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## Dynamic modelling of health risks during wastewater influenced urban flooding

### Modélisation dynamique des risques sanitaires liés aux inondations urbaines influencées par des eaux usées

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## RÉSUMÉ

Les risques sanitaires sont rarement pris en considération dans la gestion des inondations et la planification des adaptations aux changements climatiques en milieu urbain. Ce document décrit une méthode pour relier la modélisation dynamique des inondations urbaines et l'évaluation quantitative des risques microbiens (EQRM). La méthode permet de mieux comprendre l'interaction entre les inondations urbaines et les risques sanitaires causés par le contact direct de la population avec les eaux de crue, et met en avant des options permettant de réduire les maladies de la population grâce à la gestion intelligente des risques d'inondation urbaine. Le modèle déterministe, MIKE Flood, a été utilisé pour calculer la concentration d'agents pathogènes dans les eaux de crue. L'exposition aux agents pathogènes a été estimée en multipliant la concentration avec les valeurs d'ingestion d'eau dans les publications existantes. La probabilité d'infection a été déterminée en appliquant les relations dose-réponse et la simulation de Monte Carlo. Le résultat a donné lieu à un certain nombre de cartes dynamiques de risques sanitaires indiquant la variation des risques sanitaires dans le temps et l'espace. La méthodologie est démontrée sur deux études de cas, l'une concernant un pays en voie de développement souffrant d'un mauvais assainissement et l'autre portant sur un pays développé où l'adaptation aux changements climatiques est le problème principal. Le premier cas présente le risque de choléra dans la ville de Dhaka, au Bangladesh. Le second cas présente le risque d'infections bactériennes et virales en cas d'inondation à Copenhague, au Danemark.

## ABSTRACT

When managing urban flooding and planning urban climate change adaptations, health risks are rarely taken into consideration. This paper describes a methodology for linking dynamic urban flood modelling with Quantitative Microbial Risk Assessment (QMRA). The method provides an understanding of the interaction between urban flooding and the potential health risks caused by direct human contact with flood water and options for reducing the burden of disease in the population through the use of intelligent urban flood risk management. The deterministic MIKE Flood model, which integrates the sewer network model in MIKE Urban and the 2D surface model MIKE21, was used to calculate the concentration of pathogens in the flood water. The exposure to pathogens was estimated by multiplying the concentration with literature values for the ingestion of water for different exposure groups (e.g. children, adults). The probability of infection was determined by applying dose-response relations and *Monte Carlo* simulation. The results are dynamic health risk maps showing the variation in the health risk in time and space. The methodology is demonstrated in two cases.; one case from a developing country with poor sanitation and one case from a developed country, where climate adaptation is the main issue. The first is the risk of cholera in the City of Dhaka, Bangladesh. The second case is the risk of bacterial and viral infections during floods in Copenhagen, Denmark.

## KEYWORDS

Copenhagen, Dhaka, dynamic model, infection, wastewater

## 1 INTRODUCTION

The effect of climate change becomes evident during flood events in cities, caused by cloudbursts – extreme precipitation events - that have become more frequent since 1950 (Christensen *et al.*, 2014). The greatest risks in connection with climate change are concentrated in urban areas. The vulnerability is primarily linked to extreme weather conditions such as extreme cloudbursts and storm surges. The European Floods Directive and the prospect of huge financial losses have caused many cities and municipalities to work on climate adaptation – including cloudburst security – but almost all climate adaptation concentrates on damage evaluation in relation to economic losses. During urban floods, the flood water commonly contains wastewater, which poses a disease risk by direct or indirect contact. In developed countries, microbial health risk is usually not a parameter that is considered in cloudburst security.

After severe flooding events in Copenhagen in 2010 and 2011, cloudburst security became a priority for politicians and planners. The estimated economic loss for these two incidences was 800 and 1200 million EUR, respectively. The floods were also an eye-opener regarding health risk. After the 2011 cloudburst, five cases of Leptospirosis (Weil's Disease) were observed, one of which was fatal. All cases concerned people who had cleaned up their basements after the cloudburst. These people were probably exposed to sewage contaminated with rat urine, which can contain the bacterium *Leptospira*. An investigation among professionals working with tidying and cleaning up basements that had been subject to flooding revealed that 22% of them became ill (Wójcik *et al.*, 2013).

In the Netherlands, 871 families were asked about the occurrence of illness in the weeks after a flood. The study showed that in flooded areas, 26% had stomach infections, 29% had flu-like symptoms, 21% had skin problems and 16% consulted their doctor. The occurrence of symptoms was 3 and 6 times higher than in the areas without floods (de Man *et al.*, 2015).

In developing countries, the extent of flooding and its consequences in terms of illness are more severe. In Dhaka, Bangladesh, parts of the city are regularly inundated during monsoon, and several long-term floods events have occurred over the years (Mark *et al.*, 2015). In a country with endemic cholera, this poses a serious threat.

To substantiate and quantify health risks during floods, we have combined two existing technologies into one tool: 1) Urban flood models, and 2) Quantitative Microbial Risk Assessment (QMRA).

## 2 METHODOLOGY

### 2.1 Flood Models

Urban flood models are a coupling of one-dimensional (1D) sewer models and 2D hydrodynamic surface models. The 1D sewer model calculates water transport and water level in the sewage system, while rainwater fills the sewer, and when the sewer system capacity is exceeded, the water rises up through the gullies and spreads on the surface (2D model). The concept is illustrated in Figure 1.

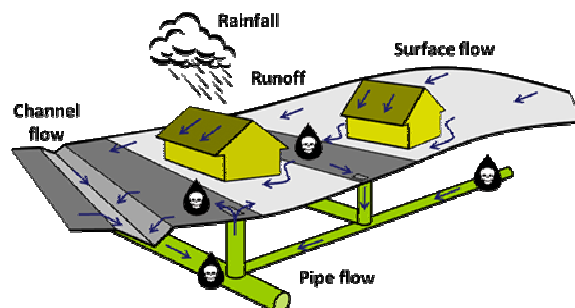


Figure 1: Combination of 1D sewer model combined with 2D surface model.

For parts of central Copenhagen, a flood model was set up that covers 12 km<sup>2</sup>. The model is relatively detailed and consists of approx. 6000 sewer wells and 500 km of pipes. The area has a combined

sewerage system, designed to handle a 10-year rainfall. During more intense rainfall, flooding will occur with a mix of wastewater and storm water.

For the central parts of Dhaka, the hydrodynamic flood model covers 39 km<sup>2</sup>. The model was calibrated for a major flooding event that occurred in September 2004 (Mark *et al.*, 2015).

## 2.2 Quantitative microbial risk assessment

Quantitative microbial risk assessment (QMRA) calculates the probability of infection and disease from human exposure to pathogenic microorganisms. QMRA is based on an identification of the pathogens, which pose a health risk in a real (or hypothetical) situation. The content of pathogens in wastewater depends on the diseases that occur in the population in its catchment area. The dose that people are exposed to is the product of concentration and the volume of water ingested. We used the flood model to determine the proportion of wastewater in the flood water.

Many of the parameters included in QMRA vary over time, or are uncertain due to a lack of accurate data. Uncertain parameters were described as distributions, and a *Monte Carlo* (MC) simulation was used to carry out the calculations. The result of a MC simulation is also a distribution and can be presented in different ways (as percentiles, means, *etc.*). It should be noted that the uncertainties of this type of calculations are large, and the results must therefore be considered as a “best guess”.

In developed countries, one of the most common diarrheal diseases is caused by Norovirus. For the Copenhagen case, the average concentration of Norovirus in undiluted wastewater was estimated to be  $2 \cdot 10^4$  virus particles/L, based on published data on the incidence among the population. The amount of water ingested depends on personal behaviour. Children were assumed to ingest between 0 and 4.6 ml during a flood event, on average 1.7 ml (*de Man et al.*, 2015). The fractional Poisson model was used as the dose-response relationship (Messner *et al.*, 2014).

In the Dhaka case, the modelling effort focused on cholera infections. Based on a measurement campaign, the mean concentration of *V. cholerae* in undiluted wastewater was assumed to be 46/100 mL). The intake was assumed to be highest for small children in poor areas, with a mean of 37 ml/d (Mark *et al.*, 2015).

## 3 RESULTS AND DISCUSSION

Using the coupled hydrodynamic and QMRA models to describe the dynamic health risk, we obtained an estimate for the spatial variation of flood depths, wastewater proportion, pathogen concentration and infection risk.

For the Copenhagen case, maps were drawn that describe the wastewater concentration in the flood water during a “future” 100-year rain event, *i.e.* a scenario that includes the anticipated effects of climate change. The probability of Norovirus infection for an exposed person was calculated for all model cells and all time steps, *i.e.* the QMRA model was directly coupled to the hydrodynamic model. Figure 2 shows the risk map of Norovirus infection for the 100-year rainfall, for a specific timestep during the flood event. This is a situation comparable to July 2, 2011, when large parts of the area were flooded. In certain parts of town, the probability for a norovirus infection would be high in this scenario, due to a significant fraction (up to several per cent) of wastewater in the flood water.

For the Dhaka case, pollution maps were created that show the concentration of wastewater in the flooded areas. A dynamic risk map (simulation) is available on Youtube:

<https://www.youtube.com/watch?v=oJIDThnYweQ&feature=youtu.be>

The results of the health risk assessment for Dhaka indicate a strong effect of age and class. Children were calculated to have approximately a factor 10 higher probability of being infected with cholera than adults. Inhabitants of slum areas were estimated to have approx. a factor 100 higher probability of being infected than inhabitants in middle class areas of the town.

Although the absolute numbers of the probability of infection are quite uncertain due to the uncertainty of available data, the results indicate areas of town where risk mitigation measures would have the greatest effect.

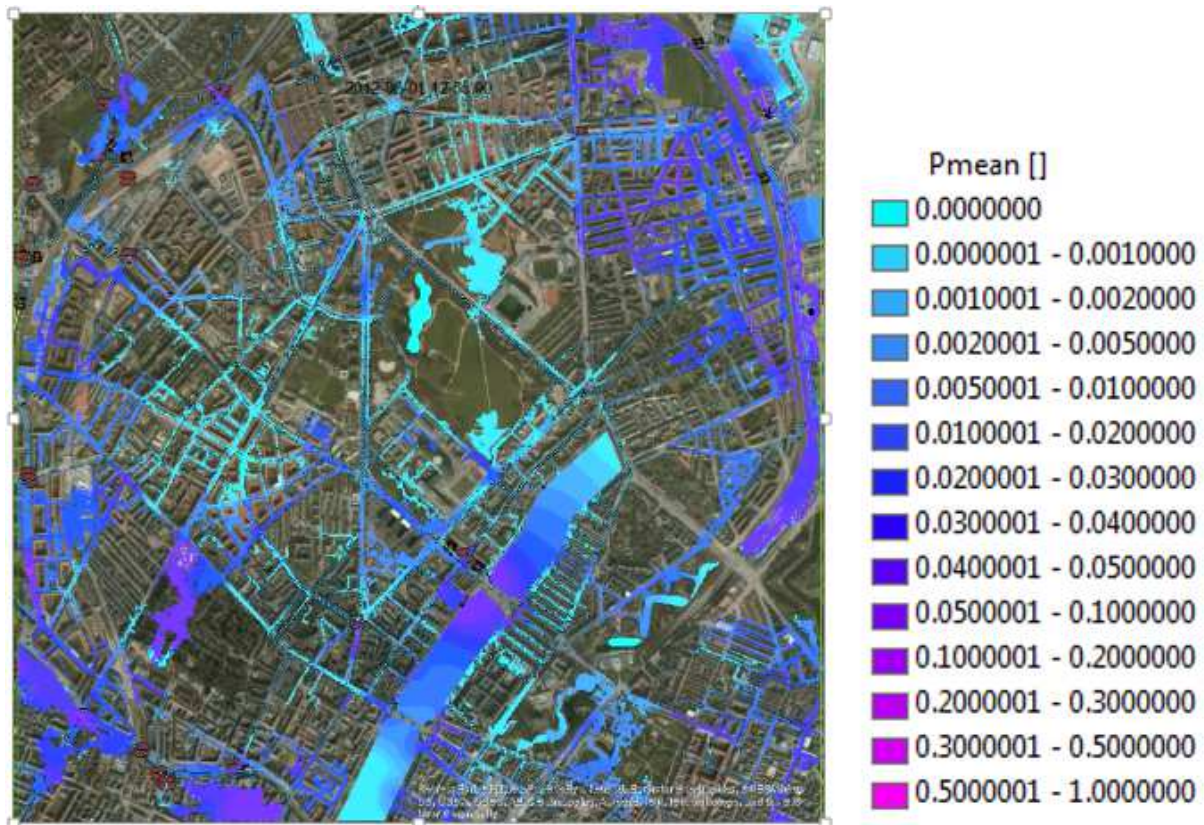


Figure 2: Risk map for Norovirus infection. Copenhagen, future 100-year rain (still frame from dynamic simulation)

## 4 CONCLUSIONS

Health risk is a factor that should be included when planning safety precautions against floods. Hydrodynamic modelling coupled with QMRA may be a useful tool to identify areas in which health risks during flooding will be critically high, and to illustrate the extent of the problem to decision makers. In a second step, city planners may use the risk maps to prioritise actions in specific parts of the city – for example to reduce the amount of wastewater that will be on the surface during a flood.

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