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Flood damage assessment for Dhaka City, Bangladesh

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ABSTRACT: Flood damage assessment is a key component in the development of city flood risk management strategies. A flood damage assessment model is being developed by combining flood hazard information (depth, extent, velocity, duration, etc.) with geographic information (land use/cover, buildings, infrastructure, etc.), social-economic data and population demographics to estimate urban flood impacts. In this paper, Dhaka city is adopted to demonstrate the approach for damage modeling. Analysis show that coarse resolution modeling in such a densely developed urban area can lead to either over- or under-estimation of the flood damage, depending on the thresholds to distinguish building and non-building cells in modeling. Increased accuracy can be achieved by fine resolution modeling but this would lead to large data sets that require long computational times. The paper demonstrates some key issues for damage assessment using advanced technology for a City like Dhaka.

1 INTRODUCTION

This paper has been written as part of the research project Collaborative Research on Flood Resilience in Urban areas (CORFU). The aim of CORFU is to investigate flood risk management practices in Europe and Asia through joint investigation, development, implementation and dissemination that will enable more scientifically sound management of the consequences of urban flooding in the future.

The study aims to develop a set of tools that can be applied to assess various types of flood damage. Because of the different availability of data in the case study cities, flexibility is one of the main concerns in the development of the tools. Therefore, all the tools developed in CORFU will be used in the various case study cities in Europe and Asia to ensure their applicability. The overarching aim of the CORFU project is to improve the flood resilience of cities, by developing and investigating the effectiveness of different resilience strategies. Therefore, the development of an appropriate damage model is an important objective of the research. If the model cannot measure the effectiveness of different resilience measures, then it would not be fit for purpose.

With better access to advanced technology and resources (data, institutional setup), more developed countries conduct research to come up with better management tools. Less developed countries that are more vulnerable could benefit from these technologies. Often though, these tools are not built for different socio-economic settings. The paper focuses on the application of damage assessment tool and how it can be made suitable for different case study areas and what are the challenges experienced in using these tools. Dhaka, the capital of Bangladesh, was chosen as one of the case study areas, as it is has a large population that is vulnerable to flooding due to geographic and socio-economic conditions and provides a completely different setting that can be found in Europe.

2 BACKGROUND

Dhaka is one of the most densely populated cities in the world. The average population density in the central part of the city is 48,000 per km^2. With the rapid urbanization and development of city infrastructure, combined with the reduction of water storage and percolation areas, flooding and water logging from local rainfall has reached a dangerous magnitude. The drainage in Dhaka is dependent on two aspects (IWM, 2008):

- Operation of a storm-water drainage system including pumps and regulators
- Water levels on peripheral rivers

Thus, flooding in Dhaka may occur due to: congestion of storm-water/wastewater drainage systems inside the City area; the high water level in the peripheral rivers under which circumstance drainage is only possible through pumping; and the intrusion of floodwater from the peripheral rivers to city area through the drainage routes.

Greater Dhaka including areas beyond Dhaka City Corporation expands 259 km^2. It is bounded by the Balu River on the east, the Tongi Khal on the north, the Turag-Buriganga Rivers on the west and the Dhaka-Demra-Chittagong Road cum embankment on the south. The drainage system of Greater Dhaka is divided into two regions, Western part and Eastern part. Western Dhaka is flood protected. The total flood protected area is around 143 sq. km.The area under Eastern Dhaka is not flood protected. The total area is around 116 sq. km. The study focuses on Central Dhaka (part of Western Dhaka) as the main City lies within this region. It also includes part of Eastern Dhaka that is under development. The Central part has pipe conduits for storm water drainage whereas the eastern part still has open channels. Elevation of the City varies from 0.5 m to 12 m above sea level. 70% of the City Area is within 0.5 to 5 m. Dhaka has many low lands, which usually act as temporary detention basin for flood. Topography of the City is continuously being changed through human interventions.

There are no formal techniques established for flood damage assessments currently. In the past, it has been observed that after a flood event different government departments or agencies carry out their own surveys or interviews in an ad-hoc basis to assess the direct tangible damages. In 2004, at the direction of the Prime Minister, a national workshop on Options for Flood Risk and Damage Reduction in Bangladesh was organized (Siddiqui et al, 2006). The proceedings from the paper provide some information on sector damages in and around Dhaka city. Another study was conducted by International Union for Conservation of Nature (IUCN) to assess the damage caused by the 1998 flood. The study idea was to draw up a holistic picture of the damage due to flooding by assessing the impairment of different factors of the City’s environment, e.g., human health, water, sanitation, housing, waste management, transportation, biodiversity, infrastructure, utilities, etc. (Nishat et al, 1999). These two major studies shed some light on damage assessment due to flooding in Dhaka City but no other assessment exists which might aid in the decision making process for flood risk management. The work conducted for this research will develop an understanding of estimating damage related to flooding in Dhaka City, which can be readily utilized by the stakeholders during their planning and decision making process. Development of these tools will steer the policymakers away from traditional flood management practices, towards more real time and effective decision making which should improve the overall flood management framework.

3 METHODOLOGY

The impact asessment in CORFU comprise three damage model components:

- Direct tangible damage
- Indirect tangible damage
- Intangible damage

This paper only deals with the direct tangible damage component. Direct tangible damage refers to the physical damage caused to property and contents in both residential and non-residential (industrial and public sector) sectors by direct contact with flood.

The estimation of direct damage involves four steps, according to Messner et al. (2007). The first of these is to select an approach, depending on the spatial scale, the objective of the study, the availability of resources, and the availability of pre-existing data. Secondly, the direct, tangible damage categories that are being considered must be determined. Thirdly, the data is collected, and fourthly, the calculations are undertaken. To quantify flood damage, it is important to decide upon the categories of flood damage that will be considered. The flood damage classification should meet two requirements.

Firstly, the flood damage categories should cover as much of the damage that could be reasonably expected to occur. For example, only considering residential property will mean that important categories like industry being ignored. However, to take another example, it may not be necessary to consider agricultural damage in urban areas.

Secondly, when classifying the objects at risk, the categories should be sufficiently detailed to allow a differentiation between the various objects. A balance should be struck between, on one hand, selecting groups that are reasonably homogeneous, and on the other hand, matching the number of categories with the resources (time and money) and data available to assess them.

Two major studies done in UK for flood damage assessment (Messneret al. 2007, Chatterton et al. 2008) found that households (residential property) and businesses (commercial and industrial property) constitute a significant proportion of the total direct tangible impacts, as well as infrastructure (including communications and utilities). In the summer 2007 floods in England, damage to residential property was estimated to be £1.2bn, or 38% of the total damage. This compares to the Saxony study which listed the damage to residential property as 33% of the total damage. In these two studies, agricultural losses were a small percentage of the damage. The CORFU project is focused on urban areas (cities), agricultural damage is ignored although agriculture may present in some cities. So, it was concluded that in CORFU three broad categories should be considered: residential properties, non-residential properties, and infrastructure.

In the approach presented here, residential and non-residential property damages have been merged as building content damage, assuming that the depth-damage curves (DDCs) are available for both types of properties. The literature on damage assessment describes several methodologies for estimating direct tangible flood damage. Many of these methods rely on coarse resolution data, so that only grid-cell can be used to represent the depth of flooding in a building. For the CORFU case studies, different resolution terrain data will be explored for the hydraulic modeling. This would give the opportunity to investigate approaches different from the literature for damage assessment from flood depth.

Figure 1 shows the data requirements for calculating building content damage. The hazard information can be related to the flood depth, duration, velocity, contamination and land-use. The land-use data is used to select the appropriate DDC that should be applied to estimate the damage. The current version of the toolbox only takes maximum flood depth, land-use and DDCs as the basic data required for the assessment.

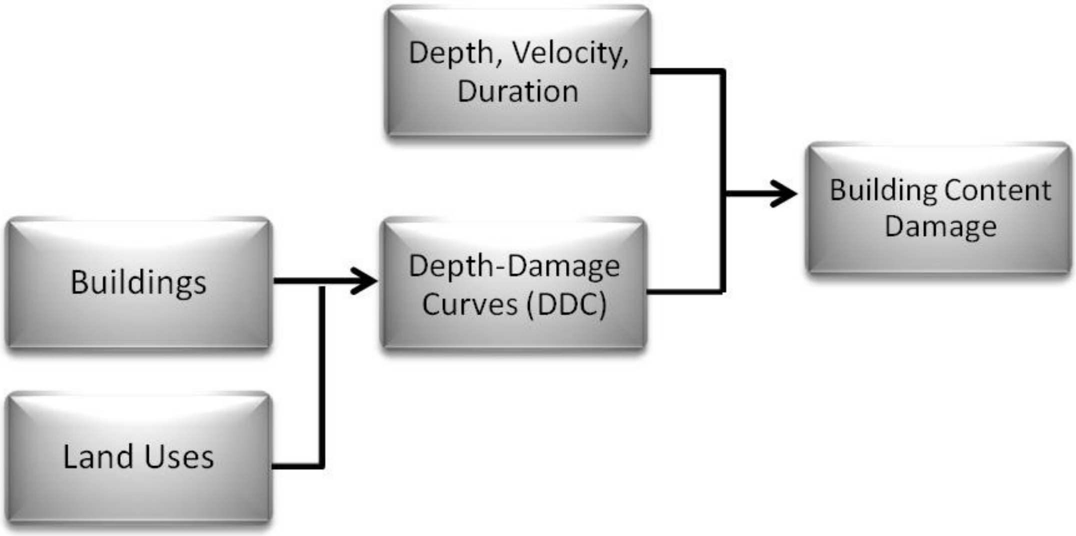


Figure 1. Direct damage estimation in CORFU

4 DEVELOPMENT OF TOOLS FOR DHAKA CASE STUDY

Availability of appropriate and large information to assess floods damage is a big challenge for the Dhaka case study. In order to account for all the information (input) required for the tools, a significant amount of effort was given to collect and prepare data for the Dhaka case study. The steps undertaken to develop the models for Dhaka are described in the following sections.

4.1 *Land use data collection and preparation*

Dhaka City has developed from a small town of about 1 km^2 with 0.2 million people during the pre-Moghul period (1600s). The city now has a population of 11-12 million and is likely to grow into one of the mega cities in the world with a projected population of over 20 million by 2015. Dhaka Metropolitan Development Plan (DMDP) was developed in 1995 by the City Development Authority (RAJUK) and it has a 20 year planning horizon (1995-2015). In 2009-10, as a part of the same Plan RAJUK have completed a “Detailed Area Plan” (DAP) for Dhaka city, which is intended to capture the policies and recommendations of the Structure Plan and Urban Area Plan of DMDP. DAP provides aggregated land-use for different parts of the City.

For damage assessment, aggregated land-use or object based land use could be utilized. Object-oriented data records individual properties and buildings, whereas aggregated data, by its nature, records aggregated information of more or less homogeneous areas. Object oriented data was also collected and prepared for the study area. No central agency is responsible for keeping record of object oriented data. So data were collated from various sources. These data were then updated so that they can be used together. Object oriented data contains actual building footprints and associated land-use information. The associated land use information are:

- Building use – 1st tier
- Building use – 2nd tier
- Building use – 3rd tier
- Structure type of building
- No of stories
- Construction year

The land-use in Dhaka City is changing very fast, so it is important to know the time period which the data represents. The prepared data represents 2005-2006.

Figure 2 shows the changing landscape of Dhaka City in a small period of time. In order to account for future changes in land-use, urban growth modeling will be performed as a part of the research. The intention that underlies the data collection is find out whether sufficient data is available to perform urban growth modeling for City like Dhaka.

Urban growth modelling,which is currently under development, will provide a mean to assess the spatial characteristics of urban growth behaviour for a specific metropolitan area. This behaviour is driven by economic and demographic development while guided by local characteristics. Within the CORFUmodelling framework, the aim of the model is to express future spatial consequences of socioeconomic scenarios, flood impacts and responses for the given urban case study locations, in this case Dhaka City.

2001 2004 2008

Figure 2.Urban growth in Dhaka City

The growth model is based on a 2D-cellular automata (CA) in which cells expressing specific land use characteristics that change state depending on internal growth characteristics and external pressures. The internal growth characteristics are derived using a supervised learning algorithm, which is trained by historic growth data. This means that the generic growth model is adapted to fit the local characteristics of a case-study area. Furthermore, spatial constraints and external pressures (e.g. land demand) expressed within scenarios and measures create a distribution of likelihood for future urbanization which is fulfilled in a deterministic or probabilistic fashion. The growth model's output is primarily a land use distribution for some future point in time. These are translated into possible land cover characteristics, which provide spatial and physical characteristics, required for the flood modelling and impact assessment. It has to be noted that the output can include multiple instances in time for a given scenario and response portfolio; the model expresses the urban dynamics within a range of years.

4.2 *Maximum flood depth*

The damage caused by flooding can be related to characteristics, such as its depth, velocity and duration of flooding. In this paper the damage is estimated based on the depth of flooding which is important and also relatively easy to determine. In order to determine the depth of flooding associated with various types of rainfall events, mathematical models were developed for the Dhaka City storm water system.

The drainage model was developed for the two areas mentioned earlier. MIKE Urban, developed by DHI, was used to create the drainage model for Central Dhaka. The drainage network for Central Dhaka contains a network of underground pipes and some open channels. In this network there are 9.7 km of box culverts, 40 km of open channels, and 134 km ofpipes. The City drainage system was schematized from secondary data collection and stakeholder consultation. Accurate record of the drainage infrastructure was difficult to find. So information from different sources was cross-verified. The drainage system in the study area is significantly governed 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 gate and a battery of pumps. Outfall water level observed during monsoon was used for the scenario. The typical gate operation and pump operation rule was also used.

The Eastern part or Eastern Dhaka includes the un-developed area of the City. It is a low lying area and the drainage system works through the natural channels. During the monsoon period, the overtopping of river banks causes flood each year. IWM developed a MIKE 11 model to analyze the Easternpart for a previous study. The catchments and the networks of the Eastern model were updated using the latest data. The Eastern model is in fact a part of the North Central Region Model (NCRM) of Bangladesh. The open channels in the Eastern part are closely connected with the rivers of this region and the water level and flow in the regional rivers greatly influence the open channels. The model was developed so that it can account for the regional influence of the rivers and at the same time has the details of the open channels in the eastern part.

To simulate the urban flooding more accurately, 1D-2D coupled model was developed which can replicate overland flow processes. The 2D model works using grid-based cells and was built for both Eastern and Central Dhaka. The grid size of the two models is very important for analysis. The cell size used in both models for the study area was 25m.The 1D-2D model that was developed is based on DHI product named MIKE FLOOD. The model creates an interface between 1D model computation and overland flow in the grid system of MIKE 21. So, it is important to use a good DEM data for the 2D analysis. Figure 3 shows the flood maps generated for Central Dhaka using the model.

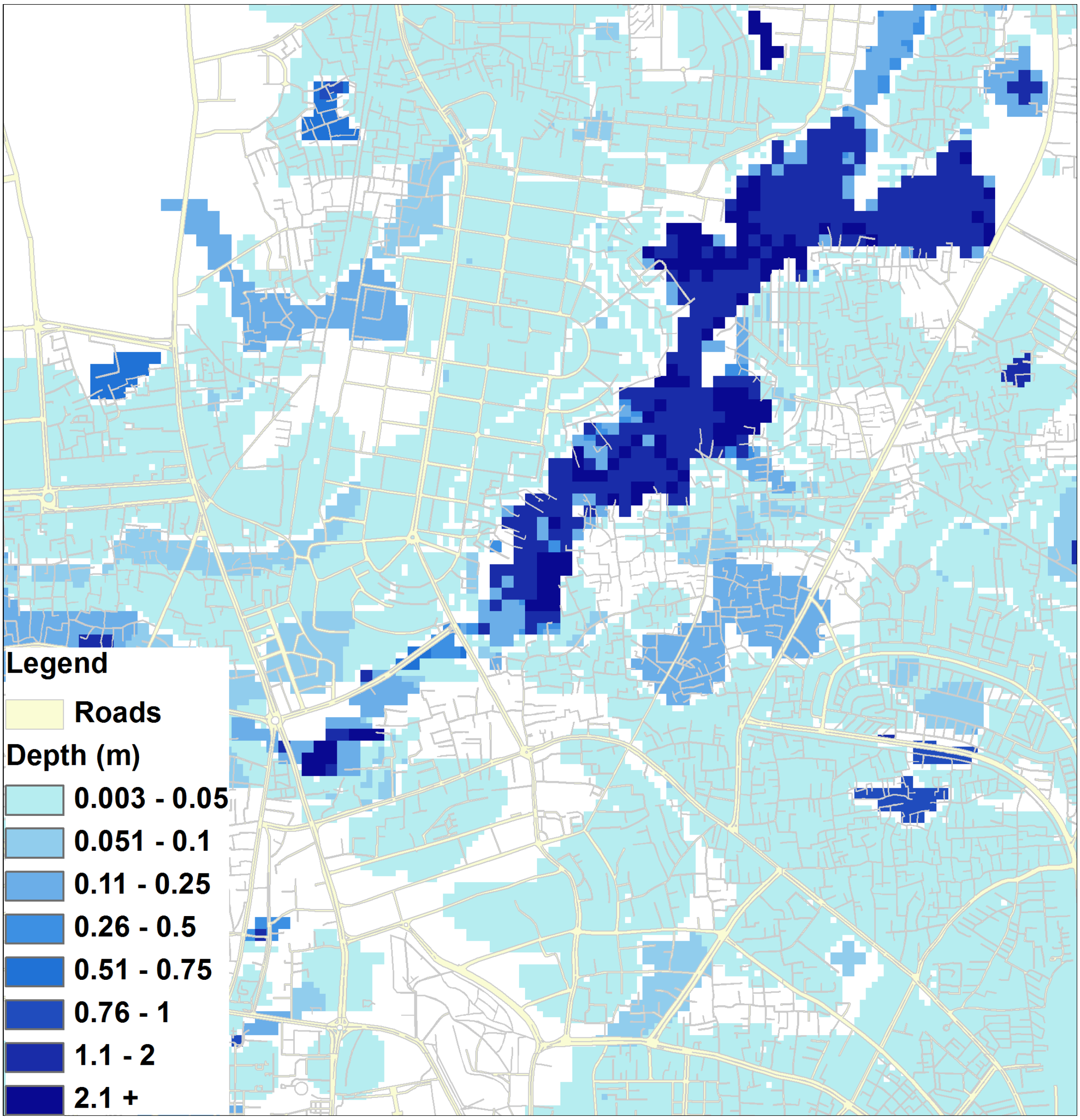


Figure 3.Flood map of Dhaka City

4.3 *Depth Damage Curve*

The Depth Damage Curves (DDC) can be developed through empirical approach, which uses historical data to develop the relationship between the inundation characteristics and the damage. The other approach is synthetic. Some authors have differed slightly on the meaning of this term. On the one hand, Merz et al. (2010) have described this approach as being developed by applying “what-if” scenarios. On the other hand, Edmund Penning-Rowsell, quoted in Messner et al. (2007) that a synthetic approach does not mean that it is artificial, but rather that it involves the synthesis of all data, including historical data. Merz argued that the synthetic approach and the empirical approach can be combined, whereas Penning-Rowsell would see this as a synthetic approach, with the empirical and synthetic approaches being mutually exclusive. This minor difference is largely semantic, but for the purposes of the CORFU project, it would be clearer if we distinguish the purely synthetic approach which relied on “what-if” analyses, from the empirical approach, and call the mixed class an empirical-synthetic approach, as per Merz et al. (2010).

The empirical approach has been used in multiple studies and relies on the existence of reliable historical flood damage data. Examples of such studies include work in Brazil (Nascimento et al., 2007) which used a reference flood event from 2000, work in Japan (Dutta et al., 2003), or the work in Germany (Merz et al., 2004). If such empirical data exists, it should be used, even if in conjunction with a synthetic approach. Such damage data can be collected either from official agencies, or from insurance companies. In contrast, the purely synthetic approach has been used in the UK’s Multi-coloured Manual, where expertise was used to build a database of absolute damage curves for over 100 building types. No standard DDCs have been established for Bangladesh. In a recent study for Khulna City (ADB, 2010) depth damage curves were developed for 5 land use categories. The categories were a) residential; b) commercial; c) industrial; d) manufacturing; e) roads. The curves were developed from household survey data and focus group discussionsconducted for the study. The damage was represented as a percentage in relation to depth. Khulna is the 3rd largest City in Bangladesh, so the data can be useful in generating DDCs for Dhaka City. The Dhaka case study aims to improve these damage curves through surveying a larger group and also conducting more focus group discussions. The damage curves developed for residential and manufacturing land use in the Khulna study are shown in Figure 4.

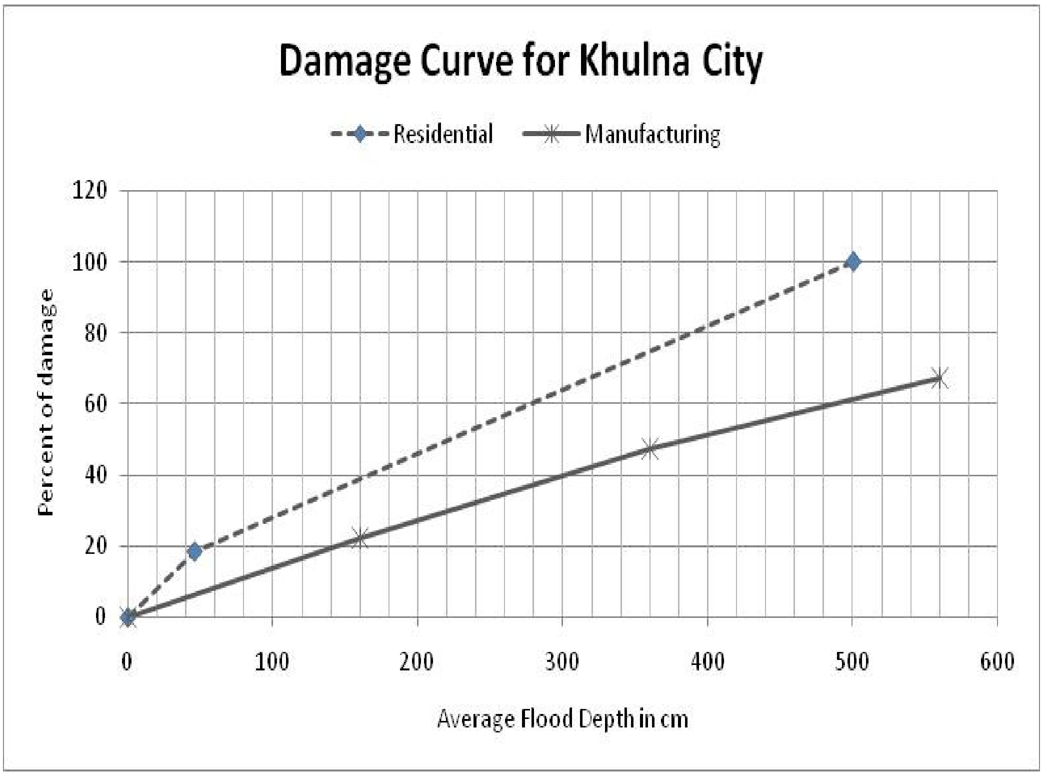
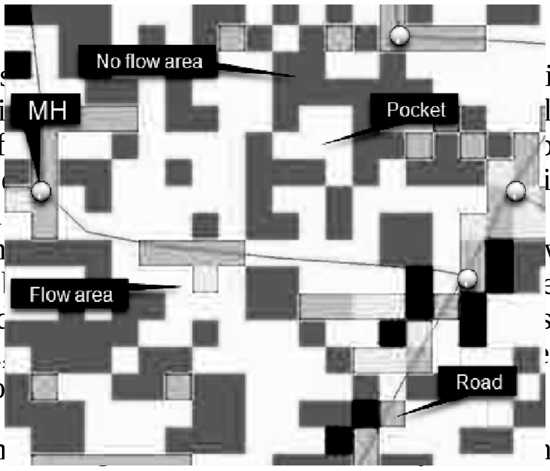


Figure 4.Damage curve developed for Khulna City Study

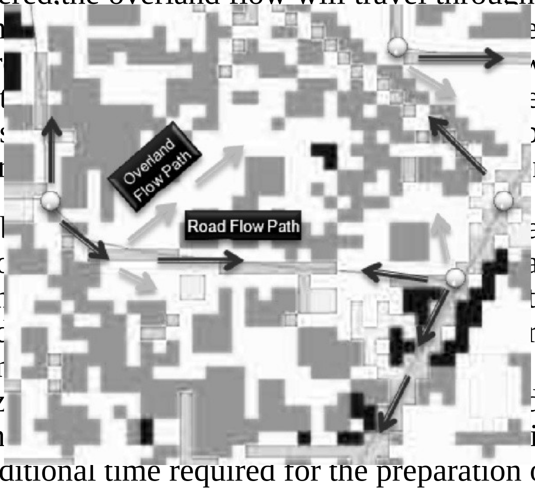
5 CHALLENGES



Several challenges lie ahead for the Dhaka Case s is
densely built, so large number of objects can be found i le
is appropriate for modelling. As the different models f be
similar. Finer scale data produced in one model will los in
a coarser resolution. But then again the finer resolution 5
shows some effects of grid size on land-use and overlan w
raster land-use data generated from vector data. It can es
can be greatly affected by the grid size. When two build se
to each other such that both are located in a coarse cell, ed
by a single cell. This will lead to inaccurate estimation o

The DEM used in traditional overland flow m ny
infrastructure such as building or roads. In CORFU, overland flow modeling consideration of building footprints and other infrastructures will be explored. If building and infrastructure are not considered,the overland flow will travel through buildings freely which leads to under estimation of
floodin esistance to the flood flow, which will be ignored if
they ar vs the error that can be generated if a coarser grid is
used. I ent a road if the cell size is too coarse. It also creates
pocket building footprints inaccurately. All of these create
inaccu n.

Many and use types are close to each other such that the
selecti age assessment process.The same can be said for
overla t. Overland flow process is also affected by cell size
for hy restimate or underestimate flooding depth and thus
affecti the computation resource restricts the selection of
cell siz dy, the computation time is 3hrs for 25 m grid runs
over th is reduced this time will to increase, not to mention
any additional time required for the preparation of data.



(a) (b)

(c) (d)

Figure 5: a) Landuse data converted to 5m grid cell; b) Landuse data converted to 10m grid cell; c) Overland flooding process in 5m cell; d) Overland flooding process in 10m cell;

6 CONCLUSION

This paper describes the various tasks that are undertaken in the CORFU project in order to formulate flood risk management strategies that will be suitable for conditions prevailing in Europe and Asia. Within these two continents nine case study areas will be investigated and each area has its own unique characteristics. The framework of CORFU investigates four core components of flood risk management, one of which is damage assessment. Damage assessment in the CORFU project utilizes advanced technology to develop a tool for direct damage estimation. The Dhaka case study explores how this tool will suit the condition of Bangladesh. Some of the challenges that were identified were also pertinent to other case study areas. The input and output data that will be required for flood damage assessment for a City like Dhaka may be quite different than what might be relevant for Europe. It was found that no standard damage curve exits for the country, nor does exist fine resolution topographic data which might be required for hydraulic analysis of a densely built City. The findings from Dhaka Case study as well as other case study areas, will contribute in developing a damage assessment tool that will applicable to countries with different geographic and socio-economic setting.

7 ACKNOWLEDGEMENTS

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