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An integrated framework for high-resolution urban flood modelling using geospatial technology: A Case study of Adayar sub basin.

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Abstract:

Recently, the flooding in Chennai cities is more devasting, due to the accumulation of water for a short spell of rain. So, a need is felt to use high accuracy terrain data for accurate mapping in urban flood environment. With the latest technology LiDAR, an accurate ground data i.e DEM of 1m resolution is prepared for preparation of flood inundation mapping. In this study the objective is to generate flood inundation maps for Adayar sub-basin using 2D models for for the year 2005 and 2015. From the results it is found the runoff from the existing drainage network, is significant which highlights that the inundation in the area of Thiru vi ka watershed is higher. Therefore, an alternate flood mitigation solution through modeling techniques is performed for this study. At last, the study concludes with feasible solutions which provides an insight for the similar cities.

Keywords: *Thiru vi ka watershed, Hydrodynamic model, Time area method, Flood mapping.*

Introduction:

Urban flooding is the inundation of land which occurs due to the concrete surface and industrialization which reflects in extreme flood scenario such as rainstorms (Tu, 2014). Furthermore, in most of the cities an urban drainage pipeline network is not laid according to the design rainfall standards (Xie et al. 2016). Thus, results in the increase of urban flood disasters. Therefore, a need is felt to study the problem of flooding. Hence, the study computes runoff generated in road, especially in the hot spots location in the cities for finding flood inundation.

Advancements on urban studies have been conducted across the globe with the aim to alleviate the problems of flooding with the aid of advanced 2D hydrodynamic models for the prevailing drainage pipeline network (Zhou,2014). Various attempts by the researchers have been to study the urban models because of its capabilities in addressing the problems of urban drainage pipeline system completely along with integration of GIS. A study by Hlodversdottir et al. (2015) performed the urban runoff volume considering the storm water drainage from the catchment of coastal area for flood risk mapping in the central of the Reykjavík. Another interesting author Bouchenafa et al. (2014) attempted the research on flooding in an underground staircase in an urban environment. Here, the researcher developed an empirical equation 'Q' for flow rate at the outlet of staircase of the building. Thus the study ended up by mitigating the flooding through urban flood control measures.

With review of research paper in mind, this study is being conducted on Thiri vi ka sub basin for different scenarios through Mike Urban model. The model illuminates the drainage pipeline networks under different rainfall which is capable of providing mitigation measures for the urban floods to eradicate future problems. Further, the solutions from model gives an idea for best decision-making solutions for proper design of urban drainage pipelines network systems in near future.

2. Study area description

2 .1 Thiru vi ka micro watershed

The total area of this study holds Thiru vi ka micro watershed of 6.23 sq.km. The location of the study is from north latitude 13°1'8.513'' N and 13°3'29.645''N and east longitudes 80° 11'9.106''E and 80°15'54.819''E. The Figure 1 shows the representation of the entire eight

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micro watershed. Among which Thiru-vi-ka micro watershed of the selected storm water drainage network is selected for this study as shown in the figure 1.

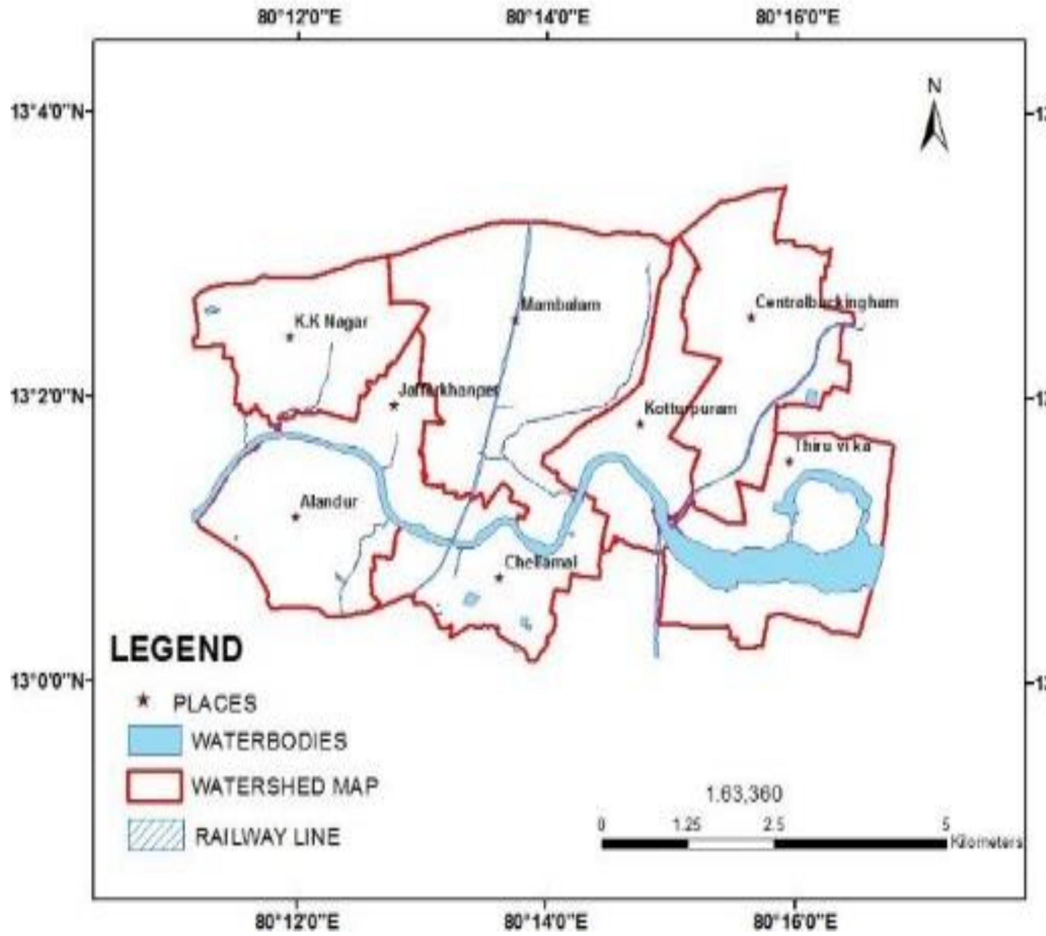

Figure 1 Representation of storm water drainage network for Thiru vi-ka micro watershed

The location of this study is located in the north–eastern part of Tamil Nadu on a flat coastal plain. The elevation of the terrain ranges from around 6.7 meters up to 60 m high. The Adayar river near the kathipara causeway carries flow throughout the year with an average discharge of 89.43 mcm /year during northeast monsoon period from October to December. The Adayar, the river originating from the Chembarambakkam lake in Kanchipuram district, is the long river which winds through Chennai , Tamil Nadu, India, and joins the Bay of Bengal at the Adyar estuary. During the cyclonic period, the backwaters from the sea enters the land area up to 3 to 4 km.

2.2 Data Collection

The eight micro watersheds of the study area represents different imperviousness areas which contributes to the runoff. Among which the Thiru vi ka micro watershed have different imperviousness values for different areas based on the topography of the terrain. The storm water runoff from the micro watersheds flows towards the storm water drainage for calculating the excess flood inundating the area. The impervious values for the study area are calculated `based on the ortho imagery prepared land use/land cover. The initial loss defines the total rainfall that occurs prior to the commencement of overland flow. This loss, takes into account the depressions of micro watershed. For this study, initial loss is assigned from the works stated

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by (Chow et al. 1988). Therefore the calculation for time of concentration is done using Kirpich's formula. The details of input given to the model for imperviousness value is 68.03% and Time of concentration T_c is 15.32 minutes.

The hydraulic losses in the pipe was estimated using manning roughness coefficient. The manning coefficients adopted for different types of material are taken from the literature chow et al. (1988).

Then, with the help of ArcGIS desktop, the nodes and links corresponding to the drains was effectively incorporated. Later, data's of pipe nodes and drainage link were imported into the Mike Urban model environment (Yao, 2012). Lastly, inside the model there are 181 nodes, 191 concrete round pipes of diameter of the pipe is 0.6, 0.9 and 1.2 and 1.5 m and four drainage outlets in the study area as shown in the figure 2.

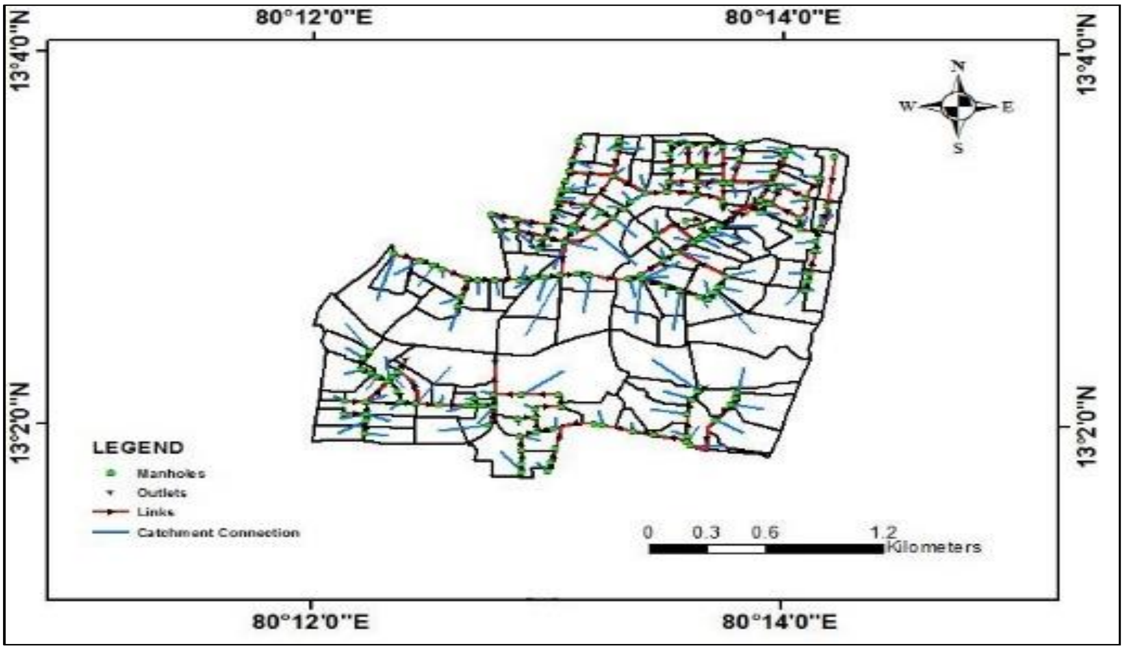

Figure 2. Representation of storm water drainage network for
Thiru vi-ka micro watershed

2.3 Rainfall description

2.3.1 Rainfall details

The hourly rainfall information is collected from Indian meteorological department for the gauge station meenambakkam in the study area for the year 2005 and 2015 which is used for model calibration and validation as shown in the (figure. 3 & 4).

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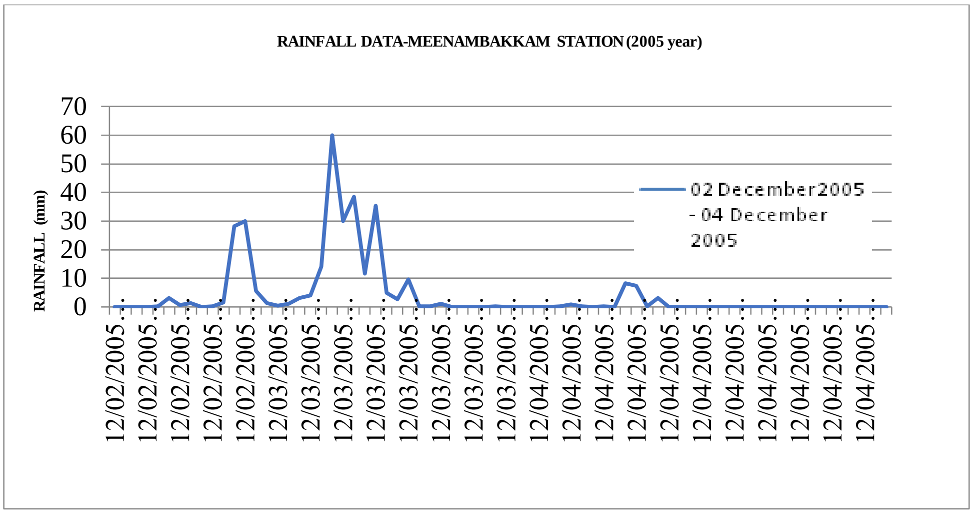

Figure 3 The hourly rainfall data (part) for Meenambakkam station from 2nd December – 4th December 2005

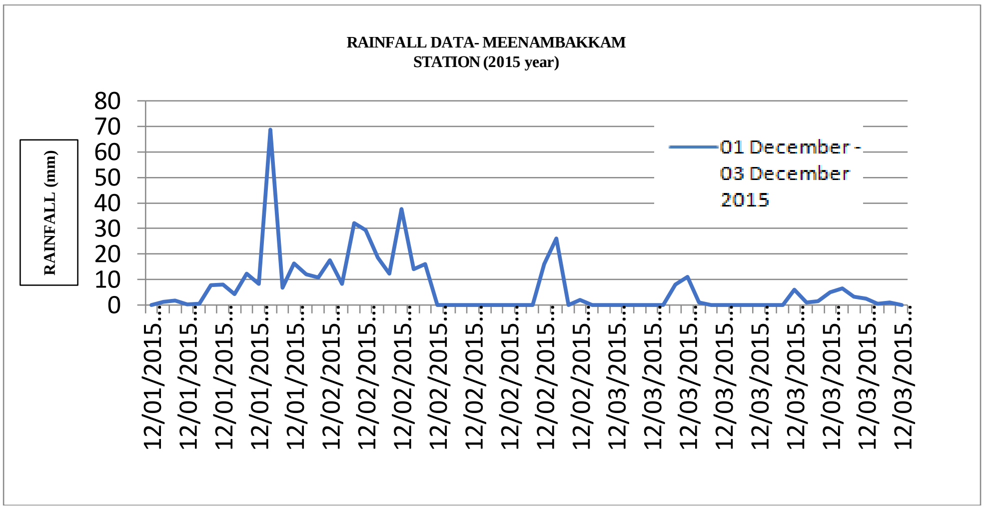

Figure 4 The hourly rainfall data (part) for Meenambakkam station from 1st December 2015 – 3rd December 2015

3 Model Description

3.1 Mike Urban

The time-area rainfall-runoff model is used to derive the runoff hydrograph based on a given excess rainfall hyetograph. In this method, the micro watershed is divided into a number of small watersheds separated by isochrones. This procedure is known as time area histogram. In an urban model system, the nodes and links are used to connect the sub-catchments of study area (USEPA, 1999; Ahmadi, 2012). Finally the Thiru vi ka area is parted into 118 micro watersheds for existing scenario and 180 micro watersheds for revised scenarios.

The parameter imperviousness has been calculated for each micro watershed according to the percentage of different land use surfaces. The equation for calculating impervious percentage is shown in Equation 1 as:

$$\Phi = (A_1 * \Phi_1 + A_2 * + \ldots\ldots + A_n * \Phi_n) / (A_1 + A_2 + \ldots\ldots\ldots\ldots + A_n) \qquad (1)$$

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Where φ=imperviousness of the whole micro-watershed, $φ_i$ imperviousness of each type of surface, A_i area of each surface.

Secondly the parameter initial loss and hydrological reduction factor which refers to rainfall were assigned as 0.6 mm and 0.90 respectively in all the micro-watersheds from the literature pertaining to Indian micro watershed condition (Deepak Singh Bisht et al. 2016).

And at last the parameter time of concentration (T_c) for each micro watershed is calculated using Kirpich's formula as shown in Equation 2:

$$T_C = \frac{0.01947 * L^{0.77}}{S^{-0.385}} \quad (2)$$

where L is the total length of the storm water bv drains and S is the slope of the micro watershed. The runoff obtained from the micro watershed is then fed as input to the storm water drainage network for calculating flood carrying capacity of the drains.

The Mike urban product is used for free surface and pressurized flow in case of one-dimensional unsteady flows. The governing equations is built on solving conservation of continuity and momentum.

Here, general equation of continuity of mass is given by Equation 3 as:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \quad (3)$$

And the governing equation of unsteady flows based on momentum is given by Equation 4 as:

$$\frac{\partial Q}{\partial t} + \frac{\partial(\propto\frac{Q^2}{A})}{\partial x} + g * A\frac{\partial y}{\partial x} + g * A\, I_f = g * A\, I_o \quad (4)$$

where: Q = Discharge of flow (m^2s^{-1}),A = cross sectional area (m^2), y = flow depth (m), g = acceleration of gravity, [ms^{-2}],x = distance in the flow direction (m) t = time period, [s], a = velocity distribution coefficient, I_o= bottom slope, I_f= friction slope.

The friction loss in the pipe is calculated by Equation 5 as:

$$I_f = \frac{\tau}{\rho g R} \quad (5)$$

where τ = tangential stress, [Nm^{-2}], ρ = density, [kgm-3], R = hydraulic radius, [m].

In this model there are two types of boundary condition such as micro watershed load boundary condition and external water level boundary condition. In this study rainfall data in a time series format is defined as a micro watershed load boundary data and constant water level data at the outlet as a downstream boundary condition.

In this study, the dynamic wave method is chosen for simulating the model. This method performs the full momentum equation, such as acceleration forces, inertia force, friction force and gravity force for simulation of fast transients and backwater profiles.

3.2 Mike 21

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The parameters of the micro watershed area were displayed as shown in the table 2. Initially, the micro watersheds with different land covers were provided inside the model for the study area.

Table 2. The experimental parameters of Mike21.

Parameter Time	Time step (s)	Drying depth (m)	Flooding depth (m)	Manning number
Value	1	0.002	0.003	0.03

Then, the corresponding impervious value of each land use type were computed and given as input to the model and finally, calculated automatically through the model. The other parameters present in the model were set according to the recommendation value handbook and the empirical range of actual situation (Son et al., 2016).

3.3 MIKE FLOOD

The MIKE FLOOD is an integrated 2D model connected through links provided between 1D drainage model and 1D overland flow model. Thus the linkages between among the models are called urban links which permits for transfer of water between the two models. when a manhole is overtopped, water is transferred from the drainage model to the overland flow, and then 1D-2D mike flood cell is linked to a manhole while flooded water is transported . The exchange of water between the two models is calculated using equation below:

$$Q_{UM21} = C\,(H_U - H_{M21})\,W\sqrt{2g\ HU - HM21}\ (\ HU - HM21)\ /\ max\,(H_{M21}\,,\,H_U) - Hg$$

3.4 Calibration and Verification of the model

In this study, the 2D model was used to simulate the watershed flooding from the inadequate pipe size of the drainage system (DHI,2012). The DEM of study area were incorporated through ArcGIS whereas the Mike 21 model were computed through Mike Zero. The model were calibrated and validated with the available measured and simulated water depth (Rong et al., 2017). The calibrated data are shown in Table 4.

Table 4. Calibration results of Mike urban model.

Parameter	Initial Value	Calibrated value
Average velocity of surface confluence	0.3	0.2
Hydrological reduction factor	0.9	0.9

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Initial water loss	0.0006	0.0015
Manning coefficient of pipeline	0.015	0.013

4 Results and analysis of the study

The required input were fed into the model for the computation of runoff and later the model is calibrated and validated. In this study, the investigation of the different flood scenario such as existing and revised drains contains three purposes such as: typical flood inundated area, storm water network load and flooding spot (SAC, 2008). From the model results, this study found the runoff volume generated is more in existing drainage network than that of the revised drain as because of the increase in size of the storm water drainage (Han et al 2015).

4.1 Runoff hydrograph

The results from the model indicates the peak runoff, accumulated flow and gradually runoff coefficient of sub catchment area increases slowly with the increase of rainfall. The model results can be viewed in the Mike view module. The flood depth at the nodes and the runoff at various micro watersheds are generated by the model. And also the flood carrying capacity of the storm water drains are also determined using the Mouse model. The runoff hydrograph have been computed for Thiru vi ka micro watersheds for two scenarios namely existing drains and revised drainages for the flood event 2005 and 2015 as shown in the Table 3.

Table 3 Runoff hydrograph of Adayar micro watershed for the year 2005 and 2015

Name of the micro watershed	Runoff hydrograph for existing drainage 2005 (m^3/s)	Runoff hydrograph for existing drainage 2015 (m^3/s)	Runoff hydrograph for revised drainage 2005 (m^3/s)-	Runoff hydrograph for revised drainage 2015 (m^3/s)
Thiru-vi-ka	64.12	91.58	83.6	148.01

From the table, it is clear the runoff discharge from the micro watersheds have been reduced up to 19.48 m^3/s for the year 2005 and similarly for the year 2015 the runoff discharge from the micro watersheds have been reduced up to 56.43 m^3/s after increasing the size of the storm water drainage network.

4.2 Generation of flood inundation map (Existing Drainage Network)

The flood inundated area of Thiru-vi ka watershed are Santhome high road, South beach avenue, Cresent park at the Adayar outlet, Durgabhai deshmuk road, Ponniamman temple street, Beasant avenue road as depicted in the Figure 4.

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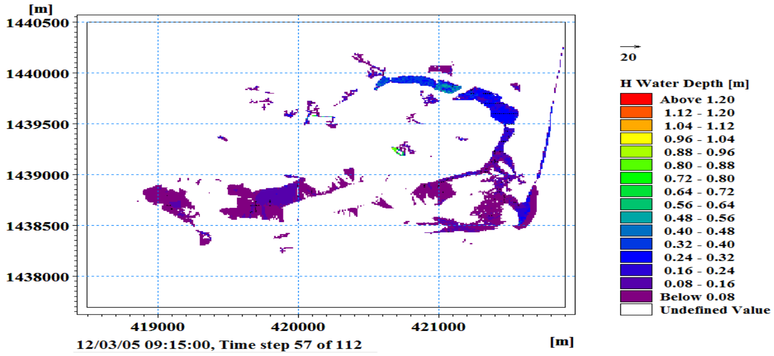

Figure 4 Flood inundation map for the Thiru-vi-ka micro watershed for the year 2005

Due to large amount of rainfall during the year 2015 the inundation of the micro watershed is more compared to 2005 year as shown in the Figure 5.

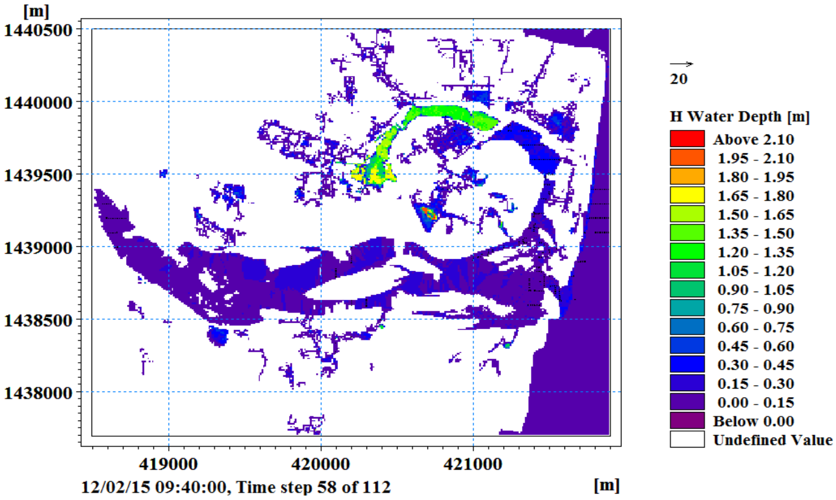

Figure 5 Flood inundation map for the Thiru-vi-ka micro watershed for the year 2015

The simulated results shows the flooding occurs near the Santhom road at the duration 09:40 am and lasted until the rainfall ended in 12:00 pm. Both the water level and the discharge of overflow in the peak nodes are of major concern.

Moreover, the overflow nodes occurred in certain areas are due to the poor drainage capacity and undulating terrain elevation. These results from the model and observed data are both found consistent as depicted in the figure 5.

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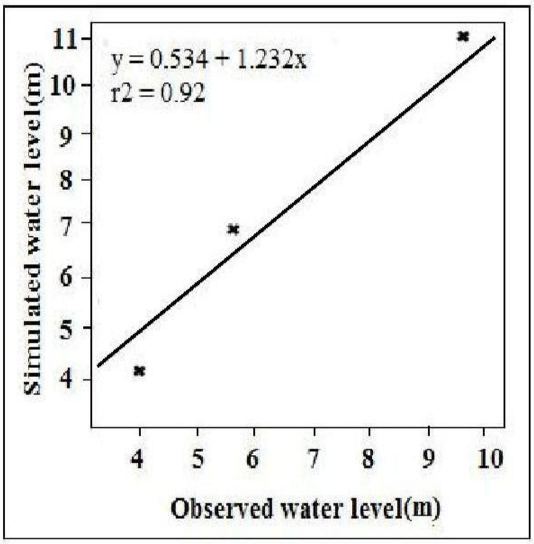

Figure 5.47 Comparison of observed and simulated water level for 2005 flood event

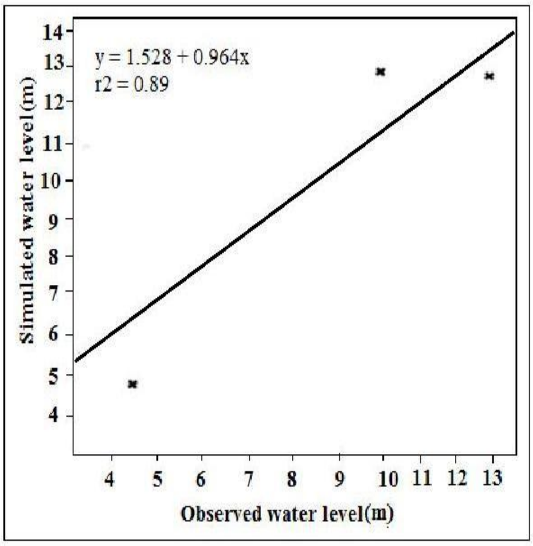

Figure 5.48 Comparison of observed and simulated water level for 2015 flood event

4.3 Generation of flood inundation map (Revised Drainage Network)

In this paper, the flood mitigation measure is adopted for Thiru vi ka watershed is applied with the help of geospatial technology. The different models used in this research helps to form a holistic and flexible tool for better flood mitigation study.

Flood has been mitigated through revised storm water drains. From the results of MIKE URBAN software, the total flood volume inundated in the Thiru vi ka micro watershed during 2005 flood event was found to be 0.088 MCM. But after the revised size of the drains the flood volume has reduced to 0.085 MCM. The flood inundated map for revised drains is shown in the Figure 6.63. Likewise the total flood volume inundated in the Central buckingham canal micro watershed during 2015 flood event was found to be 0.132 MCM. But after the revised size of the drains the flood volume has reduced to 0.128 MCM. The flood inundated map for revised drains for 2015 flood is shown in the Figure 6.64.

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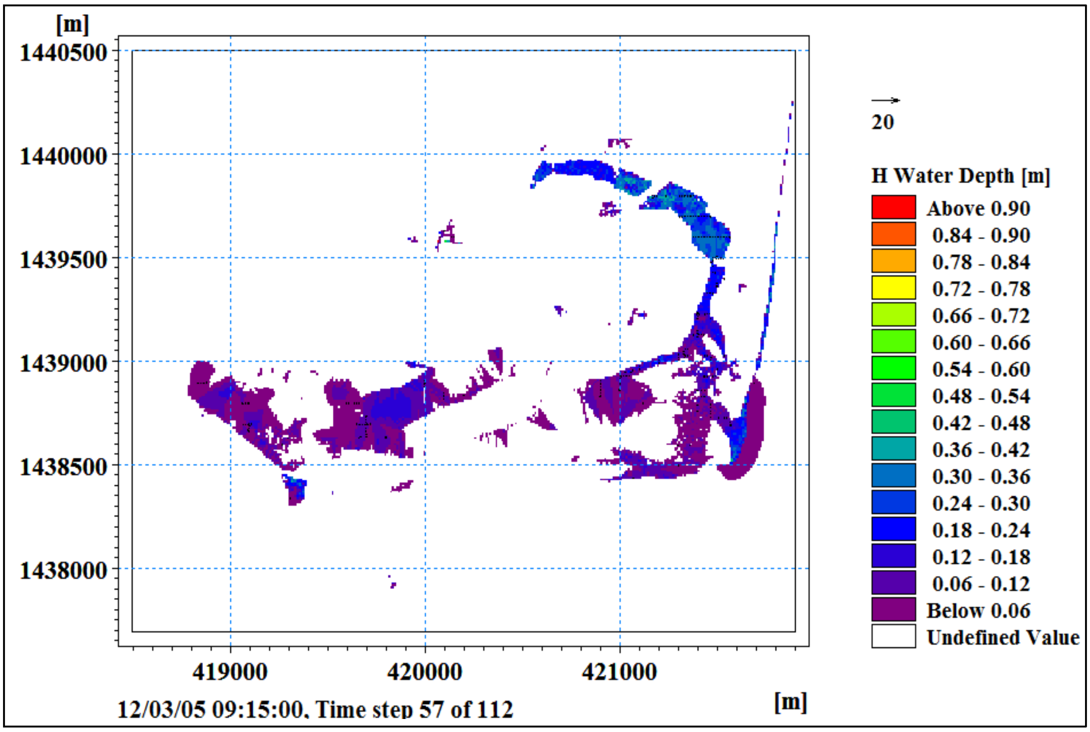

Figure 6.63Flood inundation map of revised storm water drainage network of Thiru vi ka micro watershed for the year 2005

Some portion of a flood has been mitigated through revised storm water drains. The balance flood volume of 0.003 MCM for 2005 flood and 0.004 MCM for the 2015 year flooded out from the drains has been discharged through surface canal draining into the river. By implementing the suggested mitigation measure, the urban flooding volume has been reduced to great extent.

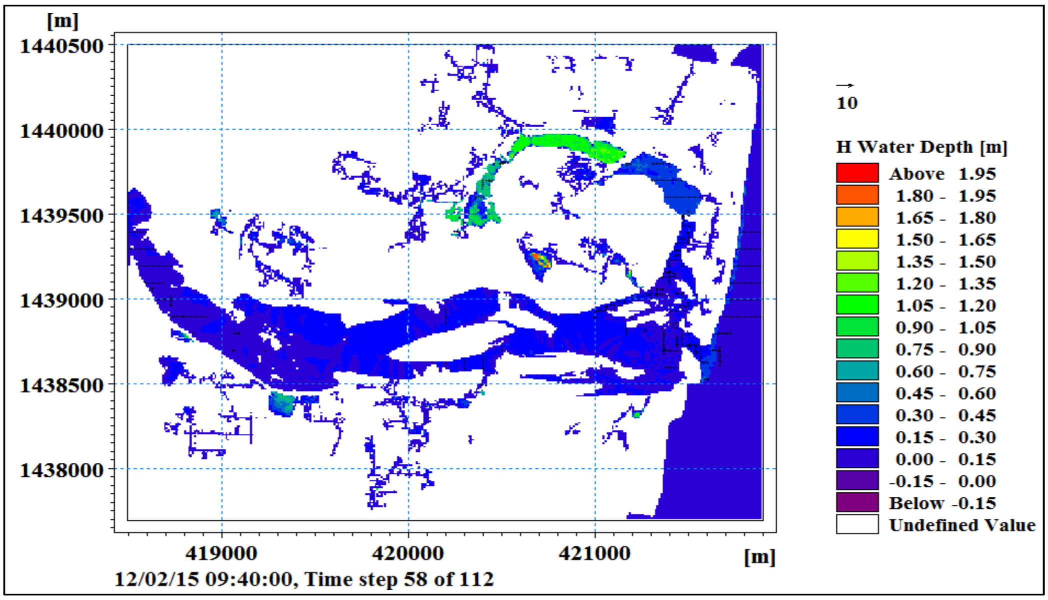

Figure 6.64 Flood inundation map of revised storm water drainage network of Thiru vi ka micro watershed for the year 2015

5 Conclusions and Recommendations

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In this paper, the urban flooding problems was successfully examined. The flood events of different rainfall data in years are computed using surface runoff method called time-area. From the model, results found that the flooding heaviness in hot spots region is greater than rest of the other area with the rise of amount of rainfall. Therefore, it deeply insights the technical problems faced in the urban flooding which will be useful for the urban planners for the best flood early warning system of study area. It is suggested to adopt different artificial recharge techniques like roof top harvesting with wide range of field investigation for effective urban flood mitigation study. This study further strengthens the basis research in taking best decision for effective sustainable urban planning.

Competing interests. The authors declares that they have no conflict of interest.

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