Weather Forecasting and Flood Simulation for Sustainable Land Use Management: Bentota River Basin in Sri Lanka

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Abstract

Flood simulation modeling related to land use management is very important for mitigation and integration of disaster risk reduction in the development process. Flood estimation data obtained through gauging stations, Geographic Position System (GPS) devices and participatory-based mapping are poor in accuracy, and current software for flood simulation is costly and requires a vast amount of input data. Hence, it is essential to have a proper method to simulate flooding in the context of changes in rainfall patterns in a relatively fast and accurate manner for flood-prone areas of Sri Lanka. This study analyzes the time series characteristics of total monthly rainfall and maximum daily rainfall of the Bentota River basin applying Mann–Kendall (MK) tests to rainfall trends as major input data for a flood simulation model which has been developed applying Arc Geographic Information System (GIS) software and Python scripting. The model combined various factors such as rainfall, slope, hydrology, soil, land use, storm water drainage, and human behavior factors. The developed flood simulation model showed a good level of consistency between observed and simulated results, with 64.03% accuracy. Maximum daily rainfall of this area shows a general increasing trend, whereas total monthly rainfall shows a general decreasing trend. According to the results of this study, there will be an extreme variability of rainfall once every 5 years during any month from April to July resulting in a minor flood situation in the area. Introducing riparian buffers, a flood resistive green home gardening model, green paving, rain water harvesting, drenching inland waterways, and converting selected marshy lands as park areas could be implemented as sustainable land management strategies for flood disaster risk reduction in the area. Farmers and the local community will be the main beneficiaries of the findings of this study. Moreover, decision makers could make decisions based on this prediction relating to future flood occurrences, vulnerable areas, and flood levels. The approach adopted in this study will also be useful for other researchers, agriculturalists, and planners to identify future climatological influences and to develop flood simulation models for other river catchment areas.

Keywords: Flood simulation, time series analysis, sustainable land use management, disaster risk reduction.

Introduction

The term "flood" is defined as "the inundation of an area by unexpected rise of water because of extreme rainfalls or dam failure" (Disaster Management Center [DMC-SL], 2005). Statistics reveal that every year flood damage comprises 40% of total losses resulting from all natural disasters in the world (Bian & Han, 2015). Hence, flooding is considered to be one of the most common and most harmful natural disasters globally. Being a tropical country positioned across the path of two opposing monsoon systems, Sri Lanka has been severely affected by floods for centuries (DMC-SL, 2005). Furthermore, DMC-SL shows that floods accounted for 73% of the total occurrence of natural disasters in the decade 1995–

2005. Extreme low-pressure situations which develop in the Bay of Bengal and the Northeast (November–February) and Southwest (May–September) monsoon systems have direct effects on the rainfall patterns in Sri Lanka (Ratnayake, 2008). Occasional high seasonal rainfall forced by La Nina occurrences and cyclonic storms originating in the Bay of Bengal are typically the main causes for distressing floods in Sri Lanka (Silva et al, 2012). Hence, there is a burning need for weather forecasting, prediction of flood levels, and flood inundation areas to provide early warning alerts and thus to lessen flood damage to life and property. These are needed not only to make the community aware of the vulnerable areas susceptible to flooding under future climate change scenarios but also to prepare land use management strategies for flood-prone areas.

Flood estimation data in Sri Lanka are currently obtained through gauging stations, GPS devices, and participatory-based mapping approaches. These have a poor level of accuracy. Existing commercially developed software on flood simulation is costly, and requires a vast amount of input data to achieve a relatively accurate result. It is essential to have a proper method to simulate flood inundation information in the context of changes in rainfall patterns in a relatively fast and accurate manner for flood-prone areas of Sri Lanka. Hence, this study analyzes the time series characteristics of the recorded weather data of total monthly precipitation and maximum daily rainfall with a view of developing a flood simulation model and sustainable land use management strategies for reducing flood risk in the future. The study uses the Bentota River basin as the case study. We present an integrated model where various factors are combined, such as rainfalls, slope of the area, hydrology pattern, soil types having different saturated water levels, land cover/land use activities having different infiltration capacities, existing drainage systems, existing storm water discharge systems, and human behavior factors.

Riverine floods are most common in Sri Lanka since 103 rivers and related catchments are distributed across the whole country. Floods can distribute large amounts of water and suspended sediment over vast areas, restocking valuable soil nutrients to agricultural lands. In contrast, soil can be eroded by large amounts of fast flowing water, ruining crops, destroying agricultural land/buildings, and drowning farm animals. Damage caused by flooding annually results in multiple losses in the country. Flooding is a natural phenomenon which cannot fully be prevented. Yet losses resulting from flooding can be minimized by proper flood mitigation measures (Smith & Ward, 1998). If the implementation of flood mitigation adjusts the spreading of flood losses to lessen the expected expense of such losses, then the cost of risk taking is reduced as well (Miguez & Magalhães, 2010). Mhonda (2013) states there are two main categories of flood mitigating strategies, namely, structural and nonstructural. Structural strategies are engineering works (e.g., canalization and rectification, dredging, and dike construction). Nonstructural strategies are non-engineering-based strategies (loss sharing, disaster aid, flood hazard mapping, flood forecasting and warning, flood risk management, institutional arrangement, and preparedness). As flood disasters cause multiple losses to society, it is very important to take measures to mitigate such disasters (Ratnayake, 2008). Mitigation of flood disasters requires the contribution of all acting agencies and the partnership of the community. Above all, the contribution of weather forecasting is enormous since all mitigation measures rely on the recorded patterns and future predictions of the climate parameters.

Weather forecasting is an account of the weather that is predicted to occur in a particular area during a specified time period (Buckle, 1996). By having reliable forecasted data on the meteorological parameters and weather patterns which are highly influencing on flooding, it can have a high impact on the probability of predicted flood warnings. Flood warning systems deliver advance warning of flood events that can potentially minimize risk to human lives while concretely reducing all types of possible losses (Wallingford, 2006). Therefore, weather forecasting is essential for the mitigation of flood disaster. Forecasting weather patterns alone, however, is not sufficient for flood mitigation. Calculation of flood magnitudes and the identification of vulnerable areas are required in order to minimize losses through preparedness before the disaster and enable agencies to take effective and efficient migratory measures. Flood simulation using weather forecasting data contributes significantly to this purpose (Nandalal & Ratnayake, 2010).

The distressingly disastrous nature of flooding in many parts of the world inspired the researchers to undertake multiple attempts to develop methods of “Flood Simulation Modelling.” “Flood simulation models” model the behavior of flood occurrences. Flood forecasting relies on flood simulation models (Jiang, Chen, & Wang, 2015), and several flood forecasting models have been proposed during recent years using many methods such as geographic information systems (GIS) and mathematical algorithms (Barredo & Engelen, 2010; Basos, 2013; Jiang et al., 2015; Miguez & Magalhães, 2010; Yerramilli, 2012).

Even though multiple factors cause flooding, some key parameters are frequently used by flood simulation modelers to develop flood simulation models. These parameters include factors which generate weather dynamics, affecting surface water runoff and the hydrology cycle (Jiang et al., 2015), such as the maximum daily rainfall during a calendar month and the slope of the area, which is highly related to the velocity of water flow (Freeze & Witherspoon, 1967), the hydrology pattern of the river floodplain system (Thomaz, Bini, & Bozelli, 2007), different soil types that have different saturated water levels (Poesen & Hooke, 1997), different land use and land covers that have different infiltration values (Bratha, Montanaria, & Morettib, 2006), the structure of drainage systems (which is very important to manage floods) (Bratha et al., 2006), and some human factors, such as unauthorized land filling, filling of low lands and so on (Lehner, Döll, Alcamo, Henrichs, & Kaspar, 2006). As flood risk management shifts from structural defense against floods to a more comprehensive approach, the effect of land use planning and management has been highlighted broadly in recent decades (Nandalal & Ratnayake, 2010; Thampapillai & Musgrave, 1985; Venkatesh, 2008). In the comprehensive approach, prevention, protection, preparedness, response, and recovery, as the cycle of disaster risk reduction, are considered in the management and prevention of flood disasters. Movements concerned with avoiding development in flood-prone areas, adapting future development to the risk of flooding, improving protection measures, and promoting appropriate land-use, agricultural and forestry practices, and many other measures in this sense are considered to be very important (Barredo & Engelen, 2010).

Study Area

For this study, the Bentota River bank basin has been selected because it faces the natural phenomena of flooding during the rainy season. The total paddy land area of the Bentota River bank basin is 4,530 acres. More paddy lands are cultivated during Maha season from

September to February, and cultivated paddy lands were submerged by the floods for a long period during the Yala season from March to August in most years. The Bentota River is connected to the sea through the Bentota Estuary, located at 62 km from Colombo and consists of a few beautiful islands. The Bentota River originates from a 1,000-ft hilly plateau above Pitigala, and flows about 30 miles westerly. The Bentota River basin is located in the wet zone. Average highest temperature in the Bentota River basin is about 29°C during March and April and its average lowest temperature is about 26°C during June, July, and August each year, whereas the mean temperature is 27.3°C. Mean total monthly rainfall in the Bentota River basin is 328 mm. The Bentota River basin has received the highest total monthly rainfall, 1,069 mm, with the effect of southwest monsoon during the month of May and with the effect of a second inter monsoon during the month of October in the past. Mean annual rainfall in the area is 3,933 mm, ranging from 3,096 to 4,699 mm.

Major tributaries of Bentota River are Welipenna Ganga, Pelawatta Ganga, Elpitiya Ela, and Pitigal Ganga. The catchment area of the Bentota River is 622 km^2. Average annual runoff is 1,250 Minimum Control Measure (MCM). The Bentota River provides water for cultivation to 2,862 km^2 (4,500 ha) of paddy lands in both left and right banks. The Bentara River Right Bank Scheme coming under the purview of the Divisional Irrigation Engineer, Kalutara is divided into two sections, namely, Meegama and Ittapana. Out of the total Rignt Bank (RB) command area of 965 ha, the presently irrigated area is 340 ha (35% of the command area). Fairly large marshy areas and abandoned paddy areas exist. The Meegama section is located to the west of Welipenna River which is a tributary of the Bentara River. This section is situated around the villages, namely, Adikarigoda, Kotapitiya, Andawala, Devagoda, Meegama, Kurudippita, Ritiketiya, Indigastuduwa, and Bondupitiya in the Matugama and Beruwala Divisional Secretary’s areas. The Ittapana section is located to the east of Welipenna Ganga. This section is situated around the villages of Moonamalwatta, Kannana, Ittapana, Madawita, Lulbadduwa, and Halwala in the Walallawita Divisional Secretary’s area.

The Bentara River Left Bank Scheme coming under the purview of Divisional Irrigation Engineer, Ambalangoda is divided into two sections, namely, Dedduwa and Rantotawila, the main paddy lands irrigated by it. Out of the total Left Bank (LB) command area of 1,660 ha, the presently irrigated area is about 50% to 80%. Fairly large marshy areas and abandoned paddy areas exist. Some parts of the scheme are now being rehabilitated through local funding; the scheme would have a good potential for further development. Coconut and paddy fields are located in lower reaches of the area. Rubber and tea plantations are in mid- and higher elevations. Figure 1 indicates the land use map of the area.

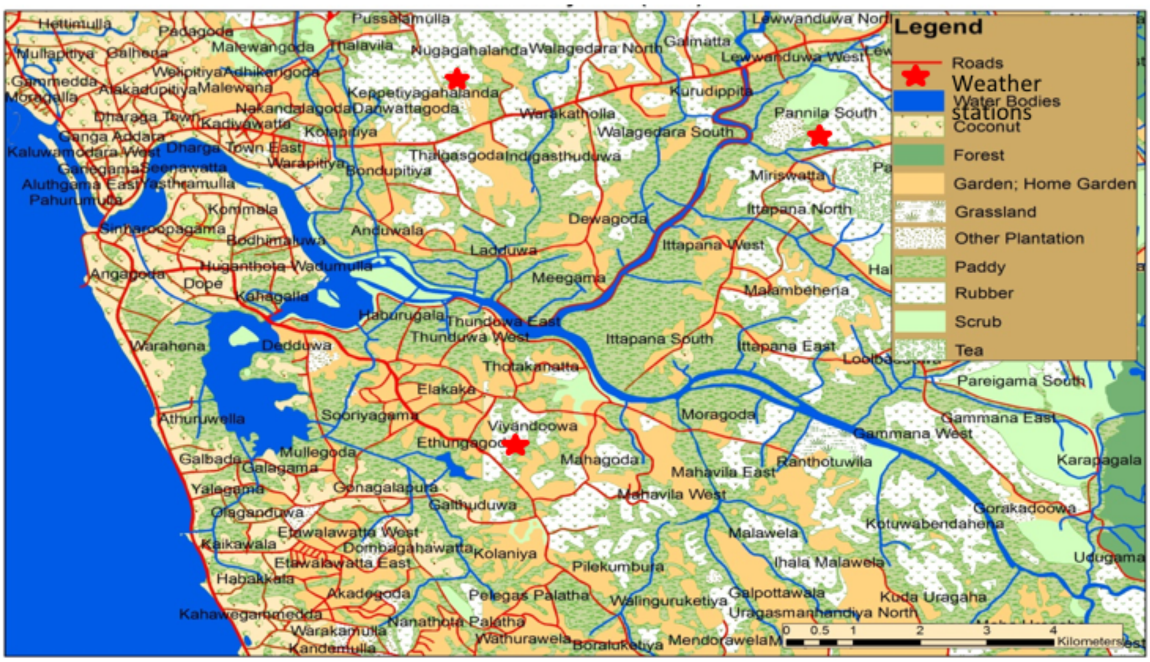

Figure 1. Land use and land cover distribution of the Bentota River basin in year 2010.
Source: Survey Department (2010).

Data and Methods

Weather data on total monthly rainfall and maximum daily rainfall value for all months from 1986 to 2015 recorded at all three weather stations located in the Bentota River basin (Figure 1) were purchased from the Metrological Department in Sri Lanka. According to Aziz, Anokye, Kwame, Munyakazi, and Nuamah (2013), weather station data provide accurate information on weather conditions around the vicinity of the instrument. Therefore, it is assumed that the rainfall data recorded from all three weather stations in the Bentota River basin perfectly reflect the real weather conditions of the area. The collected rainfall data were analyzed by applying a time series analysis method and correlation analysis to derive regression equation and to forecast the duration of future flood occurrences and maximum daily rainfall values for flood simulation model.

Kim and Jaun (2003) show that time series data are analyzed to understand the underlying structure and function that produces the observations. Aziz et al. (2013) show that time series analysis can be applied by assuming that a time series data set has at least one systematic pattern. Box and Jenkins (1970) show that time series analysis has two most common patterns in trends and seasonality. Trends are generally linear or quadratic, and moving averages or regression analysis is often used to derive a trend line. Seasonality is a trend that repeats itself systematically over the time. Understanding the mechanisms of time series data allows the development of a mathematical model that explains the data in such a way that prediction or monitoring can occur. In this study, time series analysis is used to forecast maximum daily rainfall and total monthly rainfall and to identify future flood occurrence periods.

The general time series plot of collected weather data indicated a cyclical pattern due to the effect of seasonality component and an irregular way indicating an increasing or decreasing trend. Weather data subjected to time series tests were analyzed by applying decomposition method that includes trend, cycle, seasonal, and irregular components. First, Moving Average (MA_{12}) and Centered Moving Average (CMA_{12}) methods were applied sequentially to make the time series in to smooth curve reducing the impacts on seasonality and irregularity (Buckle, 1996). The decomposition method $\{Y_t = f\,(S_t, I_t, T_t)\}$ was applied with the multiplicative model to identify trend cycle and seasonal analysis (Keredin et al., 2013). When applying the decomposition method, the patterns of seasonal and irregular component (S_t, I_t) were identified by dividing the original observation by the CMA values. The average seasonal data (S_t) for each month were calculated later on. Then the seasonally adjusted data were computed by dividing the original observation by the seasonal component which can be known as "de-seasonal data";

$$Y_t \,/\, S_t = T_t \, x \, I_t \qquad (1)$$

The trend line equation was derived by applying simple linear regression analysis, and trend values (T_t) were calculated considering original observation of weather data as dependent variable and time (t) as independent variable. Independent variable (x) of total monthly rainfall and maximum daily rainfall analyses is time (t), considered as number of months from the month of start year of each station. The multiplicative model (Equation 1) was applied for forecasting weather data (Box & Jenkins, 1970). Pearson correlation coefficient value was calculated to identify the reliability and the accuracy of the forecasted values by comparing them with original observation of weather data. These developed multiplicative models were used to forecast the total monthly rainfall and maximum daily rainfall values from 2016 to 2025.

Mann–Kendall (MK) trend test was used to determine whether there is a decreasing or increasing trend of time series. MK trend test is also the most widely used methods since it is less sensitive to outliers (extraordinary values within time series data) and it is the most robust as well as suitable for detecting trends in rainfall (Keredin et al., 2013). The null hypothesis [H_0] for these tests is that there is no trend in the series. The three alternative hypotheses that there is a negative, nonnull, or positive trend can be chosen. The MK tests are based on the calculation of Kendall's tau coefficient of association between two samples, which is itself based on the ranks with the samples. In the MK trend test, the first series is an increasing time indicator generated automatically for which ranks are obvious, which simplifies the calculations. Statistical software for Microsoft Excel (XLSTAT) was used to calculate the *p* value of this test, if there are no ties in the series and if the sample size is less than 50. The *S* statistic used for the test and its variance is given by the following equation:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{Sgn}\left(X_j - X_i\right) \qquad (2)$$

$$\mathrm{Var}(S) = \frac{n(n-1)(2n+5)}{18}$$

where *n* is the number of observations and x_i (i = 1…n) are the independent observations.

The seasonality of the series was taken into account by using the seasonal MK test. This means that for the monthly data with seasonality of 12 months, one will not try to find out whether there is a trend in the overall series, but if from one month of January to another, from one month of February to another and so on, there is a trend. For this test, first, all Kendall's tau coefficients for each season are calculated; then an average Kendall's tau is calculated. The variance of the statistic can be calculated by assuming that the series are independent (e.g., values of January and February are independent) or dependent, which requires the calculation of a covariance. XLSTAT is used to calculate the *p* value of this test and a normal approximation to the distribution of the average Kendall tau.

A flood simulation model was developed in the GIS environment by using ArcGIS Model Builder tool, Python scripting, and mathematical algorithms. Model Builder is an application in the ArcGIS software to create, edit, and manage models. Model Builder can also be thought of as a visual programming language for building workflows. Python is a free, cross-platform, open-source programming language that is both powerful and easy to learn. Python was introduced to the ArcGIS community at Version 9.0. Since then, it has been accepted as the scripting language of choice for geoprocessing users and continues to grow. The language is widely used to perform advanced level calculations and raster analysis.

The accuracy of the simulated flood levels of the entire inundation area was checked using the method of "Classification Accuracy Assessment" (Cleve, Kelly, Kearns, & Moritz, 2008). This method uses "Kappa coefficient" to test the consistency of the actual values and simulated values using the following formula:

$$\text{Kappa Coefficient} = \frac{n\sum n_{kk} - \sum n_{k+} n_{+k}}{n^2 - \sum n_{k+} n_{+k}} \quad (3)$$

where n is number of validation points, n_{kk} is the difference between actual value and predicted kth value, and $n_{k+}n_{+k}$ is the difference between sum of actual values and sum of predicted values. Kappa coefficient values are possibly categorized based on the agreement on the accuracy of the simulated flood levels such as *poor* to *very good* (<0.2, 0.2–0.4, 0.4–0.6, 0.6–0.8, and 0.8–1.0; Cleve et al., 2008). The developed integrated flood simulation model was validated in real-ground situation considering the actual flood inundation areas and flood inundation depths. For that, several field visits, questionnaire surveys, and focused group discussion were carried out to map out the actual flood level and respective GPS points to collect the details concerning the actual flood inundation areas, flood occurrences periods, flood level, flood losses, and preventive methods.

Two submodels (Figures 2 and 3) were prepared using the ArcGIS Model Builder and the Python scripting to identify flood-prone area and flood level. The ArcGIS Model Builder was used to identify flood-prone areas considering contours, soil layer, land use and land cover layer, hydrology layer, and forecast maximum daily rainfall (Figures 1 and 4). Contours with 1-m interval were converted into a Digital Elevation Model to consider the elevation of the area for this model. Considering the trend component of time series analysis of maximum daily rainfall of all weather stations, maximum daily rainfall value by year 2025 was calculated based on the maximum daily rainfall in year 2014 as 444 mm. Accordingly, 452 mm, 429 mm, and 441 mm are the forecasted maximum daily rainfall for Agalawwatte, Bentotawatte, and Pallegoda weather stations and these values were interpolated using inverse distance weighted interpolation method(Tomczak,1998) Initial abstraction of the water by different land use types were considered using runoff equations. Euclidean distance values were calculated considering the distance to water bodies. 10 m × 10 m pixel size was considered for the analysis.

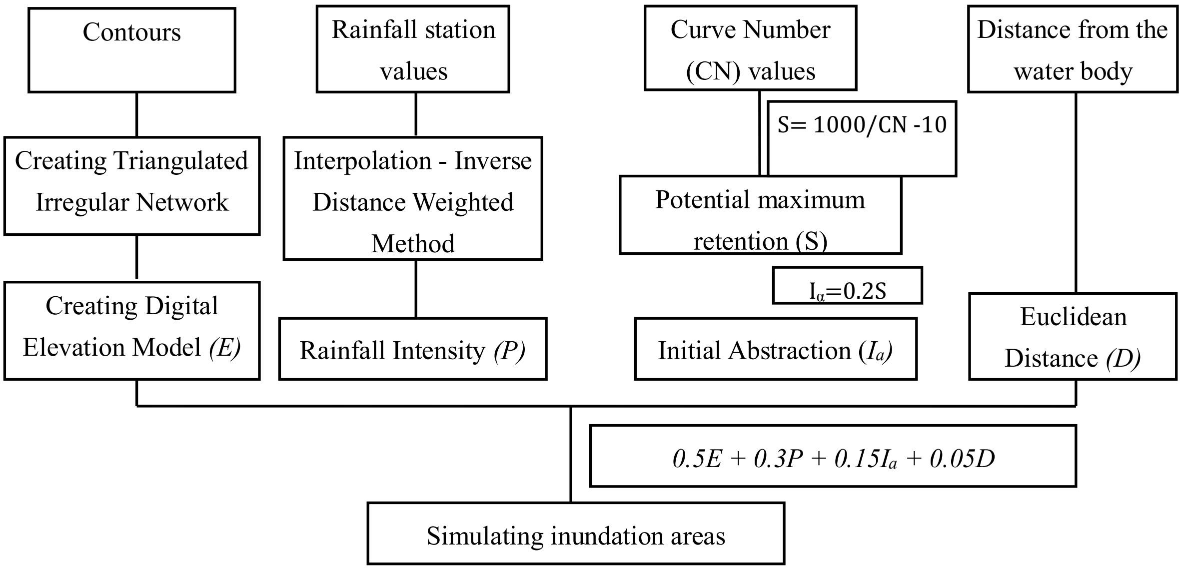

Figure 2. Model 1 – Simulation of inundation areas.

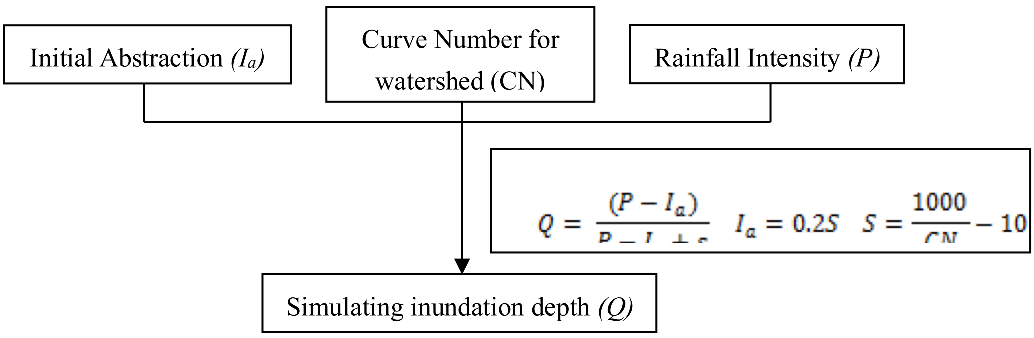

Figure 3. Model 2 – Simulation of inundation depths.

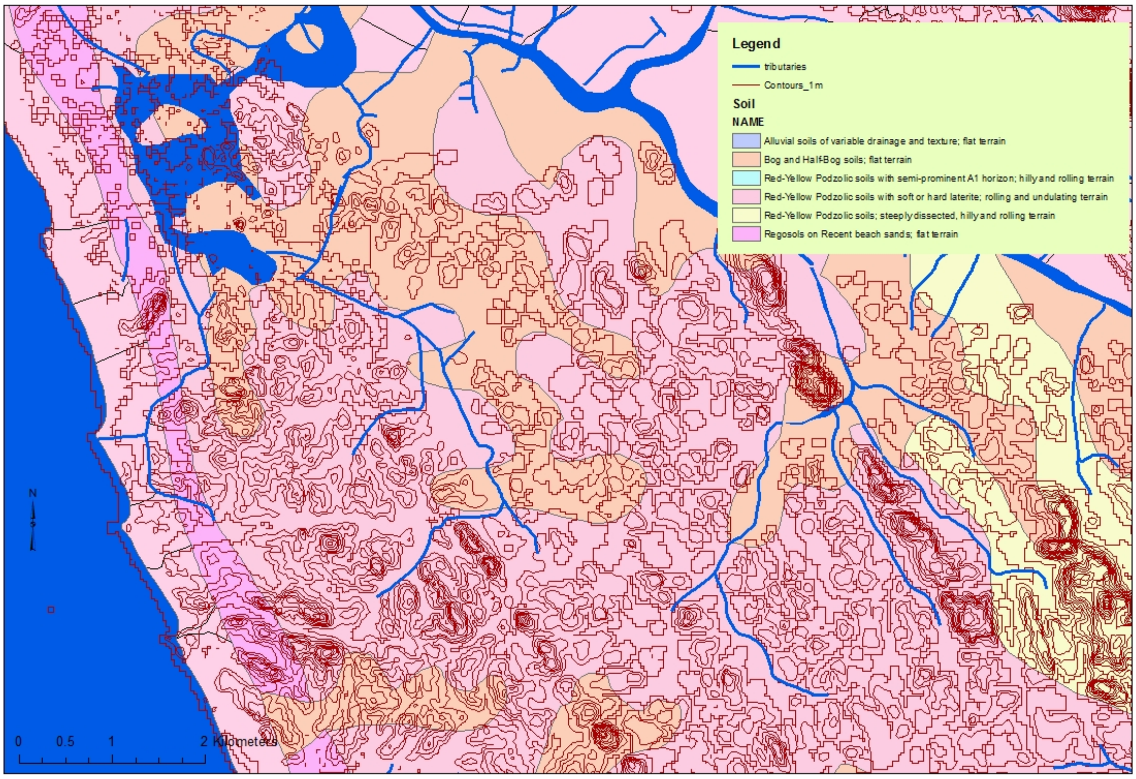

Figure 4. ***Contours, soil layer, and hydrology layer of the study area.***

Source: Survey Department (2010).

For Model 2, Initial Abstraction and Rainfall intensity values were obtained for each pixel based on the results from Model 1. The curve number for the watershed area was obtained related to the soil and cover conditions of the watershed by different land use types. The runoff model is used to identify flood depth of the area. Python script was developed to apply Technical Release 55 (TR55) equation (Equation 4) to calculate flood depth of area.

$$Q = \frac{(P - I_a)^2}{P - I_a + s} \qquad (4)$$

where Q = depth of runoff (in), P = rainfall (mm), I_a = initial abstraction (in), S = potential maximum retention after runoff begins (in)

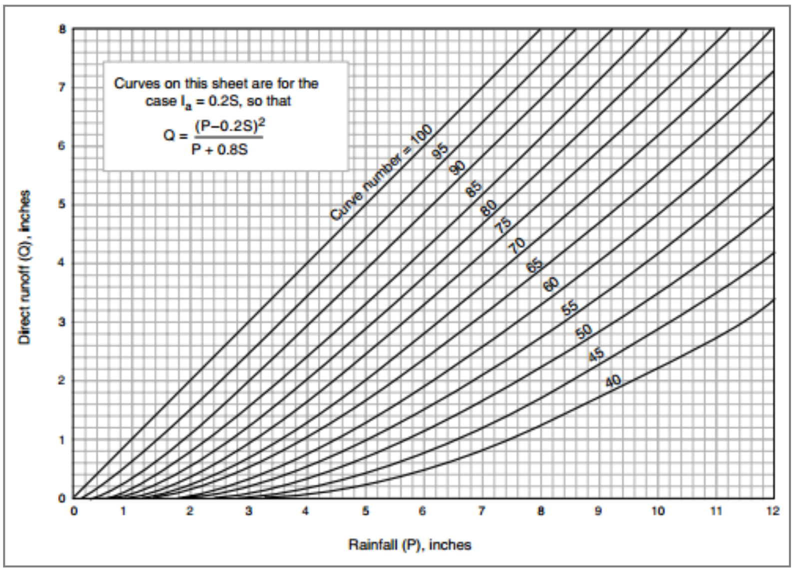

Figure 5. Runoff curve numbers (CNs).

Source: Silva et al, (2012).

TR-55 presents simplified procedures for estimating runoff and peak discharges in small watersheds. Initial abstraction (I_a) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. I_a is highly variable but generally is correlated with soil and cover parameters. By removing I_a as an independent parameter ($I_a = 0.2S$), this approximation allows use of a combination of S and P to produce a unique runoff amount. S is related to the soil and cover conditions of the watershed through the curve number (CN). Mass rainfall is converted to mass runoff by using a runoff curve number given by Figure 5. CN is based on soils, plant cover, and amount of impervious areas, interception, and surface storage.

Results

Trend component of time series analysis of total monthly rainfall of overall Bentota River basin shows a decreasing trend with –0.0507 mm decline per month ($Y = -0.0507x + 335.86$). Pearson correlation coefficient value between actual and forecasted total monthly rainfall values of overall Bentota River basin for each month indicates a positive strong linear relationship with 0.683 correlation coefficient value and it emphasizes that the forecasted values are more or less similar to actual values. In MK's test, the computed *p*-value (0.723) is greater than the significance level (0.05) and one cannot reject the null hypothesis H_0 says that there is no trend in the series of total monthly rainfall. In Seasonal MK Test, the computed *p*-value (0.849) is greater than the significance level (0.05) and one cannot reject the null hypothesis H_0 says that there is no trend from one month to another in the series of total monthly rainfall. The computed *p*-values of two MK tests are greater than the significance level 0.05 for total monthly rainfall of all three weather stations that implying no trend in the series even from one month to another. Considering the seasonal component and trend component of time series analysis of total monthly rainfall, average actual total monthly rainfall for each month during 1986–2015 and average forecasted total monthly rainfall for each month from year 2016–2025 for all three weather stations and overall Bentota River basin were calculated. Pearson correlation coefficient values between average actual total monthly rainfall and average forecasted total monthly rainfall values for each month of all three weather stations and overall Bentota River basin are near to 0.9 and it highlights the accuracy of the prediction of total monthly rainfall up to 2025. Bentota area may have high total monthly rainfall during May and October in future under the prevailing climate change scenario.

Trend component of time series analysis of maximum daily rainfall of overall Bentota River basin shows an increasing trend with 0.0166 mm increment per month (Y = 0.0166x + 71.55). Pearson correlation coefficient value between actual and forecasted maximum daily rainfall of overall Bentota River basin for each month indicates a positive moderate linear relationship with 0.479 correlation coefficient value. In MK's test for maximum daily rainfall of overall Bentota River basin, the computed *p*-value (0.035) is lower than the significance level 0.05, the null hypothesis H_0 should be rejected, and accept the alternative hypothesis H_a says that there is a trend in the series of maximum daily rainfall of overall Bentota River basin. Seasonal MK Test of maximum daily rainfall of overall Bentota River basin shows that there is a trend from one month to another in each year since p value (0.043) is lower than the significance level. The computed *p*-values of two MK tests are greater than the significance level 0.05 for maximum daily rainfall of Pallegoda and Bentotawatte weather stations that implying no trend in the series even from one month to another. But *p* value (0.025) of MK test and *p* value (0.023) of Seasonal MK Test for maximum daily rainfall of Agalawatte station are lower than the significance level; there is a trend in the maximum daily rainfall of Agalawatte station and from one month to another in each year as well. Considering the seasonal component and trend component of time series analysis of maximum daily rainfall, average actual maximum daily rainfall for each month during 1986–2015 and average forecasted maximum daily rainfall for each month during 2016–2025 for all three weather stations and overall Bentota River basin was calculated. Pearson correlation coefficient values between average actual maximum daily rainfall and average forecasted maximum daily rainfall values for each month of all three weather station and overall Bentota River basin are near to 0.9 and it highlights that Bentota area may have high maximum daily rainfall during May and October in future under the prevailing climate change scenario. The degree of variations of maximum daily rainfall of all three weather stations is relatively high, the highest is at Pallegoda and the lowest is at Bentota Watte.

The dates, where maximum daily rainfall value is more than 200 mm in all three weather stations and overall Bentota River basin from 1986 to 2015, were evidenced by the past flood records of the area, and comparatively minor flood situations could be observed in 1993, 1998, 2003, and 2008 by indicating flood occurrence period as once in 5 years and major flood situations could be observed in 2010 and 2014. According to the past flood records of the area, comparatively minor flood situation can be defined as when maximum daily rainfall of each weather station is between 200 and 300 mm and major flood situation would be when maximum daily rainfall of each weather station is between 350 and 450 mm. According to the above time series analysis, the Bentota River basin may have high total monthly rainfall and maximum daily rainfall during May and October in future and also low rainfall situations during January and February under the prevailing climate change scenario. There will be an extreme variability of rainfall once every 5 years during any month from April to July making minor flood situation in the area.

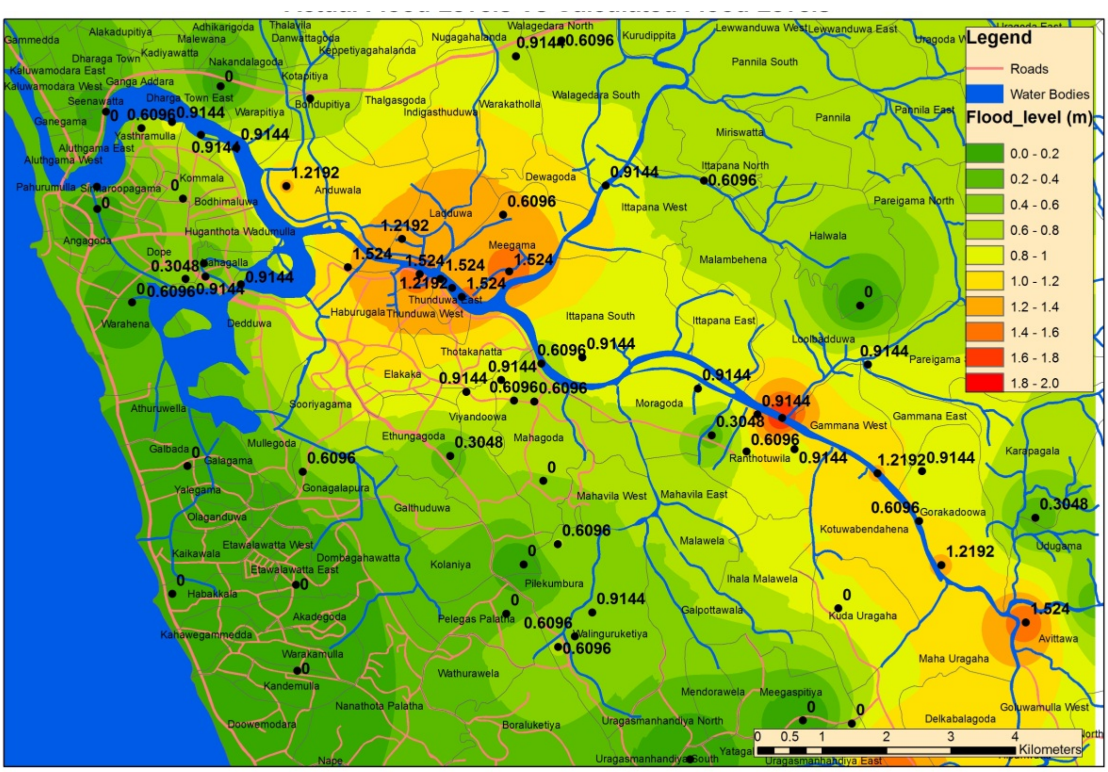

Figure 6. ***Simulated flood inundation areas and depth in the Bentota River.***

Figure 6 shows the flood inundation areas and inundation depths simulated from Models 1 and 2. The highest simulated flood level, 1.65 m, is recorded in Thunduwa, east area of left bank of the Bentota River, and Gammamna, west aea of the right bank of the Bentota River. Lowest simulated flood levels of 0 cm indicates major part of the coastal belt area and around 10 cm flood levels have been showed in Gonagalapura, Mahagoda, Atawalawatte, Akadegoda, in left bank area, and Bondupitiya, Nakandalagoda, and Indigastuduwa areas in right bank area. The surrounded areas of the Dedduwa lake such as Kahagalla, Dedduwa of left bank side, and Meegama, Ittapana, Lewwanduwa, and Walagedara areas of right bank side are the moderately flood inundation areas, where flood level was between 40 and 60 cm during May when flood situation occurred in those areas.The accuracy of the simulated flood levels were assessed by applying classification accuracy method, considering 75 actual flood level values which were randomly recorded with relevant GPS points. In this validation process, Kappa coefficient for the above simulated flood model was received as 0.6403 which reflects strong correlation between measured and modeled results with 64% accuracy.

Discussion

Collapsing Bentota River banks have been experiencing several issues such as increase in sedimentation of the river, water flow hindrance, loss of eco systems, and associated problematic situations that lead to inundation of near paddy lands and walking ways of inner villages. Grass beds and river bank plantation would be introduced to surroundings of Bentota River and major water ways of the area which are already vulnerable to river bank erosion in rainy seasons (bio retention areas: Yathramulla, Pahurumulla, Thunduwa East, Moragoda, Right bank: Aluthgama East, Kaluwamodara, Darga Town, Meegama, Warapitiya). These tree buffers (Figure 7) can even help mitigate flooding by absorbing and slowing down the down surface runoff. "Plant a Tree, Save a River" (by Christina Catanese) emphasizes that having forests in close proximity of river is highly beneficial to water quality, ecosystems, and humans. These vegetated strips of land (*Kumbuk* and *Bamboo*) are often referred to as "riparian buffers" or as "bio retention areas." Riparian buffers also greatly maintain cool stream temperatures. It reduces runoff, increases infiltration, removes the waste materials and pollutants, and purifies water in one hand. Also it minimizes the sedimentation of river and maintains river capacities, ultimately to overcome floods in surrounding areas.

Figure 7. Tree plantation along both sides of the Bentota River.

Increased sedimentation of all irrigated canal systems has obstructed the water flow and created problematic situations that lead to inundation of surrounding paddy lands and home gardens of inner villages (Figure 8). Therefore, there is a need for drenching and renovation of inland water ways (Athuruwella Ela, Lunu Ganga, and Pahurumulla Ela) and irrigated and irrigated canals (Wadubokka Stream, Wekumbura Stream, Thunduwa Stream, Thotakumbura Stream, and Berethuduwa Stream regularly, both short term and long term, as a strategy for controlling flood in the area and enhancing irrigated water supply for paddy cultivation.

Figure 8. Inland irrigated canal system.

Flood Resistive Green Home Gardening Model (Figure 9) is proposed to practice flood vulnerable areas. This house will be including green roof, roof rain water collecting system, raised platforms in the roofs of home, seed and food storage, raised wells and latrines, rain garden, and floating vegetable garden. This housing model will reduce energy use, air pollution, and greenhouse gas, and will improve human health, living comfort, quality of life, storm water management, and water quality. At the same time, floating vegetable gardens (Figure 8) can be operated in high flood inundation areas. This will be a good solution to utilize abandoned paddy lands for other crop cultivation without controlling its nature as low land. There will be no legal restrictions for this kind of floating cultivation.

Figure 9. Flood Resistive Green Home Model and floating vegetable gardens.

Introduction of green paving for all home gardens will increase the water absorption ratio and ground water recharge by reducing surface water runoff rate during rain. Rather than concrete paving, green paving will be preferable to reduce flood. The agroclimatic diversity in the area with its high rain fall distributed over 4 months during each season and a reasonably moderate temperature allows for growing a variety of horticultural crops and practicing rain water harvesting to store rain water for usage in the four dry months in the year (Figure 10). These rainwater harvesting tanks will facilitate to reduce surface water runoff rate during raining in the area.

Figure 10. Home gardens with rain water consumption and conversion of a marshy land as a park.

The selected marshy lands, which have been abandoned, in the Bentota area can be converted as the park area (Figure 10), as a place for gathering and entertainment and indirectly as a means for proper land use management and a flood, bank slips, and waste reduction measure. Enhancement of natural environment and safety is a part of land use management. So this solution with above actions is worth to invest and construct for a new sustainable landscape infrastructure for future developments. The project, as a whole, avoids flooding and water pollution and will lead functions effectively.

Conclusion

Flood is the most devastating disaster in Sri Lanka. The most common flood type in the island is riverine flooding. Accurate weather forecasting and effective land use management are more important than other measures for flood disaster risk reduction. Simulation modeling is capable of providing a platform to understand, experiment, and plan the real ground situation in a practical way where high cost and more time-consuming methods of experimenting on the ground become unnecessary. The Bentota River basin receives the highest total monthly rainfall from the southwest monsoon during the month of May and from the second inter monsoon during the month of October. Maximum daily rainfall in the overall Bentota River basin shows an increasing trend with 0.0166 mm increment every month, while total monthly rainfall shows a decreasing trend with –0.0507 mm of decrement every month. The Bentota River basin may have high total monthly rainfall and maximum daily rainfall during the month of May and October in the future and also during low-rainfall situations during January and February under the prevailing climate change scenario. There will be an extreme variability of rainfall once every 5 years during any month from April to July, but mostly in May, resulting in a minor flood situation in the area. The highest simulated flood level of 1.65 m is recorded in Thunduwa east area of the left Bank of the Bentota River and Gammamna west area of the the right bank of the Bentota River. Zero flood sitations are indicated for a major part of the coastal belt area.

As land use management strategies, grass beds and river bank plantation are targeted to improve the surroundings of the Bentota River, with major waterways of the area already vulnerable to river bank erosion in rainy seasons. There is a need for regular drenching and renovation of all inland irrigated canals, both in the short- and long-term, as a strategy for controlling flooding in the area. A Flood Resistive Green Home Gardening Model is proposed for flood vulnerable areas. At the same time, floating vegetable gardens can be created in high flood inundation areas. Introduction of Green paving for all home gardens will increase the water absorption ratio and ground water recharge by reducing surface water runoff rate during rainfall. Rain water harvesting can be practiced to store rain water for usage during the four dry months of the year. The selected marshy lands in the Bentota area, which have been abandoned, can be converted to facilitate a park area. There is a good level of consistency between the observed and simulated results. The flood modeling approach presented in this research can be considered as an indirect flood estimation method to simulate the flood information of river catchment areas in an accurate manner. However, the accuracy of the model outputs is solely based on the accuracy and reliability of the input data used in the model. For example, contour data with fewer contour intervals and a considerable number of rainfall station values is used as input data for model calibration. Pixel size is also a major determinant of deciding the accuracy of simulated outputs spatially. The greater the pixel size, the lesser the accuracy of spatial outputs. On the other hand, less pixel size requires more detailed information. The farmers and the community of the area will be the main beneficiaries of the findings of this study as they can be made aware of future climate change impacts and flood information. Decision makers should formulate land use development plans for the Bentota area by considering the above-mentioned future climatological influences and flood inundation areas and levels identified as major outcomes of this research. The approach and the methodology adopted in this study will be useful for other researchers, agriculturalists and planners to identify future climatological influences and to develop flood simulation models for other river catchment areas and other decision-making purposes.

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