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Health effects of the 2021 flooding in Limburg

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Abstract

Heavy rainfall caused flooding of the Meuse River in Limburg, the Netherlands, July 2021. This paper presents a descriptive overview of short-term and intermediate phase health impacts that occurred within a month after the floods, focused on (perceived) general health complaints and COVID-19 incidence. Data were collected through a questionnaire distributed to health professionals and through the SARS-CoV-2 National surveillance programme.

Most questionnaire respondents reported an increase in psychological complaints such as fear, stress, and depression among their patients directly and one month after the floods. Elderly and children were mentioned as specific vulnerable groups for health effects. The respondents noted a clear relationship between the extent to which people were affected and the occurrence and severity of the health complaints. More SARS-CoV-2 was detected in Limburg around the time of the flooding, however this coincided with the fourth wave of cases. The increased COVID-19 risk could not be attributed independently to evacuations and other circumstances related to the flooding.

The floods and subsequent disruptions have, according to health professionals, led to higher numbers of reported psychological symptoms and may have caused an increase in the number of SARS-CoV-2 infections in the region. Long-term health impacts of the floods have yet to be studied but would have to consider potential secondary effects in addition to mental health and COVID-19.

Keywords

Floods, Netherlands, COVID-19, stress

1 Introduction

Large parts of the Meuse River basin in the province of Limburg in the Netherlands were affected by unforeseen and unprecedented rainfall and flooding on the 13th and 14th of July 2021. The two-day precipitation amounts and discharges of the Meuse River were exceptional, especially in the summer season. The annual probability of occurrence for both precipitation and peak discharges were estimated at one in hundred to thousand years (Strijker *et al.*, 2023). Precipitation accumulated between 160 to 180 mm in two days over a large region, including parts of Belgium and Germany. Drainage from the Belgian and French Ardennes entered the Meuse River in the Netherlands from the south and continued in a northern direction. There, the main river branch is joined by several tributaries, of which the rivers Geul, Geleenbeek, and Roer were most severely affected by flooding (southern part of Limburg, Figure 1).

Management measures were taken according to plan and included water diversions, demountable barriers, and, in some places, placement of emergency sandbags along riverbanks. More than 50,000 people were evacuated in anticipation of the flood wave from homes, companies, campsites, care institutions, and a hospital. Electricity failed in several places. Emergency shelters were made available for the few people who could not arrange alternative accommodation (less than 5% of evacuees) (Endendijk *et al*., 2023). In some areas where the water rose too fast to set up evacuation, inhabitants fled the area on their own or with help of caregivers. No direct casualties occurred in the Netherlands, contrary to Belgium (at least 42 fatalities) and Germany (more than 180 fatalities) (BMI, 2022). During and after the flood event, the municipal health services of the flooded region (GGD Limburg-North and Limburg-South) warned about possible chemical and microbiological contaminations in the floodwater and sludge, with potential health risks for people and animals. These warnings were spread via their websites, national television, and newspapers. On one warm day after the floods (July 21st) it was advised not to swim at official swimming locations close to the Meuse River and its tributaries. The combination of evacuations, the ongoing COVID-19 pandemic and threats to water quality prompted this rapid assessment of associated health impacts in the flooded region.

Health effects of floods can be diverse and vary over time (Ahern *et al.*, 2005; Messner & Meyer, 2006; de Jong *et al.*, 2023). Several types of health risks peak at different moments in time after the onset of flooding and may last a long time (Alderman *et al*., 2012). They can be classified as immediate health impacts (hours after the flooding), short-term (days after a disaster), intermediate phase (start of recovery; days to weeks) and long-term (weeks to months after the onset of the disaster) health impacts.

Immediate health impacts of floods occur as flooding spreads and while the land is inundated, i.e., within hours of the floods, depending on how long it takes for the water to recede. These impacts include deaths from drowning and accidents such as electrocution, as well as from injuries (Alderman *et al*., 2012; Ivers & Ryan, 2006). In addition, there are risks of hypothermia and wounds caused by detached objects (Ivers & Ryan, 2006). Moreover, floods cause stress for those involved (Euripidou & Murray, 2004; Fernandez *et al*., 2015). People may be in shock, worried about missing persons, uncertain about the duration of the flooding, and there may be concerns about the necessities of life. Displaced persons who cannot stay with relatives or friends need to find accommodation at emergency locations. As direct surveys would potentially add to the stress of people affected by the flooding, an indirect approach was selected to assess the immediate health impacts in Limburg. Hence, we sent a questionnaire to health professionals, asking how they perceived changes in health complaints of the population immediately after the floods.

Short-term health impacts appear within days and can include abdominal pain and diarrhoea as a result of ingesting water or food that is contaminated with pathogens. Influenza-like symptoms and common cold complaints are possibly caused by skin contact and inhalation of small droplets of contaminated water, during flooding and related cleaning activities afterwards (De Man *et al*., 2016; Mulder *et al*., 2019). The floodwater can become contaminated with pathogens due to overflowing sewers, sewage treatment plants or agricultural stables. Pollution from these overflows has even greater consequences for human health if the drinking water supply gets contaminated (Suk *et al*., 2020). This was not the case in Limburg. Provision of drinking water along the Meuse River was not interrupted by the 2021 floods. The three drinking water companies (upstream to downstream: NV Waterleiding Maatschappij Limburg WML, Dunea, and Evides, Supplementary materials 1) frequently monitor water quality. Based on their measurements, they closed river intakes and used previously stored water to guarantee continuous supply of safe drinking water. Still, people may have been exposed to contaminated floodwater and suffered gastro-intestinal or other complaints. Gastroenteritis may affect people of all ages but poses a particular risk for the elderly, small children, and immunocompromised individuals. Other potential short time health effect are skin and eye irritations or infections, due to chemically polluted or microbiologically contaminated floodwater, respectively (Bandino *et al.*, 2015). These short-term health impacts were included in the questionnaire to health professionals.

Intermediate phase health impacts are those associated with the first phase of recovery days or weeks after the onset of the flooding, when people start returning to their homes. Mental health effects can be strong in this phase as the initial relief of having survived the floods may be followed by a second period of stress as people return to their homes and are confronted with the damage (Munro *et al*., 2017). Therefore, the health professionals were also asked about changes in complaints one month after the floods. The intermediate phase includes secondary health effects as well, such as the spread of infectious diseases with crowding of people in emergency shelters, including respiratory infections caused by SARS-CoV-2; the floods and evacuations in Limburg coincided with the fourth wave of the COVID-19 pandemic in the Netherlands. Evacuations and the implementation of emergency measures related to the flooding, such as filling and placing sandbags, may have reduced adherence to preventive measures aimed at reducing exposure to SARS-CoV-2, and increased the risk of getting infected (Simonovic *et al*., 2021). In addition, flood-induced sewage overflows may increase the transmission risk as people are exposed to the virus when wading through the floodwater and cleaning their homes (Han & He, 2021). We compared the number of SARS-CoV-2 positive tested persons in the affected region with those in other areas to assess whether the floods and evacuations affected the transmission of SARS-CoV-2.

Long-term health impacts such as protracted psychological complaints (Fernandez *et al*., 2015; Mulchandani *et al.*, 2020; Rubin & Oliver, 2020), secondary infectious health risks caused by rats or mosquitoes (de Best *et al*., 2021; Franklinos *et al*., 2019), fungal growth (Barbeau *et al*., 2010) and reduced health services, were not included in this study.

Here, we present a preliminary overview of some immediate, short-term and intermediate phase health impacts that occurred within a month after the floods in Limburg, focused on perceived general health complaints and COVID-19 incidence.

2 Methodology

2.1 General health impacts

A qualitative questionnaire was developed to give an impression of the changes in health complaints, as perceived by health professionals in the region. The questionnaire was based on results from a survey on linkages between floods and health, held among stakeholders in Bangladesh between November 2020 and January 2021 (unpublished). This supported the development of a pilot study on the integration of human health risks in the management of the Sava River in the Balkan (de Jong *et al*., 2023). The Sava study identified determinants of health risk during and after floods, which were used to adapt the questionnaire used in Bangladesh to the Limburg context. As in Bangladesh, the questionnaire was targeted at experts, in this case health professionals, and focused on perceived changes in potentially flood-related complaints among their patients. The questionnaire was distributed online via Google Forms and included 6 multiple choice and 11 open questions to allow the health professionals to expand on their observations and interpretations (Supplementary materials 2). A draft version was reviewed by two general practitioners and an occupational health physician. One month after the floods, in August 2021, the invitation to participate in the questionnaire was distributed via email to 770 general practitioners, of which 283 in the flooded areas (Figure 1) and an undisclosed number of occupational physicians in the affected region via the regional health services (GGD Zuid-Limburg and the Limburg North Safety Region) and the national association for occupational physicians (Vereniging Zelfstandige en Freelance Bedrijfsartsen), respectively. People could respond till September 7th, 2021. Answers to multiple-choice questions were analysed using MS Excel, text responses to the open questions were used clarify the concerns of the respondents. Some answers have been translated into English and cited in the results section.

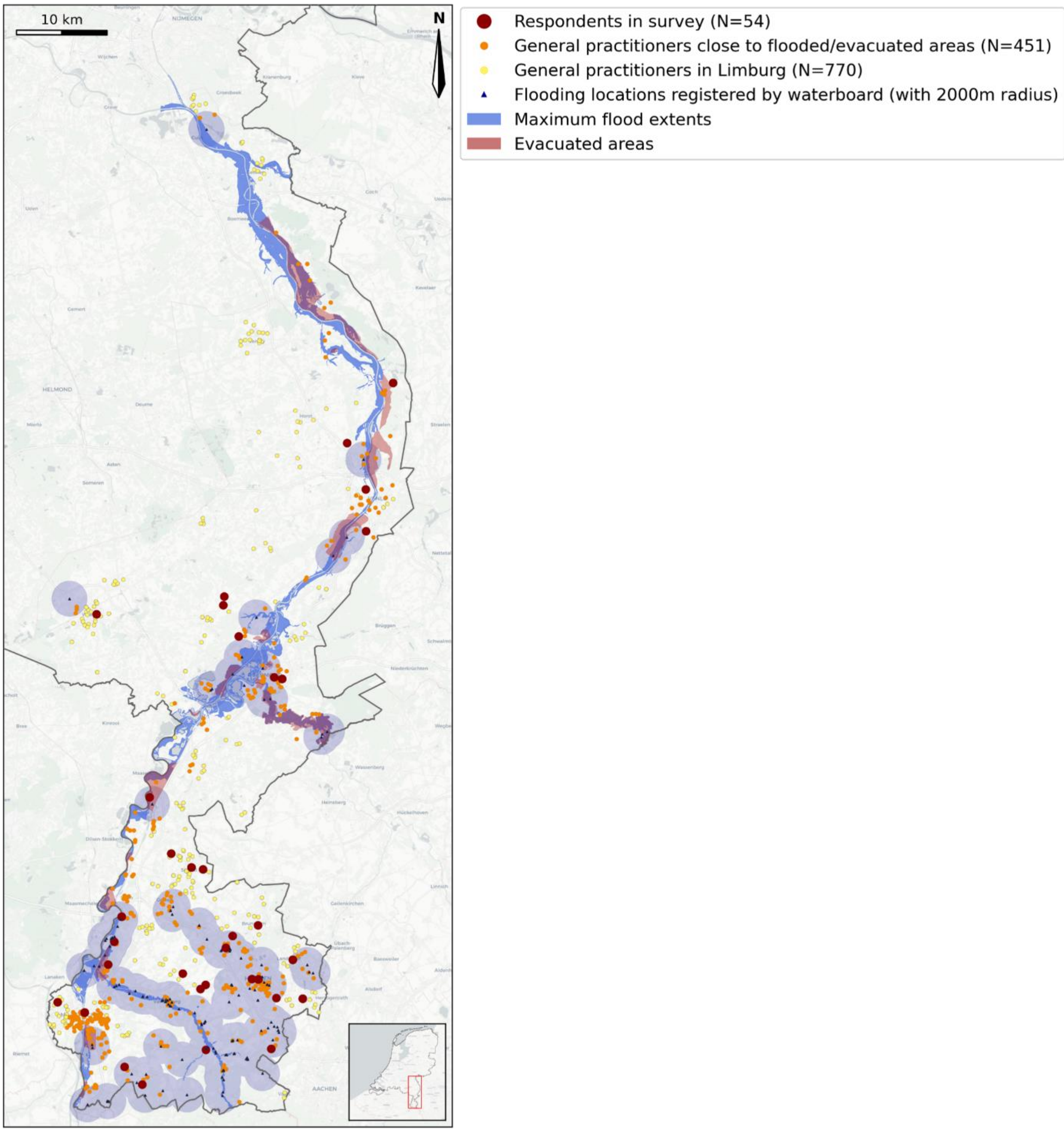

Figure 1: Area affected by floods and associated evacuations, as well as location of general practitioners and respondents in the province of Limburg in July 2021 (data sources: http://data.4tu.nl/datasets/7b356496-d5c9-46e2-b196-024a52a6c544; https://data.4tu.nl/articles/dataset/Emergency_ordinances_Limburg_floods_July_2021/16817404/1; https://huisartsen.online/limburg).

2.2 SARS-CoV-2

During the severe weather event and follow-up period SARS-CoV-2 testing (RT-PCR or rapid antigen test) was provided free of charge by the regional Public Health Service (PHS) to individuals with COVID-19 like symptoms or after recent contact with a confirmed case. During this period, national guidelines recommended testing of all symptomatic individuals or post exposure testing by antigen self-test or in one of the testing facilities of the PHS. The test results of self-tests were not registered and test results of the PHS testing facilities were shared with the National Public Health institute (RIVM). We downloaded the publicly available data on the number of SARS-CoV-2 test positive individuals per day and per week by municipality and per province from the RIVM website (http://data.rivm.nl). During the pandemic the virus load in all of the over 300 sewage treatment plants across the Netherlands was determined at least once a week. This monitoring was made possible by a partnership between the RIVM, the Association of Regional Water Authorities, and the 21 regional water boards, as mandated by the Ministry of Health, Welfare and Sport. The wastewater samples were processed and tested for the presence of viral genomic material, using a quantitative RT-PCR validated to determination of virus particle load (Geubbels *et al*., 2023). The wastewater data by municipality of Limburg were downloaded (http://data.rivm.nl). Publicly available data from Germany were assessed for the number of positive SARS-CoV-2 tested individuals per day for the two states most affected by the floods in Germany, Nordrhein-Westfalen and Rheinland-Pfalz (http://github.com/jgehrcke). Only aggregated data were available for the analysis, so age and other demographic information could not be considered.

The COVID-19 risk ratio was determined using a negative binomial model, a statistical technique to compute risk ratios when comparing count data before and after a specific event or intervention (Hilbe, 2011). Its application is particularly beneficial for analysing data exhibiting overdispersion, i.e., where the observed variance surpasses the mean. The negative binomial model extends the Poisson model by incorporating an additional parameter that captures the excessive variability present in the data, allowing for flexible variance modelling. We selected a negative binomial model because its deviance from the observed data is much smaller than a quasi-Poisson model. Risk ratio, or relative risk, is a measure of the association between an exposure or intervention and an outcome. It represents the ratio of the risk of experiencing the outcome in the exposed group compared to the unexposed group. The risk ratio is calculated by taking the exponential of the model coefficient. Significance was determined with the Z-test on the ratio between the difference in logarithm of risk ratio and the difference of standard errors. The first risk ratio is for municipalities and the second for all municipalities grouped in a province. The test shows that the difference between the two risk ratios is significant.With the negative binomial model, the risk ratio was estimated while accounting for the association between COVID-19 cases before and after the floods. Essentially, the model aims to determine whether there was evidence to support the hypothesis that the flood event led to a meaningful change in the number of new COVID-19 cases in Limburg and helps quantify the magnitude and significance of this potential impact. To examine whether the observed effects of the floods on new COVID-19 cases were consistent across different time periods, the negative binomial model was fitted with different split dates. This helped verify whether the effects were consistent over time or varied, depending on the specific time periods chosen. It also allowed identification of potential lag effects (backward and forward) or delayed impacts of the flood event.

The negative binomial model was fitted using the package MASS (Venables & Ripley, 2002) in R (R Core Team, 2021) and visualisation was performed using matplotlib (Hunter, 2007) and contextily in Python (van Rossum & Drake, 1995).

3 Results

3.1 General health impacts

The online questionnaire on perceived changes in health complaints immediately after the flooding in Limburg and a month later was fully or partially completed by 54 health professionals (Figure 1): 35 general practitioners and 5 employees of a general practice. This total of 40 respondents out of 283 general practitioner practices in the affected area means that we had a response rate of 14%. In addition, 9 occupational health physicians, and 5 employees of the two provincial health services answered the questionnaire. The respondents came from southern (30), central (6) and northern (10) Limburg; eight did not indicate their location. Almost half of them (23) had personally been affected to a greater or lesser extent by the floods, five respondents were evacuated themselves. According to a rough estimate based on the population served by these practitioners, the questionnaire would theoretically give an impression about more than 77,000 people.

Many respondents reported an increase in psychosocial complaints, ranging from stress and sadness to complaints similar to Post-Traumatic Stress Disorder (PTSD). Seventy percent (38 out of 54 respondents) reported an increase in stress and anxiety in patients immediately after the floods, and 46% (25 out of 54) noticed more fear complaints. Several respondents indicated that one month after the floods there were still more people complaining of stress and anxiety (according to 48% of respondents) and more patients with fear (according to 28% of the respondents) as compared to before the floods. Some respondents (5 out of 54, i.e., 9%) also reported an increase in depression complaints immediately after the floods, and 19% (10 out of 54 respondents) saw this increase one month later.

The respondents also indicated an increase in complaints of gastrointestinal symptoms and infections (reported by 4 respondents), respiratory infections (reported by 3 respondents) including a case of death after pneumonia, and infections of the skin and poorly healing wounds (reported by 2 respondents). Some respondents (3) expressed their own concerns about pollution in the environment, such as water quality and possible pollution in homes. Secondary complaints were also mentioned, such as joint problems and muscle pain due to a lot of carrying and lifting, an increase in insects and reduced access to health care, including home care.

About half of the respondents (24 out of 54) did not expect more health effects in the future, 15 did not say or did not know. Of the 15 who did expect follow-up complaints, some (10) mentioned psychosocial complaints such as anxiety, depression, burnout, and PTSD in people who were affected. One responded mentioned “People relive anxious moments on a regularly basis as people have lost objects that cannot be replaced (e.g. photos).” This could especially hit when “survival mode is turned off” and could be stronger when flooding occurs more frequently, as various respondents suggested. New stress can also arise in the intermediate phase from the processes of settling damage and repairs. Others pointed to the risks of infections such as *Legionella*. It was not clear to most respondents whether the health effects of flooding in the Netherlands are systematically tracked and, if so, where.

Two-thirds of the respondents (37 of 54) did not know of any absenteeism of patients due to health problems related to flooding. Those who did see this effect, mentioned fear, stress, anxiety, and depression as the main complaints (12 times). One of the respondents linked these complaints to poor sleep and fatigue, which would then become the main reason for not going to work or school. In addition, injuries, and COVID-19 infections were reported as reasons for absenteeism, as well as overworked muscles and joints. Some also mentioned that patients would be absent for practical reasons, usually taking emergency leave for evacuation, cleaning up and repairs, helping others (including informal care), having to arrange a lot or “staying at home because you can't leave a house full of water behind”, as one respondent heard from their patient. The respondents usually could not indicate how long the absence would last. This was complicated by the fact, they mentioned, that some people reported sick at work only partially and were not fully absent. In addition, the respondents suggested that people could be less productive during their working hours.

The elderly and children were mentioned as specific vulnerable groups for health effects. The respondents explained that for the elderly, sometimes, in the preceding years, the social network had disappeared because friends died, and children no longer live in the area and can therefore not offer care. They also suggested that the elderly may remember earlier floods and that this memory may cause additional stress. Many respondents saw a clear relationship between the extent to which people were affected and the occurrence and severity of the health complaints. In addition, they suggested that those with less flexibility, due to financial constraints (e.g. due to low income or starting entrepreneurs) or the lack of a social safety net, were more affected by the floods. It was also mentioned that the long-term uncertainty due to the COVID-19 pandemic had led to a reduced psychological resilience. As one respondent put it: this “unexpected threat to life and the damage to their homes and living environment was the straw that broke the camel’s back, causing these complaints.” Some respondents expressed concerns that the vulnerable groups had been hit relatively hard by the floods, rendering them even more vulnerable and insecure. In their view, this increased inequality.

Finally, various suggestions were made by the respondents, such as providing better and faster information for those affected but also for medical professionals (for example about wound treatment); fast guidance, clarity, compensation and settlement of (material) damage; attention and flexibility from employers; house-to-house enquiries among the elderly to check their need for assistance; tailor-made individual solutions in housing and with practical issues; dedicated support to vulnerable people.

3.2 SARS-CoV-2

A clear increase has been shown in the number of reported SARS-CoV-2 cases detected per week between 28-6-2021 and 1-8-2021 (Figure 2), the period during which the floods occurred in the province of Limburg, the Netherlands. The peak coincided with an increase in detected cases in the rest of the Netherlands (Supplementary materials 3, Figure S3A). There appears to be a slight delay in incidence in the south of Limburg as compared to most of the Netherlands (Supplementary materials 3, Figure S4). No clear peak was observed in SARS-CoV-2 levels in the sewage water in

Limburg's municipalities throughout this period, although the concentration increased in general (Figure 2B and Supplementary materials 3, Figure S5).

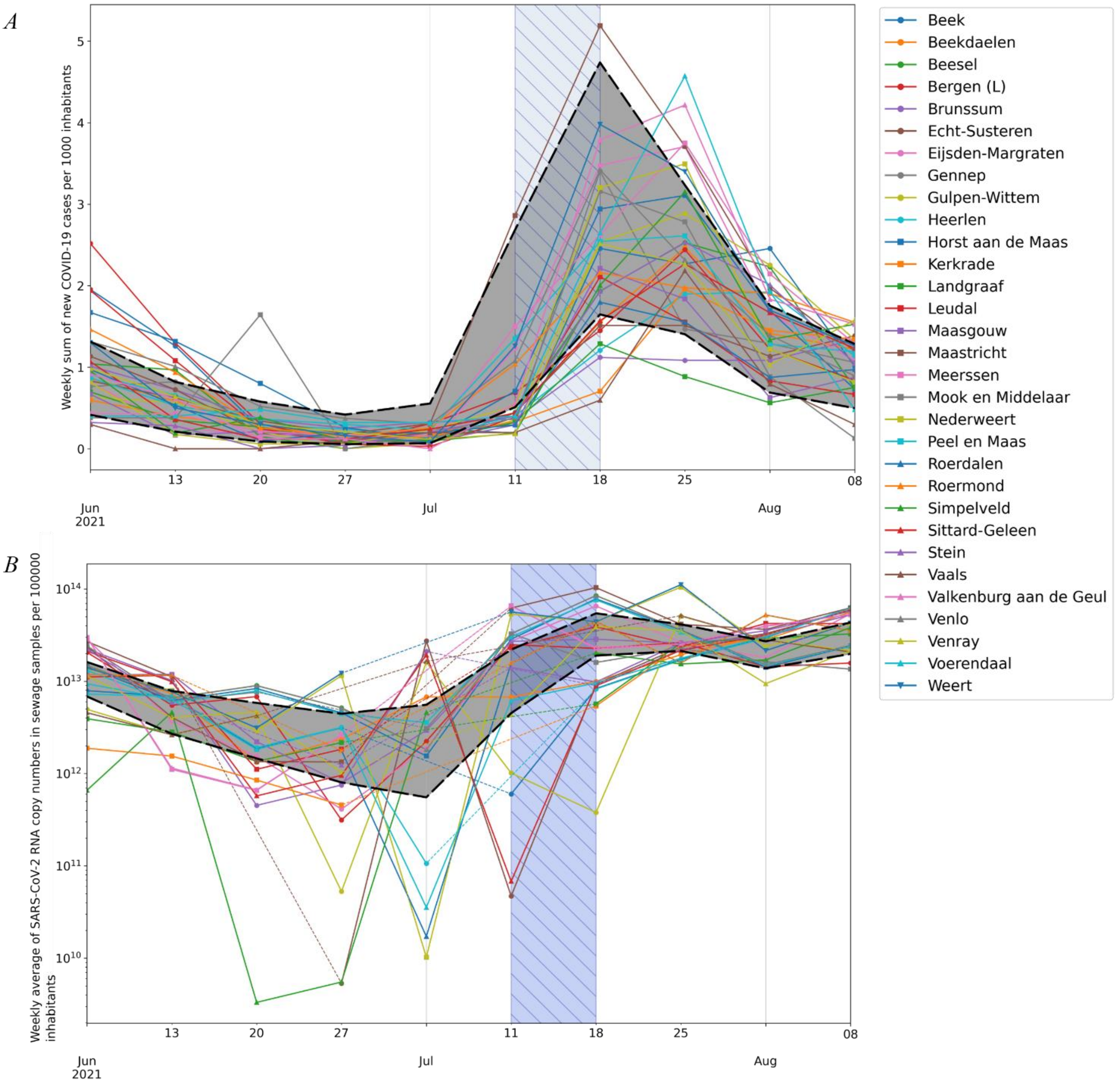

Figure 2: For the municipalities of Limburg: A) Number of reported SARS-CoV-2 cases per day (based on data from https://data.rivm.nl/covid-19/COVID-19_aantallen_gemeente_per_dag_tm_03102021.csv) and B) number of SARS-CoV-2 RNA copy numbers in sewage samples per 100,000 inhabitants (based on data from https://data.rivm.nl/covid-19/COVID-19_rioolwaterdata_gemeentenweek.csv), from June 28th till August 1st, 2021. The vertical blue striped block denotes the week of flooding in Limburg, the Netherlands. The grey area depicts 75% of the number of SARS-CoV-2 cases in all municipalities in the Netherlands. The dashed coloured lines in panel B were drawn when the SARS-CoV-2 RNA copy numbers were under the detection limit and would otherwise appear as 0 in the figure. Municipalities of Limburg that did not experience flooding or evacuation were Beek, Beesel, Brunssum, Gennep, Landgraaf, Mook en Middelaar, Nederweert, Venray, and Weert (Supplementary materials 3, Tabel S1).

Subsequently, the relative COVID-19 risk ratio was calculated for each province of the Netherlands with different split dates (Figure 3A). This was used to determine whether the number of coronavirus cases in Limburg had increased in that specific time period compared to other provinces in the Netherlands. Limburg had the highest COVID-19 risk ratio among provinces in the Netherlands, and the risk was significantly different from the other provinces, especially during the days after the flooding (Supplementary materials 3, Figure S6). Limburg as well as Noord-Brabant, Flevoland and Zeeland were all significantly different from the average value of the Netherlands. Flevoland and Zeeland were not affected by the floods but did show a higher number of reported COVID-19 cases.

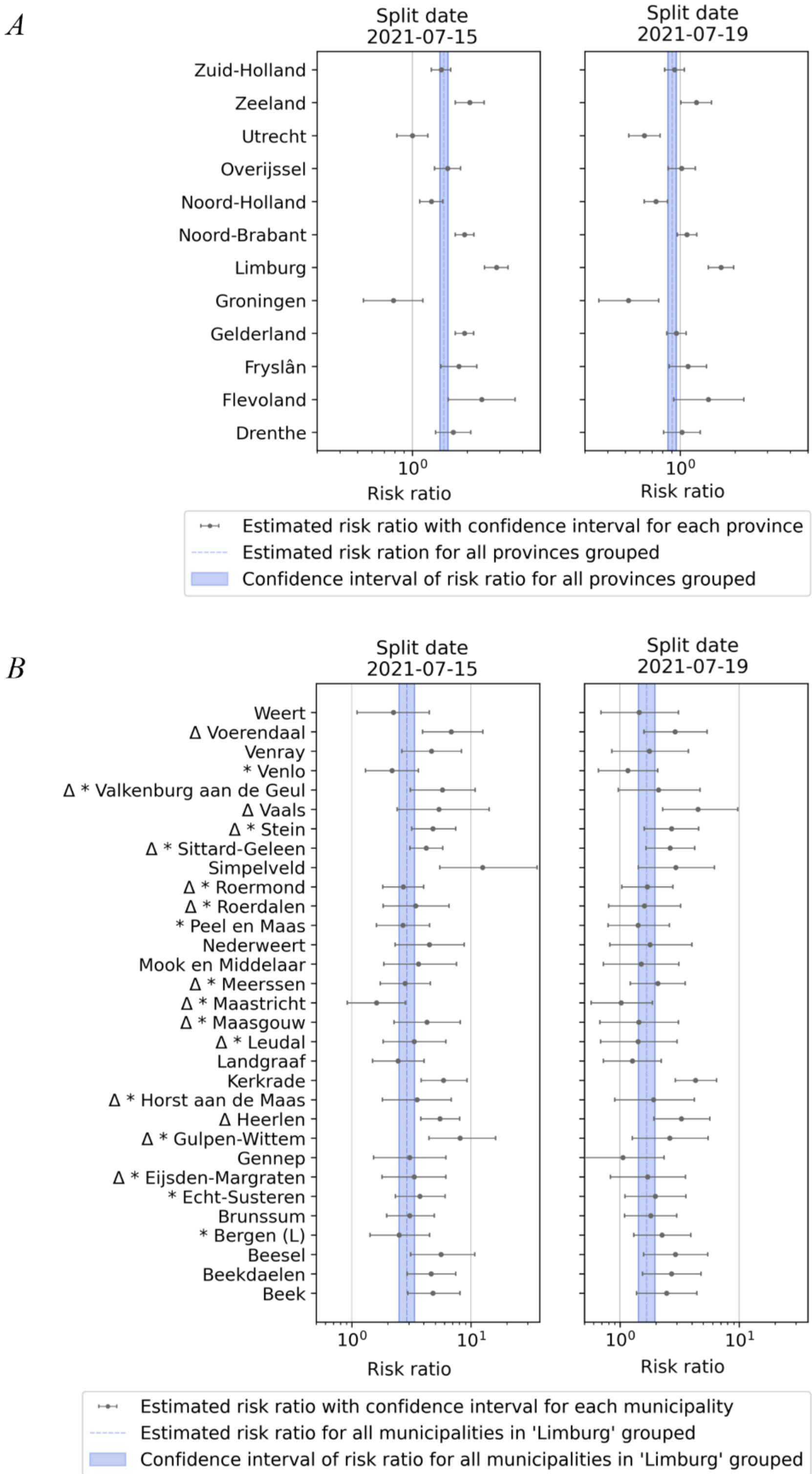

Figure 3: COVID-19 risk ratio (dots) per A) province and B) municipality in Limburg with 95% confidence intervals. The * in front of a municipality means that there were evacuations, Δ means that areas were flooded (Supplementary materials 3, Table S1).

In all municipalities of Limburg, the COVID-19 risk ratio was above 1 directly after the flooding (Figure 3B, split date 15th of July), indicating that in all municipalities the coronavirus incidence had increased after the floods as compared to before the floods, in line with the national trend of the fourth wave. The day on which the split was made had an influence on the results, with lower risk ratios when the split was made four days after the ending of the floods (Figure 4). The top five municipalities with the highest COVID-19 risk ratio (with split date 15th of July) were the municipalities of Gulpen-Wittem (8.1), Kerkrade (5.9), Simpelveld (12.5), Valkenburg aan de Geul (5.7), and Voerendaal (6.8). Two of these municipalities, Gulpen-Wittem and Valkenburg aan de Geul, dealt with (partial) flooding and evacuations. The other three municipalities had floods only. The top four municipalities with the lowest risk ratio were Bergen (2.5), Landgraaf (2.4), Venlo (2.2), Weert (2.2). Of these, Bergen and Venlo were partly evacuated. The risk ratio in Heerlen and Kerkrade was larger than the municipalities grouped and significantly different from the risk ratio of the municipalities grouped in the period between the 13th and 21st of July (for Kerkrade till July 23rd) (Figure 3B, Figure 4). Both municipalities experienced floodings but no evacuations were reported.

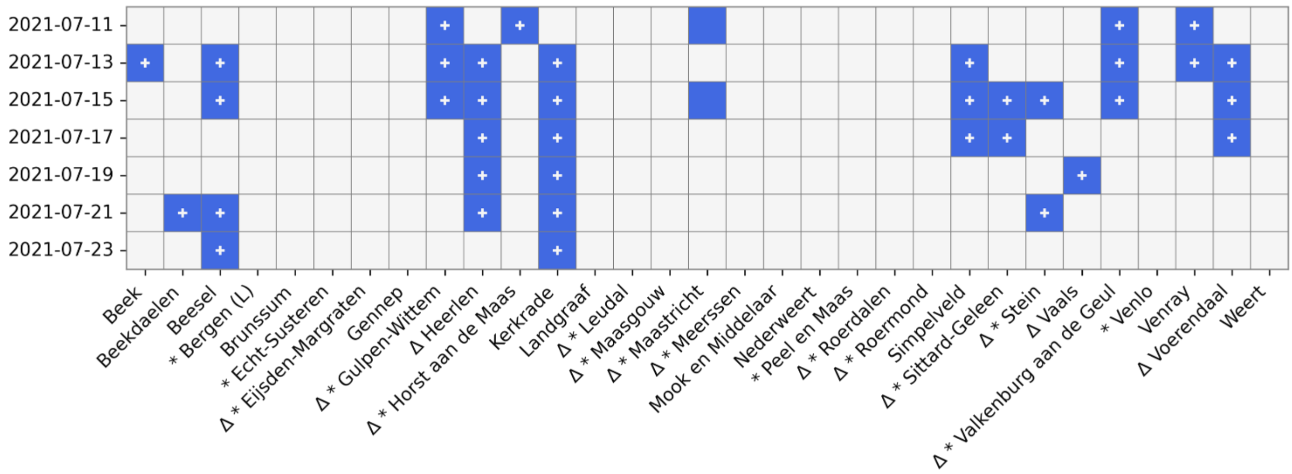

Figure 4: Differences between risk ratios of each municipality and average value for Limburg at several split dates. Dark cells denote a significant difference ($p<0.05$), while for light cells the difference was not significant. The + denotes a risk ratio of municipalities significantly larger than risk ratio of municipalities grouped. The * in front of a municipality means that there were evacuations, Δ means that areas were flooded (Supplementary Materials 3, Table S1).

To provide some perspective, the same analysis was performed for the two federal states in Germany that were heavily flooded in the same period, Nordrhein-Westfalen and Rheinland-Pfalz (Supplementary materials 3, Figure S7). The flood-impacted area was larger, and more inhabitants were affected compared to the Netherlands. The COVID-19 incidence in Germany decreased in June and started to increase mid-July (Supplementary materials 3, Figure S3B). In the Ahrweiler county the risk ratio was higher and significantly different from the average value in Rheinland-Pfalz directly after the flooding for several days (Supplementary materials 3, Figure S8). This is in contradiction to the situation in, for example, Valkenburg, where the risk ratio differs significantly from the provincial average until the end of the floods. Ahrweiler is the area that was most heavily affected by the floods in Germany and where most people died (135 people). For all the other flooded (city)counties no direct correlation could be observed.

4 Discussion

Health professionals reported increases in psychological complaints such as stress, anxiety, and fear, related to the floods among their patients. One month after the flooding some of them also indicated increased complaints related to depression. Our findings on general health impacts must be interpreted with caution as they refer to *perceptions* of health professionals. Complaints among the affected population have not been investigated directly. Yet, there is increasing evidence that highlights the long-lasting effects of a flood event on mental health and wellbeing (Ahern *et al*., 2005; Tapsell and Tunstall, 2008; Stanke *et al*., 2012; Fernandez *et al*., 2015). Scheerder (2023) stated that the urgently evacuation of hospice and care centres resulted in stress complaints, anxiety, and sleep problems in the elderly. Age has been shown to be a risk factor for the development of psychological disorders, as older people tend to be less resilient to flood-related psychological distress than adolescents and young adults (Chung *et al*., 2017). Our questionnaire came a bit too early for occupational health physicians to report any health effects of flooding since they normally see employees four to six weeks after they reported sick. The respondents who did signal absenteeism mentioned practical reasons for absence, related to cleaning of houses and administrative procedures, but also stress and shock, largely related to the experiences of the first few weeks. It is unclear if the floods led to absenteeism from work for a longer period.

Problems related to mental wellbeing as reported in Limburg not only occur in the first weeks after the floods (immediate health impact), but also weeks to months after the floods or following exposure to new events (short to intermediate health impact). The prevalence of symptoms of psychological disorders can range from 9% to 53% in the first two years after the floods (Liu *et al*., 2006; Heo *et al*., 2008; Mason *et al*., 2010; Waite *et al*., 2017). Six months after the floods Endendijk *et al.*, (2023) carried out a survey among people affected by flooding in Limburg. Among those respondents who had their streets flooded, 75% of respondents experienced high or very high stress levels (Endendijk *et al.*, 2022). Easy access to counselling and mental health services is important to reduce the mental health burden (Tapsell and Tunstall, 2008). Unfortunately, Endendijk *et al.* (2023) did not study the relation between mental health impacts and floodwater depth or financial losses. These parameters are related to increased chances to develop mental health problems (Fernandez *et al*., 2015; Waite *et al*., 2017).

Another major stress factor is forced displacement (Mason *et al*., 2010). Almost all participants who had been evacuated in Limburg indicated that they experienced at least some degree of stress (Endendijk *et al*., 2023). These results are similar to the observations of health professionals in our questionnaire directly after and a month after the floods. Getting displaced increased the chance of developing mental health issues (Liu *et al*., 2006; Mason *et al*., 2010), with a higher incidence rate when people were unaware of flooding than when they were warned (Munro *et al*., 2017). The impact or (early) warning was not studied in our questionnaire or by Endendijk *et al.*, (2023).

Six months after the floods more than 35% of respondents continued to suffer from significant stress, mainly related to damaged buildings, after-effects of uncertainty and fear during flooding, the floods' impact on others, and the compensation process (Endendijk *et al.,* 2023). Theoretically, most costs of damage (65-90%) were covered by insurance, but due to the complexity of the damages, shortage in material and personnel for construction, and the COVID-19 pandemic, processing of the claims was delayed. This not flawless settlement of damage in the aftermath of the floods is expected to add to the burden of mental problems (Scheerder, 2023).

The province of Limburg had the highest COVID-19 risk ratio of the provinces in the Netherlands, suggesting that Limburg had the largest increase in the number of new coronavirus cases in the period after the floods (Figure 3A; Supplementary materials 3, Figure S6). However, the relative risk of getting COVID-19 in the municipalities that were affected by flooding or evacuations was not significantly higher for all municipalities. For example, the town of Valkenburg aan de Geul that experienced heavy flooding, with associated intensive cleaning activities had a significantly higher risk ratio for the period before and during, but not after the floods. Roerdalen experienced flooding but its risk ratio remained below average. Most people were evacuated from Venlo (13,330 inhabitants) but the relative risk for COVID-19 remained below average. Only two out of 17 flooded municipalities (Heerlen and Kerkrade) had increased risk ratios compared to the other municipalities (Figure 3, Figure 4). Part of these results may have been caused by the fact that the floods affected small areas only, such as one street or a group of houses, while the COVID-19 data were grouped by municipality. Evacuated people may have been housed in the same or a different municipality. Hence, the results are biased by the COVID-19 incidence in the un-affected part of the municipality that did not experience flooding.

The comparison of COVID-19 risk ratios of Limburg municipalities with flooded (city) counties in Germany did not show direct correlations either. Only in Ahrweler (Rheinland-Pfalz), which experienced highest flooding and 135 casualties (BMI, 2022), the risk ratio was significantly increased for several days after the floods.

Possibly, there are too many factors related to the spread and infection of COVID-19 during flooding, which makes a calculation of risks with the number of positive tests and time as only variables too simple. Important limitations regarding the use of this negative binomial model include confounding variable, lack of causal inference and temporal dynamics. Confounding variables could include changes in testing capacity, public health interventions, population behaviour, or other major events occurring simultaneously. Lack of causal inference means that the model identifies associations only and does not establish causation. The observed changes in COVID-19 cases could be influenced by various factors beyond flooding. Temporal dynamics are not captured in this analysis of the immediate post-flood period. There could be delayed effects or longer-term consequences for transmission of COVID-19 that are not captured by the pre/post flood variable. Another limitation of our analysis is that the number of performed SARS-CoV-2 tests was not available at municipal of provincial level. Figure 2 suggests that the peak of the fourth wave for Limburg was delayed in comparison to the rest of

Netherlands, but whether this was influenced by the floods or behaviour change of people, for instance delayed testing, could not clearly be stated. On the other hand, data from the sewage surveillance suggested that during the floods the gene copy numbers were under the detection limit in many wastewater treatment facilities in flooded municipalities. However, sewage overflows took place in this period, leading to loss of virus particles in the sewage water itself. In addition, some municipalities discharge their sewage to multiple wastewater treatment plants. Moreover, the sewage data were normalised with the regular number of inhabitants, but that changed due to evacuations. Finally, other factors affecting SARS-CoV-2 transmission, such as vaccination coverage and population demographics, could not be included in the analyses since these data were not available at the right resolution.

5 Conclusions

The 2021 floods in the south of the Netherlands have impacted the health of civilians. Immediate and short-term health impacts have not been measured directly, but indirect information from our questionnaire suggests that psychological issues such as fear and stress were observed more often than before the floods, though increases in gastro-intestinal, respiratory, and skin complaints were also noticed. Since the provision of good quality drinking water has not been interrupted by the floods due to frequent monitoring, an adequate water storage capacity, and other adaptive measures, no drinking water related diseases were reported.

The dominant perceptions of intermediate phase health effects included increases in psychological complaints such as stress, anxiety, and depression, with respondents describing some profound impacts on vulnerable people. These effects may well have exacerbated existing stress and vulnerabilities related to the COVID-19 pandemic and its mitigating measures. The floods in Limburg may have affected the spread of SARS-CoV-2, since the risk ratios of Limburg were significantly different from the other provinces in the Netherlands during the days after the floods. On the other hand, at the municipal level no significant differences were found between areas in Limburg apart from Heerlen and Kerkrade.

For the long-term health impacts a follow-up study would be needed. Points of attention for such a study could be mental health and COVID-19 incidence, but also exposure to chemicals, disease vectors and mould. There is insufficient information on exposure to contaminated water or sludge left in flooded buildings and streets, and possible health effects of this. The high concentrations of some chemicals measured in the Meuse (Supplementary materials 1) could be higher in the sediment. Many people have been exposed to the sludge and sediment during cleaning activities in streets, gardens, and buildings. It might be useful to find out where the chromium and lead originated from, so that measures can be taken to prevent these substances from entering the river and flooded areas during high water. Anecdotal evidence suggests that a year after the floods receded, many houses in Limburg were still damp or wet (e.g. flooded cellars), with people complaining about rats, mosquitoes, and fungal growth. An investigation into these effects more than a year after the floods could take the complaints of inhabitants as a starting point and assess how environmental, physical, and mental determinants of health may still be affected. This could support targeted after-care and improve preparedness for future disasters.

Future research on mental health could also investigate how people respond to heavy rain, which already occurred in June 2023 when several streets got flooded again in Limburg. With climate change and associated higher frequencies of extreme weather, it would be relevant to study whether stress levels increase with (anticipation of) repetitive floods or reduce because people know what to expect and how to handle the situation. Such research could support the development of mitigation measures, as well as improved communication, to prevent anxiety and severe mental health problems related to floods. This might be particularly relevant when floods or other natural disasters occur simultaneously with other crises, such as happened in 2021 during the COVID-19 pandemic.

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Author contributions (CRediT)

AJ: conceptualization, investigation, methodology, validation, writing of the original draft, review and editing. JB: conceptualization, data curation, investigation, writing of original draft, review and editing. HK: data curation, formal analysis, investigation, methodology, validation, visualisation, writing, review. MK: supervision, review, and editing. EB: conceptualization, data curation, formal analysis, investigation, methodology, supervision, writing of original draft, review and editing.

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