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Identifying critical factors to enhance SDI performance for facilitating disaster risk management in small island developing states

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Small Island Developing States (SIDS) are highly exposed to disaster risk events that frequently overwhelm their capacity to generate and share spatial information to reduce human–economic losses. The Spatial Data Infrastructure (SDI) has been widely implemented to support information sharing and management in different domains. In this paper, we aim to identify critical factors to enhance SDI performance to facilitate Disaster Risk Management (DRM) in SIDS. We make use of a three-round Delphi survey and Kendall W coefficient to assess consensus among 28 key international experts in SDI, surveying and DRM. Our results illustrate strong experts' consensus on identifying a list of 23 most critical factors. We found that people and policy factors matter the most. The insights reported here would assist decision-makers to design roadmaps to enhance sharing of spatial knowledge to build more resilient SIDS and to support their achievement of the Sustainable Development Goals.

Keywords: Small Island Developing States, Disaster Risk Management, Spatial Data Infrastructure, Critical Factors, Kendall W, e-Delphi

1. Introduction

The Small Island Developing States (SIDS) is one of the most disaster risk-prone zones in the World. The SIDS continuously face natural and human-made disaster risk challenges that impede their progress towards sustainable development (UNISDR 2015a). The effects of such disasters (like extreme hurricanes, floods, earthquakes, forest fires, and droughts), trigger annual losses up to 20% of their total social expenditure (UNISDR 2015b).

In this context, natural disasters and climate variability severely impact major economic sector in SDIS, hinder economic growth and affect the most vulnerable populations (UNESCO, 2020; United Nations, 2014). For instance, SIDS have suffered more losses from natural hazards (17% of GDP) compared to high-income countries (3% of GDP) (OECD, 2016). In this way, the United Nations has elevated DRM to high priority status for SIDS (Shultz et al., 2016; UNESCO, 2020).

During disasters, the Spatial Data Infrastructures (SDI) have been widely recognised as a great asset to effectively integrate, process and share, dynamic information coming from different stakeholders to support disaster risk management (DRM) (Conti et al., 2018; Scholten et al., 2008). For instance, the United Nations Strategic Framework on Geospatial Information and Services for Disasters (UN-GGIM, 2018) emphasises the key role of the SDI implementation to facilitate the availability and accessibility of quality geospatial information and services across all phases of DRM lifecycle.

Despite the SDI advancement around the world, previous research stated that many nations still face major difficulties when establishing and implementing National SDI, including a lack of standardised fundamental data, inefficient bureaucratic processes and national security and privacy concerns (UN-GGIM 2020; Jabbour et al. 2019). While the strategy and the geospatial capabilities for implementing an SDI may be different for each country, the SIDS might face some common challenges for the SID implementation, owing to their social, economic and environmental similarities (UN-OHRLLS, 2015). These challenges, such as limited allocation of funding and staffing, poor infrastructure, communication and servicing, and fragile political environments, along with other organisational factors, might prevent countries from taking full advantage of SDI performance for DRM. In this study, we address the following research question to guide our work: What factors are critical to enhance the SDI performance to facilitate DRM in the SIDS? The new knowledge and insight on important and feasible factors for improving SDI performance

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offer valuable information for turning an SDI into a sound operational tool to support DRM.

Our study aims to identify critical factors to enhance SDI performance to facilitate DRM in SIDS. Herein, we conducted a three-round Delphi survey (Cole et al. 2013). Expert panelists with significant experience in research and development projects in the field of SDI and DRM participated in the whole survey. The panelists were given the chance to provide their own perspective about what factors should be included or withdrawn from the study.

To the best of our knowledge, there are no previous works in the literature regarding the identification of critical factors for enhancing SDI performance to reach a specific goal, in this case for DRM tasks in SIDS. Empirical research to date has been primarily focused on SDI issues in developed countries. Therefore, there is a paucity of systematic research that analyses specific SDI implementation challenges in developing countries, in particular in SIDS settings.

Our findings could lead to a greater understanding towards good governance of spatial data infrastructure (SDI) to attend stakeholders' needs of DRM in SIDS. This knowledge will have practical value for future SDI development in the SIDS. These insights can assist decision-makers to enable spatial information sharing to build more resilient SIDS and to support the achievement and monitoring of the Sustainable Development Goals.

The paper is structured in the following way. First, Section 2 presents a literature review, including key concepts on SDI, DRM and SIDS. In Section 3, the research method undertaken in this research is explained. Section 4 presents our results on the identification of critical factors for enhancing SDI performance in the SIDS context. In Section 5, we discuss our findings. Finally, Section 6 closes the paper by presenting our main conclusions.

2. Literature review

This section briefly introduces the key concepts of SDI, DRM and SIDS.

2.1. Spatial data infrastructure (SDI)

The SDI has already existed in many countries and in different contexts to deal with geographic information, knowledge and services in distributed environments. The SDI is about the facilitation and coordination of the exchange and sharing of geospatial data among multiple stakeholders (Crompvoets et al., 2004; Sjoukema et al., 2021).

The conception and implementation of the SDI have played a key role in improving the availability of geospatial data and services to support all DRM lifecycle phases (Yamashkin et al. 2019; Boccardo 2013; Delgado Fernández and Crompvoets 2008). However, previous research stated that systematic access to official and authoritative reference datasets through SDI cannot yet be considered an operational step for emergency mapping production workflow (Ajmar et al., 2015). This access constraint to geospatial data has a special emphasis in areas with a lack of financial resources and which have infrastructure limitations (Boccardo, 2013).

The literature suggested that research focus on SDI has been oriented on engineering challenges, evaluation of performance or operational status of the SDI implementation (Giff & Crompvoets, 2008; Gómez et al., 2019; Mulder et al., 2020; Nedović-Budić et al., 2011). Sjoukema et al. (2021, 2020) put their attention to the SDI governing system and the key processes that enable or constrain SDI governance. Other authors emphasise the necessity of more research efforts on the interaction between social and technical issues of the SDI development (Georgiadou and Stoter 2010; Grus et al. 2011; Crompvoets et al. 2008a). In the context of DRM in SIDS, Gómez, García, and Santiago (2020) work on the assessment of SDI development and its ability to strengthen the resilience of the Caribbean States.

2.2. Disaster risk management (DRM)

The term DRM refers to the legal, institutional and policy frameworks and administrative mechanisms and procedures related to the management of both risk (ex ante) and disasters (ex post) (Baas et al., 2008). This is a systematic process of using administrative decisions, organisation, operational skills and capacities aiming to lessen the impacts of natural hazards and related environmental and technological disasters (UNISDR, 2004, 2015b).

The DRM consists of a full lifecycle of actions, categorised into the following phases: (1) mitigation, comprises all actions designed to reduce the impact of future disasters; (2) preparedness, actions taken to reduce the impact of disasters when they are forecast or imminent; (3) response, emergency actions taken during both the impact of a disaster and the short term aftermath; and (4) recovery and reconstruction, process of repairing damage, restoring services and reconstructing facilities after a disaster has struck (Goldblatt et al. 2020; UNISDR 2015b; Alexander 2002). Each of these phases might bring different challenges in terms of services, data or cooperation between organisations, depending on the type of natural hazard event (Dusse et al., 2016).

At the international level, the Sendai Framework stated that effective disaster risk management contributes to sustainable development (UNISDR, 2015b). In this context, the SIDS constitutes a special case, owing to their unique and particular vulnerabilities to disasters. Some of these disastrous phenomena have increased in intensity and have been exacerbated by climate change, which impedes their progress towards sustainable development. Therefore, there is a need for sustainable and timely provision of support, including through finance, technology transfer and capacity – building from developed countries and partners tailored to their needs and priorities, as identified by them.

2.3. Small Island Developing States (SIDS)

The SIDS is defined as maritime countries that tend to share similar sustainable development challenges, including small but growing populations, limited resources, remoteness, susceptibility to natural disasters, vulnerability to external shocks, excessive dependence on international trade, and fragile environments (Boto & Biasca, 2012).

Fifty three countries and territories represent the SIDS, 39 United Nations (UN) members and 14 are non-UN Members or Associate Members of the

Regional Commissions (UN-OHRLLS, 2021). More than 50 million people live in these countries, spatially distributed across the Indian, Pacific and Atlantic Oceans with the highest concentration of SIDS in the Caribbean and southwest Pacific (Rao & McNaughton, 2019; UN-OHRLLS, 2021).

In term of the SIDS economy, OECD, (2021) states that SIDS economy is characterised by a low diversified economy, high dependent on tourism, fluctuations in the prices of the raw materials, high dependence on remittances, debt stress situations, and, volatility of private income flows. Moreover, the high concentration of population along the coastal zones, intense competition between land use options and limited resources and economic development exacerbates their inherent vulnerability (Jigyasu, 2017; UNESCO, 2020). These issues, along with the climate change and rising ocean levels, act synergistically to create disproportionate risks to natural disasters for SIDS (Shultz et al., 2016).

There is international recognition of the continuing challenge of the SIDS to fight against the effects of disasters, some of which have increased in intensity and some of which have been exacerbated by climate change, which impede their progress towards sustainable development (UNISDR, 2015a).

3. Materials and methods

For this research on identifying critical factors to enhance SDI performance to facilitate DRM in SIDS, an internet-based Delphi methodology was used. The practical reason for this alternative approach is the assumption that the advancement of Internet technologies helps to overcome inherent temporal, cost and geographical limitations for expert consultations at the international setting.

The e-Delphi survey enables an iterative consultation with multiple experts and stakeholders from different domains and organisations, spatially distributed around a region or country (Cole et al., 2013; Donohoe & Needham, 2009). Therefore, the e-Delphi survey appears to be the most suitable method for collecting and distilling knowledge by means of several rounds of global experts' consultations in the context of mobility restrictions owing to the Covid19 pandemic.

Ranging from issues of performance indicators of information technology (IT) (Nakatsu & Iacovou, 2009; Shaw et al., 2012) to identification of factors that influence IT project management capabilities (Lee & Anderson, 2006), the Delphi method has been widely used in the context of IT infrastructure governance domain.

Figure 1 summarises the methodology followed to identify critical factors to enhance SDI performance. It comprises of the following three stages: (1) preparation; (2) rounds of consultations; and, (3) convergences and consensus.

3.1. Preparation

The preparation stage of this research comprises three steps: literature review, questionnaire design and the expert panel development:

3.1.1. *Literature review*

At first, an in-depth literature review was conducted. The focus of this literature review was on finding an initial list of factors to enhance SDI performance to facilitate DRM in SIDSS. The definition of this initial list was based on comprehensive research of performance indicators and assessment approaches for SDI implementation realised by Crompvoets et al. (2008b) and the future trends in geospatial information management proposed by UN-GGIM (2020). Based on the findings of the literature review, an initial list of 106 factors was proposed. This list was divided into five categories, according to the SDI components: policy, data, technology, people and standards (Gómez et al. 2019; Crompvoets et al. 2018; Nebert 2004).

3.1.2. *Questionnaire design*

Two questionnaires were designed in this Delphi survey. Questionnaire 1 (Q1) was designed to collect participants' background and to validate and enrich the initial list of factors. Based on the outcomes of Q1, questionnaire 2 (Q2) was then designed to rank the validated list of factors in terms of their level of importance and

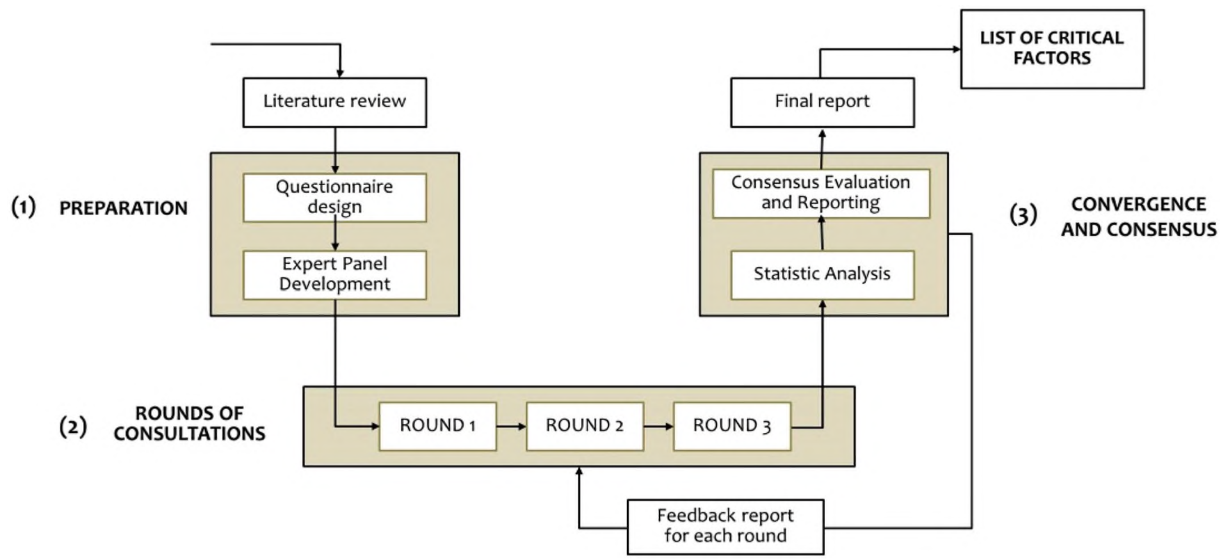

Figure 1 The stages of followed e-Delphi survey

the feasibility of implementation, using a five-point Liker scale.

3.1.3. *Expert panel development*

Given the importance of selecting the experts' panel, the panelists were carefully recruited to balance the expertise and experiences from different sectors, including governments, private companies, academia and consulting firms. To execute our study, an initial set of 78 senior researchers and practitioners with significant experience in research and development projects in the field of SDI, surveying and DRM in the context of SIDS, both national and international, were identified. These potential expert panelists were invited by e-mail to participate in this survey. From this group, 33 experts responded and agreed to participate in the full Delphi research survey; hence a response rate of 42% per cent was achieved. According to the literature, this number of expert panelists and responses rate are widely acceptable for a Delphi Survey (Miles et al., 2016; De Haes & Van Grembergen, 2008).

3.2. Rounds of consultation

In this study, the input from the experts was collected using three consecutive rounds of consultation. This number of rounds has been successfully implemented for reaching consensus among experts in information system-related research (Shaw et al. 2012; Lee & Anderson 2006; Brancheau and Wetherbe 1987). In each round, the experts needed to fill in an online questionnaire, which completion was expected to take no more than 20 min. After each round, experts received a feedback report with the summary of the results, as reference information for the next round.

In Round 1, questionnaire (Q1) was used to request experts to validate and provide feedback about the predefined list of factors, which was derived from a literature review. At first, a closed-end question asked experts whether they agree or not to add or remove any item from the list. Then, an open-end question requested experts to freely comment on each factor, if necessary. Based on the experts' responses in Round 1, the list of factors was enriched so that these factors could be meaningfully ranked in terms of their level of importance and feasibility for implementing. No other factor was added or removed after this stage. Thirty-three experts completed this Round 1 survey, from 24 August to 16 September 2020.

In Round 2, questionnaire (Q2) was used to request experts to rank, using a 5 point Likert scale, their perceived level of importance (0 = not important, 5 = highly important) and feasibility for implementing (0 = not feasible, 5 = highly feasible), of each factor in the validated list (Maeda, 2015). At this point, an individual feedback report was sent to each expert to present their rating in Round 2. The report also showed the median (middle) values of responses from the expert panelists on their perception for each factor. Thirty-two experts completed this Round 2, from 16 September to 14October, 2020.

In Round 3, questionnaire (Q3) was used to request that the experts revise their judgments on the list of factors, and the input of their peers, and which was shared in the report of Round 2. Herein, panelists were also asked to re-evaluate their rating of the perceived level of importance and feasibility for implementing each factor. This final round was completed by 28 experts, from 14 October to 17 November 2020.

3.3. Convergence and consensus

At this final stage, two statistical measures were used combinatory to assess consensus among expert panelists. While there are a number of different metrics for measuring consensus in Delphi survey, this study adjusted the suggestion of Giannarou and Zervas (2014), with the simultaneous application of the following two measures to assess overall experts' agreement with accuracy and reliability:

- The 51% of frequency distribution responding to the category 'highly important', this is between values 4 and 5 on a 5 point Likert scale (Hsu & Sandford, 2007).
- Kendall's coefficient of concordance (Gearhart et al 2013; Okoli and Pawlowski 2004; Brancheau and Wetherbe 1987).

Consensus analyses were run independently for each of the 69 factors, in terms of experts' judgments on their perceived level of importance and feasibility for implementing. These calculations were completed using the SPSS software. The outcome of this stage was a final report, which included a list of critical factors to enhance SDI performance for DRM in SIDS context.

4. Results

In this section, the most important results of a three-round Delphi survey are presented and discussed. At first, the participants' profile is briefly introduced, followed by the main outcomes from each of the three rounds of consultation. This section ends summarising the identified critical factors from the policy, data, technology, people and standards perspective. In round one, 33 expert panelists completed the survey resulting in a response rate of 42%. These panelists mostly remained committed through round two and round three where better response rates were achieved; 97% and 88%, respectively (Table 1).

4.1. Survey population

A total of 28 expert panelists anonymously completed the whole three-round Delphi survey. These experts were geographically distributed in 20 different countries (Argentina, Belgium, Czech Republic, Denmark, Dominican Republic, Ecuador, England, France, Ghana, Italy, Mexico, Netherland, Pakistan, Serbia, Singapore, South Africa, Spain, Switzerland, Trinidad and Tobago, and USA). A profile of these survey participants by type of organisation and domain of expertise is provided in Figure 2. Herein, a large number of the participants came from the university (54%), followed by

Table 1 Experts panel's response rates per round of consultation

	ROUND 1	ROUND 2	ROUND 3
Survey delivered	78	33	32
Total completed survey	33	32	28
Response rate	42%	97%	88%

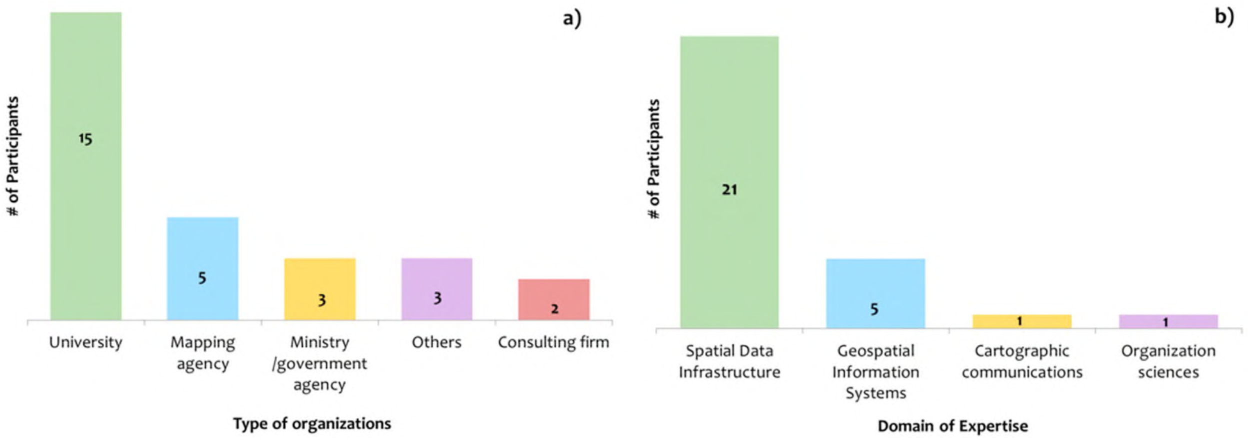

Figure 2 Distribution of participants by (a) type of organisation and (b) domain of expertise

mapping agencies (18%) (Figure 2(a)). The vast majority of the participants had the SDI (75%) as their main domain of expertise (Figure 2(b)). This was expected, as it was a chief criterion for recruiting the survey participants.

In terms of professional background, most participants defined themselves as senior professionals in geo-information management and other related geospatial domains (Figure 3(a)). Up to 36% of the participants had professional experience for more than 20 years, closely followed by 11–15 years (29%) (Figure 3(b)).

The aforementioned participants' attributes indicate that the panelists were well-qualified, in terms of their experience and knowledgeability for the reliability and validity of the results.

4.2. Round 1: defining and validating a list of factors

This study begins with a defined initial list of 106 factors, derived from a literature review. Based on 33 experts' responses in Round 1, redundancy and ambiguity were removed from the list, considering that these factors should be SMART, which stands for Specific, Measurable, Attainable, Relevant and Trackable (UNDP, 2003). In this sense, a total of 51 factors were withdrawn from the list. Moreover, experts suggested adding 14 new factors to the list. Therefore, the validated list comprised of 69 factors (Table 2). Table A1 in Appendix A presents the completed list of validated factors from Round 1.

4.3. Round 2: ranking critical factors

The aim of this round is to build consensus around the identification of critical factors within expert panelists, taking the attribute of importance and feasibility for implementing each factor into account. The primary method for assessing consensus for each of the 69 validated factors was by the following combinatory conditions: the percentage of experts ranking a factor as highly important and highly feasible, being over 51%.

After data processing, the results indicate that none of the factors achieved perfect consensus. Only 18 factors have reached the established consensus conditions, which means they have high level of importance, jointly with a high level of feasibility for implementing. Table 3 summarises the distribution of the results in Round 2.

In general terms, the results in Round 2 demonstrated that some factors are more important or feasible for implementing compared to others. Figure 4 shows Round 2 results on two axes. The horizontal axe plots the 'perceived level of importance', while the vertical axe presents the 'perceived level of feasibility' for each factor. The identified 18 critical factors appeared inside a red rectangle.

A vast majority of panelists (97%) ranked two factors related to institutional and people issues being as the

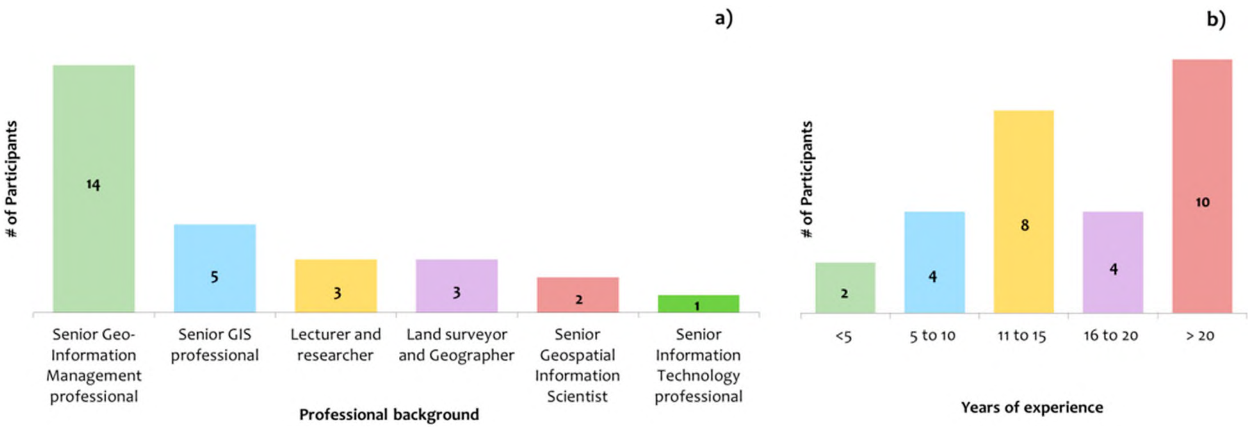

Figure 3 Distribution of participants by (a) professional background and (b) years of experience

Table 2 Number of validated factors per category

Category	Literature review Initial	Experts' consultation (Round 1) Withdraw	Experts' consultation (Round 1) Added	Validated Factors
Policy	23	11	4	16
Data	18	11	3	10
Technology	27	17	2	12
People	28	10	5	23
Standards	10	2	0	8
Total	**106**	**51**	**14**	**69**

Table 3 Number of identified critical factors per category

Category	Critical factors Round 2
Policy	6
Data	2
Technology	3
People	3
Standards	4
Total	**18**

most important for enhancing SDI performance, namely: 'establishment of an institutional framework for sharing geo-information between public institutions responsible of DRM tasks (P4)', and 'effective communication among SDI and DRM stakeholders (H3)'.

Interestingly, some factors were perceived as highly important but with a low feasibility for implementation. For instance, the 'support from political level and geo-community (H15)' was ranked as being highly important (91%), with a low level of feasibility (31%). This fact might be explained owing to the political realities in developing countries, mainly related to the lack of socio-political stability to support and maintain the SDI development (UN-GGIM 2020; Guigoz et al. 2017).

In order to assess global agreement among the 32 expert panelists in Round 2, the level of consensus was tested using Kendall's W coefficient of concordance. Herein, the reached level of consensus was $W = 0.865$, indicating strong agreement and statistically significant ($x2 = 249$, $p < .001$).

4.4. Round 3: re-valuating critical factors

In this Round, 32 panelists were requested to revise their judgment from Round 2. They were asked to rank the whole 69 factors one last time, considering their previous rating on each factor and middle values of responses from the expert panelists. Usable responses were received from 28 panelists (88% response rate).

After data processing, the results reveal that while most identified factors (Round 2) remain critical, there were important changes on the final list in Round 3, especially on the policy and people categories. In general, eight new factors were added to the list. Moreover, three factors were withdrawn from the list. Interestingly, the results identified only 23 critical factors being ranked over 51% of panelists as the most highly important and highly feasible for implementing to enhance SDI performance for DRM in the context of SIDS.

Table 4 presents a comparison between the list of identified critical factors in Round 2 and Round 3. In this table, we highlighted in light grey colour each factor

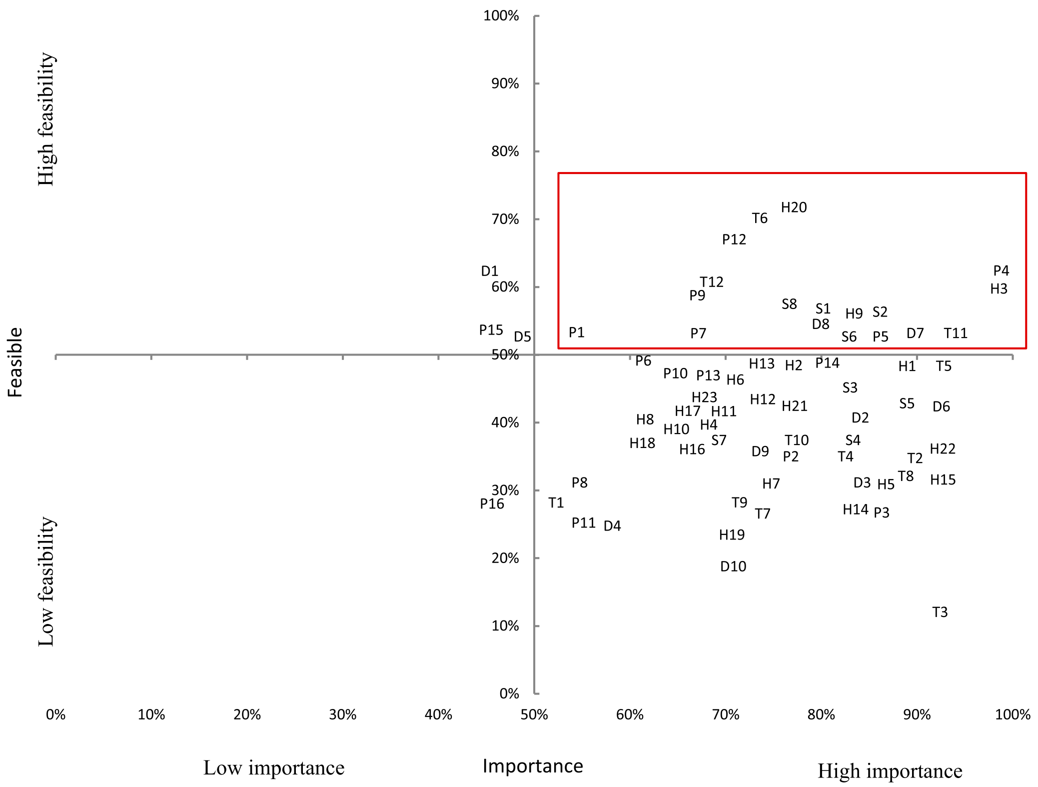

Figure 4 Perceived level of importance and feasibility for each factor (Round 2)

Table 4 Comparison of identified factors in Round 2 and Round 3

Factors		Round 2		Round 3	
		Highly Important	Highly Feasible	Highly Important	Highly Feasible
POLICY	P1- E-government policy existence	53%	53%	68%	46%
	P4- Establishment of an institutional framework for sharing geo-information between public institutions responsible of disaster risk management tasks	97%	63%	89%	54%
	P-5 Establishment of effective cooperation with regional emergency response organisations	84%	53%	86%	71%
	P7- Establishment of SDI legislation	66%	53%	68%	39%
	P9- Multi-stakeholder partnerships to develop capacity building programs on spatial data infrastructure for disaster risk management	66%	59%	68%	61%
	P12- The existence of a legislation on access to public sector information	69%	69%	75%	54%
	P13- The existence of a strong organisation(s) taking the leadership in the development of the SDI	66%	47%	82%	57%
DATA	D2- Availability of definitive versions of data sets, features, attributes, etc.	81%	41%	79%	54%
	D7- Standardised data content available through the SDI	88%	53%	71%	57%
	D8- The effective use of freely available spatial data platforms as data source of the national SDI	78%	56%	68%	54%
TECHNOLOGY	T5- Effective utilisation of access mechanism (availability, search, procedures)	91%	50%	82%	54%
	T6- Facility to use of maps for searching	72%	72%	79%	82%
	T11- The establishment of a digital platform to enable data sharing among emergency services through the SDI	91%	53%	89%	64%
	T12- The establishment of an open data Geoportal	66%	59%	71%	61%
PEOPLE	H1- Capacity building programs on mapping techniques to get more users' involvement in data collection and dissemination at the local level	88%	50%	100%	64%
	H3- Effective communication among SDI and disaster risk management stakeholders	97%	59%	93%	64%
	H9- Opportunities for trainings in spatial data infrastructure targeted to emergency services	81%	56%	86%	68%
	H11- Public outreach activities to build a culture of trust and collaboration for information sharing at the community level	66%	44%	75%	68%
	H13- SDI awareness	72%	50%	68%	57%
	H20- The national language is the operational language of the national SDI	75%	72%	75%	75%
	H21- User involvement	75%	44%	93%	54%
	H23- Workshops, collaborative resources and outreach to promote and develop common technical standards	66%	44%	75%	57%
STANDARDS	S1- Application of standards for open data file formats	78%	56%	89%	57%
	S2- Development of technical protocols to facilitate multi-stakeholders' collaboration	84%	56%	82%	50%
	S6- Technical documentation on data standards for integration	81%	53%	82%	61%
	S8- Type and use of metadata standard (ISO, CEN, FGDC)	75%	59%	75%	61%

that considerably increased its perceived level of importance or feasibility from Round 2 to Round 3; hence they satisfy the consensus conditions to be included in the final list of critical factors. The factors in dark grey colour are those that have been removed from the final list, owing to the considerable decrease in their perceived level of feasibility in the context of the SIDS.

Figure 5 presents Round 3 survey results on two axes. The horizontal axe plots the 'perceived level of importance', while the vertical axe presents the 'perceived level of feasibility' for each factor. The identified 23 critical factors appeared inside a red rectangle. Table A2 in Appendix A presents the final list of 23 critical factors.

The results in Round 3 indicate that expert panelists shifted their perceived level of importance and feasibility towards the policy and people factors. It is noteworthy that the capacity building program at the local level (H1) was ranked with the highest level of importance (100%) among all factors. Most panelists thought that people factors, namely, capacity building programs and user involvement (H21), were the most critical. One panelist remarked: 'People factors are the only ones that really matter'. Another panelist also thought that 'involve potential users is one of the easiest things and most important things to do'. Inadequate users' involvement prevents the effectiveness of apparent perfect systems.

At the final stage of this research survey, it was evaluated whether expert panelists have come to a greater level of agreement. The Kendall's W coefficient of concordance was calculated for Round 3. The reached level of

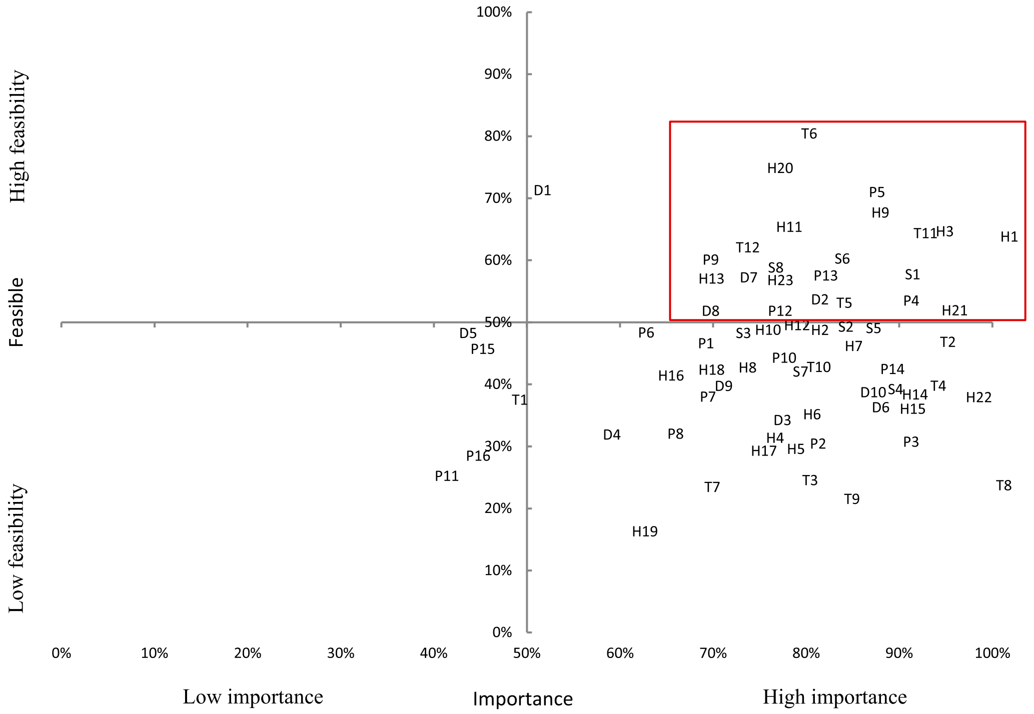

Figure 5 Perceived level of importance and feasibility for each factor (Round 3)

consensus was W = 0.901 and statistically significant (x2 = 226.966, $p < .000$). The value of W ranges from 0 to 1, with 0 indicating no consensus, and 1 indicating perfect consensus between panelists (Giannarou & Zervas, 2014; Nakatsu & Iacovou, 2009).

These results clearly indicate that there is a strong agreement among panelists, thereby providing us a fair degree of confidence in the results. These results show that conducting additional rounds was not necessary, because the high level of consensus already achieved (W = 0.901) reached near perfect agreement among panelists. Therefore, this Delphi survey was ended.

5. Discussion

In this section, we present our discussion on the identified critical factors, divided into five categories: policy, data, technology, people and standards. These insights were built upon our results from a three-round Delphi survey. The panelists' perception on the importance and feasibility of implementing each critical factor was similar throughout the research survey, but not identical. This is because at the final round, panelists chose to focus more of their attention on policy and people factors to fit the needs of DRM tasks in context of the SIDS.

5.1. Policy factors

In overall, our findings demonstrate that an established institutional framework, effective cooperation among multi-stakeholders, legislation on public information access and organisational leadership are the most critical policy factors to enhancing SDI performance for DRM tasks. Nonetheless, these factors cannot necessarily be applied at once to all SIDS, owing to the differences in the national legal systems and varying levels of maturity of SDI development (UN-GGIM, 2020). In case of most non-SIDS, however, other authors highlighted the importance of the legislation to obligate national mapping agencies to make SDI data freely available for reuse in open, machine-readable formats, without restrictions such as compulsory registration or copyright (Mulder et al., 2020). In terms of feasibility for enacting SDI legislation, three panelists agreed that this is a difficult and time-consuming process, which heavily depends on politicians' will.

5.2. Data factors

In terms of data, most panelists thought that the availability of standardised data through an SDI is a highly important and highly feasible factor. Our findings also confirm previous claims that the absence of application of standards and metadata for geospatial data hinder the construction of SDI in SIDS context (Gómez et al., 2020). Herein, one panelist remarked 'the definition of product/data specifications for datasets, metadata and services can enable interoperability and openness to multiple stakeholders'. In specific, the definition of information workflow, tools and quality thresholds, would enhance the effective data generation and sharing in response to the dynamic nature of the DRM lifecycle (Rosario et al. 2020).

5.3. Technology factors

The technology features have already been spotted as a key component of an SDI, both for developed and developing states (Sjoukema et al. 2020; Gómez et al. 2019; Eelderink, et al. 2008). In this study, the majority of expert panelists jointly agreed that the establishment of a digital platform to connect emergency services through the SDI and the facility to use of maps for searching are the most critical factors. However, in the specific context of DRM in SIDS, one panelist remarked that 'getting the right functioning devices to the right people at the right time might be a big challenge'.

5.4. People factors

In general, our results reveal that people factors are the ones that matter the most. While the human capabilities might significantly vary between different SIDS, this study found three critical people factors that suit the needs of DRM tasks: the development of capacity building programs, more effective communication among SDI and DRM stakeholders and user involvement. In this sense, Gómez et al., (2020) also state that educational level, SDI culture and individual leadership, should also be considered as key factors for SDI construction in SDIS context.

In our study, one panelist remarked that 'good people can make "bad" technical systems work and make things happen despite bureaucracy and lack of laws and regulation'. In term of users' involvement, one panelist stated that 'moving from users to participants perspective in dealing with disasters (or risks) would be a big step forward'. In addition, another panelist suggested that involving your potential users and analysing users' requirements are one of the easiest things and most important things to do.

5.5. Standards factors

The adoption of norms and standards from international organisations has been defined as a key component of an SDI (Sjoukema et al. 2020; Gómez et al. 2019; Coleman et al. 2016). In specific, this study identified the application of standards for open data file formats and the development of technical documentation on data standards as the most critical standards factors for enhancing spatial data integration and sharing through the SDI. Furthermore, one panelist stated that standards might be the major inhibiting factor to SDI implementation. Another panelist emphasised that the cost of standards testing, validation and implementations might be a major impediment in the SIDS context. In this sense, it is recommended to have champions who have implemented the standards to show their value to others, in this case, to the SIDS.

6. Conclusions

The objective of the current study was to identify critical factors for enhancing SDI performance that needs to be resolved to facilitate DRM in SIDS. In this context, our results were built upon a three-round Delphi consultation targeted to 28 international expert panelists. In this research, we found 23 critical factors, divided into five categories: policy, data, technology, people and standards. A vast majority of panelists considered that people and policy factors are the most important. We also found that our results showed a strong level of agreement among panelists, Kendall coefficient of concordance ($W = 0.901$) and statistically significant ($x2 = 226.966$, $p < .000$).

Our findings reflect that more capacity building programs are necessary to enable users' involvement in data collection and dissemination at the local level. They are critical to achieve the harmonisation and availability of spatial knowledge from local communities in a more cost-effective and trusted way. Furthermore, the establishment of a strong communication mechanism between SDI stakeholders and disaster risk managers are also critical. Accordingly, the implementation of a digital platform to enable data sharing among emergency services through the SDI is also recommended.

Our study also revealed that the establishment of policies for SDI implementation and development in the SIDS context is still in its initial stage. Therefore, there is a critical need for enabling institutional and legal frameworks, organisational leadership and multi-stakeholders' partnerships to guarantee the SDI sustainability and cooperation to anticipate and respond to DRM tasks.

We are aware that our applied research methodology encountered some limitations, namely related to the experts' panel composition. The expert panelists were mainly from the academic sector, with a small representation from government agencies, practitioners and decision-makers in SDIS. The ability to collect and analyse these local perspectives and to compare them with the results of our survey could have significantly improved the validity of our conclusions.

Despite limitations in the methodology, to the best of authors' knowledge, this work represents the most comprehensive survey on SDI for DRM in SIDS ever undertaken. The identified list of critical factors contributes practical insights to design a roadmap to harmonise and support national and regional SDI development. The insights reported here can assist decision-makers to enable timely and reliable sharing of spatial information to build more resilient SIDS and to support the achievement and monitoring of the Sustainable Development Goals.

Our future research agenda aims to work towards a multi-stakeholder's approach, including the perspective from relevant local experts and decision-makers involved in the DRM and SDI development in SIDS.

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Appendix A

Table A1 List of 69 validated factors (Round 1)

Policy factors (16)	**People factors (23)**
P1 E-government policy existence	H1 Capacity building programs on mapping techniques to get more users' involvement in data collection and dissemination at the local level
P2 Embedding SDI contributions in the mandates of public sector organisations	H2 Collaboration & self-organisation among the community
P3 Establishment of an effective funding model for the SDI development	H3 Effective communication among SDI and disaster risk management stakeholders
P4 Establishment of an institutional framework for sharing geo-information between public institutions responsible of disaster risk management tasks	H4 Improved education programs on spatial data infrastructure at the universities
P5 Establishment of effective cooperation with regional emergency response organisations	H5 Investment of resources to build capacity and to raise community awareness of spatial data and technologies
P6 Establishment of policies on open data (reuse)	H6 Involvement of professional organisations (NGOs, etc.) in the development of technical specifications to enable interoperable data exchange among emergency services
P7 Establishment of SDI legislation	H7 Open data source culture
P8 Existence of licensing harmonisation to integrate multiple data sources	H8 Open-source software culture and awareness
P9 Multi-stakeholder partnerships to develop capacity building programs on spatial data infrastructure for disaster risk management	H9 Opportunities for trainings in spatial data infrastructure targeted to emergency services
P10 The establishment of partnership arrangements with civil society and local authorities to allow effective sharing of disaster-related data from the field	H10 Organisational structure of the coordinating agency
P11 The establishment of policies for accessing privately-owned data	H11 Public outreach activities to build a culture of trust and collaboration for information sharing at the community level
P12 The existence of a legislation on access to public sector information	H12 Reports on users' requirements in key areas potentially effected by disasters
P13 The existence of a strong organisation(s) taking the leadership in the development of the SDI	H13 SDI awareness
P14 The existence of clear roles and responsibilities among involved organisations	H14 Significant number of qualified people to effectively manage and utilise geospatial information
P15 The existence of strong external evidence of the SDI benefits (i.e. a strong Business Case)The implementation of Public Private Partnerships (PPP) for facilitating cross-sector collaborations to access data and technologies for disaster risk management	H15 Support from political level and geo-community
Data factors (10)	H16 The effective usage of volunteered geographic information (VGI) as data collection method
D1 Availability of a standardised catalog of geographical symbols	H17 The establishment of an organisational leader (s) appointed by a formal mandate to support the SDI development
D2 Availability of definitive versions of data sets, features, attributes, etc.	H18 The implementation of a Learning Management System to provide online trainings on geospatial technologies targeted to emergency services and local leaders
D3 Availability of disaggregated data relevant at the local, provincial and national level for creating a shared situational awareness of the impacted communities	H19 The integration and inter-flow of datasets from different parties
D4 Capability to integrate structured and unstructured data formats	H20 The national language is the operational language of the national SDIH21 User involvement
D5 Feedback option to data	H22 Willingness to share
D6 Increase of data interoperability to enable effective data sharing between emergency services and SDI stakeholders	Workshops, collaborative resources and outreach to promote and develop common technical standards
D7 Standardised data content available through the SDI	
D8 The effective use of freely available spatial data platforms as data source of the national SDI	
D9 The effective use of crowdsourced location-based content as new data source for SDI operations	
The establishment of data maintenance agreements to ensure data quality for a wide range of applications in disaster risk management	
Standards factors (8)	Technology factors (12)

(*Continued*)

Table A1 Continued.

Policy factors (16)	People factors (23)
S1 Application of standards for open data file formats S2 Development of technical protocols to facilitate multi-stakeholders' collaboration S3 Existence of technical guidance to facilitate geocoding to link non-spatial data to a location S4 Implementation of common standards to enabling data and semantic interoperability S5 Standardisation arrangements for data dissemination and access network S6 Technical documentation on data standards for integration S7 The creation of more standards-based APIs Type and use of metadata standard (ISO, CEN, FGDC)	T1 Availability of cost-effective and accessible cloud computing services T2 Availability of reliable electricity supply and readily deployable local power generation T3 Capacity to timely response to users' demand for updated information from impacted communities T4 Connectedness of devices T5 Effective utilisation of access mechanism (availability, search, procedures) T6 Facility to use of maps for searching T7 The automatisation of information gathering processes and map creation T8 The deployment of communication infrastructure (e.g. broadband, Wi-Fi, satellite) to enable digital connectivity in disaster-prone communities T9 The deployment of sensor networks and the social media for providing real-time information services T10 The effective utilisation of smart devices to collect new data from the field after disasters strike T11 The establishment of a digital platform to enable data sharing among emergency services through the SDIThe establishment of an open data Geoportal