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Crowdsourcing and interactive modelling for urban flood management

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Abstract

Participatory modelling has become a growing concept in environmental modelling, as it allows stakeholders to be involved in various stages of model development. The majority of studies, however, have focused on the participation during model use for scenario analysis and strategy evaluation after the model has been developed. Large-scale community mapping efforts create new opportunities to establish, detail and improve flood models at the development stage by working together with local stakeholders. In this article, we propose a novel participatory modelling and mapping approach. It builds on the community mapping projects across the most vulnerable wards in Dar es Salaam, Tanzania, which uses OpenStreetMap as a data platform. The approach consists of community mapping, an automated flood inundation model development and facilitation of stakeholder involvement. The participation of stakeholders in data collection helped achieving a more accurate flood model. The participatory modelling approach made participants aware of the skills necessary to develop an urban flood model with OpenStreetMap, necessary for creating a resilient society. The level of improvement obtained through the applied participatory modelling and mapping approach demonstrates its value in hydrodynamic model development and its potential for application in data scarce areas prone to urban floods.

KEYWORDS

disaster risk reduction, hydraulic modelling, public engagement, urban drainage

1 | INTRODUCTION

The Sendai Framework for Disaster Risk Reduction 2015–2030 adopted by the United Nations and led by United Nations International Strategy for Disaster Reduction (UNISDR) highlights the significant role of stakeholders and the use of modelling tools in Disaster Risk Reduction (DRR) (UNISDR, 2015). Flood risk assessment is often done based on first, flood hazard simulations by using flood models schematised with different data, including elevation, and forced by river flow data from observations or hydrological models in the area concerned (Kollinger et al., 2003). The outputs, generally referred to as hazard layers are then used for flood risk mapping

(Apel, Thieken, Merz, & Blöschl, 2004; Lin, Wicks, Falconer, & Adams, 2006; Pelling & Wisner, 2012; Schanze, 2006; Ward et al., 2013; Winsemius et al., 2015) by combining these with exposure data and vulnerability functions. The involvement of local stakeholders becomes a necessity for locally accepted and fully supported model results. It is also valuable in the formulation of numerous flood risk management alternatives, and the identification and evaluation of policies (Maskrey, Mount, Thorne, & Dryden, 2016). This makes participatory modelling a powerful tool for informed decision support systems (Basco-Carrera, Warren, van Beek, Jonoski, & Giardino, 2017; Voinov & Bousquet, 2010).

Citizens are progressively becoming aware of the fact that they are capable of providing input to the development of models and in the planning process, requiring improvement in the traditional model development approach (Voinov et al., 2016). Additionally, flood related problems are frequently associated with several objectives and are multi-disciplinary (Almoradie, Cortes, & Jonoski, 2015; Jonoski & Evers, 2013). As a result, the involvement of citizens and stakeholders in collecting data, developing models and decision support systems has become of key importance (Assumpção, Popescu, Jonoski, & Solomatine, 2018; Sy, Frischknecht, Dao, Consuegra, & Giuliani, 2019).

Effective implementation of stakeholder engagement much dependent on the context in which it is applied (Arnstein, 1969; Hurlbert & Gupta, 2015). Recently, to foster stakeholder involvement in environmental modelling, participatory modelling has been applied in several cases; such as: improving partnerships and conflict management (Martínez-Santos & Andreu, 2010; Suwarno & Nawir, 2009); environmental planning (Beierle & Konisky, 2000; Ritzema, Froebrich, Raju, Sreenivas, & Kselik, 2010); flood risk management (Almoradie et al., 2015; Evers et al., 2012; Evers, Jonoski, Almoradie, & Lange, 2016; Jonoski & Evers, 2013); and groundwater modelling (Tidwell & Van Den Brink, 2008). These contributions demonstrate that so far, the participatory modelling approach has been used in the application phase rather than in the actual model development phase. Specifically, little has been done using the knowledge of stakeholders in data collection, development and improvement of an urban flood model. This may be particularly important in areas where there is little or no formal data available to build a hydrodynamic model.

An urban flood model requires various types of data for schematization, such as a high resolution Digital Terrain Model (DTM) (Boonya-Aroonnet, Maksimovic, Prodanovic, & Djordjevic, 2007; Meesuk, Vojinovic, Mynett, & Abdullah, 2015) and drainage network layout and various infrastructures, including roads, buildings and waterways which affect the flow in the city (Leandro, Chen, Djordjević, & Savić, 2009; Mark, Weesakul, Apirumanekul, Aroonnet, & Djordjević, 2004; Phillips, Yu, Thompson, & de Silva, 2005); and for driving the model, such as upstream and downstream boundary conditions and rainfall data (Chen, Hill, & Urbano, 2009; Vojinovic & Tutulic, 2009). Many countries do not have accurate flood models due to the limited availability of such required data at the right level of detail to encapsulate the complex nature of urban settings (Dutta, Herath, & Musiake, 2001; Farid, Mano, & Udo, 2011; Sanyal & Lu, 2006; Tellman, Saiers, & Cruz, 2016). Furthermore, developing such computer-based models demands certain skills and knowledge regarding representation of the real physical system in the model. Finally, in addition to the lack of technology and skills, poor collaboration among stakeholders may hinder the development of these types of models in data scarce environments. Participatory modelling is then proposed to alleviate some of these problems, but it needs to be planned and applied carefully. This means that there should be a clear stakeholder engagement structure, based on extensive analysis of stakeholders and their skills and level of understanding about the system in question. This is a pre-requisite for quality assurance of the developed model (Martínez-Santos & Andreu, 2010). The work presented here demonstrates that with a well-structured participatory modelling approach, it is possible to co-develop inclusively an urban flood model, even in areas that are in the initial stage data-scarce.

OpenStreetMap (OSM) is one of the recent geospatial developments being used worldwide with a strong focus on community participation (Haklay & Weber, 2008; Mooney, Corcoran, & Winstanley, 2010; Neis & Zielstra, 2014). It has a goal of developing an openly editable map of the world to overcome the lack of geo-information that exists in large part of the globe (Haklay, Antoniou, Basiouka, Soden, & Mooney, 2014). This study describes how OSM data can be used as an input for developing an urban flood model in Dar es Salaam with the support of local communities to compensate for the existent shortage of formal data. Results from the study corroborate the findings from many researchers who argue that involving communities in map development not only solves data scarcity, but it also promotes environmental equity (Panek & Sobotova, 2015; Perkins, 2007; Weiner, Harris, & Craig, 2002; Wood, 2005). Participatory mapping can therefore result in capacity development and enriching open source data for developing urban flood models.

In this study, a method on how to develop an urban flood model using semi-automated schematisation based on community mapped data is presented. The aim of the study is to obtain potential model improvements by working together with the local stakeholders, following a participatory modelling approach. The approach is limited to data collection for model schematization and improvement. In section 2, we describe the generic participatory modelling framework and method.

2 | METHOD

This study formulates a new participatory modelling method that integrates the development of a flood model with community-based data collection. It develops and applies a framework for participatory urban flood modelling based on, an iterative data collection process with a major role for the community and the stakeholders in the area concerned. The work aims at developing a 1D-2D coupled urban flood model and is formulates, tested and applied within Dar es Salaam, Tanzania (section 3). The modelling approach combines a one-dimensional (1D) model to simulate the flow through the drains, rivers and streams, with a two-dimensional model (2D) to represent the flow over the surface within floodplains and neighbourhoods surround rivers and streams.

The new framework for participatory urban flood modelling represents an interactive process that provides guidance on how to collect and improve OSM data through community mapping (crowdsourcing). It provides a practical approach on how experts can interact with the community members/citizens. The framework is summarised in Figure 1 and consists of the following iterative steps: community mapping, data collection, data quality control and identification of data gaps. The main objective of the framework is interactive data collection for purposes of model schematization and simulation.

2.1 | Community mapping

Community mapping or "crowdsourcing" has been widely used for data collection. It has been especially successful for OSM development in many countries, including in Africa. Some exemplary cases include: mapping of Kibera informal settlement in Kenya (Panek & Sobotova, 2015), mapping the newly created nation in South Sudan (Haklay et al., 2014); and iCitizen, mapping service delivery in South Africa (Haklay et al., 2014). Furthermore, mapping urban areas using crowdsourcing has become a successful way to develop open source data for slum and informal settlements.

"Crowdsourcing" is a process of attaining information from many involved contributors ("crowd"), regardless of their skill level and background (Haklay et al., 2014; Le Coz et al., 2016; Wang, Mao, Wang, Rae, & Shaw, 2018). One of the biggest advantages of this data collection technique is that it enables to work collaboratively with non-technical members of the community. This includes people who have extensive knowledge of the area, such as the location of infrastructure (e.g., waterways, roads and buildings). Some other advantages of crowdsourcing are: affordability (cheap cost), accessibility, faster way of collecting data, and its variety (Gao, Barbier, & Goolsby, 2011; Li, Huhns, Tsai, & Wu, 2016). However, it has its own major shortcomings. As the participants are less qualified, the collected data may have quality issues. One way of monitoring this problem is by applying proper training and data quality control, so that the collected data can be filtered and useful. "Mappers" need to clearly understand "what, where, how and why" to map a certain feature. Clarifying the idea on how water moves in the city can help the mappers to understand why those features must be mapped and incorporated into the flood model. Additionally, agreed upon data

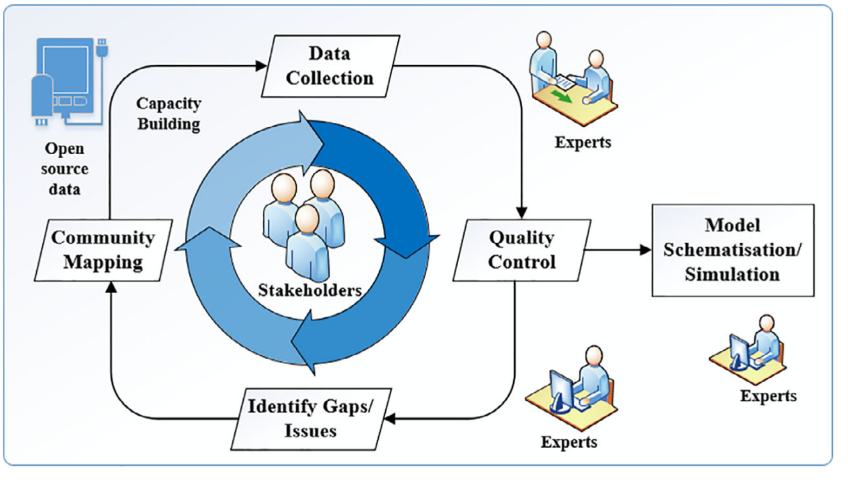

FIGURE 1 Framework for participatory urban flood modelling

model and local tools should be added to perform the mapping. Another shortcoming of this approach is that the participation is often limited to one-way data collection (Voinov et al., 2016). It is rare that the participants in data collection eventually get to discuss the obtained results. We here present an iterative data collection approach that can improve data quality and allows the participants to see and discuss the obtained results.

2.2 | Data collection

A major challenge for stakeholder participation is launching and maintaining the participatory process (Almoradie et al., 2015). For successful data contribution and usage of OSM, the data collection process requires an established community mapping in the area. Information from OSM can be used for developing the 1D-2D urban flood model. Therefore, the focus of the community mapping is on identifying, as well as gathering new data (e.g., information about features such as various waterways, buildings, and roads).

The iterative modelling process commences with the construction of an initial urban flood model (i.e., the prototype) using the existing OSM data. Assumptions can be made for any missing information about the existing waterways within the concerned area. The second iteration steps aim to improve the model with the engagement of local stakeholders. Stakeholders and local community interviews help to identify frequently flooded areas and evaluate the data assumed in the initial model development. A reconnaissance survey and field visits to the flood prone areas with the mapping group facilitates the data improvement process by comparing existing OSM data and field data.

2.3 | Quality control and identification of gaps

Quality control is one of the most significant steps in data collection, particularly to ensure that collected information is reliable and accurate (Li et al., 2016; Poser & Dransch, 2010; Wan et al., 2014). It can be obtained by going through an iterative process and by acquiring a high response rate from the contributors (Haklay et al., 2014). An established community mapping initiative conducts quality control for OSM. This initiative applies data collection according to the data model (i.e., list of detailed classification of features), digitization using Java OSM editor, data review (based on daily survey level) and municipality level data review, which may loop back to daily survey level, as spot checks are done and data is corrected (Bank, 2016). The process is combined with field visits carried out by the community mapping team. Data checks using the data model and resurveying help the mapping team to identify gaps and correct errors in their mapping. The assistance of OSM mapping expert is recommended.

2.4 | Model schematisation and simulation

Data collected by community mapping can be used for preparing the model schematisation. It represents the relevant physical features in a schematic form (as close to reality as possible). The process of refining the model through data preparation and schematisation is iterative. Model schematisation includes identifying external forces, setting up the cross-section profiles, preparing the network layout and its various structures. The schematisation technique depends on the type of software package that is used to construct the urban flood model. There are various hydrodynamic models that simulate flow through an urbanised area, including HEC-RAS (Brunner, 2002), MIKE URBAN (Bisht et al., 2016) and D-Flow FM (Castro Gama, Popescu, Mynett, Shengyang, & Van Dam, 2013). Defined workflow which uses the geometries and attributes from OSM data to translate the OSM data into a 1D-2D schematization is essential.

3 | CASE APPLICATION: MANZESE WARD FLOOD RISK ASSESSMENT

3.1 | Study area

Dar es Salaam is the largest city in Tanzania, with a population of 4.4 million. It is also the country's economic centre. Over the last 20 years, the land use has been significantly changed, primarily with urbanisation, resulting in informal and unplanned urban settlements with poor infrastructure (Kombe, 2005). This is leading to high vulnerability to flooding. Rapid urban growth and lack of resources still remain critical issues for the city (Hambati, 2014; Hambati & Gaston, 2015). Various recent studies and projects were carried out to provide an accurate mapping of the city and assessing flood risk. In 2015, Hambati and an established community hazard mapping team conducted a flood risk assessment in Dar es Salaam (Hambati & Gaston, 2015). Results of the evaluation show that flooding (i.e., pluvial and fluvial floods) represents the primary hazard in Dar es Salaam.

Programs such as Tanzania Urban Resilience Program (TURP) employ strategic measures to improve Tanzania's resilience against climate and disaster risk (Bank, 2018). In 2016, technical assessment to study the flooding condition in Dar es Salaam was conducted by Deltares, with the financial support of the World Bank (WB) (Winsemius et al., 2016). The project outcome shows that the city is prone to regular flooding. Even though the city has severe weather warnings, there is a lack of flood warnings and response actions that are taken by the local authorities and stakeholders. Lack of planning and coordination among the stakeholders combined with limited budget allocated to preparedness and response are key challenges that the local stakeholders face. Particularly, most of the budget is allocated to recovery, rather than preparedness. Moreover, disseminating accurate and timely release of early warning information is further hindered due to limited skilled human resources, technology and equipment. Despite the recent initiatives to enhance the coordination among stakeholders and communities, considerable work remains towards continuous collaboration and participation among the stakeholders.

Manzese ward in Dar es Salaam is selected as a pilot area to establish this study (Figure 2).

3.2 | Participatory urban flood modelling approach

Mapping cities with citizens has spread widely in different places through participatory mapping approach (Chambers, 2006), including in Tanzania. In Dar Es Salaam, the coordination with stakeholders and the communities for managing and planning the city has been adopted since 1992, with the technical assistance from UNCHS (Halla, 1994). This engagement was proven to be effective during the community mapping initiative in Tandale, in Dar es Salaam, as part of the community mapping project "Ramani Huria" in 2011 (Iliffe, 2015). In Manzese ward, the Ramani Huria community mapping project implemented in 2015 supported the consolidation of the mapping community and the extension of the OSM for the area. The project was supervised by the World Bank and Tanzania Red Cross Society (TRCS) and is aimed at mapping most of the city through public participation. The mapping focused on items related to flood hazard, exposure and vulnerability, including buildings and building taxonomy, (critical) infrastructure, and flood zones.

The participatory modelling employed in this study builds on these prior experiences with community mapping. Similar organisational and individual stakeholders have been mobilised, now with the objective of

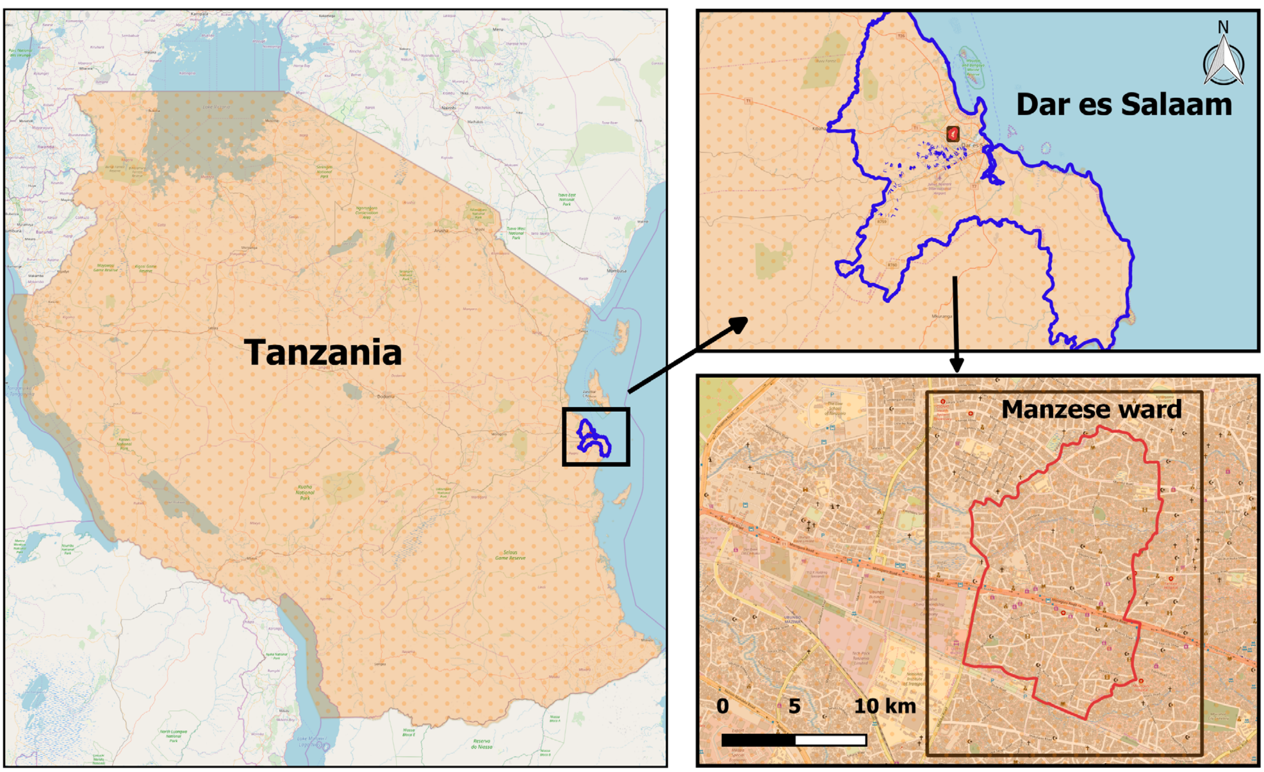

FIGURE 2 Location of Manzese ward and the model domain area, Dar es Salaam, Tanzania

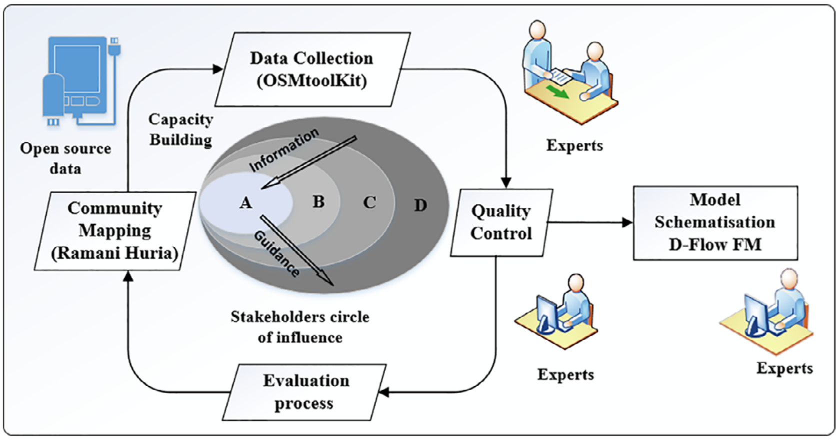

FIGURE 3 Manzese ward participatory urban flood modelling framework

developing an improved urban flood model. The adopted participatory urban flood modelling framework for Manzase Ward is illustrated in Figure 3 with specific case study context filled out. Principal element of the participatory approach is structuring the involvement of local stakeholders in the process of model development.

Engagement of stakeholders was with two main approaches, based on the results from the stakeholder analysis. The ladder of participation from Arnstein (Arnstein, 1969) was used for defining the possible levels of participation. The circles of influence approach (Cardwell, Langsdale, & Stephenson, 2008) were used for delimiting the tasks and activities of each stakeholder group. Four circles were distinguished as well as the relationship among them. These include: Circle A: Modelling team and organising team Circle B: Model user and improvement team, Circle C: Consulting and Mappers team, and Circle D: Decision-makers (Table 1). Twenty-five participants were involved from 13 organisations, including Silcon Builders Limited, Tanzania Red Cross Society, Disaster Management Department, World Bank, Humanitarian OpenStreetMap Team, Red Cross/Red Crescent Climate Centre, Tanzania Meteorological Agency, Ardhi University, University of Dar Es Salaam, Ministry of Water Resources, Ruvu river basin, Disaster Management Department, Centre for Community Initiative (NGO), Kinondoni Municipal councils, Dar Es Salaam city council, Ardhi University and Dar Es Salaam Region Office.

3.2.1 | Dar es Salaam community mapping and data collection

The consolidation of the Dar as Salaam community mapping is supported by the Dar Ramani Huria project. “Dar Ramani Huria” is a Swahili term for “Dar Open Map”. This project engages community members and local university students (i.e., University of Dar es Salaam and Ardhi University). The mapping team has the responsibility to collect data and map residential neighbourhoods, roads, rivers/streams, floodplains in the vicinity and other relevant critical infrastructure. This existing community mapping team was directly involved in the participatory modelling process. To support their task of mapping critical infrastructure, a tailor-made OSMtoolkit was developed with their collaboration. It provides guidance on the specific characteristics and features that need to be mapped. The Deltares experts developed the prototype with the established Open Street Mapping carried out by Ramani Huria community-based mapping in Manzese ward (Figure 4).

TABLE 1 Circles of influence approach used in Manzese ward

Circle	Stakeholders' group
A	• Red cross • Deltares
B	• World Bank • Universities (Dar Es Salaam & Ardhi)
C	• World Bank • HOT • Universities (Dar Es Salaam & Ardhi) • Non-Governmental organisations • Citizens organisations
D	• Provincial administrative authority • Provincial water resources authority

Features, including Ngombe River's and four other main drainages' cross-sections, were collected during the field survey. These collected data were updated in OSM and use to improve the model.

The modelling team was comprised of international and local groups, including professionals with knowledge in hydrology, hydraulics and spatial analysis. This included members of World Bank, Humanitarian

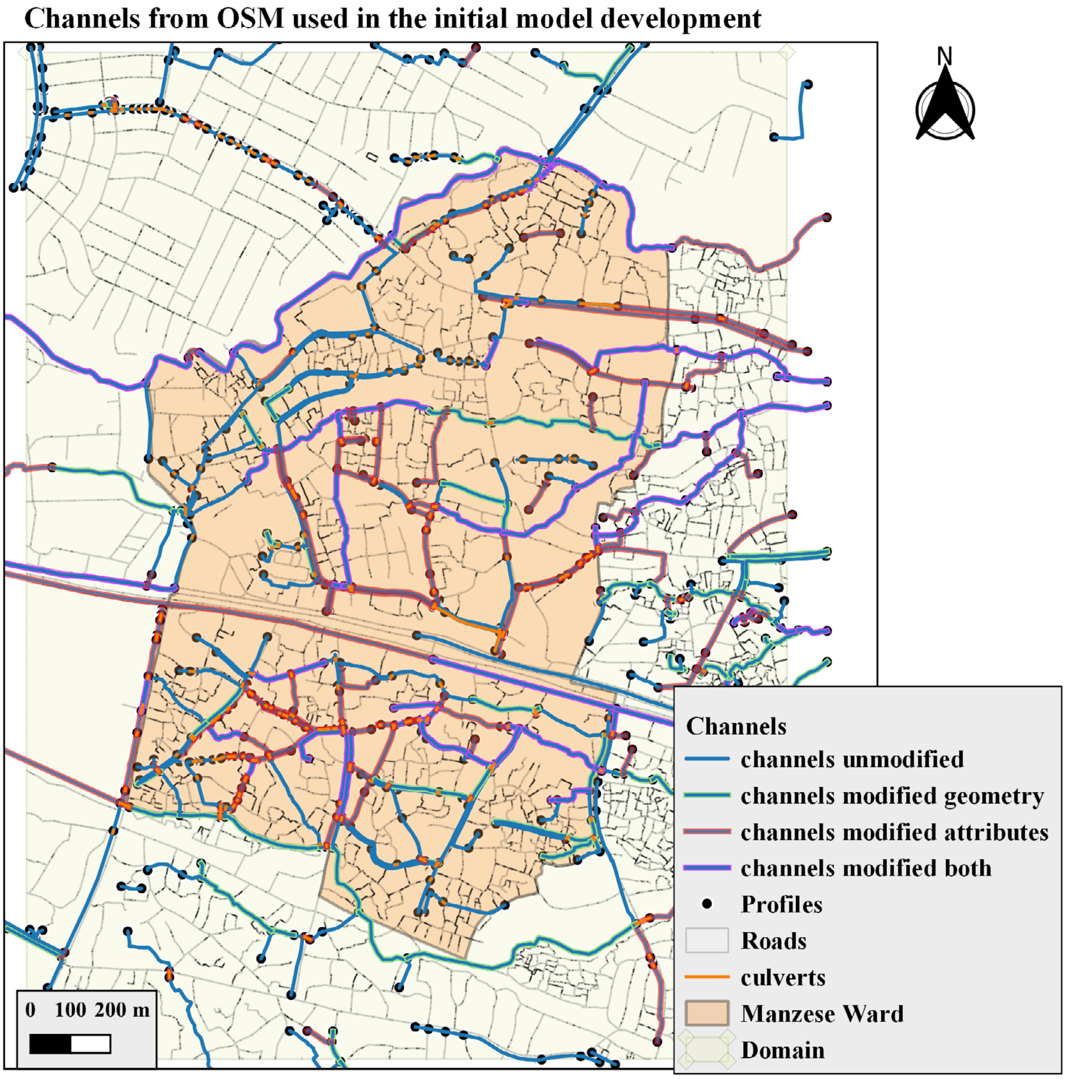

FIGURE 4 Initial OSM data used for the development of the prototype model

OpenStreetMap Team, university professors and students, local private consulting engineers and Deltares. The modelling team was involved in the validation of the model and they had tailored-made capacity building sessions on the development and use of the 1D-2D model.

3.2.2 | Data quality control and evaluation process

Three data collection methods were used in this study: interviews, a reconnaissance survey and a workshop to collect and evaluate data and model outputs. Interviews were conducted with community members to gather information about flood prone areas and infrastructure locations. A reconnaissance survey was conducted to validate the waterways' features previously collected via community mapping. The interviews were also used to identify and analyse dependencies between the stakeholders, investigate possible beneficiaries from the study and improve the stakeholder engagement process for data collection and model development. A stakeholder workshop was used to provide training to the mappers, modellers and community members about (a) flood modelling, (b) types of features that affect the flow in an urban environment, and (c) the characteristics and methods to map certain features such as drains, ditches, elevated roads and buildings.

The Ramani Huria data model is used to facilitate quality control which is continuously being updated.[1] The OSMtoolKit assisted the collection of data about the local waterway infrastructures. Evaluation of the information and the collection of new data to improve the model was carried out following the participatory data collection framework. The participatory mapping approached facilitated the improvement of data quality.

3.2.3 | Initial model schematisation

The initial model was constructed based on available OSM data, rainfall data time series from 1988 up to 2015 that were obtained from the Tropical Rainfall Measuring Mission (TRMM), two boundary inflows (i.e., Ngombe River and Mbokamu stream) that were developed using a unit hydrograph. TRMM rainfall data was used because of three main reasons: (a) lack of gauging data, (b) freely available, and (c) relatively longer time series to create a design storm. The model also included a 2 m resolution Digital Terrain Model (DTM) developed using Participatory Terrain Google Earth Engine (Deltares, 2017), spatially variable roughness based on the land use and 0.012 manning roughness values for the 1D open channels.

Semi-automated workflow is used to obtain values for key attributes (features dimensions) from the OSM datasets. The user can provide a default value for the missing information of various waterways. The available attributes of waterways or channel elements in OSM include ditch, stream, river and drain. Assumed values were provided for missing data, for instance to waterways depths and widths (as OSM only uses a rectangular profile type). Figure 4 illustrates the channels' status in the initial urban flood model for Manzese ward. Channels labelled in blue contain unmodified values. Green coloured channels are characterised with proper attributes, but assumed values were used for missing values. Red channels are defined with modified attributes. Lastly, both attributes and the geometry were modified for those channels coloured in purple. After engaging local stakeholders in mapping and modelling, the default values for some of the waterways and unmapped channels were improved.

The 2D simulation model was first evaluated and later coupled with the 1D model to include the drainages. Semi-automated workflow allowed participants to obtain a complete 2D model and all required inputs to build a 1D model from OSM. Finally, the two models were coupled to develop a completed 1D-2D model schematization. The computational time step was set to 30 sec, for better accuracy and numerical stability. The flexible mesh allows the user to have different grid sizes within the model. In this model, the size ranged from max 25 m – min 6.25 m. The external forcing of the model was a 100-year return period design storm. Upstream discharge of the rivers for the same return period was imposed over 24 hr of simulation period.

3.2.4 | Stakeholder workshop

The stakeholder workshop held on 21–23 of February 2017 in Dar Es Salaam had three main objectives. First, it was designed to be an interactive environment to further develop the technical knowledge regarding participatory mapping using OSM and urban flood modelling using D-Flow-FM. Second, it created the suitable inclusive environment to enhance the collaborative work between local stakeholders, mappers, modellers and the organising team. This propitiated the exchange of technical and local knowledge among them. Finally, the workshop focused mainly on continued training of the participants on what type of data to collect and how to bring open source data, such as OSM into an urban flood model.

Having a good insight into the existing technical and local knowledge about the area and the systems, including their understanding about hydrology and flood modelling, was a pre-requisite for designing the workshop. A semi-structured questionnaire survey was used to collect this information. This was followed by the analysis of the survey results.

A total of 25 water professionals and local stakeholders filled in the survey. Respondents had diverse backgrounds: community representatives with social science background, disaster managers, university professors and urban planners with mapping experience. The survey results showed that only five respondents had certain knowledge in hydraulics and hydrology. All participants are, to some extent, familiar with mapping. The majority (80%) had experience in mapping for data collection.

3.3 | Results and discussion of the evaluation process

3.3.1 | Overview of the stakeholder workshop

The workshop comprised training and several different working sessions. On the first day of the training, the organising team demonstrated how flood moves in the city and through an urbanised area. Game-like representations were used for illustration of how water moves in channels. Additionally, the team discussed the type of models that can be implemented in an urban setting. This included the importance of representing channel drainage flow in a 1D model and overland flow in a 2D model. With this understanding, a discussion among the participants initiated, regarding mapping important features for urban flooding. Clear understanding was established about where to map and what detail to map, in order to validate and improve the flood model.

One main activity of the workshop was data evaluation and model improvement. It started with an exercise in building the 2D model with the available data (i.e., default values were assigned for the missing dimensions of features), followed by an exercise of analysing changes with various grid resolutions. The results with the 2D model were evaluated and that led to the completed 1D-2D flood model development with D-Flow FM. Participants were asked to investigate assumed and missing dimensions of the features (For example, default 5 m width and 2 m depth were set for the rivers). During the workshop, OSM data that were used to build the initial model was first presented (Figure 4) and discussed among the participants. The participants were then asked to split into two small groups. The first group, namely the "modeller group" focused on building the 1D-2D flood model. The second group, namely the "mapper group" focused on identifying locations for data collection and validation. On the second day, while the modeller's group prepared schematisation of the initial model, the mappers group selected an area where results were identified as particularly uncertain, as well as features that have critical influence on model results, leading to decisions regarding locations for additional data collection. On the last day, the participants were out for field work to investigate and validate the data used to build the initial model. Feedback after the workshop showed that stakeholders were very enthusiast about the model improvement and further data collection.

3.3.2 | Reconnaissance survey

Selection of area for reconnaissance survey, implemented by the mapper's group was based on two main conditions: first, using their knowledge of the local area, the mapper's team were able to identify some drainage channels that were not being displayed in the OSM and non-existing channels were mistakenly mapped; second, as the initial model was built using assumed default cross-section for the rivers, it was important to validate the assumption applied to Ngombe River. By going into the study area, the drainage channels could be checked and the assumption could be validated and corrected if required. Additionally, the organising team pointed out that, in the OSM, the model domain area showed 848 intersections between roads and waterways, however, only 290 were shown as culverts. As a result, validation with field work was necessary to check if there is a culvert at the intersection, or if there is no intersection at all. The field work was facilitated with the drone image of Manzese Ward captured by the World Bank and the paper map of the drainage network prepared by the organising team using the OSM. Consequently, the channels close to Ngombe River were selected to carry out the reconnaissance survey.

In Figure 5, the channels and the river location selected for field visit are presented: point A shows channel's location missing from the map; point B and D show the channels that do not exist but created a looped drainage network; and point C represents the location of Ngombe River. On the third day, participants went to the selected locations for data collection and validation. In order to save time and cover more ground, the participants split into two groups. The first group, went to the location represented by A and B, while the second group went to points C and D.

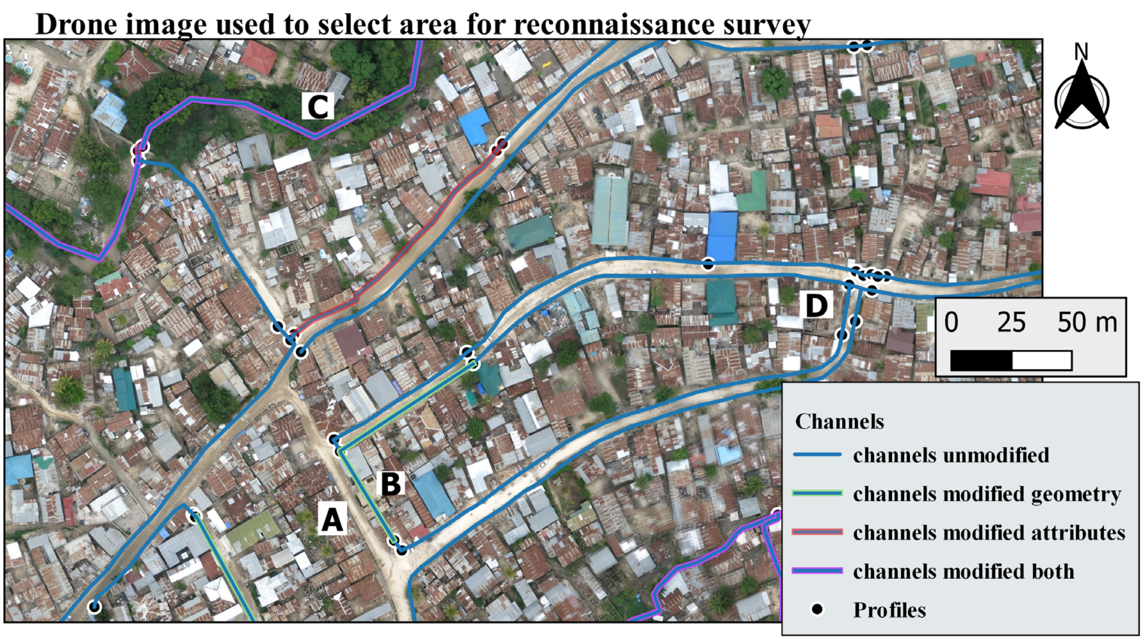

FIGURE 5 Selected area for reconnaissance survey

Field investigation helped to obtain new data about the river and the channels and these data were applied in the model. The findings from the reconnaissance survey include: (a) a trapezoidal drainage line that had not been mapped at point A was identified; (b) the channels that were seen at point B and D do not exist; and (c) the river is wider and deeper than the assumed values.

Referring to the framework for participatory urban flood modelling, the next step would be model schematisation using the collected new data. For this purpose, the collected data had to be updated in OSM platform and converted into a D-Flow FM file format. However, the OSM only support a rectangular cross-section. As a result, the improvement was implemented in the following ways: (a) the collected cross-section of a trapezoidal channel was converted into a rectangular cross-section, by considering the conveyance capacity of the channel; (b) the channels at point B and D were removed from the OSM, and (c) the new "real" assumed cross-section for river (10 m width and 3 m) was applied.

3.3.3 | Model improvement

The second (improved) model was schematised using the data obtained from the reconnaissance survey with the help of the local stakeholders. Results obtained from the second model were compared with those of initial model, to evaluate the improvement obtained with the applications of the participatory modelling approach. The first comparison was regarding the drainage channels that were mapped, but do not exist in the area, which created a loop in the channels. The second comparison was carried out on Ngombe River with the newly assumed cross-section (width and depth).

Case I: Improvement in channels

Figure 6 shows the drainage channels before (left) and after (right) improvement. The time series of water depth taken at points B and C for the initial model are presented in Figure 6a,b and after the improvement in Figure 6c,d. As aforementioned, at point A and C there were drainage channels connecting the side channels, which created a looped channel. This looped channel is created due to a mapping mistake. The reason for this mistake may be the following: usually community mapping uses a satellite or drone image to develop the OSM. Depending on the timing of taking such an image, some areas might show shading. This shading could be confusing and might seem like a drainage line, leading to a wrongly mapped channel. Unlike urban channels that drains out the coming flow, the looped network creates storage. This results in accumulation of water until it reaches the full capacity of the drainage channel (peak depth 0.17 m, Figure 6a). After the improvement (Figure 6b), those channels were removed and the water drained to the lowest point after it reached only 0.01 m. As part of the improvement, the new trapezoidal channel located below point A, has also been mapped and included in the second model.

Furthermore, at point C, before the improvement, the water depth reached 0.30 m and stayed that way until the end of the simulation (Figure 6c). After the removal of the locking channel, even though the water depth was reduced to 0.26 m (Figure 6d), it again remained the same until the end of the simulation. This is because there is no drainage network that is connected to this channel, to drain the water. In fact, this is happening physically in that drainage channel, as one of the major problems in the area is lack of proper drainage network due to unplanned infrastructure and settlement.

Case II: Improvement in the Ngombe River

Generally, after incorporating the new data, the maximum water depth in the river is higher than that developed initially. This is because there is more area in Ngombe River, as the cross-section is larger after the improvement. The initial model result of Ngombe River (1D) showed maximum water depth of 2.35 m. After the improvement, the second model, resulted a maximum water depth of 3.85 m. In Figure 7a,b, flood inundation before and after is presented. As a result of the incorporation of the new data, inundated area is smaller than before. This is more visible at the downstream of Ngombe River, where it is shown that less number of houses are flooded after model improvement. In the initial model, maximum inundation water depth (2D) of 2.21 m was calculated (Figure 7a). After model improvement, the second model resulted in a maximum inundation water depth of 2.35 m (Figure 7b). In the initial model, the river has a smaller cross-section and more water spreads as overland flow. However, after the improvement, the river channel has higher capacity, conveying more water, and the maximum water depth is also higher. This reduces the amount of water that goes to the floodplain area, which is also noticeable in Figure 8, that shows lower water depths in the inundated areas for the improved model.

Besides the comparison of the water depths in the river and the floodplains, discharge at Ngombe River was also evaluated. Having the same boundary inflow to the river in the upper reach, the outflow at the mid reach shows higher discharge in the second model. Figure 8 shows the resulting discharge inflow and outflow for both cases. As it can be seen, for the same inflow (51 m^3/s),

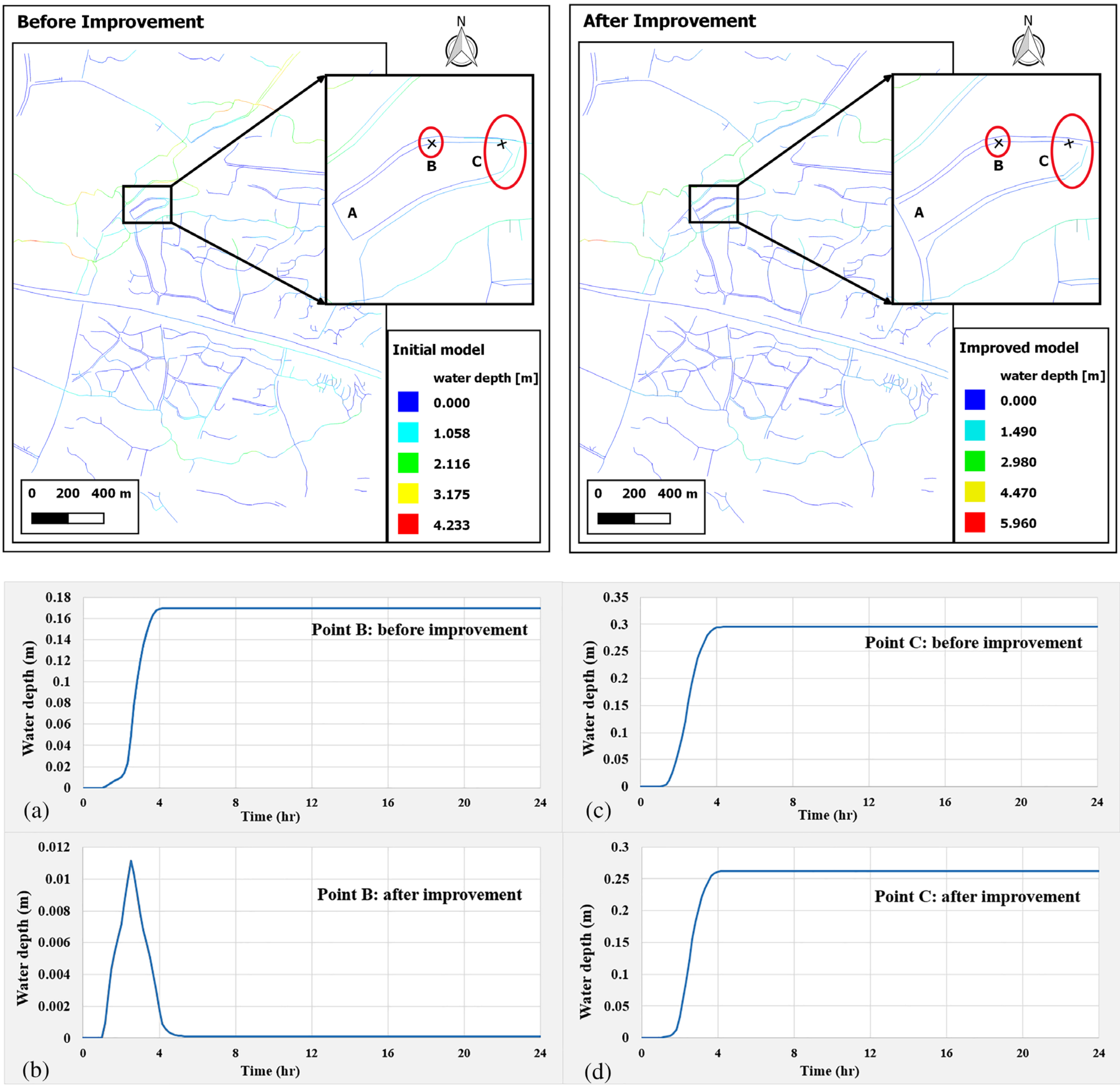

FIGURE 6 Comparison of water depth in the channels before and after the improvement

the initial model outflow was 43m^3/s and the second model resulted in 58 m^3/s. As stated in Olson-Rutz and Marlow (1992) the flow is directly related to the cross-section area, the higher the cross-section, the higher the carrying capacity. As aforementioned, there is more area in Ngombe River, as the cross-section is larger than the initial assumption.

In line with Tingsanchali (2012) and Ritzema et al. (2010), this study demonstrates, even complex urban flood model development can be supported in a data scarce environment with a structured participatory mapping and modelling approach. The results from the initial and the second model have shown how the local stakeholders can contribute in the iterative model improvement process.

On the ground that lack of observed hydrological data, calibration and validation of the developed model have not been carried out. Although there are advantages of using OSM in data scarce environments, in this case most of the data is still missing and there is inaccuracy and miss-representations of some features. For instance, the size of the drainage channels on some locations was inaccurate. However, regardless of these limitations, the level of improvement achieved with only one workshop shows the potential for further model improvement with subsequent data gathering campaign with the help of the local stakeholders. Even though the improvement seems less significant, the number of houses, schools and critical infrastructure flooded after model improvement was in line with what the stakeholders indicated. This was particularly

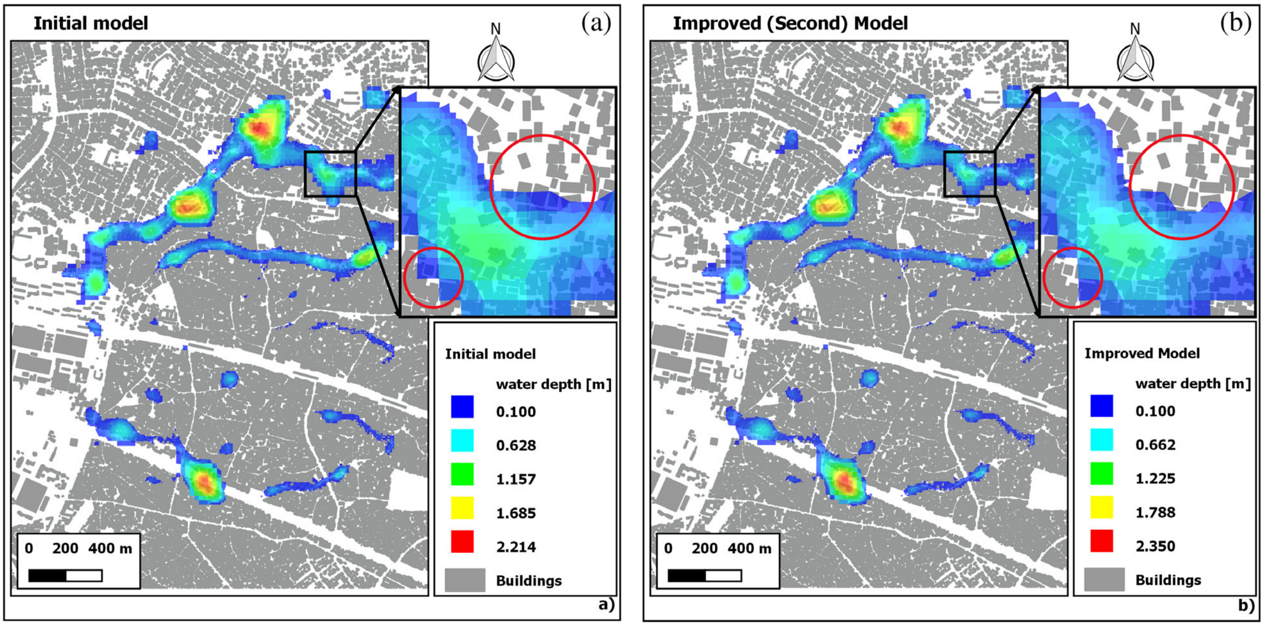

FIGURE 7 Flood inundation map for the initial (a) and the improved model (b)

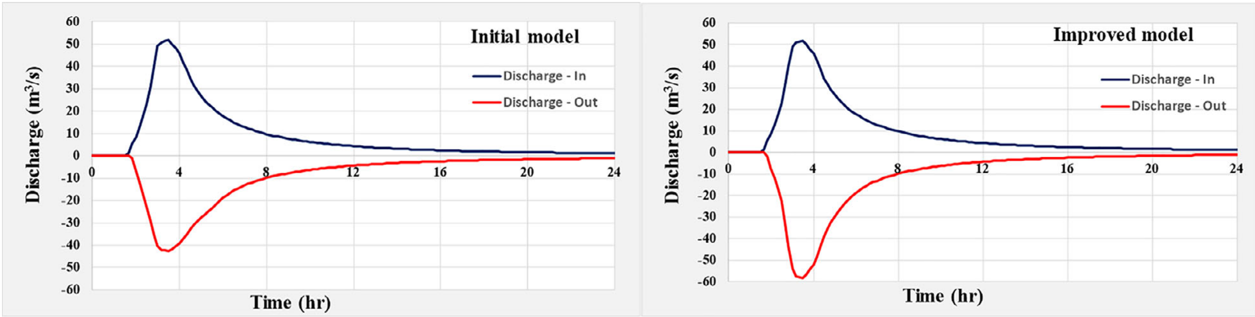

FIGURE 8 Discharge flow in the upper and outflow in the mid reach of Ngombe River for the initial (a) and improved (b) model

relevant for increasing the acceptance of the model and its results by the local stakeholders. This type of stakeholder participation creates a sense of ownership and contributes to stakeholders' capacity building (Almoradie et al., 2015; Basco-Carrera et al., 2017; Buchecker, Menzel, & Home, 2013; Cleaver, 1999; Mostert, 2003; Sadoff & Grey, 2005).

4 | CONCLUSIONS

This study examined and demonstrated the potential urban flood model development and improvement using OSM data, following applications of participatory mapping and modelling approach. The use of the developed framework for participation in the case study area promoted interaction and involvement of the locals, including the community members and stakeholders. It was used for ensuring the active participation of key stakeholders in data collection and building trust and ownership of the data for the flood model. Moreover, it facilitated the co-production and sharing of knowledge regarding the urban flood model, contributed to increased flood resilience, and strengthened collaboration between governmental, technical and scientific institutions, civil society organisations and local communities.

The approach provided novel and quite promising results regarding the use of participatory modelling and mapping approach for urban flood model development. Such participation in modelling has been predominantly used by stakeholders in other environmental models. This study demonstrates the potential of the approach in achieving improvements in hydrodynamic urban flood model development in data scarce developing countries.

In terms of future research directions, the initiated work should be further improved through mapping and improving more areas in the OSM. In this study, the collected data for improvement only covers features of waterways infrastructure. Therefore, for future model improvements, information about buildings and roads should also be updated. Furthermore, the database in OSM could also include other types of structures that are available in the concerned area. The 1D channel can be according to the type that is actually present on the ground, instead of representing all the channels as having rectangular cross sections. This may be specifically relevant for the Ngombe River, as the assumption of uniform cross-section for a natural river is not ideal. Community mapping campaigns can be extended to surveying the actual river cross-sections and their incorporation in the model.

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ENDNOTE

[1] "Dar es Salaam/Ramani Huria" (2019) *Wikipedia*. Available at https://wiki.openstreetmap.org/wiki/Dar_es_Salaam/Ramani_Huria (Accessed: July 9, 2019).

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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