

## Hydroinformatics in multi-colours—part red: urban flood and disaster management

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### ABSTRACT

Hydroinformatics found its origin in the advancement of computational hydraulics in the early 1990s but has expanded considerably, both in scope and in application areas. It is now not only being applied in the fields of hydraulics and hydrology (often indicated by the colour blue), but also in environmental science and technology (green) as well as in knowledge systems and knowledge management (yellow). This paper focuses on urban (red) applications of hydroinformatics, taking urban flood and disaster management as an example. It is part of a sequence of papers, each focusing on a particular field (colour) of hydroinformatics, which together constitute a multi-coloured rainbow of application areas that hydroinformatics has expanded into over the past two decades or so. The combined papers on “Hydroinformatics in multi-colours” were presented as the opening keynote of the Workshop on Advances in Hydroinformatics held in Niagara Falls, in June 2007. In this paper—part red of the sequence—the role of *urban* hydroinformatics in assessing effects of climate change on urban flooding and health risk is addressed in relation to the UN Millennium Development Goals and illustrated on a case study of Dhaka, Bangladesh.

**Key words** | disaster management, flood damage assessment, urban hydroinformatics

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### INTRODUCTION

Urban flooding is a prominent issue, not only at a local scale but even more so at the global level. As of 2008, more than half the world's population is living in urban conglomerations, many of which are situated at locations where large river systems meet the ocean. Hence these megacities in delta areas are quite naturally exposed to flood events coming from either direction: inland or ocean (Talukdar 2006). Due to the effects of climate change, these delta cities around the world become even more vulnerable to disasters, especially in developing countries. Since the possibility of the occurrence of floods cannot be ignored or denied, the primary focus should be on identifying probable measures to develop disaster management plans and programmes, as outlined in the United Nations Millennium Development Goals (MDGs). However, there is a continuous need to conduct in-depth research on all issues involved in disaster

management, in order to deal with these problems effectively. It is necessary not only to analyze and apply the latest scientific tools such as data acquisition and management, simulation modelling, data assimilation and improved forecasting capabilities, but also to look into these issues in an integrated manner and to develop disaster management scenarios that can cope with extreme situations. Clearly, effects of climate change and their implications for the MDGs deserve adequate attention both in scientific research and in developing appropriate technologies for early warning and disaster prevention. This is where urban and environmental hydroinformatics can greatly contribute.

The application of hydroinformatics technologies in urban water systems (a.k.a. urban hydroinformatics) has emerged as an important concept for several reasons. First, there is a growing need to manage urban water cycle on a

global basis. Second, a range of alternative technologies to process different aspects of the urban water cycle are becoming available. Third, advances in hydroinformatics have enabled to model different phases of the entire cycle locally and globally and to optimise their functioning. In particular, advances in urban hydroinformatics have made significant impacts on the development of new strategies for urban flood management. Since the safe and reliable models of urban drainage systems for operation and management are of increasing importance in both developed and developing countries, and since the systems are becoming more and more complex, there is a growing need to treat them in an integrated manner for which the support of hydroinformatics tools is invaluable.

The effects of urban flooding can be enormous and create not only physical damage, but also affect water quality and the environment and hence have a major impact on health and hygiene (Butler & Davies 2004). Flooding in urban areas often causes huge economic damage as most of the structural developments and activities take place in cities. It is common knowledge that the poor tend to suffer most from floods. In addition to human and structural damage, flooding often creates non-point source pollution when toxic substances, sediment, nutrients, pathogens and garbage are washed away into the water bodies, deteriorating the water quality (USEPA 1994). Inappropriately maintained septic tanks can overflow in the case of flooding and contaminate the receiving water bodies as well as the water supply systems. Drinking water often becomes unsuitable for drinking and other uses and poses huge health risks. Stagnant water provides fertile conditions for water-borne diseases as well as for insect-borne diseases such as malaria and dengue fever. In a case study on the effect of urban flooding for the city of Dhaka, Ahmed (2008) carried out an analysis to identify risks, damages and impacts on the interrelated physical, social and environmental factors. Some aspects are presented here.

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## EFFECTS OF CLIMATE CHANGE ON FLOODING AND HEALTH RISK

The report from the Intergovernmental Panel on Climate Change IPCC (Cruz *et al.* 2007) summarizes that, by the end

of the 21st century, the projected probability of extreme warm seasons may rise above 90% in many tropical areas. Recent studies with improved global models, ranging in resolution from about 100 to 20 km, suggest future changes in both frequency and intensity of future tropical cyclones (typhoons and hurricanes). The report on climate change shows that precipitation generally increases in the tropics and decreases in the subtropics. Moreover, there is likely to be an increase in rainfall intensity, even if the wind velocities in storms do not change. In particular, over the Northern Hemisphere, an increase in the likelihood of very wet winters is projected. Similar results apply for summer precipitation, with implications for more pronounced flooding in the Asian monsoon region and other tropical areas. Projected changes in surface air temperature and precipitation for sub-regions of Asia under highest and lowest future emission trajectory for the 2020s, 2050s and 2080s are provided in the report by Cruz *et al.* (2007).

The increased risk of floods in a number of major river basins in a warmer future climate will lead to an increase in river discharge with an increased risk of future intense storm-related precipitation events and—most likely—flooding. Some of these changes seem to be extensions of trends already underway. The climate change scenarios predicted by the IPCC identify tropical regions as the most vulnerable areas due to increased probabilities of the occurrence of disasters. The IPCC expects an increase in frequency of infectious disease epidemics following floods and storms. Flood-induced health hazards require detailed studies on how to reduce the impacts on vulnerable areas and take proper measures.

Global warming would cause an abrupt rise in water quantity as a result of snow or glacier melting that could lead to increased flooding. Increased rainfall intensity, particularly during the summer monsoon, is likely to affect flood-prone areas in temperate and tropical regions. Countries in temperate and tropical Asia will be subject to increased exposure to extreme events, including forest deterioration and increased fire risk, as well as severe vector-borne diseases. The frequency of the occurrence of intense rainfall events has already occurred in many parts of Asia, causing severe floods and landslides that often make the news.

## DISASTER MANAGEMENT AND THE MILLENNIUM DEVELOPMENT GOALS

Natural disasters exert enormous toll on the development of a country. In doing so, they pose a significant threat to prospects for achieving the Millennium Development Goals which contribute to a reduction of human vulnerability to natural hazards. According to UN reports, about 196 million people in more than 90 countries were found to be exposed on average every year to catastrophic flooding. Some 170,010 deaths were associated with floods worldwide between 1980–2000. The Millennium Development Goals (MDGs) are set out as a response to the world's main development challenges in the Millennium Declaration which was adopted by 189 nations and signed by 147 heads of state and governments during the UN Millennium Summit in September 2000. The goals set forth to be achieved by 2015 include a number of aspects, among which are (i) eradication of extreme poverty and hunger; (ii) combating HIV/AIDS, malaria and other diseases; (iii) ensuring environmental sustainability; and more. The "Road map towards the implementation of the United Nations Millennium Declaration" (UN-GA 2001) outlines potential strategies for action that are designed to meet these goals. These strategies are linked to the International Strategy for Disaster Reduction (ISDR) plan with the aim "to intensify collective efforts to reduce the number and effects of natural notably and man-made disasters".

Today, disaster reduction is a key component of United Nations Development Programme efforts in crisis prevention and recovery. The main emphasis is on capacity building in reducing disaster risk in those countries where such disasters are taking the largest toll. Damages and deaths caused by recent flooding in many parts of the world drive the need for better stormwater management approaches directed to minimising hazard risks due to urban flooding, even while addressing different climatic conditions. These considerations apply as much to major conurbations in developing countries as they do in developed countries. In this respect, disaster management in urban areas is of major concern in helping to meet the Millennium Development Goals (MDGs), especially in providing an improved urban environment affecting Goal 1: Eradicating extreme poverty and hunger, Goal 3: Promote

gender equality and empower women, Goal 4: Reducing child mortality, Goal 6: Combat HIV/AIDS, malaria and other diseases, Goal 7: Ensure environmental sustainability (especially targets 9, 10 and 11) and Goal 8: Develop a global partnership for development. The interaction of economic development with disaster risk has direct consequences for the meeting of Goals 1, 6 and 7. The interaction of social development and disaster risk has direct consequences for the meeting of Goals 3 and 8. In addition to the loss of physical assets during flood-related disasters, there are many examples of such disaster events destroying the gains of health, sanitation, drinking water, housing and education sectors that underpin social development. The exclusion of women from local decision-making circles in some countries has led to women and girls being unwilling to use hurricane and flood protection shelters. The importance of extending educational opportunities to girls and women is noted in the MDGs and has been shown to improve the delivery of disaster risk reduction. Such an educated population also responds better to warnings and it can partner with experts to design ways of protecting urban neighborhoods. The most far-reaching opportunities for disaster risk reduction within MDGs relate to Goal 8: Developing a global partnership for development. In meeting this goal there is a need for two-way relationship between disaster risk and development. Furthermore, the MDGs contain cross-cutting themes in development and disaster risk policy, each tied to specific targets and indicators for progress. They require international collaboration to be met. The risk to development stemming from natural disaster is recognized also in Millennium Declaration in Section IV, entitled: "Protecting Our Common Future". Within this section is stated the objective: "to intensify our collective efforts to reduce number and effects of natural and mad-made disasters".

The field of hydroinformatics is contributing to this strategy in a number of ways, e.g. by (i) vulnerability mapping, (ii) developing early warning systems, (iii) providing technology transfer and training, (iv) supporting interdisciplinary scientific research on the causes of natural disasters and (v) encouraging governments to incorporate disaster risk reduction into their national planning processes.

The World Conference on Disaster Reduction, held in early 2005, adopted the Hyogo Framework for Action

2005–2015, which identifies strategic objectives and priority areas to reduce disaster risk over the next 10 years. The strategic goals include incorporation of risk reduction approaches into the design and implementation of emergency preparedness, response and recovery programmes for affected communities. The overall objective is to promote “an effective integration of disaster risk considerations into sustainable development policies, planning and programming at all levels” (UN-ISDR 2002; WHO 2003). Clearly, the fields of urban and environmental hydroinformatics have a lot to contribute to achieving these goals.

### COMPUTATIONAL MODELS FOR URBAN DRAINAGE, FLASH FLOOD SIMULATION AND WATER QUALITY ASSESSMENT

Where flood flows are confined to well-defined conduits, a robust 1D model can usually be instantiated, and used to generate results safe for decision-making. However, the flows generated in urban flood disasters are normally highly complex because the morphology of the urban surface is eminently artificial, with its highly irregular geometry, and is often contrary to natural flow paths. Modelling flows in such complex geometrical situations is difficult. Small geometric ‘discontinuities’ such as road or pavement curbs can play a significant role in diverting the shallow flows that are generated along roads, through fences and around buildings. Head losses due to flow over or round such structures are difficult to accommodate. Frequently the urban flows are super-critical whereas many of the available modelling products, although they simulate flows that are in reality super-critical, in practice they use modified sub-critical flow algorithms. The use of finite difference methods in conjunction with the reduced momentum equation together with the boundary condition structure inherent to subcritical flow conditions is a standard approach used for numerical simulation of all flow regimes (i.e., subcritical, supercritical and transcritical) in most of the commercial packages. Due to incomplete equations and inadequate boundary conditions used to model supercritical and transcritical flows, such an approach may introduce unrealistic backwater effects, non-amplifying oscillations and other computational instabilities (see, for example,

Djordjevic *et al.* 2004). There is also the issue of treating the transition from channel flows to over-ground shallow depth flows. This necessitates the coupling of simulations using 1D and 2D modelling systems; see, for example, Hsu *et al.* (2000), Chen *et al.* (2006), Djordjevic *et al.* (2005), Vojinovic *et al.* (2006) and Vojinovic & Tutulic (2009).

Following the floods of 2002 in Germany and the Czech Republic, a case study for the Elbe River (Abazi 2005) looked at different modelling approaches used in flood simulation. Two different approaches were considered using the Delft Software Systems. A coupled Sobek1D2D approach was compared with the full Delft2D model. In the first approach the flow in a river is modelled as a one-dimensional flow and the flow in the floodplain is modelled as a two-dimensional horizontal flow. In the second approach the river and floodplain flows are both modelled as two-dimensional horizontal flows using a boundary-fitted 2D computational grid.

Bashar (2005) developed a coupled 1D2D hydraulic model in SOBEK linking the main branch of the Kushiyara River in Bangladesh to its tributaries Manu and Dhalai. The central role in this model’s development is its application to flood flows on the Manu–Dhalai basin and its floodplains. A number of model simulations were evaluated which showed the applicability of the coupled 1D2D model including features such as dike breach simulation, flood mapping, etc. Kaushik (2006) carried out a comparative study for 1D and 2D urban flood modelling.

The urban flooding problem of Dhaka has been studied by, for example, Kamal & Rabbi (1998), Apirumanekul (2001) and Alam (2003). The Institute of Water Modelling (IWM), previously known as the Surface Water Modelling Centre (SWMC), conducted a pilot study on storm water drainage modelling for Dhaka city in 1996. They developed a model using MOUSE to test the applicability of urban drainage modelling for analyzing the condition of Dhaka city. Due to the lack of detailed data to calibrate the model the simulation results were considered only indicative and further research to improve the model was suggested.

For the central part of Dhaka, the capital of Bangladesh, severe water logging problems are recurring every time due to even moderate rainstorms. By combining the urban drainage modelling software MOUSE (DHI) with a Geographic Information System (GIS), model-based water

logging maps (flooding depth and inundation extent maps) were produced that showed close matches to the real situation for September and October 1996 rainfall events. The study results suggest that a meaningful solution for urban drainage problems can be obtained by coupling an urban drainage model to flood depth mapping. Also, by coupling the hydrodynamic inundation model to a water quality module for pollutant transport, a risk assessment can be carried out on the epidemic spreading of diseases, as outlined hereafter.

## HYDRODYNAMIC FLOW MODELLING IN URBAN AREAS

In order to explore the rainfall-generated runoff inside urban drainage systems and the causes of flooding under pressurized flow conditions, a hydrodynamic flow model can prove quite valuable. Based on well-known formulations for hydrodynamic pipe flow, a range of simulations can easily be carried out to see how different rainfall events influence the depth and extent of flooding. In urban areas, a 1D system for underground pipe flow can be linked to a 2D model for free surface street flow, in a very similar way as mentioned above for river systems and their floodplains. All pipes, box culverts, manholes, pumps, sluice gates and outlets need to be coupled in the proper way, as schematically represented by Figure 1. Also, the proper slopes of the pipe sections and gradients in the street levels need to be accounted for in great detail, since gravity-driven flows are very sensitive to even small changes (of the order of  $10^{-4}$ ) in slopes.

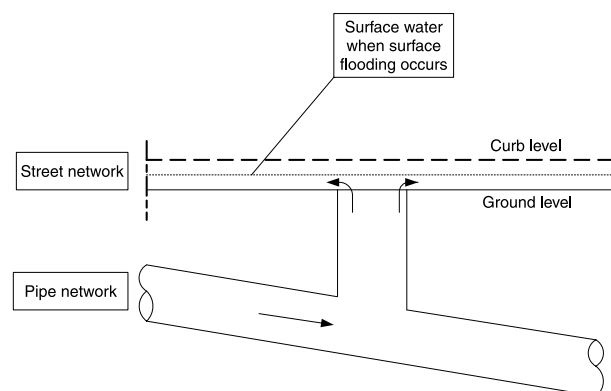


Figure 1 | Principle of simulating urban flooding (source: MOUSE manual).

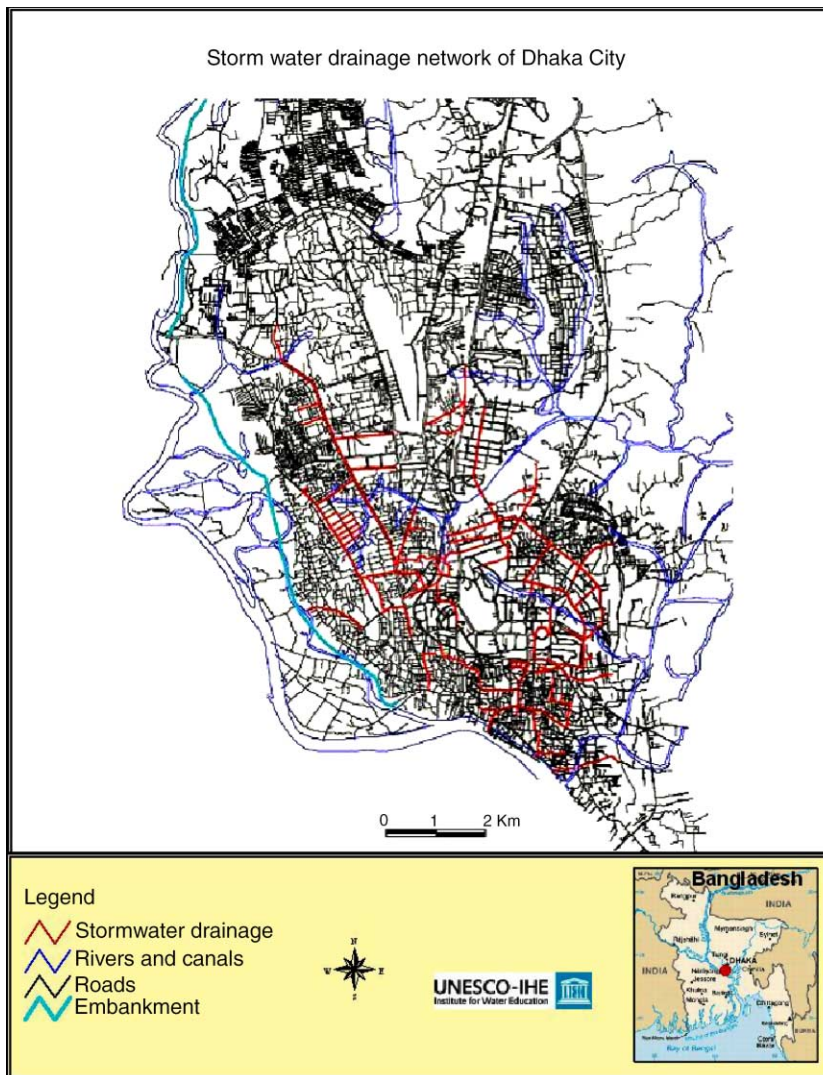
In numerical simulation modelling, nodes are placed in the streets to act as storage basins connected with manholes through weirs. The pipes are connected with the manholes whereas the streets are linked through the catch pits. Rainfall enters the sewer lines through the catch pits, which act as a temporary storage area before finally discharging into the manhole. The basin and the connected nodes have to be levelled in such a way as to allow inundation to occur in a proper (physical) way. Figure 1 shows the water level extending onto the surface area after the pipe network has reached its capacity.

As an example of the state-of-the-art in urban flood modelling, reference is made to a recent study described by Ahmed (2008) and Ahmed *et al.* (2009). Building on the urban flooding studies for Dhaka (Kamal & Rabbi 1998; Apirumanekul 2001; Alam 2003), a coupled underground pipe–overground street network schematization was developed to study storm water drainage effects for the central part of Dhaka city. By coupling a Storm Water Drainage Model with a Flood Depth Mapping Module, a study was carried out on problems related to severe water logging which occur in cases of moderate rainstorms. The MOUSE urban drainage modelling software package was used in conjunction with a conventional Geographic Information System (GIS). The model was calibrated based on previous recorded storm events and showed a close match with other observed flood events (Akhtar 2006).

The layout of the Dhaka storm water drainages system, including rivers and canals as well as roads and embankments, is presented in Figure 2. The complexity of urban storm water drainage configurations is easily observed, in particular when it is recognized that the system contains both underground pipe systems as well as overground street plans, connected through manholes and weirs that act based on threshold values in a very nonlinear way. This requires considerable effort when setting up and calibrating mathematical models. Once constructed and validated, a range of scenario's can be investigated corresponding to different rainfall–intensity–duration curves, as displayed for Dhaka city in Figure 3 (JICA 1987).

A typical longitudinal profile of the 1996 flooding scenario for Shantinagar Road in the centre of town, as presented in Figure 4, shows to what extent the water level can come up on the road surface. The results clearly prove





**Figure 2** | Layout of Dhaka storm water drainage and river/canal system (source: Ahmed 2008).

that a meaningful solution for urban drainage problems can be obtained with better confidence by using the combined urban drainage model and flood depth mapping.

## TRANSPORT OF POLLUTANTS IN URBAN SYSTEMS

Water quality modelling involves the prediction of spreading of pollutants using mathematical simulation techniques. A typical water quality model consists of a computational kernel representing physical mechanisms that determine fate and transport of pollutants in a water body. The purpose for water quality modelling in the Dhaka case study

was to analyze the water quality conditions during flooding. The model showed how pollutant concentrations propagate with increasing flood runoff from within the catchment area, thereby affecting the water quality during different flooding events.

Water quality processes in sewer systems are conventionally modelled following a 1D pipe flow module connected to a 1D or 2D street flow module. Some systems have several modules for the simulation of sediment transport processes and water quality in sewer systems. Conventionally, the transport of pollutants within the sewer network is based on the advection–dispersion equation where the substance is considered to be conservative or subject to a first-order decay

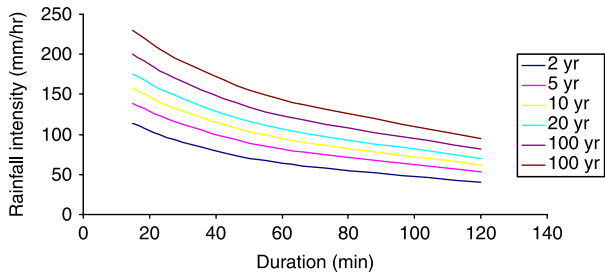


Figure 3 | Rainfall-intensity-duration (I-D-F) curve for Dhaka city (source: JICA 1987).

and Fick’s diffusion law can be applied, i.e. the dispersive transport is proportional to the gradient of the concentration. This leads to the well-known advection dispersion equation which can either be applied in 1D, 2D or 3D.

It is generally assumed that storm water runoff will contain low levels of pollutants. However, the fact is that sometimes the pollutant load is much higher than the effluent from secondary sewage plants (see for example, Rahman & Chowdhury 1999). Urban storm water pollutant loads can be assessed using BOD, COD, coliform bacteria, nitrate, phosphate and heavy metals as indicators. In the Dhaka case study the parameters selected for preliminary assessment of water quality were taken from Noble *et al.*

(2003) to be: (1) BOD (good indicator of pollutants of biological nature), (2) total coliform (determining the presence of pathogens) and (3) faecal coliform (assessing health risks from waterborne diseases).

The water quality data for Dhaka city collected by IFCDR (Khan & Chowdhury 1998) during the monsoon of 1996 was used for setting up the water quality model in the Dhaka case study area (Kunii *et al.* 2002; Ahmed 2008). The quality of the storm water was assessed for some important locations within the city. Three locations were selected as the sampling sites for assessing storm water quality, and key water quality indicators were taken to be pH, total solids, nitrate, nitrite, BOD, DO and TDS for both commercial and residential type land use.

### WATER QUALITY SCENARIO DEVELOPMENT

After calibrating the water quality model for BOD, total coliform and faecal coliform, a number of scenarios were developed in the Dhaka case study. The evolution of water quality conditions was simulated for flooding events of increasing return periods, as introduced above.

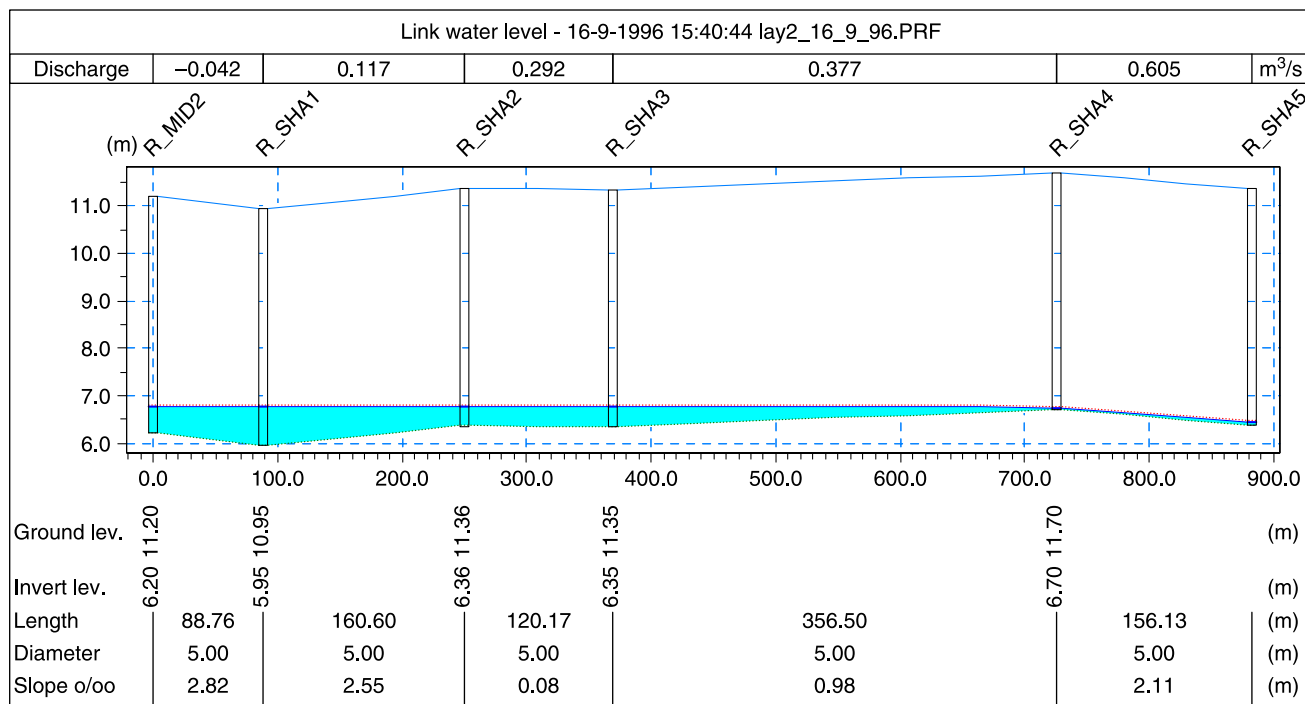
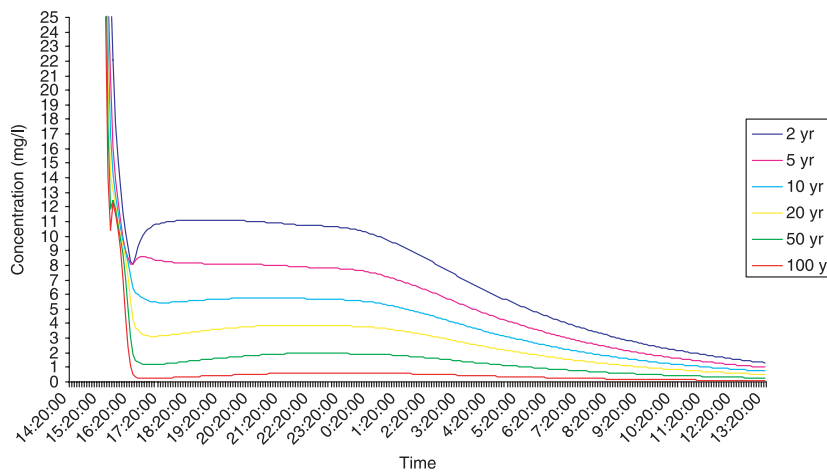


Figure 4 | Longitudinal profile of flood inundation along Shantinagar Road (source: Ahmed 2008).



**Figure 5** | Pollutographs of BOD<sub>5</sub> at Shantinagar Crossing for flooding events of different return periods (source: Ahmed 2008).

Polutographs were constructed for each of the above-mentioned indicators. A typical result of polutographs for BOD<sub>5</sub> is presented in Figure 5.

The simulation results show that initial levels of BOD<sub>5</sub> are all extremely high and well above any acceptable standard. But within a span of a few hours the level is seen to drop significantly. The BOD level decreases with higher amounts of rainfall, which is due to the fact that pollutant concentrations are based on the generated hydrodynamic flow volumes, which are larger in the case of more extreme events.

It is interesting to see that even after 1 day the concentration of BOD during flooding reaches values of about 0.5 mg/l, which is still a significant impact on the environment (Khan & Chowdhury 1998; Nishat *et al.* 2000). Total coliform and faecal coliform concentrations were also simulated in order to assess the bacteriological water quality, as these are indicators of potential waterborne diseases. The graphs of total coliform and faecal coliform show a similar trend as the BOD curves, and the values are seen to become very high and well within the range of raw wastewater values. Such high counts of bacteria could be expected in this case study, since the area where the sample was taken is a residential area which is known to generate more pollution than commercial areas (Khan & Chowdhury 1998). The model results clearly demonstrate that flood waters can have high concentrations of both TC and FC, even similar to normal wastewater levels, and therefore pose a huge health risk, as elaborated later.

## CLASSIFICATION OF FLOOD DAMAGE

Urban flooding invariably leads to damages. The extent of these damages depends on the severity of the flooding event as well as the preparedness and responsiveness of those affected. Damages can be categorized into *tangible* and *intangible* damages (see Figure 6) which is largely based on monetary classification. Damages can range from the destruction of household and physical infrastructure, to medical or psychological damage or even loss of lives in extreme cases. Tangible damages can be measured in monetary terms, such as the damage to the built environment, although such an approach relies heavily on the damage assessment procedure. In contrast, intangible damage refers to loss of, for example, cultural heritage or archaeological sites that often cannot easily be converted into monetary values.

Tangible damages can further be subdivided into *direct* or *indirect* cost (Genovese 2006). Direct costs refer to physical damage to capital assets and inventories, valued at their standard replacement costs. Indirect costs refer to effects such as the production losses of factories and loss of income of citizens. Other indirect losses are business interruption, environmental damage, and costs of cleaning and evacuation.

A detailed description of the classification of damages can be found in Vrouwenvelder & Vrijling (1996) and Jonkman (2007). Losses due to business interruption can be very significant, for example in the case of long-term closure



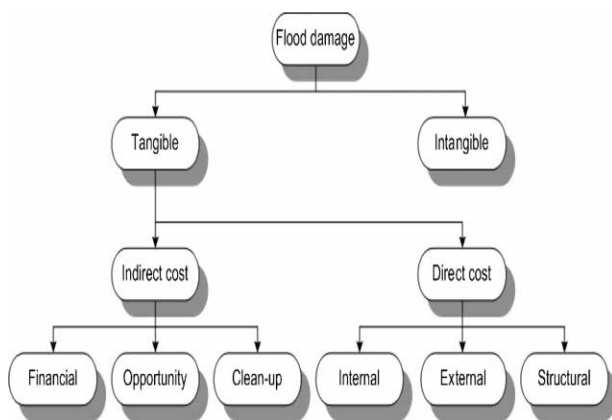


Figure 6 | Classification of damages (source: QNRM 2002).

of a national airport. Van der Veen *et al.* (2003) proposed a method for the assessment of indirect economic damage. The methods for the estimation of intangible damage are less well developed. Recent research has focused on different types of intangible flood damage in the Netherlands, such as environmental damage (Stuyt *et al.* 2007). Prior to that, Penning-Rowsell & Chatterton (1977) introduced a method for flood loss assessment as a nationally applicable standard dataset for various depth and damages for the residential sector in the UK, while Parker *et al.* (1987) constructed depth-damage curves for industrial enterprises. Vojinovic *et al.* (2008) presented the hydroinformatics framework for estimation of urban flood damages where the use of hydrodynamic models, GIS and remotely sensed data is combined within a single platform.

## APPLICATION OF GIS FOR DAMAGE ASSESSMENT

Geographical Information Systems (GIS) are widely used in urban hydroinformatics and prove to be a very effective tool in flood risk damage assessment. GIS-based flood damage assessment is relatively new but has shown to be much more powerful than conventional methods for estimating damages, due to its capability of dealing with spatial heterogeneity—provided detailed data are available. Ediriweera (2007) developed a GIS-based framework to produce hazard maps visualizing both tangible and intangible flood damages. GIS can easily demonstrate the implications of flood mitigation measures on traffic

planning and developing evacuation strategies. A damage assessment methodology as proposed by Genovesi (2006) to evaluate the damage costs of direct losses in residential areas was applied to the study area around the city of Prague, following the dramatic flooding in August 2002.

In the Dhaka case study the estimation of tangible damages was carried out within a GIS environment where locally developed depth-damage curves were applied to each and every property across the floodplain. In this way, damage assessment is greatly facilitated while the resulting flood damage maps prove extremely useful for visualizing potential effects of flooding and communicating scenario development with all stakeholders involved. The flood maps realised through GIS technology provide a clear view of the extent of the flood. In fact, hydroinformatics tools like GIS—in combination with dynamic visualization tools—are able to convey a very strong message to the policymakers about the extent and severity of different flood impacts and the effectiveness of possible countermeasures.

Indirect economic damage refers to the disruption of business and infrastructure, expenditure for temporary arrangements and market losses suffered, as well as social disruptions. Indirect flood damage costs may well exceed direct damages (EMA 2002), depending on the intensity and duration of the flood. Flooding events can negatively affect employment and income levels, especially for the poor. One way of assessing indirect losses is to multiply the number of working hours lost due to flood with the productivity rate, as an estimate of the total indirect loss (QNRM 2002). Indirect damages can be presented in similar GIS maps as for direct damage costs. In particular, for extreme events, the indirect damage costs may be considerable.

Damages to the environment and to human health (both physical and psychological) are often referred to as “intangible”. There is no commonly agreed method for assessing intangible damages because of the difficulty to properly identify, quantify and evaluate the losses incurred. It can be said that for intangible losses the best approach would be to apply either a direct survey method or follow a synthetic approach as outlined in EMA (2002). In the Dhaka case study a synthetic approach was followed to assess the intangible losses.

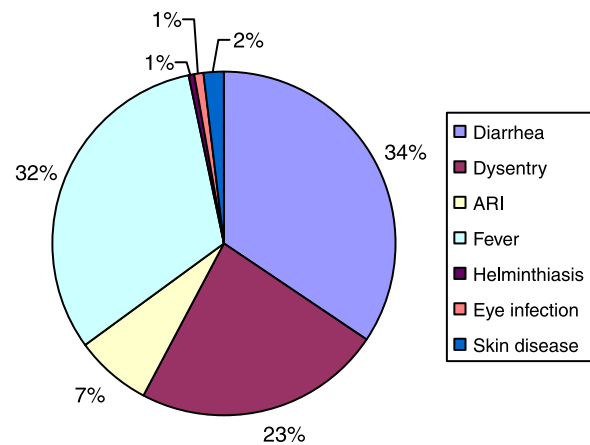
## HUMAN HEALTH ISSUES AND THE SPREADING OF DISEASES

Flooding often creates water pollution, affecting the inundated environment, thus leading to sanitation and health problems. So, the effect of flooding on the environment and, more specifically, on the water quality has to be addressed together with the consequential impact on human health. Water quality modelling can be used here to assess flood consequences for the natural environment and human health.

Often during extreme rainfall events, organic substances, solids, metals, chemical wastes from industries, clinical waste and pesticides are carried via runoff over the land surfaces, streets, parks, etc., thereby causing the water to become polluted. In the Dhaka case study, the findings from water quality modelling show that there is a high level of BOD, as well as total and faecal coliform within the first few hours of rainfall. Studies by [Kay & Falconer \(2008\)](#) and [Yang \*et al.\* \(2008\)](#) and others have revealed extreme peaks in pathogen levels immediately after severe rainfall, with levels well exceeding allowable standards.

High concentrations of BOD indicate accumulation of organic pollutants from different sources such as submerged sewerage system, direct discharge of human excreta and other household solid wastes ([Rahman & Hossain 2002](#)). Solid wastes get mixed with flood water as the waste disposal system during flooding becomes inactive. Several studies found that the BOD, coliform, DO and turbidity level is relatively high in the lakes within Dhaka city due to discharge of wastewater.

Especially in stagnant water, flooded septic tanks and leach pits are breeding grounds for mosquitoes while faecal contaminated wet soils helps the growth of intestinal worms. Water quality modelling results in the Dhaka case study showed the extent of areas within the city that are highly susceptible to diseases. During the latest flooding event of 2007 in Bangladesh, 42% of all patients admitted to Dhaka's major hospital were reportedly from the urban population areas. The distribution of some of the diseases that affected the population in the Sabujbag thana area during the flooding of 1998 is presented in [Figure 7](#) as an example of the extent of diseases that can occur in a flood-affected area.

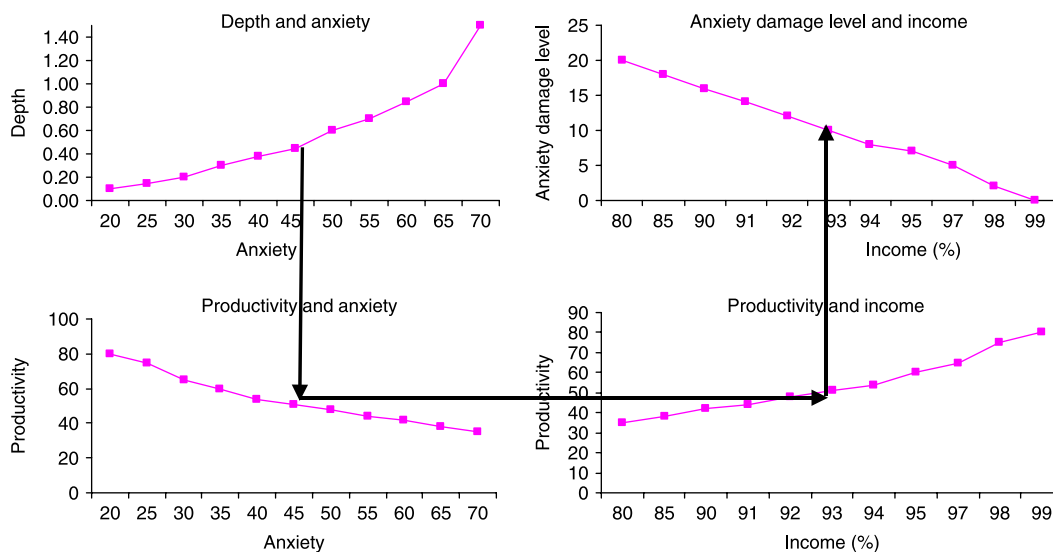


**Figure 7** | Disease profile for Sabujbagh thana during the flood of 1998 (source: BRAC Center, Dhaka).

The graph shows very clearly that most people were affected by diarrhoea followed by fever and helminthiasis. People also developed skin problems when they come in contact with sewage-mixed floodwater. There is clear evidence that morbidity is higher during and after flooding, compared with the non-flooding periods. Dengue is one of the fastest increasing and life-threatening vector borne diseases spread by mosquitoes during floods. Results for the Dhaka case study show that more than 10,000 people were infected and 144 died due to dengue in the month of August 2002.

## ASSESSMENT OF COMBINED DAMAGES

Floods deteriorate the quality of life of people by causing disruptions. Quality of life refers to the degree of well-being felt by an individual or group of people. Unlike standard of living, quality of life is not a tangible concept and therefore cannot be measured directly. Quality of life can be split into two components: (i) physical well-being and (ii) psychological well-being due to, for example, stress and anxiety. It was found from surveys that there is a nonlinear relationship between anxiety and flood depth. The anxiety level builds up as the flood depth increases. In Dhaka, people are used to flooding. Therefore, floods of smaller depth do not create too much anxiety. People get stressed and start to worry when the flood level goes beyond half a metre depth. However, even at 1.5 m flood depth, anxiety



**Figure 8** | Curves to estimate intangible indirect damages (source: Ahmed 2008).

levels do not reach the tolerance limit of 80%. Based on the anxiety level the productivity values can be determined. Productivity decreases as people get tense because of a flood. Consequently, productivity loss leads to loss of income as well.

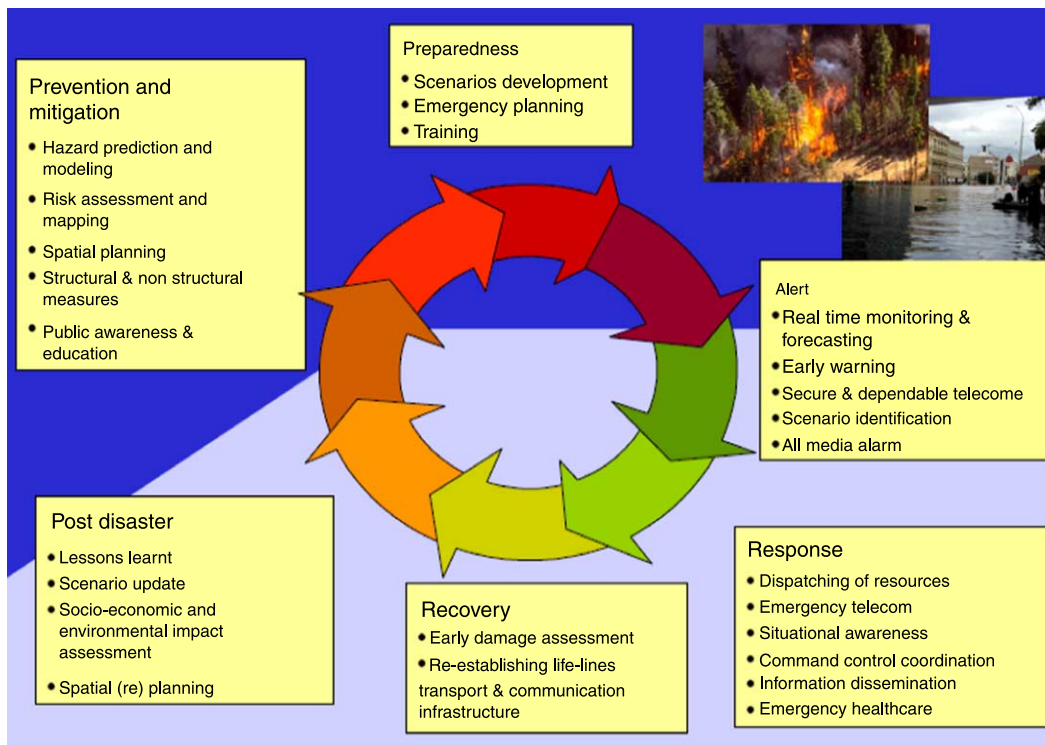
In the Dhaka case study, the depth of flooding and flood-affected areas were determined by applying hydrodynamic modelling in a GIS environment. In addition to the physical processes, a social survey of the people residing in the study area was carried out to assess how intangible losses in the form of anxiety and decreasing productivity and income levels could be evaluated. Intangible losses were not calculated in monetary terms as data about the number of the affected population residing in that region was unavailable. However, indirect intangible damages can be obtained following the procedure as presented in Figure 8.

## DISASTER MANAGEMENT AND EMERGENCY PLANNING

Emergency or disaster management is the preparation, support and reconstruction of society when natural or man-made disasters occur. This is not intended to be an intermittent sequence of events but an ongoing process by which individuals, groups and communities manage hazards in an effort to avoid or ameliorate the impact of disasters

resulting from the hazards (Price & Vojinovic 2008). The traditional approach of disaster management follows a cyclic approach of activities prior, during and after disaster events as outlined by Messer (2003). In the pre-emergency phase, the main emphasis is on reducing the vulnerability of communities to possible impacts of natural phenomena. Measures include risk-mapping, application of building codes and land zoning as well as structural measures such as the construction of dams against flooding. This phase comprises prevention, mitigation and preparedness. During a disaster event, the response mechanisms are activated and measures carried out in accordance with the prepared plans. This phase is usually relatively short, lasting of the order of days or weeks. Response measures taken immediately before and during the initial stages of the event can greatly minimize the effects of hazards created by any disaster. Such measures deal with saving life and protecting property and include search and rescue, provision of emergency food, shelter and medical assistance. The effectiveness of responding to disasters largely depends on the level of preparedness.

In the post-emergency phase recovery activities are carried out, assisting communities to return to a proper level of functioning. A recovery process usually takes much more time, in some cases up to (many) years. Typical activities in this phase include: restoration of essential services and installations, as well as long-term measures of



**Figure 9** | Disaster management cycle (source: adopted from <http://egy.org/files/IDRC>).

the reconstruction of buildings and infrastructure. The ‘Disaster Management Cycle’ as outlined in Figure 9 implies that disasters and their management are a continuum of inter-linked activities. The scope is to avoid natural disasters by reducing the adverse impact of natural hazards through proper implementation of effective prevention measures and continuous preparedness and awareness (UNDP 2004).

## NON-STRUCTURAL MEASURES AND FLOOD HAZARD MAPPING

Several studies (Green 1998; Faisal *et al.* 1999; Osti *et al.* 2008; Vojinovic & Teeffelen 2007) have stretched the need for both structural and non-structural measures to manage floods. The importance and need for non-structural measures is specially realized when structural measures fail to provide effective results in the face of flood disasters. Both structural and unstructural measures should be technically sound, environment friendly, socially accepted

and cost-effective in order to be part of the community-based planning and implementation (Osti *et al.* 2008). According to Green (1998), current trends in disaster management and planning practices follow a more balanced approach by combining both structural and non-structural measures. Flood Hazard Mapping as a tool for disaster management during the evacuation phase has been widely applied in countries like, for example, Japan. These maps can be prepared on the basis of food frequency, water depth, flow velocity, etc., obtained from numerical model simulations described above, using the latest GIS technologies to store and present the results in an easily understandable way. The positive effects of non-structural measures for flood strategy formulations are highlighted by Hansson *et al.* (2008), taking Vietnam as an example.

Environmental degradation can lead to disasters and have a major impact on human health and quality of life. The current disaster management approach in combination with an ICT-based framework (viz. environmental and urban hydroinformatics) can be very effective tools to help develop disaster management and emergency planning in

order to reduce risk. The Disaster Management Cycle used by the EU in hazard prevention policy research is presented in Figure 9.

In view of the recent trend in climate change, urban and spatial planning should consider adaptive management strategies, e.g. flood zones should be delineated based on the peak flood depth instead of the average flood depth. Modern-day flood risk management requires the use of latest technologies, notably GIS, remote sensing and web-based application. The emphasis nowadays is on accounting for uncertainty in decision-making. “Integrated flood risk management” and sharing knowledge across nations and communities will enhance the understanding and aid in achieving a common strategy in flood risk management (Begum *et al.* 2007).

## PUBLIC AWARENESS AND AGENCIES COORDINATION

Public awareness and participation in disaster prevention and management are crucial and should cover all phases of any disaster event. Lack of public awareness about their role and absence of public involvement in preparation and maintenance often create problems in disaster management. An awareness-building programme to educate all people about the purpose and function of flood protection and drainage infrastructure is worth the investment. The capacity of communities should be developed so that they can learn to take first-hand measures before, during and after flood events. Apart from implementation of a master plan, successful flood mitigation and storm water management requires proper coordination of all governmental organizations. A clear distinction of the tasks of each government agency and proper communication with the general public at large are urgently needed for flood disaster management. It should be apparent from the above that, precisely in this field, urban hydroinformatics has a lot to offer in master planning and flood mitigation management.

## CONCLUSIONS

The effects of urban flooding are manifold, including physical and structural damage, health issues, hygiene,

water quality and environment. Flooding in urban areas can create huge economic losses since most of the structural developments and human activities are located there. Sewage water gets mixed with flood water and contaminates receiving water bodies and water supply systems. Urban hydroinformatics is capable of making a valuable contribution to urban flood and disaster management by combining science, technologies and social considerations into a holistic coherent framework.

Present-day hydrodynamic modelling packages can simulate flows in urban drainage systems in conjunction with free surface street flows. Water quality modelling is capable of assessing pollutant transport in floods. Climate change scenarios are used to explore future trends. Both tangible and intangible damages due to flooding can be identified, and direct as well as indirect costs assessed using different approaches. Results are easily evaluated in a GIS environment. Human health issues are expressed in terms of Disability Adjusted Life Years (DALY) estimates indicating the extent of epidemic diseases caused by floods. An Anxiety–Productivity–Income relationship relates personal anxiety to the level of productivity and income loss in the case of flooding.

In order to demonstrate the issues involved in urban flood and disaster management, a case study carried out for the city of Dhaka in Bangladesh was used here, following Ahmed (2008) who identified potential flood damages and their impact on physical, social and environmental factors, leading to disaster management scenarios and planning options. Dhaka was selected as the case study since it is one of the fastest growing megacities in the world with a long history of flooding problems which continue to threaten residents’ life and livelihood.

Flood mitigation measures for cities like Dhaka can best be developed following an integrated approach to storm water drainage and pollution control. A synergy between structural and non-structural measures is required to obtain sustainable solutions that can effectively deal with flood events. Effective flood disaster management in megacities heavily relies on coordinated efforts of government organizations—including public participation—in the planning and implementation of disaster management policies and guidelines. In all these areas urban hydroinformatics can greatly contribute.



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