 539). Knowledge that cannot be shared with outsiders can be placed in this category, and its practice and dissemination can continue within the communities, away from scientists, practitioners, and policy-makers.

6. Limitations to adopting the knowledge integration process

In promoting the use of this process, three limitations are noted: (1) the size of the community where the tool can be applied; (2) the kind of hazards and for which local and indigenous knowledge can be validated and integrated with science; and (3) the commitment of participants necessary to follow through with the process.

First, it should be noted that most of the action research was implemented in small communities. Approximately half the sites (5 out of 11) were villages with population of between 3500–5000, while three were smaller villages with less than 1000 people (Lipang, Indonesia being the smallest with approximately 350 people, while all three sites in the Philippines were larger than those in Indonesia and Timor-Leste, the largest being Angono with more than 100,000 people). Most sites were described as homogeneous (i.e., sharing the same religion and/or beliefs and ethnicity). A lot of adjustments would need to be made if this process were to be used in larger, more diverse, and urban contexts.

Second, this process, developed out of research on hydro-meteorological hazards, may not be relevant to other hazards particularly those that take place sporadically, such as earthquakes and tsunamis. The infrequency of such events would make it difficult, if not impossible, to go through the validation process with communities and with scientists, as described above. The process could be adapted for use in hazards that can occur in a shorter time span, such as volcanic eruptions. It is precisely because the observations of nature that enable communities to predict hydro-metrological hazards are closely aligned to their livelihood activities, which make documentation, assessment, and validation possible.

Third, integrating different knowledges is a long-term process that requires the building of trust and relationships, and the commitment of all stakeholders involved. The process should be undertaken through participatory action research where key community members are involved in the full process and local community researchers are trained and mentored to do the research and go through the process on their own. This requires community engagement and open communication, and close linkages between communities and external scientists and researchers. The scientists need to recognize the significant contributions local and indigenous knowledge can make in disaster risk reduction and climate change adaptation, as well as the important role scientists can play in complementing local and indigenous knowledge with science. The key to the successful implementation of the "LIVE Scientific Knowledge" tool is the commitment of all parties to go through the participatory process to take time to build trust and agree on the immediate and long-term objectives of such a process. Community organizing processes adopted in Community-Based Disaster Risk Management (CBDRM) can be used, such as mobilizing community leaders, implementing awareness-raising activities, strengthening local organizations, and establishing linkages with local government officials. This process would be most successful if local and national government entities support these endeavors and enact policies to promote local and indigenous knowledge and research on such knowledge as priorities in their disaster risk reduction and climate change adaptation strategies. It is also an on-going process in which regular monitoring and evaluation is necessary, since local and indigenous knowledge is not static. It would be ideal if this process could be conducted every time a disaster risk reduction or climate change adaptation plan is revised. For example, in Indonesia, provincial disaster management plans are composed every five years, and local action plans for disaster risk reduction are formulated every three years. The costs associated with this would be rather high, thus an abbreviated process could be adopted for such purpose.

7. Conclusions

Local and indigenous knowledge is key to increasing the resilience of coastal and small island communities to hydro-meteorological hazards and the impacts of climate change. However, it has yet to be fully harnessed by scientists, practitioners, and policy-makers. We believe that such knowledge needs to be integrated with science and technology before it can be used in policies, education, and actions related to disaster risk reduction and climate change adaptation. In this paper, we present a process for integration, in which scientists, practitioners, and communities jointly undertake observation, documentation, and validation of local and indigenous knowledge, which are then selected for integration with science.

Integration of local and indigenous knowledge with science is an important process which enables practitioners and scientists to implement activities and research to increase resilience in coastal and small island communities. This integration also makes it possible for decision-makers to put into practice policies that support such activities. Such actions promote the use of local and indigenous knowledge and empower communities to use their knowledge supplemented with outside knowledge, to continue to make informed decisions about managing their adaptation and disaster risk reduction strategies. At the same time, through this process, local and indigenous knowledge that help communities build their resilience but cannot be explained by or integrated with science are categorized separately. Such knowledge would continue to be practised by communities, away from scrutiny by scientists, policy-makers and practitioners.

It is important to recognize that using local and indigenous knowledge for disaster risk reduction and climate change adaptation is not a panacea; it can have limitations, as described above. The objective of this paper is thus to demonstrate the use of a process that can promote an integrated approach for hydro-meteorological hazard risk reduction and climate change adaptation, thereby increasing the overall resilience of communities.

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