Comments Anonymous Referee #1	Response	Changes in manuscript
I recommend the section 1.1 Sensitivity analysis includes to chapter 2. Methods. It should be described more preciously how were stated the scenarios for sensitivity analysis. As well described more preciously how were stated total damage costs and total damage area.	Thank you for this comment. I will add a few lines to explain the scenarios and the total damage cost and damaged area to improve the clarity of the text.	By changing the structure of the text, it is stated more clearly how the scenarios were constructed and what total damage cost and damage area is.
The authors used average values for the material cost and the building surface area – are these values market values in Jamaica? Or? How was state average maximum road damage? Also how was stated average cost of the crops?	The material cost and building surface area are average market values in Jamaica from 2012, that we've received from ODPEM. I will adapt the text to clarify this. The average road damage is based on the average road value in developing countries, as stated by Collier et al (2013). I will add the source for this information. The average crop values were gathered from FAOSTAT. It is true that these average values are not properly explained in the text and I will clarify and adapt this.	I've added the sources of the different damage factors and average values in chapter 3.1 Benchmark model. Furthermore, I've clarified that the damages values used are average market values from either Jamaica or from developing countries.
How the authors mean the expression in row 29 (chapter 2)… Eleven other scenarios, each with "less or less" detailed input…	This expression was meant as "less input data or less detailed input data". The second "less" thus belongs to "detailed".	To clarify this, I've added commas in the sentence: "Eleven other scenarios, each with less, or less detailed, input data…".
Please express clearly (row 29, chapter 5) the resulted indication which data is indispensable and which data can be adopted, replaced or ignored in a risk assessment. Will these data be valid for Jamaica study	It is true that this section needs some extra clarification. In this research, the scenario that uses population density has the best results. Furthermore, the importance of an adequate road network in order to improve the visual result, has been indicated. In order	A few lines are added to this chapter (chapter 5, last paragraph) in order to clarify the results of the research.

only or generally?	to validate this results, other research areas need to be tested. This will help in determining the possibilities of general use.	
Figures – I recommend formal correction – in Fig 4 and Fig 8 is missing marking S1, S11, S12.	Thank you for noticing this, I will add the missing markers in all figures.	Figures are re-entered with the markers in place.
Another formal correction is in row 11 in chapter 4 – Figure 9.	This was indeed an error that I've overlooked. Thank you for pointing this out, I will adjust it.	"Fout! Verwijzingsbron niet gevonden" was removed from the text.
Formal correction – use jointly: benchmark or bench mark.	I've checked the text and all 'bench mark' notations are corrected into 'benchmark'.	I've checked the text and all 'bench mark' notations are corrected into 'benchmark'.
The newer investigations in the field of interests – flood risk assessment model should be presented in the paper (chapter 1)	Thank you for this comment. I will expand the introduction by adding recent developments in the field of flood risk assessment.	In the introduction section, I've added some flood risk assessment tools, as well as some other flood risk assessments done recently.
I recommend including more peer reviewed journals as reference in the introduction section as well as in the Methodology section.	By adding the recent developments in the field of risk assessment, more journals will be added. Furthermore, the clarifications needed in the methodology section will also be supported by extra references.	In both sections, more journals were added.
Comments Anonymous Referee #2	**Response**	**Changes in manuscript**
Major comments		
Three damage types are considered in the paper: building, road and crop damage, whereof building damage accounts for 90% of the overall losses (see p.7, line 2). First, the choice of these three damage types should be better justified in the paper, ideally on the basis of empirical loss	Thank you for expressing this concern. It is indeed true that the choice of the three types of damages is not justified in the paper. For this research, I've consulted a Multi-Hazard Risk Assessment performed for Annotto Bay by ODPEM, that also discusses the 2001-flood. In this report, the elements at risk were discussed and the three types that	In chapter 2. Methods, I've added a few lines to explain the choice of the three damage types.

data from Jamaica or other SIDS-countries so that the importance of these three damage types becomes clear and can be discussed later.

Second, the sensitivity analysis should not only look at effects on the overall damage estimations, but also at effects on each of the three damage models, separately, in order to have a better understanding on the models' reaction and sensitivity. For this, the damage models used should be explained in more detail and model choices should be better justified.

Finally, results should be presented and discussed per damage type and with regard to the initial research question and motivation, particularly the relevance for the analyses for Small Island Developing States (SIDS). For example, the transferability of your assumptions (e.g. 3 persons per household) and the models used (e.g. building damage based on Dutta et al 2003) should be discussed more critically. Actually, the sensitivity of the model to such assumptions should be investigated in the paper. For

suffered most damage were buildings, agriculture and roads. (population also suffered, but is not taken into account in this study, since this is a pure economical damage study). I will clarify this in the paper and also add a few references of other studies that use the same types of damage models.

The numbers for the effects on the separate damage models are available as intermediate result of the research, so I can add them to the text. Not all of them are interesting, but it is true that it will help in a better understanding of the sensitivity. In the methods section, I will explain each model more precisely and in the results section, I will clarify the effects on the result per damage type.

Furthermore, I will clarify in the text that '3 persons per household' is not an assumption, but an average for the town of Annotto Bay, gathered from WRA. The damage functions of Dutta et al are chosen since there are many similarities between Jamaica and Japan when it comes to geography and building procedures. I will adapt the text to explain the choice of these functions. I will also add the results in the text of 2 or 4 people per household to show the effects on the overall result and to help explain that some numbers have to be known and cannot be estimated without knowledge of the

The numbers of the separate damage models were added in the results section to better explain the models' sensitivity.

In chapter 3.2, I've adapted the text to clarify that 3 people per household is not a presumption, but an average, gathered from WRA.

In chapter 3.1, I've added the reasons of choosing the damage functions from Dutta et al., for building damage as well as for crop damage.

I've added the resulting damage costs of the model run with an average of 2 or 4 people per household in the discussion section. In the methodology section, I've added an extra line to

example, what would be the outcome if you assumed 2 or 4 people per household? A sensitivity analysis should answer such a question.	region.	emphasize the importance of an accurate number of people per household.
The benchmark scenario that is based on the inundation of the 2001-event and the best available data to estimate damage should be better justified and descripted. Ideally, it should be accompanied by an event description and official information on its impacts (physical damage and ideally financial losses per damage type as overall figure). In addition, the use of the best available data as benchmark is somehow contradictory to the findings of Apel et al. (2009), which are mentioned twice as a motivation for this study (p. 2, line 12/13 as well as line 26/27).	I will adapt the paper and add the numbers that we have on the actual event to help justify the choice of benchmark. However, not all information is available for the real event, so a complete justification cannot be added. I understand that you see it as contradictory to use the best available data with the findings of Apel et al, mentioned in the introduction. This research, however, is not a search to lower uncertainty of the output model, but a test to see which data has the highest influence on the result of the model, to test its sensitivity. Therefore, we chose to work with the best available data, as done before in many other studies, to then check if all input data is necessary to generate the same result. I agree that the research goal should be stated more clearly and I will adapt the text to clarify this. Of course, this does not mean that uncertainty is not important and in further research, this will be investigated.	The numbers available from the 2001 flood are added at the end of chapter 3.1 Benchmark map. Furthermore, the research aim is explained more clearly in this section, explaining the choice of S1 as benchmark result.
Focus and structure of the paper need some improvements, as well. The introduction should summarize the most important findings of the	I will add some recent papers on flood risk assessment and the most important findings in the introduction section.	The papers were added to the introduction to help state the importance of the research.

relevant literature as well as the contributions that this paper (or this case study) adds to the scientific literature.
 	
The method section is quite brief, since most of the methods are explained in the results section. You should clearly separate methods, results and discussion.
	Thank you for your view on the methods and results section. It's true that these are not clearly separated. This is due to the fact that the paper discusses 12 scenarios, each with their own methodology. Explaining these all in the methods section before showing any results, seems confusing for the reader. That is why the authors propose to change the structure of the text as follows: chapters 2 and 3 would be combined in one chapter, named 'Methods and Results'. Then, each type of damage would be discussed separately, first the methodology, than the results:
	
	2. Methods and Results
	  2.1 Benchmark map
	    2.1.1 Method
	    2.1.2 Result
	  2.2 Building damage sensitivity
	    2.2.1 Methods
	    2.2.2 Results
	  2.3 Road damage sensitivity
	    2.3.1 Methods
	    2.3.2 Results
	  2.4 Crops damage sensitivity
	    2.4.1 Methods
	    2.4.2 Results
	  2.5 Data type sensitivity
	    2.5.1 Methods
	    2.5.2 Results
	I know it is not the standard way of structuring a paper, but considering the content of the paper, this structure gives a clear overview of the research. Does this seem like a good possibility for you?
	
	I will rewrite the discussion and conclusions
		The structure of the text was adapted as suggested in order to clearly separate the methods from the results.

	according to your comments.	
Discussion and conclusion should address the initial research questions as well as the overall motivation of the research to highlight the contribution of this paper to the scientific literature. What can be learned from this analysis – in the specific area, for SIDS countries and beyond?		The discussion is rewritten to clarify the results of the study, while the conclusion is rewritten to emphasize the answers given on the research questions and the important findings.
Conclusions should be based on the findings. The current general conclusion on the suitability of vector and raster data can be questioned in this respect.	That is true. I will adjust this conclusion. The raster data scenarios had less accurate results. This can be due to resolution and generalization of the vector data. I will adapt the text that this conclusion clearly reflects the findings of this study.	The paragraph of the conclusion concerning the raster data was adapted and now reflects the results of the research.
Minor comments		
P1., line 24/25: Why do you mention flood losses in the UK as example? This does not make sense in the context of the paper.	This is definitely a fair point since the context of the paper focuses on flood losses in developing countries. Since this does not contribute to the paper, I opt to remove this example from the text.	The UK example has been removed from the paper.
The crop section (3.4) is not understandable. Provide more basic information on the agriculture in the investigated area and the damage models used.	I will add information on banana plants and on other crops, frequently grown in Jamaica. I will explain how the plants cope with water and how the damage functions are generated. This will help in clarifying the	Extra information on banana plants and other crops was added in chapter 3.1. The crop section (3.4) was rewritten to make it

	overall crop damage model.	understandable.
Present the scenarios and the underlying data and assumption in a matrix table to provide a better overview of the different scenarios.	Thank you for this idea, it will help in clarifying the differences in scenarios. I will add this matrix to the general methodology.	I've added the matrix as Table 3, providing an overview of what data is used in which scenario.
The meaning of the metric "spatial difference" is unclear, in particular with regard to the comparison of different scenarios.	I understand the confusion since the spatial difference is calculated as a percentage. In the comparison with other scenarios, another percentage (the difference with S1) is then calculated. To avoid this confusion, the spatial difference will be calculated as an absolute number, and a formula with the exact calculation will be added to the text. Furthermore the percentage of difference with S1 will be added to the tables with the results of other scenarios, so the reader can immediately get an idea of the similarities between scenarios. This will not only be done for the spatial difference, but also for the total damaged area and the total damage cost.	The equation for spatial difference is added in Eq. (1) in chapter 2.
Change model parameters/input data gradually so that the sensitivity of damage models becomes clearer (see above).	The parameters are not chosen randomly, but are seen as a form of input. Since this research aims to test the sensitivity of the model towards different types of input data, there was opted not to change the parameters gradually, but to use different types of input data and to change the level of detail of the available data. This is, however, a very interesting point of view in regards to further research and validating results of different study areas.	The text was not adapted but this comment is definitely an interesting point of view for further research.

Analysing the sensitivity of a flood risk assessment model towards its input data

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Abstract. The Small Island Developing States are characterized by an unstable economy and low-lying, densely populated cities, resulting in a high vulnerability to natural hazards. Flooding affects more people than any other hazard. To limit the consequences of these hazards, adequate risk assessments are indispensable. ~~Adequate~~Satisfactory input data for these assessments is hard to acquire, especially in developing countries. ~~For the case study of Annotto Bay, Jamaica, a flood damage assessment model was created. This model generates a damage map for the region based on the flood extent map of the 2001 inundations caused by Tropical Storm Michelle. In this study~~Therefore, in this study, a methodology was developed and evaluated to test the sensitivity of ~~the~~ a flood model towards its input data in order to determine a minimum set of indispensable data. In a first step, ~~For the case study of Annotto Bay, Jamaica,~~ a flood damage assessment model was created for the case study of Annotto Bay, Jamaica. This model generates a damage map for the region based on the flood extent map of the 2001 inundations caused by Tropical Storm Michelle. Three damages were taken into account: building, road and crop damage. Twelve scenarios were generated, each with a different combination of input data, testing one of the three damage calculations for its sensitivity. One main conclusion was that population density, in combination with an average number of people per household, is a good parameter in determining the building damage when exact building locations are unknown. Furthermore, the importance of roads for an accurate visual result was demonstrated. ~~Finally, the accuracy of raster input data, based on satellite imagery, was proven to be lower than vector data.~~

Keywords: *SIDS, flooding, risk assessment, damage map, sensitivity analysis*

1 Introduction

Natural hazards have a great economic impact on countries worldwide. The losses as a result of earthquakes, cyclones, landslides, flooding and tsunamis are estimated at up to 300 billion USD per year (UNISDR, 2015). Natural hazards do not only cause economic but also human losses. Between 1975 and 2008, over 2.2 million people died due to natural hazards worldwide (ISDR, 2009). Floods affect more people worldwide than any other hazard (UNISDR, 2015). Not only low-income countries suffer from severe inundations. ~~The economic damages caused by flooding in the UK, for example, mount to an average of 250 million USD per year (Penning Rowsell, 2014).~~

Low-lying, densely populated areas with unstable economies have little protection against natural hazards (UNESCO, 2014). Many of these areas can be found in the SIDS (Small Island Developing States), which are located in the regions of Latin America, the Caribbean, East Asia and the Pacific, and are expected to lose 20 times more of their capital stock in disasters each year than Europe and Central Asia (UNISDR, 2015). In Jamaica, for example, economic damage due to flooding was estimated at 1.5 billion USD over a period of four years (ODPEM, 2013b).

To limit the consequences of flooding, many governments revert to technical interventions, such as dams, levees and flood forecasting. These approaches, however, have shown limited success in several countries (Gall et al., 2011; Deckers et al., 2010), leading to new approaches that focus on flood risk management rather than flood control (Institute for Water Resources, 2009). One of these approaches is a quantitative flood risk assessment, indicating the high-risk areas by estimating the possible damage caused by a flood hazard. The output of this method can help decision makers in identifying the most vulnerable regions and allocating the right resources and funds to the right locations. The technocratic interventions, as mentioned before, can thus be applied more effectively and sensibly.

In many developed countries, a risk-based flood tool has been developed, for example the HIS-SSM model for the Netherlands (Kok et al., 2005), the LATIS model for Flanders, Belgium (Vanneuville et al., 2005), the HAZUS-MH Flood Model for the USA (FEMA, 2009) and the FLEMO model for Germany (Apel et al., 2009).

The use of such risk assessment models has, however, been limited, due to questions about the uncertainty and reliability of the results (Merz et al., 2004). Since these methodologies are built on input data that each have their own accuracy and uncertainty, the output of the methodology has an uncertainty that is very difficult to quantify (Yu et al., 2013). Furthermore, an increase of the input data accuracy doesn't automatically imply a decrease of the output's uncertainty (Apel et al., 2009). ~~However~~Nonetheless, the existing models are being optimized and are used as decision tool in urban planning projects as is the case in Flanders, Belgium~~.~~ (Deckers et al., 2010).

In developing countries, the limited data availability forces researchers to find other types of input data for flood damage and risk assessments. Kumar and Acharya (2016), for example, have performed a flood risk assessment in Kashmir Valley, India, using satellite imagery as input. Kwak et al (2015) created a rice crop damage map for the Cambodian floodplain using satellite imagery combined with a DEM and land use data. Other studies have attempted to provide adequate damage and risk results by using vector data, for example the risk assessment for Annotto Bay, performed by ODPEM (2013a).

Since the necessary input data is hard to find in developing countries, ~~Especially in countries like the SIDS, where data availability is very limited,~~ a thorough assessment of the data needed should be done. What are the minimum data requirements to build a reliable model? What is the sensibility of the model to the different datasets? These are the questions that need to be answered whilst keeping in mind that a certain degree of uncertainty is inherent to the methodology.

This paper investigates the different types of data used in a flood risk assessment for Annotto Bay, Jamaica, and their influence on the overall result by performing a sensitivity analysis on the risk assessment model with different combinations of input data. The output of every combination is tested on its accuracy based on the estimated total material loss and

affected area and the geographic positions of high- and low-risk areas, compared to the benchmark output that uses all available data.

1.1 Sensitivity analysis

Data and methodology uncertainties are inherent to every risk assessment model (Carrington & Bolger, 1998). Since they can influence decision-making, these uncertainties have been quantified in several previous studies (Yu et al., 2013; Apel et al., 2004; Apel et al., 2008; Weichel et al., 2007). More and more exact data, however, does not always translate in a decrease of the uncertainty, since the influence on the final result differs for each input data set (Apel et al., 2008).

In many SIDS, geographic and statistical data availability is a major issue. Moreover, the data available has a questionable accuracy (Glas et al., 2015). It is therefore important to define the importance and influence of every input data set. With a sensitivity analysis, the influence of all input data on the overall result and its degree of detail is determined. When the sensitivity of a model towards its input is known, the minimum required data and the level of detail in order to get an accurate result, can be deduced. Although uncertainty analyses are frequently performed in the literature, sensitivity analyses to determine the necessity of the input data are rare. Nonetheless, this information is useful in setting up an uncertainty analysis. The impact of an input data set on the final result can serve as an indication of the impact of the uncertainty of this data set on the overall result and its uncertainty.

In this study, the input of a flood risk assessment performed for Annotto Bay, Jamaica (Glas et al., 2015), was used as case study for the sensitivity analysis, because in 2012 a lot of accurate data was collected for this town in the framework of another research program (ODPEM, 2013a). Since hydraulic and rainfall data is scarce in this region, and return periods of floods are unknown, this quantitative risk assessment focuses on material damage due to inundations caused by the Tropical Storm Michelle, in 2001 (WRA, 2002).

1.2 Study area

Annotto Bay is a small coastal town in the northeast of Jamaica. The town is vulnerable to several natural hazards, of which storm surges and riverine flooding are the most severe (ODPEM, 2013a). This is due to the high-risk location of the community. Not only is the town situated close to the coastline, but it is also enclosed by the Blue Mountains. This topography, together with the presence of four rivers traversing Annotto Bay, causes the rapid flooding of the community whenever perpetuation occurs in the mountains (WRA, 2002). Since the highest point of the town is only three meters above Mean Sea Level, Annotto Bay suffers severely from storm surges as well. There are about 5,500 inhabitants in the area, living mainly in concrete and wooden buildings (Statistical Institute of Jamaica, 2012). The land use in the study area and the locations of the rivers, roads and buildings is shown in Figure 1.

All damage calculations made in this study were based on the flood map of the inundations on both the 28th and the 29th of October, 2001, caused by Tropical Storm Michelle. The city of Annotto Bay was largely flooded for two days (Figure 2).

Houses, infrastructure and crops were damaged, however, since the flow velocity was less than 0.3 m/s, there was only little severe structural damage (ODPEM, 2013a).

2. Methods and results

In this chapter, the methods and results of the sensitivity analysis are discussed. In a first step, ~~First, in order to perform a sensitivity analysis,~~ a benchmark flood risk model was determined. This model was created using all available data and was based on the Flemish LATIS methodology (Deckers et al., 2010) and on a risk assessment performed by ODPEM (2013a). In ~~this~~ the bench-mark risk assessment, geographic information was combined with the replacement values of the elements at risk and with the damage factors. Replacement values represent the cost to rebuild an element when it is totally destroyed, while the damage factors are an estimate of the degree of destruction based on the flood level, in feet, at the location of the element at risk. Hence, the damage factor will be a number between 0 and 1, with 0 being no damage at all and 1 being complete destruction. The three types of elements at risk that suffered most damage according to ODPEM (2013a) were buildings, crops and roads. Due to limited information on other types and the impact of the flooding on these elements at risk, only the ~~d~~Damage costs for buildings, crops and roads ~~of buildings, crops and roads~~ were~~are~~ ~~thus~~ calculated by multiplication of the replacement value by the damage factor to generate a damage map, indicating the total damage cost per square meter for the study area. The input data of this model is listed in Table 1.

This first assessment, the benchmark, is called Scenario 1 (S1). Eleven other scenarios, each with less, or less detailed, input data than S1, were tested and compared to this first one. Table 2 shows an overview of all scenarios and Table 3 provides a matrix showing what data was used in which scenario. The scenarios are discussed per sensitivity. Four types were tested: building damage sensitivity, road damage sensitivity, crops damage sensitivity and data type sensitivity. In each section, the methods are discussed first, followed by the results. ~~, with the input data that was used and the data that was not used, in order to test the sensitivity of the model towards this data type.~~

For each scenario, four elements were compared: the spatial difference, the visual output, the total damage cost and the total damaged area. To test the first element, all damage maps were converted into raster maps with a resolution of 5 meters. Then, the value of every pixel was compared to the values of its neighbors. The spatial difference ~~was~~ is defined in Eq. (1) as the probability that a pixel has a different value than its neighbor:

$$SD = \frac{\sum_1^n \frac{P_{sd}}{P_s}}{n} \tag{1}$$

where SD is the spatial difference, P_s the number of neighbouring pixels, P_{sd} the number of neighbouring pixels with a different value and n the total number of pixels. The concept of spatial difference is also~~, as~~ demonstrated in Figure 3. The value of the spatial difference is thus a tool to describe the level of detail of a damage map. Since the resulting damages ~~are~~ were assigned to classes in the final maps, this level of detail ~~may~~ would be difficult to deduct from only the visual mode of representation. Together with the total damage cost, which is the sum of the calculated building, road and crops damages,

and the total damaged area, the visual result and the spatial difference determine the influence of each type of data on the overall result.

All scenarios were modeled in ArcGIS 10.2 using Python. The methodology of the risk assessment was automated through a script written in the ArcPy module. Although small differences exist between the scenarios, caused by the use of different or less input data, the overall methodology remains the same.

3. Results

23.1 Benchmark map

2.1.1 Method

To generate the benchmark map, three types of damages were assessed. The benchmark damage map shows the output of the flood risk assessment model for Annotto Bay. This model focuses on three types of damage: building, road and crop damage. The cost of these damages was calculated separately for each type and then combined to generate an overall damage map of the region, as shown in

Figure 4. Table 3 contains the three numeric elements on which the comparison of the scenarios is based: the total damage, the total damaged area and the spatial difference, as calculated for S1.

Building damage calculations were based on the exact GPS position of all of the buildings in Annotto Bay, as well as their building materials and the number of floors (ODPEM, 2013a). By using average Jamaican market values, calculated by ODPEM (2013a) for the material cost and the building surface area, a maximum damage value was determined per building. Subsequently, the real damages were , according to Dutta et al (2003), calculated by multiplying these maximum damage values were multiplied with a damage factor, based on Dutta et al (2003), based on the water levels. The damage factor were transferred from Japanese damage functions, as retrieved from Dutta et al (2003), and the water levels were retrieved from as shown on the 2001 flood map (ODPEM, 2001). The Japanese damage functions could be transferred to Jamaica due to the similarities in geography and building engineering procedures. Most Japanese and Jamaican buildings are constructed in a similar manner with solid concrete or wooden walls. The distinction between these two building types is made in the damage functions as well as in the building database of Annotto Bay. These calculated real damages were then summed up per land use polygon, in order to generate a clear view of the building damage.

The damage to roads was calculated using the road network dataset (ODPEM, 2013a). This dataset divides the roads into four classes, each with their own properties, for example the width of the road. The line dataset was converted into polygons, based on the different widths. Using the an average maximum road damage, calculated by Collier et al (2013) for developing countries, and and combining this with the damage factors from the Flemish LATIS flood risk assessment tool (Deckers et al., 2010), the real damage was then calculated for all roads.

Finally, the crop damage map was generated. A difference was made between banana plantains and other crops, due to the different reaction to inundations and the different average cost of the crops. As bBanana plants can only survive water

saturated conditions up to 48 hours because of their fragile roots (Rajamannan, 2004), t. The duration of the flood is thus especially important for banana these plants, since a two-day flood, as this was the case in 2001, causes 100 percent destruction of the plants. For the damage calculations of the other crops, an average was used of the damage factors of eight crop types defined by Dutta et al (2003). These crops are commonly cultivated in Japan as well as in Jamaica. Therefore, the crop damage functions could also be transferred. The maximum crop damage value was based on information from FAOSTAT (2014) and was then multiplied with this damage factor to determine the crop damage cost. Since the damage factor for the banana plantains was 1, their real damage value was equal to the maximum damage value.

Since there is only very limited information on the exact consequences of the 2001 flood, the benchmark model could not be validated. However, the small amount of information that was available, could serve as an indication. The number of affected houses, for example, was 749 (ODPEM, 2013a), while the benchmark model calculated this at 799. The overestimation can be explained by the generalization done by the model, that does not take into account the fact that some houses will resist better than others and will thus have no damage. There was no comparable data for road and crop damage. The lack of validation increased the uncertainty of the model immensely. However, this research did not take into account the uncertainties of the input data or the model, since the aim of this research was to investigate the sensitivity of the model towards its input data. Hence, tTo identify the influence of each type of input data, S1 was thus an acceptable benchmark.

2.1.2 Results

The benchmark damage map visualizes the output of the flood risk assessment model for Annotto Bay, as shown in Figure 4. Table 4 contains the three numeric elements on which the comparison of the scenarios is based: the total damage, the total damaged area and the spatial difference, as calculated for S1. The total damage cost is calculated at 7.49 million USD, of which 7.08 million USD, or 94.6% is damage to buildings.

2.23.2 Building damage sensitivity

2.2.1 Methods

In the next four scenarios, the sensitivity of the flood risk model towards the data used to calculate building damage was investigated. In S2, the information concerning materials and the number of floors was deletedremoved and replaced by average values for all buildings in Annotto Bay. , while iIn S3, the location of the buildings was also eliminated, leaving only the number of buildings in the total study area as information. In this casescenario, after testing the available data in and around the study area, including the exact building locations and the land use data, 90% of the buildings was presumed to be in urban areas and the other 10% in rural areas. In S4 and S5, pPopulation information was used to determine the building damage in S4 and S5, based on the presumption average number of 3 people per that a household, or per one building, consists of 3 people (WRA, 2002). In the former scenarioS4, the population density per statistical sector was used to

calculate the number of buildings. In ~~the latter~~S5, however, only the total number of people in the study area was known. Here, the same assumption was made as in S3 about the division of buildings between rural and urban areas.

2.2.2 Results

Figure 5 shows the visual result of the four scenarios, while Table 5 shows the calculated damage, the damaged area and the spatial difference in comparison to the benchmark results of S1. Visually, no big changes can be observed in the indication of the high-risk areas. The slightly lower spatial difference in S3 and S5 does indicate a decrease in the level of detail. While S2 gives the result that is most similar to the result of S1, the table clearly shows an important difference of 19.75% in the calculation of the total damage cost. This percentage rises to 20.88% when only taking into account the building damage. Although the visual result of S4 is less detailed than the benchmark, the spatial difference of 0.04~~5.52%~~ indicates a similar level of detail as in S1. Moreover, this scenario gives the best result towards the calculation of the total damage. The calculated building damage of S4 is 6.59 million USD, which is 6.96% lower than the calculated building damage in S1.

2~~3~~.3 Road damage sensitivity

2.3.1 Methods

Scenarios 6, 7, 8 and 9 were used to assess the sensitivity of the risk assessment towards the road data. In S6, the road classes were presumed to be unknown, giving all roads the same average width. S7 ~~The seventh scenario does~~ did not take the roads into account. In S8, the location of the roads was~~is presumed to be unknown~~eliminated and therefore, they were~~are~~ calculated as a percentage of the land use. After analysing the available data in and around the study area, the percentages ~~are~~ were set at 5% roads in urban areas and 2% in rural areas. S9 only used the road network to divide the land use polygons, but ~~does~~ did not take them into account in the damage calculations.

2.3.2 Results

The road cost is only a small share of the total calculated damage. This is clear when comparing the total damage of the four scenarios to the damage of the benchmark in Table 6. S6, for example, generates almost identical numbers ~~than~~ as S1. Visually, these scenarios are almost identical. However, when assessing only the road damage, S6 generates a damage cost of 41 thousand USD, which is 20.59% higher than the calculated damage cost of 34 thousand USD in S1.

There is a significant difference in damaged area between S1 and S8. Since the threshold value for road damage is 0 feet and the road damage is spread over the entire study area in S8, all flooded areas have damage. Moreover, visually, S8 shows a different, less accurate, result than the other scenarios, as shown in Figure 6. The scenario has a low spatial difference of 0.01~~8.75%~~. The total road damage cost of 32 thousand USD, however, is only 5.88% lower than the damage cost in S1.

Although S7 clearly has a better visual result than S8, indicating the areas without any damage more accurately, the spatial difference of this scenario is ~~even~~ lower. Due to a larger damaged area in S8, more pixels are taken into account in the spatial

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difference calculations, increasing the possibility of having neighboring pixels with a different value. The level of detail is thus higher in S8, but the visual result shows large deviations from S1. The removal of the roads in S7 and S9 only has a small effect on the total damage and damaged area, but it does have an important influence on the level of detail, as proven by the spatial differences. The ninth scenario, nonetheless, does have a more accurate visual result then the other road scenarios, due to the use of the road network to divide the land use polygons.

23.4 Crops damage sensitivity

2.4.1 Methods
Scenario 10 tested the sensitivity of the model by assuming the difference between banana plantains and other crops wais unknown. An average maximum damage value was calculated from the values for banana plants and other crops, grown in Jamaica. The damage factor used was also an average, but only of the damage factors of other crops, since the damage factor for banana plants was 100% for every water depth, due to the duration of the flood.

2.4.2 ResultsThis was done by using an average maximum damage value and the damage factors for the other crops, since the damage factors of the banana plants are based on time and not water height.
Since the real damage value of the crops is rather small in comparison to building damage values, S10 only has a small effect on the result. Therefore, the visual view of the map is almost identical to the benchmark damage map. This can be seen in Figure 7. Furthermore, Table 7 demonstrates that the calculated total damage and damaged area differ only little from the values that were generated by the model used for S1. However, the crop damage cost in S10 of 154 thousand USD in S10 is 58.60% lower than the crop damage cost of 372 thousand USD in S1.

23.5 Data type sensitivity

2.5.1 Methods
The last two scenarios looked into the sensitivity of the model towards the input data type. In the benchmark model, all input data was vector data. In areas with little data available, however, a lot of information will have to be gathered from satellite imagery. Therefore, all input data in S11 and S12 was converted to raster data with a resolution of 10mx10m for S11 and 30mx30m for S12 to simulate satellite data. The former resolution was chosen since several commercial high-resolution satellite systems, e.g. SPOT, satellites provide images with a world coverage with thisese resolutions. SPOT, for example, is a commercial high resolution satellite system that provides images with 10 meter resolution. The Landsat program uses the latter resolution and . This enterprise has an online service, providesing free images through an online service. with a 30 meter resolution. The calculations for the building damage were based on population data, in the same way as in with . Ththe same method was used as in S4.

2.5.2 Results

Therefore, S4 is also included in Table 7.

Although the two damage maps, as shown in Figure 8, visually do not differ a lot from the maps of S1 and S4, Table 8 shows that the total damage cost is substantially higherbigger than the cost in S1 and S4. All three separate damage costs show a large overestimation compared to S1 and S4. The road damage cost, especially, is 27 times larger in S11 and even 78 times larger in S12 than in S1. This is due to the fact that road damage is calculated per pixel, and the pixels in both scenarios have a resolution larger than the width of the roads. Hence, tThe area assigned to roads is thus overestimated.

The total damaged area is also slightly larger, due to the conversion of the polygon flood map to a raster map. Since the input of the scenarios was raster data, every pixel has been calculated separately. Therefore, the level of detail, and thus the spatial difference, is higher than in S7, S8 and S9. When comparing the results of S11 and S12, it can be stated that the spatial difference shows a growing decrease of accuracy as the resolution of the raster data increases. Moreover, the visual result is less detailed and gaps arise in the final map.

43. Discussion

In all scenarios, more than 90% of the total flood damage consists of building damages. Consequently, scenarios that test the models sensibility for building data show the largest deviations in the total damage. Figure 9 shows the deviation for every scenario to from the total cost of S1.

When looking at the scenarios focussing on building damage, S4 has the best result, with a deviation of 6.58% in relation to the result of S1. This scenario has calculated the damage cost based on population density per statistical sector. In the case study of Annotto Bay, the benchmark study made use of the exact GPS locations of all buildings in the region. In many other areas in the SIDS, this detailed information is not available. Population data, however, exists for most regions free of charge. Since the results model gives a good result, visually as well as in the total damage cost, this scenario must definitely be investigated further. The importance of an accurate average number of people per household was proven by running the same model with an average of 2 and an average of 4 people per household instead of the average of 3, as given by WRA (2002). When testing the former, the total damage cost of 4.83 million USD is 35.55% lower than S1, while the latter gives a resulting cost that is 21.75% higher than the resulting damage cost of S1.

When only relying on Figure 9Fout! Verwijzingsbron niet gevonden., it could be stated that the model is not sensitive to road data at all. However, not only the total damage must be taken into account, but also the spatial impact and the total damaged area have to be included. In Figure 10, the last factor is given. It is clear that S8, the scenario where roads are taken into account as a percentage of the land use, is not a good simplification. Since buildings have a threshold value to be marked as 'inundated' of 1,5 feet, but roads are marked immediately as flooded, the total damaged area in S8 is a big overestimation of the reality. This is affirmed by the visual result, showing a lot of damaged area with a low cost per square meter.

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Although S7 scores very well for the total damage as well as for the total damaged area, the result is a lot less accurate than the benchmark map. This becomes clear when looking at Figure 11, that visualizes the deviation of the spatial difference of all scenarios in relation to S1. In this figure, three scenarios that test the influence of road data have the highest deviation and thus show significantly less detail in their damage map. Although the roads are negligible for the total damage and the damaged area, they are, nonetheless, an indispensable part in creating a visually accurate map.

Visually, as well as in total damage and damaged area, the difference between crops and banana plantains has a small effect on the results, as shown in Figure 11. It must be stated that this is the case for this case study of Annotto Bay, where building damage is the major type of damage. When looking into other regions, where agriculture has a more important role, the difference between crops can be a lot more significant for the results. This has to be further investigated.

Finally, S11 and S12 have shown the sensitivity of the flood model towards the input data type. In this case, all input data was converted to raster data. Although the visual result was similar to the benchmark, there was a clear difference in the total damage and the damaged area. Therefore, vector data has the preference when working in a relatively small study area. When some input data is vector and other raster data, it should be considered to vectorise the last type in order to avoid losing detail. This methodology will give the most accurate result.

54. Conclusion

In industrialized countries, several risk-based flood tools were developed to predict and estimate the damages caused by inundations. Although, a lot of detailed data is fed as input for these models, a certain degree of uncertainty is inherent and can never be fully be eliminated. However, such tools are constantly being optimized and are adopted for urban and rural planning in order to prevent damages from future inundations caused for instance by climate change or high degrees of urbanization.

In developing countries the detailed data needed by these models is not available. Therefore, to determine if the methodology used in the developed countries can be transferred to developing countries, it is necessary know what the sensibility of the models is towards the input data.

For this research, a risk-based model based oninspired by the Flemish LATIS was used for the case study of Annotto Bay. The results show that it is indeed possible to reduce the level of detail substantially, without adding significantly to the model uncertainties.

Since the 2001 flood especially hit the urban areas of Annotto Bay, the building data was the most significant type of data in this study. The scenario that uses the population density and the average number of people living in one buildingper household to calculate the number of buildings as a simplification for the exact location of the buildings produced the best results. The deviation of the total damage cost was only 7% in comparison to the benchmark. As the population data is globally availability, in many cases for free, this is an important finding that can be transferred for case studies in other areas. It must be stated, however, that an accurate number of people per household is indispensable in this scenario.

~~This sensitivity analysis of the Annotto Bay flood model is a first step in determining which data are indispensable in the risk assessment.~~ To do so, a benchmark model was created, using all available data to generate a result as accurate as possible. The damage map of this scenario 1 was used to compare with 11 other scenarios, each with a different combination of data. By comparing the visual result and the total damage and damaged area, the sensitivity of the flood risk model towards the different data could be determined.

Since the 2001 flood especially hit the urban areas of Annotto Bay, the building data was the most significant type of data in this study. The best result with simplified data was retrieved from the scenario that uses population density as input data, as well as the estimation average of 3 people living in one building. In the resulting damage map, the high risk areas were correctly indicated and a good level of detail was achieved. The total damage cost was 7% more than the cost of S1, but in light of the significant share of building damage, this is still a satisfying result. Furthermore, the global availability of population data, in many cases for free, is an important factor to take into account when applying the flood risk model in other regions. It must be stated, however, that an accurate number of people per household is indispensable in this scenario.

Another finding of this study is the importance of road data. ~~Furthermore, the importance of road data was proven in this study.~~ Although ~~the~~ roads have a small effect on the overall cost, they do have a role in the visual end result. An accurate road dataset helps to divide the land use, and to determine the building damage more precisely. In this light, the possibility of using remote sensing images to create road datasets must be investigated, since many available datasets do not include all roads. When using satellite imagery, the road classes cannot be taken into account, but this has been proven to have little impact on the result. Furthermore, a~~A~~ complete dataset can definitely help in defining building damage, since every building must have access to a road and will thus ~~be~~ most likely be located close to this road. Combining this information with population data should be investigated further.

~~must definitely be investigated.~~

No conclusions could be made from the sensitivity analysis towards crop data, because, in this case study, the impact was too small. The results showed little difference between the benchmark scenario, ~~were very positive, showing little difference between S1,~~ where crops and banana plantains were treated separately, and the scenario where an average cost was used. To further investigate the impact of crop data, a more rural area should be investigated. However, it can already ~~there can~~ be concluded that the difference between crops and banana plantains can be eliminated in ~~a~~ study area s where ~~especially the~~ urban areas are most affected by flooding.

Finally, the data type plays an important role in the accuracy of the final result of a risk assessment. Using raster data, from satellite imagery for example, causes an overestimation of the~~in~~ total damage and the damaged area~~.~~, due~~~~ to the resolution, which causes loss of information detail. Therefore, satellite imagery should always be vectorised before using it as input data in the risk methodology. ~~Vector data should thus be used when possible. If some input data is vector and other raster, vectorising the raster data is opted to avoid losing information or detail.~~ In further research, more types of raster data with different resolutions should be tested, as well as combinations of raster and vector data.

This sensitivity analysis of the Annotto Bay flood model gives an indication is a first and important step in determining to which data is indispensable and which data can be adapted, replaced or ignored in a risk assessment. Although the road damage has a small impact on the overall damage cost, this data type is indispensable for an accurate visual result. Furthermore, it is shown that population density data, in combination with an average number of people in a household, is an adequate replacement of the exact housing locations as input data for building damage. However Nonetheless, more research should be done in other regions to validate the results of the sensitivity analysis and to investigate the impact to the damage types in different situations.

This sensitivity analysis of the Annotto Bay flood model is a first and important step step in determining which data are indispensable in the risk assessment.

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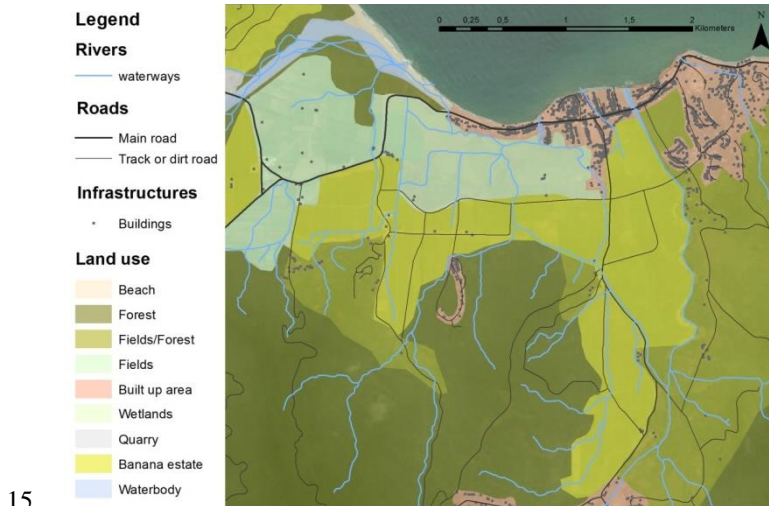
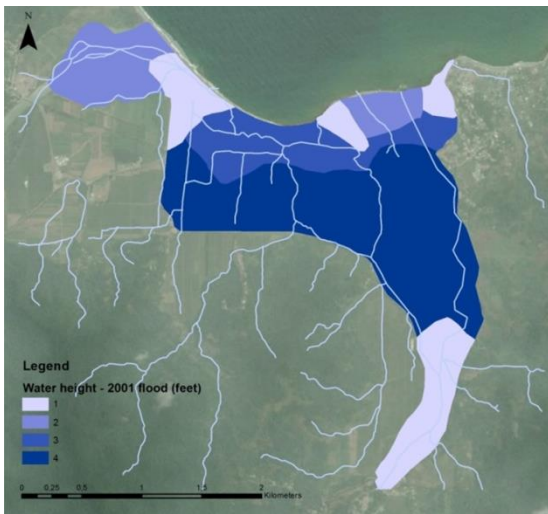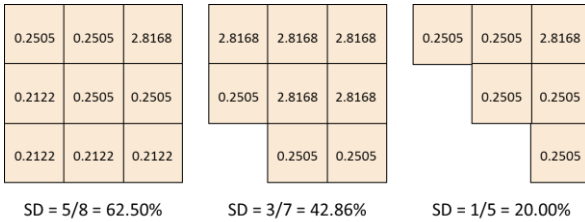**Figure 1: Situation map Annotto Bay, Jamaica (Glas et al, 2015)**

Figure 2: Flood extent of 2001 inundations caused by Tropical Storm Michelle in Annotto Bay, Jamaica (Glas et al, 2015)

0.2505	0.2505	2.8168
0.2122	0.2505	0.2505
0.2122	0.2122	0.2122

SD = 5/8 = 62.50%

2.8168	2.8168	2.8168
0.2505	2.8168	2.8168
	0.2505	0.2505

SD = 3/7 = 42.86%

0.2505	0.2505	2.8168
	0.2505	0.2505
		0.2505

SD = 1/5 = 20.00%

5   **Figure 3: Calculation of the spatial difference (SD) of three center pixels with SD = {number of neighboring pixels with different value} / {number of neighboring pixels}**
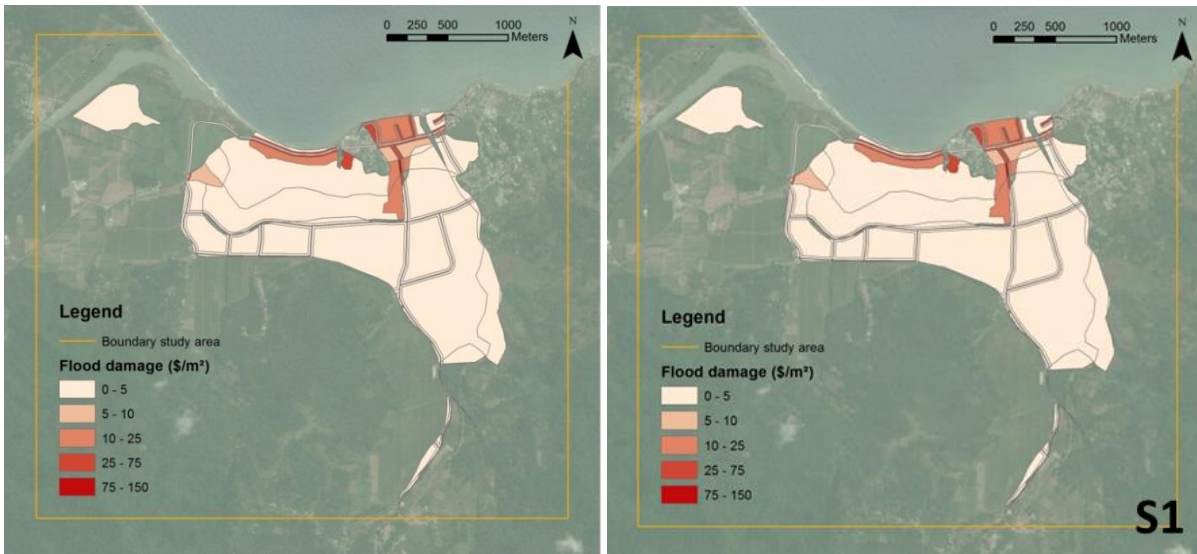
Figure 4: Scenario 1 (S1): Benchmark damage map of Annotto Bay, using all available input data
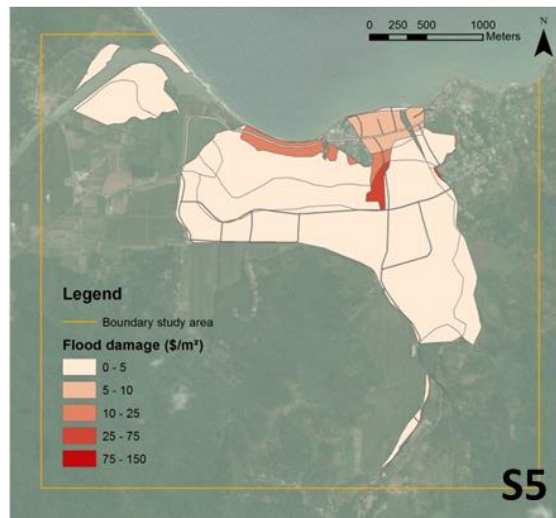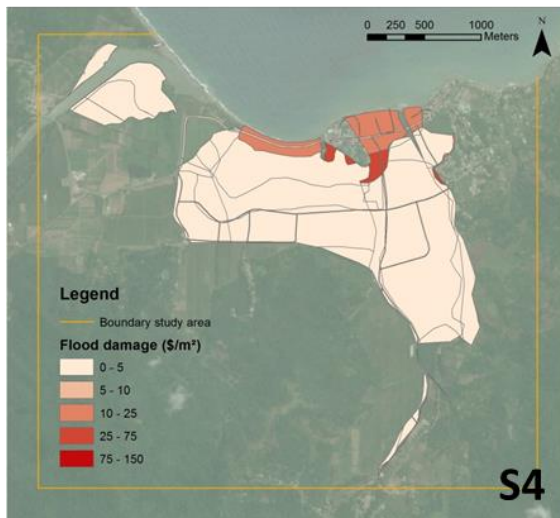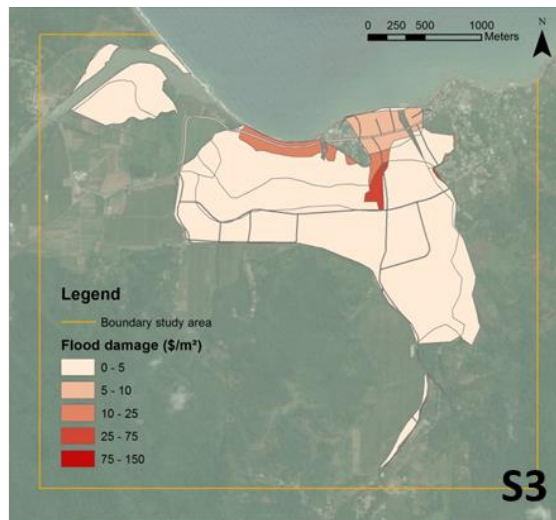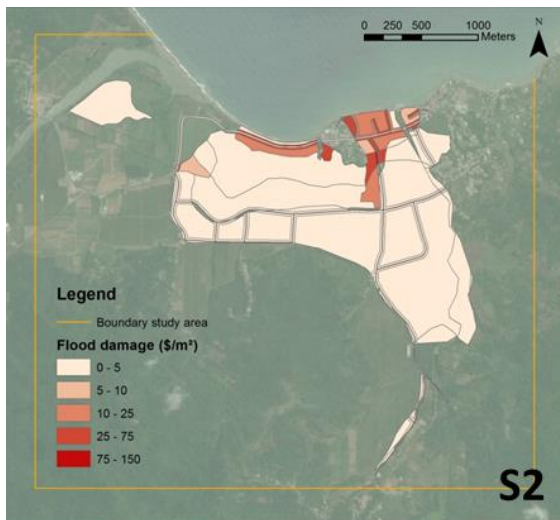
Figure 5: Damage maps for Annotto Bay for S2, S3, S4 and S5. (Top left: (S2) Building materials and number of floors unknown, Top right: (S3) Building locations, materials and number of floors unknown, Bottom left: (S4) Building density is calculated based on population density, Bottom right: (S5) Building density is calculated based on number of people in study area.)
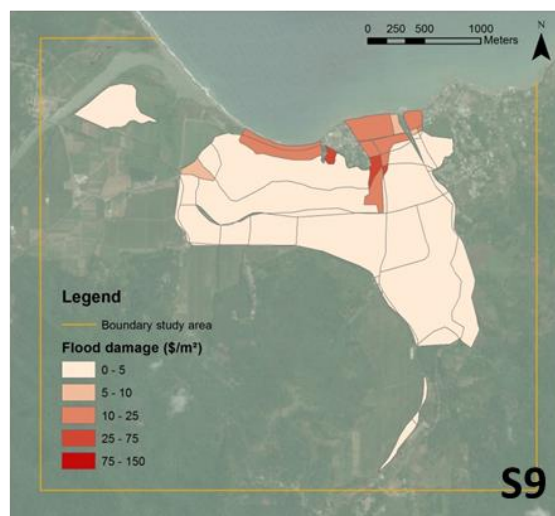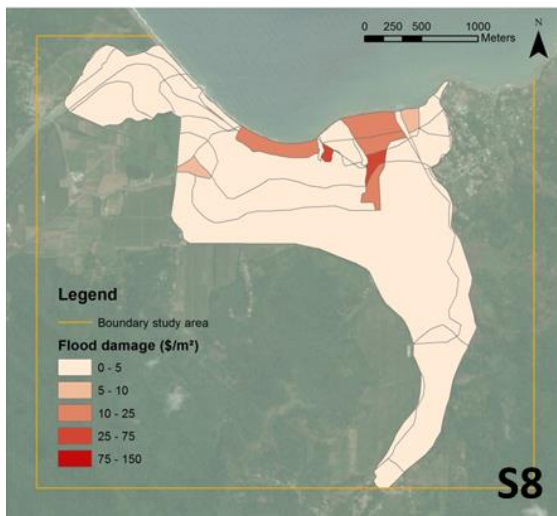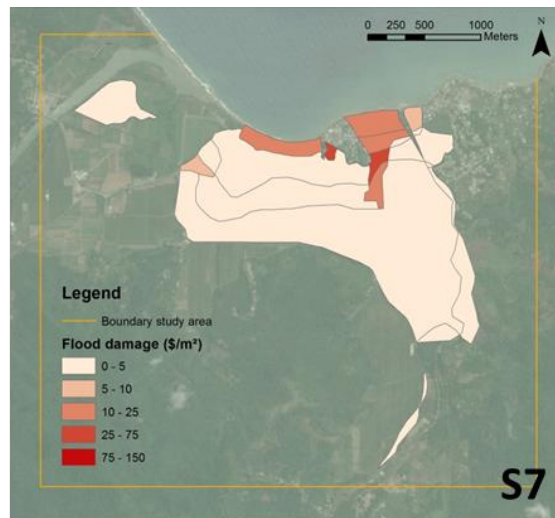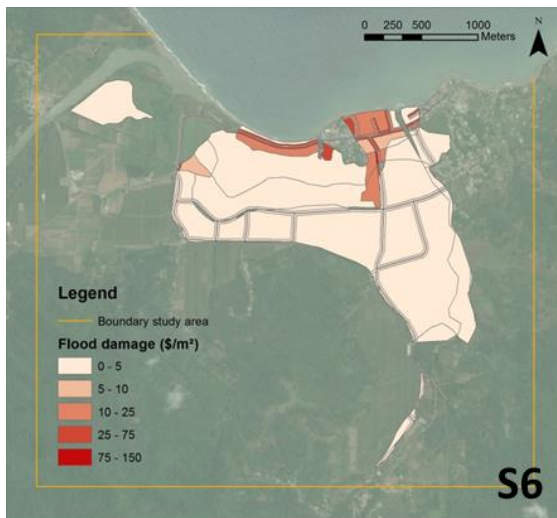
Figure 6: Damage maps for Annotto Bay for S6, S7, S8 and S9. (Top left: (S6) Road classes are unknown, Top right: (S7) All roads are unknown and not taken into account, Bottom left: (S8) All roads are unknown but taken into account as a percentage of land use, Bottom right: (S9) Roads are only used to divide land use polygons – no road damage.)
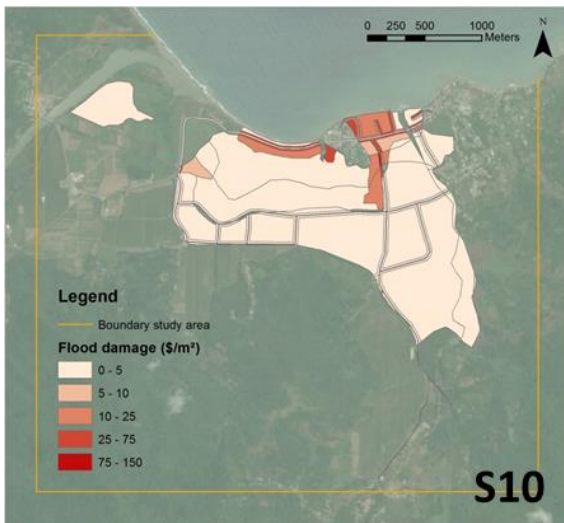
Figure 7: Damage map for Annotto Bay for S10 (Difference between banana plantains and other crops is unknown.)
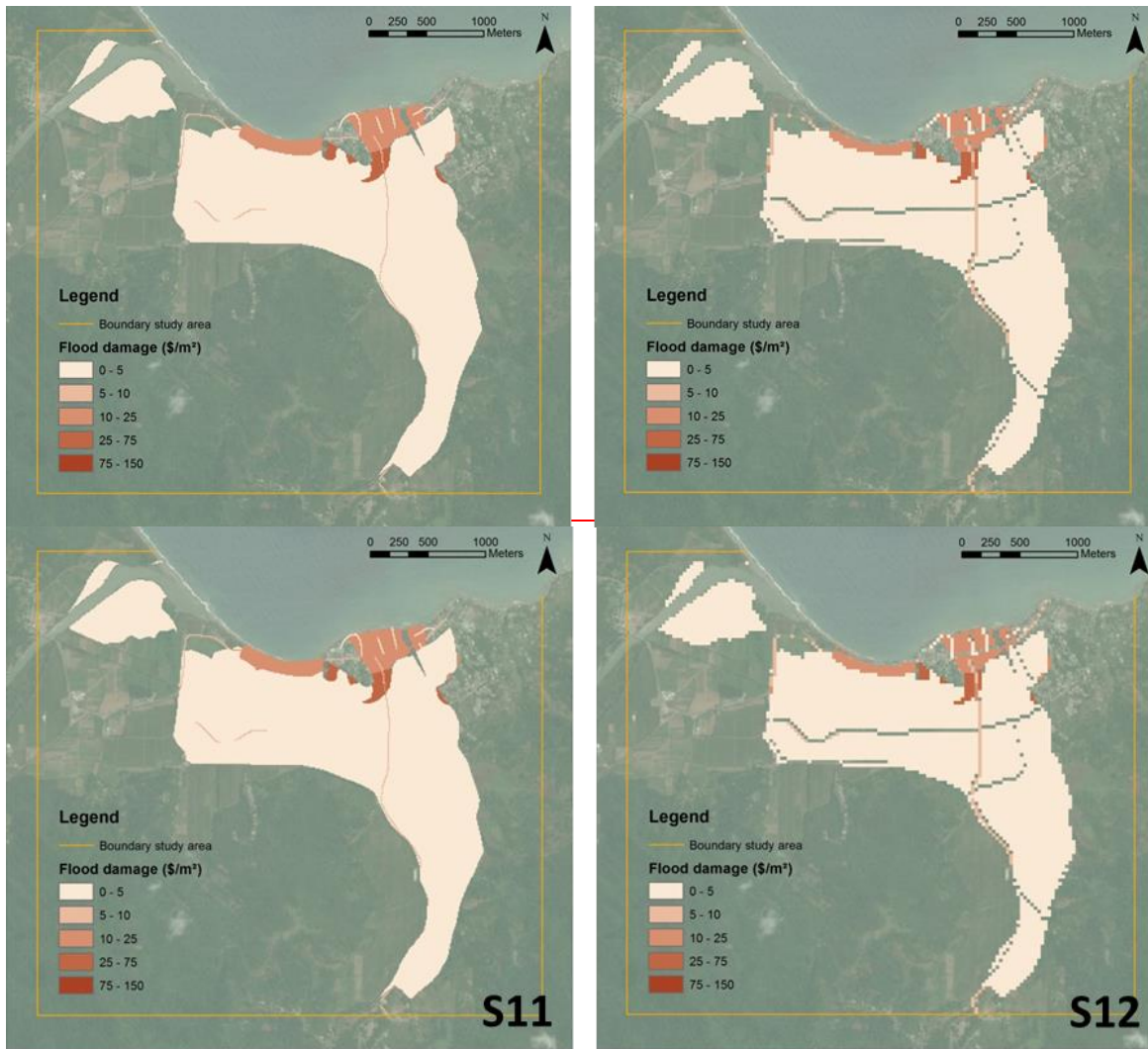
Figure 8: Damage maps for Annotto Bay for S11 and S12. (Left: (S11) Raster approach (10x10) based on population density, Right: (S12) Raster approach (30x30) based on population density.)
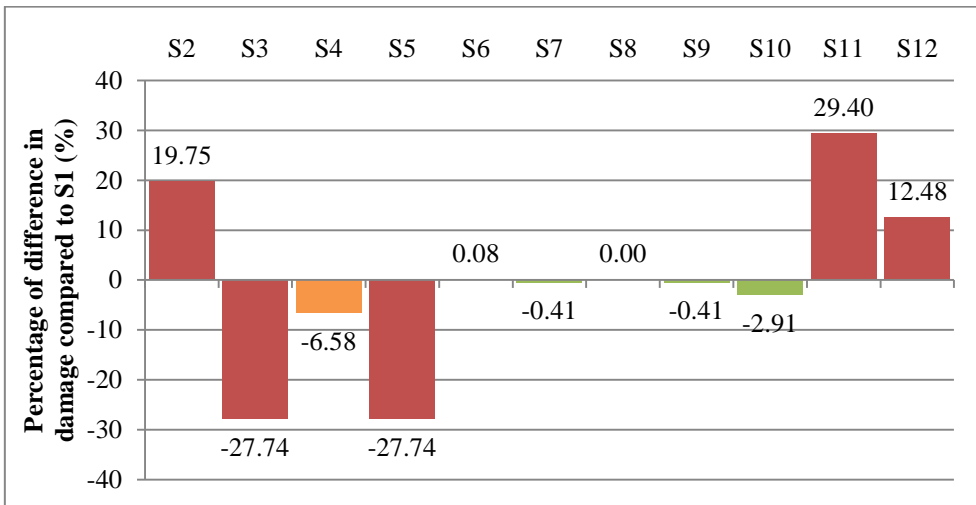
Figure 9: Deviation of total damage of all scenarios in relation to S1 (=0)
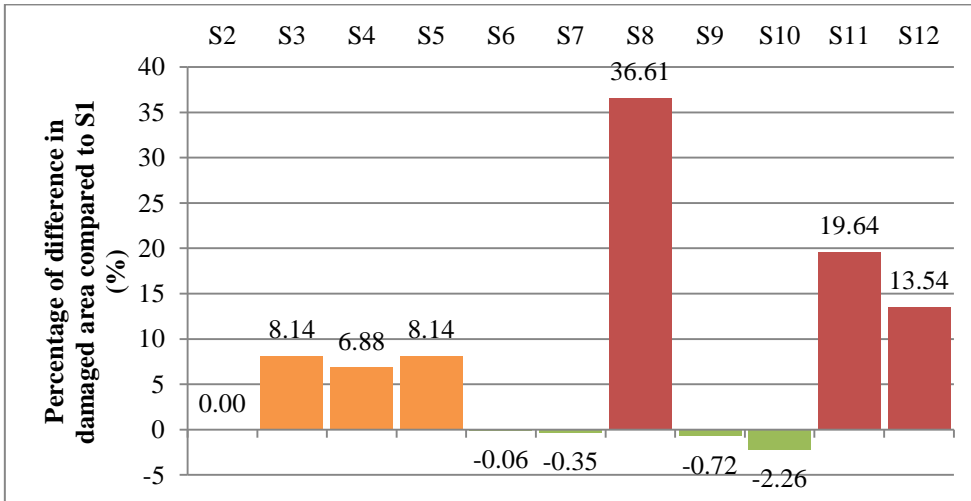
5   **Figure 10: Deviation of total damaged area of all scenarios in relation to S1 (=0)**
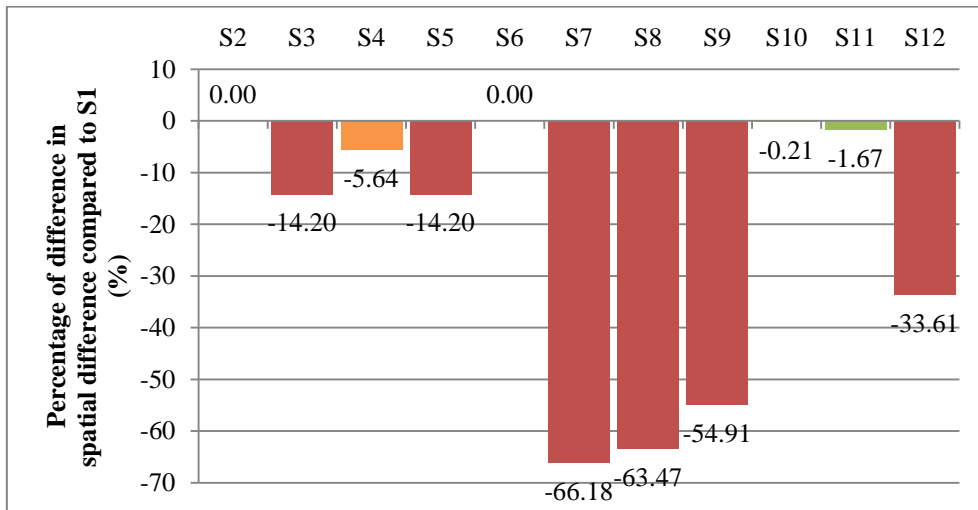
Figure 11: Deviation of spatial difference of all scenarios in relation to S1 (=0)

**Table 1: Data used in the Annotto Bay flood risk assessment (Glas et al., 2015)**

DATA	TYPE	SOURCE
Landuse	Polygon	NLA (2001) + update based on DigitalGlobe satellite imagery (2010)
Roads	Polyline	ODPEM (2013a)
Buildings	Point	ODPEM (2013a)
Population density	Polygon	Statistical Institute of Jamaica (2012)
Average crops values	Table	FAOSTAT (2014)
Average building values	Table	ODPEM (2013a)
Critical buildings	Point	ODPEM (2013a)
2001 Flood extent	Polygon	ODPEM (2001)
Damage functions	Table	Dutta et al. (2003)

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Table 2: Overview of investigated scenarios in the sensitivity analysis

SCENARIO	DESCRIPTION	USED INPUT DATA
S1	**Detailed approach**	Land use data Roads (classes) – line 2001 flood data Building locations + materials + number of floors
S2	**Building materials and number of floors unknown**	building locations average material values average number of floors
S3	**Building locations, materials and number of floors unknown**	number of buildings known presumed to be equally spread in the urban area
S4	**Building density is calculated based on population density (3 people per building)** Population density is used to determine number of buildings in statistical sectors	
S5	**Building density is calculated based on number of people in study area (3 people per building)** Number of people in the study area is used to determine number of buildings	
S6	**Road classes are unknown** Average values for the width and the cost of the roads are used	
S7	**All roads are unknown and not taken into account** No roads data is used	
S8	**All roads are unknown but taken into account as a percentage of land use** (5% in urban areas, 2% in rural areas) No roads data is used, but the damage is calculated based on a percentage of land use	
S9	**Roads are only used to divide land use polygons – no road damage** Roads are used as a division tool, not to calculate damage	
S10	**Difference between banana plantains and other crops is unknown** In the damage calculations, the same damage factors and maximum costs are used to determine the cost of the crops and the banana plantains	
S11	**Raster approach (10mx10m) based on population density** All input data (vector) is converted to raster data with a resolution of 10 meters	
S12	**Raster approach (30mx30m) based on population density** All input data (vector) is converted to raster data with a resolution of 30 meters	

Table 3: Overview of the input data used per scenario

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Building locations	✓	✓				✓	✓	✓	✓	✓	✓	✓
Number of floors	✓					✓	✓	✓	✓	✓	✓	✓
Building material	✓					✓	✓	✓	✓	✓	✓	✓
Average building values	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Critical buildings	✓	✓					✓	✓	✓	✓	✓	✓
Number of buildings			✓									
Population density				✓								
Number of people					✓							
Roads	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓
Road classes	✓	✓	✓	✓	✓	✓				✓	✓	✓
Average road values	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓
Landuse data	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Banana plants - crops	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Average crop values	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2001 Flood extent	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Damage functions	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 4: Calculated total damage, total damaged area and spatial difference for S1

	TOTAL DAMAGE ($)	TOTAL DAMAGED AREA (m²)	SPATIAL DIFFERENCE ~~(%)~~
S1	7 490 000	3 182 000	0.04~~8.79~~

Table 5: Calculated total damage, total damaged area and spatial difference for S2, S3, S4 and S5 in comparison to S1

	TOTAL DAMAGE ($)		TOTAL DAMAGED AREA (m²)		SPATIAL DIFFERENCE ~~(%)~~	
S1	7 490 000		3 182 000		0.04~~8.79~~	
S2	8 969 000 ~~5 412 000~~	+19.75 ~~6 997 000~~ ~~5 412 000~~	3 182 000	+0.00	0.04~~8.79~~	+0.00
S3	5 412 000	−27.74	3 441 000	+8.14	0.04~~1.11~~	−14.20
S4	6 997 000	−6.58	3 401 000	+6.88	0.04~~5.52~~	−5.64
S5	5 412 000	−27.24	3 441 000	+8.14	0.04~~1.11~~	−14.20

Table 6: Calculated total damage, total damaged area and spatial difference for S6, S7, S8 and S9 in comparison to S1

	TOTAL DAMAGE ($)		TOTAL DAMAGED AREA (m²)		SPATIAL DIFFERENCE ~~(%)~~	
S1	7 490 000		3 182 000		0.04~~8.79~~	
S6	7 496 000	+0.08	3 180 000	−0.06	0.04~~8.79~~	+0.00
S7	7 459 000	−0.41	3 171 000	−0.35	0.01~~6.62~~	−66.18
S8	7 490 000	+0.00	4 347 000	+36.61	0.01~~8.75~~	−63.47
S9	7 459 000	−0.41	3 159 000	−0.72	0.02~~2.16~~	−54.91

Table 7: Calculated total damage, total damaged area and spatial difference for S10 in comparison to S1

	TOTAL DAMAGE ($)		TOTAL DAMAGED AREA (m²)		SPATIAL DIFFERENCE ~~(%)~~	
S1	7 490 000		3 182 000		0.04~~8.79~~	
S10	7 272 000	−2.91	3 110 000	−2.26	0.04~~8.78~~	−0.21

Table 8: Calculated total damage, total damaged area and spatial difference for S11 and S12 in comparison to S1

	TOTAL DAMAGE ($)		TOTAL DAMAGED AREA (m²)		SPATIAL DIFFERENCE ~~(%)~~	
S1	7 490 000		3 182 000		0.04~~8.79~~	
S4	6 997 000	−6.58	3 401 000	+6.88	0.04~~5.52~~	−5.64
S11	9 692 000	+29.40	3 807 000	+19.64	0.04~~7.71~~	−1.67
S12	8 425 000	+12.48	3 613 000	+13.54	0.03~~2.18~~	−33.61