The development of a flood damage assessment tool for urban areas

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ABSTRACT

The Collaborative Research on Flood Resilience in Urban Areas (CORFU) project is funded by the European Commission to investigate the impact of flooding in cities and to develop strategies to enhance flood resilience. The project explores the impact of key drivers including urbanisation, socio-economic trends and climate change in eight European and Asian cities. The development of resilience strategies relies on a comprehensive assessment of flood impacts. These impacts can be categorised as tangible (those that can be measured in monetary terms) or intangible (such as health impacts that can be difficult to quantify.

Flood hazard information (depth, extent, velocity, etc.) for different scenarios, obtained from hydraulic models, along with data on land use or cover, building features, infrastructure, and demographics are applied to determine these impacts. The nature and scale of the damage, the availability of required information, and the characteristics of case studies are taken into account to develop a generic and flexible flood damage assessment model that can be broadly applied to European and Asian cities. In this paper, Dhaka city is adopted to demonstrate the direct tangible damage assessment tool.

KEYWORDS

Cities, flood modelling, GIS, impact assessment

1 INTRODUCTION

The Collaborative Research on Flood Resilience in Urban areas (CORFU) project is funded by the European Commission's Seventh Framework Programme to investigate the impact of flooding in urban areas and to develop strategies and measures to enhance flood resilience. The project explores the relevance and impact of key drivers including urbanisation, socio-economic trends and global climate change in eight European and Asian cities (Barcelona, Beijing, Dhaka, Hamburg, Incheon/Seoul, Mumbai, Nice and Taipei), with the emphasis on technology transfer, knowledge exchange and mutual learning. The development of flood resilience strategies relies on a comprehensive understanding and assessment of flood impacts. These impacts include damage to property and contents, as well as human health and environmental impacts. The project aims to develop tools that can be applied in different contexts and can assess these various types of flood damage.

Typically, flood hazard information, such as the depth of flooding, its extent, its duration, and the flow velocities, for various scenarios can be obtained from hydraulic modelling and used to assess the consequences of corresponding events. Data on land use or cover, building features, key infrastructure, and population demographics can also be used to determine the resulting flood impacts.

This paper focuses on the development of a tool that can be applied in cities to assess the impacts known as direct tangible damage (its precise meaning is explained in the following section). This tool is flexible and can incorporate the different data formats available in the case study cities, and works with hydraulic modelling results. The tool is developed using a commonly available GIS software package to allow its wide transmission and application.

In this paper, Dhaka city is used to demonstrate the direct tangible damage assessment tool in a densely developed megacity.

2 METHODS

2.1 Conceptual underpinning

There is an extensive literature on flood damage or impact assessment (Messner et al., 2007; Merz et al., 2010). One of the first considerations is the classification of impacts. Typically, a two-fold distinction is made, using two characteristics. The first of these is to distinguish between impacts that can be described as *tangible* or *intangible*. The former category includes those impacts that can be easily quantified in monetary terms. This includes impacts such as the physical damage to property and contents. The latter includes those categories such as the health or environmental impacts of flooding, where although it may be possible to put a monetary value on these losses, it is a controversial area, and there is unlikely to be consensus on the exact values. Another way of putting this distinction is to say that tangible damage relates to goods where a ready market value exists (McKenzie et al., 2005). Intangible damage therefore relates to those goods where no ready market value exists.

The second distinction is between *direct* and *indirect* impacts or damage. Direct impacts are those that result from the direct contact of the flood water with the affected object. A contrast is made with indirect impacts where there is some spatial and temporal distance between the flood waters and the damage. An example of this is the interruption to business that occurs, as a result of the breakdown of a supply chain.

Direct tangible damage, therefore, relates to the damage to contents and property that occurs as a result of direct contact between flood waters. This property can consist of residential property, including houses and apartments and their contents, as well as industrial and commercial property, and public or government property. In this paper, the development of a tool to assess the direct tangible damage to flooding is described. Therefore, indirect tangible and intangible impacts are ignored.

The most common method used to assess the direct tangible damage to property is through the use of damage functions. These functions relate the characteristics of the floodwaters to the damage that is caused. They have a long history, beginning with the work of Gilbert White in the 1940s, and have become the standard approach in flood modelling studies (Smith, 1994). These functions are usually applied as a relationship between the flooded depth and damage, although there are studies where other characteristics such as flooded duration and flow velocities are considered (McBean et al., 1988). These functions are usually specific to their region of application and how they are developed is strongly influenced by the nature of historical data that is available, as well as the time and financial resources. The tool described in this paper will not specify a particular type of damage function or how these functions are developed.

2.2 Tool development

Given this conceptual background, the objective was to develop a tool that could be applied in the various case study cities. It would be desirable for the tool to be flexible, as the data are highly variable in the different cities. The tool also had to be developed in a framework that could be widely distributed. In addition, because much of the data required in flood damage assessment is spatial, it would be advantageous for the tool to work in a GIS framework.

For these reasons, it was decided to develop the model using Python scripts within an ESRI ArcGIS software environment (ESRI Inc., 2011). Python is an open-source language that can be used in conjunction with different GIS software packages. Therefore, the scripts developed within the project can be easily translated for use with other GIS software packages by changing the syntax to match the corresponding functions in that software. ArcGIS software has many built-in geoprocessing functions that allow operations with spatial data, and the added flexibility of being able to produce user-defined tools. It is also compatible with the hydraulic modelling outputs from the DHI produced MIKE Urban software package (DHI Water., 2009).

The specific algorithm used to estimate the flood damage is summarised in the following section.

2.3 Flood damage estimation algorithm

The technique that lies at the heart of direct tangible damage assessment is to associate a building, a group of buildings, or an aggregated land-use area with a function that relates the hazard characteristics to the damage it causes, and then to use these functions to relate the observed or modelled hazard characteristics to an estimate of the damage. The tool was developed to perform these calculations by means of a few relatively simple algorithms. More precisely, the tool incorporates a suite of algorithms, which depend in part, on the specific format of input data.

Typically, building data are presented within a GIS environment as individual polygons which can contain associated attributes such as their principal use, their year of construction and their building materials. Each building will also typically contain a unique identifier. Land-use or land-cover data are also often presented in polygons, although often covering larger areas than the individual building polygons. The building and the flood depth data typically have different formats, and need to be converted into the same format to simplify the data processing. Hydraulic models commonly use regular grids to represent the ground elevation data.

If bare DEM data, which do not represent building heights, is used in the hydraulic modelling, water is free to flow through the buildings. This type of modelling often results in more than one flood depth value inside a building, and the selection of flood depth will affect the damage assessment significantly. For example, selecting the maximum depth at any point within a single building will lead to overestimates of the flood damage. To avoid using extreme values, the flood damage per unit area within building cells are calculated, and then summed across each building in the modelled domain.

If the building data is presented in a polygon format, and the hydraulic modelling results are in a raster format, the first step in the calculation is to convert the former into a raster format. A raster grid will contain data on one attribute. To retain the land or building use code and the unique ID for each building, the building polygons are converted into two raster grids. These raster files provide the index values of land use and building ID that can be associated with the damage calculation.

The scale of these rasters can be the same as that of the hydraulic modelling results. However, in many cases, the scale of the buildings is smaller than that of hydraulic model grid cells. It is not untypical in large urban areas to have hydraulic model grid cells of 25 – 50m, whereas the buildings can be a few metres across. If the resolutions of the building use and flood depth rasters are too coarse, the damage modelling will be less accurate. Therefore, it is recommended that the resolution of these new building index rasters should be finer than that of the hydraulic modelling grid. A further difficulty in the conversion from a polygon format of the buildings to a raster format is that the building boundaries do not align with the raster grids. During the conversion process, a buffer is adopted around each building to ensure that all building areas are covered by a raster cell. To remove the extra areas introduced by using the buffer, a finer cell is applied to clip out the non-building areas. In very densely developed areas, a difficulty arises, where buildings of different land-uses may be very close to each other. The cell size could be further reduced but this will increase computing time, and a trade-off is required between the precision of the building raster, and the computing time required to produce it.

The next step is to relate the building-use code to the appropriate depth-damage function that will be applied to it. At this stage, the index in the building-use raster is used to specify the corresponding depth-damage function. Each depth-damage function is represented by a number of discrete pairs of depth and damage values. The damage for each cell is calculated by using these functions to relate the flood depth to the damage. As the modelled depth will vary continuously, it is necessary to interpolate between these pairs. The custom ArcGIS functions were not suitable for this process, so an external executable program was developed to perform this flood damage calculation. A second executable was developed to sum the damage per unit areas over each building, by relating the damage per grid cell to the unique building identifiers, thus producing a total damage value for each building.

2.4 Case Study, Dhaka City

Dhaka, one of the project's case study cities, was chosen to demonstrate the applicability of the tool. It is the capital city of Bangladesh, with a population of 12.5 million. The UN has projected its population to be 20.9 million in 2025 (United Nations Population Division, 2010). As its population is greater than 10 million, it is one of the 19 cities in the world that were recognised by the UN as a megacity in 2007 (UN Habitat, 2008). Dhaka lies in the delta of the Ganges-Brahmaputra-Meghna system, and has a high risk of flooding. The city itself is surrounded by a network of rivers; the Turag lies to the west, the Buriganga to the south, the Balu to the east, and the Tongi Khal to the north (Faisal et al., 1999). The Greater Dhaka area has an area of approximately 275km^2, and consists of a western zone, which has some protection against flooding, and an eastern zone, which does not.

Much of the population lives in informal settlements, which in the eastern part of the city are in some of the lowest lying land, and increases their vulnerability to the flooding hazard. Dhaka has witnessed severe flooding in recent years, with notable flooding events in 1998 and 2004. In 1998, almost the entire eastern zone, and 20% of the protected western area was inundated (Faisal et al., 2003). Figure 1 shows the flood prone areas in Dhaka, along with the distribution of slum, or informal settlements.

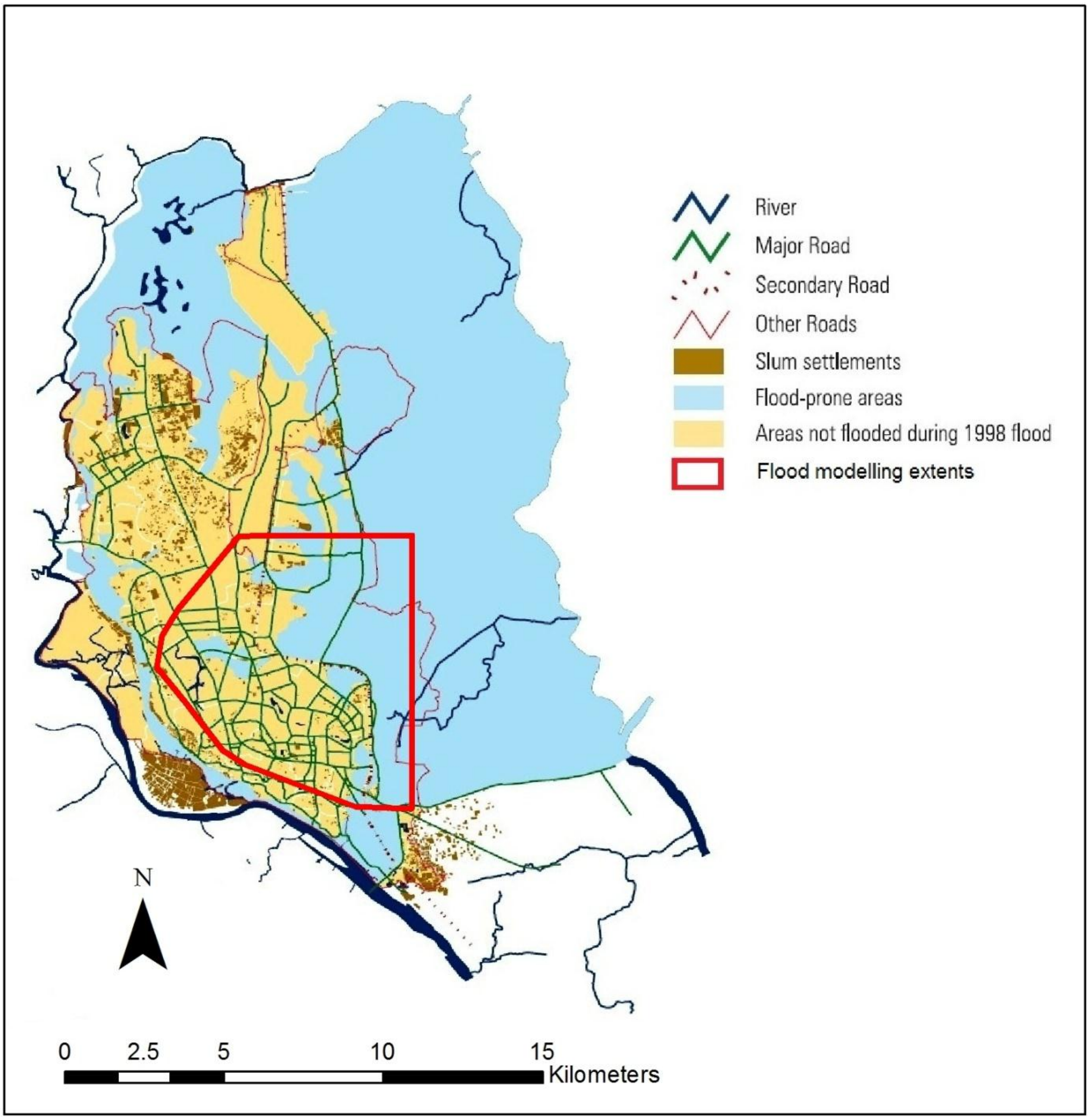

Figure 1 - Flood prone areas in Dhaka (adapted from UN Habitat, 2008)

With the rapid urbanization and development of city infrastructure, the flood risk is expected to rise (UN Habitat, 2008). As Dhaka is the seat of government for a country of approximately 120 million people, and provides many essential services and functions, effective flood risk management is essential to Dhaka and Bangladesh as a whole.

2.5 Data

There are four principal types of data required in this modelling study. These are topographic data, flood or hydraulic modelling results, information on the land-use or building types, and the depth-damage functions. More detail on these data types and where they were obtained is given below.

2.5.1 Topographic data

Data on the topography of Dhaka were provided by the Institute of Water Modelling in Dhaka. The elevation data was provided at a resolution of 25m grid cells, covering a grid approximately 14km by 14km.

2.5.2 Flood or hydraulic modelling results

Hydraulic modelling results were taken from a MIKE Urban model run for a single event. The area represented by the MIKE Urban model represents the central part of Dhaka which covers approximately 45 km^2. The storm water is drained through a combination of surface drains and underground pipes. A 1D-2D coupled model was also developed using MIKE Flood to simulate the overland flow during flooding. The scenario that was used represented a moderate historical rainfall event. The event was chosen so that widespread flooding would be observed in the system, but without producing extreme levels. The drainage system in the study area is significantly dictated by its outfall water level condition. It includes a large reservoir for storm water detention. The flow from the detention pond is controlled by a 10 vent sluice gates and a battery of pumps. Outfall water level observed during monsoon was used for the scenario. Typical gate operation and pump operation rule was also used. The model has not been calibrated with a specific event. The results from the scenario showed the model can reasonably capture the characteristics of the drainage system.

2.5.3 Building data

Building data was provided by the Institute of Water Modelling in Dhaka. Because of the nature of much of the unplanned development in Dhaka, combined with its rapid population growth, this data will not provide a perfect representation of the present state of Dhaka. However, the data provides sufficient information from which to perform the damage estimation. This data contains information on the location of the building and on its use, which will enable damage functions to be associated with each building. Where individual building data are not available, polygons that cover larger blocks or districts, assuming fixed proportions of different building use types, could be used. The data for Dhaka contain information on 150,000 buildings in a polygon format, and lists attributes of each building such as its principal use, year of construction and building material, and includes a unique building identifier.

2.5.4 Depth-damage functions

Depth-damage functions were taken from the UK's Multicoloured Handbook (Penning-Rowsell et al., 2010). These functions have been developed for the UK, and of evidently, would not be suitable for reliable modelling in a location as far removed such as Dhaka. However, as the main objective of this study is to demonstrate the proof of concept, these functions were deemed appropriate. Further work is being conducted at the Institute of Water Modelling in Bangladesh and the United International University in Dhaka to develop damage functions that are appropriate for Dhaka. This will enable a reliable estimation of the total damage within Dhaka.

In this study, 10 building-use categories were chosen, with 10 corresponding functions. These 10 categories and their functions are shown in in Figure 2. The depth-damage functions were not adjusted to reflect the local currency exchange rate, and are presented in UK Pounds Sterling (GBP).

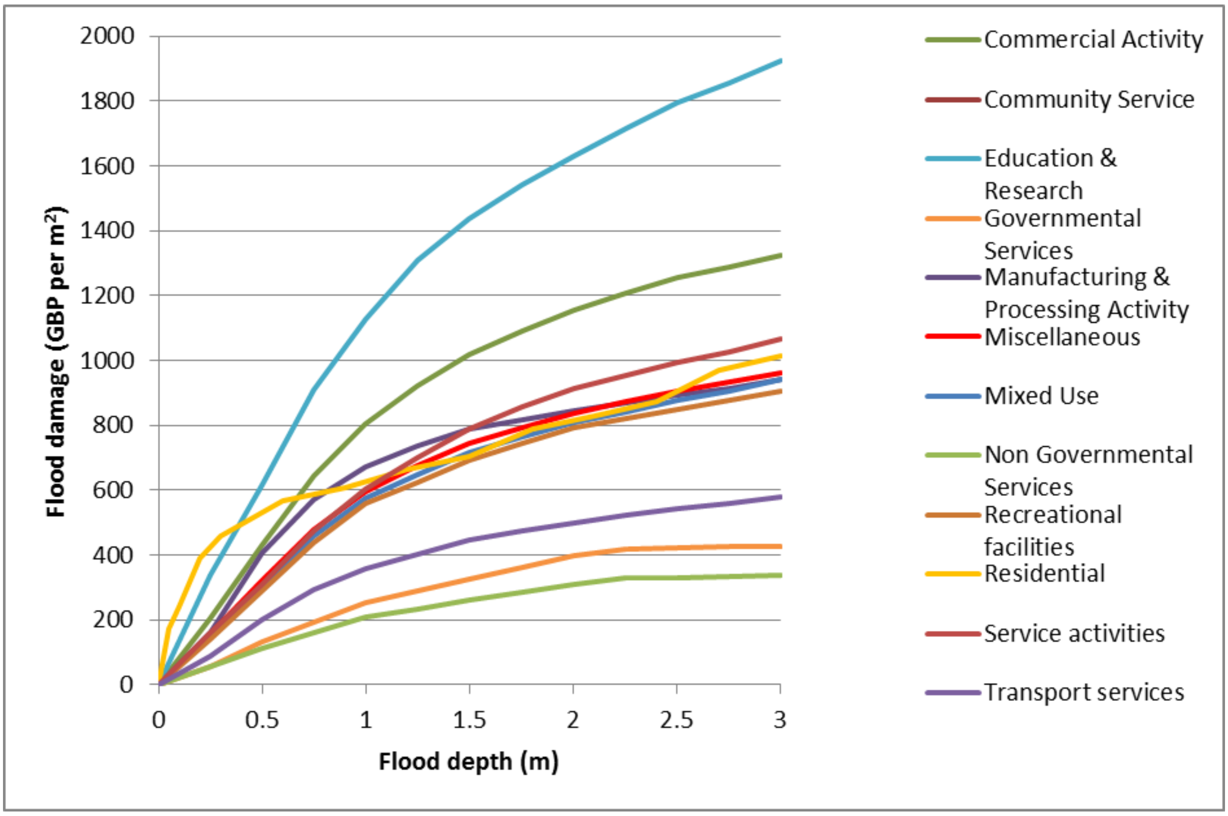

Figure 2 - Flood depth - damage functions

3 RESULTS AND DISCUSSION

Figure 3 shows the flood map for the modelled area of Dhaka. The mean modelled flooded depth in the inundated areas is 0.85m, although greater depths are modelled in smaller areas. It can clearly be seen that the flooding is widespread.

The tool firstly produces a raster grid, with 5m by 5m cells, that represents the different building uses, to which separate depth-damage functions could be applied. The results of this raster grid for a 1 km by 1 km section in the centre of Dhaka are shown in Figure 4. By combining the different depth-damage functions for each building-use with the flood depth information, the damage per unit area values are calculated. The results of this calculation are shown in **Figure 5**. The damage per unit area results have been categorised, where damage values in the lowest quintile are classified as a 'low' damage per unit area, the middle quintile as a medium damage per unit area, and the fifth quintile as a 'high' damage per unit area.

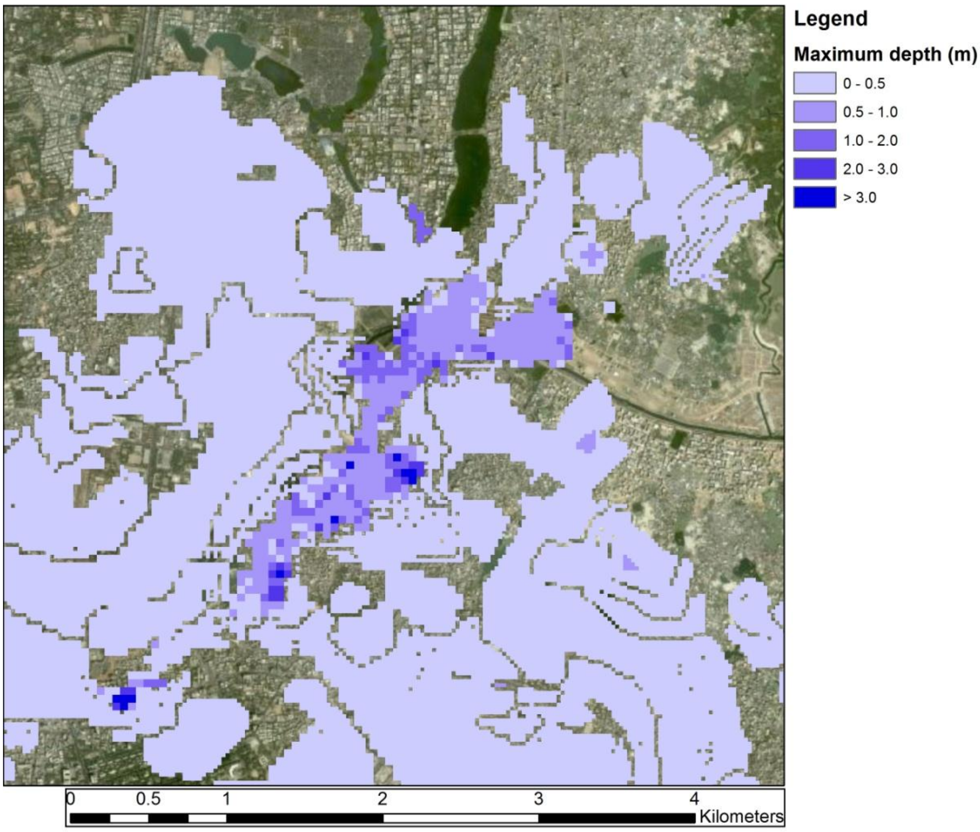

Figure 3 - Flood map for Central Dhaka

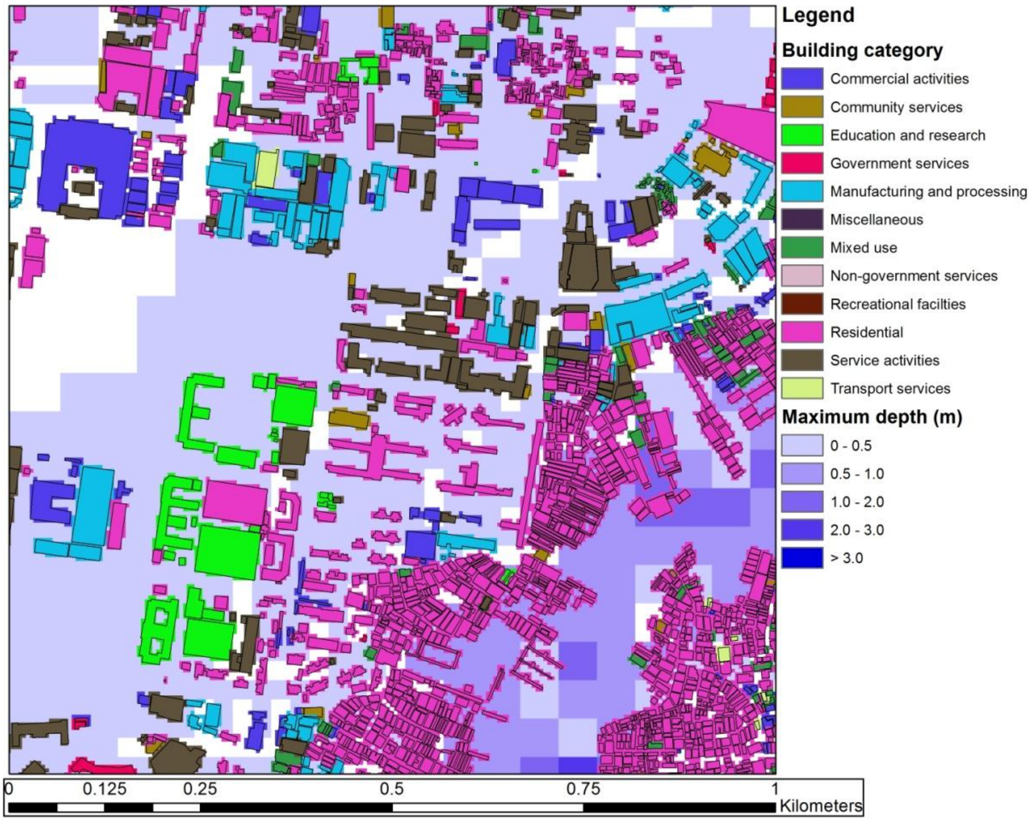

Figure 4 - Building use classification

As each building has a unique numerical identifier, the damage for each original building polygon is calculated. The results for the damage for each building are shown in Figure 6. As with the previous results, these are presented as low, medium or high building damage, depending on the quintile in which the damage per building result is contained.

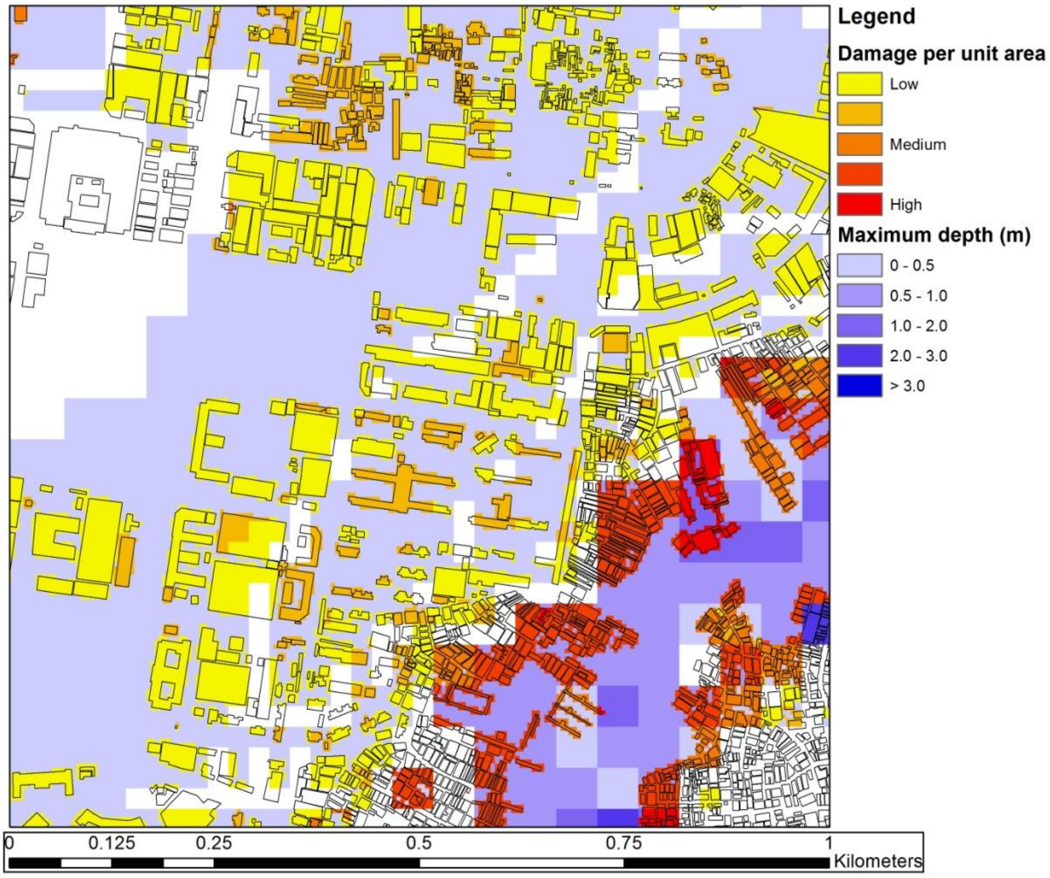

Figure 5 - Building damage per unit area

The results presented here represent a proof of concept rather than reliable figures that could be used in a study to estimate the benefits of any flood resilience strategies. Further results will be presented in forthcoming publications as progress is made on the more accurate development of depth-damage functions.

4 CONCLUSIONS

This paper has described the ongoing development of a tool to allow the estimation of direct tangible damage in urban areas. The tool has been applied to a case study in Dhaka, Bangladesh. Although the results are at this stage preliminary, they do show the potential for such a tool, which can be applied in the other case study cities in the project. The tool has several advantages. Firstly, it will work in a commonly available GIS software environment, ArcGIS. As it has been developed using a combination of Python scripts, ArcGIS geoprocessing functions and external executable programs, all the code is available for inspection by the tool user. It can be easily adapted for cross-platform applications. The tool is not simply a black box, but the underlying algorithms, and the relationship between inputs and outputs can be understood by the user. The tool will continue to be developed to introduce further elements that incorporate indirect tangible and intangible damage estimation techniques, including health impacts based on the modelling of the transport of pollutants and pathogens, and consequent exposure times. This will enable the tool to provide a comprehensive assessment of all the impacts that result from flooding in urban areas. Within this paper, issues surrounding data uncertainty and reliability have not been explored, although some of the issues in Dhaka City are addressed in a forthcoming conference paper (Khan et al, 2012). Further research will be focused on analysing the effects of different data resolutions, which are due, in part, to the limitations in handling large data sets, as well as the effects of uncertainty and data reliability on the results from impact assessments in Dhaka and other cities.

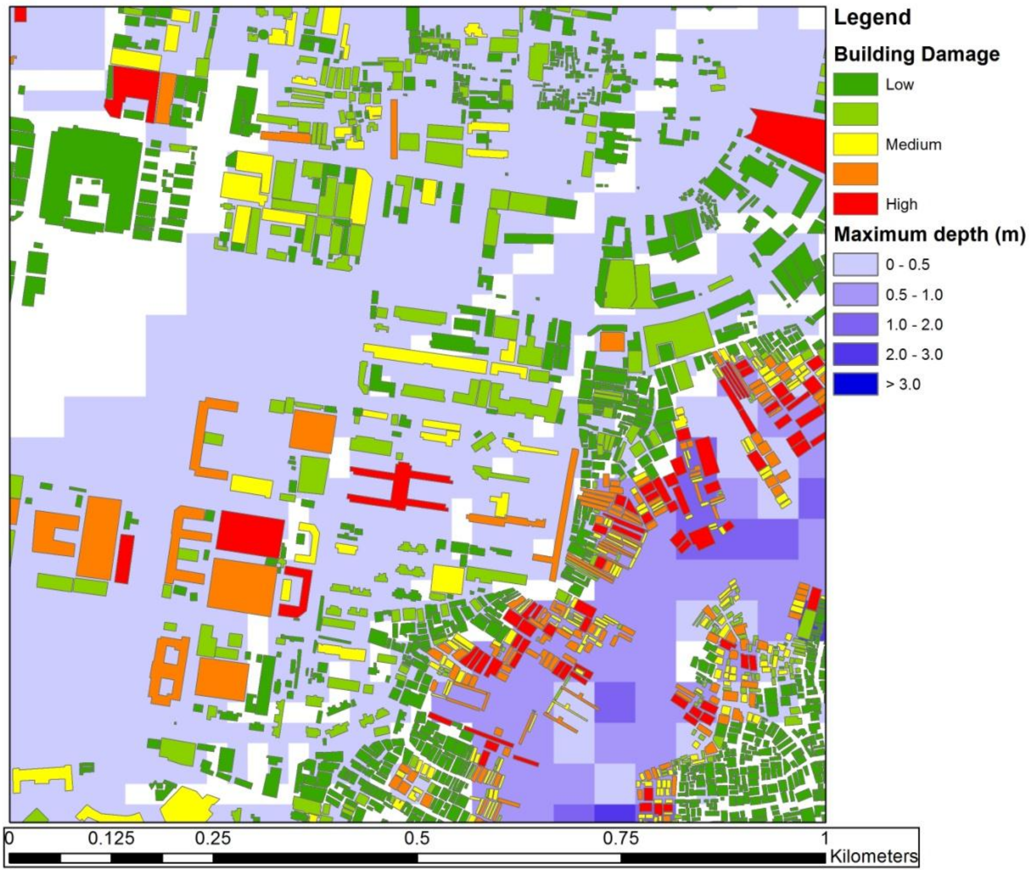

Figure 6 - Damage per building

5 ACKNOWLEDGEMENTS

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