A METHODOLOGY TO ANALYZE EXTREME FLOODING UNDER FUTURE CLIMATE CHANGE SCENARIOS FOR COLOMBO

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ABSTRACT

Colombo, the commercial capital of Sri Lanka, is located in the flood plains of the Kelani River. Therefore, Colombo is more vulnerable to flooding during the heavy rainy seasons (April-June and September-November). Furthermore, it has been identified that Colombo has undergone climate changes over the past years with very random change of rainfall anomalies. This study was focused on analyzing the extreme flooding scenarios due to climate change in Colombo area. Future climate conditions in the Kelani basin with different Global Circulation Model (GCM) data was analyzed to define extreme rainfall scenarios for the Kelani basin taking future climate change into account. Flood inundations in Colombo area under extreme rainfall scenarios were modeled and possible adaptation measures were identified to reduce the impacts in the area.

KEYWORDS: Climate change, extreme rainfall, flood modeling

1. INTRODUCTION

Sri Lanka experiences floods, droughts and landslides as climate-induced disasters. The wet zone of the country especially the Kelani, Kalu and Gin river basins suffer from floods mostly during monsoon seasons (April-June and September-November). Every year floods cause serious damages to lives and properties in the low land areas of the flood plains. Colombo, The commercial capital of the country is also located in the lower reach of Kelani river. Therefore, Colombo is highly vulnerable for flooding during rainy season. With the effect of global climate change, it would either reduce or increase. This paper summarizes a methodology to analyze extreme flooding under future climate change scenarios for Colombo.

1.1 Climate change studies in Sri Lanka

Researchers have started studies on climate change in the middle of the 19th century and most of them were descriptive in nature. However, a number of scientific studies have been done since the later part of the 20th century.

Domroes (1996) has done a research on rainfall variability of Sri Lanka and found very large fluctuations during the periods of 1953-1993 and 1931-1960 time durations. In Sri Lanka every year rainfall decreased average by 10mm. However, the trend shows an inconsistency in annual total rainfalls showing both increasing and decreasing trends. It was difficult to identify any region of Sri Lanka with a negative or positive trend. The seasonal trends were controversial to that of annual though many similarities were noticed. It was noticed a very strong negative anomaly during the period 1960-1993 and it was more striking decrease over the entire last 140 years.

Basnayake et al. (2007) studied on rainfall scenarios for Sri Lanka under the anticipated climate change with some model predictions. It was depicted that the south west monsoon, Northeast monsoon and annual rainfall are projected to increase in future.

Recently, De Silva et al.(2007) carried out a study related to climate change data downscaling for Sri Lanka. They have used the outputs from UK hardly center for climate prediction and research model (HadCM3) for selected scenarios for 2050. The scenarios were selected from the special reports of IPCC on emission scenarios (SRES). Two scenarios, named A2 and B2 were mainly used. According to the results obtained, it was suggested that, during the wet season, average rainfall decreases by 17% (A2) and 9% (B2) with rains ending earlier and potential evapotranspiration increasing by 3.5% (A2) and 3% (B2). Consequently, the average paddy irrigation water requirement increases by 23% (A2) and 13% (B2). Moreover, the study suggested that the rainfall in Colombo during May to September period will increase by 43-57% (A2) and 19-27% (B2). Therefore, the increased rainfall will have serious effects on infrastructure as well as urban settings which are built by filling the marshy lands and paddy fields.

2.0 METHODOLOGY

Mainly, four components were performed separately in analyzing the extreme rainfall and flood scenarios. Those are, analysis of past extreme event data, downscaling of climate change data for future, frequency analysis to obtain extreme events and flood inundation modeling.

2.1 Analysis of past extreme event data

Several past events were analyzed for both rainfall and discharge to understand the behavior of extreme rainfall and flood events. According to the data, it was observed that mainly the extreme events can be categorized into three as heavy rains in both upstream and downstream, heavy rains only in upstream and heavy rains only in downstream. According to the category, flood event and damages are different. Since it was identified that the both upstream and downstream rainfall need to be analyzed, two stations, Digalla and Colombo were selected in upstream and downstream respectively according to the data availability.

2.2 selection of GCM data and downscaling

After analyzing the past events both rainfall and floods, future events were also predicted using several GCM data. Considering the 1960-2000 as the base line data, the best GCM which gives the best correlation was selected to obtain the future climate change data. According to IPCC SRES emission scenario, both A2 and B2 emission scenarios were analyzed for both stations upstream and downstream. A2 emission scenario was selected for this as at present it has been identified that the most matching scenario for Sri Lankan conditions is A2 (De Silva et al., 2007). The A2 storyline and scenario family describe a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuous increasing population. Economic development is primarily regional oriented, per capita economic growth and technological changes are more fragmented and slower than other storylines (IPCC, 2001) B2 emission scenario was also selected as a comparison source.

After the selection of the best GCM which has the best correlation among the selected GCM sources HadCM3,CSIRO Mk2 and CGCM2, those GCM data were downscaled using Statistical Downscaling Model (SDSM) and delta change method. Daily rainfall data of future time durations, 2010-2030, 2031-2060 and 2061-2090 were obtained from IPCC data sources and downscaled using SDSM and delta change method.

2.3 Frequency analysis

Daily rainfall data were analyzed to oblation the annual maximums and from those annual maximums, extreme rainfall scenarios for the several return periods were obtained. Several distributions as given in the equations 1-Gumbel distribution, 2-Log Pearson type III, 3-Log normal distribution and 4-Plotting position with weibull formula was used to obtain the extreme rainfall events.

2.3.1 Gumbel distribution (Extreme value type I)

$$p(x) = \exp\left[-\exp\left(-\frac{x-u}{\alpha}\right)\right] \text{(chow 1988)}$$

where $p(x)$ is the probability of an event not exceeding x, u and α are the parameters of the distribution. Reduced variate y can be expressed as,

$x = u + \alpha y$ then, $p(x) = \exp(-\exp(-y))$

where, $u = \mu - 0.5772\alpha$ and $\alpha = \frac{\sqrt{6}s}{\pi}$

μ is mean and s is standard deviation. Return period, *T*, can be defined as the reciprocal of the exceedence probability. Then, the reduced variate y becomes,

$$y = -\log_e\left(\frac{T}{T-1}\right)$$

2.3.2 Log Pearson type III

The first step is to take the logarithms of the hydrologic data. The logarithms of base 10 are used for the analysis.

$$y = \log(x)$$

The mean ($\bar{y}$), standard deviation, (S_y) and coefficient of skewness (C_s), are needed to be calculated. The frequency factor, K_T, depends on the return period and coefficient of skewness.

The values of K_T for different return periods and skewnesses can be obtained from readily available tables for log Pearson 3 or Pearson type 3 distributions.

Therefore, the value of Y_T can be obtained as,

$$y_T = \bar{y} + K_T S_y$$

$$X_T = 10^{Y_T}$$

2.3.3 Log normal distribution

Log normal distribution can also be calculated as the same procedure as log Pearson type III and the C_s value in log normal distribution is zero.

$$Y_T = \bar{Y} + K_T S_y$$

$$X_T = 10^{Y_T}$$

2.3.4 Plotting position

The most commonly used formulas are Weibull and Gringorten's. This study used only Weibull formula as given below.

$$P = \frac{m}{n+1}$$

where, P is probability of exceedence, n is total number of events and m is rank of event arranging according to descending order (m=1 for the largest value).

2.3.5 Testing the goodness of fit

Testing of the goodness of fit of the extreme value distributions were done with Chi-squared method. The χ^2 test statistics is given by,

$$\chi^2 = \sum_{i=1}^{m} \frac{n[f_s(x_i) - p(x_i)]^2}{p(x_i)}$$

where m is number of intervals.

Simply, this is the squaring of differences between the observed and the expected numbers of occurrences, dividing by the expected number of occurrences in the interval and summing the result over all the intervals.

A χ^2 distribution with v degrees of freedom is the distribution for the sum of squares of v independent standard normal random variables z_i. This sum is the random variable χ^2_v,

$$\chi_v^2 = \sum_{i=1}^{v} z_i^2$$

In the test, $v = m - p - 1$; where m is number of intervals and p is number of parameters fitting with the proposed distribution.

If the fitness is perfect, then $\chi^2_c = 0$. Here, a level of significant α = 5% is used. The hypothesis probability function is fit if $\chi_c^2 \langle \chi^2_{1-\alpha, n-p-1}$

After the comparison of all the extreme events from several distributions, the best fit one for many data sets was selected for the flood modeling. Extreme event analysis was carried out for both past data and also downscaled future rainfall data.

2.4 Flood inundation modeling

After analyzing extreme events, those daily data were converted into hourly data using a relationship obtained from analyzing the past rainfall data series. An hourly rainfall (h_i) can be defined as,

$$h_i = R_T * r_i$$

where R_T is total rainfall of the day and r_i is the calculated percentage of each hour using historical data.

Flood inundation modeling was done using Flood Modeling Software (FMS) developed by UN University, Japan with University of Tokyo, Japan. NKGIAS software developed in Nippon Koi Company Limited was used with the FMS model as an interface. The flood modeling system consists of 2-D surface overland flow module and 1-D river network flow module and a distributed flood inundation model which combines the 2-D surface overland flow module and 1-D river network flow module.

2.4.1 Governing equations

River network flows are gradually varied unsteady flow in open channels which can be expressed

mathematically by conservation of mass and momentum equations as below.
Mass conservation equation (continuity equation)

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

Momentum equation

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+g\left(\frac{\partial z}{\partial x}+S_f\right)=0$$

where t is time, x is distance along the longitudinal axis of the water course, A is cross-sectional area, Q is discharge through A, q is lateral inflow or outflow distributed along the x-axis of the watercourse, g is gravitational acceleration, z is water surface level with reference to datum and S_f is friction slope.

Manning's formula is used to estimate friction slope, S_f for turbulent flows as,

$S_f=\frac{n^2 Q|Q|}{A^2 R^{4/3}}$ where n is Manning's roughness and r is Hydraulic radius.

In the diffusive wave approximation of the Saint Venants's equation, the convective acceleration terms of the momentum equations are neglected. Hence, the equation can be simplified as,

$$S_f=-\frac{\partial z}{\partial x} \quad \rightarrow \quad Q=\frac{1}{n}AR^{2/3}\frac{-\frac{\partial z}{\partial x}}{\left|\frac{\partial z}{\partial x}\right|^{1/2}}$$

Fully implicit Finite difference scheme was used to solve non-linear partial differential equations with forward difference scheme as given below.

$$\frac{A_i^{t+1}-A_i^t}{\Delta t}+\frac{Q_{i+1}^{t+1}-Q_i^{t+1}}{\Delta x}=\frac{q_i^{t+1}+q_i^t}{2}$$

For channel networks, diverging and converging channel junctions are the most important consideration as given by,

$$\sum Q_k=Q_0+\frac{ds}{dt}$$

where s is the storage within the junction. Junctions with negligible storage volumes can be written as, $\sum Q_k=Q_0$

Network solution algorithm is, $[A]X=B$ where [A] is coefficient matrix, X is vector of unknown variable, z and B is vector intercept value.

In 2-D overland flow modeling, it includes governing equations as momentum equation in X and Y directions and continuity equation and diffusive wave approximations in X and Y directions.

Conservation of mass and momentum equations are used for deriving 2-D gradually varied unsteady flow. Overland flow equations are the 2-D expansion of 1-D open channel flow Saint Venant equations as given by,
Mass conservation equation

$$\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}+\frac{\partial h}{\partial t}=q$$

Momentum equations

In X direction;

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\left(\frac{\partial z}{\partial x}+S_{fx}\right)=0$$

In Y direction;

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\left(\frac{\partial z}{\partial y}+S_{fy}\right)=0$$

where u and v are velocities of flow in X and Y directions, z is water head elevation from datum, S_{fx} and S_{fy} are friction slopes in X and Y directions respectively. The friction slopes can be evaluated using a uniform, steady-flow empirical resistance equation such as Chezy's or Manning's equations.

Diffusive wave equation approximations,

X direction; $\frac{\partial h}{\partial x}=S_{ox}-S_{fx}$

Y direction; $\frac{\partial h}{\partial y}=S_{oy}-S_{fy}$

where S_{oy} and S_{ox} are bed slopes in X and Y directions respectively.

Existing conditions of the flood protection systems at Kelani basin was reviewed and possible adaptation strategies to cope for the future extreme events were suggested accordingly.

3.0 RESULTS AND DISCUSSIONS

3.1 Analysis of past data

From the analysis for the past events, mainly six events were identified which was behaved as extreme events recently.

Table 1: main rainfalls and floods in Kelani basin during 1980-2008

Flood date			06/06/89	06/05/92	4/21/99	11/22/05	04/29/08	06/01/08
Water level (mMSL)		Nagalagam Street	2.8	1.54	2.01	1.72	1.75	1.8
		Hanwella	11.56	8.27	9.39	9.07	9.91	9.51
Daily rainfall(mm)	Colombo	Day before	12	494	285	270	13	35
		Flood day	3	16	29	49	1	56
	Hnawella	Day before	10	260	198	271	24	57
		Flood day	9	12	32	38	1	98
	Digalla	Day before	N/A	99	61	162	169	131
		Flood day	N/A	3	79	28	0	140
	Dunedin	Day before	54	132	103	N/A	247	0
		Flood day	4	3	24	N/A	0	20
Discharge (m3/s)		Nagalagm Street	1,822	1,164	1,280	1,210	1,408	1,500
		Hanwella	2,745	1,076	1,282	1,209	1,408	1,308

Those events and their components are given in Table 1 and Figure 1 shows the Kelani basin with the considered rainfall stations and study area.

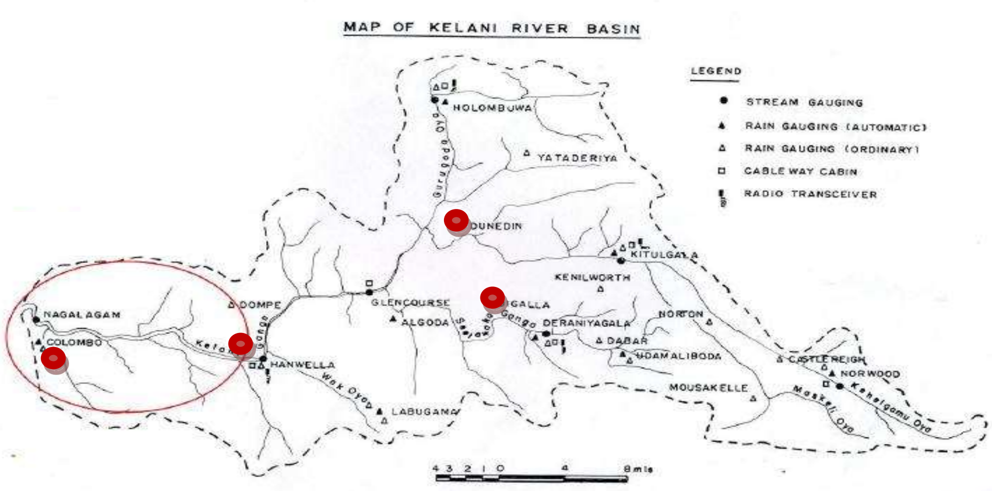

Figure 1: Map of Kelani basin with considered rainfall stations and selected area for flood inundation model

According to the past data, it was observed that mainly 3 extreme event categories can be identified. Heavy rains Upstream(1989, 2008), heavy rains downstream (1992) and heavy rains both upstream and downstream (1999, 2005). However, it was observed that even though the extremely heavy rainfall alone in downstream, it does not produce the biggest flood event (i.e 1992). Future rainfall scenarios also analyzed in these three categories.

3.2 Downscaling and analyzing of GCM data

Being an island, it creates a lot of problems in GCM data for Sri Lanka. Most of the GCMs due to its high resolution consider Sri Lanka as a sea area.

However, as all the land areas are having data, some data can be obtained from the globally available GCMs. Most of the island countries such as UK and Taiwan etc. use regional climate models (RCMs) to have the climate change data (Fowler et al., 2004). Sri Lankan situation was not developed well and at present no any regional models are available for the area. Only few studies have been done with climate change data and they have used the proportional percentage changes given by GCM data where the changes to baseline data were applied (De silva et al., 2007). Several GCMs were considered to select the best GCM for Sri Lanka. However, very few GCMs had data for Sri Lankan land area. A comparison of monthly averaged daily rainfall over 30 year period (1960-1990) with observed data of Colombo was analyzed for correlation coefficients (R^2). Same procedure was adopted for Digalla rain gauging station as well. CSIRO -Mk2 gave the highest correlation among the others for both stations. Therefore,CSIRO-Mk2 data was used for downscaling using Delta change method. Since processed data with some predictors is needed for SDSM downscaling model, HaDCM3 model was used as it was the only GCM which has processed data for SDSM for Sri Lankan land area.

According to the downscaled data at Colombo using SDSM, the daily means and maximums of future rainfall decrease in both A2 and B2 emission scenarios. As observed with the results, there was not much difference in daily mean rainfall for the two SRES scenarios. However, daily mean rainfall is expected to change for the future rapidly than the past time periods. Fluctuations of daily mean rainfall are higher in future than the base line period. Moreover, it shows a decreasing of rainfall than the base line for the whole year except April.

3.3 Extreme events

The annual maximum rainfall of Colombo and Digalla obtained from two GCMs and downscaled using two methods were used for the frequency analysis in finding out the extreme events. Log normal distribution was considered for the extreme value analysis at Colombo as all the downscaled data sets were not fit with all the other extreme value distributions previously considered. Extreme events at Colombo under climate change conditions were analyzed with 30 year periods. The base period was considered as 1961-1990 for Colombo and 1985-2000 for Digalla. As shown in Figure 2, it was observed that, there was not much deference in the extreme events for future under CSIRO-Mk2 GCM data for Colombo. However, with HadCM3 GCM data, there was a reduction in 2 and 5 year return period events for all three durations, which means reduction in frequent flooding. As shown in Figure 2, it can be observed that, there will be increment in extreme events during 2031-2060 periods with GCM data of HadCM3 model. With CSIRO-Mk2 data, there is not much significant difference in extreme events for three durations.

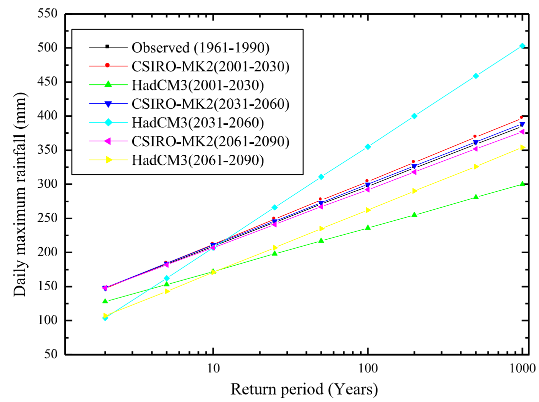

Figure 2: Frequency distribution of extreme events for Colombo under A2 scenario

Figure 3 show the extreme events for Digalla from both GCM data under A2 SRES scenario.

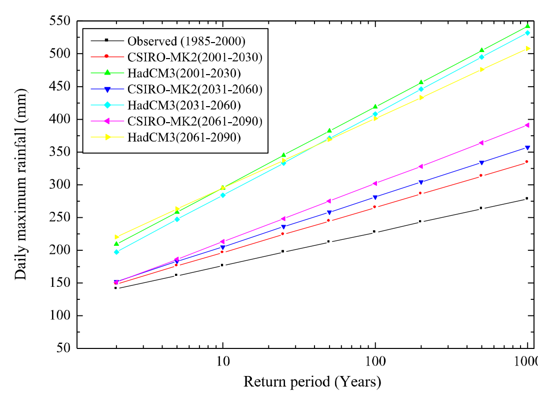

Figure 3: Frequency distribution of extreme events at Digalla under A2 scenario

Though the extreme events seemed to increase compared to extreme events at Digalla for 1985-2000 period, compared to the extreme events at Colombo, it has closer values with CSIRO-Mk2 GCM. With HadCM3 data, it gives extreme events higher than the base line extreme events at both Colombo and Digalla.

Tables 2 and 3 shows the summery of the extreme events as average of 2 model projections as well as preferred model projection for Colombo and Digalla respectively.

Table 2: Extreme event summery for Colombo under A2 scenario

Return period (Years)	Daily rainfall (mm)				
	1960-1990	Average of ensembles		Preferred model (CSIRO-MK2)	
		Future value 2001-2030	% increment over the baseline	Future value 2001-2030	% increment over the baseline
2	148	130	-11.9	147	-0.7
5	183	168	-8.2	184	0.5
10	209	197	-5.9	212	1.4
25	244	235	-3.9	249	2.0
50	271	263	-2.8	277	2.2
100	297	292	-1.9	304	2.4
200	324	320	-1.1	332	2.5
500	359	358	-0.2	369	2.8
1000	385	387	0.4	397	3.1

Table 3: Extreme event summery for Digalla under A2 scenario

Return period (Years)	Daily rainfall (mm)				
	1985-2000	Average of ensembles		Preferred model (CSIRO-MK2)	
		Future value 2001-2030	% increment over the baseline	Future value 2001-2030	% increment over the baseline
2	141	180	27.3	148	5.0
5	161	219	35.9	176	9.3
10	176	248	40.9	196	11.4
25	197	287	45.8	224	13.7
50	212	317	49.3	244	15.1
100	227	346	52.4	265	16.7
200	243	376	54.5	286	17.7
500	263	415	57.6	313	19.0
1000	278	444	59.7	334	20.1

As given in Table 3, it was observed that extreme rainfall events at Colombo have very small increment with the preferred model and decrement with average model values. However, only two GCM data were used and many GCM data needs to be used as uncertainty in GCM data are higher. According to the results, in Digalla, it shows larger increments in extreme rainfall events.

3.4 Flood inundation modeling

For scenario analysis, past major floods and future floods which can occur with climate change impacts were considered. For the flood inundation modeling for future under climate change conditions, 10, 25, 50 and 100 year return period rainfall events at Colombo were considered. As explained in section 2.4, hourly rainfall values were generated for the extreme rainfall events. Extreme events obtained under A2 SRES scenario with CSIRO-Mk2 GCM data was used as it gives the highest extreme events for Colombo.

Upstream inflow water levels were generated as percentage increments in water level. This was done as it was difficult to predict the complex hydrology of the upstream of the Kelani basin using only one station. Moreover, availability of long historical data to calibrate a hydrological model for the upstream area was a problem. Therefore, percentage increments of 10, 20, 30 and 40 were considered. This was considered since a previous study (De Silva, 2007) had obtained the increments in runoff at Colombo under climate change conditions were range between 13.2 to 40 percent. Therefore, in the critical situation in the upstream, discharge will increase only up to that point and percentage increments of 10, 20, 30 and 40 were considered. Moreover, a 0.5 m increment of tidal water level was also considered as predicted for the climate change conditions (Nilanthi and Show, 2006).

Inundation areas and water levels at Nagalagam gauging station were observed with future scenarios. With the water level at Nagalagam Street gauging station, there are prepared flood inundation area maps available. With the prepared maps, if the water level at Nagalagam Street is known, the area under water can be obtained and necessary precautions can be taken.

The water levels at Nagalagam Street for different future scenarios considered with past extreme events are given in Table 4 and 5. It can be observed that unless 30 % of upstream flow increment is not there, flood event is not as severe as 1989 flood event. 1989 flood event is considered as one of the most devastating flood event in the history. According to the extreme rainfall analysis at Digalla, those did not show much increment in extreme events in future climate data with CSIRO-Mk2 though HadCM3 overestimated the events.

Therefore, Future flood events would not be much severe than the past.

Table 4: Water levels at Nagalagam street for different future and past flood scenarios

Scenario		Water level at Nagalagam Street (mMSL)
Rainfall return period (Years)	Upstream inflow increment (%)	
10		1.69
25	10	2.05
50	20	2.44
100	30	2.85
10 yr rainfall with 0.5m increment in tide		1.94
1989 event		2.81
2005 event		1.72
2008 event		1.81

Table 5: Comparison of past extreme flood events with future scenarios

Category	Return period (Years)	Past floods	Future floods	
		Water level at Nagalagam (mMSL)	Water level at Nagalagam (mMSL)	Inundated areas(km2)
HR DS*	500	1.94	1.69	94
HR US**	100	2.80	3.28	230
	80	1.75	2.85	208
HR US & DS***	20	2.01	3.28	235
	15	1.72	2.85	219

*-heavy rains downstream, **-heavy rains upstream
***-heavy rains both upstream and downstream

As given in Table 5, It can be seen that inundation areas will increase for the future events than the past extreme flood events. Normal upstream water levels (discharges) of 4 year return period flood event water level was incremented by 10%, 20%, 30% and 40 %. Moreover, as predicted, 0.5m sea level rise was also considered and it was observed that sea level increase also cause for an increment in inundating areas.

The results obtained above for the inundated areas may have some discrepancies due to some of the problems in the modeling process. To have a proper hydrodynamic modeling process, it is a must to represent the river geometry well. However, in this modeling approach, due to the limitations in simulation time, a coarser resolution grid was used as 250-500m. River width is in the range of 50-100m. Therefore, it was not possible to have the exact hydrodynamic in the river.

Kelani River tends to become meander as the study area is low line area. To have proper 1-D river geometry, it is necessary to have more cross section data. However, due to the availability of data, only 9 cross sections were used for 35km length river section. Moreover, the cross sections were given as trapezoidal sections and this was not much accurate to represent the river as number of cross sections was also less.

Downstream boundary was given from tidal data at Colombo. The location of tidal gauge is somewhat far away from the river estuary and it cannot be placed exactly well due to that. Even a small increment or decrement in tidal level cause a same amount of change in observed water level as well.

Presence of quite a larger number of off stream storages cause for the volume error in observed and simulated hydrographs as those were not taken into account in the modeling system.

3.5 Adaptation strategies

According to the extreme flood scenarios modeling it was observed that if the climate change effects take in place in the upstream areas as estimated in flood modeling, there will be more flood events than the recent past. Therefore, proper adaptation measures are needed to take in place to mitigate and to reduce the damages.

Since the uncertainty is there, when designing for climate change impacts, it is always better to go with non structural measures since non-structural measures well addresses for uncertainty. As being more reversible and sustainable measures, non-structural measures will not make problems for the future generation. Possible non-structural measures for the area can be described as below.

As mentioned in the previous section as well, there are number of existing flood protection works. It will be easy to improve them or have a proper coordination to make them in a better way than implementing new ones. i.e. the routine works of flood protection systems needed to place in proper manner. It was observed during the site survey, that the flood gates were damaged. If the routine works have been done properly, those will not be cause for the damages. Therefore, **proper maintenance and improvement of existing flood protection systems** comes as the fist suggestion for adaptation.

Proper coordination between all the relevant authorities will make a successful flood protection system. Most of the areas get flooded due to blockages in drainage systems. Improper disposal of garbage to the canal systems and improper clearing of the canal banks cause blockages and bank destructions of canals. These create problems due to blockages during floods especially in densely populated Colombo area. If proper coordination between Colombo Municipal Council and Land Reclamation Authority, which are taking care of canal system and garbage disposal respectively is done, these problems can be controlled well.

Improve the efficiency of the flood warning system with more sophisticated technology, where mal functioning would be less, can help for better flood management. Moreover, having a proper, wider data base for the basin area will improve the research activities and hence, it would be beneficial to improve the systems with new technologies. i.e. having more number of rain gauging stations as well as stream gauging station where observations are continuous will be helpful for model the existing and past situations properly and predict for future in more certain ways. **Improve the data base** of rainfall, stream flows cross sections along the river and inundated areas with continuous longer duration. Computerizing of the data will be helpful to transfer the data to relevant authorities and analyzing them.

Moreover, illegal low land filling also cause for flooding. Marshy lands and wet lands are higher as the area is low line flat land. Therefore, most of them act as detention storages and illegal filling of low lands and marshes can create flooding problems severe. Enforcement of law for prohibiting low and marsh land filling should be taken place.

Since the risk areas has been identified with the flood inundation maps, buildings which occupied larger number of people such as **schools, hospitals etc are needed to relocate to the safer areas.**

Implementing of a flood insurance scheme will be helpful in sharing the damages due to floods. With the flood inundation maps prepared in this study and stage damage curves developed for the area (Subasinghe K., 2008) can be used together to generate flood loss maps. Flood loss maps can be used to decide the premiums of the insurance according to the damage levels.

Implementing rainwater harvesting systems can benefit in reducing flash floods especially in Colombo area where built up areas are more than 95%. Harvesting rainwater and keep them in underground tanks will help to solve problems in water shortages, which are occurring just after the flood event. Formulating a rule to have a roof top rainwater harvesting system in every building and monitor the rule will be able to succeed in this method. Moreover, planting street trees, making pervious areas as pavements will increase the detention areas and it will reduce the runoff in canals and helpful for reduce flooding.

Increasing awareness of people regarding increments of flood events which can be taken place due to climate changes in future will force them to adhere to the adaptation measures suggested. Most of the people in those areas are well educated. Therefore, awareness will improve their adaptive actions.

4.0 CONCLUSIONS

Changes in seasonal rainfall amounts were observed due to climate changes.

Amounts of extreme rainfall events in the future in Colombo will remain closer to past data though upstream station seems to have quite higher values than the past data. The increment of extreme event is 1.5-2.5 percent with preferred model (CSIRO-Mk2) and with the average of several GCMs, it was a reduction in Colombo. However, for the upstream areas an increment of extreme events (more than 20 percent) was observed with CSIRO-Mk2 model data.

Flood inundation areas will increase due to climate change conditions.

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REFFERENCES

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