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An Analysis of Stream Flow and Flood Frequency: A Case Study from Downstream of Kelani River Basin, Sri Lanka

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River floods in Sri Lanka are mainly associated with extreme rainfall events. The Kelani and Kalu rivers are recorded the highest flood frequencies and the accompanying flood damages among the river basins in wet zone (UNDP, 2011). Therefore, the specific objective of the study is to estimate the temporal probability of occurrence of flood events in downstream of Kelani river basin. Secondary data were used for the study. Daily discharges data were obtained from Hanwella gauging station for the period of 1990 to 2019 from the Department of Irrigation, Sri Lanka. Trend analysis, normal distribution and flood frequency analysis have been used. The results of the study revealed that there was a bi-modal pattern of discharges that occurred in June and October. The results also indicated that ten return periods were covered the total period of 30 years, and there was a 97 per cent probability of flood occurrence almost annually and 64 per cent probability of occurring once every two years. This study, therefore, was recommended to design flood control structures for mitigating flood risk; and to determine the economic value of flood control projects and the effect of encroachments on flood plain.

Keywords: *floods, frequency, downstream, return period, probability*

Introduction

Global climate change has led to an increase in the magnitude, frequency, and intensity of natural disasters over the years (Perera 2017). By analyzing the historical and recent data, many scientific studies have revealed that, floods are the most catastrophic and frequently occurring natural disaster together with damaging in terms of cumulative and annual expected losses over the world. According to the United Nations International Strategy for Disaster Reduction (2017), over the last 20 years from 1995 to 2015, floods were responsible for 47 per cent of all weather-related disasters, affecting 2.3 billion people (56 per cent), the majority of whom (95 per cent) live in Asia. Further, the number of floods per year has risen to an average of 171 in the period from 2005 to 2014, up from an annual average of 127 in the previous decade. Because of flood is a component of hydrological cycle of drainage basin (Baishya 2013) and flooding therefore cannot be stopped. However, their impacts may be mitigated and managed to some extent.

Therefore, due to the global climate change, flood risk is a significant issue in many countries all over the world. Sri Lanka is one of such countries which have seasonal flooding problem since seasonal flooding is more frequent and common

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occurrence in Sri Lanka than the other natural disasters (Jegarasasingam 2017). Especially, variability of both annual and seasonal rainfall in Sri Lanka has increased during recent decades due to climate change. Jayawardena et al. (2017) have noted that changes in annual as well as Southwest monsoon seasonal rainfall compare to the baseline climatology period from 1975 to 2005, clearly indicate that positive rainfall anomaly in the wet zone will be risen with the time under high as well moderate emission scenarios.

Accordingly, when considering to Sri Lanka, the country has experienced several notable flood events in more recent years. The Global Climate Risk Index Report 2019, which launched at the Climate Summit in Katowice (COP 24), ranked Sri Lanka as the second among the most affected countries by extreme weather events. The ranking was regarding the heavy landslides and floods after strong monsoon rains in the Southwestern region of the country in 2017. Consequently, the Kelani river basin experienced a total of 350 mm of rainfall across three days from 15th to 17th May in 2016 after the devastating flood in 1989. 23 Divisional Secretariats (DS) divisions (out of 37) in the Kelani river basin were affected by the 2016 Flood. Out of them, 15 DS divisions were affected significantly.

According to the Ministry of Disaster Management in Sri Lanka (2016), the Colombo district has affected 228,871 members of 54,248 families in the 10 DS divisions consisting of Colombo, Homagama, Kaduwela, Kesbawa, Kolonnawa, Kotte, Maharagama, Padukka, Seethawaka and Thimbirigasyaya, while the Gampaha district has affected 74,003 members of 17,485 families in the 13 DS divisions consists of Attanagalla, Biyagama, Divulapitiya, Dompe, Gampaha, Ja-ela, Katana, Kelaniya, Mahara, Meegamuwa, Meerigama, Minuwangoda and Wattala. This flood was characterized by low peaks and longer duration of inundation owing to the rainfall distribution pattern over the catchment (Hettiarachchi 2020). By far the worst affected division countrywide is Kolonnawa where 155,062 people were affected, which is 81 per cent of the total population in this division. In this context, flood hazard is the most significant issue in downstream of the Kelani river basin than the other extreme events.

Especially, downstream of the Kelani river basin has consisted of nine sub-drainage basins namely, Lower Kelani Ganga, Pallewela Oya/ Maha Ela, Lower Middle Kelani Ganga, Kolonnawa Ela, Biyagama, Pagoda Oya, Upper Middle Kelani Ganga, Wak Oya/ Kalatuwawa, and Pusweli Oya. Downstream of the Kelani river basin overlaps with four districts (Colombo, Gampaha, Kalutara, and Ratnapura) as well. Therefore, a large area is inundated almost annually due to the floods in the Kelani river.

Further, according to the Department of Irrigation in Sri Lanka (2020), the main causes for recent flooding in the Kelani river are high-intensity rainfall occurred within a short duration, the inadequacy of the drainage system to cater for a higher return period rainfall, flow hindrances in secondary canal system causing localized flooding, unauthorized constructions encroaching water bodies, the inadequacy of outfall capacity of the drainage network, reduction of retention areas, and dumping of solid waste into canals result in the reduction of capacity. In addition to that, other indirect causes of flooding in the Kelani river basin are lack of investment for drainage projects, unplanned town development, lack of co-ordination among Agencies, and lack of public awareness.

The Kelani river basin suffers from floods mostly during South-west monsoon (SWM) and it causes serious damages to human lives and their properties in the lowland areas of the flood plain almost annually. However, the catchment receives considerable amounts of rainfall during North-east monsoon (NEM), and inter-monsoonal periods too (Hettiarachchi 2020). Due to the heavy rainfall and the steep terrain of the upper catchment, lower basin of the Kelani River is subjected to heavy floods. Especially, the Floodplain is formed below Glencourse gauge which is about 53 kilometers upstream of the sea outfall. Below Hanwella (about 35 kilometers from the sea), the flood plain becomes wider following the flat landscape (Hettiarachchi 2020).

Furthermore, due to the relatively small island setting, the demand for land in the growing urban areas has led to the expansion of cities to land prone to flooding, and which are often deemed unsuitable for habitation (Dissanayake et al. 2018). The outskirts of the metropolitan region of Colombo are pushing into wetlands along the Kelani river basin, which results in environmental degradation and increased exposure of the local population. Many of these settlements are built up on floodplains, which means that the poorest demographics are most vulnerable to flooding events and habitually end up being displaced (United Nations Office for Disaster Risk Reduction 2019).

As has mentioned before, the downstream of the Kelani river basin is a highly populated zone and high distribution of agricultural lands in the river basin. Similarly, due to the barriers of drainage systems in the area because of the construction and extension of utility services, and due to the formation of some areas as marshy lands, there had been small-scale floods. Together with, the marshy lands and water retaining area affected by the canal network in downstream of the Kelani river basin form the land suitable for Paddy cultivation, but still, crop damages occur due to severe flooding in this region (UDA 2019). Floodwaters transport sediments and nutrients to enrich the soil, which is deposited on flood plains. Among the agricultural land uses, paddy lands are flooded purposely to take advantage of this natural fertilization process. However, the exact loss of paddy production will depend upon several factors including crop variety, the growth stage of the plant, level of inundation or flood depth, and length of flooding period of duration.

Moreover, People tend to gather close to rivers or concentrate in the coastal areas because water is a resource before being a threat, and therefore a high level of risk, in flood-prone areas, a tendency will likely increase in future. Owing to the adverse nature of flooding in Sri Lanka, it is needed to do many researches and identify the best practices regarding to the flood management. In this regard, stream flow and flood frequency analyzes are primary steps in the flood control process because it is essential for the identification and prioritization of the top priority areas, selecting the best practices and best designs to flood reduction and land use planning. Therefore, this research will try to the analysis of flood occurrences. This will further help to design the appropriate land use planning and engineering measures in flood-prone areas and managing the annual flood menace in downstream of the Kelani river basin.

Accordingly, the main objective of the study is to analyze the stream flow and flood frequency in downstream of the Kelani river basin. The specific objective of this study is to estimate the temporal probability of occurrence of flood events between 1990 and 2019.

Literature Review

A flood is a natural hazard that can be categorized as hydro-meteorological hazard. A flood can be simply defined as water overflowing onto usually dry land. However, different definitions can be adopted to describe flood events. USGS (2020) defines a flood as "any relatively high stream flow overtopping the natural or artificial banks in any reach of a stream". Furthermore, hydrologists define floods as a sudden peak in the water level due to the sudden increase in water discharge. Therefore, floods occur because of the rapid accumulation and release of runoff waters from upstream to downstream, which is caused by extremely heavy rainfall.

Characteristics of Floods

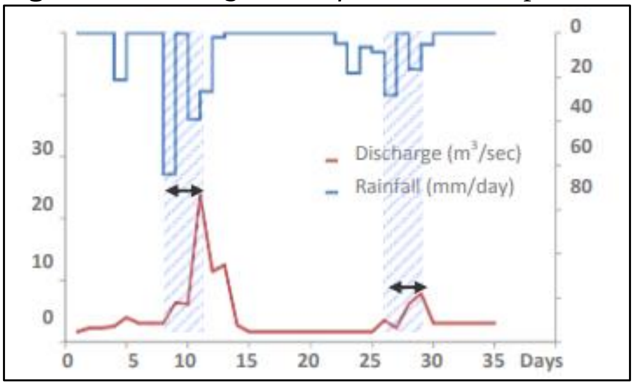
According to Van Westen et al. (2011), flood can be characterized by the triggering factors, spatial occurrence, duration of the event, time of onset, frequency, magnitude and secondary events. These characteristics can help in categorization of different types and levels of flood as well as it enable to compare different hazards with each other. Therefore, floods can be triggered by different natural and anthropogenic phenomena. Sometimes it is prolonged rainfall that causes floods, sometime torrential rains or storms cause flooding situation.

Spatial occurrence refers to the area and the extent of the area affected by the flood. Floods do not occur randomly. They occur in areas that are in geographical proximity to water bodies, where prolonged rainfall occurs or in areas with poor drainage system. These characteristics enable to categorize the flooding events. The extent of the area covered by the flood can be small for example in the case of flash floods; it affects only a village, town, or a city. While riverine floods can affect many a city on its way (Van Westen et al. 2011).

Duration of the event means the time span between the start and end of the flooding or the event that caused the flood. Usually this is difficult to be defined for floods as the recede very slowly and does not vanish completely, rather the flood water moves from one area to another. When attention to the time of onset of the flood, it is the time span between the start of the event causing the flooding and the time when the flood has actually occurred, for instance, the delay between the rainfall and the peak discharge.

Figure 1 represents the temporal relation between discharge rate and rainfall in a monsoonal area. In the figure, two flood events are recorded: the first at the 11^{th} day, and the second, smaller than the previous, at the 29^{th} day; they are caused mainly by the rain fallen in the 8^{th} day, and in the 21^{st} day. The figure also represents the area with blue stripes and the two arrows show the time lapse between the precursor (rainfall) and the hazard pick (flood max discharge) (Van Westen et al. 2011).

Figure 1. *Discharge - Rainfall Relationship*



Frequency of flood events mean how often the flooding occur in a given time period, for example, a year. Flood recurrence intervals can range from multiple times a year to once in 10 years or even 30 years. It allows scientists/ researchers to understand when a flood of certain magnitude and intensity will occur in a given area. Magnitude refers to the energy released during the hazardous event (Van Westen et al. 2011).

Seasonality refers to the season that has the most probability for flood. In South Asia including Sri Lanka, the probability of floods is highest in Monsoon period (July - August) as compared to the rest of the year. This is due to the seasonal winds (monsoon) that blow over South Asia in this period. By knowing the season for the flood hazard, it can be taken steps to prevent, mitigate or in the worst case prepare for the hazard (Van Westen et al. 2011).

Intensity of floods is the damage caused by it. It can be characterized by depth of inundation, volume of inundation, velocity of flow and rate of rise of water. The more the depth of water, more will be its volume, velocity, and its damaging capacity. A high rate of rise for water also means less preparation time for people in the area (Van Westen et al. 2011).

Types of Floods

Floods can be categorized in different ways based on several criteria. According to their duration, flood can be divided into different categories as Slow-onset floods, Rapid-onset floods, and Flash floods. Also, floods can be categorized according to the water source (origin), geography of receiving area, cause, and the speed of onset. The water source of floods can originate from the ocean (coastal floods), rivers (fluvial floods), from underground (groundwater floods) and from rain (pluvial floods) (EC 2020, Klijn 2009).

Floods in Sri Lanka can be classified in several different ways. One of the more common and useful ways of classifying floods is based on the source and the nature of flooding. Accordingly, the types of floods are riverine floods, flash floods, localized floods, floods caused by reservoir operation and floods caused by reservoir breaching (Disaster Management Centre 2012).

Triggering and Causative Factors of Flooding

Floods can be triggered by different natural and anthropogenic phenomena. Sometimes, it is prolonged rainfall that causes floods, and sometimes torrential rains or storms cause flooding situations. However, floods are not always triggered by heavy rainfall. They can result from other phenomena, particularly in coastal areas where inundation can be caused by a cyclone, a tsunami, or a tidal surge due to attractive forces of the sun and the moon. Dam failure also results in flooding of the downstream area, even in dry weather conditions. Further, in the dry season, high average temperature can result in increased melting of the snow, hence high discharge downstream in some countries especially in India. Similarly, lack of permeable surface and high groundwater table in a region can also trigger a flood. On the other hand, as an endogenic factor, floods can be caused by earthquakes (Van Westen et al. 2011).

When focused on causative factors, floods mainly occur due to unplanned rapid growth and development of urban areas interfering with floodplains (Balabanova and Vassilev 2010). The additional causes of floods are deforestation, climate change, change in weather patterns, improper waste management, changes in land use, bad farming practices, poor dam construction, as well as the characteristics of the catchment area, drainage network, and the river channels. The triggering and causative factors of flooding are shown in Table 1.

Table 1. *Factors Contributing to Flooding*

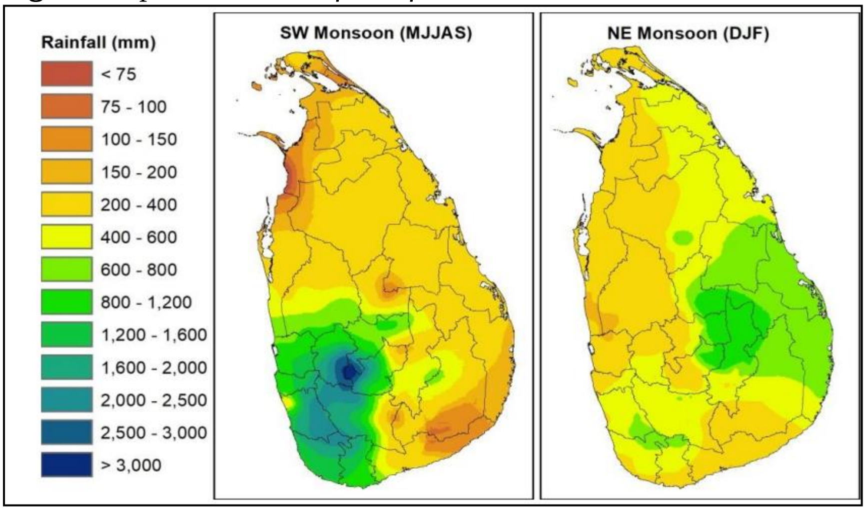
Meteorological Factors	**Hydrological Factors**	**Human factors aggravating natural flood hazards**
• Rainfall • Cyclonic storms • Small-scale storms • Temperature • Snowfall and snowmelt	• Soil moisture level • Groundwater level prior to storm • Natural surface infiltration rate • Presence of impervious cover • Channel cross-sectional shape and roughness • Presence or absence of over bank flow, channel network • Synchronization of run-offs from various parts of watershed • High tide impeding drainage	• Land use changes (e.g., surface sealing due to urbanization, deforestation) increase runoff and may be sedimentation • Occupation of the flood plain obstructing flows • Inefficiency or non-maintenance of infrastructure • Too efficient drainage of upstream areas increases flood peaks • Climate change affects magnitude and frequency of precipitation and floods • Urban microclimate may enforce precipitation events

Source: Van Westen et al. 2011.

Flood Patterns in Sri Lanka

Floods are the most common and hazardous natural event than the other natural disasters in Sri Lanka. Especially, there is a significant spatial and temporal pattern of river floods in Sri Lanka. When considering the annual flood pattern, it can characterize by two distinct monsoon seasons, specifically the SWM (from May to September) and NEM (from December to February). Therefore, the country is subjected to floods twice a year. The rainfall distribution pattern during SWM and NEM in Sri Lanka is illustrated in Figure 2. According to Figure 2, the SWM brings heavy rains to the western and southern slopes of the central highlands while the NEM brings rains to the eastern side of the central hills and lowlands. Therefore, major riverine floods are mainly associated with extreme rainfall received during the above two monsoon seasons.

Figure 2. *Spatial Pattern of Rainfall in SWM and NEM Seasons in Sri Lanka*



In addition to these monsoon seasons, the country receives torrential rainfall because of the development of low-pressure systems or tropical cyclones frequently form in the Bay of Bengal. Accordingly, most of the cyclonic floods occur from October to December (Basnayake et al. 2019). As well, historical records show that most cyclones hit the east, north, and north-central areas of the island (Yoshitani et al. 2007). The Vavuniya district shows a higher flood probability due to cyclonic storms. Even though the annual rainfall is lower than the Western highlands, Vavuniya and Mullaitivu in the north have recorded the highest rainfall intensities in the island (Zubair et al. 2020).

Flood River Basins in Sri Lanka

Among the major river basins, the Kelani, Gin, Kalu, Nilwala, and Mahaweli rivers are more vulnerable to the occurrence of floods. Therefore, they can be called as main flood-prone basins in Sri Lanka. Especially, according to the UN-Water (2006), 36 major river basins out of 103 natural river basins have been classified into three main groups as south-west monsoonal; north-east monsoonal; and both monsoonal river basins.

Accordingly, the Kalu, Kelani, Gin, Nilwala, and Bentota rivers; the Attanagalu Oya, and the Maha Oya in the wet zone are included in group one viz. south-west monsoonal river basins. These rivers are more subjected to floods triggered by the SWM that arrives in late May, thus the districts of Kalutara, Kegalle, Gampaha, Ratnapura, Colombo, and Gall are inundated (Disaster Management Centre 1999). However, the Kelani and Kalu rivers are recorded the highest flood frequencies and the accompanying flood damages among the river basins in the wet zone (United Nations Development Programme 2011). The slight gradients encountered in lower parts of the river mainly cause the floods in the Kelani river basin due to the extremely heavy and prolonged rainfall in the upper catchment areas.

Further, according to the UN-Water (2006), 26 river basins, including the Mahaweli river, Maduru Oya, Kirindi Oya, Maha Oya, Mee Oya, Deduru Oya, Malwathu Oya, and Mundeni Aru are fallen into group two viz. northeast monsoonal river basins. These river basins are in the dry zone and covered a significant spatial distribution of the country. Therefore, a large area of the country is inundated during the NEM due to the heavy rains.

The Mahaweli river in the dry zone and the Walawe river basin, which spreads across the semi-arid zone of the southern part of the country are included in the third group viz. receiving rainfall from both monsoon seasons. Accordingly, the Mahaweli and Walawe rivers can call as bi-monsoonal rivers. In addition to that, the Deduru Oya also falls into the third group. However, this river is not strictly bi-monsoonal.

Effects of Flooding

Floods are one of the most frequent occurring natural disasters that directly and indirectly has sever effects on human and the environment (Hewitt 2013). The direct damages are those who cause harm by contact of flood water with property, humans, or other objects. Indirect damages are those who occur outside the flood event itself (World Meteorological Organization 2008). The most important parameters influencing flood impact are water depth, duration of flooding, flow velocity, sediment concentration, sediment size, wave or wind action, pollution load of flood water and rate of water rise during flood onset (Genovese 2006). The losses due the floods are shown in Table 2.

Table 2. *Categorization of Flood Losses*

	Tangible Direct Losses	Tangible Indirect Losses	Intangible Human and Other Losses
Primary	Damage to: • Buildings (e.g., houses) • Contents of buildings • Infrastructure (e.g., roads, bridges) • Crops and animals	Loss of, or disruption, to: • Agricultural production • Industrial production • Communications (e.g., road, rail, and telecommunications) • Health care and education services • Utility supplies (e.g., electricity)	• Loss of life • Physical injury • Loss of heritage or archaeological site
Secondary	• Flood causes fire and fire damage • Salt in seawater contaminates land and reduces crop yields • Flood cuts electricity supply, damaging susceptible machines and computer runs	• Lost value added in industry • Increased traffic congestion and costs • Disruption of flow of employees to work causing "knock-on" effects • Contamination of water supplies • Food and other shortages • Increased costs of emergency services • Loss of income • Increased household costs	• Increased stress • Physical and psychological trauma • Increase in flood-related suicides • Increase in water-borne diseases • Increase in ill health • Increase in post-flood visits to doctors • Hastened and/or increased mortality
Tertiary	• Enhanced rate of property deterioration and decay • Long-term rot and damp • Structures are weakened, making them more damage prone in subsequent floods	• Some businesses are bankrupt • Loss of exports • Reduced national gross domestic product	• Homelessness • Loss of livelihoods • Total loss of possessions (i.e., uninsured) • Blighted families • Lost communities where communities are broken up

Source: World Meteorological Organization 2008.

Floods can also bring positive effects of many benefits such as recharging ground water, making soil more fertile and increasing nutrients in some soils. Especially, flood waters provide much needed water resources in arid and semi-arid regions where precipitation can be very unevenly distributed throughout the year. Freshwater floods particularly play an important role in maintaining ecosystems in river corridors and are a key factor in maintaining floodplain biodiversity. Also, flooding can spread nutrients to lakes and rivers, which can lead to increased biomass and improved fisheries for a few years. For some fish species, an inundated floodplain may form a highly suitable location for spawning with few predators and enhanced levels of nutrients or food. Fish such as the weather fish make use of floods in order to reach new habitats. Bird populations may also profit from the boost in food production caused by flooding.

Recent Trends in Floods of Sri Lanka

The nature of catastrophic floods has also changed in recent years in the world with an increase in the frequency of flash floods, acute riverine, and coastal flooding. Besides, urbanization has significantly increased flood runoffs, while recurrent flooding of agricultural land, particularly in Asia, has taken a heavy toll in terms of lost production, food shortages, and rural under-nutrition (United Nations International Strategy for Disaster Reduction 2017). Therefore, the occurrence of flood events shows an increasing trend in most regions of Sri Lanka. According to the study of national climate change adaptation strategy for Sri Lanka - 2011 to 2016 undertaken by the Environmental Ministry of Sri Lanka, it has been reported that increased the intensity of rainfall in the wet zone due to climate change is expected to increase the propensity for flooding in flood-prone rivers (Perera 2017).

Further, the total number of flood events in Sri Lanka is recorded high. According to the historical data, flood events have increased over the years with 25 large floods that occurred between 2000 and 2013 due to the intensity and frequency of extreme weather events. Intense rainfall above 300 mm within 24 hours caused to occur flash floods in 2010, 2011, and 2012 due to the climate change impacts.

Moreover, with an increase in the number of flood events, the associated flood damages such as the number of building damages, crop damages, and infrastructure damages have been also increased. Further to this, another flood impacts such as the number of injuries and affected people have also sharply increased as obvious from the past few years. However, there is a significant decline in loss of lives due to flooding since 2003 (Consortium of Humanitarian Agencies 2016).

The number of districts affected by floods has also increased. According to the Consortium of Humanitarian Agencies (2016), the most vulnerable districts which were affected by floods during the last 40 years from 1974 to 2015 are Batticaloa, Ampara, Colombo, Gampaha, Kalutara, and Ratnapura districts respectively. In addition to that, the Hambantota district can be identified as a new vulnerable district in Sri Lanka affected by floods from 2000 to 2013. Accordingly, Hambantota, Tissamaharama, and Ambalantota divisions are prone to flood in this district.

Theoretical Review

Trend Analysis

A common feature of time series data is a trend. Using regression, we can model and forecast the trend in time series data. Accordingly, in this study, linear regression analysis was used to analyze the stream flow pattern in the downstream of the Kelani river basin. A regression based trend analysis was conducted using linear trend model by using the following equation.

$Y = mx + c$ Equation (1)

Where *m* represents the rate of changes and *c* represents the *y* intercept of the line. The R-squared (R^2) value ranging from '0' to '1' or the 'corrected R squared' (R^2) which is adjusted for degrees of freedom indicates the explanatory power (goodness of fit) of the model.

Flood Frequency Analysis

Flood frequency analysis is one of the significant studies of river hydrology (Yadav 2002). It is based upon the historical records and provides an estimate of exceedance probability or recurrence interval of the flood of a particular magnitude (Gilard 1996). This is analyzed based on the maximum rainfalls, maximum discharges, or water levels, which is the largest instantaneous peak flow occurring at any time during the year by Gumbel's method, Log-Normal and Log Pearson III Type method. The estimation of the frequencies of the flood is important to understand the previous records of flood events to evaluate future possibilities of such occurrences.

In this study, the flood frequency analysis was done by using Gumbel Extreme Value Distribution. Gumbel's extreme value distribution which is one of the most widely used probability analyses of extreme values in hydrologic and meteorological studies for prediction of flood peaks and maximum rainfalls was used to estimate the temporal probability of occurrence of flood events in the area. Accordingly, the objective of frequency analysis was to find out discharges at different return periods using extreme value distribution by Gumbel method (Manandhar 2010, Van Westen et al. 2011) as mentioned below.

The annual maximum flood values were arraigned from low to high (ascending order) and assigned lowest rank 1 to the lowest value and assigned the highest rank N to the highest data value. Left sided probability of each event was calculated by equation 2 (Van Westen et al. 2011).

$$P_L = \frac{R}{N+1}$$ Equation (2)

Where,

PL = Left side probability (probability of having less values in the series)
R = Rank
N = Total number of observations/ Numbers of years

The T (return period/ recurrence interval) was calculated for each observation by equation 3 (Van Westen et al. 2011).

$$T = \frac{1}{P R} = \frac{1}{1 - P L}$$ Equation (3)

Plotting position for each observation was calculated by equation 4 (Van Westen et al., 2011).

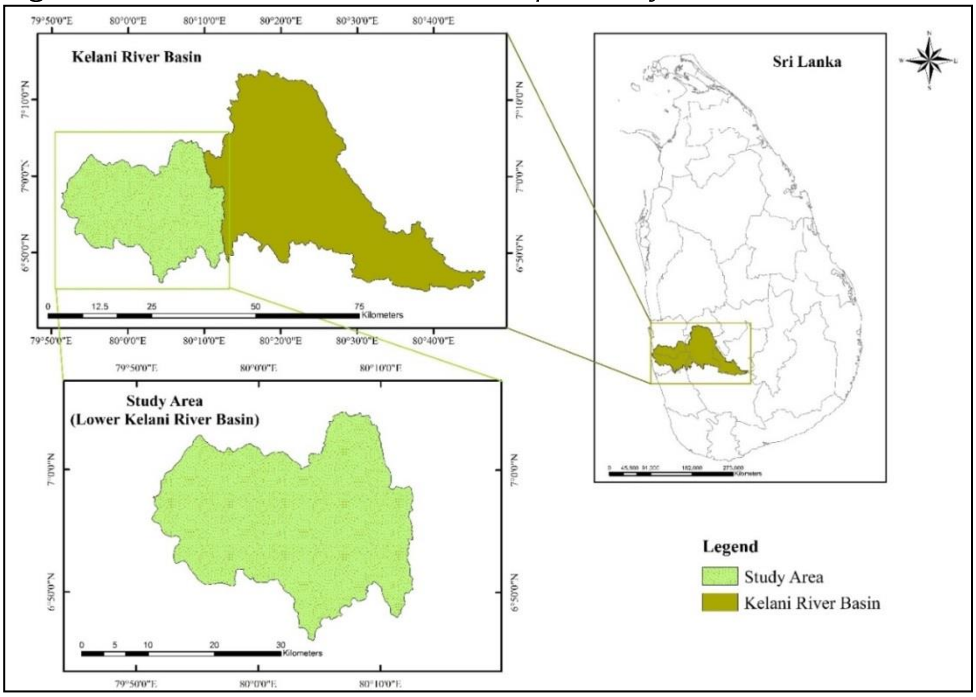
$$Y = -\text{In}(-\text{In}P_L)$$ Equation (4)

Methodology

Study Area

The Kelani River is the second largest river and the third largest watershed in Sri Lanka. It is also the fourth-longest river in Sri Lanka (Mallawatantri et al. 2016). This river basin is located totally in the wet zone of the country. The Kelani river basin receives an average annual rainfall of 3,450 mm and corresponding to a volume of about 7860 MCM out of which nearly 43 per cent discharges into the sea (Ministry of Irrigation & Water Resource Management 2018). The Kelani river basin is located at the coordinates between Northern latitudes 6° 46$^{/}$ & 7° 05$^{/}$ and Eastern longitudes 79° 52$^{/}$ & 80° 13$^{/}$ (De Silva et al. 2016). With the experience of the previous flood records of the Kelani river basin, the downstream or lower reach of the Kelani river basin was selected as the study area of this study. The absolute and relative location of the study area is illustrated in Figure 3.

Figure 3. *Absolute and Relative Location of the Study Area*



According to Figure 3, the selected study area is in the Western and Sabaragamuwa provinces of Sri Lanka and located at the coordinates between Northern latitudes 6° 46′ & 7° 05′ and Eastern longitudes 79° 52′ & 80° 13′. Accordingly, the study area covers the flood plains below Glencourse gauging station in Kegalle district up to the Nagalagam Street gauging station in Colombo district. The total length of the Kelani river in the study area is about 55 kilometers. The total land area of the study area is about 810 square kilometers. The study area is in the wet zone of Sri Lanka and, it receives an annual rainfall varying from 500 mm to 4,000 mm with an average mean annual rainfall of about 2,440 mm over the elevation range of the basin.

Data Used for the Study

The study was mainly based on secondary data. As hydrological data, daily discharge data were gathered for a period of 30-years between 1990 and 2019 from the Department of Irrigation, Sri Lanka to estimate the temporal probability of occurrence of flood events in the study area. Similarly, these hydrological data were collected from the Hanwella gauging station, which is located downstream of the Kelani river basin.

Different reports, press statements, annual reports, annual symposium proceedings, and other documents both published and unpublished by the relevant authorities including Disaster Management Centre, Ministry of Agriculture, as well as other local and international organizations, were used to identify the flood profile of the country containing the study area and its impacts. Further, other related literature such as books, journals, technical reports, and research papers were referred from different sources such as libraries and the World Wide Web through the Internet. Information found in the newspapers was also used.

Data Analysis Methods

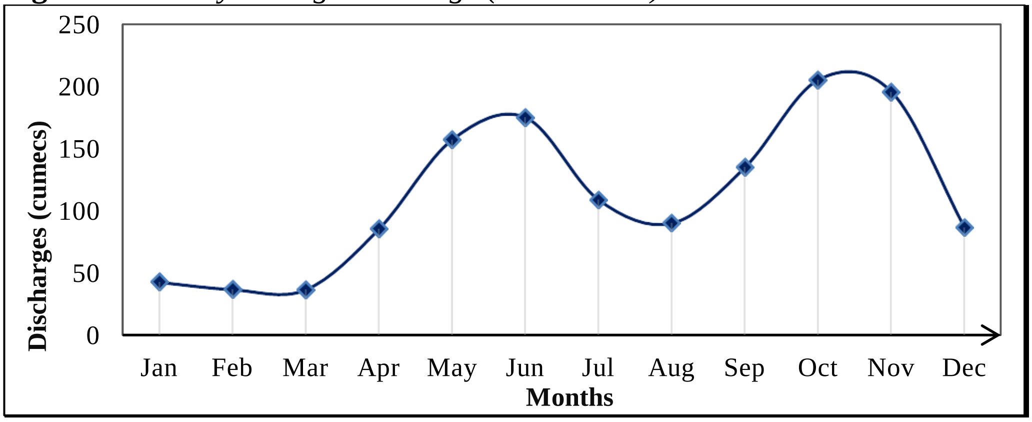
To estimate the temporal probability of occurrence of flood events, stream flow analysis by using normal distribution, trend analysis by using regression method and flood frequency analysis by using Gumbel's extreme value distribution were used.

Results and Discussion

Stream Flow Analysis

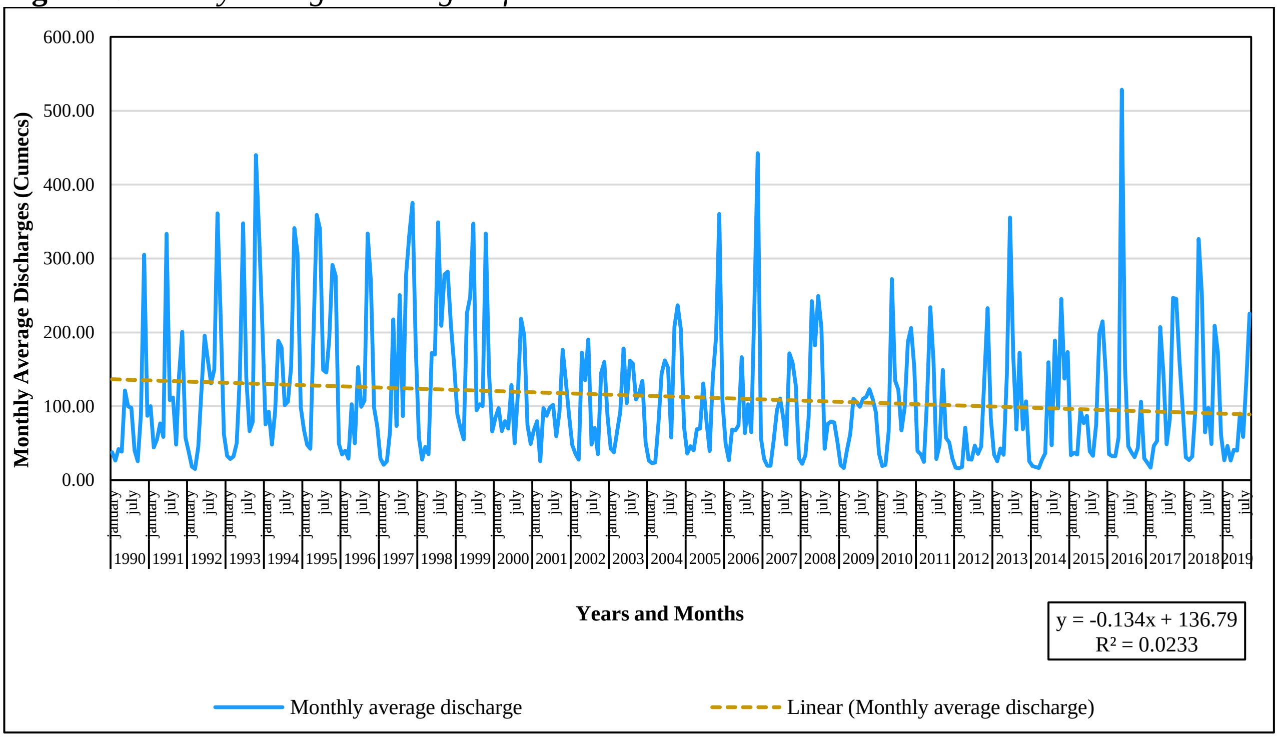
The normal distribution analysis and trend analysis were conducted to identify the stream flow pattern in downstream of the Kelani river basin. The mean of daily and monthly discharge data of each year was used as the descriptive statistic to determine the normal distribution of stream flow in the study area. Trend analysis was conducted using monthly average discharge data based on the regression analysis method (Sharma et al. 2018). Therefore, the monthly average discharges for the period from 1990 to 2019 are represented in Figure 4. According to Figure 4, there was two peaks in the year, which reveals the bi-modal pattern of discharge in downstream of the Kelani river basin occurred in June (175 m^3/s) and in October (205 m^3/s). The annual average discharge of the river basin was 113 m^3/s.

Figure 4. *Monthly Average Discharge (1990 – 2019)*



The result of time series trend analysis was indicated that a decreasing (negative) trend in monthly average discharges over the period (Figure 5). During the period, the maximum average discharge was recorded in 2016 with the average discharge of 528.66 m^3/s in May while the lowest was recorded in the year 1992 with the average discharge of 15.26 m^3/s in March.

Figure 5. *Monthly average discharges of Kelani river at Hanwella*

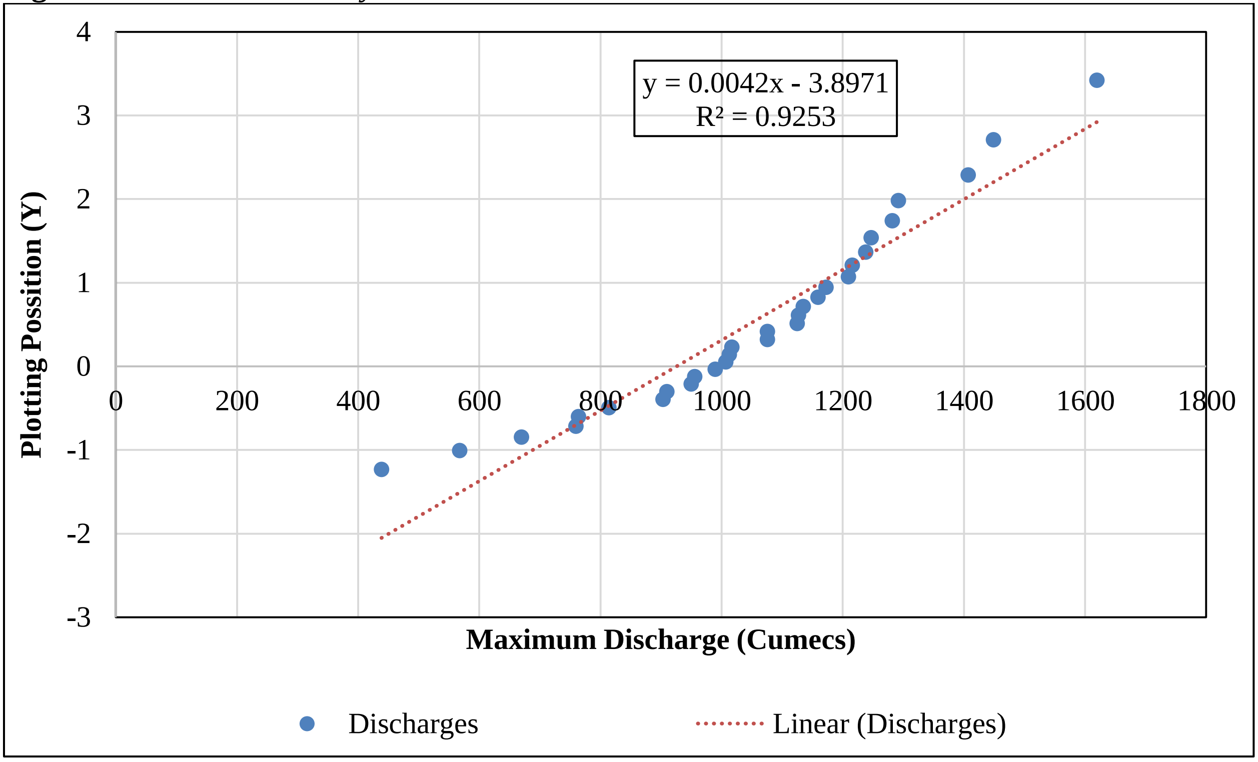


According to Figure 5, it is also evidenced that there were many variables in discharges of the Kelani river over the study area during the period between 1990 and 2019. The significant increases of discharges in the graph were indicated the flood hazard events in the study area. Therefore, it is important to calculate the probability of occurrence of historical flood magnitudes and return periods to assess flood risk (Yadav 2002, Sharma et al. 2018).

Flood Frequency Analysis

The objective of flood frequency analysis was to calculate the magnitude of extreme events at their frequency of occurrence using probability distributions (Yadav 2002, Sharma et al. 2003). Accordingly, the results of the flood frequency analysis are shown in Figure 6 and Table 3. Figure 6 shows the plotting positions of the discharges while Table 3 shows the calculation steps of flood frequency based on Gumbel's distribution method (Manandhar 2010).

Figure 6. *Gumble Probability*



Accordingly, ten return periods were covered the total period of 30 years between the first and the last occurrence of high flood events as 1, 2, 3, 4, 5, 6, 8, 10, 16, and 31. The return periods and the probability of occurrence for each observation of downstream of the Kelani river basin are shown in Table 4.

Accordingly, as shown in Table 4, the study area had been affected ten times by low annual maximum discharges range between 439 m^3/s and 956 m^3/s; eight times by discharges range between 957 m^3/s and 1127 m^3/s; four times by discharges range between 1128 m^3/s and 1210 m^3/s; two times by discharges range between 1211 m^3/s and 1238 m^3/s with return periods of 1, 2, 3 and 4 years respectively. Therefore, the study area was experienced with a very high and high probability of flood occurrences with one and two-year-return periods. In other words, it was observed that there was a 97 per cent probability of flood occurrence almost annually and a 64 per cent probability of occurring once every two years. The study area was also experienced with a moderate probability of occurrences of three and four years return period floods. Further, the results were revealed that there was a less probability of occurrence of 5, 6, 8, 10, 16, and 31 years return period floods with relatively high discharge data.

Table 4. *Maximum Peak Discharges for Various Return Periods at Hanwella*

Annual maximum discharges (Cumecs/ m^3/s)	Frequency	Return period	Probability of occurrence	Hazard level
439 - 956	10	1	0.968	Very High
957 - 1127	8	2	0.645	High
1128 - 1210	4	3	0.387	Moderate
1211 - 1238	2	4	0.258	Moderate
1239 - 1247	1	5	0.194	Low
1248 - 1282	1	6	0.161	Low
1283 - 1292	1	8	0.129	Low
1293 - 1408	1	10	0.097	Low
1409 - 1449	1	16	0.065	Very Low
> 1450	1	31	0.032	Very Low

Especially, the study area experienced several more severe flood events in the most recent, for example, the probability of occurrence of the 2016 flood at the same magnitude could be once in 31 years (probability = 0.032). Also, the return period of floods in 2017 was 15.5 years (Table 3). Accordingly, the results of flood frequency analysis of the study area can be used to design bridges, culverts, dams, and flood control structures for mitigating flood risk; to define flood plains; to determine the economic value of flood control projects and the effect of encroachments on the flood plain (Yadav 2002, Sharma et al. 2018).

Table 3. *Summary Table: Extreme Value Distribution by Gumbel Method*

Year	Maximum Discharges in Cumecs	Re-arranged discharges	Rank (*R*)	P_L	P_R	Return Period (*T*)	Y
1990	568	439	1	0.032258065	0.967741935	1.03	-1.23372204
1991	1007	568	2	0.064516129	0.935483871	1.07	-1.00826445
1992	1076	670	3	0.096774194	0.903225806	1.11	-0.84817244
1993	1292	760	4	0.129032258	0.870967742	1.15	-0.71671372
1994	1172	764	5	0.161290323	0.838709677	1.19	-0.60133299
1995	764	814	6	0.193548387	0.806451613	1.24	-0.4960537
1996	1135	904	7	0.225806452	0.774193548	1.29	-0.39748472
1997	1216	910	8	0.258064516	0.741935484	1.35	-0.30346609
1998	1017	950	9	0.290322581	0.709677419	1.41	-0.21249718
1999	1282	956	10	0.322580645	0.677419355	1.48	-0.12345767
2000	990	990	11	0.35483871	0.64516129	1.55	-0.03545588
2001	670	1007	12	0.387096774	0.612903226	1.63	0.0522616
2002	760	1013	13	0.419354839	0.580645161	1.72	0.140368602
2003	814	1017	14	0.451612903	0.548387097	1.82	0.229501376
2004	904	1076	15	0.483870968	0.516129032	1.94	0.32029204
2005	950	1076	16	0.516129032	0.483870968	2.07	0.413398773
2006	1210	1125	17	0.548387097	0.451612903	2.21	0.509536687

2007	1076	1127	18	0.580645161	0.419354839	2.38	0.609513182
2008	1408	1135	19	0.612903226	0.387096774	2.58	0.714272302
2009	910	1159	20	0.64516129	0.35483871	2.82	0.824954504
2010	956	1172	21	0.677419355	0.322580645	3.10	0.942981875
2011	1247	1210	22	0.709677419	0.290322581	3.44	1.07018592
2012	439	1216	23	0.741935484	0.258064516	3.88	1.209008835
2013	1159	1238	24	0.774193548	0.225806452	4.43	1.362838126
2014	1125	1247	25	0.806451613	0.193548387	5.17	1.53659934
2015	1013	1282	26	0.838709677	0.161290323	6.20	1.73789269
2016	1620	1292	27	0.870967742	0.129032258	7.75	1.979412778
2017	1449	1408	28	0.903225806	0.096774194	10.33	2.284915186
2018	1238	1449	29	0.935483871	0.064516129	15.50	2.707679652
2019	1127	1620	30	0.967741935	0.032258065	31.00	3.417637092

Conclusion

When considering the Kelani river basin, it is recorded as a highest flood frequency and the accompanying flood damages among the river basins in wet zone. Specially, flood frequency is the concept of the probable frequency of occurrence of a given flood. For the design of engineering works, it is not sufficient to identify only the maximum observed flood, it is also necessary to find out the frequency of occurrence of the flood. Therefore, the specific objective of the study is to estimate the temporal probability of occurrence of flood events in downstream of Kelani river basin. The results of the study revealed that there was a bi-modal pattern of discharges that occurred in June and October. The results also indicated that ten return periods were covered the total period of 30 years between 1990 and 2019, and there was a 97 per cent probability of flood occurrence almost annually and 64 per cent probability of occurring once every two years.

According to the outcomes of the study, it can be said that stream flow and flood frequency analyses are important concepts and techniques for reducing flood damages in an area and for the designers of the flood control works. As well as flood frequency information can be applied to controlling land uses and settlements on flood prone areas and many other applications. This study, therefore, was recommended to design bridges, culverts, dams, and flood control structures for mitigating flood risk; to define flood plains and for modeling purposes; to determine the economic value of flood control projects and the effect of encroachments on the flood plains in downstream of the Kelani river basin.

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