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Community resilience – Systems and approaches in remote settlements

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ABSTRACT

This paper explores community resilience to climate-related disasters in the Arctic using the example of a tsunami event in the Uummannaq fjord systems. In 2017 the fjord experienced an avalanche-induced tsunami that devastated one settlement while another was abandoned. Investigations revealed unstable cliff sides at two nearby sites that could trigger large avalanches. The result of another event could be waves of up to 23 m. A model for community resilience is presented and explored through onsite observations, maps, archival material and interviews. The analyses show what impact such events can have on the communities in the fjord system and the current level of community resilience. Such an event will also affect long-term liveability, leading to the potential abandonment of settlements. Especially the effect on critical infrastructures like access to energy, telecommunication, fuel, freshwater, food and healthcare will significantly reduce liveability. A collectivistic culture, local knowledge and the level of trust among community members somewhat mitigate these effects but will not offset the general lack of preparedness. In order to ensure sustained liveability in the six remaining communities, there is a need for investments in the relocation of critical infrastructure, emergency preparedness planning and the recovery of critical activities.

1. Introduction

The tsunami came with no warning, and people were unaware of the impending danger until it impacted their lives. On the 17th of June 2017, a 9–10 m high wave hit two settlements in the Uummannaq fjord system, resulting in four people dead and nine injured. Further investigations showed that a cliff side some 30 km away had slid into the water, causing a tsunami that hit the settlements of Illorsuit and Nuugaatsiaq. Following the Uummannaq fjord event, the Greenlandic government, with support from Norway and Denmark, conducted a survey that revealed a significant danger from the area and that could have a much greater impact [17]. A total of seven settlements and one town potentially faced a life-changing event from a tsunami of up to 74 m in height. The estimated time for the wave to arrive at the first settlement was just seven minutes. The report could not say when such a new landslide might occur.

Based on lessons from the event, the Greenlandic emergency response and police issued a report containing steps to take to save lives and property of the 2200 people living in the fjord (Naalakkersuisoqarfik, 2018). The report recommended the abandonment of the two nearest settlements and re-evaluating the feasibility of keeping two others, provided that the municipality ensures an adequate protection level. Post-event, a warning system was discussed using active resident monitoring and an alarm system using loudspeakers.

For historical reasons, proposals to abandon settlements are highly controversial in Greenland (Hendriksen, 2013). Over the years, many settlements have been abandoned either by force or as people moved for employment and welfare benefits. Around 70 settlements remain in Greenland, and its people have little appetite to reduce that number. Due to this local pressure, the municipality, together with the local emergency response and police, started to work toward plans that would save as many settlements as possible while at the same time assuring a relatively high level of safety. Besides the Greenlandic emergency response, the plans required local participation and help from larger nations with more rescue resources (Synnestvedt, 2021). However, there continue to remain doubts about the effectiveness of such plans given the harsh Arctic environment, long distances, and lack of local resources.

The capacity to save lives and ensure liveability have the highest priority in preparing for a possible tsunami event. However, it has proven challenging to organise local exercises that achieve this aim [27]. Much of the work done by the municipality of Avannaata and the

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government of Greenland focused on risk identification and analysis (Grønlands [19,28]). A primary concern is that it is unknown when another event could occur, leaving decision-makers with an unknown frequency but tasked with preparing for an incident with a catastrophic consequence. It was not until 2021 that the emergency preparedness (Police, Fire department and Hospital) conducted an exercise in Uummannaq, the central town in the area. Until then, the focus was on monitoring the mountainside, emergency sirens in the communities, planning for lookouts, and training locals in tsunami identification. After the exercise, the emergency preparedness chief stated, 'If we were to experience a tsunami, then we must know how the emergency preparedness is to act. That is why we must carry out more disaster drills in the future, and the citizens will have the opportunity to practice with us' [27]. While saving lives is a high priority, it has proven challenging to muster an adequate response given the available resources. The municipality has prioritised local low-tech solutions, such as human lookouts and awareness training, while more advanced measures are yet to be specified and designed.

Maps of the area show that in most cases, critical infrastructure and places of employment will be destroyed, damaged, or impacted through secondary effects. The continued liveability in these communities relies on access to critical infrastructure and the possibility of making a living through a place of employment. In Greenland, critical infrastructure is defined as access to energy supply, telecommunication, freshwater, and heliport (Grønlands [19]). In towns, critical infrastructure also includes the local healthcare centre, schools, buildings that can hold many people, and the local police and fire station. Damage to these essential services is challenging for emergency preparedness efforts to avoid in the Uummannaq fjord system, as they are often positioned below the potential flood line. In case of an event, this would mean that, even if evacuation plans worked, the communities would struggle to maintain essential functions as they would not constitute places of liveability.

Climate change in the Arctic entails dramatic impacts on communities, including threats to liveability. Saving lives during an event is essential, but a response must include the ability of the settlements and towns to be resilient to these changes, ensuring that people have access to services post-event. This paper highlights the need for a resilience approach to climate change impacts, including critical infrastructure, housing, and employment. Community resilience looks beyond the events themselves toward recovery and what comes after. The holistic approach includes the impact of culture, trust and trustworthiness, and distributed sensemaking as a foundation for robustness; all of which are enablers of coordination, cooperation, and organising and distributing responsibility in the community. Using reports, maps, and observations from Uummannaq fjord, the paper explores how the Greenlandic government prepares for a landslide event. The paper seeks to answer the research question: How can communities in the Uummannaq fjord system impacted by climate change-induced tsunami events ensure sustained liveability through a community resilience approach?

The paper is structured as follows. First, the context is presented, outlining the concept of current community challenges, specific hazards, and initiatives that communities have taken. The section follows the theoretical framework on organisational resilience and its application to communities, thereby presenting a framework for community resilience. Second, the methodology is detailed, using a deductive approach based on the paper's proposed theoretical framework and empirical foundation. Third, follows an analysis of the communities in the Ummannaq fjord system, in which possible gaps are identified and discussed. Fourth, the paper presents an analysis of community resilience using the proposed model. The final section concludes, answers the research question, and discusses the concept of community risk in an Arctic context.

1.1. Context

Climate change is evident in the Greenlandic context in several ways. In recent years, the country has experienced wildfires, prolonged storms, increased rains, receding permafrost, drought, and, in 2017, a tsunami event [14,17,20,45,46]. While these events cannot be directly linked to climate change, they represent a pattern in which more people are impacted by what they perceive as catastrophic events that significantly impact their lives. The Arctic has likely warmed at more than twice the global rate over the past 50 years, and it is virtually sure that surface warming in the Arctic will continue to be more pronounced than the average global warming throughout the 21st century [24]. Also, extreme heat events have increased since 1979, and minimum temperatures have risen at about three times the global rate, which has resulted in ice melt, less sea ice, reduction in permafrost, an increase in bergy waters, as well as wildfires ([5]; Clear [6,24,37]). IPCC has high confidence in future permafrost warming, thus decreasing permafrost extent with increased risk of hazardous impacts, including loosening material from otherwise frozen cliff sides. Reductions in spring snow cover extent have occurred across the region since 1978. This development will continue with further warming, despite a likely increase in winter snow in the far northern continental regions and the central Arctic.

The municipality of avannaata is the most northern district in Greenland and was formed in 2018 when Qaasuitsup was split into two, Qeqertalik being the southern part. Avannaata covers some 522,700 km^2, and some 10,820 inhabitants live in the four towns (Ilulissat, Uummannaq, Upernavik and Qaanaaq) and 23 individual settlements. The primary source of income comes from fisheries, hunting, and tourism. Within the Uummannaq fjord systems lies Karrat fjord, located in the northern part that, until the 2017 event, had seven settlements and one town (Uummannaq) (see Fig. 1). About 30 km from the now abandoned settlement of Nuugaatsiaq is a steep cliff side (indicated on the map) that became unstable on the 17th of June 2017, resulting in an avalanche and a tsunami that reached nuugaatsiaq around seven minutes later and Illorsuit in 13 min (see Table 1). The result was four dead and nine wounded in Nuugaatsiaq, which significantly impacted the settlement of an estimated 84 individuals.

Further investigations by the Geological Survey of Denmark and Greenland (GEUS) showed that a significant part of the cliff side was unstable, and a much more destructive event could occur [17]. Four areas were considered dangerous enough to create another tsunami event that could potentially have devastating consequences. Karrat 1 and 2 would primarily impact the two nearest settlements that already witnessed the 2017 event and Karrat 3 (A + B) represented the worst-case scenario (see Fig. 2). The decision was to abandon the two nearby settlements as any scenario would result in a catastrophic event. In April 2022, GEUS identified another cliff side that could trigger a landslide further south at Kigarsima (See Figs. 1 and 2) [18]. The initial estimation was that an event originating from there would have fewer consequences than Karrat 3 but would still present a significant danger to the communities. A landslide at this location would reach the settlements and towns faster than from Karrat but would be less damaging due to the lower total mass of the slide.

The analysis shows the maximum runup height as the baseline for how infrastructure is affected by the tsunami. The GEUS report showed that a tsunami would create a wave of up to 74 m high if the Karrat 3 A + B were fully released (see Table 1). However, for settlements and the town of Uummannaq, the runup height would be significantly lower, with a maximum of 23 m impacting Qaarsut. The time of impact for the Kigarsima site is based on the average wave speed of the 2017 tsunami and the approximate distance from the avalanche site. All figures are estimates and subject to change as more data becomes available, but they are considered the best estimation currently available.

Based on Greenland's GEUS report and emergency response capacity analysis, the Greenlandic police issued recommendations to the Greenlandic government (Grønlands [19]). These included monitoring the cliff side, making plans for crisis communication, early warning systems, evacuation plans, analysis of critical infrastructure, and making the emergency response capacity in the area more robust. The report also highlighted the need for more research into resilience and the ability to

Fig. 1. Uummannaq Fjord system (authors' creation).

Table 1
Settlements and tsunami impact.

Settlement/ Town	Inhabitants	Impact Kigarsima (min)	Runup height Kigarsima (m)	Impact Karrat (min)	Runup height Karrat 1 (m)	Runup height Karrat 2 (m)	Runup height Karrat 3 B (m)	Runup height Karrat 3 A + B (m)
Nuugaatsiaq	0	–	–	7	6	6	32–72	37–74
Illorsuit	0	14	4	13	3,7	3,9	19–35	20–43
Qaarsut	174	13	10	26	–	–	9–20	11–23
Niaqornat	35	15	5	23	–	–	9–14	11–17
Uummannaq	1407	15	5	30	–	–	6–13	6–14
Saattut	226	14	5	35	–	–	4–10,5	5–10,5
Ukkusissat	154	5	7	26	–	–	5–6,5	5,5-7,5
Ikerasak	233	22	2	38	–	–	4–10	4,5–11

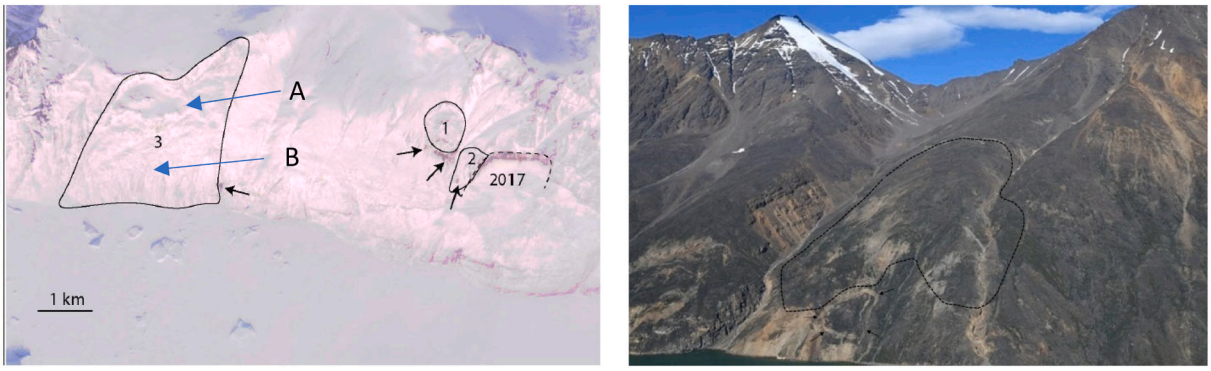

Fig. 2. Karrat Fjord cliff side - left [17] and Kigarsima - right [18].

recover critical societal functions after a possible event. The police stated, 'The report has not focused on how the authorities are working to restore society after a tsunami. It also does not analyse in detail when a contingency event ends and the recovery phase begins. The working group assesses that the restoration of society will be an extremely relevant and important topic to shed light on in any further work.'

Based on these recommendations, this paper seeks to explore community resilience and the ability of the remaining settlement and town to recover from a possible tsunami event sometime in the future.

2. Theoretical framework

Community resilience is a concept that centres on how social systems are affected by and recover from realised hazards [7,50]. Here, the concept is defined as the community's ability to absorb disturbances and retain its critical activities and structure after a disaster. Communities differentiate themselves from other forms of organising by being loosely coupled and connected through geographic, social, and cultural bonds, making a cohesive whole ([7]; L. A. [9]). The boundaries can, in this way, be challenging to define in contrast to other organisational forms where there is a clear distinction; for example, a company or organisation. Analysing communities as interacting agents rather than individuals who manage risks independently suggests alternatives to how these loosely coupled networks make decisions.

Communities are distinct from other forms of entities as they have clear boundaries to other organisations through five characteristics: they have interdependent parts, adapt and pursue goals in the external environment, their internal environment comprises separate but interdependent technical and social subsystems, and they can pursue these goals through different means, and rely on optimisation of social and technical subsystems to do so [52]. Community resilience is both intrinsic to the community, as something the community has, and extrinsic as it relies on the support of external actors to become resilient. The national and local government's role is as an external but integrated part of the community as they provide training, risk assessment, plans and financing for any activity related to resilience within the community. The municipalities and communities are responsible for enacting policy decisions and prioritising these resources. It is hence possible to analyse communities independently from external actors as all enactment related to resilience is done at this level.

Being part of the community is subjective and connected with one's sense of place rather than being a member of a particular organisation [11,51]. While there can be good reasons for relocating people to what is, objectively, a safer location, doing so can have significant cultural and social consequences [12,44]. For example, after the 2017 tsunami, most people were moved from the two settlements, Illorsuit and Nuugaatsiaq, to Uummannaq. While the move was objectively the right thing to do, as the communities were in danger of more tsunamis, there were significant human consequences [26,28]. Especially in Illorsuit, there is a wish among the former residents to return to the settlement despite the threat of another event [38,40]. Given the nature of communities, it is difficult to engage in many risk management approaches available to other organisations, such as making adjustments to staff, moving location, or competency development.

The concept of resilience stems from the idea that organisations can recover successfully from the effects of realised hazards [41,42]. It entails the processes that lead to increased adaptability of infrastructure deemed critical to an organisation and how such a system manages its efforts before, during, and after an event. Central to organisational resilience theories is the ability to respond to, monitor, learn from, and anticipate how events unfold [22,53]. By displaying these features, a system can become resilient to events that have the potential to destroy something of collective value, such as critical infrastructure. This approach enables the enactment of a range of reactions, from practical decision-making on the ground to sophisticated and predictive reactions, to quantify the tactical steps needed to enhance resilience [32]. The aim is to engage in a virtuous circle of continuous improvement of prevention, absorption, recovery, and adaption [42]. Strategic foresight entails actors understanding parts of the future as it emerges, not as a predetermined end but as a series of possible likely outcomes to which the system has developed the ability to react. Several models have been presented for what constitutes community resilience, what it should entail, and how to include the approaches in urban planning [8,35]. Broadly, these models can be characterised by the technical, social, and management domains. The technical approach to community resilience focuses on how technology can positively influence resilience before, during, and after an event [54,55]. The social domain focuses on the cohesion of society and the ability of communities to adapt to, and recover from, disasters [2,23,31]. Management is possibly the largest domain within resilience theory, and focuses on how social systems engage with, structure, and respond to disturbances in their context [3,21,30]. These domains contribute to our understanding of how systems respond to, and recover from, disturbances by applying solutions that can be technical, social, or systems orientated. The following model attempts to create an inclusive approach that includes all three aspects into one coherent model.

Community resilience is the ability of a social system to negotiate what it considers collectively valuable, steps taken to ensure its protection from deviations from the norm, and if needed, its recovery. Variations between different social systems come from the context of a community and the resources it has available. Hence, community resilience is context-specific and decoupled from the resilience of communities in other parts of a given society. For example, the community resilience is different in Uummannaq, with just over 1400 individuals, compared with Qaarsut where only 174 live, just 20 km to the west. Community resilience incorporates culture, trust, and trustworthiness, distributed sensemaking, cooperation, coordination, organising, and responsibility (see Fig. 3). The first three (culture, trust and

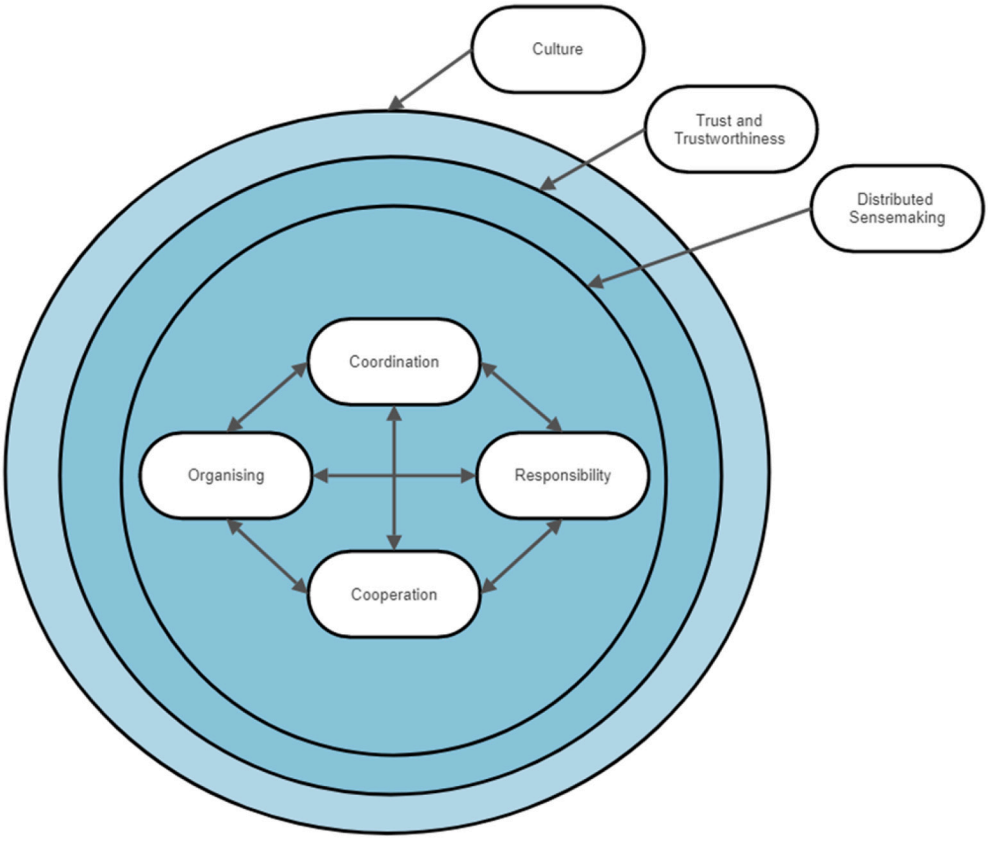

Fig. 3. Model of community resilience.

trustworthiness, distributed sensemaking) are overreaching domains that influence all aspects of community resilience. The last four elements (cooperation, coordination, organising, and responsibility) have to do with how the community organises itself to become resilient.

Culture is the beliefs, customs, knowledge, and practices that community members accept and identify with as part of their daily lives [4,16,29]. Communities express culture through artefacts that they consider essential to their coherence. These can be a central place where people meet, such as a culture house or the town hall, but they can also be traditional places that have to do with community heritage. Values are also part of the culture as they express what members believe to be a priority. An underlying presumption is that living a traditional life, working with and living with nature, is what brings status to individual members of many settlements in Greenland. Another assumption is that if help is needed, it will also be provided if possible, which explains why so many volunteered when the 2017 event occurred.

Trust and trustworthiness are the willingness to be vulnerable to another person based on the belief that he or she is competent, open, concerned, and reliable (S. [10,13,33]). Communities with a high level of cohesion will have the preconditions necessary to build trust among their members. Thereby, decision-makers are in a position to be regarded as trustworthy in situations where they take on different roles; for example, during an incident where volunteer fire fighters or reserve police officers shift from their civilian jobs to the role of crisis management professionals. Role shifting is linked to culture, as members with a high level of trust can utilise their trustworthiness when acting in other capacities.

Distributed sensemaking is a community's ability to organise in ways that enable it to identify a change in context that it wants to keep stable and predictable. Central to creating meaning is the culture and trust that a given society has in decision-makers, as they both form the premise for their authority [34,43,48]. If a critical event occur, it can recognise it and, based on the information, create meaning as to what actions to take. The ability to make sense is based on the activity, the role, and the experience of decision-makers in obtaining relevant information, and how the community coordinates among its members. Sensemaking is a precondition for community resilience in all decision-making when applied to cooperation, coordination, organising, and assigning areas of responsibility within the system. Social systems aim to improve continuous learning processes, thereby embedding collective experiences such as retrospective knowledge, best practice, and past decisions into a uniform structure or norms. The system aims to ensure that routine activities are conducted according to agreed standards and produce a uniform output. Some systems are transferable across different organisations and can help produce similar outputs across different entities without additional adaption. Using standards reduces the need for clear communication and the number of cues needed to make risk decisions, decreasing the time the organisation needs to act on given information.

Cooperation is the ability and willingness of a community to work together before, during and after an event. Cooperation includes complementary actions by agents that achieve shared values and favourable outcomes for social systems, grounded in trust as relational parties grow in confidence in each other's motives in the relationship. The cooperation reflects the willingness of relational agents to work together when conditions demand better utilisation of resources. Both formal and informal ties exist that the community can utilise to improve its ability to identify emerging risks and thereby take steps to reduce consequences through due diligence. These loosely coupled networks can be activated as needed, increasing resources to engage with a specific threat. For example, snow scooter clubs are working on identifying areas with a risk of avalanches in some places in Greenland. Warning information is distributed through social media for the benefit of the community. There is no formal agreement between the community and the scooter clubs

that they should do this work, but it is regarded as a way to share relevant information. Spontaneous volunteers are also a group who are part of the network and are an engrained part of Greenlandic culture.

Coordination is the effort to provide unity of action to pursue common goals. It is the added information processing and activity accomplished when multiple related parties pursue objectives that a single agent pursuing the same purpose would not achieve [36]. Thus, parties coordinate efforts to maximise utility to the benefit of both parties. Coordination requires three conditions: there have to be two or more parties; all parties must have responsibilities to perform specific tasks; and the purpose of the combined effort is to achieve a mutual purpose (ibid). There can be different levels of commitment within the community to coordinate activities. After the 2017 event in Karrat Fjord, many spontaneous volunteers arrived at the two affected settlements despite the considerable personal danger. However, their efforts were not centrally coordinated, and none knew who was actually at the scene, making it difficult for the emergency response to gain situational awareness. While the community much appreciated the volunteers' commitment to providing support, it was a poor utilisation of resources, which potentially could have triggered the use of search and research resources.

Organising centres around a community's critical activities and establishes a hierarchy based on roles, competencies, and capabilities [49]. Both formal and informal forms of organising exist, which the community can utilise in case of an event. Individuals might have multiple roles if and when a situation requires it. For example, a fisher can quickly work in a search and rescue capacity, or a home can be converted into a place for people whose houses have been destroyed. Under most circumstances, the organising centres on fixed roles, competencies, and capabilities, completing the day-to-day critical activities needed for society to function. However, if the situation changes, the community can reorient its resources and organisation toward a given threat. In 2017, the sports hall in Uumannaq was converted into an evacuation centre, and many private homes were opened up to evacuees.

Responsibility defines decision-making boundaries for formal and informal roles within the community. Formal responsibilities will, under normal circumstances, be connected to specific jobs that the community needs to perform. These can be responsibilities for energy production, food storage, or other areas linked to critical activities. Formal roles include volunteering, such as the scooter club, dogsled club or being part of the local football club. Informal obligations exist due to expectations that a person take on a leadership role, or members are looking for guidance and advice. A community with clearly defined areas of responsibility is believed to be better positioned to react to a disturbance.

3. Methodology

The methodology tests community resilience as a social system's ability to negotiate collectively the steps needed to ensure the protection and recovery of its critical activities. The aim is to show the current level of community resilience in each settlement and town using the community resilience model by describing the infrastructure under threat from a tsunami event, its available resources, vulnerabilities, and preparedness. Empirical evidence came from maps, reports, newspaper articles, and onsite visits from April to May 2022. The data includes information on the preparedness level in Avannaata municipality, infrastructure, and the current state of the Karrat Fjord and Kigarsima cliff sides. Information about national preparedness has been collected from the Greenlandic police, fire department, Avannata municipality, and the Greenlandic government. The onsite visits to four out of six communities confirmed the location of the particular infrastructure and emergency response capacity, which could not be identified using maps or other offsite information. The communities visited were Qaarsut, Uummannaq, Saattut, and Ikerasak, while Niaqornat and Ukkusissat were inaccessible during the period. The last remaining settlement was reached through local contacts and telephone, providing information on the placement of infrastructure and preparedness levels.

Fig. 4 is an example of the maps used and includes the maximum roundup height (indicated in red), the location of all buildings, roads, and other infrastructure, and the location of the designated local evacuation centre. Onsite visits revealed the exact use of each building and location of fixtures not on the map, such as garbage dump, fishing equipment and boats, outside storage, and vehicles.

Besides the primary empirical evidence collected onsite, the study also used secondary sources from local media and government reports. Three criteria for quality assurance apply when evaluating the sources that are complementary to those used as secondary sources [15]. This method provides the most conservative approach to reliability and for generating themes.

- Firstly, they should have a direct link to Uumannaq fjord and emergency response.
- Secondly, individual themes should be mutually exclusive.
- Thirdly, they should maintain a close resemblance to the language used by other sources.

Using these sources exposed the research to the possibility of bias, which could influence the analysis and the final recommendations. The following steps were taken to ensure that this bias did not influence the findings. Firstly, a literature review was used to construct the community resilience model. A deductive approach limited the likelihood of gaps and that certain elements are under- or over-represented. Secondly, the data was supplemented by primary sources such as onsite observations and interviews with key stakeholders. This data helped locate the sources and place them within a broader context.

The study focuses on communities capabilities to be resilient rather than using specific resilience vocabulary. The approach made it possible to identify how communities understand and use their capacity to identify, mitigate, or accept threats to critical activities. The communities do not explicitly work with community resilience but have handled multiple disruptions during their long history.

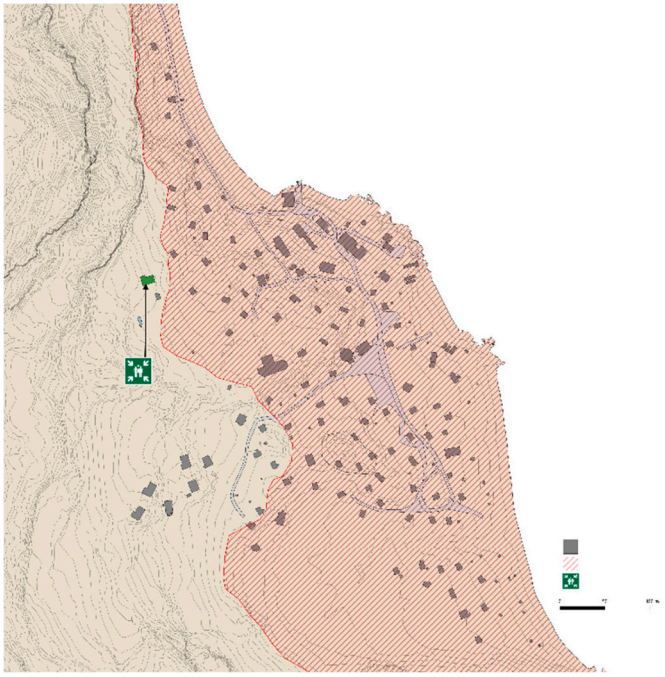

Fig. 4. Example of a map (Qaarsut) (Avannaata municipality, 2022).

4. Analysis

The analysis focuses on the six settlements and towns in the Uummannaq fjord system: Qaarsut, Niaqornat, Uummannaq, Saattut, Ukkusissat, and Ikerasak. Each site is investigated as to the impact of a potential tsunami event using the Kigarsima, Karrat 3 Block B, and Karrat 3 Block A + B events. The following section accounts for infrastructure and the effect that a given event at Kigarsima and Karrat 3 will have locally and the effect on community resilience. During the event, there would be a large debris field from fishing equipment, boats, spare parts, containers, and other waste, which would expand the scope of destruction caused. The runup number indicated is therefore regarded as the minimum.

Local preparedness levels vary significantly between the different sites. The emergency response in Avannaata municipality has a strength of approximately 10 permanent employees and around 380 part-time employees, eight fire stations and 28 smaller stations in settlements. A lack of training and access to full-time and volunteer personnel, and outdated or worn-down equipment limits the preparedness organisation's ability to respond at all levels [39]. In 2018, Avannaata allocated no funding for training, and there was no local governance structure to engage in crisis management. Both towns and settlements lacked people and staff with the right qualifications. In the municipality, just over 1/3 of fire fighters had basic training, 17% of stations had training in specific functions, while 50% of the team leaders and just under 40% of the incident commanders had necessary qualifications. According to the budget, the costs for the fire brigade in the former Qaasuitsup (now Qeqertalik and Avannaata) municipality were 15.5 million Danish kroner in 2018. The number corresponds to the previous year but is lower than the costs in the last 15 years. Greenland's government and the municipality have added additional funding for emergency exercises, equipment, and monitoring [27,47]. In 2022, the budget will be 13.1 million Danish kroner with additional funding for specific equipment that is urgently needed [1]. In the Uummannaq fjord system, two trained police officers have responsibility for the five remaining settlements and the town. In a crisis, the police can get support from two more reserve officers who are not trained but can do some of the routine jobs. In the town, only two police officers are available, supported by two extra people (reserve officers) with little formal training. In the communities, one deputised community member at each settlement will coordinate the local response but does not have a minimum level of training.

The government of Greenland has allocated additional funding to implement a monitoring system, which will provide early warning in case of a tsunami [25]. The 4.4 million Danish kroner system consists of deformation cameras and on-the-ground sensors, which will be a significant addition to the existing system in Qaarsut, Niaqormat, and Ukkusissat based on physical surveillance. The system will provide the settlements and the town with forewarning of an upcoming event and thereby time to organise their response. Emergency plans rely on being given enough response time so that community members can prepare themselves and take actions that will mitigate or stop the tsunami from having consequences. Due to data processing and the need for accuracy, the expectation is that it will take between two and five minutes from when a slide is triggered and the alarm system is activated. The time delay will be subtracted from the impact times described in Table 2, significantly reducing the available response time for some sites. This limitation means communities must prepare most of their actions before the event and ensure coordination. There needs to be a transparent chain of command so that decision-makers know whom they need to coordinate with, which external resources need to be included, and to ensure that the response organisation is known to everyone. No such preparedness plans exist to coordinate the police, fire department, hospital, municipality, or other actors. This weakness will be even more salient when there is a lack of resources in all sectors. The resources of the police are especially essential as they will coordinate the local response.

Qaarsut is a small settlement some 20 km west of Uuummannaq.

Table 2
Infrastructure affected in Qaarsut.

Infrastructure Qaarsut	Kigarsima	Karrat 3 Block B	Karrat 3 Block A + B
Airport	Not affected	Not affected	Not affected
Fish factory	Affected	Affected	Affected
Diesel supply	Affected	Affected	Affected
Electricity plant	Affected	Affected	Affected
Gas storage	Affected	Affected	Affected
Water storage	Not affected	Affected	Affected
School	Not affected	Not affected	Affected
Fire station	Affected	Affected	Affected
Telecommunication	Not affected	Not affected	Affected
Church/chapel	Affected	Affected	Affected
Settlement office	Affected	Affected	Affected
Grocery shop	Affected	Affected	Affected
Kiosk	Affected	Affected	Affected
Culture house	Not affected	Not affected	Affected
Nursing station	Not affected	Not affected	Not affected

Around 174 people live in the village, where the primary source of income is from the airport, fish factory, and tourism. Qaarsut is home to the regional airport, from which emergency response equipment is made available. There is equipment and personnel within the settlement for minor incidents, such as a house fire. The tsunami warning system uses physical surveillance: a guard acts as a lookout for changes to the water level. This form of warning system is dependent on the individual and is subject to uncertainty as to effectiveness if no landslides are detected within the foreseeable future. Avannaata municipality is developing evacuation drills and grab-boxes that can be utilised in case of an event. The projection is that only six houses in the settlement will be untouched when Karrat 3 Block A + B is triggered.

Given the location and nature of the infrastructure, it remains uncertain what the liveability will be in Qaarsut post-event. In Qaarsut, most of the infrastructure affected by the wave would exclude the airport and nursing station, which would remain unaffected regardless of the scenario. If Block A + B is released, the school, telecommunication, and culture house would be the remaining buildings. The infrastructure impacted includ communication, accessing food, freshwater, and energy. The local governance structure would also be subjected to disruptions if the settlement office and church were affected by the event. Given these extensive changes to the settlement, it is highly likely that Qaarsut would not retain its liveability post-event.

Niaqornat is located 57 km west of Uummannaq. Around 35 people live in the village, and the primary source of income is from fishing and tourism. Equipment and personnel are available to manage minor incidents within the settlement, such as a house fire. Like in Qaarsut, the tsunami warning system uses physical surveillance, with a guard acting as a lookout for changes in water level. This warning system is dependent on individual competence and is subject to uncertainty as to effectiveness if no landslides are detected within the foreseeable future. Avannaata municipality has developed evacuation drills and grab-boxes that can be utilised if an event should occur (Tables 3–7).

In Niaqornat, all infrastructure except telecommunication would be affected by the wave. Given the location and nature of the infrastructure, it remains unlikely that these could survive an event given their current placement. The critical infrastructure would be impacted, including the ability to provide housing and access to food, fresh water, and energy. The local governance structure would also be subjected to disruptions as the settlement office and church were affected by the event. Given these extensive changes to the settlement, it is highly likely that Niaqornat would not retain its liveability post-event.

Uummannaq is the region's largest city, with a population of just over 1400, and has the most complex infrastructure of all the sites, and is an important staging point in case of a tsunami. The town is also an important economic driver for the region as the centre for tourist development, fisheries, and education. The fire station has the equipment to manage the most common incidents, such as mountain rescues,

Table 3
Infrastructure affected in Niaqormat.

Infrastructure Niaqormat	Kigarsima	Karrat 3 Block B	Karrat 3 Block A + B
Fish storage	Affected	Affected	Affected
Heliport	Affected	Affected	Affected
Diesel supply	Affected	Affected	Affected
Electricity plant	Not Affected	Affected	Affected
Gas storage	Affected	Affected	Affected
Water storage	Not Affected	Affected	Affected
School/church	Affected	Affected	Affected
Telecommunication	Not Affected	Not Affected	Not Affected
Settlement office	Not Affected	Affected	Affected
Grocery shop	Affected	Affected	Affected
Nursing station	Affected	Affected	Affected

Table 4
Infrastructure affected in Uummannaq.

Infrastructure Uummannaq	Kigarsima	Karrat 3 Block B	Karrat 3 Block A + B
Heliport	Not affected	Not affected	Not affected
Fish factory	Affected	Affected	Affected
Diesel supply	Not affected	Not affected	Not affected
Electricity plant	Not affected	Not affected	Affected
Gas storage	Not affected	Not affected	Not affected
Water storage/supply	Not affected	Not affected	Not affected
School	Not affected	Not affected	Not affected
Nursery	Not affected	Not affected	Not affected
Fire station	Not affected	Not affected	Not affected
Telecommunication	Not affected	Not affected	Not affected
Church/chapel	Not affected	Not affected	Affected
Municipality office	Not affected	Affected	Affected
Grocery shop	Affected	Affected	Affected
Central warehouse	Affected	Affected	Affected
Court	Not affected	Not affected	Not affected
Kiosk	Not affected	Not affected	Not affected
Culture house	Affected	Affected	Affected
Health centre	Not affected	Affected	Affected
Collegium	Not affected	Affected	Affected
Habour	Affected	Affected	Affected
Retirement home	Not affected	Not affected	Not affected
Sports hall	Not affected	Not affected	Not affected
Museum	Not affected	Not affected	Not affected
Post office	Affected	Affected	Affected

house fires, or rescues on the ice. In 2021, the municipality conducted one emergency exercise involving a possible tsunami event, and more are planned in the coming years. Especially vulnerable is the health centre, situated close to the shore just north of the harbour, which would be affected in both Karrat 3 scenarios. The evacuation centre (located at the sports hall) has a critical role as the region's primary place for

Table 5
Infrastructure affected in Saattut.

Infrastructure Saattut	Kigarsima	Karrat 3 Block B	Karrat 3 Block A + B
Fish factory	Affected	Affected	Affected
Heliport	Not Affected	Not Affected	Not Affected
Diesel supply	Affected	Affected	Affected
Electricity plant	Not Affected	Affected	Affected
Gas storage	Affected	Affected	Affected
Water storage	Affected	Affected	Affected
Fire station	Not Affected	Not Affected	Not Affected
School	Not Affected	Not Affected	Not Affected
Church	Not Affected	Not Affected	Not Affected
Telecommunication	Not Affected	Not Affected	Not Affected
Settlement office	Not Affected	Not Affected	Not Affected
Grocery shop	Not Affected	Affected	Affected
Nursing station	Not Affected	Not Affected	Not Affected

Table 6
Infrastructure affected Ukkusissat.

Infrastructure Ukkusissat	Kigarsima	Karrat 3 Block B	Karrat 3 Block A + B
Fish factory	Affected	Affected	Affected
Heliport	Not Affected	Not Affected	Not Affected
Diesel supply	Affected	Affected	Affected
Electricity plant	Affected	Affected	Affected
Gas storage	Affected	Affected	Affected
Water storage	Not Affected	Not Affected	Not Affected
School	Not Affected	Not Affected	Not Affected
Church	Not Affected	Not Affected	Not Affected
Telecommunication	Not Affected	Not Affected	Not Affected
Settlement office	Not Affected	Not Affected	Not Affected
Grocery shop	Not Affected	Not Affected	Not Affected
Nursing station	Not Affected	Not Affected	Not Affected

Table 7
Infrastructure affected in Ikerasak.

Infrastructure Ikerasak	Kigarsima	Karrat 3 Block B	Karrat 3 Block A + B
Fish factory	Not Affected	Affected	Affected
Heliport	Not Affected	Not Affected	Not Affected
Diesel supply	Not Affected	Affected	Affected
Electricity plant	Not Affected	Affected	Affected
Gas storage	Not Affected	Affected	Affected
Water storage	Not Affected	Not Affected	Not Affected
School	Not Affected	Not Affected	Not Affected
Church	Not Affected	Not Affected	Not Affected
Telecommunication	Not Affected	Not Affected	Not Affected
Settlement office	Not Affected	Not Affected	Not Affected
Grocery shop	Not Affected	Not Affected	Not Affected
Nursing station	Not Affected	Not Affected	Not Affected

healthcare and a centre for coordination in a mass casualty event. The nearest alternative is Ilulissat, around 170 km away, significantly reducing the capacity to manage an emergency.

Significant parts of Uummannaq would be affected in both scenarios, especially the health care centre and central warehouse, which is a concern as it is part of critical infrastructure. In the worst-case scenario, the town's economic drivers would be severely affected as the two fish factories, a grocery shop, and an electricity plant provide power for homes and companies. In the short term, the grocery shop would not be able to provide food and necessities, which would significantly affect Uummannaq and the settlements that would also lose access to essential

wares. The disruption would mean that food and other wares would have to be taken from Qaarsut by helicopter or sailed by boat in the first hours and days. The two fish factories store ammonium, used in frozen fish production. There is a likelihood that a spill would occur from one or both factories, which could affect most of the town, including the evacuation centre. Long-term effects on the harbour area, municipality office, post office, and collegium would impact liveability. The plan is that Uummannaq will act as a regional emergency response hub and coordination centre, at least in the initial hours and days. In terms of community resilience and, thereby, the ability to restore critical functions of society, the key priorities will be restoring electricity to the city, an alternative site for distributing food, and recovery of the health care centre.

Saattut, situated on a small island, is vulnerable to critical incidents like flooding. The settlement is located 24 km northeast of Uummannaq and is the home of 226 people. Within the settlement there is equipment and personnel available to manage smaller incidents, such as a house fire. The principal place of employment is a fish factory operated by Royal Greenland, fishing, and occasional visits from tourists.

Most of the critical infrastructure is close to the harbour area, as it is easier to maintain here but makes it vulnerable to disruptions. Saatut will be affected by the tsunami, which would impact access to power, jobs, water, and food as all these utilities are placed within the flooding zone. The school, telecommunication, nursing station, settlement office, and most private homes would be unaffected by a tsunami. Also, the heliport would not be affected, making it easier for the emergency response to evacuate wounded residents. Critical infrastructure and places of employment are within the scope of destruction, which would affect liveability. There would be no electricity or fresh water following an event, and it would take time to re-establish these activities. As Saatut is on an island, there are fewer options to locate alternative freshwater sources in an interim period, which means that it has to be brought by boat or sled.

Ukkusissat is 42 km north of Uummannaq and, like other sites in the region, reliant on fisheries and the local fish factory. Within the settlement, equipment and personnel are available to manage more minor incidents, such as a house fire. Ukkusissat is on a steep slope, meaning that a tsunami will mainly impact the harbour area. In contrast to the other sites, Ukkusissat will be affected just as much by a Kigarsiam tsunami as if Karrat 3 was released, but will have less time to prepare. The short response time has prompted the emergency response to station a tsunami guard responsible for identifying changes to the water level. As there is no early warning system in place, it is more than likely that the settlement would not receive any forewarning if it does not have physical surveillance.

Due to their location close to Ukkusissat's harbour, critical infrastructure such as fuel, electricity, and heating, would be affected by an event. Given the size of the community and scope of disruption, there would be a significant change in access to power, jobs, water, and food as these utilities are placed within the flooding zone. The local fish factory would be disrupted and, therefore, unavailable as a place of employment. Housing would remain relatively intact, with most private homes located above the flood line. Long-term liveability would depend on the ability to reconstruct the local fish factory and the harbour area.

Ikerasak is 45 km southwest of Uummannaq. Around 233 people live in the settlement, and the primary source of income comes from fishing and the local fish factory operated by Royal Greenland. The settlement does not have a fire station but has equipment available to manage the most common incidents, e.g., house fires. If a tsunami were to be triggered in Karrat Fjord, Ikerasak would be the last settlement impacted by the wave due to its location.

Ikerasak would, like most other settlements, be impacted by the tsunami on its ability to provide electricity, heating, and jobs. Housing would be relatively unaffected, but there would be no access to critical infrastructure such as electricity and gas for households after the event. Oil, diesel, and petrol storage would also be affected and could cause additional damage. The importance of the fish factory to liveability is also central to sustaining the community, and its restoration would have a high priority if the community. As with other sites with a fish factory, there is a chance of an ammonia spill that could affect the settlement depending on the wind direction.

4.1. Community resilience

As presented in the community resilience model, seven elements contribute to resilience when estimating to which degree a given community will be robust to deviations from the norm. First, culture, trust and trustworthiness, and distributed sensemaking form the foundations for a resilient society. Secondly, coordination, responsibility, cooperation and organising are instrumental for the ability of a community to respond to events effectively.

Culture is the beliefs, customs, knowledge, and practices that community members accept and identify with as part of their daily lives. All settlements and even the town of Uummannaq are small societies where people are closely connected and isolated from the rest of Greenland. There is thick sea ice for several months, preventing fresh food and vegetable resupply. During these periods, community members rely on their network and ability to catch food to diversify from the frozen foods available at the local store. People in all communities are, in this way, interconnected and interdependent for even basic needs. The culture also reflects these premises as members will share resources and provide help to those in need. A testimonial to this behaviour was witnessed in 2017 when local fishers and hunters rushed to help the two settlements, Nuugaatsiaq and Illorsuit, despite an unknown and possibly high danger to themselves. Local knowledge is necessary as it helps people prepare for known events that the community has experienced before. Over generations, people in the settlements and the town of Uummanbnaq have developed strategies and norms for behaving during different forms of natural hazards. Over time, this knowledge has helped communities survive and recover from Arctic disasters. While local knowledge is essential during events that the communities have experienced, there are gaps when it comes to events that supersede community experiences. This culturally embedded knowledge is insufficient and could even be counterproductive to crisis management efforts as communities rely too heavily on embedded experiences rather than scientific insights.

Trust and trustworthiness are the willingness to be vulnerable to another person based on the belief that he or she is competent, open, concerned, and reliable. For communities to be resilient to critical events, there needs to be a high level of trust that competent members of society will provide help. Trust and being trustworthy rely on the members responding to an event to be regarded as competent to manage the task at hand, be open in communication, show concern for citizens, and ensure that the level of service meets the community's expectations. As shown in the 2018 report on the preparedness level, there is a lack of trained team leaders and incident commanders in the municipality [39]. Emergency response equipment is also lacking or in poor condition, eroding trust. In addition, the coordinating authority, the police, only have two trained police officers in Uummannaq to coordinate the initial effort. Preparedness planning also needs refinement to address issues that can arise before, during, and after a tsunami event. While evacuation plans will ensure that community members know where to meet, there is less knowledge of the next steps and what comes after. While trust exists between community members, the lack of emergency preparedness is a factor which will influence people's behaviour. For example, the emergence of spontaneous volunteers can signify a lack of trust in formal emergency response capabilities.

Creating meaning in the community is connected to how it makes sense of the changes it is experiencing. Distributed sensemaking centres on how social systems collectively engage in understanding the change, and the actions a community decides to take to mitigate or ignore identified threats. The communities in the Uummannaq fjord system are still negotiating what should be the norm as to how the threat of a

tsunami should be approached and managed. While there is little or no discussion as to what people should do during the event, there is also not much agreement about what to do before and after. The current lack of coordination between central actors, e.g., police, emergency response, and the hospital, will add to the lack of a commonly agreed reality and long-term planning. When the fundamentals in this way are absent, it is difficult for other actors, such as the municipality offices, fish factories, utilities, child care centres, and schools, to lay plans for their organisations.

Effective coordination is central when there is a lack of resources upon which the community can draw. As already described, only two police officers in Uummannaq would coordinate efforts in the first hours. The presumption is that other additional coordinating resources would be able to take over after that time. In the capital of Nuuk, the Greenlandic emergency coordination centre (GBS) would be convened and manage logistics and communication with other municipalities, the Arctic command, and the Danish emergency response. However, it can take hours or days to reach all communities, so the local staff would be heavily engaged in coordinating activities in the initial phases. As the power stations at most places would be affected, there would only be a limited time (between four and eight hours) window in which the mobile phone system would be working. From that point, it would only be possible to communicate via VHF or satellite telephones. All communities have access to VHF systems, but these can easily be listened to by outsiders; therefore, a secure satellite system is preferred. However, not all communities have these systems available, and there is no guarantee that the local municipality representative has the phone with them. Emergency response would have to visit each site to set up a system as there is a high likelihood that communication will be unavailable. Hence, it is unlikely that the communities in the Uummannaq fjord system would be able to retain coordinating capabilities in the hours following, due to the lack of a functioning mobile network.

The allocation of responsibility boundaries for formal and informal roles within the communities is dependent on the social structures at each site. Some formal roles exist, such as the community leader (*bygd foged*) who has authority in the absence of local police presence, and sometimes a local nurse or health professional. Three of the communities have a local fire station and fire fighters who would also be able to help in the initial phases of a tsunami event. However, most of these resources have only received basic training with little experience managing a major incident such as a tsunami. The expectation is that there would be significant material damage and casualties. As described above, there is a tradition of sharing resources and providing help to people in need. These informal structures contributed significantly in 2017 and would also be important in future events. Most community members know how to conduct themselves in the harsh Greenlandic environment, and the more experienced would be able to take charge of the situation. Without preparation and plans for after the event, there is a time limit for how long the communities would be able to sustain themselves.

The willingness of the community to work together before, during, and after an event is a strength. The local emergency response has only carried out a few exercises since the 2017 event focused on how the community should act during an event. In 2021, the national emergency response (GBS) and Arctic command conducted an exercise near the capital of Nuuk but without the participation of local response actors from the Uummannaq fjord system. There has not been any crisis management training of the coordinating resources in Uummannaq that would support cooperation between the main three agents: police, emergency response, and the local hospital. The emergency preparedness is preparing grab-boxes with supplies, but these are still under development and need further refinement before they are an effective tool in the response.

Organising includes the ability of communities to create systems that will ensure that they are prepared before, during, and after the event. Equipment like emergency packs, sleeping bags, tents, mattresses, food, and spare parts can be difficult to procure on short notice and have to be in stock before the event at a location accessible within a limited timeframe. The limited-time window means that each community need a local inventory to sustain people and components for critical infrastructures, such as diesel engine parts, chemicals, and filters and parts for wastewater systems. There would be limited access to power and heating, communication, freshwater, shelter and food following an event. The international maritime organisation recommends that ships traversing the Arctic have supplies and equipment to maintain survivors for five days. The emergency organisation could apply a similar approach to communities, ensuring that residents have enough supplies and shelter for the first three to five days before help arrives or additional supplies arrive. Such an approach would provide emergency response coordination enough time to access and make priorities between different sites depending on individual needs.

No one knows exactly how a tsunami event would evolve. In all scenarios, it is proposed that communities use their local knowledge, monitoring systems, and preparedness organisation to reduce the number of unknown variables they will need to manage during and after an event. Decision-makers in the community gain strategic foresight through learning, equipment, local knowledge, and practical experience. Strategic foresight will strengthen decision-making and increase robustness, helping communities gain confidence in handling scenarios within their responsibility domain. The decision-makers understand the impact a possible tsunami may have and will make decisions based on their foresight as to what will occur, based on distributed sensemaking, trust in the decision made, and a culture of support.

5. Discussion

The communities in Uummannaq fjord systems face a significant challenge in case of a tsunami event from Karrat 3 A + B and Kigarsima. Critical infrastructure and other cultural or social structures would be affected or destroyed. A lack of trained emergency response personnel that would be able to coordinate locally makes the communities even more vulnerable to disruptions. There is not much equipment at the individual settlements that can be used in case of a tsunami, which means that the majority would come from private homes or what the settlement office might have available. Half the settlements would lose their administrative office if a tsunami occurs, further reducing robustness. Also, most would lose their gas and oil supply storage, significantly affecting liveability, especially during the winter. Most houses would have their oil and gas source but need to be resupplied at some point. With the lack of training and modern equipment, vulnerable infrastructure, and low capacity to coordinate and support emergency efforts, the communities would likely be poorly equipped to deal with a possible tsunami event. Improvements to the warning system would provide some warning, but this would only be enough to ensure that inhabitants could run to higher ground or a designated meeting point. In this way, the ability to muster an adequate response is limited to saving lives, and less so to the effectiveness of preventive and protective barriers or in preparing communities to recover. Organisational capacity to take tactical and operational decisions is also hampered by the lack of emergency plans that are coordinated with the main stakeholders. Some exercises have been conducted, but these have typically been internal training within one agency or not involve the local response, such as the exercises in Nuuk in 2021. Local exercises would strengthen sensemaking capabilities and the coordination skills of incident commanders.

There are gaps in community resilience to a tsunami affecting the settlements and town in the Uummannaq fjord system. However, this does not mean that the communities are without the capacity to respond. A strong culture of support and trust in the community are essential elements that would impact the outcome of an event should it occur. Also, local knowledge would influence distributed sensemaking, ensuring that people know what action to do despite the lack of other forms of warning systems or until the installation of the new alarm

system. While these attributes may positively affect the outcome, it is difficult to predict what the result would be and to what extent it would change the overall outcome.

6. Conclusion

The community resilience model was used to test the resilience of communities in the Uummannaq fjord system. The model contained three elements: culture, trust and trustworthiness, and distributed sensemaking, which are overarching domains that influence all aspects of community resilience. The four elements of coordination, responsibility, cooperation, and organising centre on how a community organises to be resilient to specific events; in this case, tsunamis.

The paper has sought to explore how communities in the Uummannaq fjord system impacted by climate change can ensure sustained liveability through a community resilience approach. The analyses show how climate change impacts communities in the Uummannaq fjord system using the possible tsunami event in Karrat Fjord and Kigarsima. The model shows what impact such events can have on the sustained liveability of the six communities still inhabited in the fjord system. The argument is that communities are currently vulnerable to a possible tsunami event and liveability. Especially, critical infrastructure, such as access to energy, telecommunication, fuel, freshwater, grocery shops (food), and healthcare will significantly reduce community resilience. The conclusion is that, under the current conditions, the communities in the Uummannaq fjord system would not be able to manage a possible tsunami event with their current level of resilience nor recover their critical activities within a satisfactory timeframe.

The paper shows how it would be possible for communities in the Uummannaq fjord system to ensure sustained liveability through a community resilience approach. The communities have strengths that support their resilience and will form the building blocks for their robustness beyond the crisis. There is a strong culture of helping out when a crisis occurs, supporting efforts to strengthen community resilience. However, while these are essential elements of community resilience, they will not suffice in ensuring the effective management of a tsunami event. If community resilience is to be strengthened, investments in the relocation of critical infrastructure, emergency preparedness planning, and the recovery of critical activities must be made in all communities in the Uummannaq fjord system.

Communities can improve their resilience by engaging in a virtuous circle of learning and improvement. There have previously been emergency exercises in Uummannaq, and these experiences could serve as building blocks for training in coordination, cooperation, organising and assignment of responsibilities during disastrous events. Further building on the existing culture of experience-based knowledge as an approach to building non-theoretical knowledge has been proven difficult for individuals to translate into concrete action. Taking a holistic approach to community resilience means that authorities work to improve the performance of individual emergency actors (police, fire department and health services) and that volunteers, private enterprises and utilities like energy, telecommunication and water services become participants in the preparedness efforts. These communities are small even for Arctic standards (35 to 1407 individuals), and it would be unrealistic to expect that preparedness infrastructure could stand alone without the active participation of all types of actors. The task of the Greenlandic government is to provide funding and train local actors to improve their ability to coordinate, cooperate, organise and assign responsibilities in case of a disastrous event. Taking a bottom-up approach that will, eventually, impact the prevailing culture, build trust and trustworthiness and improve the distributed sensemaking process that is essential in case of a tsunami event.

As we witness climate-related disasters across the globe, the same challenges apply to the ones faced by communities in the Uummannaq fjord system. The approach and model are a step toward creating a general approach that takes on the practical challenges of building community resilience. However, much work remains in exploring the limits of the presented model and the practicalities of creating a robust social system. For research, practice and societies that utilise the approach, it is possible to improve resilience before, during and after an event. Such work includes the design of governance structures and innovations in critical infrastructure design, including energy and telecommunication for remote settlements. Research and practical procedures on the organisation of command and control and how networks of communities can support and organise together to improve their combined capacity to respond. Combined with plans for how to re-establish critical functions at remote sites in case their access to critical infrastructure is lost or destroyed, it is possible to achieve significant improvements to resilience.

CRediT authorship contribution statement

Jacob Taarup-Esbensen: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation.

Declaration of Competing Interest

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Data availability

Data will be made available on request.

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