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Impact-based forecasting in South East Asia – What underlies impact perceptions?

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ABSTRACT

The move towards impact-based forecasting presents a challenge for forecasters, who must combine information not just on what the weather might *be*, but also on what the weather might *do*. Yet different hazards and impacts are qualitatively distinct, meaning such information cannot be easily or straightforwardly integrated. The present study aimed to provide a way of characterising seemingly disparate impacts. In a collaboration between UK psychologists and partners from three meteorological organisations in Indonesia, Malaysia and the Philippines, the psychometric paradigm was employed to investigate how forecasters and stakeholders perceive weather-related impacts. Participants provided ratings of nine categories of impacts on a total of 10 characteristics, as well as providing an overall impact severity rating. Principal components analysis revealed differing component solutions across countries, which explained around 75% of the variance in perceptions. There were some similarities across all countries, with the characteristics 'worry' and 'destructiveness' loading positively together, as well as 'likelihood of harm' and 'seriousness of harm'. We did not find strong evidence to indicate that forecasters and stakeholders perceive impacts in different ways. Our results highlight the complex nature of impact perceptions, which are characterised not just by objective factors such as impact scope and duration, but also subjective factors, such as worry and perceived severity.

Author contributions

AJLH conceived the study; AJLH and SCJ designed the study with input from all authors; SCJ programmed the study; AW, SA and

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RMM were responsible for data collection in Indonesia; NBMK and CSNBCM were responsible for data collection in Malaysia; LM, MCM and EC were responsible for data collection in the Philippines; SCJ analysed the data; AJLH advised on analysis decisions; SCJ wrote the manuscript; AJLH edited the manuscript; All authors commented on the manuscript; RB co-ordinated the international collaboration.

1. Introduction

Extreme weather events are perceived as the top risk in terms of likelihood and eighth in terms of impact within the global risks landscape [1]. In the years between 2000 and 2019, natural hazards such as tsunamis, volcanoes, earthquakes, cyclones, floods and landslides killed over 1.23 million people, affected over 4.03 billion people and led to $2.97 trillion's worth of economic losses [2,3]. Despite the fact that many of these events are well forecast, with timely warnings issued, the vast negative consequences for communities still persist. One communication measure aimed at reducing the adverse consequences associated with such events is the shift towards multi-hazard impact-based forecasting (IBF), whereby forecasts include information not just on what the weather might *be*, but also on what the weather might *do* (World Meteorological Organization [[4,5]. By including anticipated impacts within a forecast, it is clearer what mitigative action is required to minimise such consequences. In contrast to traditional weather warnings, which focus primarily on the hazard, impact-based warnings (IBWs) further consider *exposure* ("who and what may be affected in an area in which hazardous events may occur" [[4]; p. 4]) and *vulnerability* ("susceptibility of exposed elements … to suffer adverse effects when affected by a hazard" [[4]; p. 4]), as well as hazard characteristics in order to identify likely impacts [6]. The importance of both likelihood and impact information can be illustrated through consideration of the 'impact risk matrix' [4]; see Fig. 1). The impact risk matrix is often used in IBF and provides a traffic light scheme, whereby warnings from 1 (Green – Minor) to 4 (Red – Take Action) are issued depending on the combination of impact likelihood and severity. This risk matrix has been adopted by a number of meteorological organisations across the globe, from the United Kingdom to Australia [7]; see Ref. [4] and is in the process of being developed in South East Asia [8] – the focus of the present study.

Existing research on IBF and the efficacy of IBWs has focused on their effects on measures such as understanding, risk perceptions and behavioural intentions [9–16]. However, this research has largely focused on the general public as users of the forecasts, rather than focusing on those higher up the warning value chain process [17], such as forecasters and stakeholders (used here to refer to disaster managers, civil protection agencies, emergency services) who are part of the chain of organisations involved in the production of a warning [18]. As a result, there is a gap in our understanding of forecasters' decision-making processes. These processes are complicated by the subjective nature of IBWs. That is, traditionally, weather warnings are based on (typically objective) weather-based factors (e.g., wind speeds of at least x mph), whereas impact-based forecasts additionally require determining the scale and magnitude of a given impact.[1] This is an especially complex task, requiring integration across, and/or comparison of, qualitatively distinct hazards and impacts. Focusing on forecasters and stakeholders from Indonesia, Malaysia and the Philippines, the current study aims to investigate how they assess and characterise seemingly disparate impacts. Understanding these decision processes is key to ensuring the efficacy of IBWs, whether this be via a risk-based matrix approach, or alternative approaches such as cost-benefit analysis and multiple-criteria analysis (e.g., Refs. [19,20].

1.1. Risk perceptions

The current study builds on past research using the psychometric paradigm, developed by Slovic and colleagues (e.g., Refs. [21,22]. The paradigm involves asking individuals to characterise the 'personality of hazards' by rating hazards on a series of qualities such as severity, controllability, familiarity and level of knowledge, which influence perception and acceptance of risk [23]. Principal components analysis (PCA) can then be used to group these characteristics into 'principal components', which explain the majority of the variance in the original ratings. For instance, 'personal knowledge' and 'newness' might co-vary and thus contribute to a single factor – 'knowledge'. Typically, psychometric research has found that risk perceptions for a variety of hazards can generally be explained by two components, termed 'dread' and 'knowledge' (e.g., Refs. [21,22,24], with the greatest perceived risk associated with high dread and low levels of knowledge/familiarity.

South East Asia is one of the world's most natural hazard prone areas [25] with countries such as Indonesia, Malaysia and the Philippines at high risk from a large number of natural hazards, including tsunamis, volcanoes, earthquakes, cyclones, floods and landslides. Such hazards are perceived as old, well-known, immediate, hard to control, involuntary, generally catastrophic (i.e., killing large numbers of people at one time), causing widespread and disastrous consequences [26–30]. However, not all hazards are perceived similarly, with earthquakes perceived as more dangerous and posing a greater risk to society than windstorms and floods [31].

The component solutions found for risk perceptions of natural hazards are mixed. Some studies have found a 'dread' and 'knowledge' component [27], or a single component which combines both [32]. Other more novel components explaining variance in risk perceptions have also been proposed, such as: 'personal effect', which relates to the number of exposed people and the degree to which people were personally affected by the hazard [27]; 'controllability' [30,32], and 'impact' (relating to likelihood, threat to life, financial loss and dread [30]).

[1] Although algorithms are being developed for some specific impact estimates (e.g., Refs. [63–65], determining the severity of an impact is still typically a subjective undertaking and thus the research in this manuscript is pertinent to the development of such tools. These algorithms require initial parameterisation, likely including a subjective assessment of severity at some level. Forecasters are likely to be well-placed to feed into such modelling decisions.

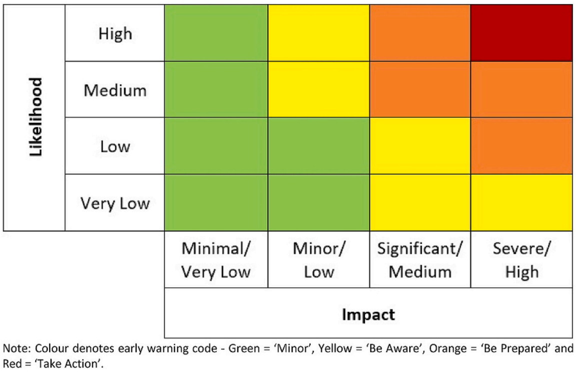


Fig. 1. Impact Risk Matrix proposed in Ref. [4]. Note: Colour denotes early warning code - Green = 'Minor', Yellow = 'Be Aware', Orange = 'Be Prepared' and Red = 'Take Action'.

1.2. Impact perceptions

Thus far, the psychometric research featuring natural hazards has only indirectly considered the impacts associated with each hazard. Yet should forecasters (or indeed any other professional) be tasked with forming an impact warning (for instance, when automation or modelling is not available), they must take account of not just the hazard itself, but also the potential impacts each one might have. These range from road closures, damage to property, disruption to municipal services, injuries, and even fatalities, with the extent of these impacts determined by levels of exposure and vulnerability in affected areas, as well as the hazard severity [6]. Whilst automation is desirable to increase the speed with which warnings can be produced, understanding the severity of these impacts is also key to the development of that automation [7]. This is recognised in the addition of impact information to the MOGREPS (Met Office Global and Regional Ensemble Prediction System) ensemble forecast tool - creating MOGREPS-W (MOGREPS-Warnings; [33].

The importance of a consideration of impacts is clear from some previous studies investigating ecological risks – those that pose a "risk to the health and productivity of natural environments" [34]; p. 45), such as nuclear power plants, deforestation and waste incineration. Such risks are complex in both the number, and scale, of their consequences (impacts) [34–36]. The aforementioned studies found that the most important component underlying risk perceptions was 'ecological impact', which related to characteristics including the geographical scope of impacts, number of people affected, reversibility and risk to human health [36]. The components 'human benefits', 'knowledge of impacts' (including predictability, observability, and immediacy of impacts) and 'controllability' also contributed to the final solution. Similar results have been found by Ref. [37] in their study of ecosystem risks predominantly relating to climate change. The component 'impacts' explained the greatest amount of variance in risk perceptions and comprised of 13 characteristics, including number of people affected, threat to health, the scope, duration and destructiveness of impacts, as well as negative emotion.

1.3. Current study

The research reviewed above clearly demonstrates the importance of impact characteristics in shaping risk perceptions of hazards. However, rather than seeing impacts as a component of risk perceptions of *hazards*, the current study takes a different approach by focusing on risk perceptions of *impacts*. The three countries included in the present investigation (Indonesia, Malaysia and the Philippines) have begun to develop 'impact tables' – a collection of varying impacts associated with a specific hazard for use in IBF. These tables currently differentiate impacts by scope and duration, though we suggest that other (more subjective) impact characteristics are also likely considered by individuals when formulating a forecast or interpreting a warning. In the current study, we therefore aim to investigate which components best explain risk perceptions for impacts (hereafter referred to as impact perceptions), both for forecasters and stakeholders. This approach will allow us to compare perceptions of different impacts and begin to explore how forecasters and stakeholders perceive the risk of impacts, and if they are based on similar component structures. Our research questions were as follows:

1. Which components best explain impact perceptions? For instance, do we replicate the 'dread' and 'knowledge' components seen in previous risk perception research?
2. What are the differences (by component) in perceptions of each impact? For example, are impacts relating to people (e.g., displacement/evacuation) seen similarly to impacts relating to damage (e.g., damage to property) or are the former more dreaded?
3. How do forecasters and stakeholders perceive the risk of impacts? That is, are impact perceptions for forecasters and stakeholders explained by the same components?

2. Method

We conducted the same study design across the three countries and thus in the following report the methodology generally, highlighting differences between countries as appropriate. The pre-registered country-specific methodology can be found at: https://osf.io/rkz7v/?view_only=08f20763e7a2416caafec0085390cb39.

2.1. Participants

A description of the study and the survey link was emailed to forecasters and stakeholders identified by the South-East Asia collaborators,[2] with reminder emails sent throughout the data collection period (indicated in Table 1). For full demographic details of each sample, see Table 1.[3] The Philippines also carried out an IBF training seminar during the data collection period, attended by stakeholders from several Local Government Units (LGUs) in Metro Manila and Metro Cebu, where they were also reminded about participating. Participation in the study was not remunerated. Ethical approval was granted from the Departmental Ethics Chair for Experimental Psychology (University College London).

2.2. Questionnaire

Participants were presented with a range of impacts and asked to rate each impact on a series of 10 characteristics, using a 7 point Likert scale (as used previously by Refs. [34–36,38,39]. Impact tables already differentiate impacts by 'scope' and 'duration.' The eight additional characteristics were selected as most relevant from previous literature (e.g., Refs. [34–36,40]; see Table 2).

Participants were asked to rate nine categories of impacts,[4] based on the Impact Category Criteria used in Gunawan et al. [41,42]; presented in the context of either 'heavy rainfall' (Philippines, Indonesia) or 'river flooding' (Malaysia).[5] To aid understanding, each category was accompanied by a number of severe impacts from within that category (see Table 3), with participants asked to rate each category on the characteristics (for an example, see Fig. 2) in the context of a specific hazard.[6]

Participants were also asked to give an overall severity rating for each impact category (as in Refs. [35,43,44] – "How severe do you judge this impact to be?", rated on a 7 point scale, from 'Not at all severe' to 'Highly severe'. The order of this question (i.e., whether it came before or after ratings of the impacts and characteristics) was counterbalanced.

On the advice of the local authors, materials were presented in English in Malaysia and the Philippines, and translated into Bahasa for Indonesian participants. Although a complete back translation was not possible, the translation was undertaken by SA and RN and checked by AW, with random selections additionally checked by RB and SCJ.

2.3. Procedure

The study was run online using Qualtrics, with participants able to complete the study in more than one session (in total, the current task involved 99 ratings per participant, which took around 20–30 min to complete). Before beginning the main task, participants were asked a series of demographic questions. They were asked to indicate: gender (male/female/prefer not to say); age; their area of work (meteorology/disaster management/civil protection/emergency services/other – Please indicate if, in your work, you typically use forecasts/or prepare them) and their level of experience with IBF (little or no experience/some training/some experience/a lot of experience).

Participants were first presented with instructions for the task. On the next screen, participants were presented with one of the impact categories presented in the context of a specific hazard and asked to rate the impact on 10 characteristics, on seven-point Likert scales (see Table 1). Both impact categories and characteristics were presented in a random order. The subsequent screen showed another, randomly presented impact category, and so on and so forth, until the participant had rated the full set of impacts. Participants were also asked to provide ratings of the overall riskiness of the impacts, with the order of this question (i.e., whether it came before or after ratings of the impacts and characteristics) counterbalanced.

Participants subsequently completed a related study (see https://osf.io/rkz7v/?view_only=08f20763e7a2416caafec0085390cb39 Study 2 – Impact Decision Warning Thresholds), in which participants were presented with both impact and likelihood information, and asked to indicate which warning level they would assign given this information. Finally, participants were thanked and debriefed. For an outline of the procedure, please see Fig. 3.

2.4. Data preparation

We recoded the 'controllability' and 'predictability' items, such that higher scores on all characteristics reflected perceptions that have typically been associated with higher risk ratings (following [45,46]. Specifically, 'Not at all predictable', 'Not at all able [to control the effects of the impact]' were recoded as 7, equivalent to (for example) 'Extremely worried'.[7]

[2] The decision to send the survey link to the South-East Asia collaborators to distribute to stakeholders was a pragmatic decision, made in light of the COVID-19 pandemic. This meant that the UK team were unable to visit the countries and establish in-person relationships with stakeholders themselves.

[3] We pre-registered that we would aim to collect as many participants as possible (minimum of 30 per group) within a specified timeframe (four weeks). The decision to settle on 30 participants was made for pragmatic reasons: (a) the specialist nature of the sample meant there were limited numbers of participants at each organisation to recruit from and (b) following feasibility discussions between the UK and South-East Asia authors. Given our difficulties with obtaining this minimum number of participants after four weeks, we subsequently extended the data collection period. No analyses were undertaken before the decision was made to stop data collection.

[4] The decision to ask participants to rate impact categories rather than individual impacts was made because the countries' existing impact tables contained at least 42 impacts - rating each of these impacts on each of the ten characteristics (minimum of 420 ratings) was not a feasible task to request our sample to undertake.

[5] These impacts were chosen following discussion between SCJ, AJLH and the authors from the specific countries, noting hazards of particular concern.

[6] In Indonesia and Malaysia, we did originally pre-register that we would present participants with the impacts twice, once in a context free condition, and once in the context of a hazard (either heavy rainfall or river flooding, depending on the country). Following feedback from potential participants that the study was too long; we removed the context free condition. Participants therefore only completed ratings of the impacts in the hazard context condition. This was necessary to ensure completion of the survey by participants.

[7] We originally (mistakenly) pre-registered that scores on 'immediacy' items would be recoded, though did not do so for the analysis reported here, given higher scores on immediacy ('experienced far into the future') are associated with higher risk ratings.

Table 1
Participant information for partner countries.

Country and Partner Organisation–Full completions (n)	Demographics		Data Collection Period
	Forecasters	Stakeholders	
Indonesia -BMKG - 96	89 44 male, 43 female, 2 prefer not to say, aged between 17 and 45 (Mdn = 27.5, one missing) IBF experience: 21.3% little or no experience; 31.4% some training; 42.6% some experience; 4.5% a lot of experience.	7–5 male, 2 female aged between 21 and 47 (Mdn = 21) Approached those from: National Disaster Management Agency, Regional Disaster Management Agency Jakarta Role: 28.6% disaster management, 71.4% 'use forecasts' IBF experience: 42.9% little or no experience; 42.9% some experience; 14.2% a lot of experience.	November 22nd, 2020–January 20th, 2021
Malaysia - MetMalaysia - 57 (one unspecified job role)	51 22 male, 26 female, 3 prefer not to say, aged between 26 and 49 (Mdn = 38) IBF experience: 50.9% little or no experience; 15.7% some training; 31.4% some experience; 2.0% a lot of experience.	5–1 male, 4 female, aged between 30 and 41 (Mdn = 39) Approached those from: National Disaster Management Agency Drainage and Irrigation Department Role: 60.0% disaster management, 40.0% 'use forecasts' IBF experience: 40% little or no experience; 60% some experience.	November 27th, 2020–January 20th, 2021
Philippines -PAGASA–54	28 15 male, 13 female, aged between 25 and 62 (Mdn = 32.5) IBF experience: 39.3% little or no experience; 32.1% some training; 28.6% some experience.	26–16 male, 10 female, aged between 22 and 62 (Mdn = 35) Approached: Disaster Risk Reduction and Management Officers from several Local Government Units in Metro Manila and Metro Cebu Role: 92.3% disaster management, 3.8% emergency services, 3.8% 'use forecasts' IBF experience: 34.6% little or no experience; 42.3% some training; 23.1% some experience.	November 11th, 2020–January 20th, 2021

Table 2
Impact characteristics used in the study.

Characteristics
Destructiveness of impacts
How destructive is this impact? *(No destructive effects to Complete destruction)*
Duration of impacts
Please rate the duration of this impact *(Short term to Long term)*
Worry
How worried are you when you think about this impact? *(Not worried at all to Extremely worried)*
Number of people affected
How many people will be affected by this impact? *(Very few people to Great number of people)*
Scope of area affected
Please rate the scope of this impact in terms of the size of the area affected *(Small isolated effects to Widespread effects [countrywide])*
Seriousness of harm
How seriously do you think this impact may harm human health? *(Not seriously at all to Extremely seriously)*
Likelihood of harm
How likely is it that this impact will harm human health? *(Not likely at all to Extremely likely)*
Controllability of impacts
To what degree are people able to control the effects of this impact, for instance by taking mitigative action? (*Not at all able to Completely able*)
Predictability of impacts
To what degree can this impact be predicted? *(Not at all predictable to Very predictable)*
Immediacy of impacts
How immediate is this impact, in terms of how soon its effects may be experienced *(Experienced immediately – Experienced far in the future)*

Whilst a 'don't know' option was not explicitly included in the study; participants were able to skip questions. As per our pre-registration, we followed the protocol of Fife-Schaw and Rowe [47] and checked whether any of the impacts had >15% missing responses, though none did. Given that missing data is problematic for principal components analysis, individual missing values were replaced by the mean value for that item (the specific characteristic of the impact in question; as in Ref. [46].

Table 3
Impact Categorisation by Country..

Impacts
Physical/psychological harm or ill health
[I] (e.g., danger to life – fast flowing streams/deep water; widespread incidents of communicable diseases)
[M] (e.g., some loss of lives/fatalities, widespread water borne diseases; people dying from water borne diseases)
[P] (e.g. communicable and waterborne diseases epidemic [leptospirosis etc]; widespread cases of injuries and diseases, emotional and psychological traumas; prolonged confinement in the hospital; multiple deaths)
Displacement/evacuation
[I] (e.g., large communities not accessible/cut-off for a prolonged period; widespread displacement of affected communities)
[M] (e.g., widespread homelessness)
[P] (e.g., large communities not accessible/cut-off for a prolonged period [2 weeks+])
Damage to property
[I] (e.g., widespread flooding of settlements, widespread damage to property)
[M] (e.g., widespread destruction of properties)
[P] (e.g., widespread damage to property)
Damage to infrastructure
[I] (e.g., widespread flooding of roads, major roads; bridges damaged or washed away; widespread damage to buildings; breakage of dam walls)
[M] (e.g., bridge(s) complete structural destruction; widespread complete destruction; total destruction of monitoring instruments)
[P] (e.g., destruction of public infrastructure; widespread damage to powerlines and pipelines; total damage to buildings/structures)
Damage to natural environment/agriculture
[I] (e.g., loss of livestock; damage to crops)
[M] (e.g., large/complete loss of crop/livestock; agricultural land degradation)
[P] (e.g., major damage [60%+] to crops and livestock; extended regional-scale destruction of crops and livestock)
Disruption to utilities
[I] (e.g., widespread, prolonged disruption to essential services [water, electricity, etc]; widespread disruption of access to drinking water)
[M] (e.g., widespread water, electricity and communication services cut-off for several weeks; widespread no access to clean water)
[P] (e.g., prolonged interruption of water, power, and communication services [2 weeks+]; widespread and prolonged contamination of water supply; discoloration of water with pungent odour; prolonged food unavailability due to hampered supply of food)
Disruption to transport
[I] (e.g., widespread transport routes and travel services severely affected; closure of low-lying bridges; airport closure)
[M] (e.g., widespread water, electricity and communication services cut-off for several weeks; widespread no access to clean water)
[P] (e.g., roads not passable to all types of road vehicles)
Disruption to key sites
[I] (e.g., widespread, prolonged disruption to hospitals and schools; prolonged strain on emergency personnel)
[M] (e.g., total shutdown of public services such as schools, healthcare services, district offices; national shortage of medicine)
[P] (e.g., disruption of public services for an indefinite period; school class suspension for a prolonged period [2 weeks+])
Disruption to business
[I] (e.g., loss of livelihoods)
[M] (e.g., national scale economic impact; financial implications of loss of crops/livestock [import-farmer])
[P] (e.g., prolonged [2 weeks+] suspension of government operations; loss of livelihoods)
Note: Example impacts are colour coded by country: [I] Indonesia, [M] Malaysia, [P] the Philippines.

Note: Example impacts are colour coded by country: [I] Indonesia, [M] Malaysia, [P] the Philippines.

2.5. Planned data analysis

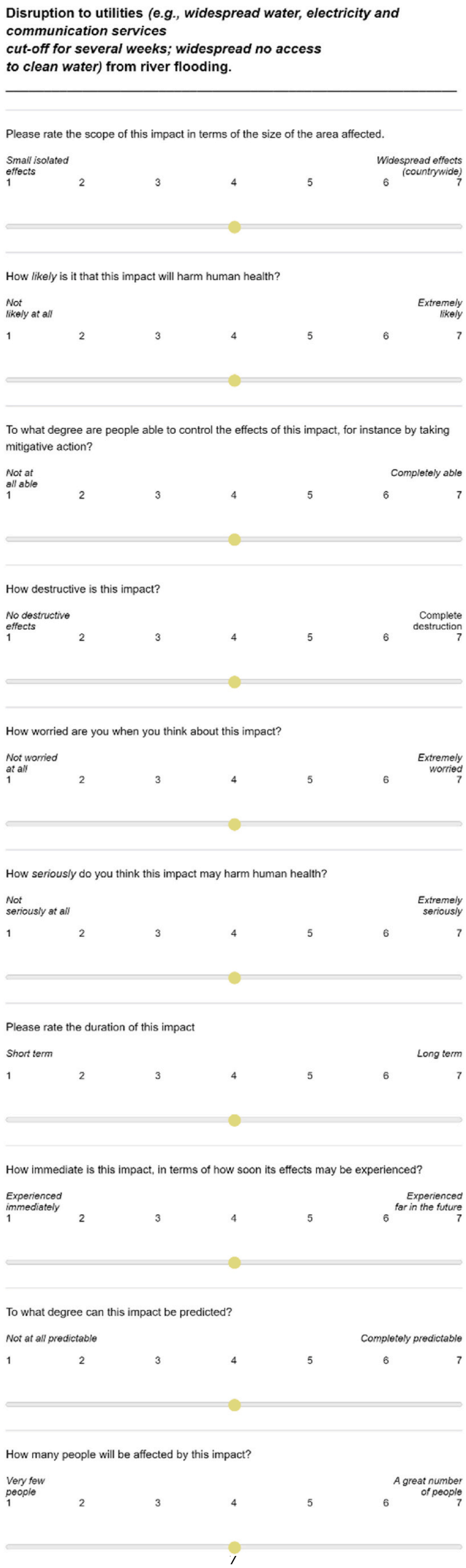
We specified a minimum number of participants (n = 30) for each group (forecasters and stakeholders) in our pre-registration, but this was not reached in the Indonesian or Malaysian samples (seven and five stakeholders, respectively). We therefore only conducted analysis on the forecaster group in these samples.[8] Although we fell slightly short of 30 in the Filipino sample, 28 forecasters and 26 stakeholders represented a far greater number of stakeholders than in either of the other two countries, and provided an approximately even distribution between forecasters and stakeholders. We thus continued to conduct analyses on both groups in this sample.

Within each country, we focused our analysis at the aggregate level (aggregating over forecasters), and initially focused on differences among impacts (see Ref. [48]. In the Filipino sample, we also explored the differences between forecasters and stakeholders and thus additionally aggregated over stakeholders.

A correlation matrix was created, featuring all of the variables in the principal components analysis (PCA), in order to check that all of the variables had at least one correlation where $r \geq 0.3$ [49]. In all four samples (Indonesia, Malaysia, Filipino forecasters, Filipino stakeholders), all of the variables had at least one correlation above this level.

For each of the countries, a PCA of the aggregated forecaster data on the ten characteristics was conducted, with an additional PCA of the aggregated stakeholder data conducted for the Filipino sample. These four PCAs were conducted using a Varimax rotation, chosen because such rotation results in more interpretable clusters of factors [50], and has been used in previous psychometric studies featuring impact characteristics [35,36]; see also [21]. We retained components on the basis of the eigenvalue over one [51], the scree

[8] Although we did not pre-register any exclusion criteria, in the Indonesian sample, one participant had missing data for all but the overall severity ratings, so we excluded them from analysis, leaving a total of 88 forecasters. In the Malaysian sample, four participants had missing data on two or more blocks, so we excluded them from analysis, leaving a total of 47 forecasters.



Disruption to utilities ***(e.g., widespread water, electricity and communication services cut-off for several weeks; widespread no access to clean water)*** **from river flooding.**

Please rate the scope of this impact in terms of the size of the area affected.

Small isolated effects — *Widespread effects (countrywide)*

1 2 3 4 5 6 7

How *likely* is it that this impact will harm human health?

Not likely at all — *Extremely likely*

1 2 3 4 5 6 7

To what degree are people able to control the effects of this impact, for instance by taking mitigative action?

Not at all able — *Completely able*

1 2 3 4 5 6 7

How destructive is this impact?

No destructive effects — Complete destruction

1 2 3 4 5 6 7

How worried are you when you think about this impact?

Not worried at all — *Extremely worried*

1 2 3 4 5 6 7

How *seriously* do you think this impact may harm human health?

Not seriously at all — *Extremely seriously*

1 2 3 4 5 6 7

Please rate the duration of this impact

Short term — *Long term*

1 2 3 4 5 6 7

How immediate is this impact, in terms of how soon its effects may be experienced?

Experienced immediately — *Experienced far in the future*

1 2 3 4 5 6 7

To what degree can this impact be predicted?

Not at all predictable — *Completely predictable*

1 2 3 4 5 6 7

How many people will be affected by this impact?

Very few people — *A great number of people*

1 2 3 4 5 6 7

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Fig. 2. Screenshot of the 10 characteristic ratings for the impact category – 'disruption to utilities'.

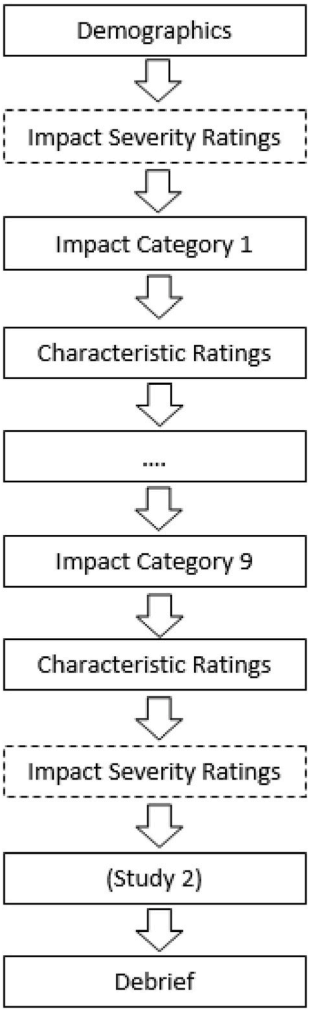

Fig. 3. Flow Chart of Procedure. Note: Dashed box represents counterbalanced nature of severity ratings.

plot [52], and the proportion of variance criteria. Where characteristics cross-loaded on more than one component, we selected the component where the characteristic had the highest loading. A breakdown of the full loadings can be found in Tables S1- S4.

3. Results

3.1. Principal components analysis

Across all four samples, the final principal component solutions explained a considerable proportion of variance in impact perceptions, ranging from 67.4 to 93.0% (see Table 4). We see some similarities in component structure across the countries, with the same component appearing in both the Indonesian sample, as well as the Filipino stakeholder sample – that of 'destructiveness/scope'. Characteristics loading heavily on this 'destructiveness/scope' component were 'worry' (extremely worried), 'destructiveness' (complete destruction), 'scope of area affected' (widespread effects [countrywide]). This was the primary component and explained almost 50% of the variance in impact perceptions in both samples. Additionally, the component 'severity', comprising of 'seriousness of harm' (extremely serious), 'likelihood of harm' (extremely likely to harm human health) and 'controllability' (completely able [to control effects of impact]) was also found in both the Malaysian and Indonesian sample, though accounted for less variance in the latter (a breakdown of the full loadings can be found in Supplementary Materials).

Looking more specifically at the relationships between characteristics, we see that several characteristics consistently pair together across the four samples. Worry and destructiveness loaded positively together, such that impacts which were perceived as more destructive were also more worrisome. Secondly, seriousness and likelihood of harm load positively together, such that impacts which

Table 4
PCA component solutions by country.

Country		Component 1 (Variance, Reliability [α])	Component 2 (Variance, Reliability [α])	Component 3 (Variance, Reliability [α])	Component 4 (Variance, Reliability [α])
Indonesia		**Destructiveness/scope (48.2%, .948)** Destructiveness (complete destruction) Worry (extremely worried) People affected (great number of people) Scope (widespread effects, countrywide)	**Severity (25.6%, .834[a])** Seriousness of harm (extremely serious) Likelihood of harm (extremely likely to harm) Controllability (completely able to control effects of impact)	**Timescale (10.9%, .532)** Immediacy (experienced far into the future) Duration of impacts (long term) Predictability (not at all predictable)	N/A
Malaysia		**Severity (42.0%, .924[a])** Seriousness of harm (extremely serious) Likelihood of harm (extremely likely to harm) Controllability (completely able to control effects of impact)	**Dread (25.4%, .755[b])** Predictability (very predictable) Worry (extremely worried) Destructiveness (complete destruction)	**Extent (14.6%, .678[c])** People affected (very few people) Duration of impacts (long term)	Scale (11.0%, .735) Scope (widespread effects, countrywide) Immediacy (experienced far in the future)
Philippines	Forecasters	**Destructiveness/duration (44.8%, .894)** Seriousness of harm (extremely serious) Likelihood of harm (extremely likely to harm) Worry (extremely worried) Destructiveness (complete destruction) Duration of impacts (long term)	**Scope (22.6%, .750)** Scope (widespread effects, countrywide) People affected (great number of people) Immediacy (experienced far into the future)	Predictability (16.1%, .522ˆ) Controllability (not at all able to control) Predictability (not at all predictable)	N/A
	Stakeholders	**Destructiveness/scope (49.6%, .901)** Worry (extremely worried) Destructiveness (complete destruction) Scope (widespread effects, countrywide) People affected (great number of people)	**Intensity (21.9%, .890)** Seriousness of harm (extremely serious) Likelihood of harm (extremely likely to harm) Duration of impacts (long term) Immediacy (experienced far into the future)	Predictability (11.3%, .152[b] +) Controllability (not at all able to control) Predictability (very predictable)	N/A

Note: Components in bold represent final solution. Reliability analyses: [a] = included controllability as originally coded, [b] = included predictability as originally coded, [c] = included people affected reverse coded. ˆ 'poor' reliability [53],+'unacceptable' reliability [53].

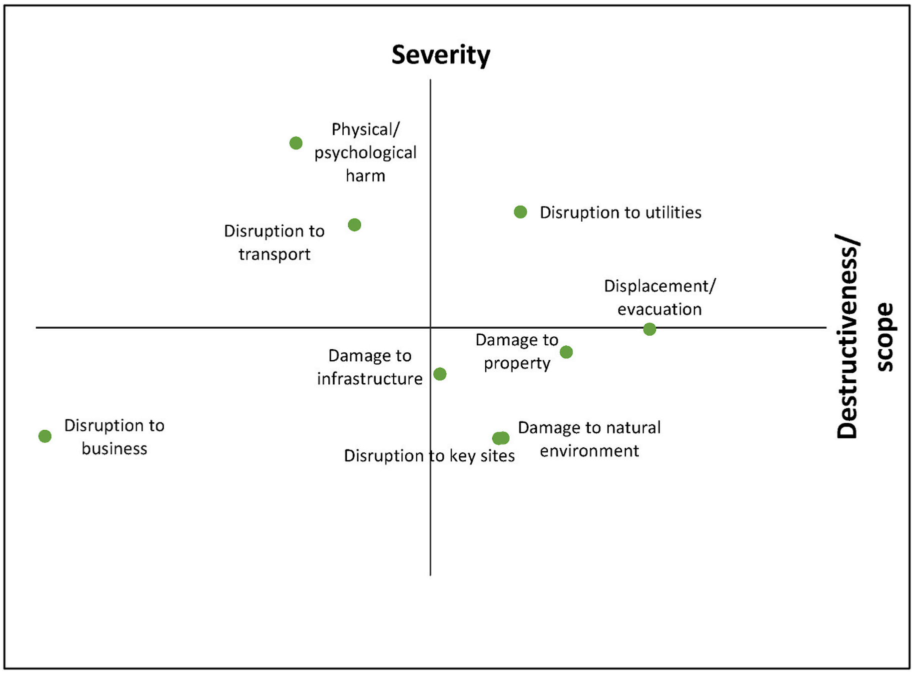

Fig. 4.]Indonesia – Forecasters – Location of impacts within the two-component space.

were perceived to be more serious were also perceived as more likely to cause human harm. In all samples other than Malaysia, scope and number of people affected also load positively together, such that countrywide impacts are perceived as affecting more people.

3.1.1. What are the differences (by component) in perceptions of each impact?

We computed component scores for each of the impacts (i.e., original variables multiplied by optimal weights = the score the impact achieves on the retained component) as in Ref. [46]; 2008) to capture differences in impact perceptions. Figs. 4–7 provide an overview of the relative differences in perceptions of each impact at an individual country level. For the Indonesian and Malaysian forecasters, we see that both physical/psychological harm and disruption to utilities were perceived as severe (Figs. 4 and 5). For the Filipino forecasters, physical/psychological harm, displacement/evacuation and disruption to utilities were perceived as destructive and enduring (Fig. 6). For the Filipino stakeholders, we see that impacts associated with danger to people – physical/psychological harm and displacement/evacuation were perceived as the most intense (Fig. 7).

3.2. Overall impact severity perceptions

We originally pre-registered that, using the non-aggregated data, we would regress overall severity ratings onto each of the ten characteristics (as in Refs. [43–45], adding characteristic × group interaction terms in the Filipino sample to investigate differences between groups. Ideally, a regression will have a minimum of ten participants per predictor included in the model [54], which we fell considerably short of in all three countries. We present the results of these regressions in the Supplementary Materials for completeness, but draw the reader's attention to the fact that these analyses are likely underpowered and lack reliability.

3.3. Unplanned, exploratory analysis

We tested for differences in overall severity ratings between impacts separately for each country (see Fig. 8). In Indonesia, a one-way ANOVA showed there was a significant difference in overall ratings between impacts $F(8, 783) = 4.18$, $p = < .001$, $\eta_p^2 = 0.04$. A Tukey HSD post-hoc test showed that disruption to business was perceived as significantly less severe than damage to property, damage to infrastructure, damage to the natural environment, disruption to utilities and disruption to transport (see Table 5.).

In Malaysia, a one-way ANOVA showed there was no significant difference in overall ratings between impacts $F(8, 414) = 1.05$, $p = .40$.

In the Philippines, a 9 (impact) × 2 (group) ANOVA showed there was no significant difference in overall ratings between impacts $F(8, 468) = 0.62$, $p = .76$, nor between groups, $F(1, 468) = 0.024$, $p = .88$. There was also no interaction between impact and group, $F(8, 468) = 0.35$, $p = .95$.

4. General discussion

The current study extends previous research using the psychometric paradigm by applying it in a novel context, that of impact-based forecasting and, in particular, impact perceptions. Similar to risk perceptions, we show that impact perceptions comprise of qualitative characteristics other than simply likelihood of harm. In all four samples across the three countries, the final component solutions explained almost three quarters of the variance in impact perceptions. Interestingly, we did not consistently replicate the 'dread' component found in a variety of contexts, including natural hazards [21,27,30,32,45]. Speculatively, this may relate to the characteristics of our sample, who work with the weather daily and are used to considering its impacts from a professional viewpoint. Here, their focus might be more on translating existing, measurable hazard characteristics such as intensity, duration, extent into impacts [6], rather than other more 'subjective' characteristics such as controllability and severity, which have been found to contribute to the 'dread' component [21,22,24]. Nevertheless, we note that all of the primary components did share some characteristics otherwise identified as contributing to 'dread', such as worry, destructiveness and seriousness of harm.[9]

Although the precise component structures differed across the four samples, there were some similarities across the countries. The component 'destructiveness/scope' was identified in both the Indonesian and Filipino stakeholder sample, which related to worry, destructiveness, people affected and scope of area affected. This component shares similar characteristics to the 'impacts' component identified in Ref. [37] study of eco-system risk perceptions, which comprised of 13 characteristics including number of people affected, threat to human health, destructiveness, scope of impacts, and negative emotion regarding the risk. The component 'severity' was found in both the Malaysian and Indonesian samples, which related to the likelihood and seriousness of harm characteristics, and controllability. This component can be likened to the 'potency' component found in Ref. [28] study of natural and manmade risks, which was determined by degree of dread and likelihood of fatal consequences and the 'impact' component in Ref. [30] study of natural hazards, comprising of likelihood of occurrence, threat to life, potential effect on quality of life, financial loss, and fear.

We also saw similarities in the way that certain characteristics loaded together across the countries. For instance, worry and destructiveness always loaded together, with greater destruction associated with greater worry. Additionally, likelihood and seriousness of harm also always loaded together, such that more serious harm was associated with increased likelihood of harm, yet this is contrary to what one would typically expect, as more severe events are usually rarer than less severe events (c.f. [55]. The [4] Impact Risk Matrix implicitly treats impact severity and likelihood as independent. However, individuals might not see them as independent. Indeed, interpretations of likelihood information could be influenced by the severity of the impacts described [56–59]. This notion of

[9] Whilst forecasters themselves might dread the 'unknown' associated with a move to IBF (as highlighted by an anonymous reviewer), the current study did not address this question, focusing only on perceptions of the impacts themselves, rather than perceptions of IBF as a concept.

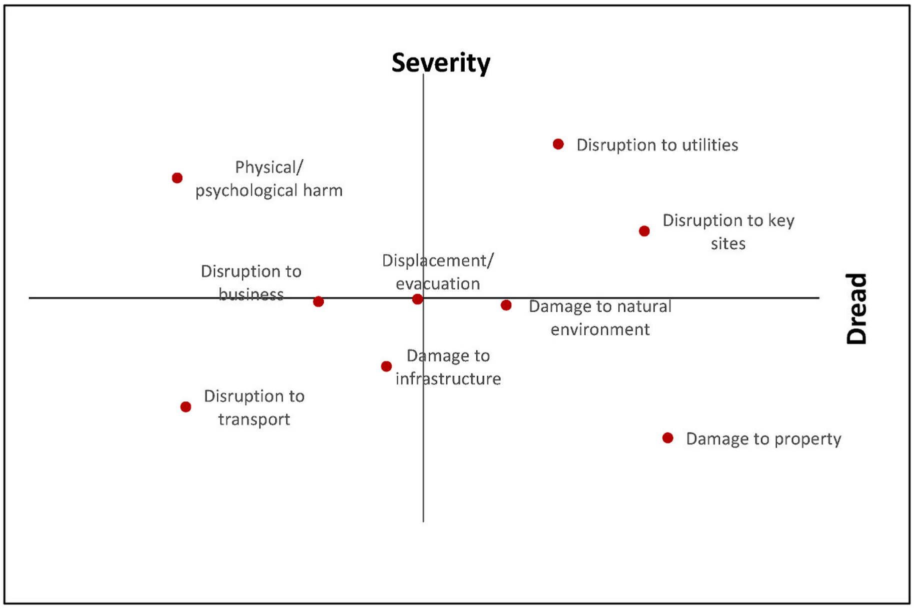

Fig. 5. Malaysia – Forecasters – Location of impacts within the two-component space.

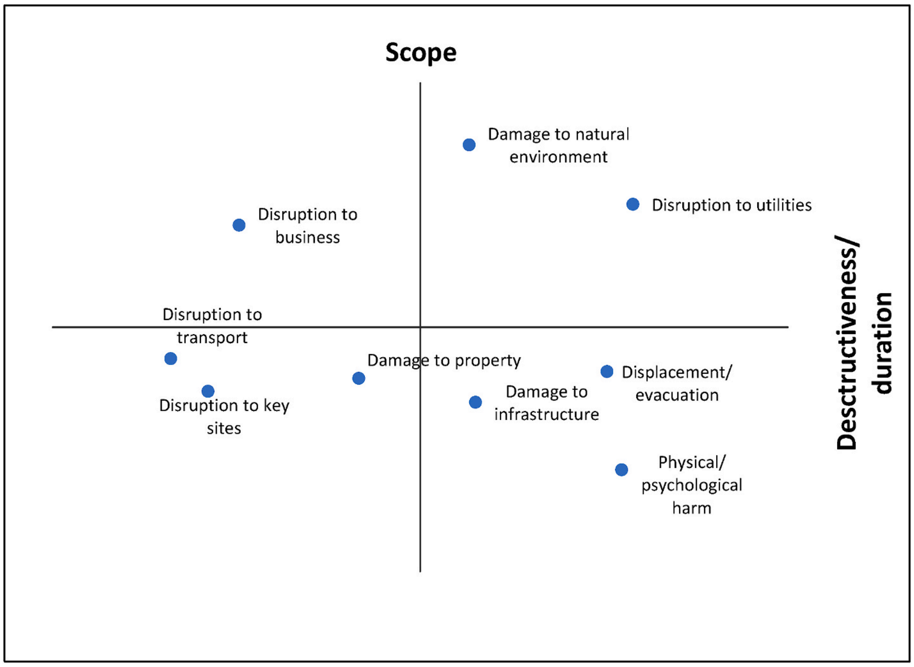

Fig. 6. Philippines – Forecasters – Location of impacts within the two-component space.

non-independence could be consequential for any forecast which requires a combination of likelihood and severity information, and the communication of likelihood information. IBFs are likely to always have this feature. Whilst the anticipated impacts may be communicated in a non-probabilistic format, such as (for example) reporting the maximum possible number of affected people [60], a *hazard's occurrence* at a particular location is likely best considered probabilistic [2,3].

Some of our findings contrasted with the results of previous research, namely in relation to the characteristic 'controllability'. Typically, research using the psychometric paradigm has found the characteristic of controllability contributes to a 'dread' component, in which greater dread/severity is associated with a reduced ability to control the risk [22,24]. However, we found that controllability loaded negatively, such that greater severity was associated with the ability to control the effects of the impact. This difference could be attributed to the way the question was phrased, which included the example of being able to take mitigative action (i.e., "To what

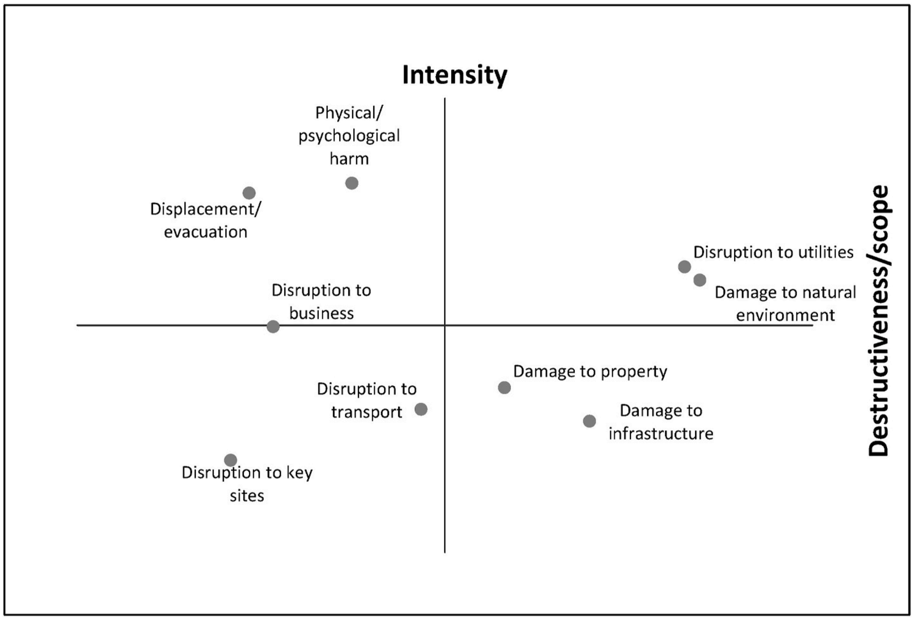

Fig. 7. Philippines – Stakeholders – Location of impacts within the two-component space.

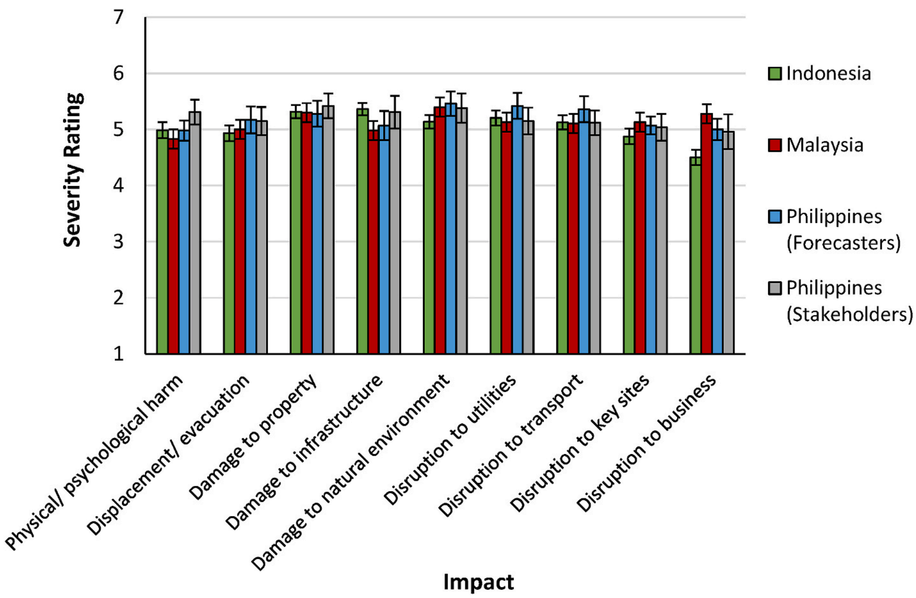

Fig. 8. Overall Mean Severity Ratings for Each Impact by Country. (Error bars represent ±1 Standard Error [SE]).

degree are people able to control the effects of this impact, for instance by taking mitigative action?"). Whilst all of the impacts could be described as difficult to control in that they are natural hazards, they do differ in how much mitigative action one could take. For instance, one could reduce physical/psychological harm or ill health by evacuating individuals, but disruption to utilities or transport is potentially less surmountable, and the mitigating actions less clear. Relatedly, if controllability and severity are associated, then the severity of the impact might influence need/inclination for taking action, such that more action is taken in response to more severe impacts. Indeed, our sample of professional meteorologists and stakeholders may have experience of specifically seeking to identify mitigation actions for those impacts that are most severe.

4.1. Comparing perceptions between forecasters and stakeholders

Our third research question involved a comparison between forecasters and stakeholders, examining whether there was a common structure to their impact perceptions. Owing to difficulties recruiting stakeholders in Indonesia and Malaysia, we were only able to

Table 5
Results of Tukey HSD post- hoc test for Indonesia.

Impact	Mean	SE
Disruption to business	4.50[a]	0.14
Disruption to key sites	4.88[ab]	0.14
Displacement/evacuation	4.93 [ab]	0.14
Physical/psychological harm	4.99 [ab]	0.14
Disruption to transport	5.13[b]	0.13
Damage to natural environment	5.14 [b]	0.12
Disruption to utilities	5.20 [b]	0.13
Damage to property	5.32 [b]	0.12
Damage to infrastructure	5.36 [b]	0.11

Note: Impacts which share a superscript ([a] or [b]) do not have significantly different mean ratings.

investigate this question within the data from the Philippines. Here, we found slightly different component structures – in the forecaster sample, we found a two-component solution, comprising of 'destructiveness/duration' and 'scope'. In the stakeholder sample, we found a two-component solution, which comprised of 'destructiveness/scope' and 'intensity'. Although these solutions were different, as highlighted in the Results section, there were pairs of characteristics which loaded together in both groups – specifically worry and destructiveness, likelihood and seriousness of harm, and scope and number of people affected. Additionally, there was no statistical evidence (in the form of a Group × Characteristic interaction) that the two groups' perceptions reliably differed. We therefore tentatively conclude that initial indications are positive, with impact perceptions seemingly similar across forecasters and stakeholders. We highlight, however, that these are *initial* indications, especially given the sample size for both groups was small, and thus the interaction test is underpowered. Moreover, the fact that these initial indications are positive for similarities between stakeholders and forecasters in the Philippines provides no indication as to the likelihood of observing the same results in other countries. The Philippines have specifically undertaken to involve stakeholders fully in their development of IBWs, as evidenced by the organisation of numerous workshops [8] as well as the ability to recruit these participants for the current study. Such efforts likely serve to increase the degree of shared perceptions between the groups.

4.2. Further considerations

The psychometric paradigm has been previously criticised for its reliance on aggregate data [61]. In the current studies, data was aggregated across individuals, rather than impact, and thus meant a reliance on ten units of analysis. This suited our research interest in the specific differences in perceptions between impacts. Moreover, the paradigm was most appropriate given the novel context of the current research (see also [62].

The applied nature of this research meant that we needed to recruit professional forecasters and stakeholders, who were working full-time and already had considerable demands on their time, which was exacerbated by the COVID-19 pandemic. We were therefore unable to recruit as many participants as we would have liked, particularly stakeholders. That the Philippines managed to recruit almost equivalent numbers of stakeholders as forecasters is a strong testament to the concerted efforts they have made to build relationships with civil protection and disaster managers (see Ref. [8]. The development of partnerships between meteorological organisations and stakeholders is crucial for the success of impact-based forecasting [4]. Such collaboration will result in a range of benefits, including improved risk assessments and monitoring, early warning and, ultimately, enhanced responses to natural hazards.

5. Conclusion

Impact-based forecasting requires the integration of qualitatively different impacts. Despite the development of automated technology to assist with this, determining the severity of impacts still involves a level of human input. This research indicates that impact perceptions are psychologically complex and driven by factors other than simply likelihood, duration or scope. Less objective (and harder to quantify) characteristics such as 'seriousness of harm' and affective responses such as 'worry' also influence impact perceptions. Perceptions of impacts do not seem to drastically differ between forecasters and stakeholders, at least on the basis of the current data. Continued collaboration with stakeholders is key to ensuring that this can be monitored over time.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2022.102943.

References

[1] World Economic Forum, The Global Risks Report 2021, sixteenth ed., 2021. http://wef.ch/risks2021.
[2] United Nations Office for Disaster Risk Reduction, The Human Cost of Disasters: an Overview of the Last 20 Years (2000-2019), 2020, https://doi.org/10.18356/79b92774-en.
[3] United Nations Office for Disaster Risk Reduction, *Deterministic & Probablistic Risk*. Prevention Web, 2020. https://www.preventionweb.net/understanding-disaster-risk/key-concepts/deterministic-probablistic-risk.
[4] World Meteorological Organization, WMO Guidelines on Multi-Hazard Impact-Based Forecast and Warning Services, 2015. https://library.wmo.int/doc_num.php?explnum_id=7901.
[5] World Meteorological Organization, WMO Guidelines on Multi-Hazard Impact-Based Forecast and Warning Services - Part II: Putting Multi-Hazard IBFWS into Practice, 2021. https://reliefweb.int/report/world/wmo-guidelines-multi-hazard-impact-based-forecast-and-warning-services-part-ii-putting.
[6] B. Merz, C. Kuhlicke, M. Kunz, M. Pittore, A. Babeyko, D.N. Bresch, D.I.V. Domeisen, F. Feser, I. Koszalka, H. Kreibich, F. Pantillon, S. Parolai, J.G. Pinto, H. J. Punge, E. Rivalta, K. Schröter, K. Strehlow, R. Weisse, A. Wurpts, Impact forecasting to support emergency management of natural hazards, Rev. Geophys. 58 (4) (2020), https://doi.org/10.1029/2020RG000704.
[7] M. Harrowsmith, M. Nielsen, M.C.J. Sanchez, E. Coughlan de Perez, M. Uprety, C. Johnson, M. van den Homberg, A. Tijssen, E. Mulvihill Page, S. Lux, T. Comment, The Future of Forecasts: Impact-Based Forecasting for Early Action, 2020, https://doi.org/10.13140/RG.2.2.12366.89920.
[8] R. Beckett, A. Hartley, Progress on the development of impact based forecasting in South East Asia, Met Office (2020) 1–87.
[9] M.A. Casteel, Communicating increased risk: an empirical investigation of the National Weather Service's impact-based warnings, Weather, Clim. Soc. 8 (3) (2016) 219–232, https://doi.org/10.1175/WCAS-D-15-0044.1.
[10] M.A. Casteel, An empirical assessment of impact based tornado warnings on shelter in place decisions, Int. J. Disaster Risk Reduc. 30 (February) (2018) 25–33, https://doi.org/10.1016/j.ijdrr.2018.01.036.
[11] E.R. Meléndez-Landaverde, M. Werner, J. Verkade, Exploring protective decision-making in the context of impact-based flood warnings, J. Flood Risk Manag. 13 (1) (2020), https://doi.org/10.1111/jfr3.12587.
[12] R.E. Morss, C.L. Cuite, J.L. Demuth, W.K. Hallman, R.L. Shwom, Is storm surge scary? The influence of hazard, impact, and fear-based messages and individual differences on responses to hurricane risks in the USA, Int. J. Disaster Risk Reduc. 30 (September 2017) (2018) 44–58, https://doi.org/10.1016/j.ijdrr.2018.01.023.
[13] D. Mu, T.R. Kaplan, R. Dankers, Decision making with risk-based weather warnings, Int. J. Disaster Risk Reduc. 30 (March) (2018) 59–73, https://doi.org/10.1016/j.ijdrr.2018.03.030.
[14] S.H. Potter, P.V. Kreft, P. Milojev, C. Noble, B. Montz, A. Dhellemmes, R.J. Woods, S. Gauden-Ing, The influence of impact-based severe weather warnings on risk perceptions and intended protective actions, Int. J. Disaster Risk Reduc. 30 (March) (2018) 34–43, https://doi.org/10.1016/j.ijdrr.2018.03.031.
[15] A.L. Taylor, A. Kause, B. Summers, M. Harrowsmith, Preparing for Doris: exploring public responses to impact-based weather warnings in the United Kingdom, Weather, Clim. Soc. 11 (4) (2019) 713–729, https://doi.org/10.1175/WCAS-D-18-0132.1.
[16] P. Weyrich, A. Scolobig, D.N. Bresch, A. Patt, Effects of impact-based warnings and behavioral recommendations for extreme weather events, Weather, Clim. Soc. 10 (4) (2018) 781–796, https://doi.org/10.1175/WCAS-D-18-0038.1.
[17] Q. Zhang, L. Li, B. Ebert, B. Golding, D. Johnston, B. Mills, S. Panchuk, S. Potter, M. Riemer, J. Sun, A. Taylor, S. Jones, P. Ruti, J. Keller, Increasing the value of weather-related warnings, Sci. Bull. 64 (10) (2019) 647–649, https://doi.org/10.1016/j.scib.2019.04.003.
[18] B. Golding, M. Mittermaier, C. Ross, B. Ebert, S. Panchuk, A. Scolobig, D. Johnston, A Value Chain Approach to Optimising Early Warning Systems, 2019. https://www.undrr.org/publication/value-chain-approach-optimising-early-warning-systems.
[19] D. Randjelovic, K. Kuk, M. Randjelovic, One Integrated Approach in Determination of Impact of Weather Factors on the Public Health, in: Proceeding of the First American Academic Research Conference on Global Business, Economics, Finance and Social Sciences, 2016.
[20] D. Rogers, V. Tsirkunov, Costs and Benefits of Early Warning Systems. Global Assessment Report on Disaster Risk Reduction, 2010.
[21] B. Fischhoff, P. Slovic, S. Lichtenstein, S. Read, B. Combs, How safe is safe enough? A psychometric study of attitudes towards technological risks and benefits, Pol. Sci. 9 (2) (1978) 127–152, https://doi.org/10.1007/BF00143739.
[22] P. Slovic, Perception of risk, Science 236 (4799) (1987) 280–285, https://doi.org/10.1126/science.3563507.
[23] P. Slovic, The Feeling of Risk: New Perspectives on Risk Perception, Routledge, 2010, https://doi.org/10.4324/9781849776677.
[24] K.T. Fox-Glassman, E.U. Weber, What makes risk acceptable? Revisiting the 1978 psychological dimensions of perceptions of technological risks, J. Math. Psychol. 75 (2016) 157–169, https://doi.org/10.1016/j.jmp.2016.05.003.
[25] World Economic Forum, Why Asia-Pacific Is Especially Prone to Natural Disasters, 2018. https://www.weforum.org/agenda/2018/12/why-asia-pacific-is-especially-prone-to-natural-disasters/.
[26] I.O. Adelekan, A.P. Asiyanbi, Flood risk perception in flood-affected communities in Lagos, Nigeria, Nat. Hazards 80 (1) (2016) 445–469, https://doi.org/10.1007/s11069-015-1977-2.
[27] N.C. Bronfman, L.A. Cifuentes, Risk perception in a developing country: the case of Chile, Risk Anal. 23 (6) (2003) 1271–1285, https://doi.org/10.1111/j.0272-4332.2003.00400.x.
[28] W. Brun, Cognitive components in risk perception: natural versus manmade risks, J. Behav. Decis. Making 5 (2) (1992) 117–132, https://doi.org/10.1002/bdm.3960050204.
[29] L. Henrich, J. McClure, E.E.H. Doyle, Perceptions of risk characteristics of earthquakes compared to other hazards and their impact on risk tolerance, Disasters 42 (4) (2018) 761–781, https://doi.org/10.1111/disa.12284.
[30] M.C. Ho, D. Shaw, S. Lin, Y.C. Chiu, How do disaster characteristics influence risk perception? Risk Anal. 28 (3) (2008) 635–643, https://doi.org/10.1111/j.1539-6924.2008.01040.x.
[31] T. Kunz-Plapp, U. Werner, RISK21 - coping with risks due to natural hazards in the 21st century, in: W.J. Ammann, S. Dannenmann, L. Vulliet (Eds.), RISK 21 – Coping with Risks Due to Natural Hazards in the 21st Century, Taylor & Francis, 2006, pp. 101–108, https://doi.org/10.1201/9780203963562.
[32] J.C.L. Lai, J. Tao, Perception of environmental hazards in Hong Kong Chinese, Risk Anal. 23 (4) (2003) 669–684, https://doi.org/10.1111/1539-6924.00346.
[33] R.A. Neal, P. Boyle, N. Grahame, K. Mylne, M. Sharpe, Ensemble based first guess support towards a risk-based severe weather warning service, Meteorol. Appl. 21 (3) (2014) 563–577, https://doi.org/10.1002/met.1377.
[34] L.J. Axelrod, T. McDaniels, P. Slovic, Perceptions of ecological risk from natural hazards, J. Risk Res. 2 (1) (1999) 31–53, https://doi.org/10.1080/136698799376970.
[35] T. McDaniels, L.J. Axelrod, P. Slovic, Characterizing perception of ecological risk, Risk Anal. 15 (5) (1995) 575–588, https://doi.org/10.1111/j.1539-6924.1995.tb00754.x.
[36] T. McDaniels, L.J. Axelrod, N.S. Cavanagh, P. Slovic, Perception of ecological risk to water environments, Risk Anal. 17 (3) (1997) 341–352, https://doi.org/10.1111/j.1539-6924.1997.tb00872.x.
[37] J.K. Lazo, J.C. Kinnell, A. Fisher, Expert and layperson perceptions of ecosystem risk, Risk Anal. 20 (2) (2000) 179–194, https://doi.org/10.1111/0272-4332.202019.

[38] L.M. Cunha, A.P. de Moura, Z. Lopes, M. do Céu Santos, I. Silva, Public perceptions of food-related hazards: an application to Portuguese consumers, Br. Food J. 112 (5) (2010) 522–543, https://doi.org/10.1108/00070701011043772.
[39] P. Sparks, R. Shepherd, Public perceptions of the potential hazards associated with food production and food consumption: an empirical study, Risk Anal. 14 (5) (1994) 799–806, https://doi.org/10.1111/j.1539-6924.1994.tb00291.x.
[40] G. Fernandez, A.M. Tun, K. Okazaki, S.H. Zaw, K. Kyaw, Factors influencing fire, earthquake, and cyclone risk perception in Yangon, Myanmar, Int. J. Disaster Risk Reduc. 28 (2018) 140–149, https://doi.org/10.1016/j.ijdrr.2018.02.028.
[41] O. Gunawan, J. Mooney, T. Aldridge, Natural Hazards Partnership Hazard Impact Framework, first ed., 2017. http://www.naturalhazardspartnership.org.uk/wp-content/uploads/Hazard_Impact_Framework_1st_ed.pdf.
[42] R. Hemingway, O. Gunawan, R. Dankers, S. Cole, Perception of Hazards and Impacts Activity Write-Up, 2016.
[43] C. Bassarak, H.R. Pfister, G. Böhm, Dispute and morality in the perception of societal risks: extending the psychometric model, J. Risk Res. 20 (3) (2017) 299–325, https://doi.org/10.1080/13669877.2015.1043571.
[44] G.T. Gardner, L.C. Gould, Public perceptions of the risks and benefits of technology, Risk Anal. 9 (2) (1989) 225–242, https://doi.org/10.1111/j.1539-6924.1989.tb01243.x.
[45] S.C. Jenkins, A.J.L. Harris, M. Osman, What drives risk perceptions? Revisiting public perceptions of food hazards associated with production and consumption, J. Risk Res. (2021) 1–15, https://doi.org/10.1080/13669877.2020.1871057.
[46] M. Siegrist, C. Keller, H.A.L. Kiers, Lay people's perception of food hazards: comparing aggregated data and individual data, Appetite 47 (3) (2006) 324–332, https://doi.org/10.1016/j.appet.2006.05.012.
[47] C. Fife-Schaw, G. Rowe, Research note extending the application of the psychometric approach for assessing public perceptions of food risk: some methodological considerations, J. Risk Res. 3 (2) (2000) 167–179, https://doi.org/10.1080/136698700376653.
[48] N.C. Bronfman, L.A. Cifuentes, M.L. Dekay, H.H. Willis, Accounting for variation in the explanatory power of the psychometric paradigm: the effects of aggregation and focus, J. Risk Res. 10 (4) (2007) 527–554, https://doi.org/10.1080/13669870701315872.
[49] A.P. Field, Discovering Statistics Using SPSS: and Sex and Drugs and Rock "N" Roll, fourth ed., Sage, 2013.
[50] R.F. DeVellis, Scale Development: Theory and Applications, third ed., Sage, 2012.
[51] H.F. Kaiser, The application of electronic computers to factor analysis, Educ. Psychol. Meas. 20 (1) (1960) 141–151, https://doi.org/10.1177/001316446002000116.
[52] R.B. Cattell, The scree test for the number of factors, Multivariate Behav. Res. 1 (2) (1966) 245–276, https://doi.org/10.1207/s15327906mbr0102_10.
[53] D. George, P. Mallery, IBM SPSS Statistics 26 Step by Step, Routledge, 2019, https://doi.org/10.4324/9780429056765.
[54] C.R. Wilson Van Voorhis, B.L. Morgan, Understanding power and rules of thumb for determining sample sizes, Tutor. Quant. Method Psychol. 3 (2) (2007) 43–50, https://doi.org/10.20982/tqmp.03.2.p043.
[55] C. Leuker, T. Pachur, R. Hertwig, T.J. Pleskac, Exploiting risk–reward structures in decision making under uncertainty, Cognition 175 (2018) 186–200, https://doi.org/10.1016/j.cognition.2018.02.019.
[56] A.J.L. Harris, A. Corner, U. Hahn, Estimating the probability of negative events, Cognition 110 (1) (2009) 51–64, https://doi.org/10.1016/j.cognition.2008.10.006.
[57] A.J.L. Harris, A. Corner, Communicating environmental risks: clarifying the severity effect in interpretations of verbal probability expressions, J. Exp. Psychol. Learn. Mem. Cogn. 37 (6) (2011) 1571–1578, https://doi.org/10.1037/a0024195.
[58] G. Villejoubert, L. Almond, L. Alison, Interpreting claims in offender profiles: the role of probability phrases, base-rates and perceived dangerousness, Appl. Cognit. Psychol. 23 (1) (2009) 36–54, https://doi.org/10.1002/acp.1438.
[59] E.U. Weber, D.J. Hilton, Contextual effects in the interpretations of probability words: perceived base rate and severity of events, J. Exp. Psychol. Hum. Percept. Perform. 16 (4) (1990) 781–789, https://doi.org/10.1037/0096-1523.16.4.781.
[60] T. Geiger, K. Frieler, D.N. Bresch, A global historical data set of tropical cyclone exposure (TCE-DAT), Earth Syst. Sci. Data 10 (2018) 185–194, https://doi.org/10.5194/essd-10-185-2018.
[61] M. Siegrist, C. Keller, H.A.L. Kiers, A new look at the psychometric paradigm of perception of hazards, Risk Anal. 25 (1) (2005) 211–222, https://doi.org/10.1111/j.0272-4332.2005.00580.x.
[62] M. Siegrist, J. Árvai, Risk perception: reflections on 40 years of research, Risk Anal. 40 (2020) 2191–2206, https://doi.org/10.1111/risa.13599.
[63] G. Aznar-Siguan, D.N. Bresch, CLIMADA v1: a global weather and climate risk assessment platform, Geosci. Model Dev. (GMD) 12 (7) (2019) 3085–3097, https://doi.org/10.5194/GMD-12-3085-2019.
[64] R. Hemingway, J. Robbins, Developing a hazard-impact model to support impact-based forecasts and warnings: the Vehicle OverTurning (VOT) Model, Meteorol. Appl. 27 (1) (2020) 1–17, https://doi.org/10.1002/met.1819.
[65] T. Röösli, C. Appenzeller, D.N. Bresch, Towards operational impact forecasting of building damage from winter windstorms in Switzerland, Meteorol. Appl. 28 (6) (2021), https://doi.org/10.1002/met.2035.