Journal of Integrated Disaster Risk Management

IDRiM Journal

IDRiM FOR A SAFER WORLD

Volume 10
Issue 2
ISSN: 2185-8322

Journal of Integrated Disaster Risk Management

TABLE OF CONTENTS (Volume 10, Issue 2)

IDRiM (2020) 10 (2) **ISSN: 2185-8322**
DOI10.5595/001c.18136

Journal of Integrated Disaster Risk Management

Original paper

Memory, risk, and regional identity: Assessing the socio-cultural impacts of tornadoes in Oklahoma, USA

Ashley Allen[1]

Received: 16/08/2020 / Accepted: 05/11/2020 / Published online: 26/11/2020

Abstract Tornadoes are often seen as a way of life in the Great Plains region of the United States, with many stories of deadly storms originating before the 20th century. Because of this historic connection between people and their environment, residents of states such as Oklahoma develop distinctive sociocultural relationships to extreme weather, particularly associating tornadoes with social memory and regional identity. In this paper, I assert that shared memories of historic tornadoes are impactful to Oklahomans' regional identity as it relates to residents' relationships with risk. Multiple qualitative methods, including interview and archival research were used in order to identify the importance of this relationship to Oklahomans as a social group. Much importance is also placed on connecting the present to the past, and many Oklahomans have adopted tornadoes as a symbol of strength. While memories of these tornadic events do not negate the risks of living in a potentially dangerous environment, they also do not imply that risks should be avoided. Rather, facing these risks is seen as a practice in endurance that many Oklahomans believe they were built to face.

Key words: memory, risk, identity, hazards, tornadoes.

1. INTRODUCTION

When I interviewed an Oklahoma meteorologist about the importance of tornadoes in Oklahoma, he reiterated the idea that tornadoes and the risks involved are part of Oklahoman

[1] Geology and Geography, Ohio Wesleyan University (OH)

IDRiM (2020) 10 (2) **ISSN: 2185-8322**
DOI10.5595/001c.18136

identity. Speaking of his own fascination with tornadoes, he said “I always had mixed emotions, because they scared the daylights out of me sometimes, but I really liked it.”

The risk of tornadoes and the conscious societal decisions to keep on in the face of these risks are meaningful to many individuals and communities within Oklahoma. Listening to, engaging with, and sharing tornado stories can help people to establish important societal connections to memories of tornadoes past while using learned information to make decisions regarding future tornadic activity. More bluntly, my research shows how, by talking about the weather, Oklahomans have created a relationship to risk that is based on ideals of strength and community rather than apathy or fear.

This paper focuses on the socio-cultural impacts of the five deadliest tornadoes in Oklahoma (see Figure 1), which occurred in Woodward in 1947, Snyder in 1905, Peggs in 1920, Antlers in 1945, and Pryor Creek, colloquially and for the purposes of this paper referred to as “Pryor,” in 1942 (see Figure 2). Hilary Geoghegan and Catherine Leyson (2012) contend that researching weather qualitatively lets us understand and consider the day-to-day identities of those effected by extreme events, and how knowledge of everyday weather effects local understanding of extremes. This local understanding is the crux of what makes extreme weather events so culturally significant. Extremes disrupt normal activities and demand immediate attention, and their consequences are immediately meaningful. As Georgina Endfield and Lucy Veale (2017) wrote, “Indeed, while we make history in normal weather, extreme weather shapes history” (7).

Each of the tornadoes discussed is still significant to the cultural fabric of the community it devastated. By understanding what people shared about historic tornadoes and how those that received it engaged with that information, researchers can better understand how historical weather experiences are significant in shaping memories and identities even amongst current residents (Veale, Endfield, and Naylor 2014).

Weather is something that people experience, and these experiences influence culture and identity, though most often those stories are told through the perspectives of physical scientists (Meyer 2014, Endfield and Morris 2012, Geoghegan and Leyson 2012). Human experiences with weather are important for a multitude of reasons, mostly because it is the one thing that every person must deal with every day. Individuals make small and large decisions according to their daily weather report (who among us has found themselves without a necessary sweater or umbrella?). On a larger scale, weather impacts public health, travel, and community and regional economies (Endfield and Veale 2017, Geoghan and Leyson 2012, Peppler 2010, Danielson 1990).

Georgina Endfield and Carol Morris (2012) write that “climate and its cultural significance have, in effect, become decoupled, and popular conceptualisations and discourses of climate, and its manifestations through local weather, have been replaced by a global, and predominately scientific, meta-narrative” (1). This shift in discourse is something that many researchers are trying to correct, because it is also important to understand, especially in the context of extreme weather events such as tornadoes and how they effect memory and identity.

IDRiM (2020) 10 (2) **ISSN: 2185-8322**
DOI10.5595/001c.18136

Figure 1. Location of Oklahoma within the United States (cartography by author).

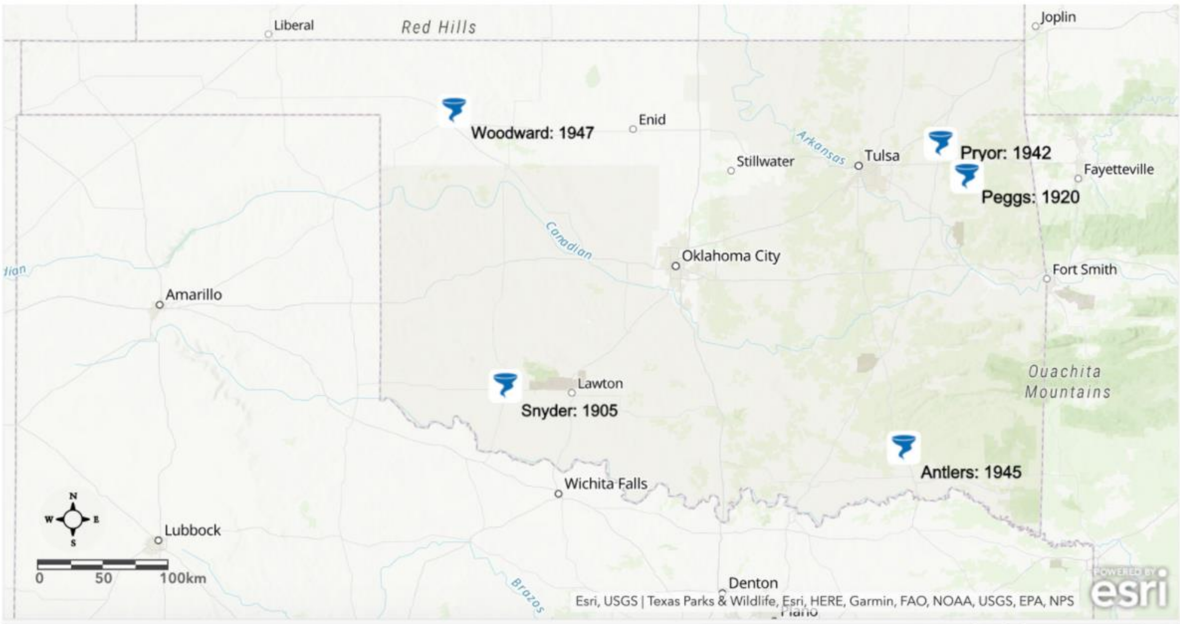


Figure 2. Locations of five towns where Oklahoma's deadliest tornadoes occurred (cartography by author).

In this paper, I focus on the memory work that these tornadoes accomplish through the sharing of individual stories and the creation of community narratives, which impact regional identity. In the context of this research, "memory work" refers to process of working through loss and trauma by revisiting the past, as discussed by Pierre Nora (1989) and Karen Till (2005) among others. This regional identity aligns with a sense of "Oklahomaness" as originally

IDRiM (2020) 10 (2) **ISSN: 2185-8322**
DOI10.5595/001c.18136

outlined by Howard F. Stein and Gary L. Thompson (1991). In this definition, Oklahomaness encompasses what it feels like to be Oklahoman.

In this paper, I outline the creation of "Oklahomaness" through the concepts of reflection (an understanding and awareness of risk), responsibility (an acceptance of risk and sharing of memories and community support), and regional identity (what makes someone Oklahoman in the context of this memory work). Through this framework, I show that tornado stories are meaningful to many individuals and communities within Oklahoma, and the social connections of talking about tornadoes, recent or not, are important to regional identity.

2. Methods

Multiple methods were employed for this study to show a complete picture of the significance these tornadoes have in Oklahoma's social memory, which is memory that is articulated and shared within social groups over time, often with the express purpose of creating connections and relationships between individual and group identities (Fentress and Wickham 1992).

The methods used to connect tornado stories to different aspects of memory work included archival research using the Oklahoma Historical Society research archives in Oklahoma City, the Oklahoma State Archives in Oklahoma City, Northeastern Oklahoma State University in Tahlequah, Oklahoma, and the Pryor Public Library, aided by their genealogy librarian, accessing museum and exhibition collections in Woodward, Kiowa County, Jackson County, Antlers, and Pryor, focusing on oral histories, recorded interviews with residents (both written and orated), letters, and autobiographical statements from community members. I also conducted 32 personal interviews in-person and over the phone.

To find interviewees, I placed ads in local newspapers and several Facebook groups, while concurrently hanging physical flyers in community meeting places asking for people to call or e-mail if they were willing to tell their tornado stories. Most of interviewees were survivors of the tornado or relatives of survivors. The other interviewees include members of the community that have grown up hearing stories, historians and museum employees, and a television meteorologist. Throughout this work, pseudonyms were assigned to interviewees who are not public figures and/or did not have previously publicized oral histories or interviews regarding their stories.

3. Reflection and Responsibility

The evaluation and management of risk is a social and political action that is often linked to memory. Memories of past hazard events impact risk perception and response, because they are directly linked to community awareness of risks and community understanding that hazards can and probably will occur again (Garnier 2019, Quevauviller, Ciavola, and Garnier

2017; Svenvold 2005). Writer Mark Svenvold (2005) explained this by saying, "Tornado season in Oklahoma can be seen as a reverse lottery, with everyone wondering Who will it get this year?" (211). This understanding that tornado activity in Oklahoma is not a matter of if, but when, led many residents to assign meaning to these storms in a way others may not. Tornado stories have become ingrained in the cultural fabric of Oklahoma, reminding residents of this risk, but also of the importance of community and coming together.

Geoff Wilson (2012) discussed how these memories can influence communities when it comes to risks and decision making. When communities learn from past hazard events, it speeds up resilient reactions and strategies, helping communities to use their understanding of previous events to mitigate and adapt to extreme events the next time they occur (Wilson 2013). It has also been argued that social memory aids resilience on a community level (Wilson 2015). Joanne Garde-Henson, Lindsey McEwen, Andrew Holmes, and Owain Jones (2017, 2012 as McEwen et. al) actually propose the concept of "sustainable memory" as a type of community-focused memory work that is furthered because of the need to retain knowledge, help future generations understand risk and resilience by contributing to local knowledge of past hazard events (in their case, floods).

The systems by which these memories are shared also impact disaster memorialization, as explained by Boret and Shibayama (2016). They describe this particular type memorialization as "any process that contributes to the preservation of memory of a catastrophe and its victims through tangible or intangible acts of remembrance" (Boret and Shibayama 2016, 438). Their approach includes memories shared through storytelling, as well as other formal and informal memory processes.

Those who live in environments, like Oklahoma, who often find themselves in the wake of tornadic destruction tend to have an intense understanding of and relationship with risk, and they are willing to take risks in order to be good community members (Table 1, Svenvold 2005). This is exemplified by this story from Woodward:

> This young kid decided he'd better go and see if he could be of help to somebody. So while he was walking along the railroad track and he discovered two boys was laying off the edge of the railroad track in the mud and dirt. They were stuck in filth. So he went and hunted a piece of tin. It came off of a house or something. But he put it down underneath the boys. He told them he would get help [for them] soon because he couldn't get them out alone. My uncle went out looking too, and when they finally found him, they got the boys out of that stuff and brought them home.
>
> We had no electricity. We had no water. We had no gas. Nothing like that you know. But anyway, we started cleaning those two boys. We found out that they lived in a two story house and their mother hollered and she said "Come on everybody come on there's a tornado!" And they just got to the bottom of the stairs when the wind picked them up.
>
> [The boys] had been wearing jeans, but when they found them the pants they had on were blown into little strips, just half the size of my finger, and they had nothing else

> on. They were literally covered with mud from head to toe. Inside of that mud there were splinters and wood and pieces of glass. They were covered from their hand to their toes. They cried and it was awful. My uncle had a cream can full of water sitting in the house. It was all the water we had. But we used it and went to work and cleaned them up as much as we could. – Anita (*Interview Field Notes 2015, 28-30)*

Using a household's last bit of water after a major tornado is a risky decision that no one should take lightly. However, this interviewee indicated that it was something she would do for any of her neighbors she felt needed help. This assumption of personal risk for the betterment of someone else is not unique to Oklahoma, but being friendly, helpful, and community oriented in the face of an emergency is part of Oklahoma's regional identity.

This kind of discussion and passing on of local knowledge happens a lot in Oklahoma, as shown here through my interviews. In this context local knowledge (also discussed as community, lay, traditional, Indigenous, or informal knowledge), are concepts understood to be common or ingrained within cultures, and they are increasingly cited as important to the role of understanding extreme weather events, as well as understanding how communities will adapt, understand, and manage future occurrences (Klockow, Peppler, and McPherson 2014, McEwen et al. 2012; Kitahara 2014).Many of my interviewees grew up hearing stories of major storms from older family members, teachers, and members of their community (Table 1). One interviewee, speaking about her father, said "He said it looked like a disaster area and you could hardly find nothing, and nothing really looked like... you know like you would remember it" *(Marylin, Interview Field Notes 2015, 111*). Though it may seem like a small statement, the simple understanding that these events bring chaos and change the landscape can help prepare future generations for what could come their way (Peppler, Klockow, and Smith 2018; Garde-Henson et. al 2017; Klockow, Peppler, and McPherson 2014)

Randy Peppler, Kimberly Klockow, and Richard Smith (2018) discussed the perception of community risk in Central Oklahoma through the employment of focus groups in Norman, Newcastle, and Moore. Interestingly, many of their subjects equated home with security, perceiving less tornado risk despite scientific evidence. In contrast, my interviewees seemed to embrace the notion of risk as part of the community they chose (Table 1). This assertion alone shows the power of memory work. The interviewees in this study have confronted the most violent tornadoes in history, whether in experience or through social memory processes, and accept that one could hit again (Table 1, Table 2). Further, the cultural significance of these storms encourages people to keep telling their stories, perpetuating the idea that tornado risk is not only something that Oklahomans live with, it's something that makes them Oklahoman in the first place.

I found that one of the key components of Oklahomaness with regard to extreme weather was an acceptance of risk, rather than merely an assumption that tornadoes could occur. The vast majority of interviewees from Woodward not only discussed the tornado of 1947 but went on to compare it to the tornado that hit the town in 2012, with one survivor saying, "it wasn't as bad as the last one, but I always knew it could happen again." Another explained her fear for her family, comparing it to what she had experienced decades before:

> And then when the second one hit here in Woodward [in 2012] my granddaughter was living up on that end of town where she and her three kids had just left and gone to somebody's house when that thing hit. And it got the house they were living in. So they were lucky they weren't hurt. So we're all worried. It was pretty scary for a few years after that. Teresa *(Interview Field Notes 2015, 39).*

An interviewee from southwest Oklahoma told me a story from his childhood that is exemplary of this kind of understanding. He said:

> Woodward psyched us out. … I remember some of the warnings early on … and it was a big deal when it happened. … you know it's scary after that. Seiling finally got hit. I don't know how old I was, but I was in elementary school. And my grandma's house is where everybody would gather on a Saturday night. At grandma's house the men would play cards and drink whiskey and the women would cook pies and cakes or whatever for the next day for Sunday. But the guy living next door to us, just to the west, had a cellar. And one night it was stormy and they blew the sirens. And you know, a town like that is an isolated town. You don't have much communication, but we all would pile on over to the to the cellar and everybody got in there and the wind was really picking up.
>
> Well, my uncle and my granddad decided they were not going to the cellar. They never went to the cellar. They stayed in there playing cards and we were down there in the cellar and you got the big concrete vent I guess, and you could hear it coming. You can you hear this roar. And anyway, then it passed and we opened the door. We found granddad on one side of the cellar door and my Uncle on the other side in the mud face down.
>
> They said they'd been beating on the door. We couldn't hear them because of the storm. And every time after that they were the first to go, so they learned a good lesson there. -- Gary *(Interview Field Notes 2015, 68-69)*

In so many words, if you get put face down in the mud once; you'll head to the cellar for the rest of your life.

4. Regional Identity and "Oklahomaness"

I found that the key components of "Oklahomaness" with regard to extreme weather were both an acceptance of risk, and an understanding that Oklahomans are always resilient and willing to stand together in the face of adversity (Table 1, Table 2). This is apparent in both the vernacular memory of Oklahoma and through formal memory systems. The Oklahoma History Center in Oklahoma City holds and displays many artifacts from tornadoes across the state. The Twister Museum in Wikita pays homage to the movie by showcasing memorabilia including replica Dorothy sensors for sale (a steal for only $5 considering the price of working weather forecasting equipment). Venues like the Plains Indian and Pioneers Museum in

Woodward, the Coo-Y Yah Museum in Pryor, and the Kiowa County Historical Society all have permanent exhibits regarding the Woodward, Pryor, and Snyder tornadoes, respectively. Memorials to tornado victims are present in Woodward, Snyder, and Antlers. Woodward's is downtown, displayed in conjunction with their World War Two and Vietnam Memorials. Snyder dedicated a memorial headstone to unknown victims in the local cemetery. The Pushmataha County Historical Society dedicated the Antlers memorial, which stands on their grounds outside the former railroad depot, which is fitting considering two of their volunteers survived the storm.

Within her work, anthropologist Sunday Moulton (2015) discusses how disaster impacts memory and identity by forming a collective narrative of each event. Though Moulton discusses memory and identity after tornado stories as venues for communities to recover and eventually forget, I claim that remembering those stories, sharing them, and learning from them creates a strong regional bond and support system that makes Oklahomans more adaptable in the face of extreme tragedy.

Table 1. Quotations from interviews reflecting key themes of reflection (an understanding and acceptance of risk) and responsibility (sharing of memories regarding community support).

Reflection	"My grandparents lived through [the Peggs tornado]. Every time we had a bad storm, my grandma would tell me about it; she said everything gets destroyed." – Molly; Peggs, OK "It seemed like even the dog remembered. He'd always want to go to the cellar after [the tornado.]" –Teresa; Woodward, OK "We always watch the radar and always have. My dad thought it might happen again, then I just got in the habit." – John; Pryor, OK "We always talk about tornadoes when we talk about home." – Ramona; Woodward, OK
Responsibility	"... my dad and my two uncles were building our house back. When it was built, the Red Cross bought our furniture for us." – Alice: Antlers, OK "My grandpa was a 16-year-old kid and he helped bury the bodies. He said they wandered around looking but they never found all of them." – David; Snyder, OK "The patrol helped keep order. I don't think we had a lot of pilfering or damage but every [business] had someone there kind of looking after the store." – Carl; Pryor, OK

IDRiM (2020) 10 (2) ISSN: 2185-8322
DOI10.5595/001c.18136

Table 2. Quotations from interviews reflecting regional identity (what constitutes "Oklahomaness" in the context of this memory work).

Regional Identity	"We tell that story every once in awhile. You know there are so many more tornadoes than there used to be." – Alice: Antlers, OK "We wrote a book about it, me and a couple of the teachers, we wanted people to know what happened to our home." – L.O.; Woodward, OK "You know being from Oklahoma, you don't mess around after tornadoes like that." – Carl; Pryor, OK "I grew up in the tornado belt, you might say." – Gary; Oklahoma City, OK "Honey I'm always ready. How long are you staying? Do you want to see where the basement door is out back?" -- Anita; Woodward, OK

My own research confirms that narratives explaining the importance of sharing and remembering past tornado stories are incredibly prevalent in Oklahoma, and almost universally involve perseverance, strength, rebuilding, and the support of the community. One of my interviewees said,

> People remember where they were when something happens like a before and after. You remember where you were when this happened or that happened, and the Woodward tornado was one of those periods of time. You remember what happened before and then that was an absolute benchmark - going from there. – Teresa *(Interview Field Notes 2015, 11)*

These benchmarks, and how we communicate them, are what make tornado memories relevant on a social and regional level. When a person or community goes through a traumatic weather event, it raises questions about what that means, what sort of knowledge that brings, and how it changes the community. In terms of loss to the physical landscape, communities work to connect to one another's experiences. Karen Reid, Ruth Beilin, and Jim McLennan (2020) discussed this in terms of community responsibility. They found that people felt a need to continue social traditions while reconstructing new, place-based identities, writing "social memory can only exist in the relationships between individuals and others (or how we imagine ourselves and others) (Reid, Beilin, and McLennan 2020, 42). In Oklahoma, those communities also take great care to ensure that their loved ones are not forgotten. One interviewee said:

> To me, if you don't tell [the story] or write it down it's gone. It's gone forever… the main thing is if you don't get it down somewhere or another it's just gone. Nobody will ever know. – L.O. *(Interview Field Notes 2015, 11)*

Stories are often as simple as explaining what a tornado looked or sounded like, or how the experience made people feel. In describing what the Woodward tornado was like, one survivor said:

> We'll never know all that happened. It was just everything was such a mess. You didn't even know where to look or go first… that was the saddest day of my life. --- Ramona (*Interview Field Notes 2015, 38*)

This kind of discussion is deceptively simple. By telling people how a tornado feels, both physically and emotionally, listeners become privy to explicit information that otherwise would be unavailable outside of experience. By continuing the tradition of telling stories of past events, the idea that a tornado could hit at any time has weaved its way into the collective narrative of many communities (Table 2). This was exemplified in many of my interviews, like this one, which was recalled by many residents of Pryor, but quoted here from my interview with the victim's cousin:

> During the storm, my cousin got swept away. He was three months old and just got ripped out of my aunt's arms. They thought they lost him and were really torn up about it. Turns out, the wind carried him seven miles out of town, and a couple found him on their property. The roads were blocked so they just took care of him for a week or so until they could take him back to town. He wasn't hurt or anything. He just went cross-eyed for a bit, but those straightened out eventually. –Jeff (*Interview Field Notes 2015, 102*)

Moreover, stories often highlight the actions of community members in helping their fellow residents have the capacity to alter the way a person feels about or sees themselves within their community. In many of my interviews with survivors, interviewees discussed their experiences in the context of their interactions with members of the community like this one, also from Pryor:

> Well I know when I first knew we were in trouble. My brother, Bob, and I were sitting out in the car in front of the bank. It wasn't raining that hard even. I turned looked out the window and saw the top had blown off the grain elevator and went about three or four blocks. I turned to Bob and said "We better get down. Here it comes!" He said "What?" and I said, "the elevator top!" I did no more than get that out and Bob jumped on top of me right before that thing hit the top of our car. I was in the floorboard. Bob said he couldn't have beat me down [further]. That was a scary time. I don't know how to tell you how it feels.
>
> Before, the town was how it had always been. Everybody knew about everybody in it. And after that it felt different. It was just a couple minutes and Tom Miller had come out [of the bank] and was trying to get that top off [our car]. People were coming from down Main Street to [get] Bob and I [out]. – Toby (*Interview Field Notes 2015, 97-98*)

The act of surviving these storms has become a point of pride for many communities as well, like Snyder, whose high school mascot is still the Cyclone, a symbol of strength, power, and

DOI10.5595/001c.18136

community pride in the face of tough opposition. One interviewee, the grandson of a survivor who grew up in Snyder, told me that even when he was growing up in the 1960s, Snyder was known as the “tornado town,” saying “My mom would take me to [the nearest city] to get my hair cut and the barber would say ‘Snyder! That’s the tornado town!’ It always made me feel kind of cool to be from here” (*A.J. Interview Field Notes 2015, 134*).

Mike Hulme (2016) discussed the fear some people experience when living in volatile climates that are prone to extreme events. What is interesting about Oklahoma is that many individual fears seem to be calmed by the idea that whatever happens, their community will help take care of them. This sense of community togetherness is part of the cultural fabric of Oklahoma, and the concept was reiterated by many interviewees when discussing past and future tornado events.

Only two survivors I interviewed discussed being fearful of storms due to their past experiences, and both followed up those assertions by telling me about their shelter plans. Multiple interviewees indicated their homes, basements, and storm shelters were available to me should the need arise, with one saying:

> Yes. You know we just always go to the cellar because we’re trying to save our life and our children and everything. We know everybody. All of our neighbors know everybody. Not so long I had a whole yard full of people out here getting in the cellar.
>
> All the neighbors around here didn't have storm shelters so right when they move in, I tell them their welcome to come if they need it. The back door is always unlocked. I would never lock the door if I thought a storm was coming. You can look and see where it is if you need it. – Ramona (*Interview Field Notes 2015, 34*).

This type of support for other community members, even when they are strangers, exemplifies the regional ideas of community and unified strength when facing these storms**.**

5. CONCLUSIONS

Memory work and memorialization, both formal and informal, shows how social memory reaches out, affects, and changes how Oklahomans become part of a community that understands tornadoes even if they do not experience them. By focusing on the memory work that is applicable to different extreme weather and natural hazard events, I answer the question of how community building is possible and how memory can create a sense of community understanding.

This work builds on hazards research to show that not only is memory work important in terms of learning about extreme hazard events, but it also helps people to adapt and mitigate future events through connecting to community. These connections range from local governments recognizing anniversaries of major events, to the commissioning of memorials and exhibits, to the act of past tornado survivors reaching out to their own or other communities in times of need. Agencies like the National Weather Service and/ or the Federal Emergency Response Administration could also benefit from these local connections. By gaining a better understanding of local knowledge, belief systems, and social structures, agencies can understand why the public does or does not respond to crucial warning systems or mitigation efforts. The lack of formal avenues for sharing tornado stories may be one of the reasons that memory is often overlooked in formal risk management procedures. By opening up lines of communication between community members, hazards specialists, and government stakeholders, a more holistic type of hazard mitigation that incorporates local knowledge of risk could be employed. This could be done through the creation of focus groups, discussions with representatives appointed from community groups, informal sharing, or a combination of the three.

To many Oklahomans, tornadoes are more than just extreme weather events or risky rare occurrences, they are an integral part of who they are and where they come from. Much importance is placed on assigning meaning to the past and talking about it in the present. With tornadoes, what should be a terrifying loss becomes an example of how Oklahomans identify as community builders, helpers, and always "OK".

REFERENCES

Boret, P. S., Shibayama, A. (2016). Archiving and Memorializing Disasters. Report of a UN International Workshop, *Journal of Disaster Research*, *11*(3).

Danielson, L. (1990) Tornado Stories in the Breadbasket: Weather and Regional Identity. B, Allen and T. J, Schlereth (Eds.). *Sense of Place: American Regional Cultures* (pp. 28-39). Lexington, Kentucky: The University Press of Kentucky.

Endfield, G., and Morris, C. (2012). Cultural spaces of climate. *Climactic Change*, *113* (1), 1-4.

Endfield, H. G. and Veale, L. (2017). Climate, culture, and weather. Endfield, G., and Veale, L (Eds.). *Cultural Histories, Memories, and Extreme Weather* (pp. 1-15). London: Routledge.

Fentress, J. and Wickham, C. (1992). *Social memory*. London: Blackwell.

Garde-Hansen, J., McEwen, L., Holmes, A. and Jones, O. (2017). Sustainable flood memory: Remembering as resilience. *Memory Studies, 10*(4), 384-405.

Garnier E. (2019). 'Lessons learned from the past for a better resilience to contemporary risks', *Disaster Prevention and Management*, *28*(6), 778-795.

Geoghegan, H., and Leyson, C. (2012). On climate change and cultural geography: farming on the Lizard Peninsula, Cornwall, UK. *Climactic Change, 113* (1), 55-66.

Hulme, M. (2016). *Weathered: cultures of climate*. SAGE Publications.

Kitahara, I. (2004), Exhibition on «Documenting disaster: natural disasters in Japanese history 1703-2003». *Annals of Geophysics*, *47*, 909-911.

Klockow, K., Peppler, R. , and McPherson, R. (2014). Tornado folk science in Alabama and Mississippi in the 27 April 2011 tornado outbreak. *GeoJournal, 79*, 791-804.

McEwen, L., Krause, F., Jones, O., and Garde-Henson J. (2012). Sustainable flood memories, informal knowledge, and the development of community resilience to future flood risk. In *Flood Recovery, Innovation and Response III* eds. D. Proverbs, S. Mambretti, C. A. Brebbia, & D. De Wrachien. Ashurst, Southampton, UK: WIT Press.

Meyer, B. W. (2014). *Americans and Their Weather*: Updated Edition. New York: Oxford University Press.

Moulton, M. S. (2015). How to Remember: The Interplay of Memory and Identity Formation in Post-Disaster Communities. *Human Organization,* 74 (4), 319-328.

Nora, P. (1989) Between memory and history: Les lieux de mémoire. *Representations*. 7-24.

Peppler, A. R. (2010). "Old Indian Ways" of Predicting the Weather: Senator Robert S. Kerr and the wWnter Predictions of 1950-51 and 1951-52. *Weather, Climate and Society*, *2*(3), 200-209.

Peppler, A. R., Klockow, E. K. and Smith, D. R. (2018). Hazardscapes: Perceptions of tornado risk and the role of place in central Oklahoma. J. S, Smith (Ed). *Explorations in Place Attachment* (pp. 33-45). London: Routledge.

Quevauviller P, Ciavola P and Garnier, E (Eds.). (2017). *Management of the Effects of Coastal Storms: Policy, Scientific and Historical Perspectives*. Chichester: John Wiley & Sons.

Reid, K., Beilin, R. and McLennan, J. (2020). Communities and responsibility: Narratives of place-identity in Australian bushfire landscapes. *Geoforum, 109*, 35-43.

Stein, F. H. and Thompson, L. G. (1991). The sense of Oklahomaness: Contributions of Psychogeography to the Study of American Culture. *Journal of Cultural Geography*. *11*(2), 63-91.

Svenvold, M. (2005). *Big Weather: Chasing Tornadoes in the Heart of America*. New York: Henry Holt and Co.

Till, K. 2005. *The New Berlin: Memory, Politics, Place*. Minneapolis: University of Minnesota Press.

Veale, L., Endfield, G. and Naylor, S. (2014). Knowing weather in place: the Helm Wind of Cross Fell. *Journal of Historical Geography*, *45*, 25-37.

DOI10.5595/001c.18136

Wilson G. A. (2012). *Community Resilience and Environmental Transitions*. London: Routledge.

Wilson G. A. (2013). Community resilience, social memory and the post-2010 Christchurch (New Zealand) earthquakes. Area *45*(2), 207-215.

Wilson G. A. (2015). Community Resilience and Social Memory. *Environmental values, 24* (2), 227.

IDRiM (2020) 10 (2) ISSN: 2185-8322
DOI10.5595/001c.21409

Journal of Integrated Disaster Risk Management

Original paper

Assessment of Social Vulnerability in the Evacuation Process from Mount Merapi: Focusing on People's Behavior and Mutual Assistance

Faizul Chasanah [1 2*] and Hiroyuki Sakakibara [1]

Received: 15/08/2020 / Accepted: 11/12/2020 / Published online: 08/03/2021

Abstract In Merapi volcano mitigation, the cooperation within/between the local communities is a key strategy for effective evacuation. In the "sister village" scenario, the meeting area and shelter have been coordinated, but people's behavior has not been fully considered yet in the vulnerability assessment and government's contingency plan. The purpose of this study is to assess the people's behavior, mutual assistance, and social vulnerability index of pedestrian evacuation in four affected regencies. First, we measured the walking speed directly, conducted interviews with stakeholders, and focus group discussions with local communities. We used the multicriteria method and focused on two factors, social and age structure (young, vulnerable, and mutual assistance between them), and risk perception (work, rain, night, alert, and destination). The index reflects the distribution of actual walking speed, mutual assistance, and the government's plan. The result showed that mutual assistance groups have a higher walking speed than vulnerable people but lower than young people. Mutual assistance coordination is crucial to support vulnerable to effective travel time. The social and age structure of the social vulnerability index has a stronger risk influence than the perception factor in the evacuation process. However, these two factors have a minor impact on social vulnerability to the total population.

Key words: Pedestrians evacuation speed, people's behavior, mutual assistance, social vulnerability.

[1] Graduate School of Sciences and Technology for Innovation, Yamaguchi University
[2] Department of Civil Engineering, Faculty of Civil Engineering and Planning, Islamic University of Indonesia
* Corresponding author Email: b506wd@yamaguchi-u.ac.jp

1. INTRODUCTION

Mount Merapi is the most active volcano in Indonesia, and the impact of the 2010 eruption was ranked third in the world (Guha-Sapir *et al.* 2016). During the last major eruption, more than 400,000 people evacuated, and over 50,000 people kept staying in the high-risk zona (Mei *et al.* 2013). In this disaster, crisis management problems such as congestion and evacuations delay were found. Congestion during evacuation not only reduces the effectiveness of evacuations but also leads to traffic accidents (Rizvi *et al.* 2007). Risk analysis is essential to develop efficient and adequate strategies for implementing the various components of development-oriented emergency aid and reconstruction planning to less vulnerable and more sustainable development measures (Federal Ministry for Economic Cooperation and Development 2004). Following UNESCO practice, Risk can be defined as = "Hazard x Vulnerability", with hazard referring to the physical events produced by an eruption and vulnerability including a consideration of the consequences for people, buildings, infrastructure, and economic activity (Scarpa and Tilling 1996).

There are four affected regencies in the Merapi eruption, and each Regional Disaster Management Agency has mitigation and prevention plans for handling this disaster. All maps about the hazard, vulnerability, and evacuation have become available and contingency plans documents have been updated by 2020. The regency governments are always improving development cooperation and the cooperation of the local community is a key strategy for effective evacuation. In the "sister village" scenario, the pair of meeting areas and shelter has been coordinated. The governments prioritize to evacuate vulnerable people from the meeting area to shelter, and young people need to evacuate from their houses to the meeting area or shelter by themselves (Boyolali District Disaster Management Agency 2019, Klaten District Disaster Management Agency 2018, Magelang District Disaster Management Agency 2017, Sleman District Disaster Management Agency 2019). Nakamura *et al.* (2017) confirmed that an effective relationship and communication with local communities is an essential factor in Community-based disaster-prevention meetings (CDPMs). It is crucial to improve not only understanding of disaster but also human communication and interaction between different generations. The risk perception is also one of the important factors in people's behavior during the evacuation process. The poor risk perception is characterized by an approximate personal representation of the volcanic processes, an excess of trust in concrete countermeasures, the presence of physical-visual obstructions, or cultural beliefs related to former eruptions (Lavigne *et al.* 2008). In this case, the community's behavior has not been fully considered yet by our government in vulnerability assessment. Therefore, the objective of this study is to observe the walking speed of the evacuation simulation, to analyze the people's behavior and mutual assistance, and to assess the social vulnerability index of social and age factor and risk perception factor.

2. DATA COLLECTION AND METHOD

2.1 Data collection

This study focuses on hazard zone III of Mount Merapi. This means that the vulnerability and risk are extremely high and the priority to evacuate is highest. The area is located within a radius of 10 km from Mount Merapi. Administratively, this volcano is located on the border between Yogyakarta Special Province (Sleman Regency) and Central Java Province (Boyolali, Klaten, and Magelang Regencies). Data collection was done through a survey. The total of survey locations is 4 regencies involving 11 villages in Boyolali, 5 villages in Klaten, 19 villages in Magelang, and 7 villages (24 hamlets) in Sleman. These spots were determined according to the government contingency scenario and hazard map. Especially, the village area in Sleman is exceptionally large so the regency government maps the risks according to the hamlet. Table 1 is a description of the survey sites.

Table 1. Detail of survey sites

Regencies	Research Location
Boyolali (11 villages)	Tlogolele, Klakah, Jrakah, Lencoh, Samiran, Surotoleng, Wonodoyo, Jombong, Cluntang, Mriyan, and Sanggup
Klaten (5 villages)	Balerante, Tegalmulyo, Sidorejo, Panggang, and Bawukan
Magelang (19 villages)	Kaliurang, Nglumut, Ngablak, Ngargosoko, Tegalrandu, Mranggen, Srumbung, Kemiren, Kapuhan, Wonolelo, Ketep, Ngargomulyo, Sewukan, Sumber, Kalibening, Keningar, Sengi, Krinjing, and Paten
Sleman (24 hamlets)	Ngandong, Nganggring, Tunggularum, Gondoarum, Sempu, Manggungsari, Turgo, Ngepring, Kemiri, Boyong, Ngipiksari, Kaliurang Timur, Kaliurang Barat, Pelemsari, Pangukrejo, Jambu, Kopeng, Batur, Pagerjurang, Kepuh, Manggong, Kalor, Kalkid, and Srunen

The purposive sampling method was used to collect the data. As secondary data, contingency plan documents from the Regional Disaster Management Agency in each regency and contingency plan documents from the village offices were checked. Primary data was obtained from the interviews with 50 stakeholders, forum group discussion with 658 local communities, and the walking speed of 518 volunteers was measured. The distribution of these respondents and volunteers already represented all affected villages. Interviews were conducted with the village leader and several stakeholders at the Regional Disaster Management Agency. The local communities participating in forum discussions and simulations consist of young and vulnerable people. Young people are defined as the group having ages 12 to 59 years old. While vulnerable people consist of breastfeeding mothers, pregnant women, children, elderly, and people with disabilities. People aged 0 to 11 years old are categorized as children, and aged more than 60 years old are categorized as elderly. The questionnaire instrument used was tested for validity and reliability using SPSS software. The test is done at a 5% level of significance. The walking speed was measured directly where volunteers were asked to walk through a route for about 250 m to 500 m distance. The observer used a walking measure tool, timer, and handy cam to record the data. The actual evacuation distance from homes to the meeting areas of each affected village is different, but the average distance is about 1-3 km. It is obtained according to the evacuation map of each village by measuring the distance from the hamlets center to the meeting areas, and confirmed by the village leader. Figure 1illustrates how the survey was conducted.

Figure 1. Documentation of interview, forum group discussion, and simulation

2.2 Data analysis

Walking speed data and mutual assistance impact are analyzed with descriptive statistics such as mean, standard deviation, and others. The Analysis of Variance (ANOVA) is also used to analyze this data. The Evacuation group and location were categorized into different groups according to their levels. The evacuation group was categorized as young without baggage, young with baggage, young and children, young and pregnant mother, young and elderly, young and disabled, breastfeeding mother and baby, pregnant mother, children, elderly, and disability. While the location was categorized as Boyolali, Klaten, Magelang, and Sleman regencies. All tests were done at a 5 % level of significance. Furthermore, the social vulnerability index was assessed with a multicriteria method.

DOI10.5595/001c.21409

2.3 Social vulnerability index

The risk analysis, risk evaluation, and risk management are part of the holistic concept of risk assessment (Glade and Bell 2004). There are two essential elements in risk assessment namely hazard and vulnerability. The probability of occurrence of a harmful natural event is defined as a hazard (Federal Ministry for Economic Cooperation and Development 2004). While the meaning of vulnerability is the characteristics of people, households, or economies that increase the likelihood to suffer damage given a hazard event. It is considered a formulation of many factors such as exposure, capacity, resilience, livelihood stress, susceptibility, sensitivity, and/or weakness (Lowe 2010). Velasquez (2003) confirmed that in case many vulnerability factors contribute to a hazard or a set of hazards, the total risk can be expressed as:

$$R = \sum_{i=1,j=1,k=1}^{n} w_i H_i * (\alpha_{ijk}) w_j V_{ij} \quad (1)$$

Where R represents the total risk, H_i represents the different hazards, V_{ij} represents the different vulnerabilities corresponding to these hazards, α_{ijk} is the social factor parameter that increases or decreases the hard vulnerability, w_j is the weight of importance of a selected vulnerability factor, and w_i is the weight of a hazard.

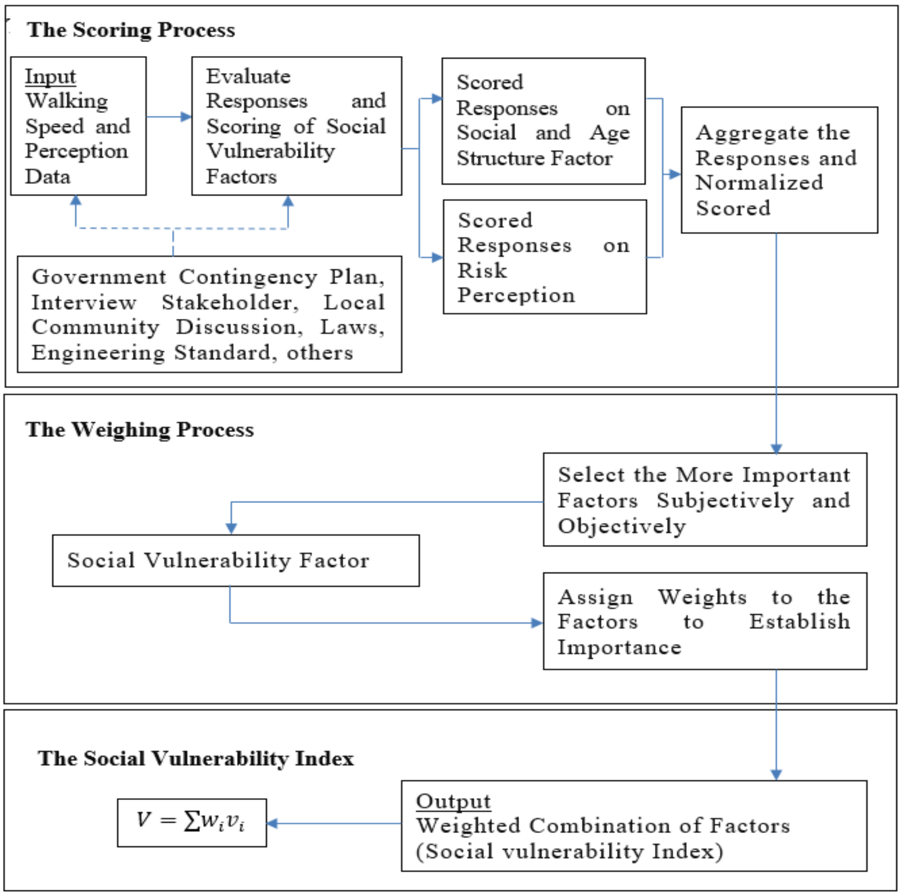


Figure 2. The assessment framework

Federal Ministry for Economic Cooperation and Development (2004) explained that vulnerability factors have four classifications. They are economic vulnerability factors, physical vulnerability factors, social vulnerability factors, and environmental vulnerability factors. Especially, the variable of social vulnerability factor consists of the traditional knowledge system, risk perception, education, legal situation and human rights, civil participation, social organizations and institutions, legal framework, politics, social and age factor, health status, power structures and access to information. There are five top categories for the most useful social vulnerability. They are gender, public health condition, public infrastructure, and migration. Previous studies have been limited to measure the social vulnerability index in a natural disaster. Consequently, additional research is needed to develop the social vulnerability index and to develop appropriate variable weighting schemes and valid indices (Fatemi 2017). Therefore, an assessment of the social vulnerability index is purposed in this research. The community behavior analysis and mutual assistance strategy are our concern to get more effective pedestrian evacuation. In this case, people behavior variable is divided into two factors consisting of social and age structure and risk perception. Young people, vulnerable people, and mutual assistance groups are classification of social and age factors. While risk perception factor considers various conditions of working, rain, night, alert, and destination understanding. The assessment method is carried out in 3 stages including decision framework, criterion design, and multicriteria evaluation. The decision framework is shown in Figure 2.

Criterion design of the social and age structure factor is very dependent on walking speed data from the simulation. Truong *et al*. (2018) confirmed that the average speed and 15th percentile crossing speed from all survey sites and crossing types are 1.49 m/s and 1.25 m/s, respectively. The overall 15th percentile speed of 1.25 m/s is close to the normal walking speed of 1.2 m/s often adopted for both green walk and flashing red do not walk time design (Austroads 2016). According to Highway Capacity Manual (HCM) and Indian Roads Congress (IRC) method, pedestrian speed results in Level of Service (LOS) varies with gender, age group, group size, and trip purpose (Sangeeth and Lokre 2019). LOS of walkways and sidewalks is classified as high if the speed is above 1.3 m/s (Transportation Research Board 2000). Each country has a different pedestrian mean speed. Pedestrian speed in developed countries is higher than in developing countries. Pedestrians of developing countries have a free flow mean walking speed of 1.2 m/s (Rahman *et al.* 2012). Also, Yosritzal *et al*. (2018) confirmed that the average walking speed during the simulation of tsunami evacuation in Indonesia was 1.419 m/s. It is varied by age and gender of the evacuee. Based on the previous study, criterion design in the current study were determined by 1.40 m/s standard because of the evacuation case approach and location of the same country. We consider the similarity of people's behavior in developing countries (Indonesia) and emergency response because studies about the pedestrian evacuation of volcanic eruptions are still limited. Meanwhile, the criterion design of risk perception factors depends on the questionnaire data from local communities. Table 2 and Table 3 clarify the scoring criteria for both factors.

Table 2. Scoring criterion design of the social and age structure factor

Categories	Score	Description	Description to Consider (values)
Young People Vulnerable People	0	Not Vulnerable	Faster than the mean walking speed standard (≥ 1.4 m/s)
Mutual Assistance Group	1	Vulnerable	Slower than the mean walking speed standard (< 1.4 m/s)

Table 3. Scoring criterion design of the risk perception factor

Score	Description	Description to Consider (values)
Work condition		
0	Not Vulnerable	Direct evacuation to the waiting area
1	Vulnerable	Returned home to meet family
Rain condition		
0	Not Vulnerable	Direct evacuation to the waiting area
1	Vulnerable	Delay until the rain stop
Night condition		
0	Not Vulnerable	Direct evacuation to the waiting area
1	Vulnerable	Delay until morning
Alert condition		
0	Not Vulnerable	Direct evacuation to the waiting area
1	Vulnerable	Delay until seeing an eruption
Understanding of destination		
0	Not Vulnerable	Understand the waiting area
1	Vulnerable	Do not understand the waiting area

The next step is to assess the social vulnerability index using the multicriteria method. Based on the guidelines of quantifying the social aspects of disaster vulnerability, Velasquez (2003) explained about equation form as follow:

$$V = \sum w_i v_i \tag{2}$$

Where V is vulnerability, w_i is weight of factor i, v_i is criterion score for vulnerability factor i.

The detailed assessment is described into four processes.

1. Determine the relative weight
   Evaluate all respondent data and scoring based on the average delay evacuation categorized as vulnerable. The score of delayed evacuation is 1 and the score of direct evacuation is 0. Where R = raw score
2. Normalized the score

Normalize the factors to 0-1 (0 not vulnerable, 1 = vulnerable).
Where *Xi* = (*Ri-Rmin*)/(*Rmax-Rmin*).

3. Calculate the criterion weights
   Subjectively, the factor weights and normalized weight of important reveal are decided. Assigning criteria uses a simple pairing procedure utilizing at nine-step scale. This value indicates the relative scale of importance including 1/9, 1/7, 1/5, 1/3, 1, 3, 5, 7, and 9. The meaning of 1/9 is less important, 1 is standard, and 9 is more important.

4. Reveal the weighted linear combination of factors
   Social vulnerability index = $w1v1 + w2\ v2 + \ldots + w_n v_n$

3. RESULT AND DISCUSSION

3.1 Characteristics of the local communities and population

We collaborated with the affected village offices to invite the members of local communities to fulfill the population proportion and people's behavior. Volunteers from local communities are fully recommended by the village leader or hamlet leader. These volunteers represent 8 types of people's behavior including young people, children, pregnant mothers, breastfeeding mothers, elderly, disability, driver, and breeder. The children were represented by ages 5 to 11 years old, the young were represented by ages 12 to 59 years old, and the elderly were those aged 60 years old or more. While breastfeeding mothers are mothers carrying babies and toddlers. The volunteers who own private cars and trucks are categorized as drivers and having cattle and or goats are categorized as breeders. Each type of volunteers consisted of both female and male. We organized 16 volunteers in each village or hamlet to conduct focus group discussions and then measured the walking speed directly. However, at the execution time, some volunteers exceeded the number of the invitation, and some lacking. This condition was caused by situations such as rain, night, and limited disabled people.

The local communities in the four affected regencies have similar characteristics. The results of the primary and secondary data collection show that the population is dominated by young people with details for the Boyolali and Klaten Regency at 64%, Magelang Regency at 81%, and Sleman Regency at 72%. The majority of the local community's livelihoods are agriculture and livestock farming. Data of students and workers outside the residence village for the affected regencies of Boyolali, Klaten, Magelang, and Sleman are about 5%, 10%, 20%, and 25%, respectively. It means that many residents stay in the villages during the daytime. This condition will influence the evacuation plan scenario if a disaster occurs at the time. As for single elderly data, the proportion of the population is exceedingly small, and elderly people usually live with their family or their homes nearby. Social culture with neighbors in these regencies is good and residents help each other. Therefore, the concept of "Mutual Assistance" between young people and vulnerable people in this evacuation case is possible to conduct.

The "sister village" scenario is a key strategy in mitigation development by the government. The cooperation concept is implemented through an agreement between the affected village and the sister village. The agreement includes the role of handling disaster emergencies such as providing shelter, logistics, and others. Sister village can be specified from the villages within the same regency or other regencies. On the other hand, evacuation transportation is the responsibility of the regency government and the affected communities. At level 3 status, the government will appeal to all residents for evacuation. Residents are expected to evacuate independently and simultaneously using their private vehicles from their homes to the meeting area and shelter in the sister village based on the evacuation map. The government will support staged evacuation from the meeting area to the shelter. In the first stage, the government will focus to evacuate vulnerable people and then young people without a private vehicle. Therefore, the effectiveness of pedestrian evacuation time from the house to the meeting area is crucial because of the uncertainty on the interval for changing from level 3 to 4 (eruption) status. A mutual assistance concept is being developed in this study to assess its effect. In the future, the government can also support this concept by conducting data collection and training for young and vulnerable people who have the status of family or neighbors. This strategy is essential for increasing public awareness, safety, and effective evacuation.

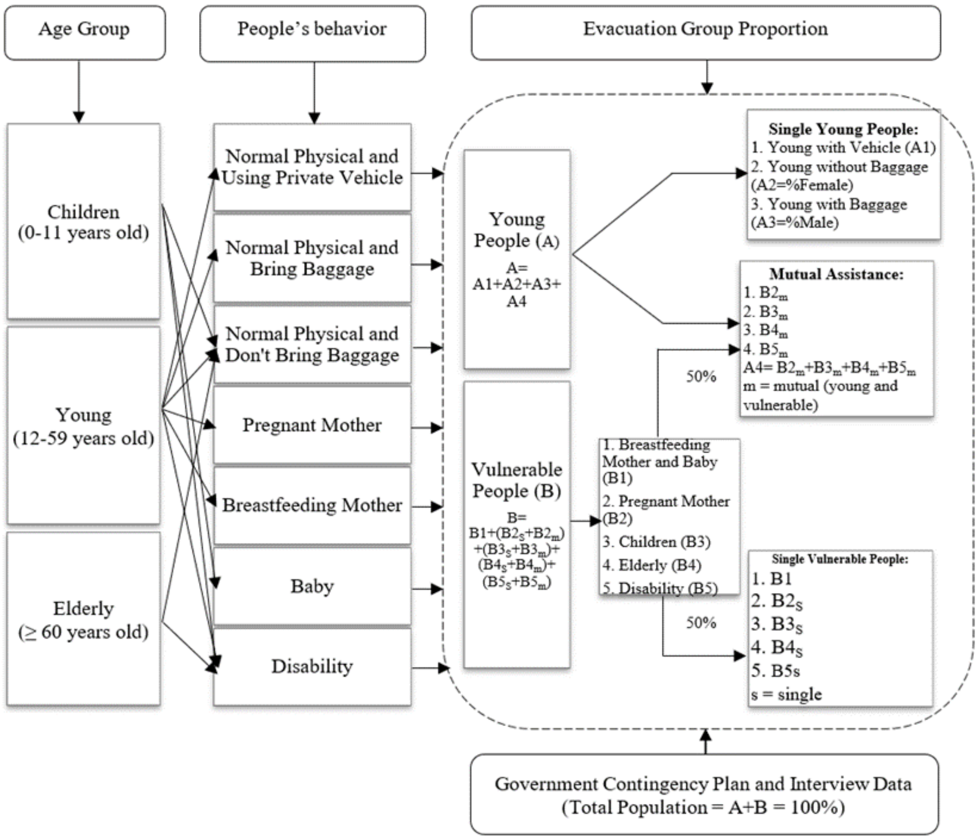


Figure 3. Conceptual of regency population

The population distribution of evacuation groups from home to the meeting area is divided into 3 groups namely young people, mutual assistance, and vulnerable people. Young people use a private vehicle and young people bring baggage are also included in the young group.

The total number of people carrying baggage is represented by the percentage of young men population. Information about the population of young and vulnerable people and data of the local community's vehicle is obtained from the village contingencies plans and interviews with the village leader. We formulated the proportion of mutual assistance and single vulnerable people by 50% and 50%. This assumption is determined according to the highest potential risk that will be handled by the government. Figure 2 is a detail of the regency population concept in the pedestrian evacuation process.

3.2 Pedestrian evacuation speed

The mean of young people's evacuation speed is 1.48 (m/s) for Boyolali Regency, 1.7 (m/s) for Klaten Regency, 1.25 (m/s) for Magelang Regency, and 1.23 (m/s) for Sleman Regency. Klaten Regency has the highest mean speed due to the downhill road conditions and good pavement. Whereas, Magelang and Sleman Regencies have a combination of surfaces between flat, uphill, and downhill which cause slower speeds. Boyolali Regency has a relatively flat and descending surface. These three regencies also have access roads from good to moderate damage. Overall, the result indicates that mutual assistance groups have a median speed between vulnerable and young people. For example, the mean speeds of young, mutual assistance (young and elderly), and elderly people in Boyolali are 1.48 (m/s), 1.22(m/s), and 0.99 (m/s), respectively. This relationship is common in all regencies. The details of the mean walking speed and standard deviation in four affected regencies are shown in Table 4, Table 5, Table 6, and Table 7.

Table 4. Pedestrian evacuation speed in Boyolali Regency

Categories	Number	Walking Speed (m/s) [Mean and Standard Deviation]	Range	
			High	Low
Young without Baggage	18	1.48 ± 0.43	2.19	1.04
Young with Baggage	6	1.28 ± 0.23	1.51	0.97
Young and Children	5	1.45 ± 0.37	1.96	1.07
Young and Pregnant Mother	9	1.21 ± 0.29	1.67	0.83
Young and Elderly	9	1.22 ± 0.35	2.02	0.84
Young and Disability	3	0.86 ± 0.17	1.04	0.67
Breastfeeding Mother and Baby	8	1.23 ± 0.30	1.79	0.90
Pregnant Mother	8	1.25 ± 0.38	1.81	0.84
Children	4	1.22 ± 0.42	1.84	0.96
Elderly	5	0.99 ± 0.11	1.15	0.86
Disability	2	1.12 ± 0.18	1.25	1.00

Table 5. Pedestrian evacuation speed in Klaten Regency

Categories	Number	Walking Speed (m/s) [Mean and Standard Deviation]	Range	
			High	Low
Young without Baggage	9	1.70 ± 0.62	2.56	1.00
Young with Baggage	2	2.58 ± 0.07	2.63	2.53
Young and Children	3	1.46 ± 0.72	2.18	0.74
Young and Pregnant Mother	4	1.09 ± 0.23	1.32	0.77
Young and Elderly	4	1.45 ± 0.48	2.13	1.00
Young and Disability	2	1.44 ± 0.15	1.54	1.33
Breastfeeding Mother and Baby	4	1.60 ± 0.52	2.10	0.99
Pregnant Mother	3	1.25 ± 0.19	1.39	1.04
Children	3	1.39 ± 0.07	1.47	1.34
Elderly	2	1.38 ± 0.21	1.52	1.23
Disability	1	0.46 ± 0.00	0.46	0.46

Table 6. Pedestrian evacuation speed in Magelang regency

Categories	Number	Walking Speed (m/s) [Mean and Standard Deviation]	Range	
			High	Low
Young without Baggage	75	1.25 ± 0.26	1.85	0.79
Young with Baggage	2	0.80 ± 0.42	1.10	0.50
Young and Children	12	1.78 ± 0.38	2.33	1.25
Young and Pregnant Mother	9	1.02 ± 0.43	1.52	0.44
Young and Elderly	9	1.10 ± 0.46	1.39	0.40
Young and Disability	7	1.05 ± 0.51	1.79	0.55
Breastfeeding Mother and Baby	18	0.90 ± 0.39	1.45	0.55
Pregnant Mother	15	0.87 ± 0.39	1.45	0.40
Children	11	1.36 ± 0.33	1.83	1.05
Elderly	15	0.95 ± 0.44	1.94	0.39
Disability	11	0.88 ± 0.45	1.47	0.39

In Table 5, it is found that young with baggage has a significantly higher speed than young people because the topographic contours tend to decrease, baggage capacity only contains important documents, and running action. Besides, the disabled person in Klaten Regency has the lowest speed (0.46 m/s) due to leg defects and old age. There are many types of disability in this case including autism child, deaf, and limp legs with or without a wheelchair. When compared to disability speed in Boyolali Regency, it has a normal walking speed because of deaf, and mild leg defect condition. While Table 6 describes that the mutual assistance group between young and children has a dramatically higher speed than young people due to the children walked faster and the assistant followed them.

Table 7. Pedestrian evacuation speed in Sleman Regency

Categories	Number	Walking Speed (m/s) [Mean and Standard Deviation]	Range High	Range Low
Young without Baggage	56	1.23 ± 0.18	1.64	0.99
Young with Baggage	14	0.95 ± 0.16	1.23	0.67
Young and Children	6	1.08 ± 0.16	1.25	0.81
Young and Pregnant Mother	11	1.02 ± 0.15	1.28	0.73
Young and Elderly	14	1.01 ± 0.11	1.15	0.80
Young and Disability	5	0.84 ± 0.24	1.26	0.69
Breastfeeding Mother and Baby	30	1.04 ± 0.28	1.56	0.37
Pregnant Mother	22	0.98 ± 0.33	1.43	0.32
Children	14	1.07 ± 0.26	1.57	0.63
Elderly	41	0.87 ± 0.26	1.38	0.55
Disability	7	1.11 ± 0.30	1.35	0.64

In this paper, the One-Way ANOVA and Independent Samples T-Test are also used to analyze the speed data. Table 8 summarizes the result of the One-way ANOVA in SPSS Statistics. The test of normality and homogeneity of variances were fulfilled. At a 1% - 5 % level of significance, the result of the test implies that the mean walking speed in four regencies is not significantly different except in the category of young with baggage. It means the four affected regencies have similar community behavior in the pedestrian evacuation.

While in Table 9, the walking speed of young and vulnerable people are compared using the independent samples T-test. The vulnerable people group consists of breastfeeding mothers, pregnant mothers, elderly, and disabled people. Children are not included in each group because they sometimes walk faster than young people. The total of samples in this test was 158 for young people and 191 for vulnerable people. The result shows that p-value (sig) < 0.05. It indicates that the mean walking speed between these groups has a significant difference at a 5 % level of significance.

Table 8. Recapitulation of ANOVA result in each category (comparison between regencies)

Categories		Sum of Squares	df	Mean Square	F	Sig.
Young People	Between Groups	.033	1	.033	1.715	.202
	Within Groups	.484	25	.019		
	Total	.518	26			
Young with baggage	Between Groups	.554	3	.185	18.076	.000
	Within Groups	.204	20	.010		
	Total	.759	23			
Young and Children	Between Groups	.318	3	.106	4.296	.016
	Within Groups	.542	22	.025		
	Total	.860	25			
Young and Pregnant Mother	Between Groups	.056	3	.019	.851	.477
	Within Groups	.640	29	.022		
	Total	.697	32			
Young and Elderly	Between Groups	.140	3	.047	1.246	.310
	Within Groups	1.161	31	.037		
	Total	1.301	34			
Young and Disability	Between Groups	.121	3	.040	1.184	.354
	Within Groups	.444	13	.034		
	Total	.565	16			
Breastfeeding Mother	Between Groups	.254	3	.085	3.338	.026
	Within Groups	1.418	56	.025		
	Total	1.672	59			
Pregnant Mother	Between Groups	.955	3	.318	2.526	.070
	Within Groups	5.544	44	.126		
	Total	6.499	47			
Children	Between Groups	.614	3	.205	2.263	.103
	Within Groups	2.533	28	.090		
	Total	3.148	31			
Elderly	Between Groups	.133	3	.044	1.591	.201
	Within Groups	1.645	59	.028		
	Total	1.778	62			
Disability	Between Groups	.485	3	.162	1.050	.396
	Within Groups	2.618	17	.154		
	Total	3.103	20			

3.3 Mutual assistance impact

Figure 3 shows the effects of mutual assistance on walking speed. Mutual assistance means that young people evacuate with vulnerable people. For young people, evacuation with vulnerable people generally means the decline of walking speed. However, the mutual assistance between young and children in Magelang Regency reaches the top speed at 1.78 m/s. This result may occur due to a lack of coordination between them. Effective evacuation time is an important goal but avoiding high risk is also essential. Therefore, mutual assistance coordination is crucial for vulnerable people's safety. Figure 3 explains that the mean speed of young people decreases sharply in four affected regencies. The biggest drop is in the young and disability group at intervals of 0.20 m/s – 0.62 m/s. On the other hand, the group speed of young and children, young and pregnant mothers, and young and elderly have a slight deflation.

Table 9. The speed comparison of young and vulnerable people according to the independent samples T-test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Speed (m/s)	Equal variances assumed	3.205	.074	8.277	347	.000	.30197	.03648	.23022	.37373
	Equal variances not assumed			8.375	345.512	.000	.30197	.03606	.23105	.37289

In Figure 4, there is a clear difference in the walking speed between vulnerable dan mutual assistance in four affected regencies. Children, elderly, and disabled people have a significant impact on this mutual assistance action. In the case of disability, the mean walking speed is increased from 0.89 m/s to 1.05 m/s. The SPSS software is also used to confirm a speed comparison of mutual assistance and vulnerable people. Test of normality and homogeneity of variances were fulfilled. The paired samples T-test result shows that p-value (sig) < 0.05. It describes that pedestrian evacuation speed of mutual assistance and vulnerable have a significant difference at a 5 % level of significance (Table 10). Especially, this vulnerable group is the elderly and disabled people.

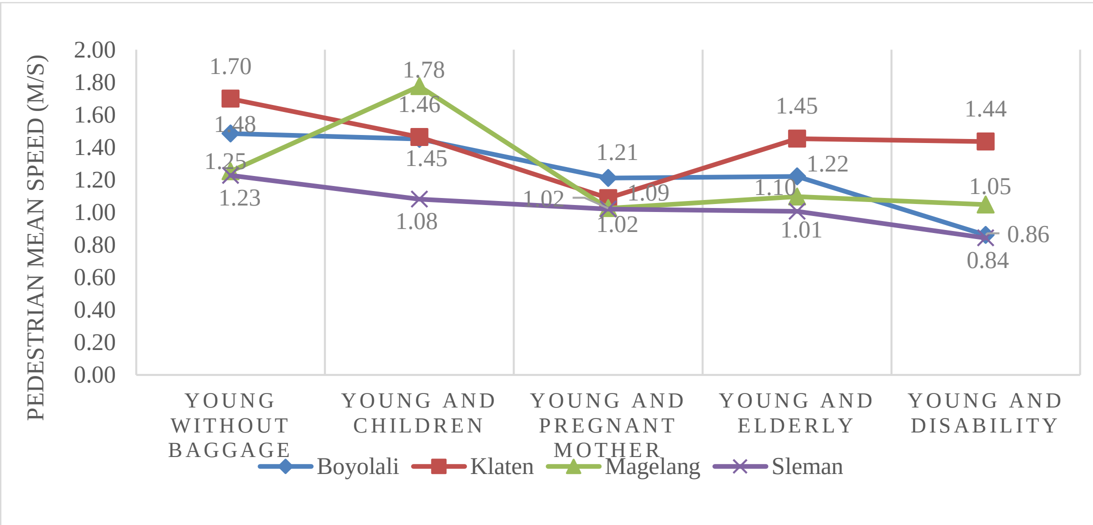


Figure 4. The mean walking speed comparison between young people and mutual assistance

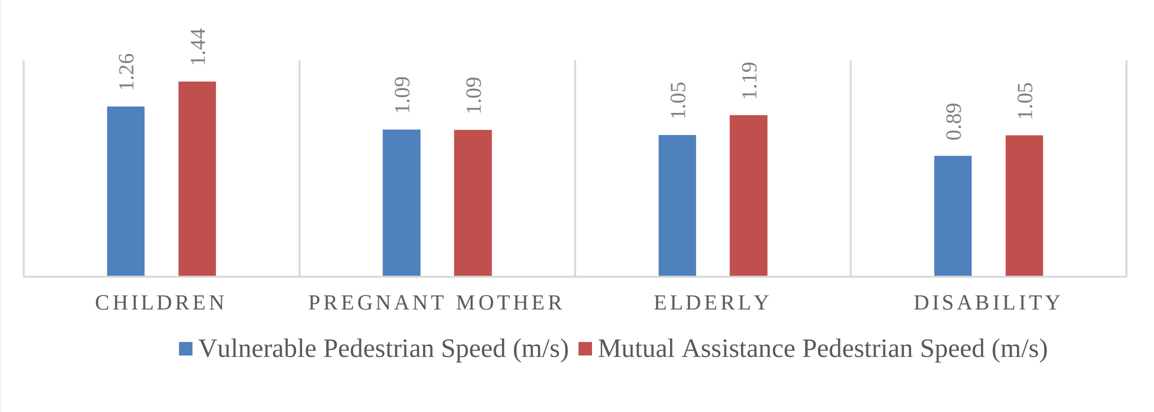


Figure 5. The mean walking speed comparison between vulnerable people and mutual assistance

Table 10. The speed comparison of mutual assistance and vulnerable people according to the paired samples T-test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Speed (m/s)	Equal variances assumed	.088	.768	2.637	135	.009	.15968	.06056	.03990	.27946
	Equal variances not assumed			2.587	103.801	.011	.15968	.06173	.03727	.28209

3.4 Social vulnerability index

The social vulnerability index is assessed from two points of view, subjectively and objectively. Then both are compared by focusing on two people's behavior factors namely social and age structure, and risk perception. We use the normalized weight of importance reveal based on a group evaluation by stakeholders and the local community to get subjective results. All affected regencies have the same weight of vulnerability. Regional characteristics involving topography, livelihoods, and community culture are similar so the calculation of criteria score each regency can be represented by a common score. Consequently, the social vulnerability index in four affected regencies is subjectively the same. In contrast to objectively, we use the weight of importance based on the total population so a different index in each regency is obtained. Detailed results of common score, vulnerability weight, social vulnerability index is referred from Table 11 to Table 14.

 ISSN: 2185-8322
DOI10.5595/001c.21409

Table 11. A common score of the social and age structure (all affected regencies)

Categories	Number	Pedestrian Speed (m/s)		Common Score (Normalized)
		Mean	Standard Deviation	
Young without Baggage	158	1.42	0.37	0.484
Young with Baggage	24	1.40	0.22	0.496
Young and Children	26	1.44	0.41	0.460
Young and Pregnant Mother	33	1.09	0.27	0.875
Young and Elderly	36	1.19	0.35	0.722
Young and Disability	17	1.05	0.27	0.908
Breastfeeding Mother and Baby	60	1.19	0.37	0.709
Pregnant Mother	48	1.09	0.32	0.834
Children	32	1.26	0.27	0.699
Elderly	63	1.05	0.25	0.919
Disability	21	0.89	0.23	0.985

Table 12. A common score of the risk perception (all affected regencies)

Categories	Criterion Score				Common Score
	Boyolali	Klaten	Magelang	Sleman	
Work Condition	0.900	0.733	0.815	0.727	0.794
Rain Condition	0.080	0.117	0.103	0.061	0.090
Night Condition	0.040	0.017	0.011	0.029	0.024
Alert Condition	0.040	0.017	0.011	0.025	0.023
Understanding of Destination	0.600	0.317	0.130	0.108	0.289

Based on Table 14, the subjective and objective assessment shows that the social and age structure factor has a higher index than the risk perception factor. It means that the social and age structure factor has strong risk influence in the pedestrian evacuation process. Overall, the subjective social vulnerability index is higher than the objective index. This phenomenon occurs because the subjective view focuses on the evacuation problem of vulnerable people and the objective view depends on the group population in the communities. The objective index in the four regencies is low due to the elderly people proportion is not large. Magelang Regency represents the highest objective index for the social and age structure factor, and Sleman Regency reflects the highest objective index for the risk perception factor. Nevertheless, both factors have a low objective index. It indicates a minor impact on social vulnerability to the total population.

Table 13. Weight of vulnerability in the subjective and objective view

No	Categories	Weight of Vulnerability (Subjective)	Regency Weight (Objective)			
			Boyolali	Klaten	Magelang	Sleman
Social and Age Structure Factor						
1	Young with Vehicle	0.000	0.488	0.432	0.130	0.439
2	Young without Baggage	0.010	0.003	0.032	0.306	0.083
3	Young with Baggage	0.029	0.003	0.032	0.301	0.082
4	Young and Children	0.087	0.200	0.200	0.025	0.144
5	Young and Pregnant Mother	0.029	0.010	0.010	0.007	0.002
6	Young and Elderly	0.087	0.070	0.070	0.104	0.083
7	Young and Disability	0.087	0.010	0.010	0.010	0.008
8	Breastfeeding Mother and Baby	0.087	0.070	0.070	0.043	0.040
9	Pregnant Mother	0.146	0.005	0.005	0.004	0.002
10	Children	0.087	0.100	0.100	0.013	0.072
11	Elderly	0.146	0.035	0.035	0.052	0.042
12	Disability	0.204	0.005	0.005	0.005	0.004
Risk Perception Factor						
1	Work Condition	0.310	0.012	0.026	0.048	0.048
2	Rain Condition	0.034	0.247	0.244	0.238	0.238
3	Night Condition	0.034	0.247	0.244	0.238	0.238
4	Alert Condition	0.517	0.247	0.244	0.238	0.238
5	Understanding of Destination	0.103	0.247	0.244	0.238	0.238

Table 14. Social vulnerability index comparison

Regencies	Index of Age Structure Factor		Index of Risk Perception Factor	
	Subjective	Objective	Subjective	Objective
Boyolali	0.806	0.324	0.292	0.115
Klaten	0.806	0.352	0.292	0.124
Magelang	0.806	0.494	0.292	0.139
Sleman	0.806	0.338	0.292	0.147

3.5 Comparison with previous studies

Yosritzal *et al.* (2018) observed the walking evacuation speed of tsunami disaster in Padang, West Sumatera, Indonesia. They involved 9 volunteers, 6 observers, 1 route with 5 segments in their simulation. In conclusion, the mean walking speed during the evacuation was 1.419 m/s. The group of age 20-40 years was found to walk 11% faster than children and 7 % faster than elderly people. Male was discovered 10 % faster than female in the same group. Jumadi *et al*. (2019) compared the evacuation scenario with an agent-based model between simultaneous and staged of Merapi Volcano in Sleman Regency, Yogyakarta, Indonesia. The results confirm that the staged scenario has a better ability to reduce the potential traffic congestion during the peak time. The time interval between the stage was divided into 5 districts namely Cangkringan, Ngemplak, Pakem, Tempel, and Turi. The average travel time to reach a major road was 23.8 minutes. However, the simultaneous strategy has better performance regarding the speed of reducing the risk. The study of Jumadi *et al*. (2019) has several limitations such as the variability of population behavior that has not been involved in this initial simulation development, and the government contingency plans have not yet been considered. Meanwhile, Nugraha *et al*. (2019) confirmed the risk assessment of Mount Merapi in the settlement area of Sleman Regency and concern on the mapping of eruption risk. The result shows that there is still a large risk in the Regency. Therefore, an appropriate strategy in mitigation planning is needed.

Klein *et al.* (2019) presented the four challenging principles for integrated community-based and ecosystem-based disaster risk reduction in mountain systems. They are governance and institutional arrangement that appropriate local needs, empowerment, and capacity-building to strengthen community resilience, discovery and sharing of constructive practices that combine local and scientific knowledge, and oncoming focused on well-being and equity. Besides, the presence of too many cooperators or defectors in the evacuation group is not conducive to safe evacuation. It is found that heterogeneous pedestrian speeds can increase the evacuation efficiency to a certain extent. The total evacuation time can be reduced if 20% of the pedestrians slow down. The evacuation time is the shortest when the radius is about 4 cells (Zou *et al.* 2020). In this present research, we focused on the local community behavior in four affected regencies especially the "mutual assistance" study. The index output reflects the distribution of actual walking speed, mutual assistance, and the government's plan updating in 2019. Therefore, this study is a development from previous research to get a more effective and practical evacuation plan for the considered by the government.

4. CONCLUSIONS

This paper presents the influence of local community behavior and mutual assistance in the pedestrian evacuation process. Actual walking speed and risk perception are the main variables. The results showed that mutual assistance can be effective to reduce any risk during evacuation. Probably, the reduced evacuation time is not so big but vulnerable people may be left if young people do not care about them. The social and age structure of the social vulnerability index has a stronger risk effect than the perception factor. However, these two factors have a minor impact on social vulnerability to the total population. In future work, it is necessary to develop an evacuation model of the breeder and cattle because they must be evacuated simultaneously at level 3 status according to the government plan. Several factors were not included in this study such as education, politics, income, health, and others. Correlations between all factors are needed to find a comprehensive assessment of the social vulnerability index and total risk. Cooperation between the local government and the community association is also needed to implement the mutual assistance strategy.

REFERENCES

Austroads. (2016). *Guide to Traffic Management Part 9*: Traffic Operation.

Boyolali District Disaster Management Agency. (2019). *Compilation of Mount Merapi Eruption Contingency Plans* (in Indonesian). Central Java, Indonesia.

Fatemi, F. (2017). Social vulnerability indicators in disasters: Findings from a systematic review, *International Journal of Disaster Risk Reduction*, Vol 22, June 2017, page 219-227.

Federal Ministry for Economic Cooperation and Development. (2004). *Guidelines: Risk Analysis-a Basis for Disaster Risk Management*. GTZ GmbH. Eschborn. (https://www.preventionweb.net/files/1085_enriskanalysischs16.pdf)

Glade, T. and Bell, R. (2004). Quantitative Risk Analysis for Landslides-Examples from Bildudalur, NW-Iceland. *Natural Hazards and Earth System Sciences* 4: 117-131. © European Geosciences Union.

Guha-Sapir, D., Hoyois, P., Below, R. (2016). *Annual Disaster Statistical Review 2015*. CRED: Brussels, Belgium.

Jumadi, Carver, S.J., and Quincey, D.J. (2019). An Agent-Based Evaluation of Varying Evacuation Scenarios in Meapi: Simulatneous and Staged. *Geoscience*, *9*, 317, (www.mpdi.com/journal/geoscience)

Klaten District Disaster Management Agency. (2018). *Contingency Plan for Mount Merapi Eruption Disaster* (in Indonesian). Central Java, Indonesia.

Klien, J.A., Tucker, C.M., Steger, C.E., Nolin, A., Reid, R., Hopping, K.A., Yeh, E.T., Pradhan, M.S., Taber, A., Molden, D., Ghate, R., Choudhury, D., Alcantara-Ayala, I., Lavorel, S., Gret-Regamey, B.A., Boone, R.B., Bourgeron, P., Castellanos, E., Chen, X., Dong, S., Keiler, M., Seidi, M., Thorn, J., and Yager, K. (2019). An Integrated Community and Ecosystem-Based Approach to Disaster Risk Reduction in Mountain System. *Environmental Science and Policy 94*(2019)143-152. ELSEVIER. (ecosystemhttps://doi.org/10.1016/j.envsci.2018.12.034).

Lavigne, F., Coster, B.D., Juvin, N., Flohic, F., Gaillard, JC., Texier, P., Morin, J., Sartohadi, J. (2008). People's Behavior in the Face of Volcanic Hazard: Perspective from Javanese Communities, Indonesia. *Journal of Volcanology and Geothermal Research 172*, 273-287. ScienceDirect, ELSEVIER.

Lowe, C.J. (2010). Analyzing Vulnerability to Volcanic Hazards: Application to St. Vincent. *Dissertation*. Department of Geography, University Collage, London.

Magelang District Disaster Management Agency. (2017). *Merapi Eruption Contingency Plan Document for Magelang Regency 2017-2020* (in Indonesian). Central Java, Indonesia.

Mei, E.T.W., Lavigne, F., Picquout, A., de Bélizal, E., Brunstein, D., Grancher, D., Sartohadi, J., Cholik, N., Vidal, C. (2013). Lessons learned from the 2010 evacuations at Merapi volcano. *J. Volcanol. Geotherm. Res. 261*, 348–365.

Nakamura, H., Umeki, H., Kato, T. (2017). Importance of Communication and Knowledge of Disaster in Community-Based Disaster-Prevention Meetings. *Safety Science 99* (2017) 235-243. ELSEVIER. (http://dx.doi.org/10.1016/j.ssci.2016.08.024).

Nugraha, A.L., Hani'ah, Firdaus, H.S., Haeriah (2019). Analysisi of Risk Asessment of Mount Merapi Eruption in Settlement Area of Sleman Regency. *IOP Conf. Series: Earth and Environmental Science 313*, 012003. IOP Publishing. (doi:10.1088/1755-1315/313/1/012003).

Rahman, K., Ghani, N.A., Kamil, A.A., Mustafa, A. (2012). Analysis of Pedestrian Free Flow Walking Speed in a Least Developing Country: A Factorial Design Study. *Research Journal of Applied Sciences, Engineering and Technology 4* (21), 4299-4304. Maxwell Scientific Organization.

Rizvi, S.R., Olariu, S., Weigle, M.C., Rizvi, M.E. (2007). A Novel Approach to Reduce Traffic Chaos in Emergency and Evacuation Scenarios. *In Proceedings of the VTC Fall*, Baltimore, MD, USA, 30 September–3 October 2007; pp. 1937–1941.

Sangeeth, K., and Lokre, A. (2019). Factors Influencing Pedestrian Speed in Level of Services (LOS) of Pedestrian Facilities. *Transportation Research Interdisciplinary Perspectives*. ScienceDirect, ELSEVIER Ltd, 3, p. 100066. (doi: 10.1016/j.trip.2019. 100066)

Scarpa, R. Tilling, R.I (1996). *Monitoring and Mitigation of Volcano Hazards: Volcanic Hazard Risk Assessment)*. Pages 675 – 698. Springer-Verlag Berlin Heidelberg. (https://link.springer.com/chapter/10.1007/978-3-642-80087-0_20).

Sleman District Disaster Management Agency. (2019). *Merapi Volcano Eruption Contingency Plan* (in Indonesian). Yogyakarta, Indonesia.

Transportation Research Board (2000). *Highway Capacity Manual: Chapter 18" Pedestrian Methodology*. Page 18-4. National Research Council.

Truong, L.T., Kutadinata, R., Espada, I., Robinson, T., Burdan, J., Costa, F., Lin, E. (2018). Walikng Speeds for Timing of Pedestrian Walk and Clearance Intervals. *Australasian Transport Research Forum 2018 Proceedings*. 30 Oktober- 1 November, Darwin, Australia. (http://www.atrf.info)

Velasquez, G.T (2003). Quantifying the Social Aspects of Disaster Vulnerability. *International Training Program on Total Disaster Risk Management*. Global Environment Information Center. United Nations University, Japan.

Yosritzal, Kemal, B.M, Purnawan, and Putra, H. (2018). An Observation of the Walking Speed of Evacuee during the a Simulated Stunami Evacuation in Padang, Indonesia. *IOP Conf. Series: Earth and Environmental Science 140 (2018) 012090*. IOP Publishing.

Zou, B., Lu, C., Mao, S., Li, Y. (2020). Effect of Pedestrian Judgement on Evacuation Efficiency Considering Hesitation. Physica A: Statistical Mechanics and its Applications, *547*-122943, ScienceDirect, ELSEVIER. (https://www.sciencedirect.com/science/article/pii/S037843711931667X)

IDRiM (2020) 10 (2) **ISSN: 2185-8322**
DOI10.5595/001c.18160

Journal of Integrated Disaster Risk Management

Original paper

Agent-based model for simulating households' self-evacuation decision in high-rise buildings under critical infrastructure failures induced by a slow-onset flood conditions – A case study in Paris

Abla M. Edjossan-Sossou[1 2*], Marc Vuillet[1], Rasool Mehdizadeh[2] and Olivier Deck[2]

Received: 29/03/2020 / Accepted: 12/10/2020 / Published online: 30/11/2020

Abstract Generating well-informed and reliable predictions for disaster evacuation is a large challenge. Crisis and disaster management policymakers have to deal with poor data quality, a limited understanding of households' behaviour dynamics, and uncertainty regarding the effects of the various actions/measures in place. Agent-based simulation models are frequently used to support decisions when planning disaster evacuation procedures. However, one of the most important aspects of this issue, which is social influence, is not often considered. Most of existing evacuation models largely overlook the importance of the households' behaviours and social influences, which leads to oversimplified models. Moreover, it is almost impossible to find models in the literature that focus on the extrinsic decision-making factors of some evacuees, such as compromised lifelines, in the case of catastrophic events. In contrast to the existing evacuation models, this paper suggests a probabilistic agent-based model that relies on the loss of different lifelines as factors affecting evacuees' decision-making in addition to some intrinsic factors that are used to characterise the propensity of households to evacuate and explicitly allow for social contagion as well as uncertainties to be considered. This model, in which all the variables are considered uncertain and Monte Carlo Simulations are run to estimate the confidence range of the predictions, is tailored to estimate the potential number of inhabitants that have not been evacuated in high-rise buildings in the face of critical infrastructure failures induced by a slow-onset flood and/or the actions taken during the related crisis, considering different uncertainties that may affect the reliability of the prediction. The model has been specifically designed to predict the dynamics of households' self-evacuations in fourteen residential high-rise buildings located in a flood-prone area in Paris. This paper

[1] Université Gustave Eiffel, Lab'Urba EA3482, Ecole des Ingénieurs de la Ville de Paris(EIVP), Paris, France
[2] Université de Lorraine, CNRS, CREGU, GeoRessources, UMR 7359, Ecole des Mines de Nancy, Nancy, France

[*] Corresponding author : Email : medjossan@gmail.com

describes the suggested model and also reports the results of an illustrative case study in which three scenarios are simulated to demonstrate the applicability of the model, to test its effectiveness and to explore the uncertainty regarding some modelling assumptions using sensitivity analysis.

Key words: Agent-based modelling, uncertainty, evacuation, social influence, flood, high-rise buildings

1. INTRODUCTION AND BACKGROUND

In light of the recent natural disasters throughout the world, governments and academics are gradually becoming aware of the vulnerability of the territories affected by these disasters. This awareness is even more important when the vulnerability could be increased by the cascading effects resulting from the level to which critical infrastructures are interconnected. Cities have started to anticipate the potential damage of major events and to identify appropriate management strategies to effectively cope with these disasters in the future to achieve their resilience objectives, including the safety and the well-being of the population.

From this perspective, ensuring the resilience of Paris and the Ile-de-France region against a major flood of the Seine river is one of the crucial challenges of the public authorities and risk management decision-makers. According to the OECD (2014a), "a major Seine flood would today have important potential impacts on well- being, and on the activities of the government and businesses". Indeed, experts estimate that a flood of the Seine river and its tributaries of the magnitude of the historic event of 1910 will cost at least thirty billion euros and affect up to 5 million residents (OECD, 2014b). During this historic flooding, the water level exceeded 8 m at the Paris-Austerlitz measuring station and rose over a period of 10 days, with receding occurring over a period of more than a month. Currently, a flood of this magnitude is estimated to be a 100-year flood.

Such an event would lead to long lasting damage and cause severe impairment to technical networks (electricity, sewage, transportation, urban heating and cooling systems, etc.). For instance, the power distribution would be significantly disturbed, as more than 377,000 domestic and business customers in Paris would experience power cuts, while an important part of road network could be blocked, making it impossible to travel from one bank to the other. There would also be thousands of residents who would undeniably seek evacuation. To date, at least 290,000 people are living within the potential evacuation zone reported in the Seine Basin (Fujiki, 2017). The serious flooding events in May-June 2016 and January-February 2018 that impacted the Seine Basin, during which some people were evacuated from their homes while others stayed in their homes without electricity (Longjumeau, Gournay, etc.), are reminders of the degree of vulnerability of the Ile-de-France Region. Consequently, it seems advisable to seriously consider that a mass evacuation may occur in the case of a major flood of the Seine, which would lead to a chronic reduction in the well-being of the people involved.

Therefore, public authorities and decision-makers started questioning their ability and preparedness to cope with a probable evacuation of people living within the potential evacuation zone, including the number of people to care for, shelter availability and locations, evacuation routes, etc. (Fujiki & Laleau, 2019). Designing appropriate evacuation plans is a crucial aspect of disaster preparedness. It is an extremely challenging task that implies responses to the following questions: who, when, where and how to evacuate? These responses will provide the information required to better plan the operational implementation of an evacuation. Thus, one of the most important steps of a potential evacuation plan in Paris is the estimation of the number of residents who must be evacuated over time to provide estimates for designing strategies to respond to the appropriate number and location of these residents.

We present herein an agent-based model for estimating people's decisions to evacuate by their own means. This study attempts to provide a tool for understanding the following question: "how many residents would decide to stay home under slow-onset major flooding that is not life-threatening to the residents but is lifeline-compromising?". The model was developed to help risk managers in the dynamic prediction of households' self-evacuation decisions in the face of the reduction of their well-being following a slow-onset flood involving cascading disruptions of critical infrastructures. This work was conducted under the RGC4 project[3], which aimed to develop operational tools to cope with technical network failures at the grand Paris scale to improve the resilience of the Paris urban area against extreme floods. While the main objective of this work is the estimation of people remaining inside their dwellings at a given time during a flooding disaster, it also aims to address three research questions.

First, it considers the effect of social contagion among neighbours, relying on the assumption that social contagion will contribute to spreading the decisions of the households that chose to leave their dwellings among their neighbours and, thus, lead to more households to evacuate (Riad et al., 1999; Kakimoto & Yamada, 2014; Bangate et al., 2017). Second, it assumes that, in the case of a chronic disaster leading to the reduction of the households' welfare, their decision to evacuate or not could be influenced by their living conditions. To the best of our knowledge, most of the existing studies modelled the evacuation decision considering mainly (recommended or mandatory) evacuation orders issued by authorities and/or signs presaging the imminent onset of the hazards as decision-making triggering event(s). The existing research has not addressed modelling evacuation with regard to the reduction of the households' well-being due to the loss of lifelines provided by the technical networks as a triggering factor of their decisions to evacuate (Tobin et al., 2011). Thus, the model is developed considering the failures of technical networks as evacuation decision triggering events. It is assumed that these events could occur solely or simultaneously with others due to cascading effects or not. It, therefore, investigates the appropriate approach to combine their effects on the households' decisions to obtain more robust outcomes. Finally, it implicitly accounts for the uncertainty

[3] https://anr.fr/Project-ANR-15-CE39-0015

DOI10.5595/001c.18160

associated with the input data and the simulation running outputs, while most of the other evacuation models do not necessarily integrate uncertainty into their reasoning (Ronchi et al., 2013; Tavares & Ronchi, 2015).

The proposed model is a probabilistic model so that various uncertainties about the quality of data, the heterogeneity of households, the evolution of the households' environment (occurrence time of the evacuation triggering events), etc. can be considered. The proposed model allows the running of Monte Carlo simulations to improve its performance through sensitivity analysis and also deals with a slow-onset hazard, which is contrary to most studies on the evacuation of people, which mainly focus on fast kinetics hazards, such as hurricanes, fire, industrial or nuclear accidents, etc. The target site of this evacuation model is the batch of residential high-rise buildings located along the Seine within the 15th district in Paris, mainly because they are the most densely populated residential buildings within the flood prone area within the Seine basin. It is assumed that the target residents have the same characteristics as most of the residents of the Ile-de-France Region (Fujiki, 2017), i.e., three persons in four are motorised and approximately 90% could ensure their self-hosting (secondary residence, hosted by parents/friends/relatives, hotels, etc.). Some of these characteristics are used in the model as intrinsic evacuation decision-making factors to estimate the residents' propensity to evacuate by their own means.

Although this model investigates the evacuation decision-making process of households living in high-rise buildings, it will not focus on the choice of escape route, the evacuation speed, the escape behaviour (collaborative vs. competitive) or the evacuation completion time, as in the few studies targeting high-rise buildings, but will account for the social influence among residents, as well as the combination of the effects of more than one evacuation triggering event. The uniqueness of the suggested model lies in the emphasis on social contagion of evacuation decision-making among neighbours, the linking of evacuation-decision making to the loss of one or more lifelines as evacuation decision-making factors besides some evacuees' intrinsic characteristics, which are commonly used in evacuation modelling, and the explicit consideration of uncertainty through a probabilistic approach.

The remainder of this paper is structured as follows. Section 2 is devoted to a state of the art household evacuation decision modelling using agent-based modelling. Section 3 describes the model developed towards obtaining the goal of this study. Section 4 presents and discuss the results of a demonstrative example to examine the applicability and the effectiveness of the proposed model. Finally, conclusions are drawn in section 5.

2. STATE OF THE ART ON AGENT-ORIENTED EVACUATION MODELLING

Due to the variety of hazards, factors influencing evacuation (decision or completion), modelling approaches and evacuation aspects investigated (information dissemination and warning, logistical concerns, mode choice, route and destination selection, timing, total demand, traffic assignment, zoning, etc.), a significant amount of work is done on evacuation modelling. This section provides an overview of the determinants of households' evacuation decisions and the use of agent-based modelling in the households' evacuation decision.

2.1 Factors influencing a household's decision to evacuate in the face of a natural disaster

Studies on whether to participate in an evacuation are mainly carried out from the individuals' or households' point of view. Generally, empirical studies or logistic regression models constructed on the basis of survey data are used to determine the factors influencing evacuation decision-making. A review of the evacuation literature shows that several factors could lead households to decide whether to evacuate an area threatened by a hazard (Dash & Gladwin, 2007; Ahsan et al., 2016). They could be of an intrinsic nature and an extrinsic nature. In short, the ability or propensity depending mostly on their intrinsic factors (Rabemalanto et al., 2020) and the willingness of households to evacuate are the main characteristics that can facilitate or hinder their evacuation decisions. Because the significance of the influence of these factors on the households' decisions could vary depending on the context (Murray-Tuite & Wolshon, 2013), identifying households likely to evacuate can prove complex (Wright & Johnston, 2010).

The intrinsic factors involve the households' socio-demographic characteristics, such as the household size (Luathep et al., 2013), the presence of vulnerable people, such as children, senior citizens or persons with disabilities (Lim et al., 2016), the ownership of and access to a vehicle (Wright & Johnston, 2010), the access to an available relocation place (Chang et al., 2009), the presence of pets (Solis et al., 2010), etc. The socio-demographic information contributes to the modelling of the behavioural features of the households at a particular location at a given time. Although the propensity to evacuate is not sufficient to predict the households' evacuation decisions successfully, it is a key parameter in the modelling of their willingness or reluctance to self-evacuate. The lower the propensity, the higher the need to be cared for by public authorities or emergency services during an evacuation. Apart from socio-demographic characteristics, the intrinsic factors may include people's risk perception (Jumadi et al., 2018).

Researchers also identified the following extrinsic factors related to households' evacuation decision-making processes: communication/information concerning the risk (Wright & Johnston, 2010), influence of the society in which the households live, such as following the example of their neighbours after observing them evacuate (Lindell et al., 2005; Nagarajan et al., 2012), environmental cues, such as sights, smells or sounds, indicating the onset of the hazard (Lindell et al., 2015), liveability or not of their dwellings and neighbourhood resulting from disruptions of lifelines provided by technical networks (Chatterjee & Mozumder, 2015), etc. Although some attention is being given to the loss of lifelines as a determinant for disaster evacuation (Kailes & Enders, 2007), only a few works tried to identify the influence of the various technical networks on the households' decision in the face of disasters. It has been found that power supply is one of the most vital technical networks, the failure of which can greatly affect the well-being of households (Schultz et al., 2003; Reed et al., 2010; Nateghi et al., 2011; Chatterjee & Mozumder, 2015).

Although previous studies prove that the households' evacuation decisions depend not only on their own characteristics or on the features of the hazard but also upon their external environment, generally, most evacuation cases are modelled considering that the evacuation process is triggered mainly by the onset of a hazard and/or the issuance of evacuation orders (Han et al., 2007; Fang et al., 2011; Madireddy et al., 2011; Zale & Kar, 2012; Song & Yan, 2016). By doing so, the models ignore the possibility that the households' decisions may be influenced by their external environment. The developed model aims to address this gap by integrating technical failures as potential triggering events of the evacuation decision process.

2.2. Agent-based modelling in disaster evacuation engineering

A plethora of studies exist on disaster evacuation modelling thanks to the increasing level of realism provided by simulations. Agent-based modelling (hereafter ABM) is one of the most used approaches to this end (like in the studies of Chen & Zhan, 2008; Christensen & Sasaki, 2008; Hawe et al., 2012; Mostafizi et al., 2017; Ukkusuri et al., 2017; Kasereka et al., 2018; Olsvik et al., 2018; etc.). Agent-oriented models allow the behaviours of heterogeneous individual components of a complex system, which function autonomously to achieve their specific desired objectives in a common environment through mutual environmental interactions, to be described (Albino et al., 2007). Each individual component or agent has its own characteristics, states and objectives. The agents are also able to make their own decisions and update their state while relying on defined rules. According to Nikolic & Kasmire (2013), ABM enables the possible complex and non-linear variations in the state of a system, across time and space to be investigated to derive and understand the plausible futures, trends, tendencies or behaviours that can occur under specific circumstances. One of the main strengths of ABM is its flexibility; the agents' attributes/goals/behaviours and modelling assumptions are easily changed to test several cases. Rangel-Ramirez et al. (2019) stated that although agent-based models "do not capture all aspects of human and social behaviour in risk situations such as grouping, social cohesion, decision-making under stress, aiding and collaborative behaviour, etc.; this is the presently most adequate modelling scheme for the representation of human behaviour during evacuation scenarios". ABM is, thus, particularly well-suited for this work due to the difficulty of determining the choice of a random population of households to stay or to leave when they receive evacuation orders and/or when their living conditions are worsened by the a slow-kinetics flood associated with technical network failures.

However, it is worth noting that ABM is a random approach by nature. Thus, the studies based on ABM could be inherently limited by the quality of the data. Generally, the existing agent-oriented models address the different aspects of evacuation modelling deterministically and do not necessarily account for the natural variations in the modelled agents' population, while the evacuee behaviours are commonly judged as the largest uncertainties (Wang et al., 2020). Indeed, most often, apart from the localisation of the agents, agent-based models consider homogenous characteristics (Rangel-Ramirez et al., 2019), which makes it difficult to properly calibrate the models, to incorporate observational data into the models (thus, they lack the diversity that exists in the real world) and to quantify the uncertainty in the outputs. In fact, evacuation plans or strategies can be effective only to the extent that managers actually use the available information to make their decisions. In places where the households' characteristics are heterogeneous, the households' decisions might vary considerably.

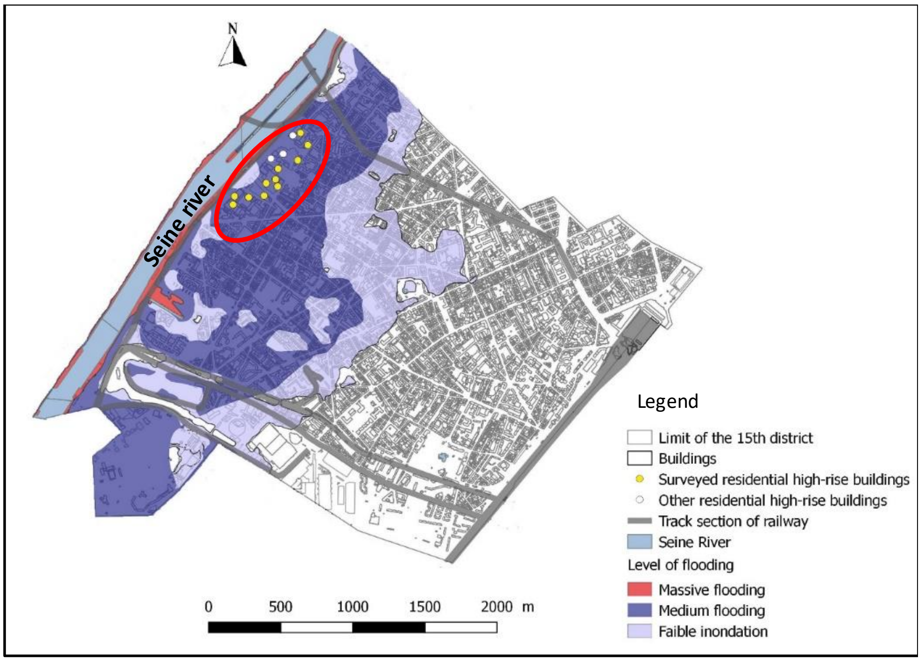
To the best of our knowledge, only a few evacuation modelling studies attempt to fill this gap by accounting for uncertainty in various ways. For instance, Fraser et al. (2014), who suggested a method incorporating, among other parameters, an uncertain evacuation departure time into an existing anisotropic least-cost path distance framework, handled the uncertainty in the evacuation time by running 500 simulations of evacuation times for each scenario and for each individual agent in the population to generate an average evacuation time. Liu et al. (2012), Lv et al. (2013), and Rangel-Ramirez et al. (2019) adopt probabilistic approaches to deal with uncertainty. In line with these few studies which account for uncertainty in the evacuation modelling, this work proposes a probabilistic model intended to systematically address the uncertainty in the input data and to provide possible values for the evacuation demand in various scenarios.

3. PRESENTATION OF THE DEVELOPED MODEL

This section provides a description of the developed prototype model that can be used as a potential training or decision-support tool by the Parisian crisis management services. The model is implemented in Mathematica and allows geographical coordinates to be imported to delineate the simulation environment through a 2D representation of each building within this environment. The model encompasses two major modules that are not editable by the user: study area and hazard modules. However, one could adapt the model to his own specific needs by introducing information describing the desired simulation outline and/or hazard. As a probabilistic model, it relies on a random sampling of almost all the variables by drawing from defined distributions (mainly uniform and normal shapes), except for the calculation timestep. Any instantiation and any simulation are thus unique and may give results differing from each other. Moreover, it is designed to run a single simulation, as well as Monte Carlo simulations while keeping in mind that a large number of a single simulation outcomes need to be studied to obtain a more realistic view of the households' behaviours and improve the confidence in the obtained results through statistically meaningful insights.

3.1 Presentation of the target site

Although the model is expected to be applicable to any evacuation situation due to the studied hazardous conditions, this first version has been developed for a specific area in Paris. The target area, representing the environment module of the model, corresponds to the 15th district in Paris. This flood-prone area situated on the Seine waterfront (Figure 1a) is characterised by a spatial concentration of approximately twenty high-rise buildings, of which 14 are of private residential use, making this the most densely populated area in Paris (INSEE, 2016). It is worth noting that the model is intended to study the evacuation of the households facing chronic disaster impacts resulting from slow-kinetics flooding. Thus, only the 14 residential buildings classified into two categories (11 co-ownership buildings and 3 social housing buildings) are selected. These towers of 20 to 30 storeys (Figure 1b) consist of a total of 3,175 apartments and house approximatively 10,000 residents.



(a)

(b)

Figure 1. Outline of the evacuation model:
(a) Flood risk zoning in the 15th district of Paris; (b) High-rise buildings

In these buildings, all the inhabited apartments are above the 4th floor. Consequently, they are above the highest water level predicted for a major flood of the Seine and the flood water will not enter them. Furthermore, there will not necessarily be any drownings, injuries, or fatalities due to the direct impact of the flood. However, because the towers have four levels of parking lots, two of which are located on two underground floors (with a height of approximately 3 meters each, they are at – 6 and – 3 meters in relation to street level), water could penetrate underground car parks, mainly by dynamic capillary rise in the foundation walls. These towers are, therefore, vulnerable even before the Seine overflows its banks due to rising water in the basement. The car parks must, therefore, be evacuated even before the residents. Moreover, the residents could face a decline of their well-being resulting from disrupted services and/or reduction in the liveability of their neighbourhood and/or dwelling. Specifically, power outages may lead to elevator shutdowns when alternate power supply devices are not available. When this situation occurs, these towers must be mandatorily evacuated; for safety purposes, the height of the buildings makes it impossible to keep people inside.

3.2 The hazard module

A key component of the model is the hazard because the different evacuation triggering events are broken down in a chronological order with regard to the water level at the Austerlitz bridge measuring station. For this purpose, a theoretical hydrograph, which mimics as much as possible one of the historic flooding experienced in 1910, was generated. Their similarity relies mainly on how quickly the maximum crest at the Austerlitz bridge (8.62 m) is reached and on their duration, which was approximatively two months of the water level being above the flood warning level (which equals to 3.4 m) with a height of approximately 6 m. The hazard module consists of a numerical approximation of the theoretical hydrograph generated. This function allows the time or the height to be automatically estimated when the height or the time is provided, respectively. This function is the basis for the activation of the events on which evacuation decisions could be based when their trigger level is reached. To account for uncertainty, the envelope brackets provided at each point of the hydrograph indicate the lowest and the highest possible water levels.

3.3 Description of the agents

The main objective is to predict the number of people remaining in their dwelling (i.e., those who will not decide to autonomously evacuate) in the face of a slow-onset major flooding of the Seine river. Thus, the agents are households not individuals, and all actions operate only on households; the assumption is that when a household decides to evacuate, all the members will actually evacuate. Table 1 summarises the agent based-simulation features.

Table 1. Agent-based simulation features

Feature	**Description**
Agents	Households
Agent attributes	Discriminating characteristics providing all the insightful information that relates to the households for their decision making. They are used to describe each household.
Agent behaviours	Evacuation decision-making: the households are able to make a dichotomous decision (stay at their home or evacuate to a safer place). For each calculation, the households follow a simple probabilistic binary rule by checking if an evacuation triggering event has occurred or is currently occurring and by observing the current state of their neighbours' dwellings (either 0 for evacuated/non-occupied or 1 for non-evacuated/ occupied). When they decide to evacuate, the state of their apartment is then updated to 0.
Interaction among agents	It relies on the social influence between households. The interaction rule is that the probability for a household to evacuate is increased by a defined factor when a given rate of its neighbours that decided to evacuate is attained.
Observed phenomenon	The model seeks to capture the complex essence of real-world households' evacuation decision-making processes and the influential interactions among households. It will allow the impact of technical network failures and the social influence on the evacuation decision making processes within the population located in the flood prone area to be observed.

The households are heterogeneous and are characterised by the following:

- an ID number;
- the building and the floor where their dwelling is located (this contributes to estimating the number of their neighbours for each household influence network);
- their size (the number of persons belonging to households not evacuated will be summed up for estimating the remaining people);
- their typology regarding their propensity to evacuate autonomously. On the basis of five household intrinsic factors, which are judged to positively influence the evacuation decision according to previous studies (mainly Fujiki, 2017), the households were

categorised into three types. These criteria include (1) having a high social index, (2) being able to self-host outside the hazard prone area, (3) owning a motorised transport, (4) having the capacity/potential to self-evacuate and (5) being aware of the risk (consciousness of the real threat on their living area). Using on real socio-demographic data of Paris, a fraction of each type in the whole studied population is calculated and integrated into the model. The three types of households are termed as follows:

- The "totally autonomous" category are those households who fulfil all five criteria. It is assumed that the higher the propensity to evacuate if needed and the higher the level of propensity to evacuate, the more likely that the household will decide to evacuate.
- The "highly dependent" category are those households who do not fulfil most of the five criteria. The greater the level of dependence, the lower the propensity to evacuate if needed and the less likely the households will be to decide to evacuate.
- The "moderately dependent" category are those households who do not fulfil a few of the five criteria. This type of household is less likely to decide to self-evacuate than those belonging to the first category, while being more likely than the highly dependent households to evacuate.

- the state of their dwelling, which can be occupied or non-occupied.

The social influence among households is examined, relying on the assertion that "while a simulation can never capture the complexity of a real event, the effect of social influence in an evacuation could be measured by manipulating the proportion of neighbours nearby that have decided to evacuate their homes" (Lamb et al., 2012). For this purpose, it is assumed that a household can have three types of social influence interactions with its neighbours. Their interaction relationship could be horizontal, i.e., when the interacting agents are located on the same floor, vertical, i.e., when they live in the same building, and slanted, i.e., when they live in different buildings (Figure 2). At this stage, the model considers only the horizontal and vertical ones.

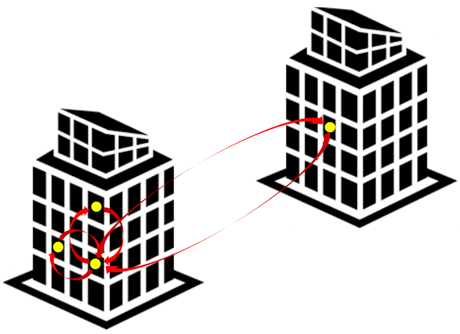


Figure 2. Social influence between households in high-rise buildings

3.4 Definition of the evacuation decision triggering events

The evacuation decision-making process does not occur prior to the flooding and begins only after a triggering event. The latter is meant as any situation that creates the conditions or involves the factors able to influence evacuation decision-making; this in turn, initiates the residents' willingness to evacuate. In evacuation modelling, when an evacuation trigger is known by the households, a temporal distribution of the departure times for those that are responsive to this specific trigger is estimated to construct a departure or response curve, which is also called a mobilisation curve. A response curve represents the proportion of the total evacuation demand over time, and it consists of the cumulative percentage of evacuees' departures over the duration of the evacuation initiated by a given trigger and is used in evacuation modelling to predict when evacuees will evacuate, should this trigger occur. In the real-world, when residents decide to evacuate, they take time to prepare themselves to leave; then, they evacuate if their departure is not hindered by any circumstance or obstacles. However, in this study, it is assumed that their evacuation is effective as soon as they decide to evacuate.

It is reported in the literature that response curves are commonly assumed to have a sigmoid or "S" shape (Fu & Wilmot, 2004). This shape is because evacuations start slowly, then increase rapidly and finally decelerate and gradually become close to nil when the maximum ratio of people who choose to evacuate tends to be reached. Evacuation decisions over time could follow several distributions, including uniform, sigmoid, Poisson, Rayleigh and Weibull distributions (Cova & Johnson, 2002; Kalafatas & Peeta; 2009). As stated by Song & Yan (2016), these curves are mainly established empirically by relying on the analysis of the households' evacuation behaviours during past disasters or emergency events. They could also be derived from prospective surveys on the households' intended evacuation behaviours in the face of future disasters (Fraser et al., 2013). Some drawbacks to response curves exist, among which is the difficulty of predicting them accurately, the insensitivity of such curves to any changes in the modelling conditions, which may influence the dynamics of households' evacuation decision-making processes, the questionability of the transferability of a given response curve to another evacuation event or a study area different from the one where this curve was established, etc.

In this model, each triggering event is defined by the following:

- The time of its occurrence or the water level at which it could occur. The same trigger could not be characterised simultaneously by both features; the two features could not be simultaneously set for an event because they are linked by the numerical approximation function used to design the hazard module of the model. When a triggering event occurs at a given time and at a specific height, two separate triggers have to be considered, relying either on the occurrence time or on the height. Additionally, if the same type of event occurs several times during the flooding, there must be as many characteristics definitions as there are occurrences.
- The list of the buildings potentially impacted by its effects.

- The response curves associated with of each of the three typologies of households. Bearing in mind that the less vulnerable people (most autonomous in the case of this study) need less time to evacuate than others (Hofflinger et al., 2019), it is assumed that the main response curve (provided by the literature or obtained from an empirical survey) will be considered as the one of "totally autonomous" households. The others are, thus, obtained by (1) multiplying the evacuation demand of the "totally autonomous" households by a reduction coefficient, as well as (2) shifting the origin of this main curve to the positive direction of the time depending on the difference among the time at which each household type starts to evacuate.

Most of the existing studies modelled the evacuation decision with regard to the issuance of (mandatory or recommended) evacuation orders/instructions (issued by authorities, emergency services or any other means), the distance of the evacuees' locations from the hazard threat or the signs predicting the imminent onset of the latter as evacuation triggering events. However, it has been proven that these factors could induce evacuation decision-making. Therefore, the model is constructed with a series of pre-listed events likely to occur when the water level at Austerlitz reaches some known heights and is liable to lead households to evacuate. They may be activated by the user by defining their specific characteristics. These triggers are as follows:

- Recommended order of the evacuation of people.
- Mandatory order of the evacuation of people.
- Mandatory order of the evacuation of cars (parked in the towers' underground parking).
- Energy supply failure.
- Urban heating failure.
- Food supply disruption.
- Neighbourhood insalubrity.
- Sewage disposal disruption.
- Dysfunction of the components of the transport system (traffic congestion, closed roads, public transport unavailability, etc.).

It could be noted that the above list does not include an important evacuation trigger when facing flooding, which is having water in the dwelling, possibly due to the specificity of the study area (as mentioned earlier; see § 3.1). In addition, one can add more triggering events if needed.

Two main scientific challenges were identified while creating the triggers module. The first challenge is the non-availability of the appropriate response curves needed for achieving a good level of realism. Indeed, the response curves to be used for each case study must ideally be generated in the target area. However, currently, there are no data which describe how Parisians living in the studied high-rise buildings (or even how people in Ile-de-France region) evacuate (or will evacuate) after the selected triggers are released. Furthermore, the existing curves

IDRiM (2020) 10 (2) **ISSN: 2185-8322**
DOI10.5595/001c.18160

found in the literature are mainly related to evacuation orders and fast kinetics phenomena (mostly hurricanes). This challenge is addressed by defining fictitious curves because, at this stage, the main aim is to ensure that the model correctly simulates the households' behaviours that are expected to occur during an evacuation resulting from the conditions studied herein.

The second challenge is about how to adequately combine the probabilities of evacuation decision-making deducted from the response curves of several triggers occurring simultaneously. It is assumed that when the situation faced by households becomes worse due to a new event, they could change their mind if they have not evacuated already because the previous triggers did not sufficiently lead them to express their willingness to leave the area. Song & Yan (2016) conducted an empirical study to question the response curve obtained when two evacuation orders are issued during a disastrous situation (Figure 3). They found that when a second evacuation order is issued 60 hours after the first one, the obtained total evacuation demand rises more quickly than the evacuation demand uniquely associated with the first order; the greater the number of evacuation triggers occurring simultaneously, the higher the total evacuation demand, which justifies the need to combine the effects of triggers.

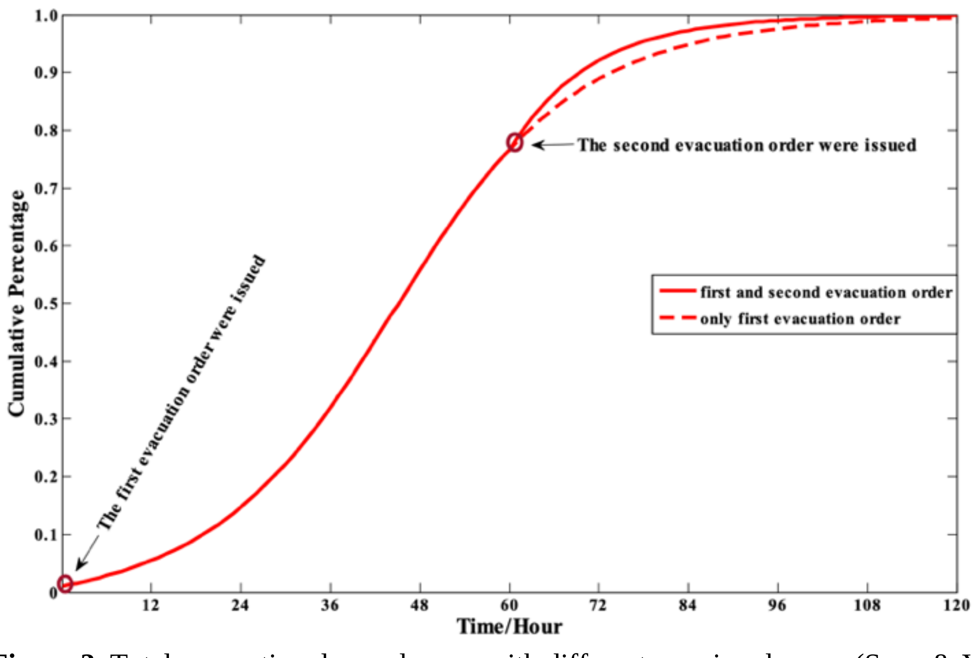


Figure 3. Total evacuation demand curve with different warning degrees (Song & Yan, 2016).

Three ways were identified and investigated. The combination is performed by applying the following criteria:

- the highest decision-making probability among the probabilities of all the triggers ("maximum option"). This option means that households decisions are only influenced by the trigger that induces the highest evacuation demand;

- the probability obtained by summing up the probabilities of all the triggers ("addition option") assuming that the events are mutually exclusive and the intersections of every pair of events are empty. That is, the households will decide to evacuate because of both events. It should be noted that maximum value of the resulting probability must not exceed 1;
- the "product option", where the probabilities associated with all the triggers are iteratively applied to the households that did not yet decide to evacuate when accounting for the influence of the triggers taken one at a time.

3.5. Calculation process

To describe and scrutinise the households' evacuation decision-making processes conveniently in theory, the related variables are identified and defined in Table 2. The variable values used are fictitious and real-world data. The real-world data are derived from the most recent data provided by the existing socio-demographic records (mainly INSEE), the critical network operators (providing the potential water levels at which their services could be disturbed and the areas of the territory that could be sensitive to these disturbances), the literature (including studies on the technical network vulnerabilities) and the results of the surveys conducted within the ambit of the RGC4 project. The real data are mainly the number of storeys and dwellings per building and the number of residents within the study target site (approximatively 10,000 persons). The fictitious data are the response curves as, unfortunately as far as we knew, no studies exist on the construction on such curves for the study area. To remedy this deficiency, a survey has been conducted within the Seine river catchment area after the 2016 and 2018 flooding events to attempt the deduction of a response curve for power outages. However, the obtained curve is not incorporated into the model, as the curve has not yet been validated.

A 1910-like flooding of the Seine does not necessarily generate stress for households living within the study area. Consequently, the model does not account for decision-making under stress. In other words, there will not be a short notice for an evacuation and households may not be evacuated from a location other than their dwelling; thus, the households are presumed to be at home at the beginning of the simulation. By doing so, the model does not account for the period of the day (diurnal, nocturnal or rush hours) conditions during the simulation. Each household is assumed to make a decision regarding what events trigger them to evacuate, should these events occur. The household evacuation decision is assumed to be an irreversible process, and once a household decides to evacuate, it would remain evacuated until the end of the simulation. It should be noted that the model is not intended for tracking the movement of households across space and time in the study area.

Figure 4 shows the flowchart of the households' evacuation decision-making model. The specific steps of the model running process are as follows:

- Step 1: Instantiate the simulation frame. At the initialisation of a simulation, the number of people present in the towers results from the non-occupancy rate and the households' sizes.
- Step 2: Define the ranges of the uncertain values or validate the by-default ranges so that a value could be randomly assigned to each variable of the model.
- Step 3: Select the combination approach
- Step 4: Run a single simulation. The outcomes are the number of households who do not decide to evacuate (occupied apartments) and, subsequently, the number of remaining people in each of the 14 studied buildings and at each calculation step. The results are presented in the form of (1) interactive tables, (2) interactive 2D maps showing the relative spatial distribution of people to potentially care for in the target area (by assigning dark red to the maximum value and scaling to the other values in accordance as in Figure 5b) and (3) dynamic graphs showing concurrently the chronological evolution of the number of remaining persons and the 1910-like flooding hydrograph (Figure 5a). One could extract the specific results of a chosen calculation step.
- Step 5: Define the number of simulations and run them (this step is needed only if one wants to run Monte Carlo simulations). The outcomes are the descriptive statistics and the statistical distribution of the number of households who do not decide to evacuate or the number of remaining residents (this could also be done for each building and at each calculation step).

The current version of the model does not have a module intended to display the animation of the simulation dynamics. The model is not able to vividly show the interactions among households (a specific building could not been displayed to observe what is happening at each storey level; a specific household could not be tracked and its evacuation decision could not be visualised as a disappearance, for instance). However, the model is not characterised by an aspatial environment given that the buildings are set in a realistic geo-spatial landscape leading to their representation on the map as a results visualisation option.

The interest of modelling all 14 of the buildings instead of focusing on the one building that is most typical relies on two main reasons. First, the need of the Prefecture de Paris is to know how many people the public authorities would need to care for within the target area. Second, the buildings are not similar. Indeed, each of them has its specific organisation and given this organisation and the triggers which affect each of them, the need for evacuation will differ from one to another. However, when using the model, one could choose to focus on the analysis of only one or some of the buildings located in the study area.

IDRiM (2020) 10 (2) **ISSN: 2185-8322**
DOI10.5595/001c.18160

Table 2. Variable definitions

Variable	Definition
Non-occupancy rate	This rate allows the generation of the number of occupied apartments in each building at the instantiation of the model because it is assumed that at the moment when the disaster begins, not all the apartments are occupied and all occupied dwellings have their occupants present. By default, it is set to 0.02 but could be user defined (real-world value; the non-occupancy rate in the 15th district of Paris in 2017 was 8.6 % with around 2% for long-lasting non-occupancy).
Timeslot	Time interval between two calculation steps. It allows the estimating of the number of calculation steps or iterations of a simulation with regard to the duration of the flooding event (which equals to approximately two months in the model). By default, it is set to 6 hours but could be user defined.
Household size	Number of persons belonging to each household. Its values are randomly generated and range from 1 to 4 (co-ownership buildings) and 3 to 6 (social housing towers) persons. Non-editable values (real-world value; the average size of household is 1.81 people in the 15th district but the high-rise buildings have highly densified population of approximately 10,000 inhabitants and the use of these values allows estimating an initial population within the area numerically close to the reality).
Fraction of non-occupied apartments at the storey level	Ratio of non-occupied apartments located on the same floor in close proximity, from which starts the effect of horizontal social influence among households. By default, it is set to 0.75 but could be user defined (assumed or fictitious value).
Fraction of non-occupied apartments at the whole building level	Ratio of non-occupied apartments of a tower, from which starts the effect of the vertical social influence among households. By default, it is set to 0.75 but could be user defined (assumed or fictitious value).
Decision-making probability increasing factor (storey level)	Improvement factor by which the evacuation decision probabilities are increased when the fraction of non-occupied apartments at the storey level is attained. By default, the average value is set to 0.25 and the standard deviation equals to 0.05. These values could be user defined (assumed or fictitious value).
Decision-making probability increasing factor (whole building level)	Improvement factor by which the evacuation decision probabilities are increased when the fraction of non-occupied apartments at the whole building level is attained. By default, the average value is set to 0.15 and the standard deviation equals to 0.05. These values could be user defined (assumed or fictitious value).
Triggers characteristics	Occurrence: the nominal value of the time OR the water level that induces the occurrence of each trigger.
	Evacuation decision probabilities for each type of household associated with each trigger; it consists of three lists of the evacuation rates corresponding to all the calculation steps following the occurrence of each trigger deducted from the response curves.
	Targeted buildings: list of the towers affected by the effects of each trigger.
Combination approach	Represents the way to combine the evacuation decision probabilities when several triggers occur simultaneously. By default, it is set to the “maximum option” but could be user defined.

IDRiM (2020) 10 (2) ISSN: 2185-8322
DOI10.5595/001c.18160

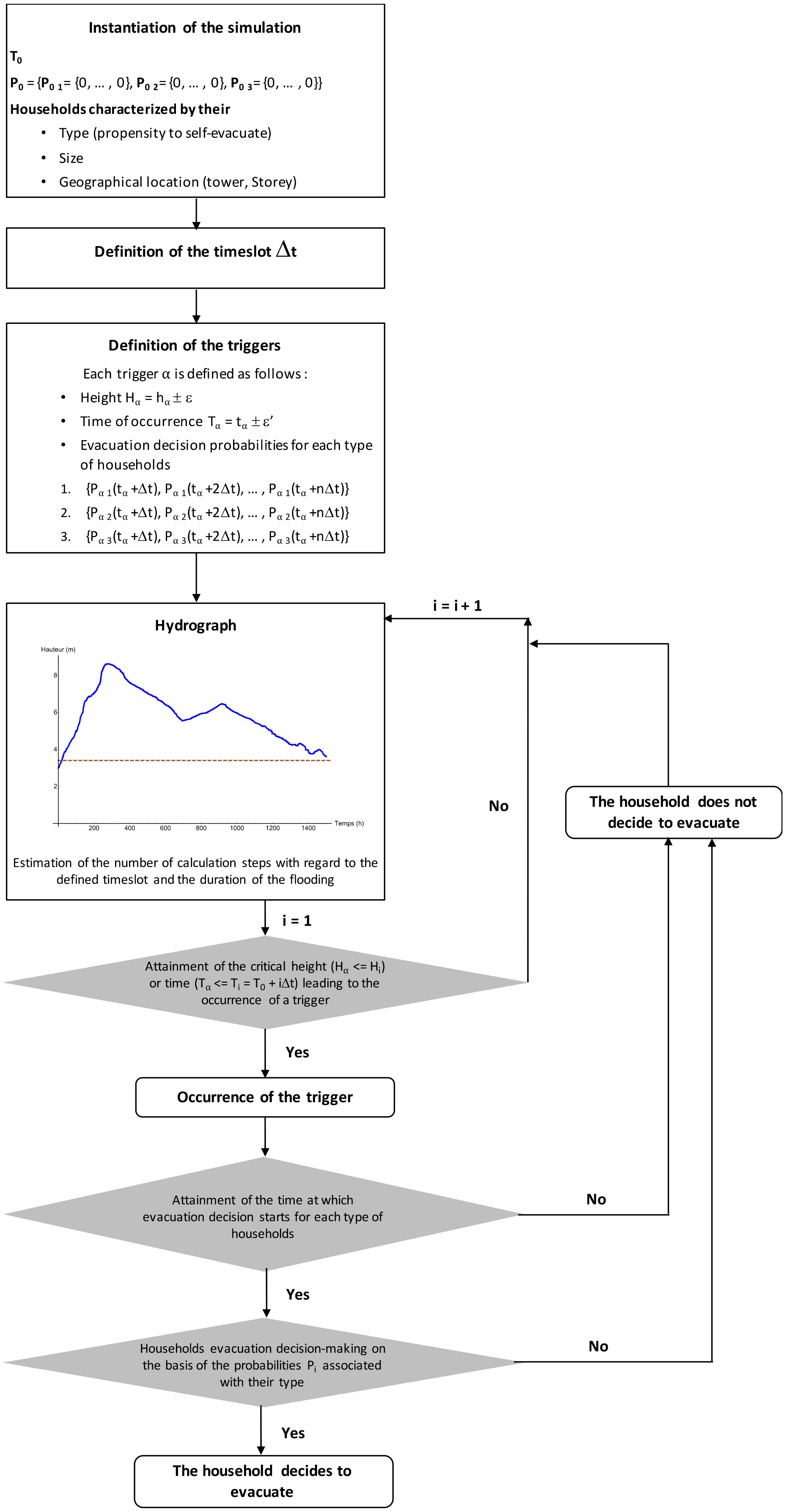
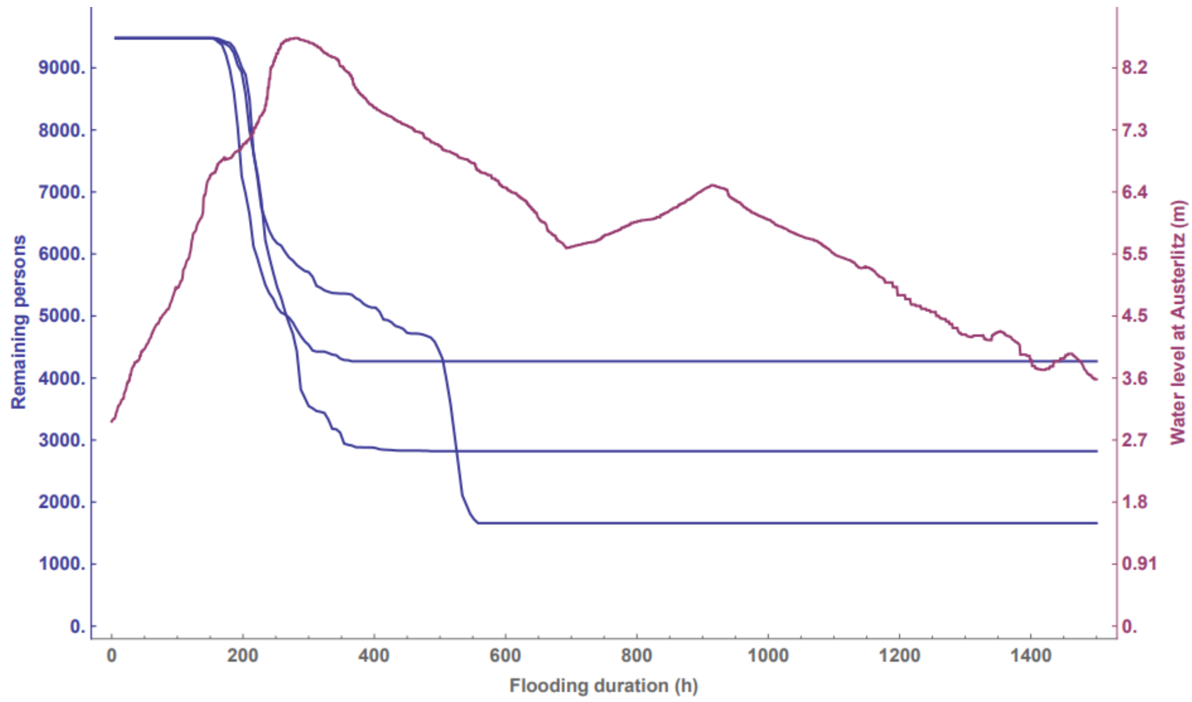
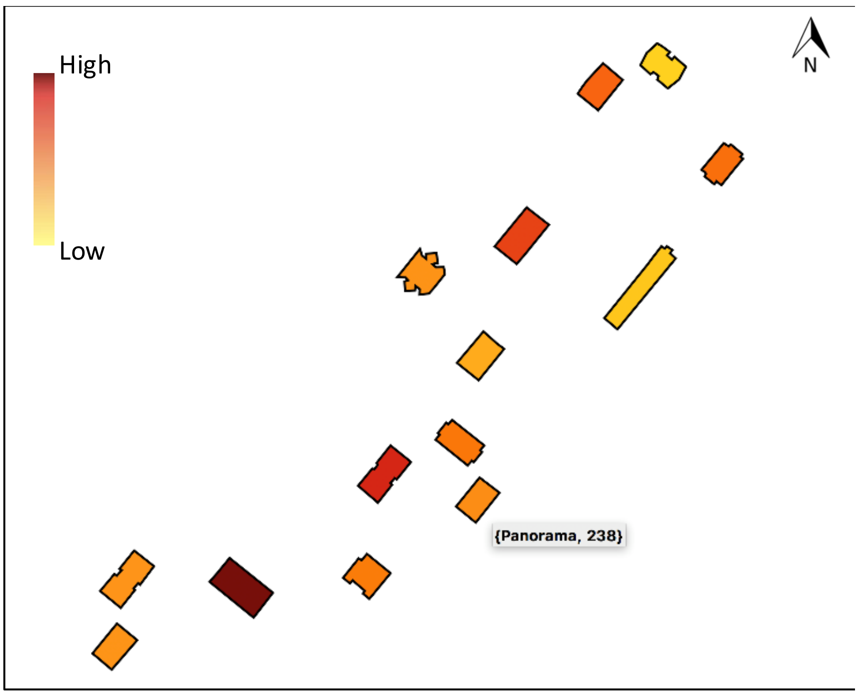


Figure 4. Flowchart of the households' evacuation decision-making modelling

 ISSN: 2185-8322



(a)



(b)

Figure 5. Samples of simulation result visualisations: (a) Graph of the temporal evolution of a scenario; (b) map indicating the number of people inside the "Panorama" tower and the relative importance of the remaining persons per building in the study area

4. AN ILLUSTRATIVE CASE STUDY

Here, we present a first study to check whether the model correctly simulates the problem under study. This study also enables an examination of the potential impact of social influence and the ways to combine several triggers. For this case study, the three following scenarios are set. The information in the brackets corresponds to the height of the water at Austerlitz station or the time of occurrence, the maximum fraction of residents which could decide to evacuate under its effects and the impacted buildings.

- Scenario 1 consists of the occurrence of the following three potential evacuation triggers: (1) the closure of the traffic lanes along the Seine river due to flooding (6.4 m, 25%, all the buildings), (2) the issuance of a recommended evacuation order (6.6 m, 35%, all the buildings) and (3) the disruption of the urban heating (7 m, 70%, only the 3 social housing towers). This scenario can be considered as a control scenario because its three events are also part of the other two scenarios.
- Scenario 2 consists of the occurrence of the following four potential evacuation triggers: (1) the closure of the traffic lanes along the Seine river due to flooding (6.4 m, 25%, all the buildings), (2) the issuance of a recommended evacuation order (6.6 m, 35%, all the buildings), (3) recommended evacuation of underground car parks (6.8 m, 70%, the 11 co-ownership towers) and (4) the disruption of the urban heating (7 m, 70%, only the 3 social housing towers).
- Scenario 3 consists of the occurrence of the following four potential evacuation triggers: (1) the closure of the traffic lanes along the Seine river due to flooding (6.4 m, 25%, all the buildings), (2) the issuance of a recommended evacuation order (6.6 m, 35%, all the buildings), (3) the disruption of the urban heating (7 m, 70%, only the 3 social housing towers) and (4) a power outage (480 hours, 90%, all the buildings).

All the simulations started with an initial population of 3,109 households (with a total of 9,480 persons, 3,576 of whom are in the social housing towers) at random apartments. These data are used for all the simulations run in this case study. With the by default timeslot of 6 hours, each simulation consists of 250 calculation steps. The results obtained from single simulations of the scenarios with the three combination approaches are presented in Table 3. It could be concluded that the theoretical structure of the model seems to be of a certain level of realism; the results show that the number of remaining people diminishes since the number of triggers increases.

The knowledge of the evacuation demand, as well as its spatial and temporal variability is a critical piece of information for adequate management planning. The temporal distributions of the number of remaining persons obtained from the three scenarios are illustrated in Figure 6. It can be observed in this figure that, due to modelling uncertainties, there are differences between the evacuation demands in the earlier hours after the beginning of the simulations, although at that moment, the three scenarios are "supposed" to be identical (as the differentiating triggers of scenarios 2 and 3 do not occur).

IDRiM (2020) 10 (2) ISSN: 2185-8322
DOI10.5595/001c.18160

Table 3. Evacuation results of the scenarios under consideration

	Combination approach		
	Maximum	**Addition**	**Product**
Scenario 1	4,364 pers. (1,715 hs.*)	4,364 pers. (1,704 hs.)	4,319 pers. (1,699 hs.)
Scenario 2	2,731 pers. (1,060 hs.)	2,256 pers. (855 hs.)	2,323 pers. (882 hs.)
Scenario 3	1,555 pers. (612 hs.)	1,510 pers. (578 hs.)	1,446 pers. (573 hs.)

* pers. means persons and hs. means households

The maps below (Figure 7a and 7b) reveal that the relative importance of the evacuation demand within the study area could change quickly. On the basis of these maps resulting from the unique simulation of scenario 3, while there are only few towers with a high level of relative evacuation demand 276 hours after the beginning of the simulation, the situation has changed 48 hours later so that there are more towers that will need great focus in the case where the public authorities will decide to evacuate people at that moment (324 hours after the beginning) instead of two days earlier. This just means that there is the same number of remaining persons inside these towers. Indeed, at 276 and 324 hours, the numbers of remaining persons in the high-rise buildings range from 290 to 727 and 183 to 568, respectively, while the tower with the most residents (12.33 % of the total evacuation demand) previously housed only 455 persons (8.4 %). To avoid the variability due to uncertainties and to implement evacuation activities on the basis of reliable results, one could also draw the maps relying on the results from Monte Carlo simulations.

To further analyse the potential effects of social influence and the combination approach, a sensitivity analysis was conducted to obtain a general understanding about how the households' evacuation decisions change with different conditions. For this purpose, a stochastic simulation was performed to obtain the average outputs for the parameters of interest. A total of 300 simulation trials with random initial spatial distributions of households was run for each scrutinised issue. The relatively high values of the obtained standard deviations (Tables 4 and 5) reveal that the simulation results may vary greatly from one to another because of uncertainties, which justifies the need for systematic Monte Carlo simulations running when using this model. Table 4 summarises the results of scenario 1 run with the application of the three combination approaches.

The histogram of the obtained results for the additive combination option is shown in Figure 8. It could be observed that these results (and the other ones from the Monte Carlo Simulations) are nearly normally distributed (a higher number of simulation trials could allow the shape of the distribution to be refined). A statistical analysis was thus conducted to construct normal probability density functions from the data obtained through Monte Carlo simulations (Figures 9 and 10). The observed variations among these results are too small to be significant (Figure 9); it could not be concluded that there is a difference between the three combination options.

IDRiM (2020) 10 (2) ISSN: 2185-8322
DOI10.5595/001c.18160

This situation may be due to the small number of the evacuation triggers probably leading to very little overlapping of their effect durations.

Table 5 summarises the results of scenario 1 run with and without social influence using the “maximum option” for the combination of triggers. The comparison of the results of the simulations performed ignoring the interactions among the households with those of simulations accounting for them shows that the number of remaining people when the households do not interact is higher than in the two other cases (Figure 10). This finding confirms the hypothesis that social influence will increase the likelihood that households will decide to self-evacuate their apartments when they encounter a major flooding of the Seine. Varying the settings for the fraction of non-occupied apartments provides more insights in the importance of the social influence degree, i.e., the higher the social relationships with their neighbours (meant by a lower fraction of non-occupied apartments at the storey or at the whole building level), the more likely the households are to decide to evacuate.

Furthermore, when focusing on scenario 1 and adopting the “maximum option” as the combination approach, the number of remaining people could not be lower than approximately 3,400 persons with regard to the maximum fraction of residents that could decide to evacuate under the effects of each triggering event and without accounting for social influence. Indeed, the results in Table 3 show that 4,364 people who will not evacuate when running a simulation of the scenario 1 and adopting the “maximum option” as the combination approach. Besides, the obtained result in Table 5 (mean= 4,402 persons and standard deviation 68) also demonstrates that the algorithm of this predictive evacuation model shows good performance. Even the results from the simulations accounting for social influence are higher than 3,400 persons. The reliability of the output is thus verified. From a technical point of view, this is a valuable step toward the validation of the model since a different result would mean that the algorithm is wrong.

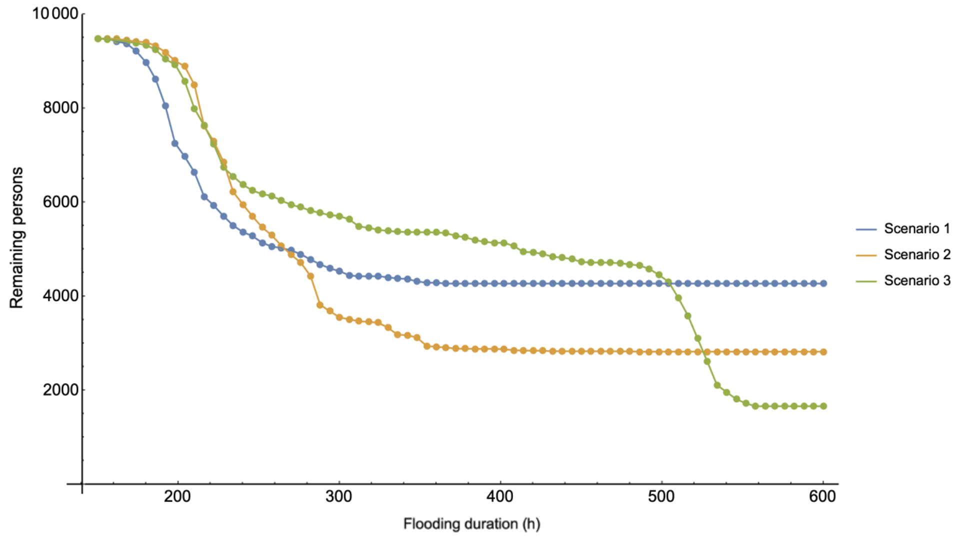


Figure 6. Comparison of the temporal evolution of persons remaining in the towers (“maximum option” results)

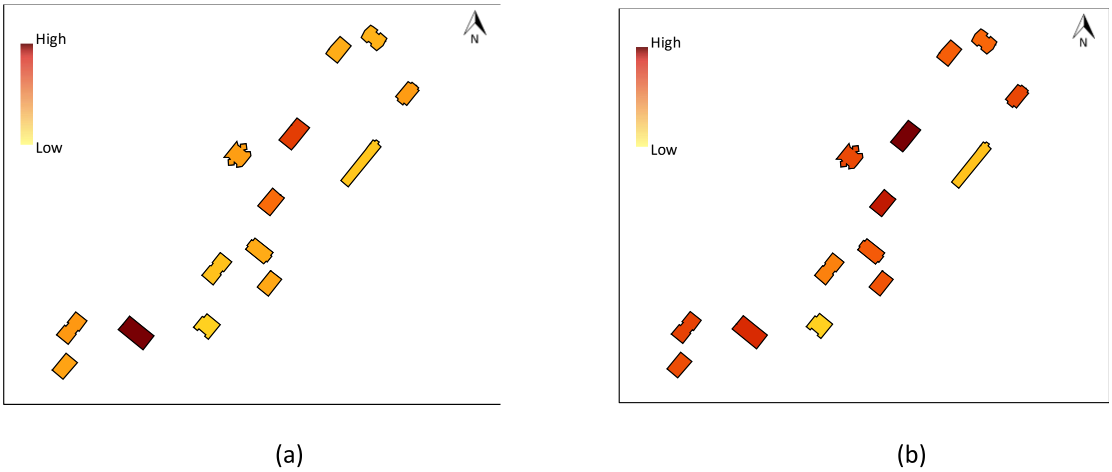


Figure 7. Spatio-temporal distributions of evacuation demands of scenario 3 (a) 276 hours and (b) 324 hours after the beginning of the flooding (unique simulation results)

Table 4. Sensitivity analysis of the effects of the combination approach on the number of remaining persons

	Maximum	**Addition**	**Production**
Mean	4,376	4,360	4,367
Standard deviation	60	63	62

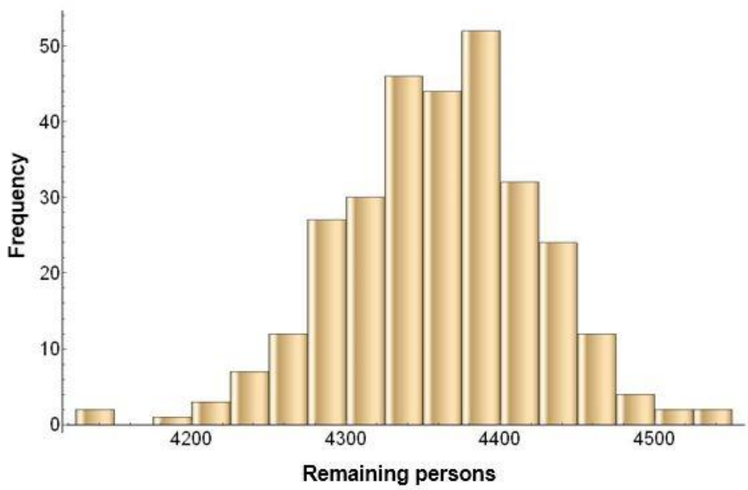


Figure 8. Histogram for the additive combination approach (300 simulation trials)

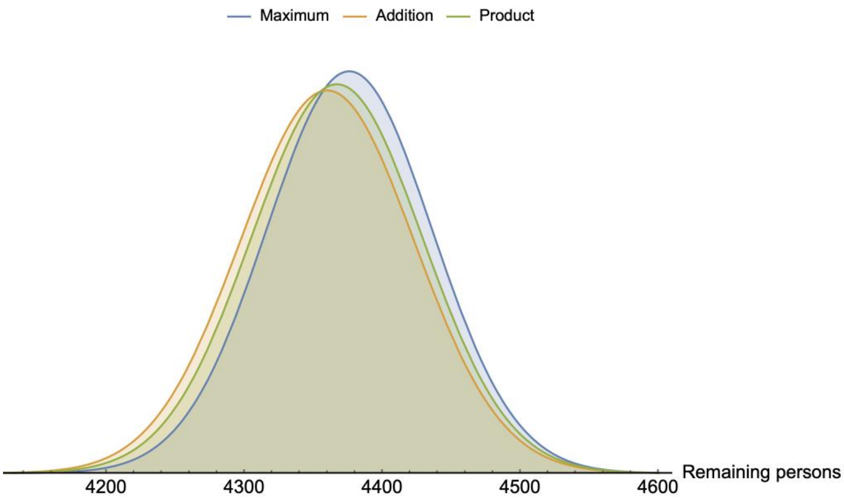


Figure 9. Statistical distributions of the remaining persons calculated with regard to the combination approach

Table 5. Sensitivity analysis of the effects of social influence on the number of remaining persons

	No social influence	**Social influence when non occupied apartments > 50 %**	**Social influence when non occupied apartments > 75 %**
Mean	4,402	4,320	4,376
Standard deviation	68	73	60

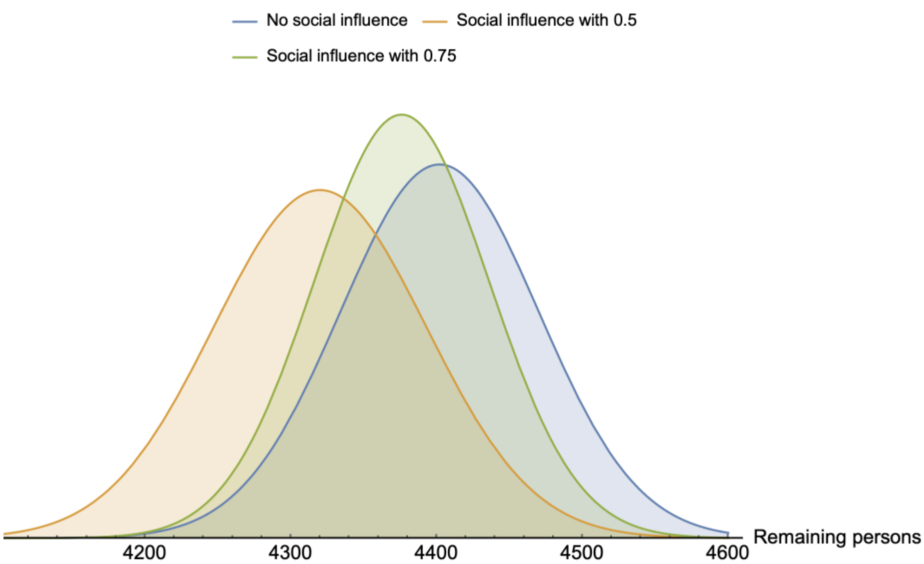


Figure 10. Statistical distributions of the remaining persons calculated with regard to social influence

5. CONCLUSIONS

The probabilistic agent-based model presented in this paper is intended to support the estimation of the evacuation demand in the towers of the 15th district in Paris. By achieving the objective of accounting for social influence, multiple triggering events and uncertainties, this model could lead to a better realism in the results when predicting the number of people to care for if evacuation of the Parisian 15th district is needed. Indeed, by accounting for evacuation decision-making factors that are not or are less commonly considered by the existing evacuation models, this study contributes to the improvement of the comprehensiveness of the evacuation determinants by the evacuation modelling engineering. Additionally, as the comprehensiveness of the decision-making factors integrated in the evacuation model increases, so does the reliability of its outputs.

Though the evacuation decision is difficult to predict due to the difficulty of determining the complex evacuees' behaviours, the illustrative case study has led to insights about this first step towards a tool for simulating households' decisions to evacuate. Globally, the model seems to correctly simulate the households' evacuation decision-making processes through the decrease in the number of people in the buildings over time as soon as triggers occur. The testing simulations demonstrate that the current version of the model can be run without identified bugs and can already be used for running a series of scenarios that could result from a major flood of the Seine river. The current version of the model can also be used for any other study area. In that case, instead of relying on the interaction rules between households located on the same storey or living in the same building, one will consider a given area around the households' dwellings.

However, one must define the proper response curves for each evacuation trigger to generate more realistic results. For this purpose and within the ambit of this study, a survey was conducted after the 2016 and 2018 floods to construct a response curve associated with power outages in the Paris urban area. This response curve is currently being integrated into the model, which is still under development. An important step remains to be performed after defining response curves. This step will consist of validating the model. Indeed, the realism of the results generated by the model can be questioned because the model has not yet been validated. As stated by Pel (2011), the validation of evacuation model outcomes is, in most cases, difficult or even impossible because real data for evacuations are limited or unavailable. However, if the data needed for the calibration and the validation are available, the model can be adjusted to simulate the households' decisions to evacuate or not with a higher level of realism. Moreover, we acknowledge another limitation of the model, which is the time-consuming computations. First, the running times vary according to the defined timeslot because the higher the number of calculation steps, the greater the number of iterative calculations needed for a simulation. Second, the model considers only triggers liable to induce households to evacuate at the expense of those that can encourage them to stay at their apartments, such as the risk management activities to reduce the risk level (the long lasting duration of the flooding makes it possible to intervene for reducing the risk or its damage).

Despite its obvious drawbacks at this stage, the model offers a constructive basis for researchers and policymakers to better investigate the evacuation demands while taking into account different households characteristics and the combination of the effects of various evacuation triggers under social influence conditions. The model is a unique and valuable tool to predict the number of households who will not decide to evacuate to help risk managers estimate the evacuation needs, such as the identification of where to take the remaining residents, the planning of safe traffic lanes and the definition of the appropriate instructions to guide people to safer places. The model also permits the raising of the important question regarding the need to construct response curves for evacuation triggers different from the evacuation orders/instructions and hazard-related features, which to the best of our knowledge, has not yet been raised in the existing literature on evacuation modelling. Future studies could further investigate this question.

REFERENCES

Ahsan, N. S., Takeuchi, K., Vink, K. & Ohara, M. (2016). A Systematic Review of the Factors Affecting the Cyclone Evacuation Decision Process in Bangladesh. *Journal of Disaster Research*, *Volume 11*, Issue 4, pp. 742-753. DOI 10.20965/jdr.2016.p0742

Albino, V., Carbonara, N. & Giannoccaro, I. (2007). Supply Chain Cooperation in Industrial Districts: A Simulation Analysis. *European Journal of Operational Research*, *Volume 177*, Issue 1, pp. 261-280. DOI 10.1016/j.ejor.2005.12.007

Bangate, J., Dugdale, J., Beck, E. & Adam, C. (2017). SOLACE a Multi-agent Model of Human Behaviour Driven by Social Attachment During Seismic Crisis. In: Proceedings of the 4th International Conference on Information and Communication Technologies for Disaster Management (ICT-DM’17), Münster, Germany, December 11-13, 2017, 9 p.

Chang, S. E., Pasion, C., Yavari, S. & Elwood, K. (2009). Social Impacts of Lifeline Losses: Modeling Displaced Population and Health Care Functionality. In: Tang, A. & Werner, S. (Eds.), Proceedings of 2009 Technical Council on Lifeline Earthquake Engineering (TCLEE) Conference, Oakland, USA, June 22 – July 1, pp 563-572.

Chatterjee, C. & Mozumder, P. (2015). Hurricane Wilma, Utility Disruption, and Household Wellbeing. *International Journal of Disaster Risk Reduction*, *Volume 14*, Part 4, pp. 395-402. DOI 10.1016/j.ijdrr.2015.09.005

Chen, X. & Zhan, F. B. (2008). Agent-based Modelling and Simulation of Urban Evacuation: Relative Effectiveness of Simultaneous and Staged Evacuation Strategies. *Journal of the Operational Research Society*, *Volume 59*, Issue 1, pp. 25-33. DOI 10.1057/palgrave.jors. 2602321

Christensen, K. & Sasaki, Y. (2008). Agent-Based Emergency Evacuation Simulation with Individuals with Disabilities in the Population. *Journal of Artificial Societies and Social Simulation, Volume 11*, Issue 3, 9 p.

Cova, T. J. & Johnson, J. P. (2002). Microsimulation of Neighborhood Evacuations in the Urban - Wildland Interface. *Environment and Planning A: Economy and Space*, *Volume 34*, Issue 12, pp. 2211-2229. DOI 10.1068/a34251

Dash, N. & Gladwin, H. (2007). Evacuation Decision Making and Behavioral Responses: Individual and Household. *Natural Hazards Review*, *Volume 8*, Issue 3, pp. 69-77. DOI 10.1061/(ASCE)1527-6988(2007)8:3(69)

Fang, Z., Li, Q., Li, Q., Han, L. D. & Wang, D. (2011). A Proposed Pedestrian Waiting-time Model for Improving Space-time Use Efficiency in Stadium Evacuation Scenarios. *Building and Environment*, *Volume 46*, Issue 9, pp. 1774-1784. DOI 10.1016/j.buildenv.2011.02.005

Fraser, S. A., Leonard, G. S. & Johnston, D. M. (2013). Intended Evacuation Behaviour in a Local Earthquake and Tsunami at Napier. Scientific report, 55 p.

Fraser, S. A., Wood, N. J., Johnston, D. M., Leonard, G. S., Greening, P. D. & Rossetto, T. (2014). Variable Population Exposure and Distributed Travel Speeds in Least-cost Tsunami Evacuation Modelling. *Natural Hazards and Earth System Sciences*, *Volume 14*, pp. 2975-2991. DOI 10.5194/nhess-14-2975-2014

Fu, H. & Wilmot, C. G. (2004). Sequential Logit Dynamic Travel Demand Model for Hurricane Evacuation. *Transportation Research Record: Journal of the Transportation Research Board*, *Volume 1882*, Issue 1, pp. 19-26. DOI 10.3141/1882-03

Fujiki, K. & Laleau, M. (2019). A Geographic Approach for Spatializing Emergency Sheltering Needs in a Crisis Situation – Case Study of a Massive Evacuation Triggered by a Major Seine Flood in Ile de France Region. *La Houille Blanche*, Number 3-4, pp. 75-83. DOI 10.1051/lhb/2019043

Fujiki, K. (2017). Etude prospective des impacts sociaux d'une inondation majeure en région Ile-de-France. Disparités socio-spatiales dans la prise en charge des populations franciliennes en situation de crise et post-crise : Une analyse cartographiée et quantifiée des besoins des ménages, de l'évacuation à la reconstruction. (Prospective study of the social impacts of a major flood in the Ile-de-France region. Socio-spatial disparities in the care of Ile-de-France populations in crisis and post-crisis situations: A mapped and quantified analysis of household needs, from evacuation to reconstruction.) Phd Thesis (In French), Université Jean Moulin Lyon 3, France, 485 p. Available online at https://tel.archives-ouvertes.fr/tel-01760843/document

Han, L. D., Yuan, F. & Urbanik II, T. (2007). What Is an Effective Evacuation Operation? *Journal of Urban Planning and Development*, *Volume 133*, Issue 1, pp. 3-8. DOI 10.1061/(ASCE)0733-9488(2007)133:1(3)

Hawe, G. I., Coates, G., Wilson, D. T. & Crouch, R. S. (2012). Agent-based Simulation for Large-scale Emergency Response: A Survey of Usage and Implementation. *ACM Computing Survey*, Article n° 8, *Volume 45*, Issue 1, 58 p. DOI 10.1145/2379776.2379784

Hofflinger, A., Somos-Valenzuela, M. A. & Vallejos-Romero, A. (2019). Response Time to Flood Events Using a Social Vulnerability Index (ReTSVI). *Natural Hazards and Earth System Sciences, Volume 19*, Issue 1, pp. 251-267. DOI 10.5194/nhess-19-251-2019

Institut National de la Statistique et des Études Économiques (INSEE – French National Institute for Statistics and Economic Studies) (2016). Population and Housing Census. Available online at https://www.insee.fr/fr/information/4172214

Jumadi, J., Heppenstall, A. J., Malleson, N. S., Carver, S. J., Quincey, D. J. & Manville, V. R. (2018). Modelling Individual Evacuation Decisions during Natural Disasters: A Case Study of Volcanic Crisis in Merapi, Indonesia. *Geosciences, Volume 8,* Issue 6:196, 30 p. DOI 10.3390/geosciences8060196

Kailes, J. I. & Enders, A. (2007). Moving Beyond "Special Needs" A Function-Based Framework for Emergency Management and Planning. *Journal of Disability Policy Studies, Volume 17,* Issue 4, pp. 230–237. DOI 10.1177/10442073070170040601

Kakimoto, R. & Yamada, F. (2014). Factors in Stimulating Evacuation Behavior during Floods. In: Proceedings of the 10th International Conference of the International Institute for Infrastructure Resilience and Reconstruction (3IR2), Purdue, USA, May 20-24, 2014, pp 75-81

Kalafatas, G. & Peeta, S. (2009). Planning for Evacuation: Insights from an Efficient Network Design Model. *Journal of Infrastructure Systems*, *Volume 15,* Issue 1, pp. 21-30. DOI 10.1061/(ASCE)1076-0342(2009)15:1(21)

Kasereka, S., Kasoro, N., Kyamakya, K., Doungmo Goufo, E.-F., Chokki, A. & Yengo, M. V. (2018). Agent-based Modelling and Simulation for Evacuation of People from a Building in Case of Fire. *Procedia Computer Science, Volume 130*, pp. 10-17. DOI 10.1016/j.procs.2018.04.006

Lamb, S., Walton, D., Mora, K. & Thomas, J. (2012). Effect of Authoritative Information and Message Characteristics on Evacuation and Shadow Evacuation in a Simulated Flood Event. *Natural Hazards Review*, *Volume 13*, Issue 4, pp. 272-282. DOI 10.1061/(ASCE)NH.1527-6996.0000070

Lim, M. B. B., Lim, H. R., Piantanakulchai, M. & Uy, F. A. (2016). A household-level Flood Evacuation Decision Model in Quezon City, Philippines. *Natural Hazards, Volume 80,* Issue 3, pp. 1539-1561. DOI 10.1007/s11069-015-2038-6

Lindell, M. K., Lu, J.-C. & Prater, C. S. (2005). Household Decision Making and Evacuation in Response to Hurricane Lili. *Natural Hazards Review*, *Volume 6*, Issue 4, pp. 171-179. DOI 10.1061/(ASCE)1527-6988(2005)6:4(171)

Lindell, M. K., Prater, C. S., Gregg, C. E., Apatu, E. J. I, Huang, S.-K. & Wu H. C. (2015). Households' Immediate Responses to the 2009 American Samoa Earthquake and Tsunami. *International Journal of Disaster Risk Reduction*, *Volume 12*, pp. 328-340. DOI 10.1016/j.ijdrr.2015.03.003

Liu, Z., Jalalpour, M., Jacques, C., Szyniszewski, S., Mitrani-Reiser, J., Guest, J. K., Igusa, T. & Schafer, B. W. (2012). Interfacing Building Response with Human Behavior Under Seismic Events. In: Proceedings of the 15th World Conference on Earthquake Engineering, Lisbon, Portugal, September 24-28, 10 p.

Luathep, P., Suwansunthon, A., Sutthiphan, S. & Taneerananon, P. (2013). Flood Evacuation Behavior Analysis in Urban Areas. *Journal of the Eastern Asia Society for Transportation Studies, Volume 10*, pp. 178-195. DOI 10.11175/easts.10.178

Lv, Y., Huang, G. H., Guo, L., Li, Y. P., Dai, C., Wang, X. W. & Sun, W. (2013). A Scenario-based Modeling Approach for Emergency Evacuation Management and Risk Analysis under Multiple Uncertainties. *Journal of Hazardous Materials, Volume 246-247*, pp. 234-244. DOI 10.1016/j.jhazmat.2012.11.009

Madireddy, M., Medeiros, D. J. & Kumara, S. (2011). An Agent Based Model for Evacuation Traffic Management. In: Proceedings of the Proceedings of the 2011 Winter Simulation Conference (WSC), Phoenix, USA, December 11-14, pp. 222-233. DOI 10.1109/WSC.2011.6147753

Mostafizi, A., Wang, H., Cox, D., Cramer, L. A. & Dong, S. (2017). Agent-based Tsunami Evacuation Modeling of Unplanned Network Disruptions for Evidence-driven Resource Allocation and Retrofitting Strategies. *Natural Hazards*, *Volume 88*, Issue 3, pp. 1347-1372. DOI 10.1007/s11069-017-2927-y

Murray-Tuite, P. & Wolshon, B. (2013). Evacuation Transportation Modeling: An Overview of Research, Development, and Practice. *Transportation Research Part C: Emerging Technologies, Volume 27*, pp. 25-45. DOI 10.1016/j.trc.2012.11.005

Nagarajan, M., Shaw, D. & Albores, P. (2012). Disseminating a Warning Message to Evacuate: A Simulation Study of the Behaviour of Neighbours. *European Journal of Operational Research*, *220*, 810–819. DOI 10.1016/j.ejor.2012.02.026

Nateghi, R., Guikema, S. D. & Quiring, S. M. (2011). Comparison and Validation of Statistical Methods for Predicting Power Outage Durations in the Event of Hurricanes. *Risk Analysis, Volume 31*, Issue 12, pp. 1897-1906. DOI 10.1111/j.1539-6924.2011.01618.x.

Nikolic, I. & Kasmire, J. (2013). Theory. In: van Dam, K. H., Nikolic, I. & Lukszo, Z. (eds), Agent-Based Modelling of Socio-Technical Systems. Dordrecht, The Netherlands, pp. 11–71

Olsvik, A., Mehdizadeh, R., Deck, O., Edjossan-Sossou, A. M., Judek, C. & Vuillet, M. (2018). Modelling Infrastructural Cascade Failure with Multi-Agent Simulation: Application to a

Case of Flooding. In: Proceedings of the 10th Materials and structures reliability symposium (JFMS 2018), Bordeaux, France, March 27-28, 2018, 10 p.

Organisation for Economic Cooperation and Development (OECD) (2014 a). Seine Basin, Ile-de-France: Resilience to major floods. Main results and recommendations. OECD Publishing, Paris, 23 p. Available online at https://www.oecd.org/gov/risk/Flood-risk-management-seine-river-executive-summary.pdf

Organisation for Economic Cooperation and Development (OECD) (2014 b). Seine Basin, Ile-de-France, 2014: Resilience to major floods. OECD Publishing, Paris, 204 p. DOI 10.1787/9789264208728-en

Pel, A. J. (2011). Transportation Modeling for Regional Evacuation. Phd Thesis, Delft University of Technology, Netherlands, 170 p.

Rabemalanto, N., Pottier, N., Edjossan-Sossou, A. M. & Vuillet, M. (2020). Household Resilience to Major Slow Kinetics Floods: A Prospective Survey of the Capacity to Evacuate in High Rise Buildings in Paris. *Natural Hazards and Earth System Sciences*, Discuss., DOI 10.5194/nhess-2020-150 (in review)

Rangel-Ramírez, J. G., Schubert, M. & Faber, M. H. (2019). Probabilistic Evacuation Assessment with Real-time Monitoring Information. In: Proceedings of the 13th International Conference on Applications of Statistics and Probability in Civil Engineering (ICASP13), Seoul, South Korea, May 26-30, 2019, 8 p.

Reed, D. A., Powell, M. D. & Westerman, J. M. (2010). Energy Infrastructure Damage Analysis for Hurricane Rita. *Natural Hazards Review*, *Volume 11*, Issue 3, pp 102-109. DOI 10.1061/(ASCE)NH.1527-6996.0000012

Riad, J. K., Norris, F. H. & Ruback, R. B. (1999). Predicting Evacuation in Two Major Disasters: Risk Perception, Social Influence and Access to Resources. *Journal of Applied Social Psychology*, *Volume 29*, Issue 5, pp 918-934. DOI 10.1111/j.1559-1816.1999.tb00132.x

Ronchi, E., Kuligowski, E. D., Reneke, P. A., Peacock, R. D. & Nilsson, D. (2013). The Process of Verification and Validation of Building Fire Evacuation Models. *National Institute of Standards and Technology (NIST) Technical Note 1822,* 79 p. DOI 10.6028/NIST.TN.1822

Schultz, C. H., Koenig, K. L. & Lewis, R. J. (2003). Implications of Hospital Evacuation after the Northridge, California, Earthquake. *The New England Journal of Medicine*, *Volume 348*, pp. 1349-1355. DOI 10.1056/NEJMsa021807

Solis, D., Thomas, M. H. & Letson, D. (2010). An Empirical Evaluation of the Determinants of Household Hurricane Evacuation Choice. *Journal of Development and Agricultural Economics, Volume 2,* Issue 3, pp. 188-196.

Song, Y. & Yan, X. (2016). A Method for Formulizing Disaster Evacuation Demand Curves based on SI Model. *International Journal Environmental Research and Public Health, Volume 13,* Issue 10, 21 p. DOI 10.3390/ijerph13100986

Tavares, R. M. & Ronchi, E. (2015). Uncertainties in Evacuation Modelling: Current Flaws and Future Improvements. In: Proceedings of the 6th Human Behaviour in Fire Symposium, Cambridge, UK, September 28-30, 2015, 13 p.

Tobin, G. A., Whiteford, L. M., Jones, E. C., Murphy, A. D., Garren, S. J. & Padros, C. V. (2011). The Role of Individual Well-being in Risk Perception and Evacuation for Chronic vs. Acute Natural Hazards in Mexico. *Applied Geography, Volume 31*, Issue 2, pp. 700-711. DOI 10.1016/j.apgeog.2010.12.008

Ukkusuri, S. V., Hasan, S., Luong, B., Doan, K., Zhan, X., Murray-Tuite, P. & Yin, W. (2017). A-RESCUE: An Agent Based Regional Evacuation Simulator Coupled with User Enriched Behavior. *Networks and Spatial Economics, Volume 17*, Issue 1, pp. 197-223. DOI 10.1007/s11067-016-9323-0

Wang, J., Wang, M., Zhou, J., Zuo, Q. & Shi, X. (2020). Simulation Based Optimal Evacuation Plan in Vertical Ship Lift: A Case Study. *Engineering Computations, Volume 37,* Issue 5. DOI 10.1108/EC-05-2019-0212

Wright, K. C. & Johnston, D. M. (2010). Post-earthquake Sheltering Needs; How Loss of Structures and Services Affects Decision Making for Evacuation. In: Proceedings of the 2010 New Zealand Society for Earthquake Engineering NZSEE Conference, Wellington, New Zealand, March 26-28, 2010, 7 p.

Zale, J. J. & Kar, B. (2012). A GIS-based Football Stadium Evacuation Model. *Southeasttern Geographer, Volume 52*, Issue 1, pp. 70-89. DOI 10.1353/sgo.2012.0002

IDRiM (2020) 10 (2) **ISSN: 2185-8322**
DOI10.5595/001c.21955

Journal of Integrated Disaster Risk Management

Original paper

Distributed Ledger Technology for an Improved Index-Based Insurance in Agriculture

Oleksandr Sushchenko [1] and Reimund Schwarze [1]

Received: 06/05/2020 / Accepted: 14/01/2021 / Published online: 31/03/2021

Abstract Climate insurance is already a hot topic due to the increased number of climate-related catastrophic events accompanied by associated losses for the economy in general and insurance companies, in particular. The extremely hot and dry summer of 2018 in some European countries highlighted existing weaknesses of the agricultural insurance mechanisms in Europe, where the farmers had to wait for months before compensation payments could be made. Our paper aims to compare features of the yield-based insurance[2] and the index-based insurance (IBI)[3] in agriculture in the light of new developments and trends in information technologies (IT). The results show that an application of the distributed ledger technologies (DLT) in combination with IBI could not only resolve existing problems, but also facilitate development of the innovative insurance mechanisms at the EU level – providing effective protection against climate-related risks and preventing a systemic risk escalation.

Key words: distributed ledger technologies, index-based insurance, climate insurance, systemic risk, European Risk Transfer Mechanism, European Stabilization Mechanism.

JEL Classification: G22, L8, O52.

[1] Economics, Helmholtz Center for Environmental Research
Email: sushchenko@europa-uni.de

[2] Yield-based insurance provides compensation equivalent to the difference between the obtained yield and the yield guaranteed at the pre-defined rate at the beginning of the contract (Atlas Magazine, 2017).

[3] Index insurance is a relatively new but innovative approach to insurance provision that pays out benefits on the basis of a predetermined index (e.g. rainfall level) for loss of assets and investments, primarily working capital, resulting from weather and catastrophic events (IFC, 2020).

IDRiM (2020) 10 (2) ISSN: 2185-8322
DOI10.5595/001c.21955

1. INTRODUCTION

Climate Change is associated with certain negative consequences (e.g. extreme weather events, natural disasters, etc.) – it poses risks to economic development and requires additional expenditures to prevent catastrophic events or to compensate the damages already caused. The World Economic Forum's (WEF) Global Risk Report 2020 recognizes climate change and its disruptive consequences as the greatest risks to economic activity (WEF 2020). Due to the increased number of climate-related extreme weather events, natural disasters and the associated losses, climate insurance has already gained considerable attention and become an important topic for the economy in general and for the insurance industry in particular. The extremely hot summer of 2018 in Europe proved that existing agricultural insurance approaches have numerous bottlenecks (e.g. farmers had to wait for months to settle the claim, the settlement of claims proved to be too bureaucratic). For the insurance companies, climate change poses new challenges, but at the same time opens up new opportunities for the development of innovative financial products. Moreover, hedge funds, reinsurance companies and institutional investors (e.g. pension and mutual funds) offer innovative instruments (e.g. catastrophe bonds) that provide an opportunity for a transfer of climate-related risks to the financial market (Hagendorff *et al*., 2014; Morana *et al*., 2019). Sometimes, however, these new market instruments conflict with existing traditional insurance products. From the insurance industry's point of view there is a large number of so-called index-based insurance solutions (IBI) as an alternative to yield-based insurance. The main advantage of IBI is the use of an independent and objective physical indicator to overcome existing problems in agricultural insurance and to achieve potential cost savings (Kath *et al*., 2018). Nevertheless, some technical aspects of IBI application in agriculture (e.g. data collection and processing) remain largely unsolved problems. These bottlenecks of IBI could be resolved through the implementation of the Distributed Ledger Technologies (DLT). The now widespread use of DLT in the crypto-currency market has highlighted some positive features of this IT solution and opened up possible ways for its application as a technical facilitator in the financial market (e.g. insurance services) (Hughes *et al*., 2019). DLT could be considered as one of the key technical solutions that could assist in connecting technologies on the corporate level with such innovations like wearables, drones and Internet-of-Things connected devices. Also, this IT-solution could accelerate transformations across insurance services and capital distribution (KPMG 2017). Additionally, application of the DLT-based platforms could improve resilience and speed up recovery efforts in a disaster through decentralized storage of the critical information to file the claims (FEMA 2019). This aspect is important due to the fact that around 30% of the humanitarian aid did not reach its intended target (Ki-Moon 2012). Moreover, only 27 % of the climate-related losses are covered by the insurance services in the EU (EEA 2020).

In this regard, a set of research questions arise. Our first research question is whether IBI is a better solution for agricultural risks than the yield-based insurance or not. Secondly, could the DLT application result in substantial time and cost savings for insurance services? And if this is the case, could an IBI-based climate insurance scheme (with application of DLT) in agriculture on the EU level improve existing European Agricultural Policy and reduce systemic risk for the entire European Financial System?

2. DATA DESCRIPTION

For the purpose of this research the authors have established a set of data on the following aspects: economic damages from weather and climate-related extreme evets for the period 1997-2017 in the EU-28 countries; insurance and compensation systems in the EU and Switzerland as for 2019; DLT-related cost and time savings for the insurance services.

The first set of data has been retrieved from the European Environmental Agency (EEA) and is based on its methodology elaborated to disclose the damages with regard to geothermal (e.g. earthquakes, tsunamis, volcanic eruptions); meteorological (e.g. storms); hydrological (e.g. floods, mass movements); and climatological events (e.g. heatwaves, cold waves, droughts, forest fires). The second set of data on the insurance and compensation systems in the EU and Switzerland has been adopted from available scientific researches and publications (e.g. Palka, 2019:2 and Vroege at el., 2019:105). The third set of data relates to the savings associated with applications of the DLT-based solutions and has been compiled from the reports prepared by various consulting agencies and research institutions (e.g. PwC, 2016).

3. CLIMATE CHANGE – A "WINDOW OF OPPORTUNITIES" FOR THE INSURANCE SECTOR

Climate change is associated with already noticeable negative consequences: increased temperature regimes, melting of ice and rising sea levels. Against this background, the international community (UN) is paying due attention to this problem by taking steps towards the establishment of a common legal framework and incentives to combat climate change and adapt to its consequences. The signing of the Paris Agreement in 2015 was an important step towards reducing greenhouse gas (GHG) emissions, delivering concrete national and civil society commitments to limit global warming to a maximum of 2° Celsius (UNFCCC 2015). In 2018, the global economy had to face losses of 225 billion USD caused by natural disasters and extreme weather events. This level is ten times higher than in 2000, and the year 2018 itself was the third year in a row with actual losses in excess of 200 billion USD. It is important to note that only 40% of these losses were covered and compensated by the insurers (Aon Benfield 2019a).

Currently, we are on a pathway to 3º Celsius of global warming (UNEP 2018). Hence, not only adaptation to climate change, but also reduction of the exposure to natural hazards and extreme weather events is of particular importance and requires appropriate measures, as well as sufficient financial resources. According to estimates of the United Nations (UN), the global annual expenditures for adaptation to climate change are ranging between 140 billion USD and 300 billion USD. By 2050, the cost of adaptation to climate change could reach a level of 280-500 billion USD. In fact, annually only 22 billion USD are being collected for the purpose of adaptation to climate change (Micale *et al*., 2018). At the same time, climate-related disasters are associated with almost 100 billion USD in annual losses. Moreover, such events could have serious social and economic consequences. For example, the number of climate-induced migrants is steadily increasing, and with regard to the actual path of global warming, we may face millions of people in the coming decades who will be forced to change their place of residence due to the adverse environmental conditions (IOM 2009). As a result, to reduce the risks of climate-related disasters another important agreement was signed in 2015 under the auspices of the UN: The Sendai Framework on Disaster Risk Reduction (SFDRR) which covers the time horizon of 2015-2030 and is aimed at protecting people's lives as well as critical infrastructure (e.g. the energy sector, transport, agriculture, etc.) (UNISDR 2015).

According to the methodology offered by the European Environmental Agency (EEA), there are four major groups of weather and climate-related extreme events that might cause economic damages: geothermal (e.g. earthquakes, tsunamis, volcanic eruptions); meteorological (e.g. storms); hydrological (e.g. floods, mass movements); and climatological events (e.g. heatwaves, cold waves, droughts, forest fires) (see figure 1). Of particular importance is the fact that climate change indirectly affects other extreme weather events that have been classified as meteorological or hydrological. Hence, climate change is responsible for the vast majority of damages experienced by the economy, financial markets and the society at large. In other words, climate change requires more effective measures to prevent the global economy and the financial system from losses and damages, and improve the resilience of the infrastructure (especially, critical infrastructure) to climate-related risks. Additionally, there is an urgent need for innovative financial products and instruments to support the above-mentioned measures with the overarching aim of providing access to the market of private climate finance.

In fact, according to the data provided by NatCatSERVICE, Eurostat and MunichRe, the extent to which climate-related losses are covered is insufficient and the best results in 2017 were achieved by the United Kingdom (UK), where insured losses accounted for over 70% of the total losses. The most critical situation in covering climate-related risks and losses was identified in Greece, Portugal, Poland and Italy – where damages from climate-related events remained almost uncovered. At the same time, very good rates were achieved by Belgium, Denmark, Lichtenstein and Luxembourg – where over 58% of the losses were insured. Additionally, Germany, France, Ireland, Iceland and Switzerland were able to cover almost 50% of the damages caused by climate-related extreme events and natural disasters (EEA 2019).

IDRiM (2020) 10 (2) **ISSN: 2185-8322**
DOI10.5595/001c.21955

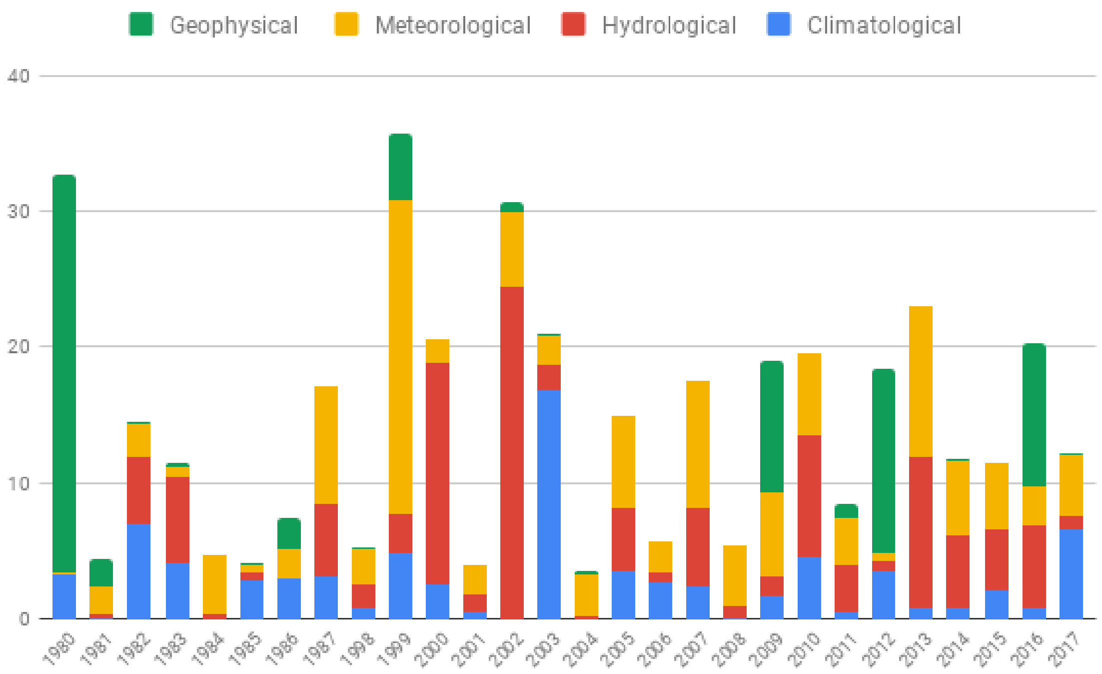


Figure 1. EU-28, economic damages caused by weather and climate-related extreme events in Europe (1980-2017), billion EUR.

Source: Own compilation, data from Munich Re.

4. A YIELD-BASED INSURANCE – PROSPECTS FOR THE EUROPEAN UNION

Three-quarters of the EU countries, including France, Italy, Spain, Austria and the Netherlands, deliver subsidies for so-called multi-risk policies of the insurers which cover weather-related risks including droughts (see table 1). Additionally, financial support comes from the EU (Peters 2018). For example, in the Netherlands and Luxembourg, agricultural yield losses in the field are determined by evaluating the dried parts of the plant, the size of the cobs or the weight of the grains. In the Netherlands, more than a quarter, in Luxembourg almost every second hectare of the affected areas, is already insured against drought damage. Demand is high, since a risk premium subsidy of 50-70% on the insurance premium is granted from national and/or EU funds. In Germany, however, a lack of subsidies and an insurance tax of 19 % on insurance premiums for droughts make risk protection completely uninteresting. In almost all other EU countries, the tax rate is near zero, and the state also provides support to risk provisioning (Rittershaus 2018).

In addition, Italy protects its farmers against weather risks with around 1.6 billion EUR, France with 600 million EUR. Only Germany, Ireland, Great Britain and a few others leave this risk to their farmers (Krohn 2018).

Table 1: Insurance and compensation systems in the EU and Switzerland.

	Hail	Storm	Heavy Rainfall	Frost	Drought
Belgium1)3)	X	X	X		
Denmark	X	X	X		
Germany2)	X	X	X	X	X
Italy1)3)	X	X	X	X	X
Croatia1)3)	X	X	X	X	
Luxembourg1)3)	X	X	X	X	X
Latvia1)3)	X	X	X	X	
Lithuania1)3)	X	X	X	X	X
Netherlands1)	X	X	X	X	X
Austria1)2)3)	X	X	X	X	
Poland1)3)	X	X	X	X	
Spain 1)2)3)	X	X	X	X	X
Switzerland1)2)3)	X	X	X	X4)	X

Note: 1) multi-peril insurance, 2) IBI, 3) state subsidies [45-60%], 4) Snow pressure

Source: Own compilation based on Grant (2010). Austria and Switzerland adopted from Palka (2019:2) and Vroege *at el*. (2019:105).

5. YIELD-BASED VS. INDEX-BASED INSURANCE

As a rule, climate catastrophes hit unexpectedly and the damage caused by such events is not precisely predictable. The "classical" insurance techniques and instruments are often not effective enough to solve the problem as the contractual compensation mechanism works on the basis of yield losses that have been observed in the past. In practice, the main claims management problem is that it often takes months to determine and settle the refunds – months during which the losses can rise further. For instance, a long-lasting moisture penetration could affect infrastructure conditions – e.g. reduce their drying capacity and make them vulnerable to the possible subsequent frost damages. Existing yield-based approaches to the insurance of climate-related risks in agriculture have two main drawbacks: fraud detection and risk modeling. The agricultural firms and farmers tend to overestimate their real losses and claim higher compensation from the insurance companies. Hence, claims management becomes very difficult and requires additional expenditures (both in terms of cost and time) to determine and verify an appropriate amount of compensation for the clients. The second negative feature of a yield-based insurance relates to the modeling of risks, especially when the average surface temperature on Earth rises faster than expected – making forecasting unprecedentedly difficult.

DOI10.5595/001c.21955

Nowadays, ex-post and ad hoc compensations are becoming more and more expensive – in the period 2014-2020 more than 65% of the insurance premiums have been paid by the EU within the Common Agricultural Policy (Hochrainer-Stingler and Hanger-Kopp 2017). In addition, yield-based insurance may not even be applicable in certain areas – for example, grasslands have different number of harvests per year and a very small difference in damages depending on the seasonal frequency of extreme weather events. Therefore, in such cases IBI could be considered as the most appropriate solution (Hochrainer-Stingler and Hanger-Kopp 2017).

IBI relies on the application of physical indicators (e.g. temperature or soil moisture, etc.) as a "trigger" for compensations. Compared to yield-based insurance, IBI has some positive features. Firstly, this approach is more objective due to the fact that indicators depend only on the physical properties of the environment. In addition, compensation is limited to a predetermined amount of money calculated on the basis of the previous events and associated losses. Another important advantage of IBI is an improved trust between insurance companies and their clients. At the same time, IBI could simplify field loss assessment, reduce bureaucracy and increase transparency – thus making it less costly for small customers like farmers (Gommes and Kayitakire 2013). Despite all the positive features, implementation of IBI is associated with certain obstacles: lack of reliable data, existing basis risk and some technical requirements. The changing risk pattern in the abrupt climate change could also jeopardize the IBI application. Additionally, the premiums per farmer are small and the insurance companies usually have to aggregate risks to transfer them to the reinsurer (Hess and Syroka 2005).

There are three different types of IBI: crop, grassland and livestock insurance. For the crop insurance we can distinguish the following types of indexes: meteorological trigger, area yield trigger, vegetation index and the combination of different factors within the crop growth model. For the grassland insurance we can identify the following types of indexes: meteorological trigger and vegetation index (remote sensing). In case of the livestock IBI, products are based on the measured livestock mortality and vegetation indexes (The World Bank Group 2011). In order to implement the most effective indicator for a crop-related IBI product several studies have been carried out examining different conditions and options. One of the studies suggests that the Normalized Drought Vegetation Index (NDVI) could be introduced in Europe, where summer temperatures are above 16º Celsius (CGLO 2020). In fact, the reaction of vegetation in summer could only be attributed to fluctuations in drought stress and not to the temperature level (Peled *et al*., 2010). More recent developments show that the application of satellite observations provides a good opportunity for innovative insurance products. For instance, in 2001 the Agriculture Financial Services Corporation (AFSC) introduced the first-of-a-kind NDVI-based pasture insurance product (Hohl 2018). In 2013, the Government of Kenya implemented the first index-based livestock insurance intervention as a component of the Kenya Livestock Insurance Program (KLIP). As a result, Andrew Mude, the inventor of this tool, received the 2016 World Food Prize (Russell 2020).

Another option is to use the so-called Combined Drought Indicator, which consists of the Standardized Precipitation Index (SPI) and fraction anomalies for the absorbed photosynthetically active radiation (APAR). The SPI is based on the data collected at the European level from different weather stations situated in the member states (Sepulcre-Canto at al. 2012). Additionally, a Hydrological Drought Index Insurance (HDII) for irrigation districts has been elaborated for Spain, where indemnity is based on the Drought Index (DI), which, in turn, is multiplied by a uniform water value for the region. Important is the fact that a transfer of water rights should be prohibited under such scheme – otherwise, the farmers could request double compensation (e.g. yield-based approach). However, if indemnity is based on the objective physical trigger, voluntary exchange of water rights is possible (as well as water banking) (Maestro *et al.*, 2016). The international financial institutions actively offer a wide range of mechanisms to cover climate-related risks, especially for developing countries with limited access to financial resources and mechanisms. For example, the International Financial Corporation (IFC) offers the Global Index Insurance Facility (GIIF) as an opportunity to facilitate access to the financial resources for SMEs, catastrophe risk transfer solutions and IBI in developing countries. From the EU's perspective, IBI could bring more benefits than negative consequences. However, there is no market for related futures across Europe and risk management is not unified across the EU (Ramsey and Santaremo 2017). In other words, on the way to the EU-wide IBI application, two problems should be kept in mind: the cost of implementation could be enormous and basis risk could sharpen the problems of market acceptance (IFAD, 2017).

6. DLT FOR A BETTER AGRIBUSINESS AND RELATED INSURANCE PRODUCTS

In recent decades, precision technologies and smart contracts have entered the agri-food systems (AFS) of this world (Xu *et al.*, 2020; Stranieri *et al.*, 2021). The origin of modern agricultural technology such as sensors, Internet of Things, enabled smart devices and smart contracts provide a ground for agriculture 4.0, and the foundation of "smart AFS". Smart AFS aim to improve the efficiency of the agriculture-food-chain in relation to physical (e.g. climate and soil), technical (sensors and machines) and business (sales contracts, insurance) factors. The best, i.e. most efficient response of smart machines to, for example, climate extremes (e.g. water scarcity) depends on communication among enabled smart devices with other intelligent nodes of the production, the sales and the risk management system in the network of agriculture and food production. Smart machines collect information of an unfolding climatic event, broadcast it to other machines in the field and nodes along the supply chain. The goal of the internet-of-agri-food (IoAF) is to broadcast system-threatening event messages such as soil moisture extremes to cropping technologies in usage, crop loss assessment and environmental hazards reports, messages to cooperative financial risk management, sales and storage, neighboring farmers and the insurance as element of smart AFS – in less time with high accuracy, in other words: at lower transaction cost.

Nowadays, a huge amount of data has to be processed to cover the needs of the insurers (as well as the insureds) at least in the two above-mentioned areas. Moreover, in the modern world, data protection becomes increasingly important for all economic agents. For this reason, companies and governments from different countries are looking more precisely at the opportunities of DLT. A starting point (being currently the most popular type of solution) has been elaborated on the basis of Blockchain. Despite the fact that this technology has some limitations (e.g. amount of the operations within a specific time horizon), the level of data protection is high enough to reduce significantly the risks of external interventions (e.g. "hacking") to get the data or important business information. Additionally, a combination of DLT with Artificial Intelligence (AI), the Internet of Things (IoT), Big Data and other innovations could give unprecedented breakthroughs for the entire insurance sector. That is why, "InsureTech" is not just a modern trend, but has already become an important part of the daily business activities of different economic sectors (see table 2).

Several important benefits could be identified for a DLT-based application of IBI, such as improved real-time exposure assessment and enhanced accident and risk prediction. Those benefits contribute to the improvement of data processing and facilitate understanding of the scenario-based assessments of different changing parameters in a real-time mode.

DLT could bring significant cost and time savings, i.e. reduce transaction costs (e.g. time for negotiations and quotations). According to the available estimations, an implementation of DLT solutions for the insurance sector could reduce time for negotiations and quotations by up to 90% (Generali 2018). As a result, reinsurers could make the process of reserve estimations easier and establish the so-called "streamlined reinsurance" operations. However, the most important advantage for all insurers is improved liquidity control.

InsurTech facilitates deeper risk assessment, offers more sophisticated preventive models, improves interactions, enhances operational capabilities, and makes efficient use of ecosystem and market resources (i.e., lower transaction costs). According to the findings provided by PwC (2016), the most important opportunity for the insurers arises from self-directed services (e.g. customer acquisition and customer services) and usage-based insurance (e.g. pay-as-you-go).

Moreover, a variety of operational benefits for the agricultural insurance relates to an improved claims management: coordinated and synchronized view and verification of the transactions and other information; enhanced third-party transactions (e.g. "claim leakage"); enforced fraud detection and better alignment with the new legal requirements for the financial institutions. Such improvements could create additional benefits through behavior-based underwriting (e.g. pay-as-you-go). Additionally, existing enhanced requirements for the financial market (e.g. Basel III, Directives 2016/2341, 2017/828) impose certain limitations on the activities of financial institutions (European Parliament; Council 2016, 2017). In this case, not only the insurance companies should comply with the existing requirements while providing their services, but also other institutional investors should pay attention to the existing limitations. In fact, new legal requirements on the financial market force institutional investors to analyze and evaluate non-financial risks while making their investment decision.

IDRiM (2020) 10 (2) **ISSN: 2185-8322**
DOI10.5595/001c.21955

Table 2: DLT-related cost and time savings for insurance services.

	Area of application	**Practical cases**	**Time/money savings**
Signing the contract and execution	Smart contracts	R3,_CatBonds, CatSwaps	up to 2-3 days, no escrow cost[4]
Microfinancing	Peer-to-peer insurance	Lydia	Average cashback of 30% of the premiums[5]
Claim management	Fraud detection	Shift Technology (Claims automation)	"hit-rate" more than 2,5 times better than standards[6] reduction of annual losses for up to 10%
Underwriting	Behavior-based underwriting	Atidot	identification of up to 25% under-insured policies[7]
Parametric insurance	Mechanism selection	Kenyan Livestock Insurance Program (KLIP)	up to 2-3 months
KYC ("Know your client") and AML (Anti-Money-Laundering Laws)	Due diligence	InterchainZ	up to 90% of time up to USD 8 billion[8]
Risk transfer	Reinsurance	B3i (Aegon, Allianz, Munich Re, Swiss Re and Zurich Re)	15-20% expenses[9]

Source: Own compilation.

Also, a set of market benefits associated with the application of DLT in the insurance sector reflects the new business opportunities. The most important improvement could be achieved in facilitating access to the services for small and medium clients. Exactly in this case the insurers could drastically reduce administrative costs and make their services more accessible for those, who were excluded from the classical schemes due to the negative cost-benefit ratios of the

[4] https://hackernoon.com/smart-contracts-a-time-saving-primer-b3060e3e5667
[5] https://p2pconference.com/speaker/tim-kunde/
[6] https://www.digitalinsuranceagenda.com/180/shift-technology-ai-that-understands-insurance-claims/
[7] http://www.oxbowpartners.com/pdfs/Atidot.pdf
[8] https://www.jdsupra.com/legalnews/using-blockchain-for-kyc-aml-compliance-25325/
[9] https://www.disruptordaily.com/blockchain-use-cases-insurance/

insurance products. Also, DLT creates a common platform for all the key participants of the insurance process and improves the efficiency of their communications. Moreover, such a platform could be considered as a common space to follow and understand the quotations workflow. The international financial institutions are trying actively to develop technical solutions for dealing with agricultural risks. For example, the UN created an incentive "New Climate Chain Coalition", which purpose is to facilitate achievement of the SDGs through implementation of DLT and elaborate better climate-related solutions to avoid frauds and address existing challenges (UNFCCC 2018).

Even despite all the above-mentioned benefits, some bottlenecks are associated with DLT application for the IBI-based agriculture insurance products. Firstly, the so-called privacy challenges emerge while analyzing the data, since data protection in the EU is / the EU countries have very complex and challenging data protection laws. The second important obstacle on the way to an application of DLT for the agricultural insurance services is associated with existing different regulations within the separate jurisdictions – this could impose some obstacles while implying different legal acts to the same operations. Another challenge is associated with the decentralized way of storing the data – no certain person or entity is responsible for the stored data.

7. SYSTEMIC APPROACH FOR CLIMATE INSURANCE IN AGRICULTURE

A pool insurance of the agricultural risks is more appropriate than individual insurance (Villarroya and Agronoma 2016). Moreover, one of the most important reasons for the introduction of a new agricultural insurance scheme at the EU level is the fact that climate change could contribute to the systemic risk escalation for the entire economic and on financial systems (e.g. cascading large scale losses after one climate-related event). According to the report prepared by the European Systemic Risk Board (ESRB), climate change will contribute to systemic risk through several channels. First of all, it is important to consider the macroeconomic impact of the sudden changes in energy use. Moreover, the reassessment of the carbon-intensive assets (e.g. stranded assets) could be an additional source for the systemic risk escalation. Additionally, an increase in the frequency and severity of the natural catastrophes and extreme weather events could lead to an aggravation of the systemic risk. The fact that climate change could increase systemic risk requires an adequate response at the EU level to protect the entire financial and economic system from escalation of the climate-driven systemic risk through establishment of the European Risk Transfer Mechanism (ERTM) (see Figure 3). With this regard, a Special Purpose Vehicle (SPV) is needed to issue debt instruments or swaps and to coordinate the new insurance mechanism in agriculture on the EU level. Furthermore, the existing patterns of reinsurance mechanisms show that the market for the alternative risk transfer capital is being driven mostly by the collateralized reinsurance schemes. Although an alternative segment of the global reinsurance market accounts for less than 20%, it shows very high growth rates in comparison with the traditional reinsurance market (see figure 2).

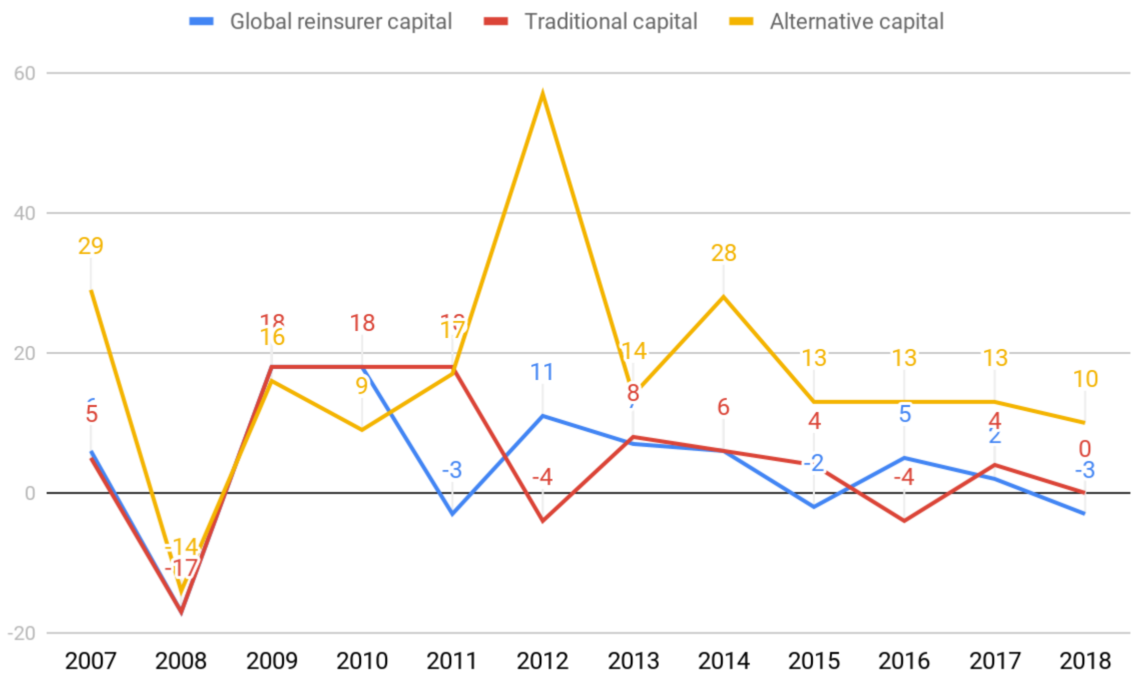


Figure 2: The growth rates of the global, traditional and alternative reinsurance capital (2007-2018), changes in %.

Source: Own compilation, data from Aon Benfield 2017 and Aon Benfield 2019b.

Within the alternative reinsurance market, the biggest chunk belongs to collateralized reinsurance schemes – 50% of the total global reinsurance capital and the most rapid growth rates in 2008-2018. The fact that synthetic instruments are still playing an important role on the financial market could be considered as a potential additional source of systemic risks (e.g. 2008 on the U.S. mortgage market). Moreover, the recently enacted Solvency II regulation recognizes derivatives or securitization as an effective risk mitigation technic and gives a green light for further application of the alternative approaches in risk transfer (Aon Benfield 2017). The existing EU Common Agricultural Policy (CAP) provides assistance for the agricultural risk management of less than 2% of the Pillar II funds and 0,4% of the total 2014-2020 CAP budget (Bardaji I., *et al*., 2016). Hence, CAP could contribute to the functioning of the new insurance system at the European level by covering the basis risks. This could be achieved through the facilities of the European Agricultural Fund for Guarantee (EAFG) which is aimed at providing direct payments (e.g. income support) to farmers. In this case, financial resources of the fund could cover the difference between actual losses and compensations.

There are two major bottlenecks in delivering protection of agriculture from climate-related risks: Time and administrative costs. Moreover, possible insurance services for small and medium should be designed to transfer part of the risks to the public or private reinsurance providers (Bardaji I., *et al*., 2016). These two aspects could be considered as evidence that the level of transaction costs is high and requires more adequate solutions at the EU level.

The fact that climate change could increase systemic risk requires an adequate response also at the EU level to protect the entire financial and economic system from escalation of the climate-driven systemic risk through establishment of the European Risk Transfer Mechanism (ERTM) (see figure 3). With this regard, a Special Purpose Vehicle (SPV) is needed to issue debt instruments (e.g. catbonds) or swaps (e.g. catswaps) and to coordinate the new insurance mechanism in agriculture on the EU level. Furthermore, the existing patterns of reinsurance mechanisms show that the market for the alternative risk transfer capital is being driven mostly by the collateralized reinsurance schemes.

A European Stability Mechanism (ESM) already exists in the European Union and is aimed at providing financial assistance to member states with severe debt conditions. It could serve as SPV to issue debt instruments and swaps in order to transfer risks to the financial market. Such an approach could equalize the costs of capital for issued catastrophe bonds (catbonds) as the creditworthiness of the EU is much higher than that of some EU member states (see figure 3, number 1). Another reason for establishing ERTM is the fact that there are different types of actors on the financial market who try to exchange debt instruments and related swaps in order to increase their profits. The example of the last financial crisis in 2008 demonstrated that ESM could not only play an important role in providing relatively cheap financial resources to all member states, but also serve as a contractor for credit default swaps. In fact, ESM should protect against possible speculations with catastrophe swaps (catswaps). After mobilization of the necessary financial resources, sovereign funds or special sovereign climate insurance agencies could use catbonds and catswaps to transfer risks via ESM to the financial market (see figure 3, number 2).

The application of DLT could allow the transfer of information and financial resources between ESM and sovereign insurance funds. Moreover, DLT could not only ensure collection and processing of climate-related information, but also provide a very high level of security and access to insurance products for small clients (e.g. small farmers). Additionally, issuance and management of the financial instruments (e.g. bonds, swaps) with the DLT application could be organized in a more efficient way and thus provide time and cost savings, facilitate the collection of financial resources and relevant data and speed up compensation payments for small and medium economic agents (see figure 3, number 3).

At the same time, the European Parliament has already adopted directives forcing big companies to disclose their level of non-financial risks. Although companies can still choose the way in which they report on their non-financial risks and results, the Sustainable Finance Action Plan and the EU Green Deal (Communication from the Commission to the European Parliament, the European Council, the Council, the European Central Bank, the European Economic and Social Committee and the Committee of the Regions 2018) provide a clear signal that concrete requirements and guidelines on non-financial reporting will be included into the revised versions of the legal acts (e.g. Directive 2013/34/EU, 2014/95/EU) (European

Parliament; Council 2013, 2014). Such amendments could require collection of the relevant data for both non-financial reporting and effective risk management.

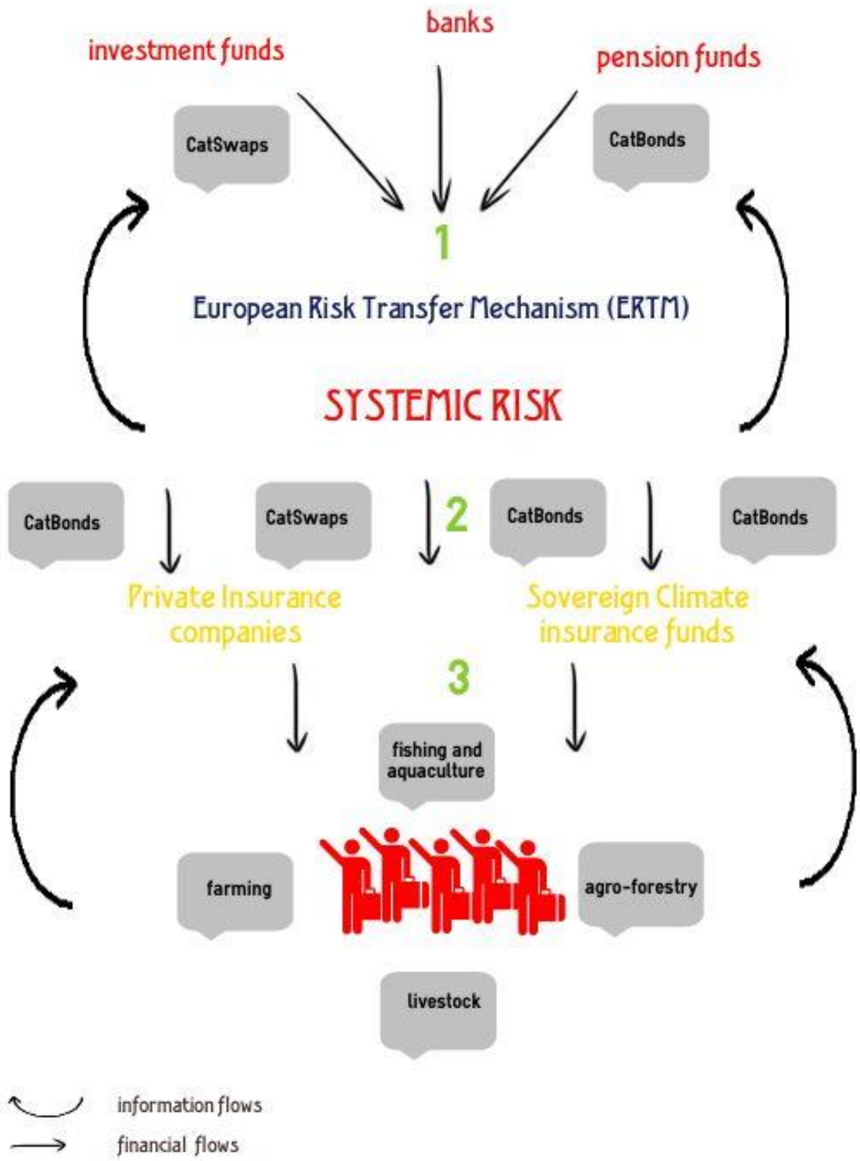


Figure 3: European Risk Transfer Mechanism (ERTM) with a combined application of IBI and DLT for agriculture.

Source: Own compilation.

Currently, pension funds and insurance companies in the EU have to analyze the level of non-financial risks while making their investment decisions. This means that major institutional investors are already paying attention to climate-related risks and trying to avoid investments with a high level of the above-mentioned risks (e.g. Directive 2016/2341/EU) (European Parliament; Council 2016).

As a result, an introduction of the DTL-based IBI insurance on the EU level (ERTM) could bring various benefits by solving existing problems in agricultural insurance and offer new opportunities for further improvements. In fact, benefits could be measured both in terms of time and cost savings on each stage and level of the insurance process. ERTM could be built on the already existing IT-solutions and its implementation could be less costly than the creation of a completely new mechanism from zero (see Table 2). The application of the DLT could grant an access for small users/customers to the insurance services on a peer-to-peer basis by reducing transaction costs and facilitating flow of payments. Moreover, in some cases peer-to-peer insurance could generate a cashback of up to 80% (see Table 2). Additionally, such a system could be considered as an effective tool to increase the rate of penetration on the market, which currently does not exceed the level of 40%. The application of smart contracts as a basis of the DLT-based insurance mechanism could not only reduce significantly time cost for signing the contracts but also contribute to time optimization in the execution the contracts (e.g. up to 2-3 days).

The DLT-based IBI on the EU level, as discussed above, is a simplified approach to deliver protection against possible losses. Such an approach allows to save time (see Table 2) and speed up compensation payments without additional verifications and calculations on the ground. An application of DLT could make the process of such payments quicker by arranging direct compensations to the accounts and facilitate risk transfer to the financial market.

8. CONCLUSIONS

The application of yield-based insurance schemes in agriculture has proven to be less effective than index-based solutions. This disadvantage is primarily related to the existing time gaps between an actual event and the compensation payments. Additionally, it is very hard to estimate actual losses. Mistrust between economic operators could be considered as one of the reasons for this. Moreover, yield-based insurance products are relatively expensive and not accessible for small costumers. From the point of view of the underwriting process, there are a number of options to replace yield-based insurance with IBI – solving the above-mentioned problems by introducing an independent and objective physical “trigger” to facilitate quick compensation payments to the clients.

DLT solutions on the crypto-currency market demonstrate some positive features of this technology and offer prospects for its application in other segments of the financial market. When using InsurTech with index-based insurance in agriculture, it is important to consider some of its specific aspects. For instance, DLT application could offer an improved real-time exposure assessment, facilitate accident and/or risk forecasting and assist in reserve calculations for the reinsurance. Furthermore, this technology could be employed in implementing behavioral underwriting.

Moreover, the application of a DLT-based IBI in agriculture could improve insurance services and facilitate the transition of risks from sovereign climate insurance funds to the financial market. An elaborated concept of ERTM could facilitate access to the services for small customers in different EU countries, improve contract execution, speed up compensation payments, contribute to the basis risk reduction, improve risk transfer and reduce information asymmetry (e.g. transaction costs). Additionally, this approach could prevent speculations on the financial market and equalize the cost of capital for different EU member states on the financial market. At the same time, facilities of some European financial institutions could be used as a Special Purpose Vehicle (e.g. ESM or EIB) to improve access to the financial market and grant control over the transactions. The most important advantage of ERTM is an opportunity to avoid systemic risks (e.g. support for the private insurance companies and sovereign insurance funds) and to protect the European Financial System from the next possible financial turmoil – making it more sustainable to non-financial risks. DLT as a component of ERTM could also facilitate the flow of information in order to facilitate and improve risk management and communication among the different economic agents.

ACKNOWLEDGEMENTS

We are grateful for helpful hints and comments from two anonymous reviewers of this journal and from Anne Wessner of the Helmholtz-Centre for Environmental Research – UFZ in Leipzig.

REFERENCES

Aon Benfield (2017) Reinsurance Market Outlook. Record Capacity Sufficient to Meet Current Demand Increase and Future Innovations. http://thoughtleadership.aonbenfield.com/Documents/20170105-ab-analytics-rmo.pdf.

Aon Benfield (2019a) Weather, Climate & Catastrophe Insights. 2018 Annual report. http://thoughtleadership.aonbenfield.com/Documents/20190122-ab-if-annual-weather-climate-report-2018.pdf.

Aon Benfield (2019b) Reinsurance Market outlook. April 2019. http://thoughtleadership.aonbenfield.com/Documents/20190403-ab-analytics-rmo-april-2019.pdf.

Atlas Magazine (2017) Agricultural insurance: products and schemes https://www.atlas-mag.net/en/article/agricultural-insurance-products-and-schemes

Bardaji I., Garrido A., Blanco I., Felis A., Sumpsi J.M. and Garcia-Azcarate T. (2016) State of play of risk management tools implemented by Member States during the period 2014-

2020: national and European frameworks. https://www.europarl.europa.eu/RegData/etudes/STUD/2016/573415/IPOL_STU%282016%29573415_EN.pdf

CGLO (2020) Copernicus Global Land Operations "Vegetation and Energy". Framework Service Contract Nº 199494 (JRC). Scientific Quality Evaluation. Normalized Difference Vegetation Index (NDVI). https://land.copernicus.eu/global/sites/cgls.vito.be/files/products/CGLOPS1_SQE2019_NDV300m-V1_I1.01.pdf.

Communication from the Commission to the European Parliament, the European Council, the Council, the European Central Bank, the European Economic and Social Committee and the Committee of the Regions. (2018) Action Plan: Financing Sustainable Growth. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0097&from=EN.

EEA (2020) Economic losses insured (1980-2019). https://www.eea.europa.eu/data-and-maps/indicators/figures/impacts-of-extreme-weather-and-2

European Parliament; Council (2016) DIRECTIVE (EU) 2016/2341 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 December 2016 on the activities and supervision of institutions for occupational retirement provision (IORPs). *Official Journal of the European Union*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016L2341&from=EN.

European Parliament; Council (2017) DIRECTIVE (EU) 2017/828 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2017 amending Directive 2007/36/EC as regards the encouragement of long-term shareholder engagement. *Official Journal of the European Union.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017L0828

European Parliament; Council (2013) DIRECTIVE 2013/34/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 June 2013 on the annual financial statements, consolidated financial statements and related reports of certain types of undertakings, amending Directive 2006/43/EC of the European Parliament and of the Council and repealing Council Directives 78/660/EEC and 83/349/EEC. *Official Journal of the European Union.* https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013L0034&from=EN.

European Parliament; Council (2014) DIRECTIVE 2014/95/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 October 2014 amending Directive 2013/34/EU as regards disclosure of non- financial and diversity information by certain large undertakings and groups. *Official Journal of the European Union.* https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0095&from=EN.

FEMA (2019) National Advisory Council. DRAFT Report to the FEMA Administrator, FEMA NAC Report, November 2019. https://www.fema.gov/sites/default/files/2020-08/fema_nac-report_11-2019.pdf

Generali (2018) Generali Global Corporate & Commercial Italy promotes the initiative to optimize corporate risks quotation, negotiation and binding processes through blockchain technology. https://www.generaliglobalcorporate.com/doc/jcr:d1076099-3628-4d67-a813-3060b7f2ca54/lang:en/PressRelease_Blockchain_Ottimizzazione_vf_ENGLISH.pdf

Grant, W. (2010) Policy Instruments in the Common Agricultural Policy. *West European Politics, Vol. 33,* Issue 1, pp. 22-38.

Gommes R. and Kayitakire F. (2013) *The challenges of IBI for food security in developing countries*. Luxembourg: Publications Office of the European Union. Proceedings of a technical workshop organised by the EC Joint Research Centre (JRC) and the International Research Institute for Climate and Society (IRI, Earth Institute, Columbia University).

Hagendorff, B., Hagendorf, J., Keasey, K., and Gonzalez, A. (2014) The risk implications of insurance securitization: The case of catastrophe bonds. *Journal of Corporate Finance, Vol. 25*, pp. 387-402.

Hess U., Syroka J. (2005) Weather-based Insurance in Southern Africa. The Case of Malawy. Agriculture and Rural Development Discussion Paper 13, p. 38.

Hochrainer-Stigler, S. and Hanger-Kopp, S. (2017) Subsidized Drought Insurance in Austria: Recent Reforms and Future Challenges. *Wirtschaftspolitische Blätter*, *6*(4), pp. 599-614.

Hohl, R.M. (2018) *Agricultural Risk Transfer: From Insurance to Reinsurance to Capital Market. John Wiley&Sons*, pp. 440.

Hughes, A., Park, A., Kietzmann, J. and Archer-Brown, C. (2019) Beyond Bitcoin: What blockchain and distributed ledger technologies mean for firms, in: *Business Horizons, Vol. 62*, Issue 3, pp. 273-281.

IFAD (2017) Remote sensing for index insurance. An overview of findings and lessons learned for smallholder agriculture, 60 p.

IFC (2020) Index Insurance – Frequently Asked Questions https://www.ifc.org/wps/wcm/connect/industry_ext_content/ifc_external_corporate_site/financial+institutions/priorities/access_essential+financial+services/giif+frequently-asked-questions

IOM (2009) Disaster risk reduction, climate change adaptation and environmental migration. A policy perspective. https://publications.iom.int/system/files/pdf/ddr_cca_report.pdf.

Kath J., Mushtaq S., Henry R., Adeyinka A. and Stone R. (2018) Index insurance benefits agricultural producers exposed to excessive rainfall. *Weather and Climate Extremes 22* (2018): 1-9.

Ki-Moon, B. (2012) Secretary-General's closing remarks at High-Level Panel on Accountability, Transparency and Sustainable Development. https://www.un.org/sg/en/content/sg/statement/2012-07-09/secretary-generals-closing-remarks-high-level-panel-accountability

KPMG (2017) Blockchain accelerates insurance transformation. https://assets.kpmg/content/dam/kpmg/xx/pdf/2017/01/blockchain-accelerates-insurance-transformation-fs.pdf

Krohn P. (2018) Bauern scheuen Kosten einer Dürre-Versicherung. https://www.faz.net/aktuell/wirtschaft/bauern-scheuen-die-kosten-einer-duerre-versicherung-15725414.html

Maestro, T., Bialza, M., Garrido. A. (2016) Hydrological drought index insurance for irrigation districts in Spain. *Spanish Journal of Agricultural Research 14*(3), e0105, 14 p.

Micale, V., Tonkonogy, B., and Mazza, F. (2018) Understanding and Increasing Finance for Climate Adaptation in Developing Countries. https://www.international-climate-initiative.com/fileadmin/Dokumente/2019/20190225_Understanding-and-Increasing-Finance-for-Climate-Adaptation-in-Developing-Countries.pdf.

Morana, C. and Sbrana, G. (2019) Climate change implications for the catastrophe bonds market: An empirical analysis. *Economic Modelling, Vol. 81*, pp. 274-294.

Palka, M. and Hanger-Kopp, S. (2019) Agricultural crop insurance in Switzerland, focusing on drought. Crop Insurance in Switzerland. IIASA FACTSHEET, 6 p.

Peled, E., Dutra, E., Viterbo, P. and Angert, A. (2010) Technical Note: Comparing and ranking soil drought indices performance over Europe, through remote-sensing of vegetation. *Hydrology. Earth Syst. Sciences., Vol. 14*(2), pp. 271-277.

Peters L. (2018) Deutsche Bauern können sich keine Dürreversicherung leisten – Dürre 2018. https://www.topagrar.com/management-und-politik/news/deutsche-bauern-koennen-sich-keine-duerreversicherung-leisten-duerre2018-9842034.html

PwC (2016) Opportunities await: How InsurTech is reshaping insurance. https://www.pwc.lu/en/fintech/docs/pwc-insurtech.pdf

Ramsey, A. F. and Santaremo, F.G. (2017) Crop Insurance in the European Union: Lessons and Caution from the United States. https://mpra.ub.uni-muenchen.de/79164/1/MPRA_paper_79164.pdf

Rittershaus, D. (2018) Oft gestellte Fragen zum Thema Trockenheit und Versicherung, https://www.vereinigte-hagel.net/de/2018/08/oft-gestellte-fragen-zum-thema-trockenheit-und-versicherung/

Russell, A. (2020) How NDVI Transformed Insurance as a Tool to Build Resilience. https://www.agrilinks.org/post/how-ndvi-transformed-insurance-tool-build-resilience.

Sepulcre-Canto, G., Horion, S., Singleton, A., Carro, H. and Vogt, J. (2012) Developing a Combined Drought Indicator to detect agricultural drought in Europe. *Nat. Hazards Earth Syst. Sci., Vol. 12*, Issue 11, pp. 3519-3531.

Stranieri S., Riccardi F., Meuwissen M., and Soregaroli C. (2021) Exploring the impact of blockchain on the performance of agri-food supply chains. *Food Control*, *Volume 119,* 107495 (forthcoming).

The World Bank Group (2011) Weather Index Insurance for Agriculture: Guidance for Development Practitioners. http://documents.worldbank.org/curated/en/590721468155130451/pdf/662740NWP0Box30or0Ag020110final0web.pdf

UNEP (2018) Emissions Gap Report 2018. http://wedocs.unep.org/bitstream/handle/20.500.11822/26895/EGR2018_FullReport_EN.pdf

UNFCCC (2015) The Paris Agreement – main page. http://unfccc.int/paris_agreement/items/9485.php

UNFCCC (2018) UN Supports Blockchain Technology for Climate Action. https://unfccc.int/news/un-supports-blockchain-technology-for-climate-action

UNISDR (2015) Sendai Framework for Disaster Risk Reduction 2015–2030. http://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_69_283.pdf

Villarroya, T.M., and Agrónoma, I. (2016) Hydrological Drought Index Insurance for Irrigated Agriculture, Tesis Doctoral. http://www.ceigram.upm.es/wp-content/uploads/2016/10/Tesis_T_Maestro_final-2.pdf

Vroege. W., Dalhaus. T. and Finger, R. (2019) Index insurance for grasslands – A review for Europe and North-America. *Agricultural Systems 168* (2019), pp. 101-111.

WEF (2020) The Global Risks Report 2020. 15th Edition. https://www.zurich.com/-/media/project/zurich/dotcom/industry-knowledge/global-risks/docs/the-global-risks-report-2020.pdf?la=en&hash=56178CE883A92B151A1789846492230C

Xu, J., Guo, S., Xie, D., and Yan, Y. (2020) Blockchain: A new safeguard for agri-foods. *Artificial Intelligence in Agriculture, Volume 4*, pp. 153-161.