Flash flood simulations based on shallow water equations to investigate protection measures for El Gouna, Egypt

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Abstract

Severe and sudden events like flash floods are considered to be one of the most hazardous environmental disasters. Therefore, predicting the whole process of flooding is fundamental to prevent urban damages. In this context, the simulation of flash floods is an important tool to analyse the flow processes in order to find solutions to the problem. In this work, a case study of the flash flood event of 9th March 2014 in the city of El Gouna in Egypt was carried out using the Hydroinformatics Modeling System (hms), a two-dimensional (2D) shallow water model developed at the Chair of Water Resources Management and Modeling of Hydrosystems, Technische Universität Berlin. The flooding processes are simulated in great detail on unstructured grids. The aim of this work is to investigate the flow field around the settlement of the study area, when structures such as storage basins and dams are adopted as protection measures for the city. Different scenarios are analyzed to find out the most suitable one, which is able to minimize the risk during the flash flood event.

1 Introduction

Flash floods are a particular kind of floods characterised by extreme intensity and unpredictability. Cities without protection measures are especially vulnerable and may suffer severe infrastructural damages and casualties. Also, arid regions such as the Sahara Desert are often affected by flash floods while their impact spatially vary with respect to the local extent of the rainfall event (Tügel, Özgen, Simons, Zhao, & Hinkelmann, 2017). The presence of dry and wide riverbeds, called wadis, lets the

Hadidi's PhD Thesis 2016 (Hadidi, 2016). Those data are the basis for the numerical simulation of that event. In particular, the flooding was generated by a heavy rainfall which had been firstly accumulated in the mountainous area, located in the west side of the domain, and then flowed through the wadi valley until the lagoons at the sea. Furthermore, the rainfall which falls directly in the area of El Gouna also lead to inundations.

Figure 1: Study area around El Gouna, Egypt (Google Earth 2017)

3.2 Geometry, boundary and initial conditions

The domain chosen for the simulation in wadi Bili is illustrated in Figure 2. The dimensions of the domain are 11 km in x-direction and 8 km in y-direction. The boundaries are open for each side of the domain. Moreover, a discharge inflow comes into the area along 30 metres on the left boundary, where the outlet of wadi Bili is located, according to the hydrograph in Figure 3 (right). Additionally, a constant rainfall over the whole domain with an intensity of 3.67 mm/h lasting for 8 hours after the beginning of the event represents the distributed source in the mass balance equation.
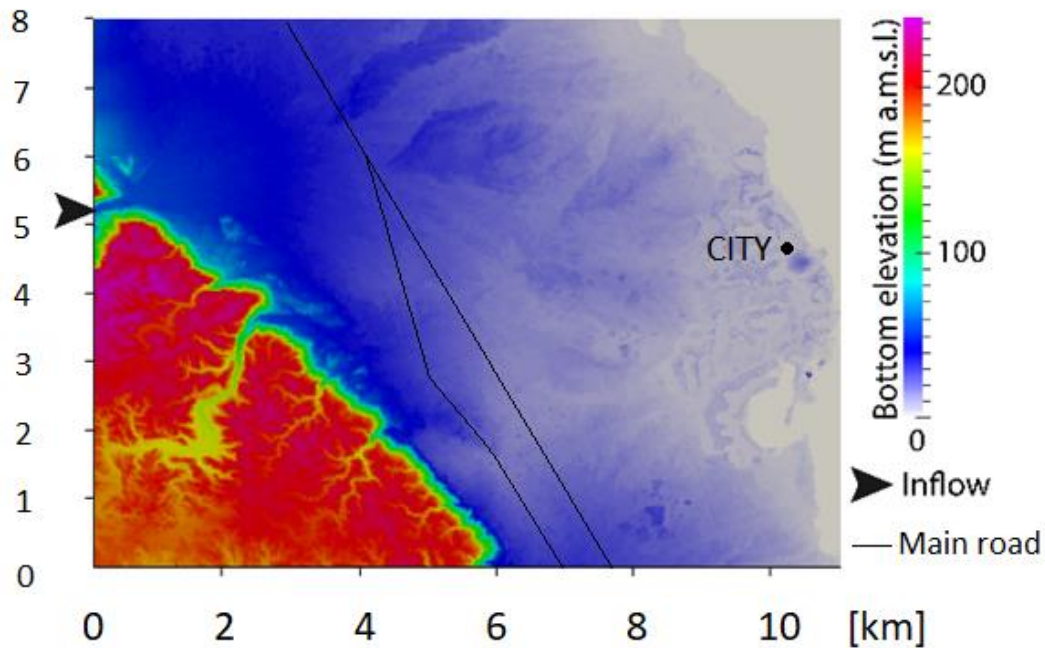
Figure 2: Digital Elevation Model (DEM) for the study area

The system is dry at the beginning of the simulation and 72 hours were simulated to see how the city is affected by the flash flood propagating through the domain, also when the rainfall event itself stopped and no additional inflow neither precipitation is entering the system. To introduce the roughness effect, the Manning's law was used with a Manning coefficient of $0.033 m^{-\frac{1}{3}} s$ representing the friction of a natural channel without vegetation.

3.3 Grid

An unstructured mesh, consisting of 562,086 triangular cells, is adopted to discretize the domain. Such a high number of cells is due to the fact that the length for most of the elements is 15 metres. Considering the spatial resolution of the DEM (30 metres), the 15m cell size ensures that at least 2 cells can represent the flow path. To increase the accuracy of the results, the eastern area nearby the city was refined. Moreover, the squared and rectangular surfaces in the grid (blue lines in Figure 3) have to be accounted for in the mesh to accurately represent the implementation of protection measures in the investigated scenarios. The same mesh should be used to compare the different scenarios to prevent any impact of the grid on the results. The grid which is illustrated in Figure 3 (left) is used in this context even to simulate the flow field without any protection structures.

Figure 3:Unstructured grid with triangular cells (left), hydrograph for inflow discharge (right)

3.4 Protection measures

While the flow penetrates the domain and circulates within it, it is possible to recognize the main flow direction: from north-west to south-east. It is also necessary to observe how the spreading of the flow throughout the study area is influenced by the topography. Some critical points were chosen (see points A, B, C, D, E, F, G in Figure 4) in order to compare water depth values in the following cases:
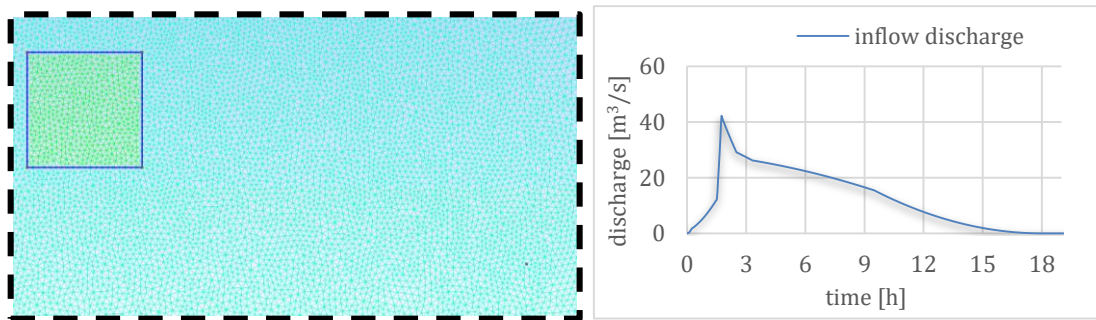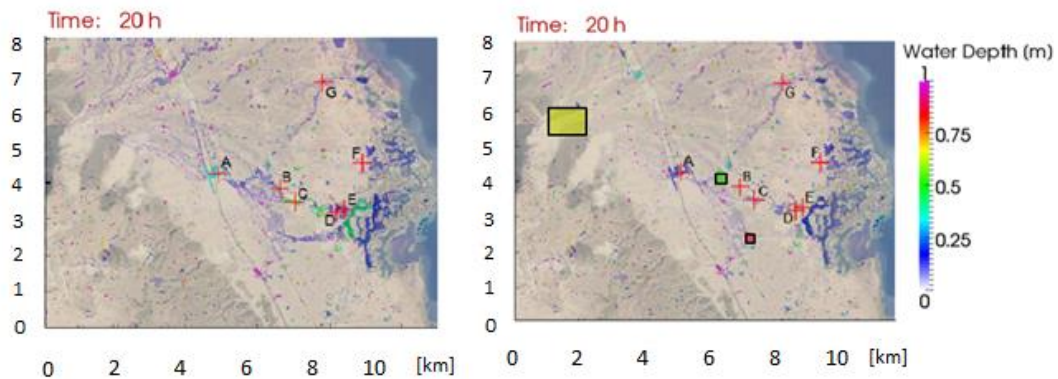
- without protections;

- a first scenario adopting a large storage basin and a dam as protection measures;

- a second scenario with a large storage basin and two little ones as protection measures.

Taking into account the large spreading nearby the incoming of the inflow in the north-west zone, the first scenario foresees the presence of a large basin able to store all the water volume coming from the larger wadi catchment. The basin, has a capability of $2.5\cdot 10^6$ m^3, while the total volume of the inflow is less, amounting to $8.65 \cdot 10^5$ m^3. Its design implies that the water in the rest of the domain is only due to the rainfall, since no overflow is observed. It presents a mild slope on the western side (5%), to avoid steep gradients in the computation. The other protection measure together with the basin is a dam indicated in the same picture with the green line. The dam consists of an inclined barrier, which hinders the flux toward the city and also redirects it to the south, deviating it from the urban area. The dam was simplified generated by creating a hole into the grid and therefore no slope could be implemented to the inclined structure. The lack of slope on abrupt gradients could have led to possible instability problems. However, the barrier is 4 kilometres long and located between the main road and the city, far away from any buildings. Its orientation was chosen to be suitable to let the water easily flow, according to the local average slope. Unfortunately, the simulation results show clearly that some natural depressions next to the dam do not allow the flow moving toward the desired direction, but let the water accumulate in front of the structure. Therefore, it seems that such a barrier should be replaced with another kind of protection, because it does not perform in the way as it was expected to. On the other hand, the large basin is considered to accomplish its function, avoiding the solution of establishing several barriers surrounding the city.
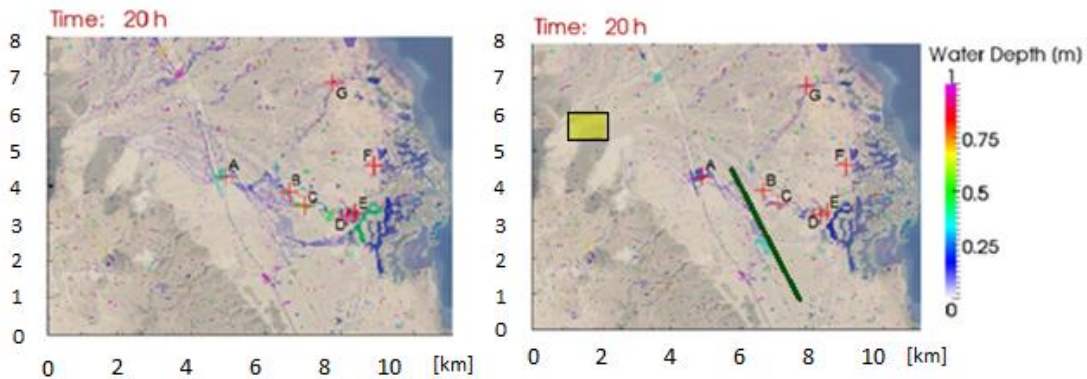
Figure 4: Water depths after 20h with no protection (left), with a large basin and a dam as protection (right)

A second scenario has been conceived in order to compare different approaches to the problem. As mentioned before, the large basin is considered to be very suitable to this situation, so it seems reasonable not to replace it with anything else. Whereas, instead of the dam it was thought to put two little basins where some natural depressions are already located. The last solution has been designed to prevent any overflow, storing the water to face eventual emergency supplying. In this context, the two little basins are indicated in Figure 5 as red and green squared shapes. This solution seems to realize a great protection for the city of El Gouna, because these kinds of mitigation measures effectively reduce water depth values nearby the urban area by storing the water as expected. In particular, comparing water depths in the case without protections to the first and the second scenario (Figure 6), the last solution has been proven to reach the lowest values undershooting 25 centimetres.

Figure 5: Water depths after 20h with no protection (left), with a large basin and 2 little basins as protection (right)

For points A, B, C, E, protection measures seem to work very well. As shown in Figure 6, the peak of the water depth without any protection is reduced at each point when measures are adopted to protect the city. They are the points affected by the passage of the main flow.

On the other hand, points D, F, G show a different behavior, since they are located in the north-east zone, where they are not influenced neither by the main flow, nor by protection measures. In fact, no variation over time is observed among different scenarios. The common trend is the reaching of a

constant value asymptotically. This means that they are located in natural depressions, so the water level rises reaching a constant value.
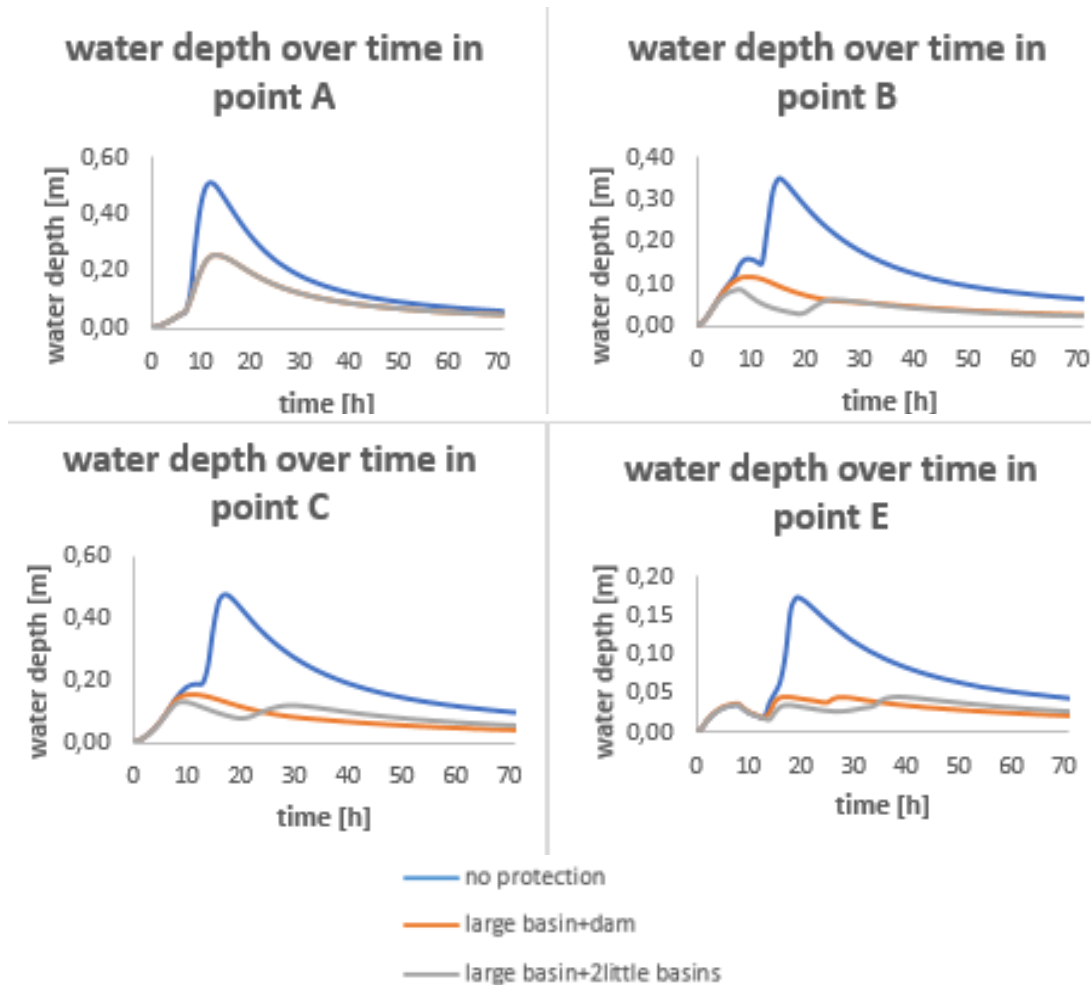
Figure 6: Water depth values for points A, B, C, E in case of three different scenarios simulated

4 Conclusions

In this study, the 9th March 2014 flash flood event in El Gouna was simulated using a 2D shallow water model. An unstructured mesh and a Digital Elevation Model have been implemented into the model to represent the studied domain. Values of water depth have been written out at some strategical points nearby the buildings in flooding conditions and then compared for the cases with different protection measures and without using them. The scenario conceived with a large storage basin near the main inflow and two smaller basins has been proven to be the best approach to protect the city with

inlets related to the simulated event. On the other hand, if a higher intensity event occurs, some overflow may represent a serious problem, strongly reducing efficiency in protection intent.

Hence, for further investigations, a new scenario would be conceived to face up to this problem, including a bypass system which connects the storage basins through a channel to the sea.

Moreover, in arid zones the influence of infiltration should be discussed for a flash flood event. In particular, implementing infiltration phenomenon in the model, still remains a central point in actual research studies. Very interesting results related to the study case are shown and discussed in Tügel's work (Tügel, et al., 2017).

Aknowledgements

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