 doi:10.20944/preprints201712.0135.v1

Article

Flood Mitigation Techniques—A New Perspective for the Case Study of Adayar Watershed

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Abstract: Mostly populous city like Chennai is subjected to frequent flooding due to its complex nature of natural and man-made activities. From the analysis of the past records of flood events of 1943,1976,1985,2005 and 2008,it has been observed Adayar watershed is subjected to cataclysmic flooding in low-lying areas of the city and its suburbs because of inoperativeness of the local drainage system, rainfall associated with cyclonic activity, topography of the terrain, encroachments along the floodplain, hugh upstream flow discharge into the river and the highly impervious area which blocked the runoff to flow into the storm water drainage. After looking into these problems of flooding, a study have been conducted on Adayar watershed to develop a 2D hydrodynamic model for the two scenarios of existing condition of storm water drainage network and revised conditions of storm water drainage network using high resolution Lidar DEM to assess the volume of runoff with respect to time and duration on flood peaks for the two flood events of 2005 and 2015.Secondly to develop a 1D flood model to predict the river stages during peak floods using MIKE 11 for the Adayar watershed. Thirdly to integrate the coupled 1D and 2D model using MIKEFLOOD for assessing the extent of inundation in the floodplain area of Adayar river. Finally results from the integrated model have been validated and the results found satisfactory. As a part of mitigation measures, two flood mitigation measures have been adopted. One measure such as revised storm water drainage system which enhances the flood carrying capacity of the drains and results in less inundated area which solves the problem of urban flooding and second measure such as regrading the river bed which reduces the floodplain inundation around the adjacent area of the river. After adopting these measures, the river is free to flow into the sea without any blockades.

Keywords: urban flood; river flood; hydrodynamic model; high resolution dem; flood mitigation measures

1. Introduction

At current; the population of the Chennai city is 46.81% as per the census of India 2011. In the Chennai city, the urban population is expected to increase by 10.129 million in 2025 from 7.557 million in 2010 and 16.278 million in 2050. Cohen [4] predicted by the year 2030 it is expected that 61% of the world's population of around 5 billion peoples will be living in urban areas. The increase in population results in industrial and urban development. So, by looking on the urban development in mind the flood carrying capacity of the storm water drains has to be designed for the future conditions in order to receive high intensity of rainfall.

Urbanization along with heavy rainfall is the cause of flooding in the Chennai city. Since urban area is closely spaced it is advantageous to apply a high resolution DEM data for accurate discrimination of urban features in the flood modelling. Plentiful researches across the world have applied LiDAR data for flood Modelling studies. A study by Jon Derek Loftis et al. [9] conducted at

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NASA Langley Research Center on sub-grid modelling technology by incorporating high-resolution lidar-derived 5m sub- grid elevation data for the hydrodynamic modelling to resolve detailed topographic features for the generation of runoff .This helps in resolving ditches and overland drainage infrastructure at Langley Research Center often accompanied with tropical storm systems. The results from the model with a NASA tide gauge during Hurricane Irene yielded a good R^2 correlation of 0.97, and root mean squared error statistic of 0.079 m. The sub-grid model more accurately predicts the horizontal maximum inundation extents within 1.0–8.5 m of flood sites surveyed. Another study by Helen Dorn et al.[7] on comparison of different data sets such as LIDAR data, Orthomap, Open street Map and official landuse data are chosen for surface roughness map generation for accurate prediction of flood. From the comparison of the data, it is found Lidar is best suitable for mapping the roughness map as it avoids the data fusion between the features

Various researches have been studied on the impact of urbanization in urban flooding using 1D hydrodynamic models, to simulate flow in sewer pipes for estimation of runoff. Recently, advanced software such as MIKE URBAN storm-water model a physical based GIS integrated model is applied by Chingnawan [3] to solve the pressurized flow using the continuity and momentum equation for Modelling the overland flow for a closed and open conduict.

Apirumanekul [2] came with an another interesting case study at Dhaka City to analyze the causes of frequent flooding occurring between two networks namely the street and pipe networks using hydrodynamic model. The model describes the exchange of flows between these two systems of pipes and the streets. The flood inundation maps are prepared using the modelling results in a GIS environment to find the best ways of flood mitigation measures by analyzing the problem faced due to inadequate drainage system prevailing.

Similarly some of the literatures are chalked out for solving river flooding problems using hydrodynamic model. A study by Agrawal et al.[1] on Bagmoti river located in Sikkim are analyzed using MIKE11 1D hydraulic model to determine the flood extent and flood depth in the river due to embankment failure and high intensity of rainfall. From the interpretation of the model results suitable flood mitigation measures are suggested. Another study by Vinay Nikam et al. [12] on Mithi river located at Mumbai is flooded due to outburst of the river and heavy rainfall which occurred on 26th July, 2005.The main aspects generating the flooding are the encroachments and habitat in flood plains of Mithi River. So in order to predict the inundated area a MIKE 11 model was used to simulate the flooding for various rainfall scenarios. Here various structural and non-structural measures have been adopted to improve the flood carrying capacity of Mithi river by widening or deepening the river bed and by providing flood protection wall at the u/s portion of the river. Likewise this study can also be adopted for other cites as well for deciding suitable flood mitigation measures.

Finally, the last stage is the mapping of flood inundation area at risk which requires accurate resolution of DEM data which can be performed using scientific tool such as MIKEFLOOD and remote sensing technique. The 2D hydrodynamic model is widely used for simulation in rivers since one-dimensional models fail to provide complete information about the flow field of extensive flood inundation. The application of 2D flood model developed using Mike by DHI 2014c [10] has gained advantage because it is capable for real-time simulations of flooding events in a relatively less computational time at fine resolution. The governing equation of the model is by mass conversion equation. Thus the present study includes the application of MIKE-FLOOD for the Adayar River flood plain. A large number of studies have been examined using this model which is discussed below.

A study for Ajoy River, in West Bengal is analyzed by Prashant Kadam et al.[11] using MIKE-FLOOD, which integrates the 1-D MIKE-11 model with the 2-D MIKE-21 model for the flood inundation mapping. The simulation of the model was carried out for two monsoon months of year 2000 as the flooding was severe during this period. Next, the MIKE-11 hydrodynamic model was calibrated with the Manning's, n, roughness coefficient and validated with the gauging station. The results from the model for the validation period gave good agreement with observed values. From the conclusion drawn, suitable flood control measures such as flood forecasting, flood warning can be implemented.

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Another study of Tuaran river basin in sabah, Malaysia by Janice Lynn [8] for the year 1999 and 2000 flood event is analyzed for the flood risk mapping. The main objective of this research was to generate flood inundation map and to provide suitable flood mitigation measures. So in order to meet the objectives, MIKEFLOOD hydrodynamic model was chosen to predict the flood encroachment map. Here, the topographic data with different resolution of DEM'S are tested for accurate prediction of flood inundation extent. Later on, the calibration of the model was executed during the year 1991 and 1992 storm events and then validated using the DID'S flood map through questionnaire survey with local residents. Hence, after validating the model it was found fit for further study. Later on, the three flood mitigation solution is adopted to mitigate flood for the selected high risk areas. The proposed solutions for the river are river deepening, levee constructions and the river straightening. Among the solutions the river deepening was found best for curtailing the effects of flooding in the upstream of the river.

2. Study area

Chennai City, one of the metropolis in India is the capital of Tamil Nadu. Chennai metropolitan area (CMA) covers an area of 1189 sq.km which lies along the east coast of Southern India. The study area covers Adayar watershed of 42.84 sq.km. It lies between the North Latitudes 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. Figure (1) depicts the study area map. The Chennai city is bounded by Thiruvallur district in the north and west, Kancheepuram district in the south and Bay of Bengal in the east. The Chennai climate is mostly hot and dry. The mean monthly temperature is in the range of 33.1 – 37.6°C; while in winter temperature fluctuates between 28.1 – 30.6°C. In the year 2003 the Nungambakkam recorded the highest 45°C on 21, May 1910.And the second highest 44.5°C was registered on 22,May 2003(SG&SWRDC,TNPWD,2005).The mean annual humidity is usually 58% to 84% and highest percentage of humidity are observed during October to January and moderate in winter.

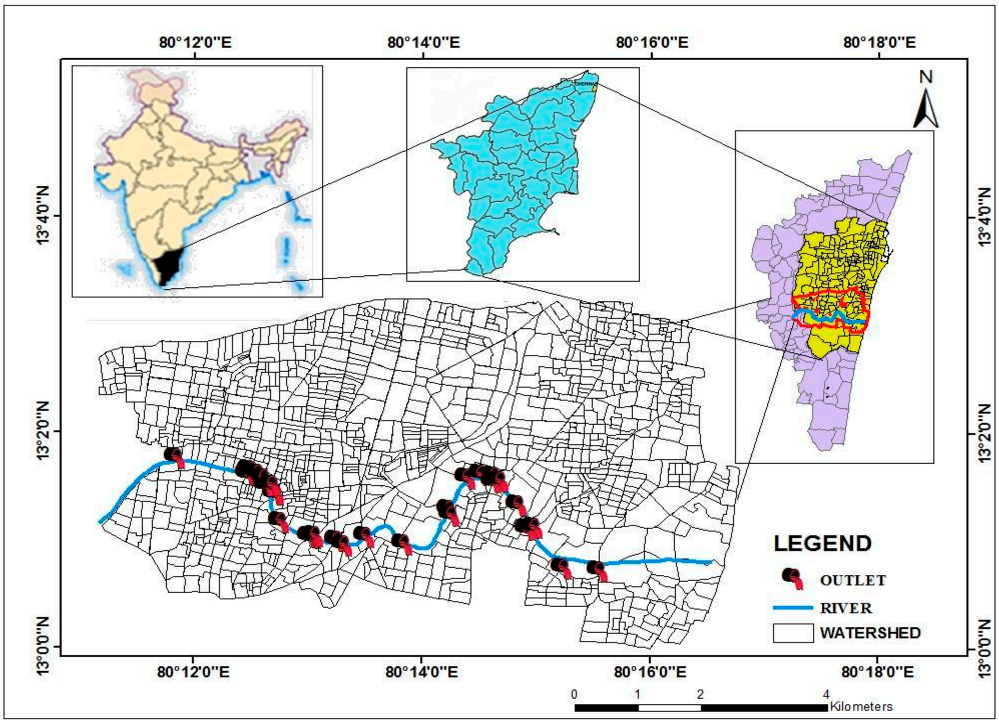

Figure 1 The study area of Adayar watershed

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3. Methodology

In this study three Modelling software were employed for flood inundation mapping and mitigation of flood for Adayar watershed. They are MIKE URBAN-1D model, MIKE 11-1D model and MIKE21-2D. These three models are integrated into MIKE FLOOD software for 2D visualization of flood as shown in the Figure (2).

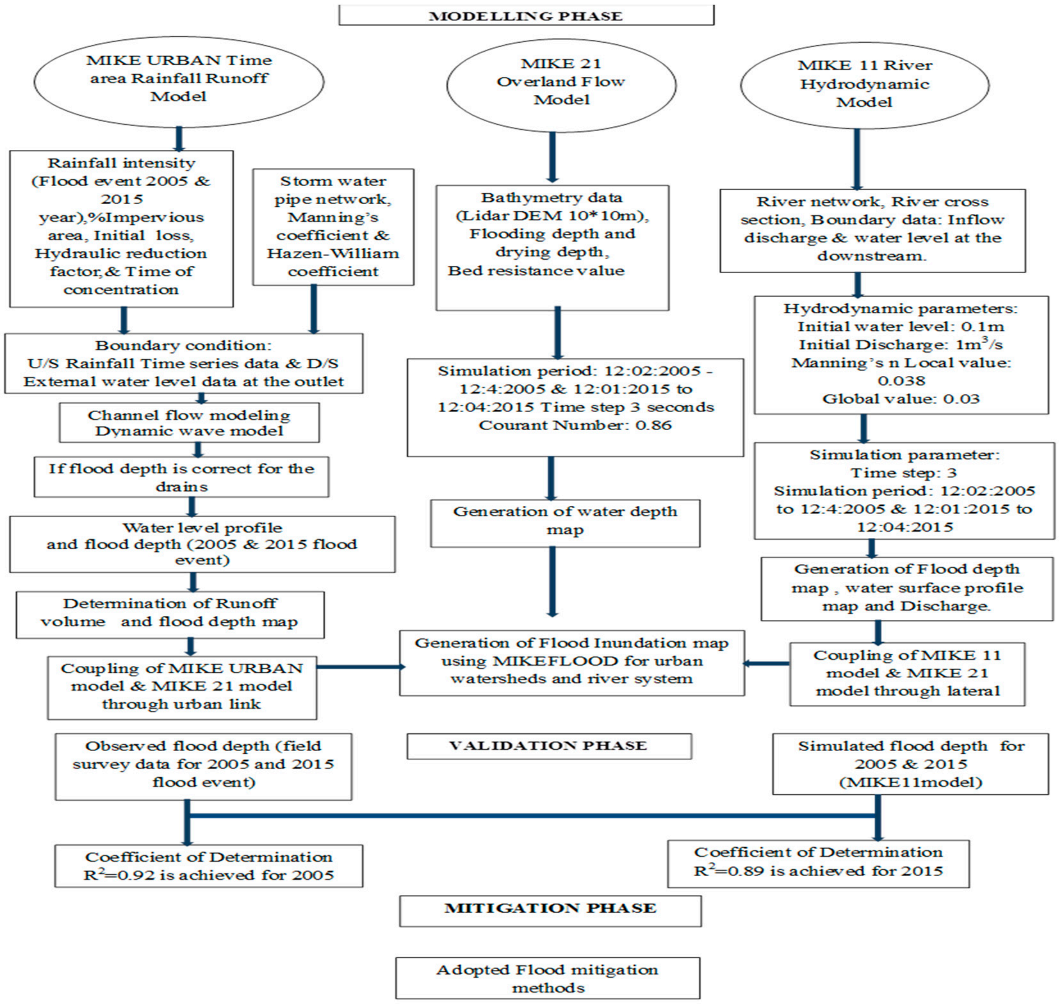

Figure 2 Framework of the methodology adopted in the study area

4. Mike Urban Model

4.1. Governing Equations

In this study, the Time-area (TA) rainfall-runoff model is used to estimate the runoff hydrograph based on a given excess rainfall hyetograph. In this model, the watershed is divided into a number of sub-watersheds separated by isochrones; i.e. the isolines of equal travel time to the outlet. This procedure is known as time area histogram. The method for the generation of the runoff hydrograph is shown in Equation (1):

$$Q_j = \sum_{K=1}^{j} E_k A_{j-k+1} \qquad (1)$$

Where *j*= Time step number, Q= Runoff discharge, E= Excess rainfall intensity, A = Area bounded by the isochrones

The imperviousness percentage of the watershed for each sub-catchment according to the percentage of different land use surfaces is calculated using the formula as shown in the Equation (2):

$$\Phi = (A_1{*}\ \Phi_1 + A_2{*}\ \Phi_2 + \ldots\ldots + A_n{*}\ \Phi_n) / (A_1 + A_2 + \ldots\ldots\ldots\ldots + A_n) \qquad (2)$$

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Where ϕ=imperviousness of the whole sub-catchment, ϕ_i imperviousness of each type of surface, A_i area of each surface.

Later, the initial loss and hydrological reduction factor were assumed to be to 0.6 mm and 0.90 respectively in all the sub-catchments from the literature relating to Indian watershed condition is given by Deepak Singh Bisht et al. [5]. And at last the time of concentration (T_c) for each sub catchment is computed using Kirpich's formula as shown in Equation (3):

$$T_C = 0.01947 * L^{0.77} / S^{-0.385} \quad (3)$$

Where L is the length of the drains and S is the slope of the catchment. The runoff obtained from the catchment is then fed as input to the storm water drainage network for computing flood carrying capacity of the drains.

The MOUSE Model is a computational tool for the computation of one-dimensional unsteady flows in sewer networks with alternating free surface and pressurized flow conditions. The computation is based on solving the vertically integrated equations of conservation of continuity and momentum.

The general equation of continuity of mass is given by Equation (4) as:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \quad (4)$$

And the general equation of momentum is given by Equation (5) as:

$$\frac{\partial Q}{\partial t} + \frac{\partial(\propto \frac{Q^2}{A})}{\partial x} + g * A \frac{\partial y}{\partial x} + g * A\, I_f = g * A\, I_o \quad (5)$$

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

The friction loss in the pipe is calculated by Equation (6) as:

$$I_f = \frac{\tau}{\rho g R} \quad (6)$$

Where: τ = tangential stress caused by the wall friction, [Nm-2], ϱ = density of water, [kgm-3], R = hydraulic radius, [m].

5. MIKE 11 River Hydrodynamic model

5.1. Governing equations for hydraulic model

MIKE 11 is a user friendly, fully dynamic, one dimensional hydraulic model used for simulating the water flows in the river. The MIKE 11 is an implicit finite difference model and a fully dynamic one dimensional unsteady flow equation used for the computation of water surface profile and flood discharge at the selected location of the river. Danish hydraulic Institute (DHI) of Water and Environment has developed this one dimensional hydro-dynamic model with other supporting modules like MIKE Zero, GIS, MIKE FLOOD, etc. for surface runoff, channel flow, sediment transport, water quality Modelling in the watershed. High order Dynamic Wave Method is used for unsteady 1D channel routing in this study. Non-linear Saint Venant equations are used here for conservation of mass, volume, momentum and continuity of flow. The equation for conservation of mass is given by Equations (7) and (8) as:

$$\rho.\mathcal{Q}.dt - \rho.\left(\mathcal{Q} + \frac{\partial \mathcal{Q}}{\partial x}dx\right)dt = \rho.d\mathcal{A}.d\mathcal{X} = \rho.\frac{\partial \mathcal{A}}{\partial t}dx.dt \quad (7)$$

$$\frac{\partial \mathcal{Q}}{\partial x} + \frac{\partial \mathcal{A}}{\partial t} = q \quad (8)$$

Equation for Conservation of Momentum equation is given by Equation (9) as:

$$\frac{\partial \mathcal{Q}}{\partial t} + \partial.(\propto.\frac{\mathcal{Q}^2}{\mathcal{A}}) \Big/ \partial x + g.\mathcal{A}.\frac{\partial h}{\partial x} + \frac{g.\mathcal{Q}|\mathcal{Q}|}{C^2.\mathcal{A}.\mathcal{R}} = 0 \quad (9)$$

Where: Q = Discharge, A = flow area, Q = lateral inflow, h = stage above datum, C = Chezy resistance coefficient, R = hydraulic or resistance radius

The solution of the equations of continuity and momentum is based on an implicit finite difference scheme developed by Abbott and Ionescu in 1967. The transformation of Saint Venant Equations is a set of implicit finite difference equations performed in a computational grid consisting of alternating Q- and h-points, i.e. points where the discharge, Q and water level h, respectively, are

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computed at each time step as shown in the Figure 4.8. The computational grid is generated automatically by the model on the basis of the user requirements. *Q*-points are always placed midway between neighboring *h* points, while the distance between *h*-points may differ.

5.2. Delineation of Adayar River network

In the present study, Adayar river network are imported from the Arc GIS software by using ortho photo imagery as a background. In MIKE 11, the river network acts as a system of points interconnected in between branches. Water levels (h) and discharges (Q) are calculated along the river branches as a function of time.The Adayar river cross section data describes the shape of the stream bed cross section obtained from the field survey by using (x, z) co-ordinates.The discharge is computed using the Manning's equation is given by Equation (10) such as:

$$Q = M\,R^{2/3}\,S_0^{1/2}\,A \qquad (10)$$

Where: M = Resistance number, R= Hydraulic radius, S_0= bed slope, A= cross sectional wetted area calculated by iteration and it is placed in the cross section table of MIKE 11HD when a certain level accuracy is reached (10^{-3}).

6. E 21- 2D Overland flow model

MIKE-21 is a Modelling system for 2D free surface flows developed by DHI 2000a [6]. The model is capable of simulating the water level and flows in response to a variety of forcing functions in coastal areas. The hydrodynamic (HD) module is the basic module in the MIKE 21 Flow model. It solves the fully, time-dependent, non-linear equations of continuity and conservation of momentum as represented by Equations (11) and (12), respectively, as given below

$$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t} \qquad (11)$$

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial y}\left(\frac{q^2}{h}\right) + \frac{\partial}{\partial x}\left(\frac{pq}{h}\right) + gh\frac{\partial \zeta}{\partial y} + \frac{gq\sqrt{p^2+q^2}}{c^2h^2} - \frac{1}{\rho_w}\left[\frac{\partial}{\partial y}\left(h\tau_{yy}\right) + \frac{\partial}{\partial x}\left(h\tau_{xy}\right)\right] + \Omega_p - fVV_y +$$
$$\frac{h}{\rho_w}\frac{\partial}{\partial xy}(p_a) = 0 \qquad (12)$$

where ζ = surface elevation (m), t= time (sec), p= flux density in x direction (m3/s/m), x, y = space coordinates (m),d= time-varying water depth (m), h= water depth (m), g= acceleration due to gravity (m/s2), C= Chezy resistance coefficient ($m^{1/2}/s$), Ωq = Coriolis parameter (s^{-1}), ρ_w = density of water and f(V) = wind friction factor.

The MIKE-21 resolves the solution using an implicit finite difference scheme of second-order accuracy.MIKE-21 model requires input parameters such as bathymetry or terrain elevation which contains the information regarding the elevations of the flood plain. The Digital Elevation Model, obtained from Lidar-DEM are used for the study area. The resolution of the input bathymetry was 10m x10 m, so the computational distance was 10 m and the time step adopted was 3 seconds for the simulations. The remaining of the input parameters such as the flood plain roughness coefficient (Manning's n) as 0.038, flooding depth and drying depth as 0.02 m and 0.03 m are provided in the model. Figure 4.13 shows the representative area of the Lidar-DEM derived bathymetry used in MIKE-21 covering the study area of the Adayar river catchment.

7. Integration of MIKE11-1D and MIKE21-2D using MIKE FLOOD software

The MIKE-11 river network was connected to the MIKE-21 bathymetry using the lateral link option available in the MIKE-FLOOD. The river bank was dynamically linked with the MIKE-21 grids using a cell-by-cell approach. Whenever the overflow takes place from the MIKE-11model, the MIKE-21 model calculates the discharge over each cell using weir formula 1. The equation for the weir formula 1 is shown in the Equation (13) as:

$$Q = w\,Ch_1^k[1 - \left({}^{h_2}/_{h_1}\right)k]^{0.385} \qquad (13)$$

Where w = width, C = weir coefficient (1.838), k exponential coefficient (1.5), h_1= depth of water above weir level upstream (H_{us} - H_w) and h_2 = depth of water above weir level downstream (H_{ds} – H_w).This equation is actually a free overflow term ($w\,C\,h^k$) combined with a scaling term for submerged

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($k^{0.385}$) that approaches 0 as h_1 approaches h_2.The MIKE-11 model has been calibrated for manning n value and validated against observed data. The simulation period for both MIKE-11 and MIKE-21 was kept as the same during the year 2005 and 2015.The model computational time step was assigned as 3 seconds, the Courant Number (CR) is given as less than or equal to 1 so as to achieve stable MIKE-FLOOD simulation run in order to aviod stability problems.

8. Results and Discussions

8.1. MIKE URBAN Model Results

The study area, Adayar watershed was divided into eight micro watersheds for building two scenarios such as existing storm water drainage system and the revised storm water drainage system for assessing the runoff by using MIKEURBAN model as shown in the Figure (3).

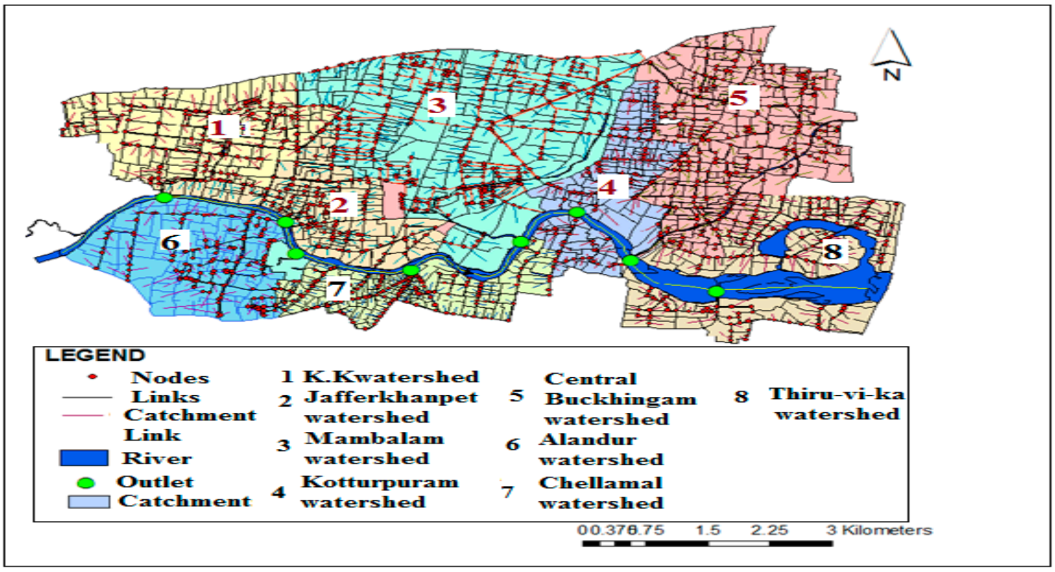

Figure 3 Illustration of the Adayar watershed in the MIKE URBAN model

The results from the model can be viewed in the MIKE View module. The flood inundation maps are prepared by integrating 1D MOUSE model and 2D MIKE 21 model using MIKE FLOOD software. The flood depths and flood extent of the flooded area are generated for the eight micro watersheds. The display of flood inundation maps for one micro-watershed for the year 2005 and 2015 are shown in the following Figures of (4) and (5).

The inundated areas of the central Buckingham canal watershed are cathedral road, Masilamani street, sivasamy salai, Muntakaniyamman koil street, Thiruvenkadam street, Luz church road, Sir CV Raman road, Pritiivi avenue. By comparision, the flood inundated area in the year 2015 is more than 1.5 m at the major drains as shown in the Figure (5).

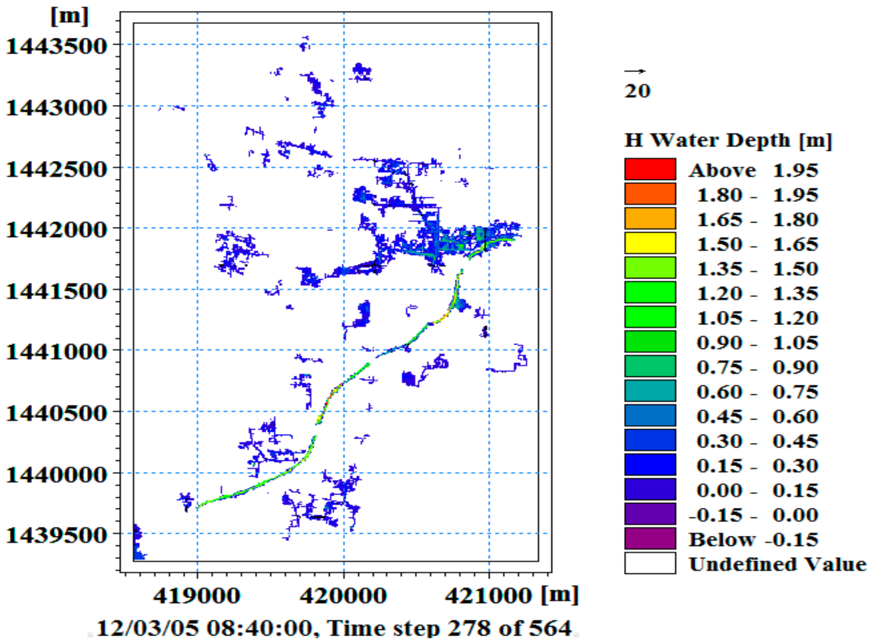

Figure 4 Flood inundation map for the Central Buckingham Canal watershed for the year 2005

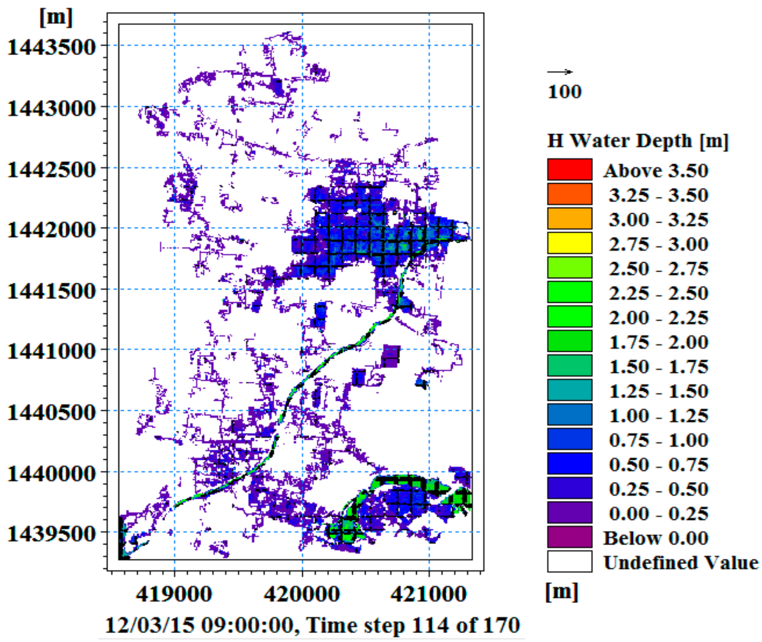

Figure 5 Flood inundation map for the Central Buckingham Canal watershed for the year 2015

Later on, runoff hydrograph for eight watersheds for two scenarios namely existing drains and revised drainages for the flood event 2005 and 2015 are calculated as shown in the Table 1. From the Table (1), it is clear after revising the size of the storm water drain more than 50% of the flood water have been discharged into the river which alleviates the flooded road.

 doi:10.20944/preprints201712.0135.v1

Table 1 Runoff hydrograph of Adayar watershed for the year 2005 and 2015

Name of the 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)
K.K Nagar	85.41	134.34	110.06	211.17
Jafferkhanpet	69.55	118.20	88.97	141.06
Mambalam Central	193.86	275.23	403.62	685.23
Buckhingham Canal	169.29	227.56	250.68	452.21
Alandur	76.99	127.97	89.71	215.39
Chellamal	33.46	110.51	54.75	174.67
Kotturpuram	54.94	93.87	75.35	113.28
Thiru-vi-ka	64.12	91.58	83.6	148.01
Total	747.62	1179.26	1156.74	2141.02

8.2. MIKE 11 River Flood Model Results

The High order Dynamic Wave Method is used for unsteady 1D channel routing in this study. The Non-linear Saint Venant equations are used for conservation of mass, volume, momentum and continuity of flow. The model gives discharge at different cross section, velocity and as well as water level profile at different locations of cross section. The water level surface profiles of Adayar river for the flood event 2005 has attained the highest water level at 3-12-2005 on 09:30:00 AM as shown in the Figure (6). From the Figure (6), it is clear their is overtopping of river banks which inundates adjacent areas.

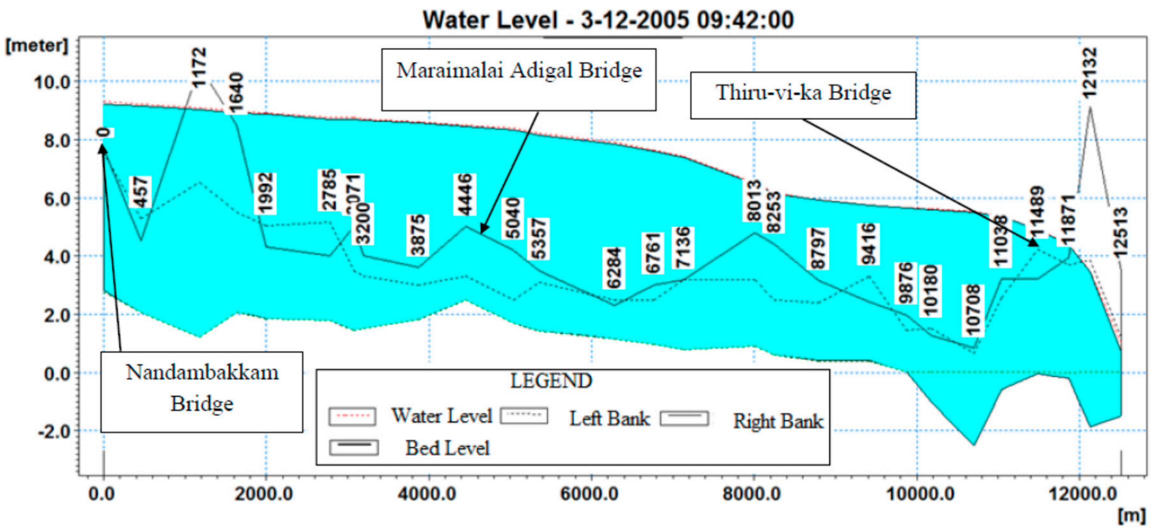

Figure 6 Water level profile of Adayar river for surveyed cross-section for the year 2005 (MIKE 11 model output)

Similarly the water level surface profiles of Adayar watershed for the flood event 2015 has attained the highest water level at 2-12-2015 on 09:30:00 AM as shown in the figure (7). From the Figures of (7), it is clear their is overtopping of river banks across various bridges which inundates adjacent areas.

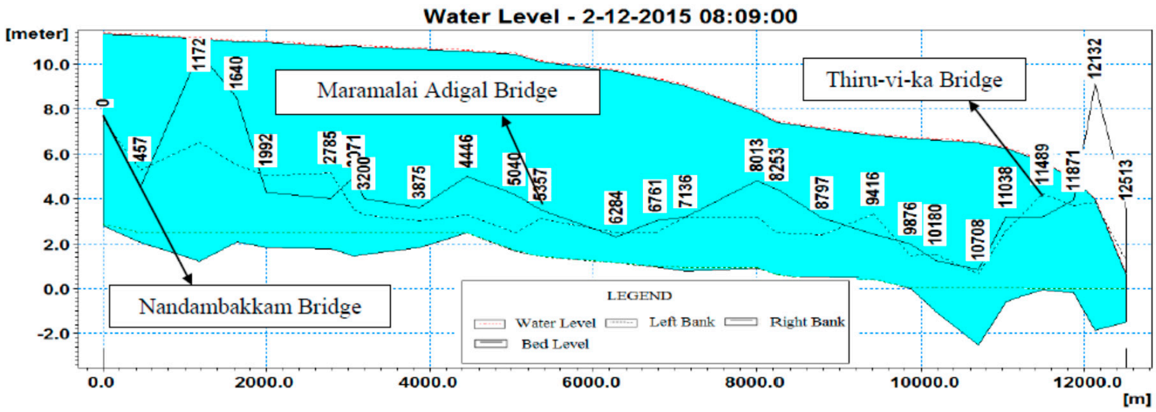

Figure 7. Water level profile of Adayar river for surveyed cross-section for the year 2015 (MIKE 11 model output)

From the model output the flood discharge, flood inundated area and flood depth with respect to duration are found. The flood discharge peak during 2005 for the existing and revised drain on 2nd December 2005 to 4th December 2005 is at 9:30 AM and during 2015 for the existing and revised drain on 1nd December 2015 to 4th December 2015 is at 9:46 AM for the Adayar river at the outlet are presented in the Figure (8).

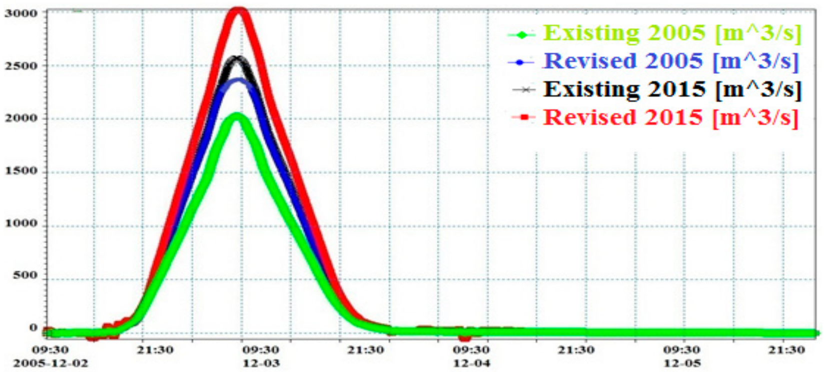

Figure 8 Flood Hydrograph for the Adayar river for the year 2005 and 2015 flood event of MIKE 11 model

From the Figure 8, it is clear that up on revised drainage network more discharge have been mitigated to the river which reduces the urban area being inundated for the year 2005 and 2015. Thus solves the problem of urban flooding.

8.3. Model validation using Error Index Statistics

The performance of the MIKE 11 model is tested against the observed water level using R^2 statistics at various locations of the Adayar river during the year 2005 and 2015. The model performance has been validated using the observed and simulated value using statistical method. RMSE is one of the commonly used error index statistics. The RMSE value less than 1 indicates better performance model. The Equation (14) for computing the RMSE is shown as:

$$\sqrt{\text{RMSE} = \sum_{i=1}^{n} \frac{(y_i^{obs} - y_i^{sim})^2}{n}} \qquad (14)$$

Where, y_i^{obs} is the observed discharge, y_i^{sim} is the simulated discharge and ^{n} is the total number of events.

The RMSE value of less than one from the model indicates good performance. Since there is lack of observed data at the other bridge location calibration and validation is found to be insufficient.

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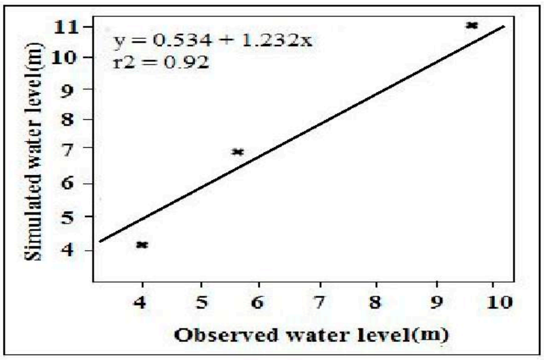
Hence the model has been validated with the available data. It has been concluded that the simulated water levels by MIKE11 have R^2 coefficient of determination as 0.92 for 2005 flood event and 0.89 as for 2015 flood event as shown in the Figure (9) and (10).



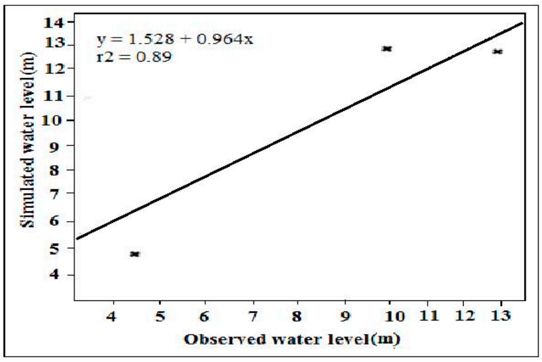


Figure 9 Comparison of Observed and Simulate simulated water level for 2005 flood event

Figure 10 Comparison of Observed and water level for 2015 flood event

8.4. Flood Mitigation Measure

In this present study, the flood mitigation measures have been carried out by two ways such as: Urban flood mitigation, River flood mitigation and flood mitigation into the sea.

8.4.1 Urban flood mitigation measure through revised storm water drainage network

Floods have been mitigated through revised storm water for eight watersheds. But the results are displayed for one Central buckhingam canal watershed alone. The watershed covers an area of about 6.61 Sq.km. From the results of the model, the total flood volume inundated in the Central buckhingam canal watershed during 2005 flood event was found to be 0.373 MCM. But after the revised size of the drains the flood volume has been reduced to 0.219 MCM. The flood inundated map for the revised drains for the year 2005 is shown in the Figure (11). Likewise the total flood volume inundated in the Central buckhingam canal watershed during 2015 flood event was found to be 0.631 MCM. But after the revised size of the drains the flood volume has reduced to 0.219 MCM. The flood inundated map for revised drains for 2015 flood is shown in the Figure (12).

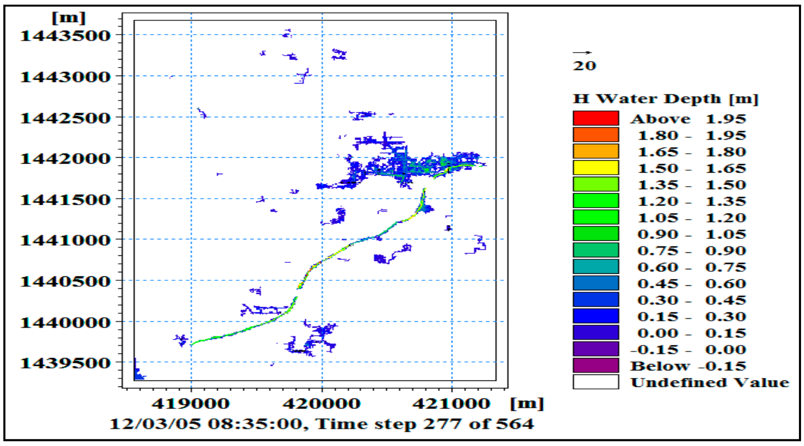


Figure 11 Flood Inundation map of revised storm Water drainage network of Central Buckhingham canal watershed for the year 2005

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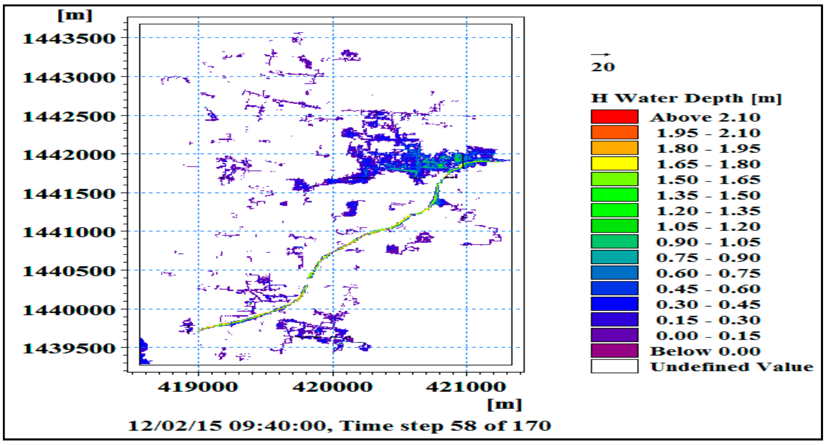

Figure 12 Flood Inundation map of revised storm water drainage network of Central Buckhingham canal watershed for the year 2015

Some portion of a flood has been mitigated through revised storm water drains. The balance flood volume of 0.154 MCM for 2005 flood and 0.34 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.

8.4.2. River flood mitigation measure through regarding the channel

Now In order to avoid flooding in the river the cross section of the river has been regraded (lowered) to 0.8 m and 1.0 m for the flood event 2005. But the results are displayed for 1.0m regarded channel as shown in the Figures (13). From the results, after regrading the river bed the flood depth has been reduced drastically and the overtopping of the banks have been controlled through this method.

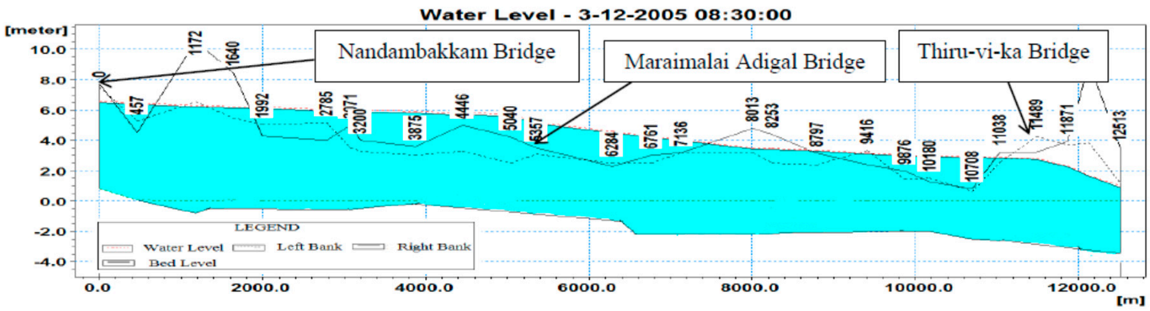

Figure 13 Water level profile of Adayar river after regrading the cross section by 1.0 m for the year 2005 (MIKE 11 model output)

Similarly for the flood event 2015, In order to avoid flooding in the river the cross section of the river has been regraded to 0.8 m and 1.0m. But the results are shown in the Figures (14) for 1.0m regarded river bed. From the results, after regrading the river bed the flood depth has been reduced drastically and the overflowing of the banks have been controlled through this technique.

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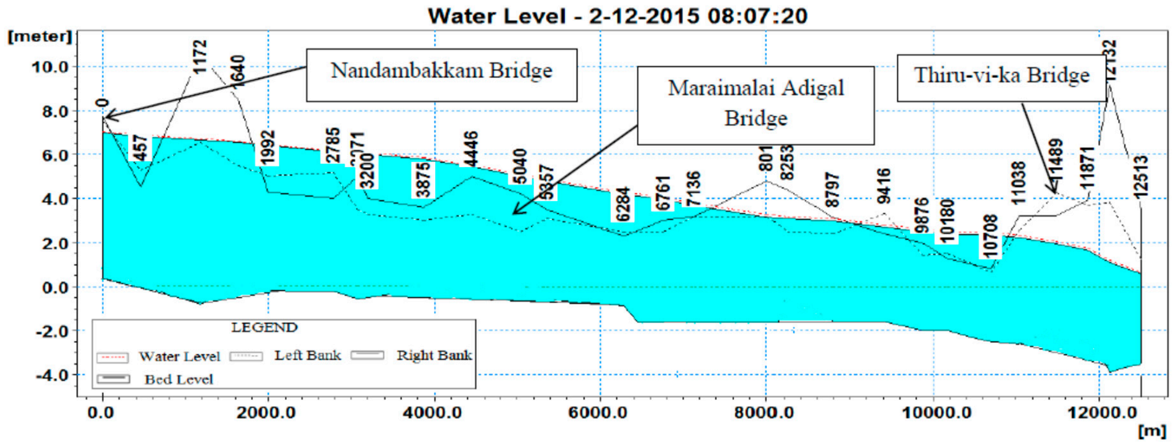

Figure 14 Water level profile of Adayar river after regarding the cross section by 1.00 m for the year 2015 (MIKE 11 model output)

8.4.3. Flood plain mapping after mitigation of the Adayar River

The Adayar river have been completely mitigated after modifying the cross sections at important locations of the bridges. Now, the river has the flood carrying capacity of 1463.48 m^3/s discharge for the rainfall of 60 mm peak during 2rd December to 3rd December 2005 without being flooded and 2332.64 m^3/s discharge for the rainfall of 68 mm peak during 1st December to 3rd December 2015.The following Figures from (15) to (18) shows the inundation map for existing cross section and regraded cross section of Adayar river.

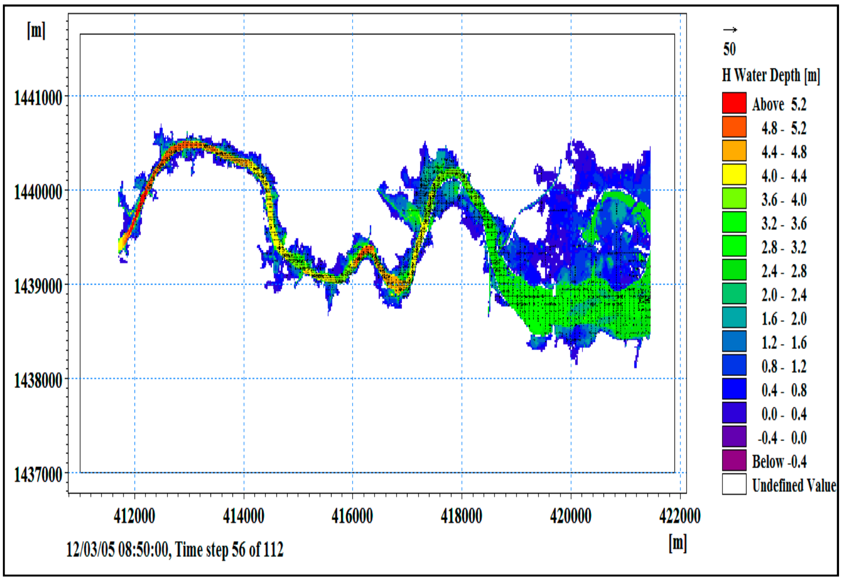

Figure 15 Flood plain mapping of Adayar river for the surveyed cross-section for the year 2005

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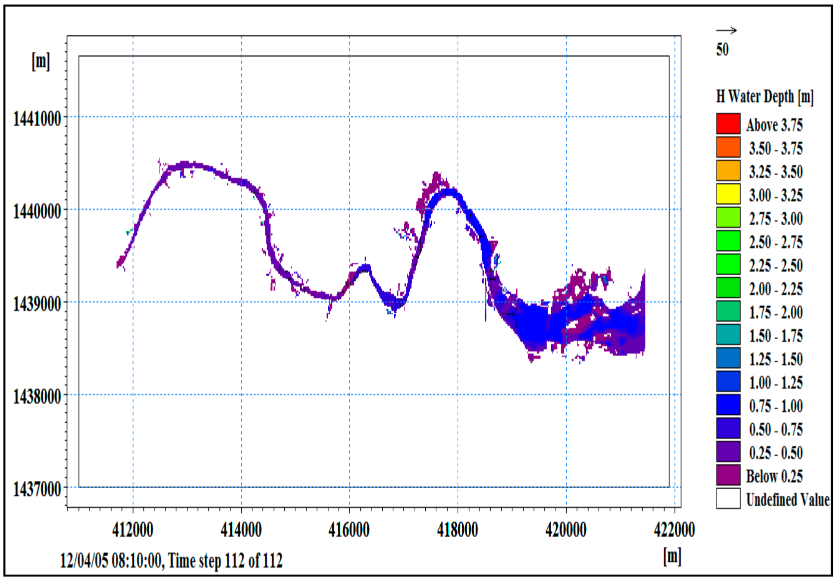

Figure 16 Flood plain mapping of Adayar river for the modified cross section of 1.00 m for the year 2005

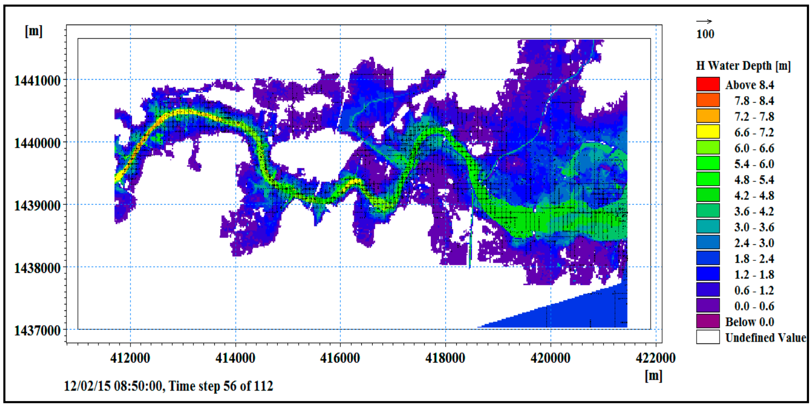

Figure 17 Flood plain mapping of Adayar river for surveyed cross section of 1.00 m for the year 2015

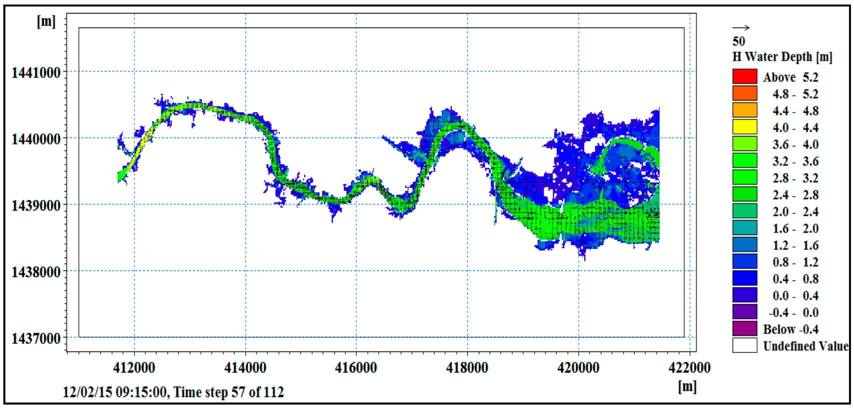

Figure 18 Flood plain mapping of Adayar river for the modified cross-section for the year 2015

Similarly, from the above Figures 15-18, it is clear the regarding of the river bed serves as a best solution for flood mitigation of Adayar river which can be adopted by the planners.

 doi:10.20944/preprints201712.0135.v1

9. Conclusion and Recommendations

Based on the objective, the Time-area (TA) rainfall-runoff model is used to estimate the runoff volume and to estimate flood depth. The volume of flood for eight Adayar micro-watersheds have been estimated for two scenarios namely existing storm water drainage network and revised storm water drainage network. 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.

In order to minimize the urban flood the revised storm drainage is adopted and the conclusions are drawn as follows:

Flood has been mitigated in the Adayar watershed through revised storm water drains. From the results of MIKEFLOOD software, the flood discharge into the Adayar river during 2005 flood event was found lesser compared to the 2015 flood event. Ultimately, this flood discharge inundates the Adayar watershed beyond the flood carrying capacity of storm water drainage network. The total runoff volume inundated in the Adayar watershed for the existing drain for the year 2005 is found to be 0.017 MCM and after revised drain the flood volume have reduced to 0.011 MCM. Similarly for the year 2015 the flood volume for the existing drain is found to be 0.022 MCM and after revising the drain the flood volume have reduced to 0.020 MCM. From the results, it clearly shows it is the best mitigation measure for alleviating the flood. The balance flood volume of 0.0053 MCM and 0.0018 MCM for the year 2005 and 2015 have been mitigated through surface canal draining into the river and ultimately into the sea. The flat topography of Chennai makes it difficult to carry excess flood water which needs immediate attention for mitigating flood waters.

In this study, hydraulic model MIKE 11 were analyzed for floodplain mapping of Adayar river for two flood events of 2005 and 2015. The model is used and is validated against the observed flood depth of 2005 and 2015 flood event. From the model results, the model gave more coefficient of determination having R^2 equal to 0.92 for 2005 flood event and R^2 equal to 0.89 for 2015 event. The balance flood discharge of 755 m^3/s of existing drain and 1,092.11 m^3/s of revised drain for 2005 flood event and the balance flood discharge of 889.36 m^3/s of existing drain and 701.51 m^3/s of revised drain for 2015 flood event from the river and urban sub watersheds has to be discharged in to the sea as a part of flood mitigation measure.

After regrading the bed of the river by 1m, the area inundated has been reduced from 14.05 Km^2 to 6.81 Km^2.Hence the suggested mitigation measure is to open the sea mouth during low tide level, removal of sand bar at the sea mouth and control of sediments solves the flood problem. By implementing the suggested measure, the river flood area will be discharged completely into the sea without any blockades for safer livelihood.

The study can be improved by incorporating the suggested recommendations. In the heavily developed Adayar watershed, the runoff water must be recognized as a valuable resource and preserve it for the stable ground water table during summer season. For the effective prediction of runoff water the model has to consider population density as well as impervious value from the landuse/ land cover map. Different methods for calculating time of concentration for urban watershed can be attempted and chosen for best urban runoff model. The climate change parameter can be included in the study for the prediction of future flood and Automatic weather rain gauge data can be considered in future at an interval of 1 hour duration rainfall for flood forecasting study. To remove formation of sand bars in the river mouths causing stagnation in Adayar river. Bank protection for the stretch 0.0 to 0.5 km -0.75 meters thick rubble gabion packing on slopes on both sides. Maintenance dredging to maintain the tidal prism. To open the sea mouth during low tide level, removal of sand bar at the sea mouth and control of sediments solves the flood problem. The available surface water can be utilized for augmenting the ground water which can considered for future study. The different methods of ground water conservation are by way of constructing percolation pits, recharge trench, roof water harvesting structures according to the site condition.The Chennai Corporation has initiated to construct rainwater harvesting structure across the Chennai city which can be analyzed for future perspective to avoid flooding.

 doi:10.20944/preprints201712.0135.v1

Acknowledgments: The authors would like to express profound gratitude to Dr. M. Ramalingam, Former Director, Institute of Remote Sensing, Anna University for his guidance, constant encouragement and invaluable support during the research work and DHI (India) Water & Environment pvt ltd. for their guidance on the analysis of hydrodynamic model.

Author Contributions: Each author had contributed to this research work. The first author, vidyapriya, had the responsibility of developing and testing the model. The second author Ramalingam helped to analyze the data and made necessary suggestion on this work.

Conflicts of Interest: The authors declare no conflict of interest.

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