FLOOD INUNDATION ANALYSIS FOR METRO COLOMBO AREA – SRI LANKA

Mohamed Mashood Mohamed Moufar* **Supervisor:** Dr. Duminda Perera**,
(MEE 13633)

ABSTRACT

The canal network in Metro Colombo area in Sri Lanka, initially constructed for transportation in 16th century, carries and discharges the flood water to the Indian ocean from the west side and to the Kelani River from northern side. The main objective of this study is to estimate the flood inundations for design rainfalls of 10, 25 and 50 years of return periods and also to assess the impact of four feasible countermeasures which are proposed for the Colombo canal network. The study area is modeled using MIKE11, MIKE21 and MIKE FLOOD to achieve the objectives. The simulation results show that the extent of inundation and the flood levels are higher when the water level of Kelani River is high in each scenario of design rainfalls. When the countermeasures are introduced individually, the flood water levels are lowered locally, but not up to the flood safety levels of the surrounding area. When all four countermeasures are introduced to the model, the flood water levels are significantly lowered than the flood safety levels.

Keywords: Colombo canal network, Countermeasures, Flood level, Inundation area, Urban floods

INTRODUCTION

Colombo is a coastal city located at the western part of Sri Lanka and it is the commercial capital of the country. Colombo district has a population over 2.3 million within 699 km^2 of area and therefore it has a high population density of 3,400 person/ km^2 (as in 2012).

The Metro Colombo basin has an extent of 105 km^2 and it is spread over seven Divisional Secretary's (DS) divisions such as Colombo, Thimbirigasyaya, Dehiwela, Kolonnawa, Sri Jayawardanapura Kotte, Maharagama and Kaduwela. The Metro Colombo basin is laid in the western wet zone of the country and it receives mean annual rainfall of 2,300 mm. Colombo area is subjected to frequent floods during south-west monsoon when it coincides with localized depressions.

The canal network of Metro Colombo basin has a long history from 16th century which was mostly used for transportation in the past. At present, the canal network acts as a passage to drain out flood water from the basin (Figure 1).

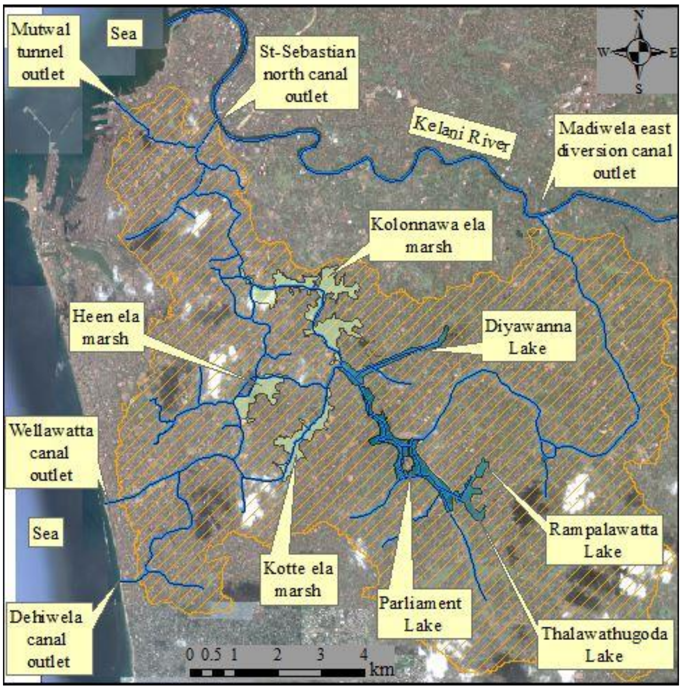

Figure 1. Layout map of the canal network in Metro Colombo basin

* Senior Engineer, Sri Lanka Land Reclamation and Development Corporation (SLLRDC), Sri Lanka
** Research Specialist, International Center for Water Hazard and Risk Management (ICHARM), Tsukuba, Japan

The total length of canals is 67 km. The canal network has five main outfalls, among them three outlets (Dehiwela canal outlet, Wellawatta canal outlet and Mutwal tunnel outlet) drain in to the Indian Ocean. Other two named as St-Sebastian north canal outlet and Madiwela east diversion canal outlet discharge flood water into the Kelani River. The canal network has a zero bed slope and the bed level of canals is -1.0 mMSL (meters above Mean Sea Level). There are three main marshy lands acting as retention areas for floods which are named as Kotte ela marsh, Heen ela marsh and Kolonnawa ela marsh. Also there are few detention ponds and lakes in upper catchment area which can store flood water such as; Parliament Lake, Diyawanna Lake, Thalawathugoda Lake, Rampalawatta Lake etc. Figure 2 shows the schematic diagram of the canal network in Metro Colombo area.

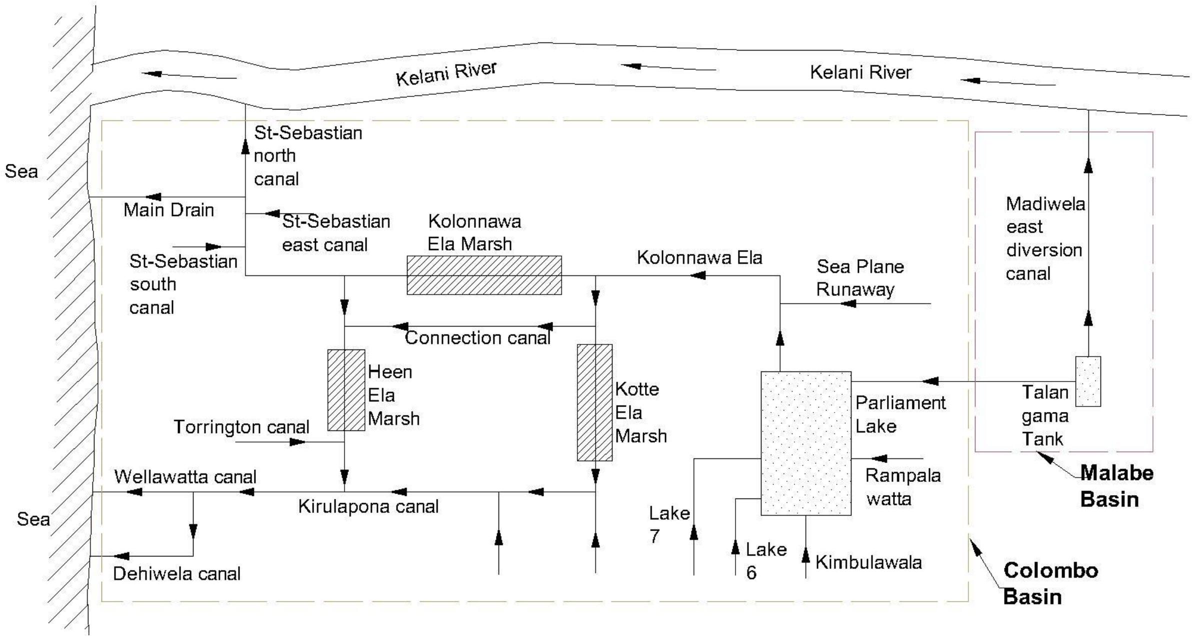

Figure 2. Schematic diagram of Metro Colombo canal network

The geographical terrain of Metro Colombo basin is almost flat, varies from 0 mMSL to 35 mMSL (most parts are laid below 3 mMSL) and therefore it is exposed to frequent floods during heavy rainfalls. Main reasons for recent flooding are; increase in surface runoff due to rapid developments, diminishing of retention areas, increasing trend of rainfall intensity and inadequate conveyance capacities of canals, structures and outlets.

The main objective of this study is to develop flood inundation maps to assess the extents of floods, flood levels and the durations of flooding for 10 year, 25 year and 50 year rainfall events within Metro Colombo area. Secondary objective is to check the effectiveness of four countermeasures which are proposed to introduce to the canal system. The feasibility of each countermeasure is assessed based on the reduction in inundation area and flood level. Number of affected people in each DS divisions are also assessed accordingly for each scenario.

THEORY AND METHODOLOGY

MIKE FLOOD is a hydrodynamic model, which consists of two sub-models: named as MIKE 11and MIKE 21. The 1-D modelling tool, MIKE 11 solves one-dimensional form of the Saint-Venant equations along the channel. The two dimensional model MIKE 21 is based on two-dimensional solution of the Saint-Venant equations along the floodplain. The MIKEFLOOD model combines best features and strengths of both MIKE 11 and MIKE 21 while minimizing limitation of each individual models.

MIKE model applies the fully dynamic descriptions and solves vertically integrated equations such as Continuity equation (Conservation of mass), Momentum equation (Conservation of momentum: Saint-Venant equation) as shown in following equations

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0$$

$$\frac{\partial Q}{\partial t} + \frac{\partial(\alpha \frac{Q^2}{A})}{\partial x} + gA\frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2AR} = 0$$

These equations are derived assuming that the water is incompressible, homogeneous, bed slope is small, has a hydrostatic pressure variation along the vertical and the flow is sub-critical.

The entire canal network in Metro Colombo basin was modelled using MIKE11. The topographical details of canals, the upstream and downstream boundary conditions, sub-catchment parameters, storage parameters, run-off parameters, initial conditions and bed resistance were the main inputs for MIKE11 model. Digital Elevation Model (DEM) of the area is imported to MIKE21 to assess the flood inundation over the basin area. The simulation was performed for 30 m grid resolution. The main parameters defined in MIKE21 model were flood depth, dry depth, eddy viscosity and Manning's number. The MIKE11 and MIKE21 models were coupled using MIKE FLOOD while defining the links between the channels and flood plains. The main steps adopted to build up the model is shown in Figure 3.

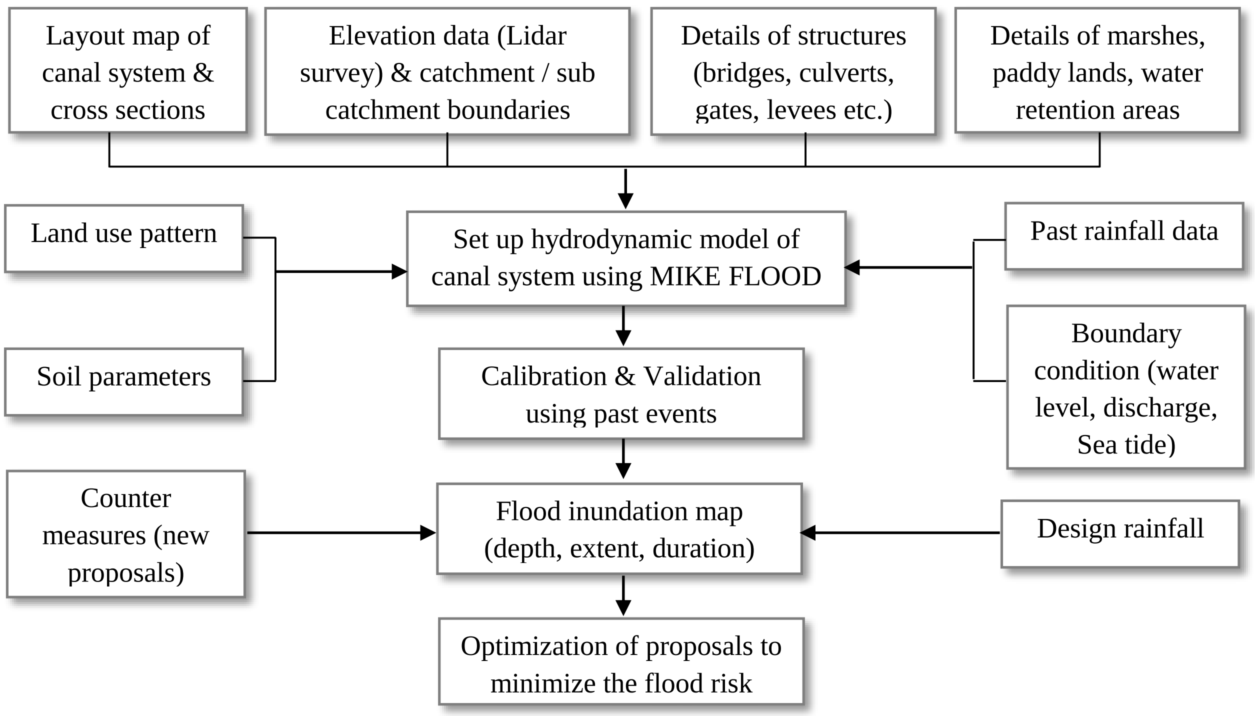

Figure 3. Flow chart showing methodology of the study

Calibration of MIKE FLOOD model was conducted for rainfall event in November 2010 for 15 days from 3rd to 18th using observed water level data along the canal network. The model was validated for the rainfall event in May 2010 from 10th to 25th using measured water levels.

The model was simulated for several design scenarios considering the design rainfalls and upstream boundary condition. Design rainfall with the return periods of 10, 25 and 50 years were considered for the simulation. Two scenarios of boundary conditions were considered as favorable and worse. The favorable condition is when Kelani River has low water level, and has a steady discharge of 100 m^3/s which is the approximate average of past 30 years measured data. The worse condition has a high water level in Kelani River with a flow discharge of 2000 m^3/s, which is the approximate maximum of past 30 years data.

Four proposed countermeasures were introduced to the model one at each for 50 year rainfall under the favorable condition and the results; inundation area and water levels were compared with the existing condition. The four countermeasures are,

1. Gothatuwa diversion canal
2. St-Sebastian south diversion canal
3. New Mutwal diversion
4. Madiwela south diversion scheme

At the final stage the model was simulated introducing four countermeasures together.

DATA

Metro Colombo basin has only one rainfall gauging station located at the premises of Department of Metrology, Colombo. The rainfall data of 15 minutes are available at this gauging station and past rainfall data from the year 1981 to 2010 were collected for this study. The sea tide levels which were used as downstream boundary condition, are measured at the gauging station located in Colombo harbor. Hourly data of sea tide levels were used for this study. The flow discharge of Kelani River at Hanwella measured by Irrigation department were used as upstream boundary condition. The water levels at 5 gauging stations along the canal system were used for the calibration and validation of the model. The summary of data which were used is listed in Table 1.

Table 1 –Summary of data used for the study

Description of data	Main source of data
Topographical layout map of canal network	SLLRDC
Survey details of canals (ie: cross sections, longitudinal sections)	SLLRDC
Details of main structures such as bridges, culverts, gates, levees etc.	SLLRDC
Details of marshes, paddy lands, water retention areas	SLLRDC
Elevation data of the basin (Lidar survey data)	SLLRDC
Water levels in canal network	SLLRDC
Water levels in Kelani River	Department of Irrigation
Discharge of Kelani River at Hanwella	Department of Irrigation
Sea tide level	Colombo harbor
Past rainfall data	Department of Metrology

RESULTS AND DISCUSSION

The model was simulated for design rainfall of 10, 25 and 50 years return periods considering favorable and worse conditions of boundary conditions. The extent of inundation are much higher in worse condition since the water level of Kelani River is high. There are considerable reductions in inundation area when the countermeasures are introduced individually, but most of the time these reductions are concentrated to the location where the countermeasure is introduced. However, when all countermeasures are introduced to the model together the reduction in inundation area is significant and the flood levels are much lower than their respective flood safety levels where the flood levels are compared.

Figure 4 and Figure 5 show how the flood has spread over five DS divisions in Metro Colombo basin for 50 year rainfall (favorable scenario) with existing condition of canal system and after introducing all four countermeasures to the canal system. The Table 2 shows the inundation area and the number of affected people in each DS divisions for the existing condition of canal system and with all four countermeasures.

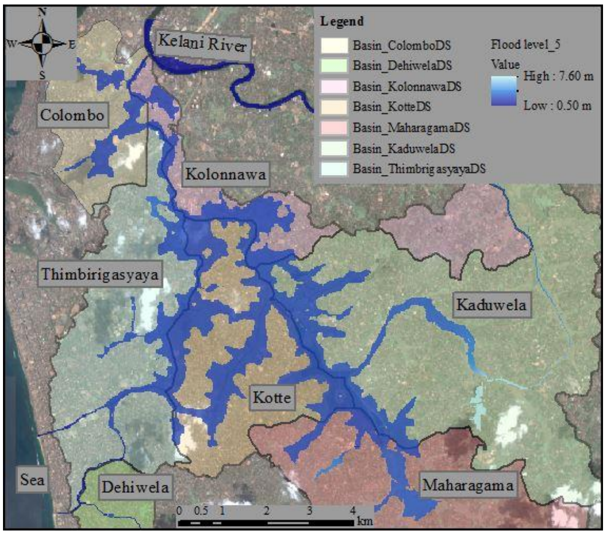

Figure 4. Flood inundation map for 50 year rainfall for favorable scenario with existing condition of canal network

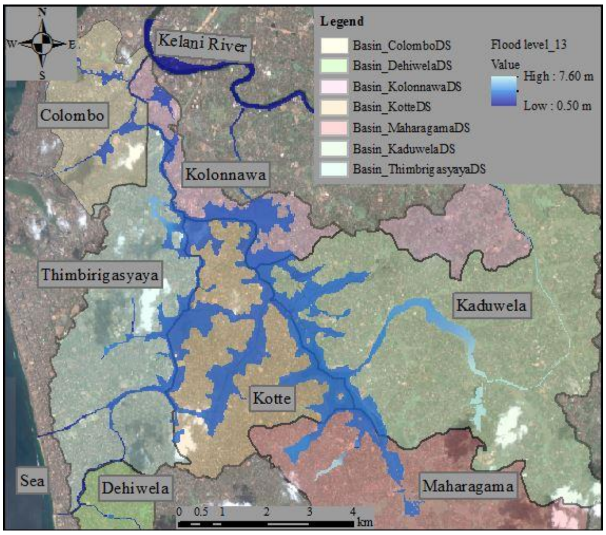

Figure 5. Flood inundation map for 50 year rainfall for favorable scenario with all four countermeasures

Table 2 –Inundation area and affected people in DS divisions with all four countermeasures (50yr rainfall)

Divisional Secretary's division	**Inundation area (km^2)**		**Number of affected people**		**Percentage reduction (%)**
	Existing condition	**With all countermeasures**	**Existing condition**	**With all countermeasures**	
Colombo	1.0	0.3	15,559	4,793	69.2
Thimbirigasyaya	1.7	0.9	16,957	9,437	44.4
Dehiwela	0.0	0.0	88	88	0.0
Kolonnawa	1.0	0.6	7,241	4,363	39.7
Sri Jayawardanapura Kotte	2.7	1.8	16,983	11,057	34.9
Maharagama	1.0	0.4	5,304	1,900	64.2
Kaduwela	1.8	1.0	5,003	2,805	43.9
Total	**9.2**	**5.0**	**67,136**	**34,443**	**48.7**

The extent of flood inundation area is 9.2 km^2 for the existing condition when there is no countermeasures introduced it is reduced to 5.0 km^2 after introducing all four countermeasures as shown in Table 2 and the percentage of reduction is around 46%. Also it shows a reduction of 49% in affected people within the entire Colombo basin with the introduction of all four countermeasures and it can be seen considerable reductions in each DS divisions.

The flood levels before and after the introduction of all countermeasures at few important locations were compared with their respective flood safety levels. The results show that, in all those locations the flood levels were lowered below their respective flood safety levels after the introduction of four countermeasures together.

RECOMMENDATION

The accuracy of the model results could be further improved if finer grid bathymetry is used as two dimensional domain. Therefore, it is recommended to use Digital Elevation Model (DEM) having fine resolution of 10m, 5m or even 1m grids. Also, it is recommended to apply the precipitation to two dimensional domain instead of applying in 1-D model. In these two cases, it is required to use a high capacity computer for the simulation of hydrodynamic modelling. Also it is necessary to adopt very small time steps for the stable model simulation. In 2-D modelling, land use pattern of the area influences the spreading of flood enormously, and therefore it is very important to develop a detailed land use map in order obtain a much reliable flood inundation map.

The model was simulated for the design rainfall developed by alternating block method. Several design scenarios could be constructed by considering design rainfall, rainfall pattern and boundary conditions and could be tested in the model. Four major countermeasures were introduced to the model one by one and all together. The feasibility of introducing more countermeasures could be studied in future in order to reduce the flood impacts in study area. Also, these four countermeasures could be optimized by changing their dimensions, levels and other geometrical parameters.

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