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SUMMARY

This report presents the draft outline of the CORFU Health Impacts Model. The model consists of assessing the risk to human health in four steps:

- *Hazard identification*
- *Hazard characterisation (or dose-response assessment)*
- *Exposure assessment*
- *Risk characterisation*

The health impacts model has four components. The first of these is the risk to human life component, and adapts a model developed in the FLOODsite project to estimate the number of deaths and injuries that could be caused by flooding. The next component relates to waterborne diseases and illnesses that can be assessed by means of a Quantitative Microbial Risk Assessment. Thirdly, the model takes account of other diseases (such as those transmitted by vectors) and suggests the use of relative risk information to estimate the impact of this disease. A similar approach is suggested to consider the mental health impacts of flooding.

Finally, the report describes how the health risks could be characterised using the Disability Adjusted Life Year (DALY).

Contents

Health Impact Assessment

1 Introduction

Floods are known to have important impacts on human, both directly and indirectly. These impacts can be immediate, such as the risk to human life and limb, as a result of deep fast flowing floodwaters. However, flooding can also increase the risk of illnesses and diseases, as people come into contact with contaminated water, or the floodwaters provide breeding grounds for vectors such as mosquitoes that can transmit them. The psychological impacts of flooding can also be significant, and the trauma that people suffer may remain for a considerable time after the floods have abated.

This report deals with the health impact assessment component of the impact assessment model. To understand the health impacts that result from urban flooding, a risk assessment framework will be adopted. This section of the report will describe this framework, and outline the key steps that should be taken to understand these impacts.

2 Risk assessment overview

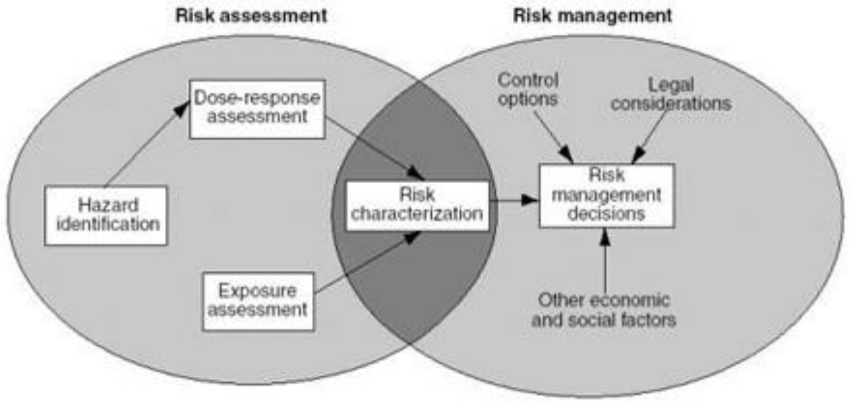
The concept of conducting risk assessments has been used in fields such as nuclear power, food technology, finance, and indeed in flood risk management. Over time, a number of different frameworks and terminologies have been developed.

The European Commission's Directorate General on Health and Consumer Affairs (SANCO) has attempted to harmonise risk assessment procedures and the terminology, and in doing so, described the four key steps, as follows: (European Commission 2000).

- Hazard identification
- Hazard characterization
- Exposure assessment
- Risk characterization

The second step, hazard characterization, is sometimes referred to as Dose-Response assessment.

These four steps have previously been described by the US National Academy of Science's earlier report on Risk Assessment for Federal Government (National Academy of Sciences 1983) , and forms part of the US's Environmental Protection Agency's Risk Assessment and Management Paradigm, which is represented in Figure 1.



Source: EPA Office of Research and Development.

Figure 1 - EPA Risk Assessment and Management Paradigm

This four step framework was also adopted by the authors of the UK's Flood Risks to People model (Penning-Rowsell et al. 2005) , which was then used as the basis for the FP7 project FLOODsite's European Risk to Life model (Priest et al. 2007) . These four steps mirror the steps adopted in the Quantitative Microbial Risk Assessment, which will form a key component of the health impacts model, and will be described in a later section.

The definitions of these four steps, quoted directly from the European Commission's report, are given in Table 1.

Table 1 - Risk assessment definitions (taken from European Commission, 2000)

Term	Definition
Hazard identification	The identification of a risk source(s) capable of causing adverse effect(s)/event(s) to humans or the environment species, together with a qualitative description of the nature of these effect(s)/event(s).
Hazard characterization	The quantitative or semi-quantitative evaluation of the nature of the adverse health effects to humans and/or the environment following exposure to a risk source(s). This must, where possible, include a dose/response assessment
Exposure assessment	The quantitative or semi-quantitative evaluation of the likely exposure of humans and/or the environment to risk sources from one or more media
Risk characterization	The quantitative or semi-quantitative estimate, including attendant uncertainties, of the probability of occurrence and severity of adverse effect(s)/event(s) in a given population under defined exposure conditions based on hazard identification, hazard characterisation and exposure assessment

These steps will be conducted slightly differently depending on the particular health impact that is being considered. For example the methodology will not be the same when the risk to life is considered as a result of fast deep floodwaters compared to the risk of disease and illness as a result of contaminated floodwaters. Before the steps are described, it is useful to revisit the literature review to describe the main health impacts that have been associated with flooding.

3 Literature review revisited

A review of the relevant literature on the health impacts of floods has been conducted to identify the most relevant hazards. This was conducted as part of Deliverable 3.1. This review is briefly revisited and summarised.

There have been several reviews on the health impacts of flooding, which were used to compile D3.3 (Hajat et al. 2005; Ahern et al. 2005; Du et al. 2010; Few et al. 2004)(. These review and other sources were used to compile a list of the most significant health risks.

The first and perhaps the most obvious health impact of flooding is the direct risk to human life through direct contact with deep and fast flowing floodwaters. This can result in the loss and life and physical injuries. The risks of death and injuries are often exacerbated by the presence of debris within the floodwater, and mitigated by effective flood warning and evacuation procedures. The greatest burden of mortality comes from drowning, heart attacks, hypothermia, trauma, and vehicle-related accidents.

A second type of impact caused by flooding is the risk to human health that results from the diseases and illness. These illnesses can be subdivided into several categories, depending on the types of pathogens that cause them and how they are transmitted.

The first major type of illness is that of faecal-oral disaeases. These can includediarrheal diseases, which can result from the ingestion of specific pathogens. These pathogens include viruses, bacteria and protozoans. For example, Cholera is caused by the bacterium *Vibrio cholerae* and is endemic in many parts of the world. *Rotavirus* is a viral pathogen, and is a common cause of diarrhea among children. *Cryptosporidium* is an exameple of a protozoan that can cause diarrhea. Other faecal-oral diseases linked to flooding include Hepatitis A, Hepatitis E, and Poliomyelitis (Polio).

The second type of illnesses or diseases caused by flooding are the vector borne diseases, typically transmitted by mosquitoes. These can include malaria, which is caused by a parasitic Protist (a type of microirganism), and Dengue Fever which is caused by the Dengue virus. Other examples include West Nile Virus. Viruses that are transmitted by arthropods such as mosquitoes are collectively known as arboviruses (*ar*thropod *bo*rne *viruses*).

Other than vector-borne diseases transmitted by mosquitoes, there are diseases that are borne by other carriers. Leptospirosis (or Weil’s Disease) is caused by a bacterial pathogen and transmitted by rodents. The pathogen is excreted into floodwaters. Leptospirosis causes a range of symptoms including fever, headaches and vomiting as well as liver and kidney damage. In July 2011, a man was killed as a result of leptospirosis, following flooding in Copenhagen in Denmark.

A further class of diseases is those caused by parastic worms that can be found in floodwaters, known as Helminths. Helminths include Cestodes (tapeworms), Trematodes (flukes), and Nematodes (roundworms). For example, Schistosomiasis is a disease caused by infestation of the body by flukes (a parasitic flatworm), and is carried by snails.

Bancroftian Filarisis is a disease common in some tropical and subtropical countries, resulting from an infection with A nematode, and is transmitted by mosquitoes (and could therefore be described as a vector-borne disease). Other helminths which cause disease can be water or soil based with the need for an intermediate carrier.

The psychological impacts of flooding can be very significant and long-lasting. Flooding can lead to common mental health disorders such as depression, anxiety, sleeplessness and irritability. Post-traumatic stress disorder is defined as one which "arises after a stressful event of an exceptionally threatening or catastrophic nature and is characterized by intrusive memories, avoidance of circumstances associated with the stressor, sleep disturbances, irritability and anger, lack of concentration and excessive vigilance" (WHO 2001). In addition, there have been studies that have linked flooding with increased suicide rates, although this is not a universal phenomenon (De Leo et al. 2013). There are several difficulties in assessing the mental health impacts of flooding. Firstly, proper diagnosis of any condition is difficult. Secondly, mental health impacts are often under-reported, and can be overlooked in comparison to the physical health impacts described above.

Finally, there are other health impacts that are difficult to classify. For example, chemical pollution may result if an industrial site is inundated. However, these risks are very specific to the individual case studies. Many of the health impacts that arise from flooding can be attributed to displaced populations. Food shortages often result and poor sanitation can lead to the outbreak of other diseases. Following the floods that struck Pakistan in 2010, UNICEF reported that malnutrition was worsened in the post-flood period. As was pointed out in the literature review, flooding has been linked with increased mortality and even seemingly unrelated conditions such as leukaemia. Other reported illnesses that follow flooding can also include skin and eye diseases, and respiratory infections such as asthma. These impacts are summarized in Table 2.

Having surveyed the health impacts that have been linked to flooding, it is important to consider which of these may be applicable in each of the case study cities. The risk to life and limb will exist in any city where flooding is a hazard, despite differing levels of vulnerability in each of these cities. Equally, the mental health impacts will be present where flooding and people coincide. However, in the case of diseases, certain diseases will not be present. For example, malaria is not an endemic health risk in any of the European case studies. Initial investigations have shown that malaria is endemic in China, Bangladesh and India. However, through discussions with project partners, malaria is not thought to be a significant risk in Beijing and can be ignored. In contrast, The Times of India reported that 80,000 cases were reported[1] between April 2010 and March 2011 in the Greater Mumbai region, so it is clearly an endemic condition which could be exacerbated by flooding.

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[1] http://articles.timesofindia.indiatimes.com/2011-04-20/mumbai/29450330_1_malaria-cases-malaria-capital-positive-cases

Table 2 - Summarised health impacts of flooding

Category	Impacts
Direct physical impacts	Death Injury Hypotherima
Illnesses and disease	Diarrheal • Cholera • Rotavirus • Cryptosporidium
	Other fecal-oral • Hepatitis A and E
	Helminth infection • Schistosomiasis • Bancroftian filariasis (transmitted by mosquitoes)
	Vector-borne • Malaria • Arboviruses (including Dengue Fever and West Nile Virus) • Bancroftian Filariasis (see above)
	Rodent-borne • Leptospirosis • Hantavirus pulmonary syndrome
Mental health	Common mental health disorders (depression, anxiety)
	Post-traumatic stress disorder (PTSD)
	Suicide
Other	Chemical pollution Respiratory disease Skin infections Malnutrition General increased mortality

Following the floods in Mumbai of 2005 which followed heavy rainfall on the 26th July 2005, the Government of Maharashtra reported on the number of cases admitted to hospitals. These statistics are presented in Table 3. In order to conduct the hazard identification in the different case studies, sources should be used to ascertain the diseases that may pose a threat to human health. This information will be used to limit the number of diseases that should be investigated in the health impacts model.

The literature review has highlighted that the relationship between flooding and different health impacts is not clear. Ahern et al (2005) concluded that there is surprising little evidence about the health impacts of flooding. This is partly a result of the difficulty in performing controlled epidemiological studies in post-flood situations.

Table 3 - Epidemiological surveillance in Mumbai

Disease/illness	Total admissions since July 29th 2005	Total number of deaths
Gastroenteritis	1318	1
Hepatitis	194	0
Enteric fever, Typhoid	53	0
Malaria	406	2
Dengue	49	0
Leptospirosis	197	10
Fever (unknown cause)	1044	45
Total	3261	57

Few et al., (2004) state that there is little evidence to link vector-borne diseases with flooding. On the other hand, there have been studies that present such a link. For example, Kondo et al., (2002) found that following the floods in Mozambique in 2000, the number of malaria cases increased by a factor of 1.5 to 2. In this case, several explanations were proposed for this increase, including the increase in refugees living outdoors in close proximity to each other. Similar increases in malaria cases were found in post-flood conditions in India (Pawar et al. 2008). Zaki and Shanbag, (2010) found an increase in the cases of both Dengue Fever (an arbovirus) and leptospirosis (rodent-borne) following the heavy rainfall and flooding that occurred in Mumbai in 2005. A factsheet from the WHO states that flooding may indirectly lead to an increase in vector-borne diseases through the increase in the number and range of vector habitats.

4 Health impact assessment methodology

This section of the report will describe the main steps taken in the health impact assessment, and will group the methods by the health risks that are considered.

- Risks to life
- Risks from waterborne diseases and contaminated floodwaters
- Risks from other diseases
- Risks to mental health (psychological impacts)

Hazard identification, hazard characterisation and exposure assessment will be described separately for each of the four categories described above. Finally, risk characterisation will be described for all the impacts, using the Disability Adjusted Life Year

4.1 Risks to Life

The framework for estimating the number of people that could be killed by floods must use the steps mentioned above to estimate quantitative relationships between the hazard, the numbers of people that could be exposed to it, and the likelihood that they would be killed or injured. A Risk to People model was developed in the UK as a government funded project. This was then extended as part of the FP7 project FLOODsite for Europe. This conceptual framework can be adapted and used in the CORFU project to be applied to European and Asian case study cities.

4.1.1 UK Risk to People model

In the UK, a Flood Risks to People model was developed by HR Wallingford. Conceptually, it posited that the adverse effects (E) on those exposed to flooding were a function of the characteristics of the flooding (F), the characteristics of the location (L), and the characteristics of the population (P).

$$E = f(F, L, P)$$

This could be expressed in another way. The flood risk to people is a function of the conditions of the flood waters, combined with the chance that people are exposed to the flood, and then combined with their ability of people to respond to a flood, all multiplied by the number of people who are at risk of flooding in the area.

In the UK's Risk to People model, a deterministic equation was used to estimate the number of people that could be killed or injured as a result of flooding.

$$N(I) = N.X.Y$$

Where N(I) is the number of people either killed or injured, N is the number of people potentially exposed to the hazard, X is the proportion of the population exposed to a chance of suffering death/injury (for a given flood), and Y is the proportion of those at risk who will suffer death/injury.

The number of people potentially exposed to the hazard could be taken from census or other demographic data sources. The proportion of the population exposed to a chance of suffering death/injury, X, is taken as the factor of the area's vulnerability and the hazard factor.

Many studies have shown that the main characteristics of floodwater that increases of risk to life are its depth and its velocity. In several studies, the product of velocity and depth was used to characterise the hazard. However, in the UK's Risk to Life model, it was argued that velocity was more important than depth, and an alternative equation was developed using SI Units of metres and metres per second, for people outdoors exposed to floods.

$$\text{Hazard Rating} = \text{Depth} \times (\text{Velocity} + 1.5) + \text{Debris Factor}$$

The debris factor was chosen as 0, 1, or 2, depending on whether the presence of debris in the floodwaters was unlikely, possible, or likely. The Hazard Rating is then a percentage.

The second part of the X, is a function of the vulnerability of the area. In the UK model, this was considered to be composed of three factors: the nature of area, the speed of onset, and the presence or not of an effective flood warning system. For each of these three factors, scores of 1 to 3 were chosen, to give a total score of the area's vulnerability from 3 to 9.

The final element of this equation is Y, the proportion of people who, if exposed, would be injured, otherwise referred to as people vulnerability. People vulnerability was assessed using a score of 10, 25 or 50% for each of two factors: the proportion of elderly people within the population, and the proportion of the long-term sick and disabled. The score was chosen for each on whether there was a lower than average, about average, or above average proportion of each of these two categories, leading to a score between 20 and 100%.

Combining these numbers gives an estimate of the number of people who would be injured from flooding. This number could then be multiplied by the aforementioned Hazard Rating to get the numbers who could be killed by floods.

4.1.2 European Risk to Life Model

This framework has been used as the basis for the FP7's FLOODsite's European Risk to Life model, although the original basic equation was amended to better explain the situation leading to the loss of life from flooding. For example, the previous model assumed that the people vulnerability was independent of the hazard rating, whereas in reality, the people vulnerability is less important in more hazardous conditions where to flooding may be extremely dangerous to everyone. The role of evacuation was not thought to be well represented in the UK's Risks to People methodology. The earlier equation was amended as follows.

$$\text{Risk to life in Europe} = f(F, E_x\ P_v, -M)$$

where, F is the flood hazard characteristics (e.g. the depth and velocity), $E_x$is the exposure of the hazard (related to the nature of the area, or whether people can avoid direct contact with the floodwaters, for example), P_v is vulnerability of people, and Mrepresents the mitigating actions, such as whether there is sufficient warning to enable people to evacuate the area entirely or seek appropriate shelter from the flood waters. This amended model is more qualitative than the UK Risk to People model which had used a deterministic equation to estimate the risk of death and injury.

As before, the Hazard Factor was estimated as a function of depth and velocity, but the debris factor was not included. Four zones were considered based on different thresholds of the Hazard Factor.

- Caution – Flood zone with shallow water or deep standing water
- Dangerous for some – Danger: flood zone with deep or fast flowing water
- Dangerous for most people – Danger: flood zone with deep fast flowing water
- Dangerous for all – Extreme danger: flood zone with deep fast flowing water.

Areas of higher vulnerability were again identified. In the Risk to Life model, areas were divided into three types of areas.

- Low vulnerability – multi-storey buildings that provide safer places for people to escape to. These areas also have well-constructed properties made out of solid materials such as concrete and brick.
- Medium vulnerability – typical residential area with mixed land use and mixed types of buildings
- High vulnerability – areas which provide little protection to individuals from flood waters. This could include campsites and mobile homes as well as poorly-constructed properties which are more vulnerable to structural damage or collapse or single storey buildings which only provide limited protection in deep waters.

The Hazard Rating and Area Vulnerabilities were used to determine what would likely be the major to human life. This is presented in Table 4.

Table 4 - Risk to life from flooding as a function of hazard and area vulnerability

Depth X Velocity	Hazard	Area vulnerability	Fatality factor
$>7m^2s^{-1}$	Extreme – dangerous for all	High (mobile homes, etc)	Hazard and building collapse dominated
		Medium (typical residential area)	
		Low (multi-storey apartments, and brick and concrete properties)	
1.10 to $7m^2s^{-1}$		High	Hazard dominated
		Medium	
		Low	
0.50 to $1.10m^2s^{-1}$	High – dangerous for most	High	Behaviour dominated
		Medium	
		Low	
0.25 to $0.50m^2s^{-1}$	Moderate – dangerous for some	High	People vulnerability dominated
		Medium	
		Low	
$<0.25m^2s^{-1}$	Low – Caution	High	Low risk
		Medium	
		Low	

At low flows and depths, the risk to life is likely to be dominated by people's vulnerability, such as their age. As the water becomes deeper and faster, the risks are likely to become behaviour dominated. This means whether people can find shelter, or conversely, whether they engage in risky behaviour. Finally, with faster and deeper waters, the hazard itself becomes dominant, and at its most extreme, the stability of buildings and shelters becomes a dominant factor.

The next part of the model is the presence or absence of mitigating factors. The principal mitigating factor is that of evacuation. If a full evacuation takes place, most people will have been able to leave the area and will not therefore be exposed to flooding. At the other end of the scale, where there is no flood warning, or if there is, the lead time is short, the majority of the population will remain in situ when flooding occurs and are thus much more exposed to the flood hazard.

4.1.3 Application to the CORFU project

In the CORFU project, this model developed as part of the FP7 FLOODsite project can be employed. However, the qualitative model should be adapted to incorporate quantitative measures. Data on the number of deaths following significant floods in the various case study cities can be used to calibrate the factors. However, significant uncertainty will remain and the figures generated should only be considered as a broad estimate of the possible risk.

4.2 Health risks associated with waterborne diseases and contaminated floodwaters (Quantitative Microbial Risk Assessment)

The next stage is to consider the diseases and illnesses that are caused by pathogens that can be found in contaminated floodwaters. A technique known as Quantitative Microbial Risk Assessment (QMRA) will be used to assess these health impacts.

The first stage (Hazard Identification) is to identify which are the most significant pathogens. As there are many different pathogens that are found in floodwater, it is recommended to consider the reference pathogens. These are the most significant pathogens, and can be used to represent whole classes of pathogens. Following the precautionary principle, the reference pathogens that are chosen should usually represent a worst-case scenario of having a high occurrence, relatively high concentrations, high pathogenicity and environmental survival. It is also vital that there is an established Dose-Response function for these pathogens.

In order to identify the most significant pathogens, it would be better to sample floodwaters. However, due to the resources currently available, sampling of floodwaters, or the untreated water in sewers in not likely to be feasible. Therefore, local data should be collected, or information collected from the literature.

Indicator organisms can be used to assess the load of pathogenic bacteria – e.g. thermotolerant coliforms, although the relationship is not always clear (Abraham 2011). However, in this paper, it is argued that a “close meshed net of monitoring of pathogens in the water of large cities is required”. In a review on waterborne diseases and pathogens in Megacities, a table of the most import water-borne disease agents was presented and this is presented in Table 5 (Abraham 2011).

Cann et al (2012) presented a table presenting the waterborne pathogens implicated in outbreaks following extreme water-related weather events were identified from the scientific literature, and these are presented in Table 6.

In a study in the UK, based on the literature survey, the most frequently identified pathogens are

- Campylobacter sputorum
- Salmonella sputorum
- Cryptosporidium sputorum
- Giardia sputorum

Campylobacters are the most commonly reported cause of bacterial gastroenteritis in the UK with an estimated incidence of 8.7/1000 population ((Adak et al. 2002), and were therefore chosen as the reference pathogen (Fewtrell et al. 2011).

For the viral reference pathogen, the decision taken in this study was more difficult. Novoviruses are the most common viral cause of GE but there is no calculated D-R relationship. The second most common viral pathogen is Rotavirus, and a D-R relationship has been established, but concentrations cannot be established by cell culture. Therefore a composite adenovirus was chosen, using the D-R characteristics based on rotavirus. This research is useful in describing how the reference pathogens might be identified.

Table 5 - Major waterborne disease agents (From Abraham, 2011)

Agent	**Disease**
Bacteria	
Vibrio cholerae	Cholera, diarrhea, cramps
Vibrio vulginus, V. alginolyticus, V. parahaemolyticus	Dairrhea, nausea, cramps
Escherichia coli STEC, etc	Diarrhea, feces with blood, vomiting (shigellosis)
Salmonella typhi	Fever, diarrhea, delirium
Chlostridium botulinum	Botulism, respiratory failure
Legionella pneumophila	Pontiac fever, Legionares' disease, pneumonia
Leptospira spp.	Meningitis, jaundice, renal failure, head ache
Wolbachia pipientis	River blindness when released from *Onchocerca volvulus*
Virus	
Adenovirus	Pneumonia, croup, bronchitis
Hepatitus A virus	Jaundice, fatigure, fever, diarrhea
Poliovirus	Polymyletis, headache, fever, spastic paralysis
Polyomavirus	Respiratory infection, leukoencephalopathy
Norovirus	Vomiting, nausea, cramps
Protozoa	
Entamoeba histolytica	Diarrhea, fatigue, fever
Cryptosporidium parvum	Flu-like symptoms, diarrhea, nausea
Giardia lamblia	Diarrhea
Parasites	
Plasmodium sp.	Malaria, transmitted by *Anopheles* mosquitoes
Schistosoma spp.	Bilharziasis, itching, fever, cough
Dracunculus medinensis	Nausea, diarrhea, allergic reaction
Taenia spp.	Cysticercosis, loss of weight
Fasciolopsis buski	Diarrhea, liver enlargement, cholangitis, jaundice
Hymenolepis nana	Abdominal pain, nervous manifestation
Echinococcus granulosus	Liver enlargement, jaundice
Ascaris lumbricoides	Inflammation, fever, diarrhea, nausea
Enterobius	Itching, hyperactivity, insomnia
Onchocerca volvulus	River blindness, itching, blindness

However, it is useful to consider a project case study city. Harris et al., (2008) studied the prevalence of different diarrhea-causing pathogens in Dhaka in floods from 1998, 2004 and 2007. Data from the 2007 floods show that *V. cholerae* is the most commonly identified pathogen causing diarrhea requiring hospitalization during flood-related diarrheal epidemics. Rotavirus was the major pathogen causing diarrheal disease in children < 5 years of age during the flood periods. However, E-coli was a major cause of diarrhea not only in children (13%) but also adults (11%). Work by Schwartz et al (2006) showed that V. cholerae was the most prominent pathogen that caused diarrheal outbreaks from 1998 to 2004. That research found that although V. Cholera increased proportionally, rotavirus decreased proportionally, although it remained one of the most important pathogens that were identified. Shigella and Salmonella were also present. Between 23 and 51% of the time, no pathogens were identified.

Table 6 - Cases of waterborne pathogens (adapted from Cann et al. (2012))

Waterborne pathogen	Scientific literature	ProMED reports
All viruses	**19 (25.7)**	**5 (2.4)**
Hepatitis virus	7 (9.5)	3 (1.4)
Norovirus	6 (8.1)	1 (0.5)
Rotavirus	3 (4.1)	1 (0.5)
Adenovirus	2 (2.7)	-
Enterovirus	1 (1.4)	-
All bacteria	**66 (89.1)**	**198 (93.8)**
Vibrio spp.	21 (28.4)	145 (68.7)
Leptospira spp.	13 (17.6)	137 (64.9)
Campylobacter spp.	10 (13.5)	8 (3.8)
Escherichia coli	9 (12.2)	9 (4.3)
Shigella spp.	4 (5.4)	-
Salmonella spp.	3 (4.1)	5 (2.4)
Burkholderia pseudomallei	3 (4.1)	9 (4.3)
Yersina enterocolitica	2 (2.7)	-
Aeromonas spp.	1 (1.4)	-
All protozoa	**16 (21.6)**	**12 (5.7)**
Cryptosporidium spp.	9 (12.2)	3 (1.4)
Giardia lambia	5 (6.8)	-
Acanthamoeba spp.	1 (1.4)	-
Cyclospora spp.	1 (1.4)	-

Having identified the most significant hazards, the next step is to characterise the hazard in quantitative terms. In the QMRA, this can be conducted using Dose–Response functions. These functions describe the relationship between the exposure and incidence of particular health risks.

$$P(inf|\mu) = \sum_{n=0}^{\infty} P(n|\mu) \times P(inf|n)$$

Where

- $P(inf|\mu)$ is the probability of infection, given a mean pathogen density
- $P(n|\mu)$ is the probability of exposure to n organisms, given a mean pathogen density
- $P(inf|n)$is the probability of infection given exposure to n organisms.

Although these can have several forms,two types of dose-response functions are commonly adopted: the exponential model and the beta-poisson model (β-poisson), although other distributions such as the Weibull Gamma, Weibull and Gompertz distributions can be used (Buchanan et al. 2000).

The exponential model is defined by one parameter, and is described in the following equation

$$P_i(d) = 1 - \exp(-rd)$$

where $P_i(d)$ is the probability of infection at a particular dose, d, and r is the parameter specific for a particular pathogen. Its form can be seen in Figure 2, with an example for Cryptosporidium parvum, quoted by Fewtrell et al (2011). The value for r in this example is 0.004005.

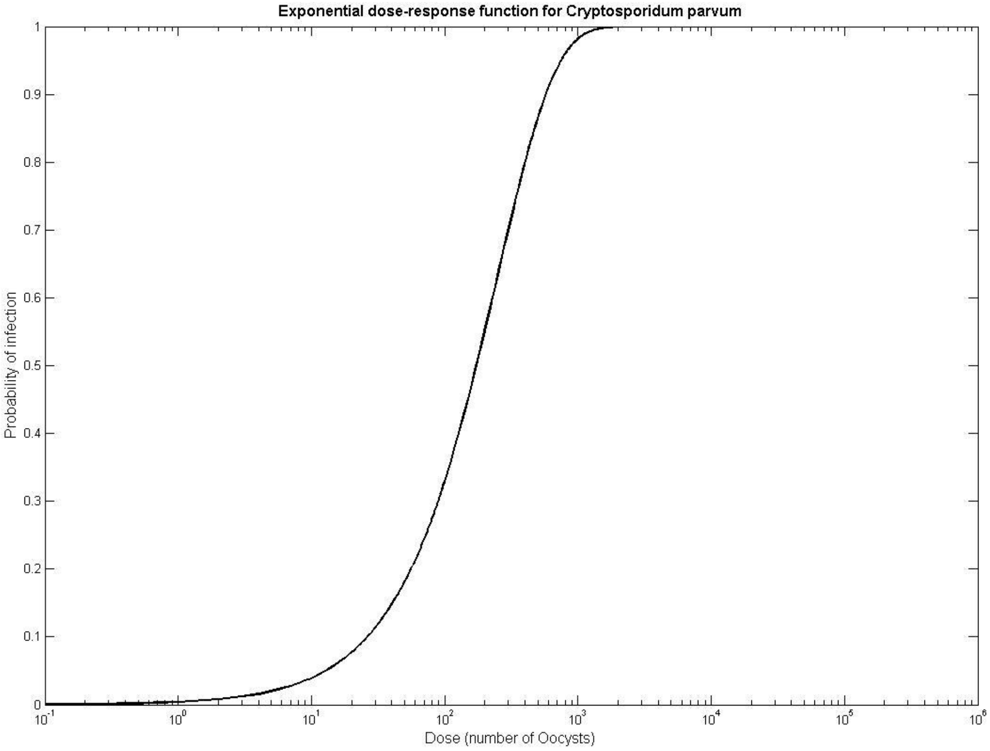

Figure 2 - Exponential D-R relationship for Cryptosporidium Parvum

The beta-poisson distribution is defined by two parameters

$$P_i(d) = 1 - (1 + \left(\frac{d}{\beta}\right)^{-\alpha}$$

where α is the model infectivity parameter, and β is the model shape parameter. An example for Rotavirus, quoted by Fewtrell et al (2011) is shown in Figure 3. The parameters for α and β were quoted as 0.265 and 0.442 respectively.

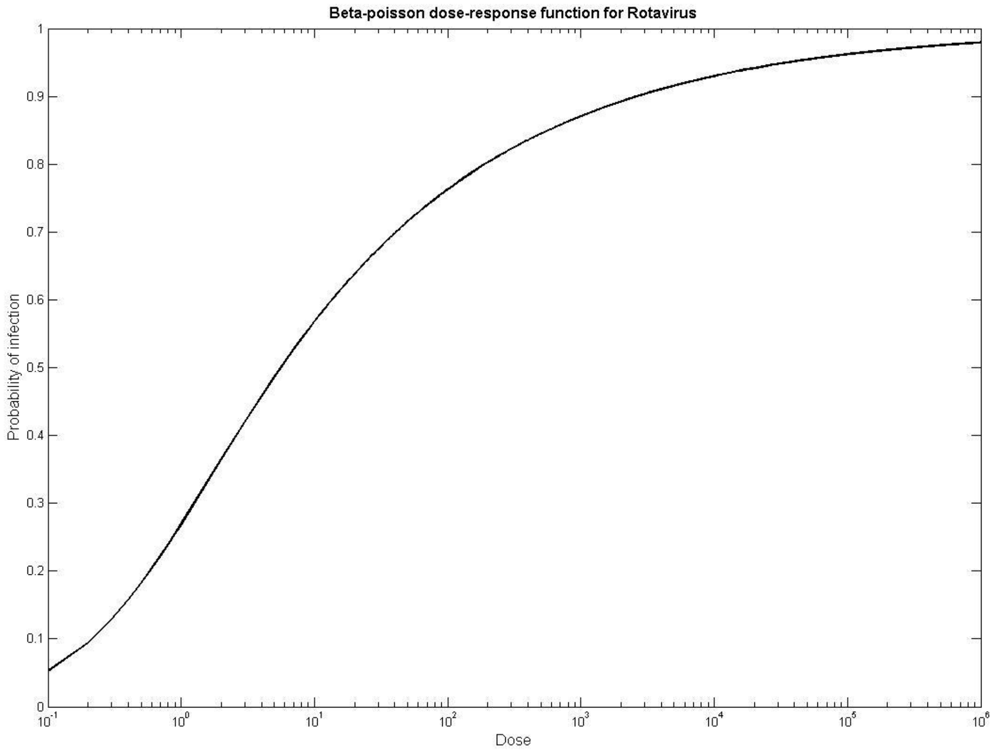

Figure 3 - D-R function for rotavirus

The next step is to consider how many people might be exposed to the pathogens and what dosage of pathogens might be ingested. In the CORFU project, one important innovation is that it is aimed to model the transport of pathogens in floodwaters. Assumptions will need to be made about the survival rate of the pathogens. Work has been conducted at DHI, and Dhaka has been used as a case study. This case study is described later in this report.

To calculate the total risk to the population through exposure to contaminated flood waters, some assumptions must be made. In the study by Fewtrell, the flooding process and exposure was divided into two stages: the withdrawal (i.e. leaving the property during the flood) and the clean-up phase. It was assumed that immersion resulted in a swallowing a single gulp of water (30mL for adults, and 20mL for children). Assumptions were also made about the different rates of immersion for different population groups. For example, it was considered that young children would have no immersion in the water as they would be lifted clear of the floodwaters, whereas the immersion rates for adults would be higher. Other assumptions will have to be made on the duration of the clean-up phase for example.

The application of this methodology to the case study city Dhaka will be described in Section 5.

4.3 Other diseases

For the estimation of the impacts of other diseases and illnesses, there is greater uncertainty. Having identified the most significant hazards, the estimation it will be necessary to make assumptions about the increased risks of people falling ill with those diseases as a result of flooding. This can be achieved by considering the relative risk. In one study, for example, Fewtrell et al., (2008) attempted to estimate the health impacts from flooding in the UK. To do so, they used statistics from earlier studies to estimate the baseline incidence and the relative risk of some certain health-related problems linked to flooding. For example, following work by Reacher et al., (2004) , asthma had a baseline incidence of 7.6%. Flooding resulted in a Relative Risk of 3.1, leading to an incidence rate of 23.6%. The results are presented in Table 7.

Table 7 - Baseline incidence rates and Relative Risks of health impacts (adapted from Fewtrell and Kay, 2008)

Disease	Baseline incidence	Relative Risk
Asthma	0.076	3.1
Earache	0.001	2.2

Where such information is available, more detailed information could be used to discriminate between certain population groups.

Lau et al., (2010) conducted a review on the relationship between outbreaks of leptospirosis with flooding, and questioned whether the burden of the disease could be increased due to climate change and increased urbanisation. The areas most at risk from the increased burden would be those where multiple risk factors might coexist, such as increased flood risk, rising temperatures, overcrowding, poor sanitation, poor health care, poverty and an abundance of rats or other animal reservoirs. This information should be used to assess the future risks of the outbreak of such diseases.

4.4 Mental health impacts

The literature has suggested that the mental health impacts of flooding may be very significant. To characterise the hazard, it would be useful to review what is known about the epidemiology of such impacts.

A review of its epidemiology was conducted by Galea et al., (2005), using studies from 1980 to 2003. The prevalence of PTSD related to natural disasters was found to range between 5 to 60%, with most of the studies showing numbers towards the lower end of this range. The review demonstrated that the biggest risk factor for developing PTSD during a natural disaster was the extent of the exposure, and therefore injured people, for example, are significantly more likely to develop PTSD. Approximate figures from the review suggested that the prevalence among direct victims of disasters is at 30-40%, 10-20% among rescue workers, and 5-10% in the general population. Other risk factors included gender (women are shown to be more likely to suffer from PTSD), pre-existing psychological disorders and low social support.

More specifically related to flooding, studies quoted by Ahern et al (2005) have shown a prevalence of 22% of PTSD during the 1993 Midwest floods, or 19% among flood victims of the 1997 Central Valley Floods in California. However, studies are limited in some cases by the fact that some of the results from these studies are self-reported. A study in India showed older people were more prone to PTSD than the younger population (Telles et al. 2009).

A meta-analysis of the risk-factors that are linked to PTSD caused by traumatic events was conducted by Brewin et al., (2000). The analysis showed similar factors were linked with a higher prevalence of PTSD, including age, education, previous trauma and psychiatric history, as well as the severity of the trauma and the lack of social support.

Huang et al., (2010) studied post-traumatic stress disorder among people in flood-hit areas in the Hunan Province in China, and developed what they claimed to be the first predictive model of PTSD using a risk-score model among flood victims in a large population. Nearly 30,000 individuals were selected for the study, of whom 25,500 participated (87% response rate). 70% of the sample was used to develop the predictive model, with the remaining 30% used to test the model's predictive skill. The prediction model used 7 variables:

- Age
- Gender
- Education level
- Type of flood (soaked flood (drainage related), collapsed embankment (river) flood, or flash flood).
- Severity of flood
- Flood experience
- Mental status before flood

These variables were used to develop a risk score, and individuals with a score higher than a certain threshold were then diagnosed as potential sufferers. The model has a positive predictive value of 23%, and a negative predictive value of 98%, although these results were dependent on the threshold value chosen. As this threshold increased, the Positive Predictive Value increased, while the Negative Predictive Value[2] decreased), showing that the model had some predictive value.

Verger et al., (2003) developed indicators for the cumulative exposure to a flooding incident in south-eastern France in 1992, and assessed its association with the incidences of PTSD five years later. The researchers found a strong exposure-effect relationship, and argued that such studies could be used to develop a greater predictive understanding of the impact of flooding on mental health.

Other psychological disorders are known to affect people affected by flooding include anxiety and depression. Most of the studies on the effects of these disorders are from wealthier countries, although a study quoted by Ahern et al (2005) focused on Bangladesh. Among 162 children aged 2 to 9 years old, 16 children were found to be very aggressive post-flood, in contrast to no reports before the flood. The prevalence of bed-wetting increased from 16% to 40%.

Ahern et al (2005) conclude that the mental health impacts of flooding, especially the long-term impacts, and their principal causes, have been inadequately researched, even in high-income settings. A study in Lewes, UK, following the floods of 1998, demonstrated a four-fold increase in psychological distress among flood-affected people (Reacher et al., 2004). An unquantified increase

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[2] The Positive Predictive Value (PPV) is a measure of the ability of the method or technique to correctly identify true. The Negative Predictive Value (NPV) is a measure of the ability to measure true negatives

in visits to doctors with mental health problems was noted in Nimes, following the floods of 1988 (Duclos et al. 1991).

As with the other diseases, information will be have to be acquired on the relative risks associated with psychological impacts, and assumptions made about the likelihood that individuals will be impacted. Where possible, attempts should be made to be made to quantify these risks.

5 Application of Health Impact Assessment for waterborne disease (cholera) in Dhaka city.

5.1 Hydrodynamic advection-dispersion modelling

During CORFU the traditional hydrodynamic modelling of urban flooding has been expanded with the modelling of pollution in the flood water. An advection-dispersion model has been added to the 2D surface flood model. Further, the water quality model in the urban drainage/sewer model has been connected to the 2D advection-dispersion model for the flood water. Hence, when the urban drainage/sewer system is overloaded and water is transferred from the urban drainage system/sewer system to the surface, then the polluted water in the urban drainage/sewer system is transferred from below ground to the surface, where it is transported with the flow and advection dispersion processes.

The new water quality flood model has been set up for the city of Dhaka. Dhaka, the capital of Bangladesh, is one of the most densely populated cities in the world. The average population density in the central part of the city is 47,671 per km^2. In recent years Dhaka has experienced rapid urbanisation and development of urban infrastructure. These developments, combined with water logging from rainfall and river flooding, have created an environment which can be detrimental to millions of people.

Flood disrupts local health infrastructure and routine health services, rendering it unable to function well during emergencies. It results in increased morbidity (incidences of diseases) and mortality during as well as after the flood. Vital primary health care programmes like vaccination can suffer heavily due to disruption of drug supply during the flood. A survey was undertaken by BRAC (a Non-Governmental Organisation) for the period of 25 August to 22 September, 1998, to produce a disease profile. Of those surveyed, diarrhoea affected 34%, Dysentery 17%, ARI 5%, fever 24%, helminthiasis 2%, eye infection 2% and skin Infection 6%. A comparison of the flood and normal situation was made, and during the flooded time, there was an increased morbidity during the period of August 1998 of 61% (Table 8).

Table 8 - Disease profile during the flood period (25 August-22September, 1998)

Disease	Percent Affected
Diarrhoea	34%
Dysentry	17%
Fever	24%
Eye infection	2%
Helminthiasis	2%
Skin Disease	6%
Acute Respiratory Infection	5%
Others	10%

The current sewage disposal system of Dhaka city is partly done through a combined sewer system and partly through a separate sewer system. Even in areas where there is a separate sewer system, much of the wastewater is discharged through the drainage system. Most of the sewerage infrastructure within Dhaka is either blocked or damaged, and as a result, many parts of the city suffer from environmental degradation and unhygienic conditions.

The flood model for Central Dhaka was developed using MIKE Urban. The model covers an area of 39.2 km^2 and has 852 sub-catchments. The rainfall-runoff process is simulated using the Urban Type A hydrological model. The percentage of pervious land based on a weighted average is 61.4%. The model has both storm sewer pipes and box culverts as part of the network. Thetotal length of the network is 112 km. The MIKE Urban model has been linked with a digital terrain model – and a flood model for the area has been established. The flood model with modelling of pollution in the flood water has been setup up for the flood in September 2004. The flood results and the dilution factors of the dry weather flow can be seen in Figure 4 and Figure 5.

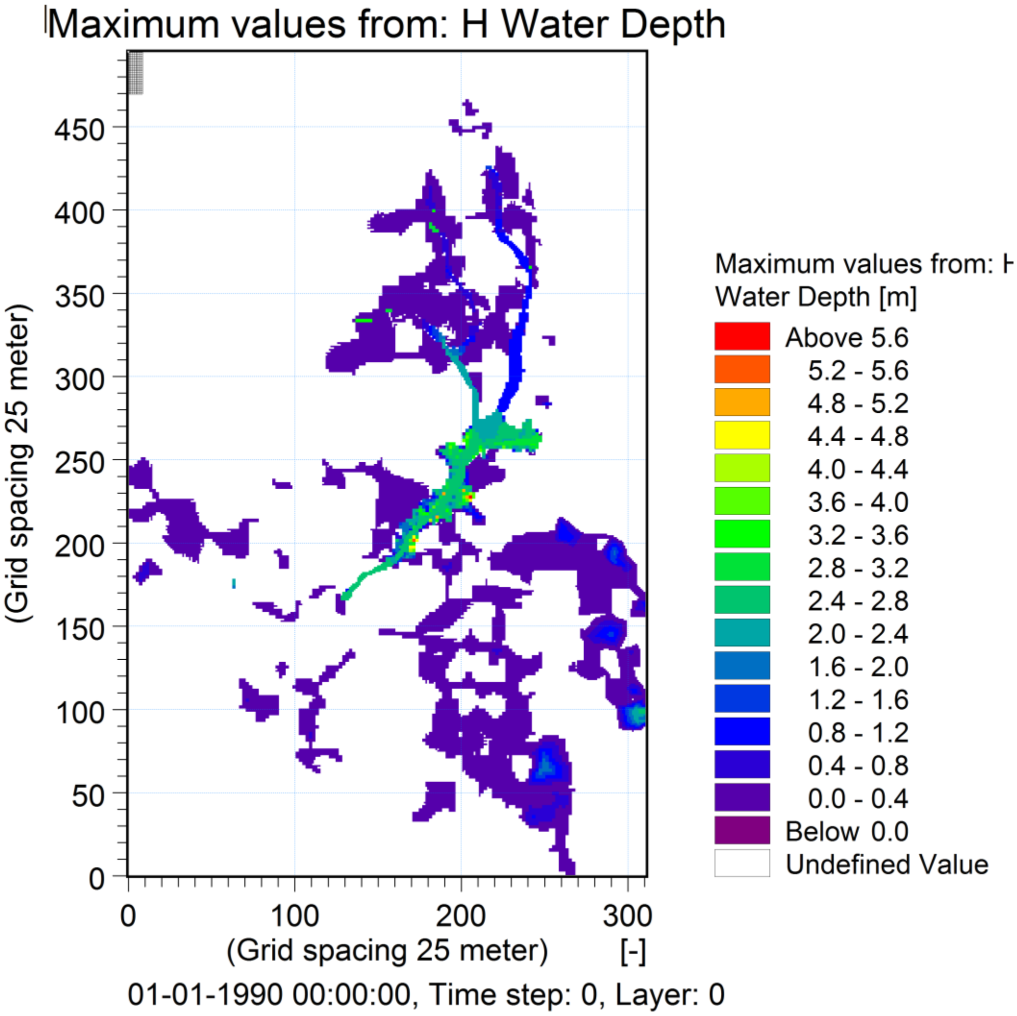

Figure 4 - The flood maps computed for the flood in September 2004

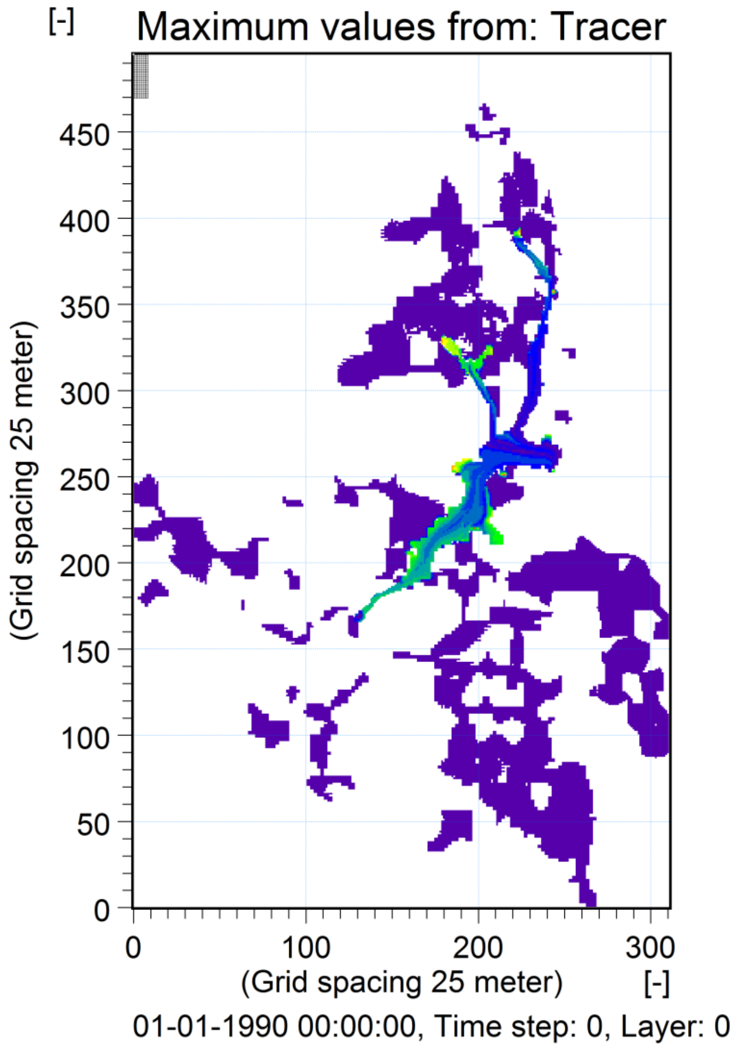

Figure 5 -The pollution map computed for the flood in September 2004. The map shows the concentration of wastewater in the flood water. The concentration is represented as a dilution factor of the wastewater concentration

The next step is to compute the health risk based on the concentrations, the selected pathogens, and their dose-response functions. The reference pathogens have not yet been selected for the risk assessment analyses. Dose-response models, obtained from the literature, will be used to estimate the probability of infection and the associated uncertainty. The application of this methodology is described in the next section.

5.2 Hazard identification and dose-response relations:

Epidemic *Vibrio cholerae* has 2 major serogroups (O1 and O139). The O1 serogroup has 2 biotypes (classical and El Tor) and each biotype has 2 major serotypes (known as Ogawa and Inaba). Since 1993 the El *Tor V. cholerae* O1 and *V. cholerae* O139 have been the dominant biotypes in Bangladesh. In 2004*, V. cholerae* O1 was the dominating serogroup. Therefore the El Tor *V. cholerae* O1 is selected for cholera risk modelling. One study has examined the dose-response relationship for

El Tor *V. cholerae* O1 Inaba. The best fit model for illness (P_{ill}) was the approximated beta-poison relation:

$$P_{ill}(cV;\ \alpha,\beta) = 1 - \left(1 + \frac{cV}{\beta}\right)^{-\alpha}$$

with α = 0.169 and β = 2,305 (N_{50} = 137).

The D/R is based on data from Levine and co-workers ((Black et al. 1987, Levine et al., 1981, Levine et al., 1988)The volunteers of the studies were students and other healthy adults from Baltimore. V. cholera was admistered with 2 g of $NaHCO_3$. The analytical method for determining the dose was traced back to Cash et al. (1974)and was by culture and therefore assumed to be comparable to our results.

5.3 Quantification of human exposure to flood water:

The exposure route of water borne diarrheal diseases is the faecal oral route. This is also the case for *V. cholerae*. Here we estimate the risk from exposure to flood water via direct ingestion and hand to mouth exposure. During a field study in Dhaka (12 Nov to 15 Nov 2013) 26 individuals and a group of children were interviewed regarding their behaviour during floods. The questions asked were related to age, frequency and duration of water contact via direct ingestion and hands. The social status of the interviewees was estimated through questions, from appearance and from their place of living. Slum areas (e.g. Koreil, UTM, WGS84 N23 46.971, E90 24.704), and areas with mixed middle class/poor (e.g. Rajabagh N23 44.559, E90 25.092) were visited. In general the exposure was related to social status and age. Small children (below approximately 5 years) in the slum areas were the highest exposed group and the upper middle class adults the least exposed.

The interviews revealed the following results:

1. Small children in slum areas are in the flood water on and off during the day.
2. Adults in slum areas and poor areas are wading or staying in the water from 1 to several hours either because of transport to and from work or by remaining in the flooded area.
3. Children in poor areas and slum areas are exposed during transport to school and often play in the water: e.g. running, playing soccer, cricket and even water polo.
4. Street vendors may stay in the flood water for extended periods exposed via hands and splashing from cars etc.
5. Middle class and upper middle class adults try to avoid contact either by staying home during the flood or by being transported by car or rickshaw. Most say they get wet hands.
6. Middle class and upper middle class children are usually restricted in access to the flood water by the parents but may be exposed going to and from school.

Table 9: Exposure groups for which the cholera risk has been estimated and models for quantification of exposure to flood water.

Group	Exposure description	Exposure/day	Reference
Small children in the slum and poor areas	The children stay partly emerged in the water for several hours. Considered exposed as children in recreational water	37 ml Gamma distribution r = 0.64, λ = 58	Schets et al 2011
Adults in slum and in poor areas	Wading 1 hour/day on the way to work or other business.	Log normal µ = 3.5 ml σ = 3,6 ml	Dorevitch et al., 2011
Middle class/upper middle class children	Exposed on the way to school etc., but exposure usually restricted by parents.	Mean: 1.7 ml 95% CI: 0 - 4.6	*de Man et al., 2014
Middle class/upper middle class adults	Avoid exposure but exposed via hands	Mean: 0.016 ml 95% CI 0 - 0.068	*de Man et al., 2014
* The set of 100,000 exposure volumes underlying the assessment of the infection risk from exposure to waterborne pathogens in urban floodwater was used for the MonteCarlo simulation. The dataset was kindly provided by Dr. Heleen de Man, Institute for Risk Assessment Sciences, Utrecht University, The Netherlands.			

5.4 Sampling and microbial analyses:

The samples for this study were taken by Institute of Water Modelling, Dhaka, Bangladesh from three locations in Dhaka (Rajarbagh (N23°44.541';E090°25.003'), Shantinagar (N23°44.868';E090°24.572'), and Paltan (N23°44.157';E090°24.930'). Seven wet weather samples were taken hourly (11.00 to 17.00) from the flood water 8 September 2013, and 7 dry weather samples (every 4 hours from 10 am to 10 am) were taken from the drainage system on 15/16 September 2013.

500 ml water samples were aseptically collected in sterile Nalgene plastic bottles following the APHA procedures (APHA, 1998)The samples were placed in an insulated box with ice packs and immediately transported to the Environmental Microbiology Laboratory of the International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b) for analysis.

The samples were analysed for Enterococci, *E. coli*, *V. cholerae* and *V. cholerae* O1 El Tor (Inaba and Ogawa).

For analysis of E. coli, 5 ml water samples from three different dilutions were filtered through a 0.22 µm pore-size membrane filter and incubated m-TEC agar plates at 35+0.5°C for 2 h and at 44.5+0.2°C for 22–24 h. Characteristic red or magenta colonies were counted as E. coli. Enterococci was analysed according to ISO 7899-2.

V. cholerae and *V. cholerae* O1 El Tor were quantified by a 3 x 3 MPN procedure. 1, 0.1 or 0.01 ml of sample were inoculated into 10 ml alkaline peptone water and subcultured on thiosulfate citrate bile salt sucrose (TCBS) agar (BD, USA) and CHROMagar Vibrio (CV) agar (CHROMagar, Paris, France). Following overnight incubation at 37°C, yellow colonies with a diameter of 2–3 mm on TCBS agar plates and pale blue colonies on CV agar plates were presumptively selected as *V. cholerae,* and confirmed based on their colonial characteristics after transferring the same colony to fresh TCBS and CV agar plates. Following overnight incubation at 37°C, colonies were identified as *V. cholerae* if they were Gram negative, oxidase positive, produced acid from sucrose but not inositol and decarboxylated lysine and ornithine but not arginine. *V. cholerae* strains were then serotyped.

5.5 Quantitative Microbial Risk Assessment

The quantitative microbial risk assessment (QMRA) was performed by MonteCarlo simulation using @Risk (Palisade, Industrial Edition, Version 6.0.1) using Latin Hypercube sampling and 40,000 iterations. The dosages was calculated based on a poisson distribution with an average calculated from the measured concentration in the dry weather samples, the dilution of the drainage water sampled in the entire duration of modelled time series.The ingested volume sampled from distributions is shown in Table 9, assuming 1 day of exposure. The risks were then calculated for the four exposure groups shown in Table 9.

5.6 Risk assessment locations.

Three locations in Dhaka with known flood occurrences were selected a priori for the risk assessment. The locations are either close to the sampling locations or selected on the basis of the field interviews. The locations are: a slum area approximately 200 m east of the Bir Shreshtha Mostafa Kamal Stadium (BSMK-Stadium, N23° 43.560', E090° 25.890') and mixed middleclass/poor residential areas in Rajarbagh (N23° 44.559', E090° 25.092') and Paltan (N23°44.208', E090° 24.710') near the sampling locations.

5.7 Results of the microbial analyses

The concentrations of *E coli* and Enterococci were in the range of 10^6 to 10^8 pr 100 ml, which are typical for raw sewage. The concentration of non O1,O139 *V. cholera* was in the range of 10^3 to 10^5 pr . 100 ml. Taking both dry and wet weather results into account it was found that the concentration of *E. coli* on average was 1.4 logunits higher than the concentration of Enterococci and 3.4 logunits higher than the concentration of non O1,O139 *V. cholera*. The concentrations had a tendency to be higher (13% to 49% on average) under dry weather conditions than under wet weather conditions. No trends were observed in the temporal variation seen over the individual sampling days.

V. cholerae O1 El Tor, Ogawa was found in two samples (300 and 300 pr. 100 ml) in Paltan and in one sample in Razarbag (360 pr. 100 ml) under dry weather conditions. The detection limit of the 3 x 3 MPN-setup was 300 pr. 100 ml. We have used the average dry weather concentration of *V. cholerae* O1 El Tor (46 *V. cholerae* O1 El Tor/100 ml) for the risk assessment.

The results of the microbial analyses are shown in Table 10.

Table 10: Enterococci, *E. coli, V. cholerae* and *V. cholerae* O1 El Tor in samples from wet weather and dry weather periods.

/100 ml Geometric mean and 1 standard deviation	*E. coli*	Enterococci	*V. cholerae*
Wet weather			
Rajarbagh	$10^{6.8\pm0.7}$	$10^{5.9\pm0.2}$	$10^{3.8\pm0.8}$
BSMK-Stadium	$10^{7.2\pm0.2}$	$10^{5.9\pm0.1}$	$10^{4.0\pm1.0}$
Paltan	$10^{7.5\pm0.6}$	$10^{6.1\pm0.1}$	$10^{4.0\pm0.9}$
Dry weather			
Rajarbagh	$10^{7.5\pm0.5}$	$10^{6.2\pm0.2}$	$10^{4.1\pm0.8}$
BSMK-Stadium	$10^{7.7\pm0.5}$	$10^{6.0\pm0.1}$	$10^{4.3\pm0.5}$
Paltan	$10^{7.7\pm0.6}$	$10^{6.1\pm0.2}$	$10^{4.2\pm0.8}$

5.8 Health modelling results

The average and 95percentiles of cholera risk are shown in Table 11. The highest estimated risk is $5.6 \cdot 10^{-3}$ for children in the Paltan slum area and the lowest risk is 10^{-6} or lower for the middle class adults. The 5-percentiles, the median risks and most of the 95percentiles were all below the detection limits of the simulation, due to sampling in a poisson distributed dose, where most events results in zero ingestion.

Children have a higher average risk than adults. The difference is highest in the middle class, 71 times higher in Razarbag, and higher in Paltan, where the adult risk was undetectable. In the poor/slum areas the childrens risk is about 10 times higher than the adults risk. The population in the slum/poor areas have higher risk than the middle class. For the children the average risk is 109 times higher in Paltan and 19 times higher in Razarbag. For adults the average risk is 145 times higher in Razarbag and higher in Paltan, where the adult risk was undetectable for the middle class.

Table 11: Estimated daily average and 95-%tile health risk at the time of the lowest modelled dilutions and at the time of the highest flood levels at the three model locations for the four selected exposuregroups. All 5-%iles and medians were 0.

Location and Dilution factor	Estimated cholera risk during the modelled at of the highest modelled concentrations			
	Children		Adults	
	Average	95-%ile	Average	95-%ile
Razarbag				
Slum/Poor	$2.2 \cdot 10^{-3}$	0	$2.1 \cdot 10^{-4}$	0
MiddleClass	$1.2 \cdot 10^{-4}$	0	$1.5 \cdot 10^{-6}$	0
Paltan				
Slum/Poor	$5,6 \cdot 10^{-3}$	0,059	$5.5 \cdot 10^{-4}$	0
MiddleClass	$5.2 \cdot 10^{-5}$	0	0	0
East of BSMK-Stadium				
Slum/Poor	$1.1 \cdot 10^{-3}$	0	$1.1 \cdot 10^{-4}$	0
**MiddleClass*	*$2.6 \cdot 10^{-4}$*	*0*	*$3.1 \cdot 10^{-6}$*	*0*
*No middleclass in this area				

5.9 Discussion

In this work we have estimated the average risk of cholera caused by contact with flood water during the 2004 flood event. The estimation is based on a calculation of the dilution of drainage/sewage water in three locations in Dhaka. The risks were estimated to be in the range between below “detection limit” of the MonteCarlo simulation and $5,6 \cdot 10^{-3}$. Typical values were 10^{-3} for children and 10^{-4} for adults in poor/slum areas, and 10^{-5} for children and 10^{-6} for adults in middle class areas. The results are well in accordance with the overall incidence of severe cholera in Dhaka City, which in 2010 was estimated to be approximately 280 pr. 100.000 (icddr,b 2011). However, direct comparison between the estimated risks and the estimated incidence would require an analysis of the population distribution and risk assessment in all the flooded areas. An annual incidence of culture-positive cholera cases in cholera endemic has been reported for slum areas in Kolkata, India and Jarkarta, Indonesia, to be 7.0/1000 and 2.0/1000 respectively for the < 5 years and 1.2/1000 and 0.27/1000 respectivly for ≥ 5 years. Hence, our risk estimates seems to be in a realistic range.

However, a number of factors influence the estimation of the risk level. The dose response relation used was based on experiments where *V. cholerae* O1 El Tor Inaba was administered to healthy adult volunteers in North America with 2 g of $NaHCO_2$. $NaHCO_2$ increases infectivity and pathogenicity. However, Levine and co-workers (Levine et al., 1981) note that dose-response relations were similar when acid-neutralizing solutions or with a standard meal of fish, rice, custard and skim milk were used. For comparison, the classical *V. cholera* useually appears less infective and requires higher doses, i.e. N_{50} in the 10^3 - 10^9 range (Hass et al 1999, CAMRA 2014). In addition, having had cholera reduces the risk of subsequently becoming ill both for children under 5 and older persons. In an endemic setting as Dhaka, generally a higher immunity can be expected than among the volunteers on which the D/R data are based on. The dose-response model used may therefore overestimate the risk of illness.

In our study, we detected *V. cholerae* O1 El Tor Ogawa, whereas the dose response relation was determined for *V. cholerae* O1 El Tor Inaba, however the attack rates of Inaba and Ogawa biotypes seem not to be significantly different.

The calculated risks are based on 3 samples out of 21 with concentrations at the limit of detection of the method. A sensitivity analysis showed close to linearity between concentration and risk at the used concentration. Error in the estimation of the concentration will therefore influence the risk estimate. A more thorough investigation of the environmental concentrations will reduce the uncertainty related to the concentration and improve the risk estimations.

Our risk model indicates that direct contact to drainage and flood water may be a significant route of cholera transmission particularly in poor/slum areas. However we cannot estimate the contribution of exposure to flood water to the total cholera disease burden. Other microbial risk studies have also identified the environmental exposure as the most important route of transmission in slum areas. Labite et al., (2010) analysed the burden of waterborne (non-cholera) infectious disease in a slum area in Accra, Ghana, and found that open drains and recreational activities accounted for 90% of the burden of disease, where as ingestion of flood water (1 ml/year) accounted for 2% of the burden of disease, and the drinking water related disease burden accounted for 6% of the disease burden. Similarly, a study from Bwaise III, an urban slum in Kampala, Uganda, found that open drainage canals and grey water in tertiary drains accounted for 63% of the disease burden, whereas the drinking water related exposure accounted for 30% of the disease burden. Because *V. cholera* is a natural occurring bacterium, the environmental compartment may be even more important for the transmission than is the case for non-naturally occurring pathogens.

The relation between the estimated risks associated with the different exposure groups depends on the authors' choice of the exposure models. We estimated the child/adult relation of cholera risk in slum areas to be 10. It is well known that the children of age below 5 bear the highest burden of cholera. In Kolkata and Jakarta the child-adult cholera incidence ratios are 5.9 and 7.4 respectively, not significantly different from our results. Exposure via drinking water is probably more or less the same for children and adults, since they can be expected to use the same source of water, and therefore not a plausible explanation of the differences between adults and children. Children are in closer contact to the environmental sources than adults because they are playing, running, swimming etc. Environmental exposure is therefore a more likely explanation to the differences between adults and children. However, a lower adult cholera risk is not only caused by lower ingested doses. Having had cholera reduces the risk of subsequently becoming ill both for children under 5 and older persons (Ali et al. 2012). In an endemic setting as Dhaka, generally a higher immunity can be expected than among adults. Our model does not take immunity into account.

We also see large differences between the slum/poor population and the middle class in Paltan and Razarbag which both are mixed population areas. For children the average cholera risk was 19 to 109 times higher in the poor/slum areas compared to the middle class and for adults the average risk was > 140 times higher. Diarrheal infections are known to be related to socio-economic factors. Of diarrheal patients from the poor Mirpur area in Dhaka (2008 – 2010) 89% lived in low income housing and only 8% in independent houses or high income residential areas and Columbara 2013 found a 50% higher cholera risk for children below 5 living in slum in Dhaka.

All in all, the methodology developed seems very promising in relating urban flooding with health risks to a population. A more elaborate description of the Dhaka case study is found in a peer reviewed paper, which has been accepted pending minor revisions at the Journal of Flood Risk Management (Mark et al, 2014).

6 Risk characterization

Having considered the first three steps in the health impact assessment, the final step is to characterise the risk. In the CORFU project, the decision has been made to characterise the risk in quantitative terms, using a measure known as the Disability Adjusted Life Year (DALY).

The DALY has been adopted by the World Health Organisation as a metric to assess the burden of diseases, injuries and risk factors on human populations (Murray & Acharya 1997). The DALY is described as combining the "time lived with a disability and the time lost due to premature mortality”. Years lost from premature mortality are estimated with respect to a standard expectation of life at each age. Years lived with disability are translated into an equivalent time loss by using a set of weights which reflect reduction in functional capacity, with higher weights corresponding to a greater reduction (Anand & Hanson 1997). DALYs have been applied in studies such as Prüss A et al (2002), which estimated the disease burden from water, sanitation, and hygiene to be 5.7% of the total disease burden (in DALYs) occurring worldwide, taking into account such diseases as diarroea and schistosomiasis.

The DALY has been used within the UK to assess the health risk from flooding (Fewtrell et al., 2008). This study considered the health impacts of pluvial flooding in the UK. This study categorised health impacts into three groups:

- Mortality and injuries
- Water-borne infections
- Other relevant flood-related diseases
- Mental health impacts

The study demonstrated that, in the UK case study, the greatest impacts on human health were related to mental health problems, something also noted in the review by Ahern et al (2005). However, this may not be the case in developing countries where the risk of disease outbreak is known to be greater.

In order to use DALYs in the health impact assessment of the CORFU project, several informed assumptions will have to be made. For each illness or disease, the following data will be required:

- How long will the illness last?
- If the illness leads to death, what is the life expectancy of the individual who died?
- What is the disability weighting that should be applied to each disease?

For the disability weighting, the first step that should be taken is to use the official data from the WHO Global Burden of Disease tables. In practice, it might be that different illnesses should have different weightings, depending on the vulnerability of the individual. However, it is unlikely that such data will become available in the CORFU project. Data on the life expectancy of individuals in different cities can be obtained from local demographic data sources.

7 Conclusions

This short report has presented a broad outline of the health impacts model that has been applied in the CORFU project. There are a number of assumptions that must be taken, particularly in regard to how the model can be applied in quantitative terms for other pathogens than Cholera. The application of the new model, developed in CORFU to the case study in Dhaka, demonstrates this new health risk model is very promising in establishing a systematic approach for linking urban flooding with health risk management

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