EPH - International Journal of Mathematics and Statistics
ISSN (Online): 2208-2212
Volume 4 Issue 2 September 2018

DOI:https://doi.org/10.53555/eijms.v4i2.23

MATHEMATICAL MODELS TO FORECAST RAINFALL FOR DISASTER CONDITIONS IN SRI LANKA

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Abstract:-
Sri Lanka is an islandsituated southeast of the southern tip of the Indian sub-continent. Floods, Draughts, Landslides, and Storms are the common occurring disasters happen in Sri Lanka. Social, Environmental, Economical and Physical impacts arise due to these disasters. In order to minimize these impacts it is imperative to have earlier knowledge on possible disaster occurrences. These disasters are fully or partially connected with rainfall variation. In this background it is imperative to have a reliable forecast of rainfall.
The study was carried out for 17 districts out of 25 in the island and it attempts to assist Agriculture, Urban and Regional Infrastructure Management, Environment and Water Management of those areas to its best capability which can take early actions on flooding events and long term drought periods due to rainfall changes. In the study Numerical methods were used to find out the mathematical models of the Northeast and Southwest rainfall for upcoming years.The objective of this model is to forecast the rainfall for near future by using previous years' rainfall data.Statistical methods are the most common methods using for rainfall forecasting although the existing statistical model cannot be used for feeding different data sets. Mathematical methods can be used to forecast annual rainfall as well as monthly rainfall even though statistical methods can be used to forecast either annual rainfall or monthly rainfall.
Polonnaruwa and Batticaloa districts shows the highest monthly rainfall variation and Hambantota and Mannar shows the lowest in 2014 and same in forecasted monthly rainfall in 2015. Kegalle district shows the highest mean annual rainfall in 2015, it has an increasing rainfall trend while Hambantota being the lowest as per the model and they also have slightly increasing rainfall trend. By using these findings people and authorized agenesis can take pre disaster responses beforehand.

Key words:-*Agriculture; Urban and regional management; Environment; Water Management; Floods*

1. INTRODUCTION

Sri Lanka is an island in the northern Indian Ocean situated southeast of the southern tip of the Indian sub-continent. The highlands, mostly 300 meters above sea level, occupy the South Central part of the island, and they are surrounded by an extensive lowland area. Two wind regions seasonally influence the island rainfall. The Southwest Monsoon (Summer Monsoon) is from May to September and the Northeast Monsoon (Winter Monsoon) from December to February. The inter-monsoonal periods, which are the transitional period between the two monsoons, are from March to April (First Inter-Monsoon) and from October to November (Second Inter-Monsoon). Rainfall during inter-monsoonal seasons is mainly due to thunderstorm activity.

This study is based on the Northeast rainfall and Southwest rainfall as the variability changes in rainfall seasons. The average annual rainfall in Sri Lanka is 1855mm. Out of which 29.5% is received during the Southwest monsoon and 25.4% during the Northeast monsoon while 14.8% occur during the first inter monsoon and 30.3% during the second inter monsoon. Northern and eastern parts of the Sri Lanka are a highly exposed area for the Northeast monsoon.The study was planned to be carried out for Whole Island though 17 districts were selected out 25 districts due to unavailability of data. These 17 districts cover all 9 provinces in country. Nuwaraeliya, Anuradhapura, Polonnaruwa, Jaffna, Mannar, Vavunniya, Trincomalee, Batticaloa, Puttalam, Kurunegala, Galle, Hambantota, Badulla, Monaragala, Ratnapura, Kegalle and Colombo districts were selected. In Sri Lanka agriculture is the dominant livelihood method that directly depends on quantity of the rainfall. Also In this context reliable forecasting of rainfall is essential for them to plan their agricultural activities. Fishery is one of main occupation type especially in coastal Sri Lanka which gets significant impact with changers of weather. Sri Lanka is also vulnerable to natural disasters such as Floods, Droughts, Landslides, and Storms etc. due to climate change and those natural disasters bring death and cause devastating losses to properties, infrastructures that make huge impact on country economy. This study further attempts to assist the water management system of those areas as well as infrastructure management. The water managers and engineers will be benefited from this model as they can plan their monthly and annual activities with prior knowledge.

Main objective is to develop suitable mathematical models to forecast the Northeast and Southwest rainfall for the upcoming years. Statistical methods are the most common methods using for rainfall forecasting although the existing statistical model cannot be used for feeding different data sets. Mathematical methods can be used to forecast annual rainfall as well as monthly rainfall even though statistical methods can be used to forecast either annual rainfall or monthly rainfall. For this study two interpolation methods in Numerical analysis were used. They are Lagrange interpolation method and Spline interpolation method.

2. Literature Survey

2.1 Natural Disaster Vulnerability

Floods mostly due to monsoonal rain or effects of low pressure systems and droughts due to failure of monsoonal rain are the most common hazards experienced in Sri Lanka. Sri Lanka is also prone to hazards such as landslides, lightning strikes, coastal erosion, epidemics and effects of environmental pollution. Based on information available on the number of events of natural disasters during the period of 1974-2008 (figure 2), it can be clearly identified floods, and landslides are most common natural disasters in Sri Lanka. According to Sri Lanka National report on Disaster Risk Poverty and Human Development Relationship 2009, the seasonal distribution of disasters shows two peaks; one from April to June and the other from October to December, representing the two monsoon seasons (Figure 3).

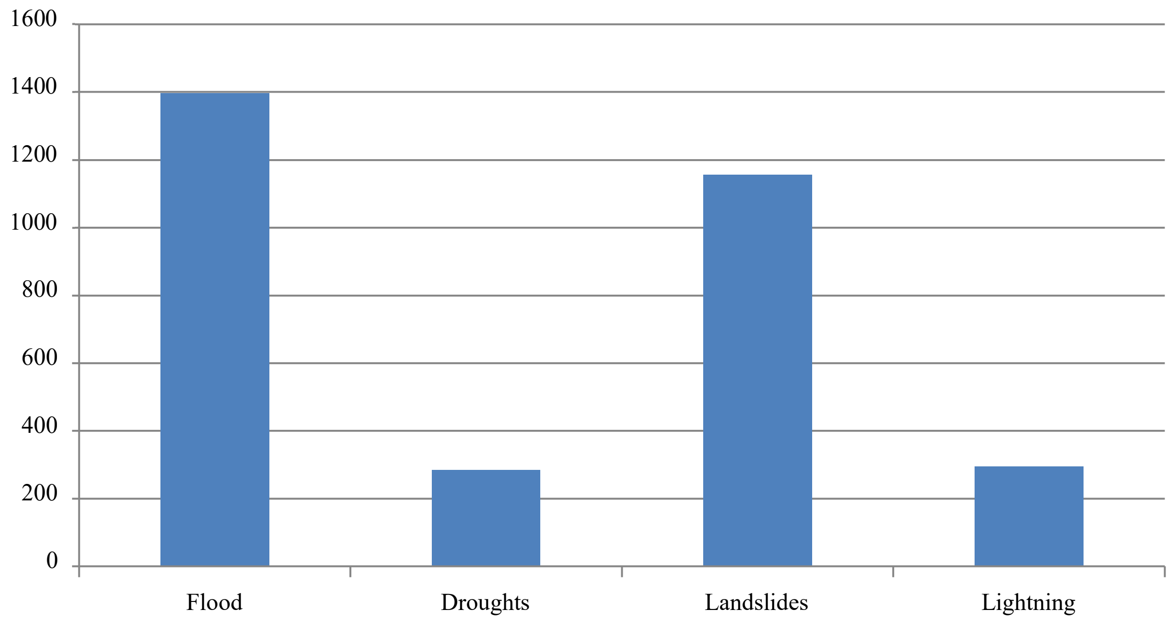

Fig 2. Number of Natural Disaster events during year 1974 to 2008 in Sri Lanka

Source: Prepared by Author based on Sri Lanka National report on Disaster Risk Poverty and Human Development Relationship report.

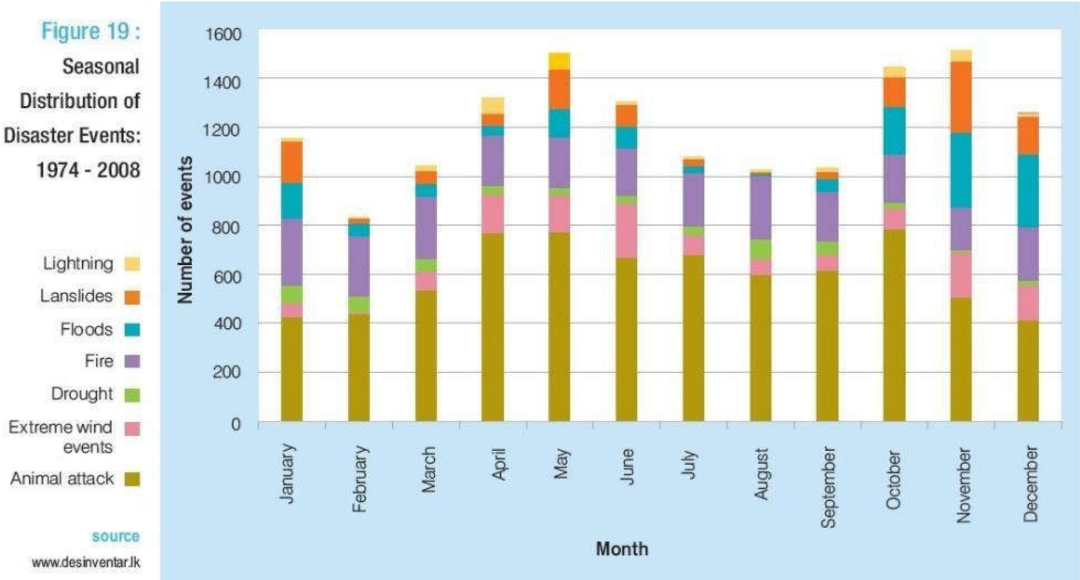

Fig.3 Seasonal distribution of disaster events 1974 – 2008

Source: Sri Lanka Disaster Profile

Sri Lanka National report on Disaster Risk Poverty and Human Development Relationship report shows that in the past 34 years, 28 million people were affected by natural disasters. About 92% of the people affected by disaster are either affected by floods (48%) or droughts (44%) without taking into consideration the Tsunami disaster in year 2004.

According to Table 1, flooding shows the most significant impact on deaths, houses and agricultural losses while droughts been the major impact on agricultural losses. Table 2 shows the most vulnerable districts for particular disaster type.

Table 1. Profile of Number of deaths, Houses destroyed and Agricultural Losses due to Disasters in Sri Lanka during year 1974-2008

Natural Disaster	Deaths	Houses destroyed	Agricultural Losses
Extreme Wind	27%	44.60%	0.18%
Landslides	25%		
Animal Attack	25%		
Flood	12%	51.32%	39.32%
Lightning	8%		
Fire	2%		2.89%
Droughts			52.89%

Source: Sri Lanka National report on Disaster Risk Poverty and Human Development Relationship report.

Table 2. Most affected disasters due to rainfall and its variation and prone districts in Sri Lanka

Floods		Landslides	Droughts
Southwest Monsoon	Northeast Monsoon		
Colombo,	Trincomalee,	Badulla	Hambantota
Ratnapura,	Polonnaruwa,	Ratnapura	Mannar
Kalutara,	Monaragala	Kegalle	Puttalam.
Kegalle,	Batticaloa,	Kandy	
Gampaha	Badulla,	NuwaraEliya	
Galle	Ampara,	Matale	
	Matale		

Source: Sri Lanka Disaster Knowledge Network

2.2 Some of most significant natural disaster events occurred recent past in Sri Lanka due to rainfall

In year 2010 November the capital city of Sri Lanka, Colombo was flooded due to heavy rain. According to the Disaster Management Centre 260,109 people from 57,920 families have been affected so far and 11 houses have been completely damaged and 257 houses have been partially damaged. The worst affected was Colombo district with 216,382 people

being displaced. The heavy rains and floods have disrupted the power supply to the city and transportation has come to a standstill due to streets submerged with few feet of water.
In October 2014, a landslide struck the Sri Lanka district of Badulla, killing at least 16 people and leaving an estimated 200 missing. The landslide occurred in a hilly region, hitting the village of Koslanda in Haldummulla division, 190 kilometers from the capital, Colombo. The landslide was triggered by monsoon rains and was about 3 kilometers long. Physical damage caused by the slide included some 150 houses buried as well as several road and railroad washouts.

2.3 *Past Rainfall Forecasting Models*

An innovative technique is utilized for rainfall forecasting using Artificial Neural Networks based onfeed-forward back-propagation architecture. Both short term and long term forecasting was attempted for groundlevel data collected by the meteorological station in Colombo, Sri Lanka., (Perera, Sonnadara and Jayewardene, 2002).Three Neural Network models were developed by Kumarasiri and Sonnadara in 2006; a one-day-ahead model for predicting the rainfalloccurrence of the next day, which was able to make predictions with a 74.25% accuracy, and two long term forecasting models for monthly and yearly rainfall depth predictions with 58.33% and76.67% accuracies within a 5% uncertainty level.There are some studies todevelop a rainfall forecasting model for Sri Lanka using Artificial Feed-Forward Neural Network (Dharmaratne and Premarathna,2004) and some methods were found out to forecast rainfall from Multiple Point Sources using Neural Networks (James and Raymond, 1999). The strategy for high-resolution forecasting was to use LimitedArea Models (LAM), three dimensional models of the atmospheric dynamics. The strength ofthese models were their ability to resolve surface forcing such as Orography, vegetation andconvective dynamics at scales not yet feasible in General Circulation Models (GCM). Inparticular, LAM includes the non-hydrostatic dynamics that govern intense convectivesystems like thunderstorms (Goswami, Rakesh, Patra and Prakash, 2010) and Hybrid Arima–Ann Model was used to forecastTamilNadu rainfall by Mahalakshmi, Umarani and SamuelSelvaraj in 2014.

All presented literature were statistical models used for a particular data set. These models are very rigid and need to be created repeatedly for new data sets, which can be observed as a limitation of these Statistical models. Even thoughStatistical methods are the most common methods using for rainfall forecasting, the existing statistical model cannot be used for feeding different data sets. Mathematical models can be used to forecast annual rainfall as well as monthly rainfall even though statistical methods can be used to forecast either annual rainfall or monthly rainfall.

3. Methodology

In this study the Northeast and Southwest monsoons are considered. Northeast and Southwest rainfall data for the 14-year period from 2000-2014 were collected by 316 meteorological stations scattered through the Island. Missing values of this series of data are few, 12% and some replaced by using the long-term mean value and some were deleted. Nuwaraeliya, Anuradhapura, Polonnaruwa, Jaffna, Mannar, Vavunniya, Trincomalee, Batticaloa, Puttalam, Kurunegala, Galle, Hambantota, Badulla, Monaragala, Ratnapura, Kegalle and Colombo districts were selected. All these districts receive either northeast monsoon rainfall or southwest monsoon rainfall. However at times some districts acquire rain from both monsoons while some districts do not acquire from either of monsoons.
According to the literature review, development of a rainfall forecasting models were done by using Artificial intelligence techniques, neural network and Arima model and very few mathematical forecasting models were found for this purpose. Therefore, several mathematical forecasting models using numerical methods were tested. They are Linear interpolation, Quadratic interpolation, Lagrange interpolation, Hermite interpolation and Spline interpolation. After comparing the accuracy of the estimates from above interpolation methods, two methods were found more reliable and suitable for this study. Hence Lagrange interpolation method and Spline interpolation method were used to develop mathematical models to estimate the rainfall.
Lagrange polynomials are used for polynomial interpolation. The interpolating polynomial of the least degree is unique. Lagrange interpolation is susceptible to Runge's phenomenon, which is a problem of oscillation at the edges of an interval that occurs when using polynomial interpolation with polynomials of high degree over a set of equally spaced interpolation points. The fact that changing the interpolation points requires recalculating the entire interpolant can make polynomials easier to use. The Lagrange form of the interpolation polynomial shows the linear character of polynomial interpolation and the uniqueness of the interpolation polynomial.
However each time a data changes, all Lagrange basis polynomials have to be recalculated.
Spline interpolation is often preferred over polynomial interpolation because the interpolation error can be made small even when using low degree polynomials for the Spline. Spline interpolation avoids the problem of Runge's phenomenon, in which oscillation can occur between points when interpolating using high degree polynomials. Lagrange and Spline interpolation at equally spaced points, yield a polynomial oscillating above and below the true function. This behavior tends to grow with the number of points, leading to a divergence.

4. Analysis

Using the two interpolation methods (Lagrange and Spline), the mathematical models were developed to estimate the rainfall for selected 17 districts for the near future.The divided difference tables for Lagrange and Spline interpolations were used, as it considers more appropriate for developing mathematical model for rainfall.,Fomenko (1993).
Lagrange interpolation method and Spline interpolation method were used to develop mathematical models for 14, 10, 8, 6 and 5 year periods for Colombo district. When considering the percentage differences between actual and forecasted

values for both interpolation methods (Table 3) 5 year period gives the lowest percentage difference that is more reliable. Therefore only most recent 5 year period was used for the further analysis of all selected districts.

Table 3. Comparison of calculated data for differenttime periods, with actual data using Lagrange and Spline interpolation methods for Colombo District

	Lagrange interpolation method			Spline interpolation method		
	Rainfall in 2014(mm)	Difference (mm)	Percentage difference (%)	Rainfall in 2014(mm)	Difference (mm)	Percentage Difference (%)
Actual rainfall	2635.00			2635.00		
Calculated rainfall by using 5 years rainfall data (2010 - 2014)	2720.38	85.38	**3.24**	2534.43	100.57	**3.82**
Calculated rainfall by using 6 years rainfall data (2009 - 2014)	2900.15	165.15	10.06	2321.20	313.80	11.91
Calculated rainfall by using 8 years rainfall data (2007 - 2014)	2997.15	362.15	13.74	2287.92	347.08	13.17
Calculated rainfall by using 10 years rainfall data (2005 - 2014)	3102.51	467.51	17.74	2168.51	466.49	17.70
Calculated rainfall by using 14 years rainfall data (2001 - 2014)	3317.82	682.82	25.91	1977.70	657.30	24.94

When considering forecasted rainfall by using Lagrange method it can be seen that the values are higher than the actual value giving an over estimation. In case of forecasting rainfall using Spline method, it gives lower estimation values than actual value. The average value from both estimated values for a particular year was examined and it gives a closer value to the actual rainfall. Therefore we used average value as the measurement for the study.
As an example, the estimated value for Colombo district in 2015 obtained from Lagrange interpolation method is a, that of obtained from Spline interpolation methods is b; The final forecasted value for Colombo district in 2015 (r) calculated as follows.

$$r = \frac{a+b}{2}$$

When comparing the actual values and the average values of the above two interpolation methods for all 17 districtsthe percentage differences are considerably small (Table 4). According to the results Kegalle district can expect highest rainfall and Hambantota can expect the lowest rainfall for 2015.

Table 4. Annual actual and forecasted rainfall values for 2014 and 2015

Province	District	Actual Rainfall (mm)	Final forecasted value 2014 (mm)	Percentage Deviation (%)	Final forecasted value 2015 (mm)
Central	NuwaraEliya	1857.70	1835.51	1.19	1728.45
North Central	Anuradhapura	2483.50	2560.51	3.10	2518.29
	Polonnaruwa	2642.40	2673.95	1.19	2662.59
Northern	Jaffna	1368.60	1404.87	2.65	1420.01
	Mannar	1052.50	1064.21	1.11	1104.50
	Vavuniya	2106.00	2114.63	0.41	2117.43
Eastern	Trincomalee	1691.50	1671.48	1.18	1585.54
	Batticaloa	2518.30	2545.04	1.06	2547.91
North Western	Puttalam	1696.60	1659.25	2.20	1424.90
	Kurunegala	2737.40	2778.72	1.51	2813.02
Southern	Galle	2677.70	2705.41	1.03	2745.92
	Hambantota	1095.70	1081.90	1.26	1075.42
Uva	Badulla	2164.40	2109.70	2.53	2138.91
	Moneragala	1852.90	1849.17	0.20	1850.21
Sabaragamuwa	Ratnapura	4710.60	4796.76	1.83	4783.53
	Kegalle	5112.20	5076.02	0.71	5142.94
Western	Colombo	2635.00	2656.40	0.81	2672.89

When we take the monthly forecasted rainfall (Table 5) the highest rainfall period for all districts is October to December and the minimum being June to August period and the month of February for some districts for year 2015. In case of actual values it can be seen that highest period being October to December and some variation from forecasted values as minimum was seen in June for majority of districts. In actual and forecasted rainfall values maximum rainfall occurred in December for most of the districts.

Table 5. 2014 2015 2014 2015

Province	District	Month of maxim u m rainfall	Actu al rainf a ll (mm)	Foreca st ed rainfall (mm)	Pecent a ge deviati o n	Month of maxim u m rainfall	Foreca st ed rainfall	Month of minim u m rainfal l	Actu al rainf all (mm)	Foreca st ed rainfall (mm)	Pecent a ge deviati o n	Month of minim u m rainfal l	Foreca st ed rainfall (mm)
Central	NuwaraEl iy a	Decem b er	438. 4	445.3	1.57	Novem b er	405.2	Febru a ry	8.12	7.61	6.28	Febru a ry	85.32
North Central	Anuradha p ura	Decem b er	666. 3	623.2	6.47	Octobe r	514.4	June	1.44	1.58	9.72	July	3.17
	Polonnaru w a	Decem b er	1129 . 6	1102.9	2.36	Decem b er	1104.6	July	21.5 0	21.82	1.49	June	28.51
Northern	Jaffna	Novem b er	496. 4	515.7	3.89	Decem b er	364.8	July	1.61	1.53	4.97	July	11.51
	Mannar	Decem b er	352. 9	374.9	6.23	Decem b er	301.1	June	0.39	0.37	5.13	July	4.23
	Vavuniya	Decem b er	469. 0	483.5	3.09	Novem b er	327.5	June	0.47	0.45	4.26	June	5.64
Eastern	Trincomal e e	Decem b er	532. 3	504.8	5.17	Novem b er	485.3	April	1.63	1.67	2.45	June	18.32
	Batticaloa	Decem b er	1164 . 2	1098.6	5.63	Decem b er	899.6	June	4.28	4.08	4.67	Augus t	6.49
North Western	Puttalam	Decem b er	472. 8	432.1	8.61	Octobe r	290.2	June	15.4 7	15.46	0.06	June	14.58
	Kurunegal a	Decem b er	584. 1	602.4	3.13	Octobe r	375.9	Febru a ry	5.15	5.03	2.33	Febru a ry	63.75
Southern	Galle	Octobe r	479. 6	490.2	2.21	Octobe r	393.0	Febru a ry	42.9 5	43.53	1.35	Febru a ry	51.62
	Hambanto t a	Novem b er	205. 4	221.6	7.89	Decem b er	321.9	July	5.71	5.42	5.08	June	15.57
Uva	Badulla	Decem b er	669. 5	643.1	3.94	Decem b er	471.8	June	2.74	2.94	7.30	June	21.77
	Moneraga la	Decem b er	450. 4	424.5	5.75	Decem b er	233.4	June	0.59	0.57	3.39	June	6.20
Sabaraga mu wa	Ratnapura	Octobe r	813. 0	820.9	0.97	Novem b er	453.5	Febru a ry	76.8 8	81.25	5.68	Febru a ry	93.34
	Kegalle	Octobe r	348. 3	364.7	4.71	Octobe r	285.7	Febru a ry	24.8 9	26.49	6.45	Febru a ry	64.73
Western	Coombo	Decem b er	476. 5	438.4	8.00	Decem b er	398.1	Febru a ry	19.5 0	17.91	8.15	Febru a ry	26.40

5. Conclusion

Statistical methods are the most common methods using for rainfall forecasting although the existing statistical model cannot be used for feeding different data sets. These models are very rigid and need to be created repeatedly for new data sets, which can be observed as a limitation of these Statistical models. Mathematical methods on the other hand can be used to forecast annual rainfall as well as monthly rainfall even though statistical methods can be used to forecast either annual rainfall or monthly rainfall. Most reliable value is average value of spline and lagrange forecasted values since it has the least percentage error. By using most recent data for the analysis gives more accurate values rather than using long term back dated data. By using least error results, the rainfall forecasting becomes more reliable in decision making in Agricultural sector, Disaster resiliency, Water and other infrastructure management and other related disciplines.

Acknowledgements
We are deeply indebted to The Director, Assistant Director and Staff of Meteorological department, Sri Lanka for providing data and other information. We appreciate the cooperation received from the staff of the Department of Civil Engineering, University of Moratuwa.

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