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Analysis of Statistical Downscaling Model (SDSM) projected future rainfall in Northwestern, Western and Southern provinces of Sri Lanka

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Abstract Even though an extensive amount of climate change studies have been carried out in different parts of the world, Sri Lanka is one of the least focused countries in this regard. Climate projections are important and encouraged to manage the futuristic adverse impacts. Identifying this research gap, future rainfall projections were carried out in three provinces in Sri Lanka, i.e. Northwestern (Puttalam and Kurunegala), Western (Katunayake and Colombo), and Southern province (Galle and Hambantota). The Canadian Earth System Model (CanESM2) under the Representation Concentration Pathways (RCP8.5) was downscaled using the Statistical DownScaling Model (SDSM). Non-parametric tests, including Mann-Kendall (MK) test and the Sen's Slope estimator, were used to determine the significance of trends and magnitude of the slope of the historical trends (1990-2019) and future projected trends (2020-2100). The trends were analyzed for four major seasons in Sri Lanka, including First Inter-monsoon (FIM), Southwest monsoon (SWM), Second Inter-monsoon (SIM), and the Northeast monsoon (NEM). The standard error and model bias at rainfall stations were 0.014-0.034 mm and 1-1.1 respectively, which are acceptable when compared to previous studies. Several significant rainfall trends were identified, including positive trends in the mid-future (2041-2070), and negative trends in the far-future (2071-2100). In addition, rainfall indices, including Rx5day, R20mm, Consecutive dry days (CDD), and Consecutive wet days (CWD) were tested in future projected and historical rainfalls. The results of the present study will be useful for policymakers for decision-making processes in water resources management and agriculture.

Keywords: Non-parametric tests, projected rainfall, rainfall indices, rainfall trends, Statistical Down Scaling Model (SDSM).

1 Introduction

Precipitation and evapotranspiration are two of the major drivers of the hydrologic cycle. These components play an indispensable role in terrestrial climatic systems linking water, energy, and carbon cycles (Katul *et al.* 2012, Vihma *et al.* 2016). The climate of the earth has been changed drastically due to the earth's natural variability and anthropogenic activities. Increases in prolonged drought periods and erratic rainfall events are some of the changes experienced in many parts of the world (Bates *et al.* 2008, Taylor *et al.* 2013). Hence, studying the changes in the climate is of major importance for research and applications for many professions such as hydrologists, meteorologists, ecologists, hydropower planners, and environmentalists. Climate changes naturally have adverse impacts on many sectors affecting the day-to-day life of humans and all other living beings (Gunasekara *et al.* 2007, Cui *et al.* 2018, Qin *et al*. 2020). Rainfall plays an important role in the formation of natural ecosystems which thrive living beings. Moreover, rainfall projections are important in many sectors including weather forecasting, disaster preparation and management, agriculture, and hydrology. The Statistical DownScaled Model (SDSM) projected an annual increase in the average temperature of 2.83°C in the 2080s for Colombo under Representation Concentration Pathways (RCP 8.5) compared to the 1961-1990 period. The annual increase in rainfall is 33% (Dorji *et al*. 2017). From 2020 to 2100 under RCP 2.6, 4.5 and 8.5 scenarios, the future annual precipitation in the Hanwella sub-catchment of the Kelani River Basin will have variations between 2100 to 5130 mm (Dissanayake and Rajapakse 2017). Interestingly, no significant trend in Sri Lanka's mean annual rainfall (MAR) has been observed during the past century. But a higher variability is evident (Jayatillake *et al*. 2005, Chandrapala NDMC, pers. comm.)

Although atmospheric temperatures are steadily rising in many regions of the world, the direction of trends in rainfall varies with the geographic location (decreasing or increasing). For instance, the amount of rainfall received in the higher latitudes of the globe is increasing, while the rainfall is decreasing in the tropical and sub-tropical regions (Trenberth *et al.* 2007). The economy of Sri Lanka is mostly based on agriculture, hence, any such decreases will cause detrimental impacts on the agriculture sector of the country. Studies report a decreasing trend in MAR during 1961-1990 of 144 mm (7%) compared to that during 1931-1960 (Chandrapala 1996, Jayatillake *et al*. 2005). Therefore, climate change is not always global warming, but it is with many other variations. Thus, the Intergovernmental Panel on Climate Change (IPCC 2007) defines climate change as "a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer". Nevertheless, the increases in Greenhouse Gas (GHG) emissions cause intensification of the variations of the hydrologic cycle, which result in changes in water availability and the occurrence of extreme events (Simonovic and Li 2003, Jiang *et al.* 2007).

The Germanwatch Global Climate Risk Index 2020 report has ranked Sri Lanka as the sixth most-affected country due to climate change in 2018 (Eckstein *et al.* 2019).

Many of the climate change studies carried out in Sri Lanka have demonstrated a steady rise in atmospheric temperatures (Fernando and Chandrapala 1992, Chandrapala 1996, Fernando 1997, De Costa 2008). However, variations of increases and decreases in rainfall levels were observed in different parts of the country by Ratnayake and Herath (2005), Jayatillake *et al*. (2005), and Shantha and Jayasundara (2005). In addition, the prevalence of extreme events has increased in the recent past in Sri Lanka (Ratnayake and Herath 2005, Imbulana *et al.* 2006, Premalal 2009, Eriyagama and Smakhtin 2010, Esham and Garforth 2013). Furthermore, droughts have been prevalent in the Mahaweli River Basin, the largest river basin in Sri Lanka in recent decades (Withanachchi *et al.* 2014). However, it should be noted that El-Nino Southern Oscillation (ENSO) also causes variations in rainfall in Sri Lanka (Malmgren *et al.* 2003). Hence, besides anthropogenic reasons, ENSO can also affect the regional climates. Sumathipala and Punyadeva (1998) and Punyawardena and Cherry (1999) reported correlations between the Southern Oscillation (SO) phenomenon and the seasonal rainfall of Sri Lanka. Premalal (2013) observed a trend for below normal rainfall for the southwest monsoon season (May-September) during El Nino event, while the trend is above normal during the second inter-monsoon (October-November).

Climate change significantly impacts agriculture. Agriculture is the main employment sector, of which nearly 30% of the country's population is engaged in Sri Lanka. This usually creates 7.8% of the Gross Domestic Product (GDP) of the country (Ministry of Agriculture 2018). However, it should be noted that most of the agriculture in the dry zone is on irrigated water. Hence, the changes and variabilities of the rainfall with prolonged drought periods and rainfall deficiencies will affect crop production on a greater scale (Ministry of Environment Sri Lanka 2011). On top of that, the hydropower sector, which is the clean energy sector contributes a large proportion of the country's energy generation. Nevertheless, De Costa *et al.* (2012) have pointed out that studies carried out in Sri Lanka in the context of climate change using readily available global and regional climate models are still lacking.

Global Climate Models (GCMs) and Regional Climate Models (RCMs) have been extensively used for the projection of future climate in different regions of the world (Jha *et al.* 2006, Agarwal *et al.* 2015). RCMs are preferred over GCMs due to the accuracy in simulating regional climates and topographic features due to the higher resolution (Sharannya *et al.* 2018). However, caveats are still seen in RCMs due to internal climate variability, imperfect conceptualization, etc. in model structures of climate models (Teutschbein and Seibert 2010). Since bias and model uncertainties are engaged in downscaling climate models, bias correction should be performed to reduce them. Bias correction methods such as linear scaling, quantile mapping, and power transformation are some of the most commonly adopted bias correction methods in literature (Chen *et al.* 2013). In addition to statistical downscaling, dynamic downscaling methods are also available in the research world. However, dynamic downscaling methods require significant computational capacities; thus, scientists prefer linear scaling for statistical downscaling. Among them (linear scaling), the

Statistical DownScaling Model (SDSM) model is a prominent tool. The availability in the public domain is one of the attractive features of the SDSM model.

Although extensive research has been carried out with downscaling of GCMs using the SDSM model for climate change studies in the rest of the world, a few research could be found within Sri Lanka. According to the best understanding of the authors' of this paper, Dorji *et al.* (2017), Imbulana *et al.* (2018), Bandara and Weerakoon (2020), Khalid *et al.* (2017), Muhinadeen *et al.* (2016), De Silva (2006), Shantha and Jayasundara (2005), De Silva (2007), Herath *et al.* (2016), Nandalal *et al.* (2012), Basnayake and Vithanage (2004) and Basnayake *et al.* (2004) have projected future rainfall in different regions of Sri Lanka based on climate models (i.e. using GCMs, RCMs and Weather Research Forecasting (WRF) and SDSM). Ratnayake *et al.* (2010), De Silva *et al.* (2012) and De Silva *et al.* (2016) have projected future rainfall in Sri Lanka by WRF and SDSM models and drove in hydrologic and hydraulic models to forecast flood inundation. In addition to these studies, RCM projections in conjunction with Artificial Neural Networks (ANNs) have been used for rainfall forecasting (Nagahamulla *et al.* 2011, Nagahamulla *et al.* 2014), future hydropower projection (Khaniya *et al.* 2020), future reservoir inflow prediction (Karunanayake *et al.* 2020), etc. in Sri Lanka. Dharmarathna *et al.* (2012) have also predicted future paddy production in the Kurunegala district using the Decision Support System for Agrotechnology Transfer (DSSAT) model with climate inputs from the SDSM model. In addition, it is noteworthy to state, Dantanarayana *et al.* (2021) have used Numerical Weather Prediction Models (NWP) to newscast rainfall in the Colombo area. Not only the rainfalls but also the future temperatures were also projected using RCM and GCMs (Basnayake *et al.* 2004, Jayatillake 2004). However, more importantly, only Dissanayake and Rajapakse (2019) have examined the impact of future climate on streamflow.

The northwestern province of Sri Lanka contributes a significant share for the paddy cultivation of Sri Lanka. Since paddy cultivated through rainfed water, understanding the future water resource availability is of paramount importance. It is of major importance to understand the future rainfall in Colombo, the major economic city of the country. In addition, no research has been carried out to analyze and identify the future climatic trends in north-western and southern provinces in Sri Lanka in detail. Therefore, this study for the first time in Sri Lanka presents the past and future rainfall trends in northwestern, and southern provinces in Sri Lanka. The rainfall trends were examined in different time scales, including monthly, seasonal, and annual scales. The future rainfall data were projected and downscaled using the publicly available Statistical DownScaling Model (SDSM). Canadian Earth System Model (CanESM2), Global Climate Model (GCM) under Representation Concentration Pathways (RCP8.5) were downscaled using the Statistical DownScaling Model (SDSM) at six rainfall gauging stations. The understanding of the future availability of water resources is imperative to crop management, design of water storage, and flood mitigation measures.

2 Materials and Methods

2.1 Study area

Sri Lanka is surrounded by the Indian Ocean, and it has a geographical area of 65625 km^2 (Sarathchandra *et al*. 2021). It is located in the tropical region of the Earth, in between longitudes 79°E and 82°E and latitudes 5°N and 10°N. Depending on the rainfall received, the country is mainly divided into four climatic zones namely the wet zone, intermediate zone, dry zone, and semi-arid zone (Alahacoon and Edirisinghe 2021). According to the climate classification, the main areas like Colombo, Katunayake, and Galle are in the wet zone, while Hambantota and Puttalam are in the semi-arid zone. However, Kurunegala is in the intermediate climatic zone (Figure 1).

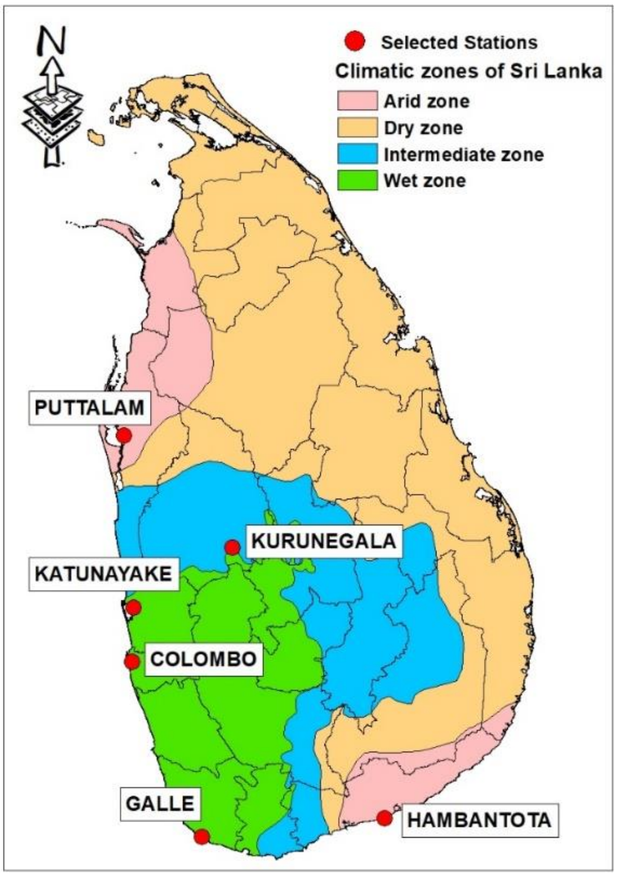


Fig 1. Selected stations in the current study

The monsoon winds bring most of the precipitation to Sri Lanka. Therefore, the rainy seasons are based on the monsoons. The first inter-monsoon (FIM) occurs from March to April and the second inter-monsoon (SIM) occurs from October to November, while December to February constitutes the northeastern monsoon (NEM), and the southwestern monsoon (SWM) occurs from May to September (Thambyahpillay 1954, Wickramagamage 2010). Therefore, the country has a rich rainfall throughout the year in most of the parts. The mean annual rainfall can be as high as 5500 mm for some places (e.g., Watawala and Kenilworth) on exposed southwest windward slopes at elevations between 1000 and 1300 m. The mean annual rainfall reaches amounts in between 800 and 1200 mm (Malmgren *et al*. 2003) to some of the areas in the southeast and northwest of the country. In addition, the average yearly temperature for the country ranges from 26°C to 28°C. Day and night temperatures may vary by 4°C to 7°C (De Silva 2006). In order to assess all these climatic regions of the country, several areas, including Puttalam, Kurunegala, Katunayake, Colombo, Galle, and Hambantota, were considered for this research. These selected stations for this study are given in Figure 1.

2.2 Observed rainfall data

Rainfall data from six meteorological stations located in north-western (Kurunegala and Puttalam), western (Colombo and Katunayake), and southern provinces (Galle and Hambantota) were used in this study. Observed daily rainfall data were purchased from the Department of Meteorology, Sri Lanka for 30 years (1990 to 2019). The station ID, name, coordinates, elevation of these stations are listed in Table 1. The obtained rainfall had missing data of less than 3%. Hence, the nearest neighbor method was used to fill the missing days of these stations.

Table 1: Stations selected for the study

Station ID	Station name	Coordinates (E, N)	Elevation (m above mean sea level)
43424	Puttalam	(79.83, 8.03)	2
43441	Kurunegala	(80.37, 7.47)	116
43450	Katunayake	(79.88, 7.17)	8
43466	Colombo	(79.87, 6.90)	7
43495	Galle	(80.22, 6.03)	12
43497	Hambantota	(81.13, 6.12)	16

2.3 GCM rainfall data

The second-generation Canadian Earth System Model (CanEMS2) was used in this study. The CanESM2 couples together an atmosphere-ocean general circulation model, a land-vegetation model, and five terrestrial and oceanic interactive carbon cycle

(Chylek *et al*. 2011). The CanESM2 can be used directly in the Statistical DownScaling Model (SDSM) since it comprises predictor variables on a daily scale. More information on CanEMS2 can be found in https://open.canada.ca/data/en/dataset/aa7b6823-fd1e-49ff-a6fb-68076a4a477c. Therefore, CanESM2 rainfalls under the Representative Concentration Pathways 8.5 (RCP8.5) were used in future climate projections. The stations showcased in table 1 were used as the locations for the data points.

2.4 NCEP/NCAR Reanalysis data

The NCEP/NCAR Reanalysis 1 project uses a state-of-the-art analysis and forecast system to perform data assimilation using past data from 1948 to date. These data are produced by the National Oceanic and Atmospheric Administration’s (NOAAs) Physical Sciences Laboratory. National Centers for Environmental Prediction (NCEP) predictor variables were used for model calibration and validation. The NCEP data were extracted for the period of 30 years from 1990 to 2019 in this study. Detailed information on NCEP data is available through https://psl.noaa.gov/.

2.5 Statistical methods and models

Mann-Kendall test

Mann-Kendal trend test (Mann 1945) is a widely used non-parametric test to determine the significance of trends in meteorological variables including rainfall, temperature, humidity, etc., and hydrologic variables such as streamflow (Khattak *et al*. 2011, Dashkhuu *et al.* 2015). No specific assumption is required for data distribution to apply the MK test (Kundzewicz and Robson 2000). The test has been widely used to detect the strength of trends in many regions of the world (Dumitrescu *et al*. 2015, Rathnayake 2019, Ruwangika *et al.* 2020, Perera and Rathnayake 2019). Equations 1 – 4 present the mathematical formulations for the Mann-Kendall test.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(x_j - x_i) \tag{1}$$

where x_j and x_i are time series values in climate data and n is number of data points and the S is the test statistics. The “sgn” function is given as the following equation.

$$\mathrm{sgn}(x_j - x_i) = \begin{cases} +1, & > (x_j - x_i), \\ 0, & = (x_j - x_i), \\ -1, & < (x_j - x_i). \end{cases} \tag{2}$$

The variation of Mann-Kendall statistics S is given by the equation 3.

$$\mathrm{Var(S)} = \frac{\mathrm{n(n-1)(2n+5)} - \sum_{\mathrm{i=1}}^{\mathrm{m}} \mathrm{t_i(i)(i-1)(2i+5)}}{18} \quad (3)$$

where $\mathrm{t_i}$ is the number of ties up to sample i. The Mann-Kendall statistics $\mathrm{Z_c}$ is given by the Equation 4.

$$\mathrm{Z_c} = \begin{cases} \frac{\mathrm{s-1}}{\sqrt{\mathrm{Var(S)}}}, & \mathrm{S > 0,} \\ 0, & \mathrm{S = 0,} \\ \frac{\mathrm{S+1}}{\sqrt{\mathrm{Var(S)}}}, & \mathrm{S < 0.} \end{cases} \quad (4)$$

The alpha value of the Mann-Kendall test was varied until a trend in the variables was detected. When the calculated p value is smaller than the alpha value, then, the null hypothesis is accepted.

Sen's slope estimator

The detected climatic trend from the Mann-Kendall test is usually quantified by the Sen's slope estimator test (Sen 1968). The governing equations for Sen's slope estimator are given by Equations 5 – 6. The Slope $\mathrm{T_i}$ for all data pairs given as Equation 5.

$$\mathrm{T_i} = \frac{\mathrm{x_j - x_k}}{\mathrm{j - k}} \quad (5)$$

And the Sen's slope estimator ($\mathrm{Q_i}$) is given as the Equation 6.

$$\mathrm{Q_i} = \begin{cases} \mathrm{T_{(n+1)/2}}, & \text{n is odd,} \\ \frac{1}{2}\left(\mathrm{T_{\frac{n}{2}}} + \mathrm{T_{\frac{n+2}{2}}}\right), & \text{n is even.} \end{cases} \quad (6)$$

RClimDex computer software

RClimDex was produced in the National Climate Data Center (NCDA) of NOAA by Byron Gleason in 2001 for the calculation of extreme climatic indices (Zhang and Yang 2004). RClimDex 1.0 version was used for this study. The 27 core indices, suggested by the Commission for Climatology (CCl)/Climate Variability and Predictability Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI) can be calculated using this computer software. These 27 indices include 16 temperature and 11 precipitation related indices. RClimDex requires R1.84 or a later version for the execution of the program (downloadable at http://etccdi.pacificclimate.org/software.shtml).

2.6 Overall methodology

The future climate (rainfall) predictions were carried out using the SDSM 4.2 version, which was developed by Wilby *et al.* (2002). This comprises a multiple linear regression model (MLR) and a stochastic weather generation model (SWG). The main processes of the SDSM model comprise screening of variables, calibration and validation of the model, and future climate prediction (this model is available to be downloaded from https://sdsm.org.uk/software.html). The stepwise procedure of SDSM is explained in detail in the SDSM manual and Hussain *et al.* (2015). The stepwise development of the SDSM model is described below.

First, the quality of the collected data sets was checked. This is to ensure that missing rainfall values are not presented in the input data sets. The data were also run to check the homogeneity using widely used homogeneity test (standard normal homogeneity test (SNHT), Buishand range test, Pettitt test, and von Neumann ratio tests) and found out that the data are in good quality. Then, the most sensible relationship between large-scale climate variables (NCEP climatic data) and local scale climatic variables (rain gauge data) was identified. The strength of this relationship was determined through two statistical indicators, the significance level ($\boldsymbol{p}$) and the partial correlation ($\boldsymbol{r}$). Thus, the strongest relationship can be determined among 26 predictor variables. The strongest variable has $\boldsymbol{p}$ values closer to 0 and $\boldsymbol{r}$ values closer to 1.

Next, the model calibration and validation were carried out by comparing the performance of simulated rainfall (*from NCEP data through the SDSM model*) against observed rainfall data. This is usually compared through several statistical indicators including Coefficient of determination ($\mathbf{R^2}$), and Nash-Sutcliffe Efficiency ($\mathbf{NSE}$). The collected 30 years of data were divided into two parts. The first 20 years (2/3rd, 1990-2008) of data were used for calibration of the model and the next 10 years (1/3rd, 2009-2019) of data were used for validation.

Finally, the CanESM climate model was used to project the climate from the years 2020 to 2100 for the northwestern, western, and southern provinces of Sri Lanka. The future rainfalls from 2020 to 2100 were generated. RCP8.5 was selected for future climate prediction in the CanESM model for future rainfall data. RCP 8.5 scenario represents the extreme case of future climate. The developed rainfall data were then processed to identify the future rainfall trends using non-parametric tests, like Mann-Kendall (MK) test and Sen's slope estimator. MK test and Sen's Slope method, which have been frequently adopted to examine the significance of the trends and magnitude of the trends present in the hydro-meteorological variables (Khattak *et al*. 2011). The tests were carried out on the monthly, seasonal and annual scales.

In addition, the observed and project rainfalls were tested for rainfall indices, including Rx5days (5-day maximum precipitation), R20mm (number of very heavy precipitation days), CDD (consecutive dry days), and CWD (consecutive wet days). The Rx5days index is a measure of heavy precipitation, while the R20mm index gives a similar meaning to heavy rainfalls. CDD and CWD are two contrasting indices for the consecutive dry and wet days. The strength of these indices was tested based on the statistical p-value. Very Strong (VS) index can be seen for $0 < p \leq 0.05$ and Strong (S) index can be observed for $0.05 < p \leq 0.1$. It should be noted that the more the p-value is the weaker the indices. A similar classification for the p value can be found in Khattak *et al.* (2011).

3 Results and Discussion

3.1 Development of the Statistical Downscaling Model (SDSM)

As it was stated in section 2, the selection of a suitable predictor variable for calibration is the first step in SDSM model development. The selected predictor variables are listed in Table 2 with corresponding $\boldsymbol{p}$ and $\boldsymbol{r}$ values. Among the 26 predictor variables in the SDSM model, the "**P*p1_fgl** (*1000 hPa wind speed*)" was found to be the dominating predictor, while "P*p8_zgl (*850 hPa relative vorticity of true wind*)" and "P*p1zhgl (*1000 hPa divergence of true wind*)" were ranked second and third most strong predictor variables, respectively.

Table 2: Details of selected predictor variables.

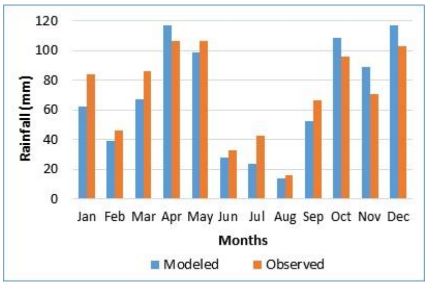
Station	Predictors	$\boldsymbol{p}$-value	Partial $\boldsymbol{r}$
Puttalam	P*p8_zgl.dat	0.0202	0.053
	P*p1zhgl.dat	0.2463	-0.026
Kurunegala	P*p1_fgl.dat	0.0007	-0.060
	P*s850gl.dat	0.0326	0.039
Katunayake	P*p1_fgl.dat	0.0928	-0.031
	P*p8_zgl.dat	0.1028	0.030
Colombo	P*p8_fgl.dat	0.0033	-0.050
	P*p5_fgl.dat	0.0221	0.040
Galle	P*shumgl.dat	0.0083	0.043
	P*p1_fgl.dat	0.0090	-0.042
Hambantota	P*p1_vgl.dat	0.0003	-0.078
	P*p1zhgl.dat	0.0130	-0.056

The model calibration and validation processes were carried out and the selected final values of variance inflation and bias correction are listed in Table 3. Not all stations required a bias correction parameter (indicated by a mean bias higher than 1) for precipitation, which involves a conditional process. Similar ranges of results for these indicators were previously obtained by Gagnon *et al.* (2005). Therefore, the model has a valid justification.

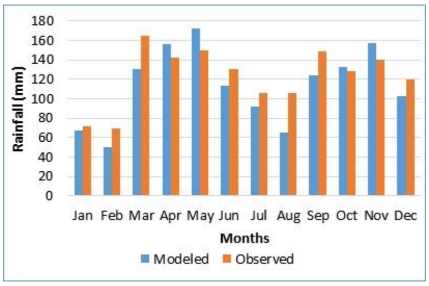
Table 3: Results of calibration procedure.

Station	Variance inflation	Standard Error (mm)	Mean bias
Puttalam	12	0.023	1
Kurunegala	14	0.019	1
Katunayake	12	0.020	1.1
Colombo	12	0.015	1
Galle	12	0.014	1
Hambantota	14	0.034	1.1

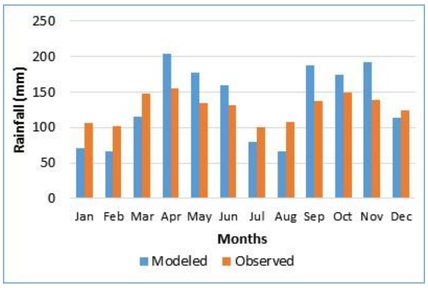
The mean monthly rainfall for observed and modeled rainfall data between 2009 - 2019 are shown in Figure 2(a-e).



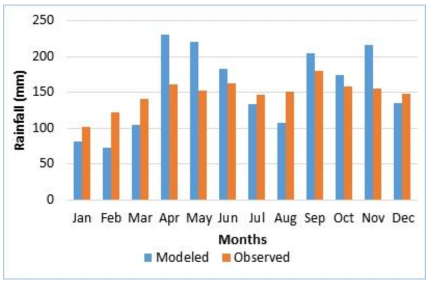
(a) For Puttalam



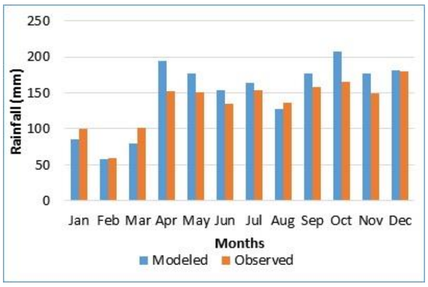
(b) For Kurunegala



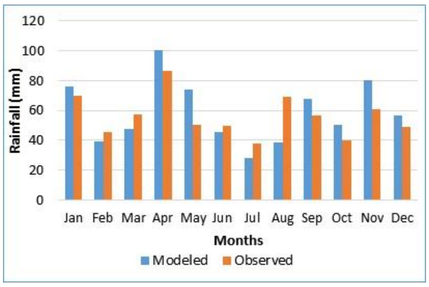
(c) For Katunayake



(d) For Colombo



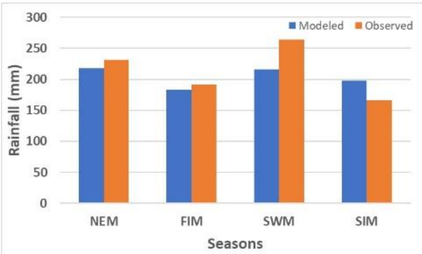
(e) For Galle



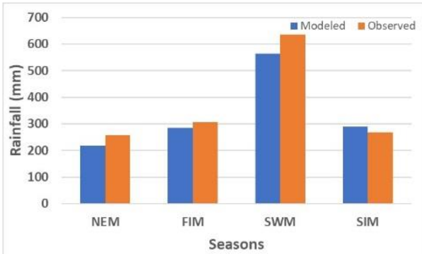
(f) For Hambantota

Fig 2. Mean monthly rainfall for modeled and observed rainfalls.

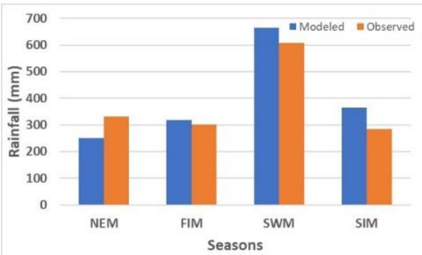
Similar monthly rainfall patterns can be observed in modeled rainfall against the observed monthly rainfall for all six stations. However, none of the stations showcase a perfect match to the observed rainfalls. It is very usual to have errors in climate projections. Nevertheless, the correlation of both data sets (modeled and observed) shows some interesting results (*Puttalam – **0.93**, Kurunegala – **0.86**, Katunayake – **0.86**, Colombo – **0.77**, Galle – **0.94**, and Hambantota – **0.69***). Puttalam and Galle have higher correlations whereas Hambantota has the lowest. However, the lowest is 0.69. This is acceptable in most climate studies. Therefore, it is evident that the validated SDSM model provides reasonable results when compared to the observed mean monthly rainfall.



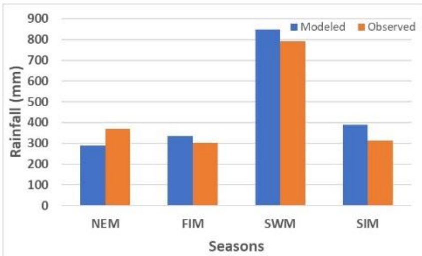
(a) For Puttalam



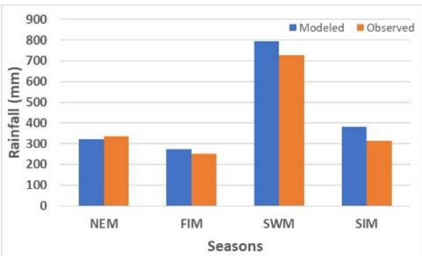
(b) For Kurunegala



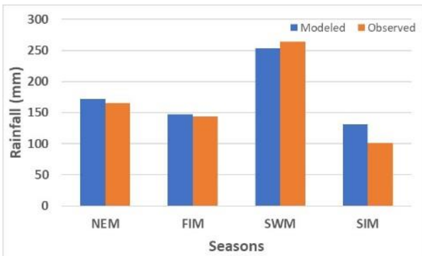
(c) For Katunayake



(d) For Colombo



(e) For Galle



(f) For Hambantota

Fig 3. Seasonal variation for modeled and observed rainfalls.

Figure 3 showcases the seasonal variation of rainfall for modeled and observed rainfalls for the six locations (a-f). The modeled data show the usual patterns of observed rainfalls. Therefore, the modeled rainfall can be used to visualize seasonal behaviour and patterns. In addition, the southwestern monsoon showcases the highest seasonal rainfall. This is expected as the northwestern, western, and southern provinces in Sri Lanka usually have higher rainfall during the southwestern monsoon.

Figure 4 illustrates the annual rainfall variation for future projected rainfall for Puttalam under the RCP8.5 emission scenario (only Puttalam is shown here). The annual rainfalls were calculated from the projected daily rainfall data. The figure presents the rainfall in three clusters as stated earlier; near future (2020-2040), mid future (2041-2070), and far future (2071-2100) and shown in a straight line for illustration purposes, even though there is no direct connection from this year's rainfall to the next year's rainfall.

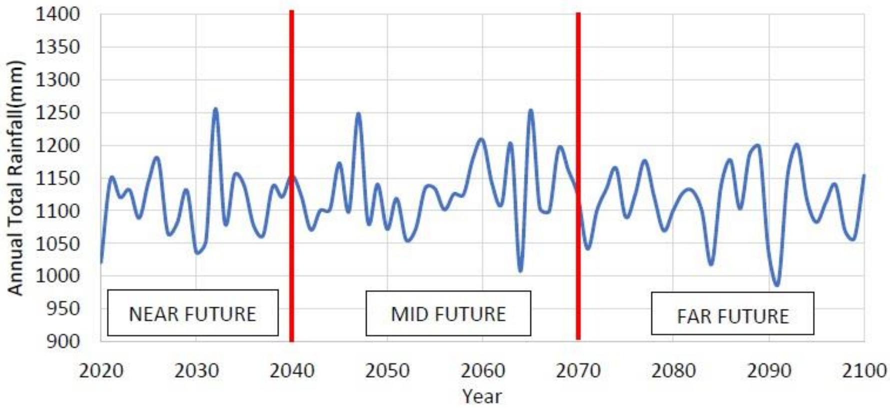


Fig 4. Annual rainfall variation for projected rainfall.

3.2 Trend analysis of historical (1990 to 2019) and future (2020 to 2100) rainfall

Table 4 presents the results of MK test and Sen's slope for seasonal and annual rainfalls at Puttalam, Kurunegala, Katunayake, Colombo, Galle, and Hambantota stations during FIM, SWM, SIM, and NWM seasons and annual scales at 95% confidence level.

Even though the increasing trends were present at all stations except Katunayake for the FIM period, only Hambantota shows a significant increasing trend, which is about 1.44 mm. The SWM and NEM are the dominant rainfall receiving seasons of Sri Lanka. However, none of the stations shows significant trends for the SWM season. However, Colombo shows a significant increase during the NEM, and it is 4.75 mm per year, which can be a significant contribution to the water resources in the Colombo district. However, Colombo is in the wet zone and frequently experienced some floods. A significant increase can also be observed in SIM for Colombo (*4.44 mm/year*). Therefore, the stakeholders may have to concern about these rainfall increments. Increasing trends for annual rainfall were identified in Colombo in previous studies (Malmgren *et al.* 2003). Increasing trends during the NEM season in Colombo demonstrated in this study are in-lined with the finding of Perera *et al.* (2020). The increasing trends in annual rainfall in Galle, Colombo, and Katunayake are similar to the direction of trends observed by Amarasinghe (2020). Therefore, the results of this study are well-validated.

Table 4: Results of MK and Sen's slope tests for seasonal and annual rainfall.

Station	Result	FIM	SWM	SIM	NEM	Annual
Puttalam	P value	0.617	0.929	0.830	0.521	0.830
	Sen's slope (mm/year)	1.25	-0.15	-1.07	1.95	-1.56
	Trend status [a]	IS	IS	IS	IS	IS
Kurunegala	P value	0.748	0.521	0.335	0.544	0.669
	Sen's slope (mm/year)	0.99	3.02	-4.1	3.54	2.16
	Trend status	IS	IS	IS	IS	IS
Katunayake	P value	0.943	0.972	0.617	0.412	0.830
	Sen's slope (mm/year)	-0.20	0.17	2.2673	-2.45	2.54
	Trend status	IS	IS	IS	IS	IS
Colombo	P value	0.392	0.617	**0.044**	**0.034**	0.354
	Sen's slope (mm/year)	3.67	-3.07	4.44*	4.75*	8.72
	Trend status	IS	IS	**S**	**S**	IS
Galle	P value	0.803	1.000	0.522	0.669	**0.034**
	Sen's slope (mm/year)	1.19	0.38	7.06	1.29	11.55*
	Trend status	IS	IS	IS	IS	**S**
Hambantota	P value	**0.042**	0.972	0.972	0.592	0.643
	Sen's slope (mm/year)	1.44*	-0.153	-0.100	1.285	3.250
	Trend status	**S**	IS	IS	IS	IS

[a] Trend status - Significant (**S**) or insignificant (IS)

Overall, the results obtained for annual trends in this study suggest that at most of the stations in western, north-western and southern provinces the annual rainfall is expected to increase even though most of them are insignificant.

Trend analysis results for projected future rainfalls are shown in Table 5. None of the gauging stations have shown any significant rainfall trends in the near future (2020-2040). Noteworthy, a distinct trend pattern cannot be observed in any temporal or spatial scales. However, positive significant trends were found in the projected rainfall for the mid future (2041-2070). Puttalam and Galle have shown rainfall increasing trends in the south-western monsoon, where these two regions get the usual significant rainfalls. Therefore, it would be interesting to see the behavior and planning strategies of water resources in the 2040s. Nevertheless, the trend patterns are turned to negative trends in the far future for the projected rainfalls. Kurunegala, Karunayake, and Galle have shown negative trends from the 2070s. Therefore, the water resources in these districts under the RCP8.5 climate scenario would be interesting to understand. Thus, pre-planning would be an essential task in the 2070s world.

Table 5: Results of MK and Sen's slope test for future projected rainfall.

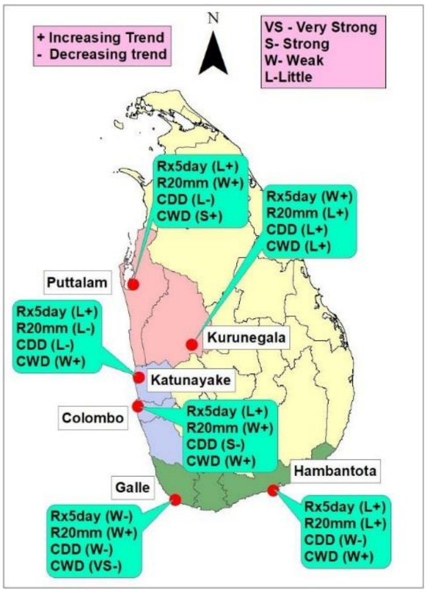
Station	For 2020-2040	For 2041-2070			For 2071-2100		
Puttalam	All seasons	FIM	SWM	SIM & NEM	FIM	SWM	SIM
Puttalam	IS	IS	**S** (1.8 mm)	IS	IS	IS	IS
Kurunegala	IS	IS	IS	IS	IS	IS	**S** (-2.2 mm)
Katunayake	IS	IS	IS	IS	**S** (-1 mm)	IS	IS
Colombo	IS	IS	IS	IS	IS	IS	IS
Galle	IS	IS	**S** (3.3 mm)	IS	IS	IS	IS
Hambantota	IS	IS	IS	IS	IS	IS	IS

Trend status - Significant (**S**) or insignificant (IS)

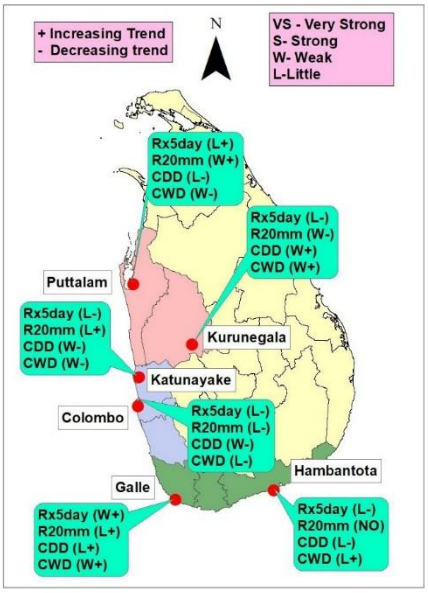
3.3 Trend analysis of rainfall indices

Trends patterns in the tested rainfall indices are given in Figure 5. The variation of Rx5day, R20mm, CDD and CWD indices were presented. Figure 4a presents these indices for the observed rainfalls in the 1990-2019 period. The Rx5day index is either in L or W for all six stations. Therefore, the heavy precipitation events were not observed in the 1990-2019 period. In addition, this observation is confirmed from the R20mm index. It is either L or W for all stations. Consecutive dry days and consecutive wet days show a similar trend; however, except for a couple of higher cases (Puttalam and Galle in CWD and Colombo in CDD).

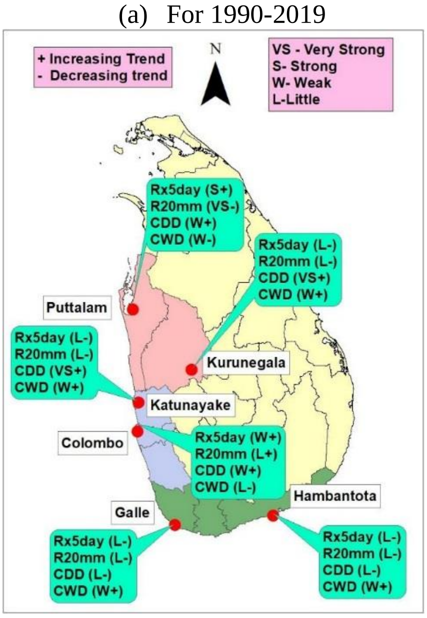
Similar trend patterns can be seen in Figure 4b for the 2020-2040 period for the projected rainfalls. It can be recalled herein that, none of the stations showed any potential trends from the non-parametric tests (*see* Table 5) for a similar time slot. However, Puttalam shows some increasing trends in Rx5day and R20mm indices for the 2041-2070 time slot. This is in-lined with the observations from the MK test. Nevertheless, a similar argument is not observed for Galle, which has positive trends in MK tests, while lower or insignificant trends in Rx5day and R20mm indices. Therefore, a valid relationship from MK test to rainfall indices is not visible. This is well accepted in the research community and time slot 2071-2100 has confirmed it.



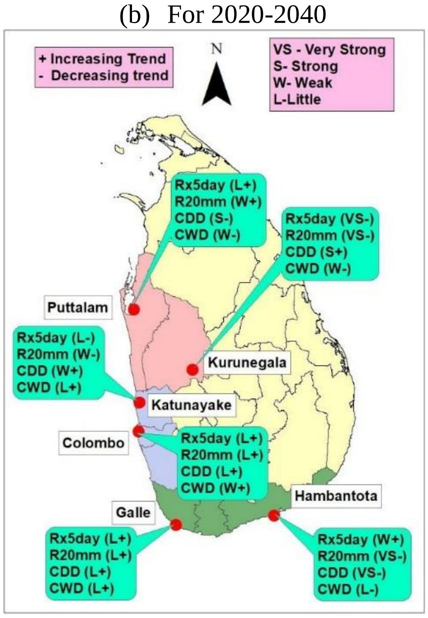
(a) For 1990-2019



(b) For 2020-2040



(c) For 2041-2070



(d) For 2071-2100

Fig 5. Trend patterns in rainfall indices.

4 Summary and conclusions

The current study showcases the future rainfall projections and their trends in three provinces of Sri Lanka, including northwestern, western, and southern provinces. These three provinces for the first time were tested for their projected rainfall under the RCP scenarios. The rainfall data from 1990 to 2019 were considered the historical period, while the future climate was projected until 2100 under the RCP8.5 scenario. Rainfall trends under the non-parametric tests showcased some positive trends in mid future (2041-2070), while some negative trends in the far future (2071-2100). However, the results from the rainfall indices are inconclusive with these trends. Nevertheless, based on the results of the study, adaptation options should be performed to mitigate the negative impact due to changes in the climate and increases in extreme events.

Therefore, this study provides some useful recommendations for providing adaptation strategies to mitigate and counteract negative impacts under future expected climatic conditions. In terms of water resources management, this study promotes rainwater harvesting not only to store rainfall water to use on dry days but also to reduce the peak surface flows on heavy rainy days. In terms of irrigation, the study proposes micro-irrigation measures whereas, changing of planting dates, and increased crop diversity are proposed for the agricultural sector.

Nevertheless, future studies should be carried out using different hydro-meteorological variables. This study was only limited to the use of CanESM-2. Future studies can be implemented with other types of RCMs and GCMs, which are able to represent the climate of the study area well.

Availability of data and materials (data transparency)

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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References

Agarwal A. Babel MS, Maskey S. 2015. Estimating the Impacts and Uncertainty of Climate Change on the Hydrology and Water Resources of the Koshi River Basin. In: Shrestha S., Anal A., Salam P., van der Valk M. (eds) Managing Water Resources under Climate Uncertainty. Springer Water. Springer, Cham, pp. 105-126. https://doi.org/10.1007/978-3-319-10467-6-6

Alahacoon N, Edirisinghe M. 2021. Spatial variability of rainfall trends in Sri Lanka from 1989 to 2019 as an indication of climate change. *ISPRS International Journal of Geo-Information* 10(2-84): 1-18. doi: 10.3390/ijgi10020084

Amarasinghe AG. 2020. Analysis of long-term rainfall trends in Sri Lanka Using CHRIPS estimates. *American Journal of Multidisciplinary Research & Development (AJMRD)* 2(11): 34-44.

Bandara IM, Weerakoon SB. 2020. Trend analysis of historical and downscaled future climate data in Deduru-Oya basin, Sri Lanka. WASO Final Virtual Conference, Norway, 15-18 December 2020.

Basnayake BRSB, Vithanage JC. 2004. Rainfall change scenarios for Sri Lanka under the anticipated climate change. In: Proceedings of the International Conference on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region. Colombo, Sri Lanka.

Basnayake BRSB, Rathnasiri J, Vithanage JC. 2004. Rainfall and temperature scenarios for Sri Lanka under the anticipated climate change. 2nd AIACC Regional Workshop for Asia and the Pacific, Manila, Philippines, 2-5 November 2004.

Bates BC, Kundzewicz ZW, Wu S, Palutikof JP. (eds.) 2008. Climate Change and Water: Technical Paper of the Intergovernmental Panel on Climate Change. Geneva: IPCC Secretariat. Pp 210.

Chandrapala L. 1996. Long term trends of rainfall and temperature in Sri Lanka. Climate Variability and Agriculture, Abrol YP, Gadgil S, Pant GB, Eds., Narosa Publishing House, New Delhi, 153-162.

Chen J, Brissette F, Chaumont D, Braun M. 2013. Finding appropriate bias correction methods in downscaling precipitation for hydrologic impact studies over North America. *Water Resources Research* 49(7): 4187-4205. doi: 10.1002/wrcr.20331.

Chylek P, Li J, Dubey M, Wang M, Lesins G. 2011. Observed and model simulated 20th century Arctic temperature variability: Canadian Earth System Model CanESM2. *Atmospheric Chemistry and Physics* 11(8): 22893-22907. doi: 10.5194/acpd-11-22893-2011.

Cui T, Yang T, Xu C, Shao Q, Wang X, Li Z. 2018. Assessment of the impact of climate change on flow regime at multiple temporal scales and potential ecological implications in an alpine river. *Stochastic Environmental Research and Risk Assessment* 32(6): 1849-1866. doi: 10.1007/s00477-017-1475-z

Dantanarayana M, Herath S, Weerakoon SB. 2021. Improving sub daily scale storm forecasting for Kelani River basin based on temporal distribution of rain events. *Journal of Climatology & Weather Forecasting* 9(1): 1-9.

Dashkhuu D, Kim JP Chun, JA, Lee WS. 2015. Long-term trends in daily temperature extremes over Mongolia. *Weather and Climate Extremes* 8: 26–33.

De Costa WAJM. 2008. Climate change in Sri Lanka: myth or reality? Evidence from long-term meteorological data. *Journal of the National Science Foundation of Sri Lanka* 36: 63–88. http://doi.org/10.4038/jnsfsr.v36i0.8048

De Costa WAJM. 2012. Climate change research in Sri Lanka – Are we investigating enough? *Journal of the National Science Foundation of Sri Lanka*, 40(4), 281–282. http://doi.org/10.4038/jnsfsr.v40i4.5041

De Silva CS. 2006. Impacts of climate change on water resources in Sri Lanka. 32nd WEDC International Conference. Colombo: Sri Lanka, 13-17 November 2006.

De Silva CS, Weatherhead EK, Knox JW, Rodriguez-Diaz JA. 2007. Predicting the impacts of climate change: A case study of paddy irrigation water requirements in Sri Lanka. *Agricultural Water management* 93(1-2): 19-29. https://doi.org/10.1016/j.agwat.2007.06.003

De Silva MMGT, Weerakoon SB, Herath S, Ratnayake UR, Mahanama S. 2012. Flood inundation mapping along the lower reach of Kelani River basin under the impact of climatic change. *Engineer: Journal of the Institution of Engineers Sri Lanka* 45(2): 23–29. http://doi.org/10.4038/engineer.v45i2.6938

De-Silva G, Weerakoon SB, Herath S. 2016. Event based flood inundation mapping under the impact of climate change: a case study in lower Kelani River basin, Sri Lanka. Hydrology: Current Research 7(1): 7–10.

Dharmarathna W, Herath S, Weerakoon S. 2012. Changing the planting date as a climate change adaptation strategy for rice production in Kurunegala district, Sri Lanka. *Sustainability Science 9*(1): 103-111. doi: 10.1007/s11625-012-0192-2

Dissanayaka K, Rajapakse R. 2019. Long-term precipitation trends and climate extremes in the Kelani River basin, Sri Lanka, and their impact on streamflow variability under climate change. *Paddy and Water Environment* 17(2): 281-289. doi: 10.1007/s10333-019-00721-6

Dorji S, Herath S, Mishra BK. 2017. Future Climate of Colombo Downscaled with SDSM-Neural Network. *Climate* 5(1-24): 1-11. https://www.mdpi.com/2225-1154/5/1/24

Dumitrescu A, Bojariu R, Birsan MV, Marin L. Manea A. 2015. Recent climatic changes in Romania from observational data (1961–2013). *Theoretical and Applied Climatology* 122: 111–119. https://doi.org/10.1007/s00704-014-1290-0

Eckstein D, Künzel V, Schäfer L, Winges M. 2019. Global Climate Risk Index 2020. Who suffers most from extreme weather events? Weather-related loss events in 2018 and 1999 to 2018. Germanwatch. Bonn. Germany.

Eriyagama N, Smakhtin V. 2010. Observed and projected climatic changes, their impacts and adaptation options for Sri Lanka: a review, in Proceedings of the National Conference on Water, Food Security and Climate Change in Sri Lanka. International Water Management Institute, Colombo.

Esham M, Garforth C. 2013. Climate change and agricultural adaptation in Sri Lanka: A review. *Climate and Development* 5(1): 66-76. DOI: 10.1080/17565529.2012.762333

Fernando TK, Chandrapala L. 1992. Global Warming and Rainfall Variability – Sri Lankan Situation. Proceedings of the 47th Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).Section E1. pp 138

Fernando TK. 1997. Recent Variations of rainfall and air temperature in Sri Lanka. Proceedings of the 53rd Annual Session of Sri Lanka Association for the Advancement of Science (SLASS).Section E1. pp 138.

Gagnon S, Singh B, Rousselle J, Roy L. 2005. An Application of the Statistical DownScaling Model (SDSM) to Simulate Climatic Data for Streamflow Modelling in Québec. *Canadian Water Resources Journal* 30(4): 297-314. https://doi.org/10.4296/cwrj3004297

Gunasekara D, Yeon K, Catherine T, Melanie F. 2007. Climate change: impacts on Australian agriculture. *Australian Commodities: Forecasts and Issues* 14(4): 657–676. DOI: https:/doi/10.3316/ielapa.970516347702109

Herath HMVV, Dayananda RGAB, Madakumbura MMGD, Priyankara WMS, Weerakon SB. 2016. WRF weather downscaling model coupled with runoff model for anticipatory flood water management of the Polgolla Barrage. 20th IAHR APD Congress in Colombo, Sri Lanka. 29-31 August 2016.

Hussain M, Yusof KW, Mustafa MRU, Afshar NR. 2015. Application of Statistical Downscaling Model (SDSM) for long Term Prediction of Rainfall in Sarawak, Malaysia. *WIT Transactions on Ecology and the Environment* 196: 269-278. DOI: 10.2495/WRM150231

Imbulana KAUS, Wijesekara NTS, Neupane BR. Eds. 2006. Sri Lanka National Water Development Report. MAI&MD, UN-WWAP, UNESCO and University of Moratuwa, Sri Lanka, Paris and New Delhi.

Imbulana N, Gunawaradana SK Shrestha, S, Datta A. 2018. Projections of Extreme Precipitation Events under Climate Change Scenarios in Mahaweli River Basin of Sri Lanka. *Current Science* 114(7): 1495-1509. DOI: 10.18520/cs/v114/i07/1495-1509.

IPCC. 2007: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, Eds., Cambridge University Press, Cambridge, UK. Pp 976.

Jayatillake H. 2004. Will there be sufficient water under internal and external changes? Walawe Basin (Sri Lanka). In J. Aerts & P. Droogers, Climate change in contrasting river basins: adaptation strategies for water, food and environment Wallingford. UK: CABI. ix, pp 264.

Jayatillake HM, Chandrapala L, Basnayake BRSB, Dharmaratne GHP. 2005. Water Resources and climate change. Proceedings of Workshop on Sri Lanka National Water Development Report. Wijesekera NTS, Imbulana KAUS, Neupane B. Eds. World Water Assessment Programme (WWAP): Paris, France.

Jha M, Arnold JG, Gassman PW, Giorgi F, Gu RR. 2006. Climate change sensitivity assessment on upper Mississippi river basin streamflows using SWAT. *Journal of the American Water Resources Association* 42 (4): 997–1015. DOI: 10.1111/j.1752-1688.2006.tb04510.x

Jiang T, Chen YD, Xu CY, Chen X, Singh VP. 2007. Comparison of hydrological impacts of climate change simulated by six hydrological models in the Dongjiang basin, south China. *Journal of Hydrology* 336(3-4): 316–333. https://doi.org/10.1016/j.jhydrol.2007.01.010

Karunanayake C, Gunathilake MB, Rathnayake U. 2020. Inflow Forecast of Iranamadu reservoir, Sri Lanka, under Projected Climate Scenarios Using Artificial Neural Networks. *Applied Computational Intelligence and Soft Computing* 1-11, https://doi.org/10.1155/2020/8821627

Katul GG, Oren R, Manzoni S, Higgins C, Parlange MB. 2012. Evapotranspiration: process driving mass transport and energy exchange in the soil-plant-atmosphere-climate system. *Review of Geophysics* 50(3): 1-25. https://doi.org/10.1029/2011RG000366.

Khalid MM, Muhinadeen M, Weerakoon SB. 2017. Rainfall forecast in the Upper Mahaweli basin in Sri Lanka using RegCM model. *Journal of Physics Conference Series* 822 (1): 1-10. DOI: 10.1088/1742-6596/822/1/012075.

Khaniya B, Karunanayake C, Gunathilake MB, Rathnayake U. 2020. Projection of Future Hydropower Generation in Samanalawewa Power Plant, Sri Lanka. *Mathematical Problems in Engineering*. 1-11. https://doi.org/10.1155/2020/8862067

Khattak MS, Babel M, Sharif M. 2011. Hydro-meteorological trends in the upper Indus river basin in Pakistan. *Climate research* 46(2): 103-119. DOI:https://doi.org/10.3354/cr00957

Kundzewicz Z, Robson A. 2000. Detecting trend and other changes in hydrological data. United Nations Educational Scientific and Cultural Organization: World Meteorological Organization.

Malmgren BA, Hulugalla R, Hayashi Y, Mikami T. 2003. Precipitation Trends in Sri Lanka since the 1870s and Relationships to El NinoSouthern Oscillation. *International Journal of Climatology* 23(10):1235-1252. https://doi.org/10.1002/joc.921

Mann H. 1945. Non-parametric tests against trend. *Econmetrica* 13(3):245-259. https://doi.org/10.2307/1907187

Ministry of Agriculture. 2018. Sri Lanka Council for Agriculture Research Policy, National Agricultural Research Policy and Strategy. ISBN 978-955-9224-67-9

Ministry of Environment Sri Lanka. 2011. Climate Change Vulnerability Data Book, Ministry of Environment: Colombo, Sri Lanka.

Muhinadeen M, Khalid MM, Weerakoon SB, Mutua F. 2016. Comparative study of WRF & RegCM weather predictions for the Upper Mahaweli river basin. 7th International Conference on Sustainable Built Environment 2016 (ICSBE 2016) Kandy. 16-18 December 2016.

Nagahamulla H, Ratnayake U, Ratnaweera A. 2014. Artificial neural network ensembles in time series forecasting: an application of rainfall forecasting in Sri Lanka. *International Journal on Advances in ICT for Emerging Regions* (ICTer) 6(2), DOI:10.4038/icter.v6i2.7151

Nagahamulla HRK, Ratnayake UR, Ratnaweera A. 2011. Monsoon rainfall forecasting Sri Lanka using artificial neural networks. 6th International Conference on Industrial and Information Systems. 305-309. doi: 10.1109/ICIINFS.2011.6038085

Nandalal KDW, Sachindra DA, Ratnayake UR. 2012. Application of WRF weather model to forecast precipitation in Nilwala river basin. *Engineer* 45(1): 51–64. DOI:http://doi.org/10.4038/engineer.v45i1.6949

Perera A, Rathnayake U. 2019. Impact of climate variability on hydropower generation in an un-gauged catchment: Erathna run-of-the-river hydropower plant, Sri Lanka. *Applied Water Science* 9:1-11. https://doi.org/10.1007/s13201-019-0925-9-

Perera A, Ranasinghe T, Gunathilake M, Rathnayake U. 2020. Comparison of different analyzing techniques in identifying rainfall trends for Colombo, Sri Lanka. *Advances in Meteorology* 1-10, doi: 10.1155/2020/8844052

Premalal KHMS. 2009. Weather and Climate Trends, Climate Controls & Risks in Sri Lanka. Sri Lanka Monsoon Forum. April 2009. Department of Meteorology, Sri Lanka.

Premalal KHMS. 2013. Change and Behavior of Rainfall Pattern in Sri Lanka with Southern Oscillation (SO) - El Nino and La Nina, SAARC Meteorological Research Centre, Dhaka, Bangladesh

Punyawardena BVR, Cherry NJ. 1999. Assessment of the predictability of the seasonal rainfall in Ratnapura using southern oscillation and its two extremes. *Journal of the National Science Council of Sri Lanka* 27(3): 187–195.

Qin P, Xu H, Liu M, Xiao C, Liu L, Tarroja B. 2020. Climate change impacts on Three Gorges Reservoir impoundment and hydropower generation. *Journal of Hydrology* 580, https://doi.org/10.1016/j.jhydrol.2019.123922

Rathnayake U. 2019. Comparison of statistical methods to graphical methods in rainfall trend analysis: case studies from tropical catchments. *Advances in Meteorology* 1-10. https://doi.org/10.1155/2019/8603586

Ratnayake U, Herath S. 2005. Changing Rainfall and its Impact on Landslides in Sri Lanka. *Journal of Mountain Sciences* 2: 218–224. https://doi.org/10.1007/BF02973195

Ratnayake U, Sachindra DA, Nandalal KDW. 2010. Rainfall forecasting for flood prediction in the Nilwala basin. Proceedings of the International Symposium on Coastal Zones and Climate Change: Assessing the Impacts and Developing Adaptation Strategies, Monash University, Australia. 12–13 April 2010.

Ruwangika AM, Perera A, Rathnayake U. 2020. Comparison of statistical, graphical, and wavelet transform analyses for rainfall trends and patterns in Badulu Oya catchment, Sri Lanka. *Complexity* 1-13. https://doi.org/10.1155/2020/7146593

Sarathchandra C, Abebe Y, Wijerathne I., Aluthwattha S, Wickramasinghe S, Ouyang Z. 2021. An Overview of Ecosystem Service Studies in a Tropical Biodiversity Hotspot, Sri Lanka: Key Perspectives for Future Research. *Forests* 12(5): 1-16. DOI:10.3390/f12050540

Sen PK. 1968. Estimates of the regression coefficient based on kendall’s tau. *Journal of the American Statistical Association* 63(324): 1379–1389. https://doi.org/10.2307/2285891

Shantha WWA, Jayasundara JMSB. 2005. Study on Changes of Rainfall in the Mahaweli Upper Watershed in Sri Lanka due to Climatic Changes and Develop a Correction Model for Global Warming. Paper presented at the International Symposium on the Stabilization of Greenhouse Gas Concentrations. Hadley Centre, Met Office, Exeter, UK.

Sharannya TM, Mudbhatkal A, Mahesha A. 2018. Assessing climate change impacts on river hydrology – A case study in the Western Ghats of India. *Journal of Earth System Sciences* 127:1-11. https://doi.org/10.1007/s12040-018-0979-3

Simonovic SP, Li L. 2003. Methodology for assessment of climate change impacts on large-scale flood protection system. *Journal of Water Resources Planning and Management* 129: 361–372. https://doi.org/10.1061/(ASCE)0733-9496(2003)129:5(361)

Sumathipala WL, Punyadeva NBP. 1998. Variation of the rainfall of Sri Lanka in relation to El Nino. In Proceedings of the Annual Sessions of the Institute of Physics, Sri Lanka, Colombo.

Taylor IH, Burke E, McColl L, Falloon PD, Harris GR, McNeall D. 2013. The impact of climate mitigation on projections of future drought. *Hydrology and Earth System Sciences* 17(6): 2339–2358. https://doi.org/10.5194/hess-17-2339-2013

Teutschbein C, Seibert J. 2010. Regional climate models for hydrological impact studies at the catchment scale: a review of recent modeling strategies. *Geography Compass* 4(7):834–860. https://doi.org/10.1111/j.1749-8198.2010.00357.x

Thambyahpillay G. 1954. The rainfall rhythm in Ceylon. *University of Ceylon Review*, vol. XII, 4: 224-273. http://hdl.handle.net/123456789/1016

Trenberth KE, Jones PD, Ambenje P, Bojariu R, Easterling D, Klein TA, Parker D, Rahimzadeh F, Renwick JA, Rusticucci M, et al. 2007. Observations: surface and atmospheric climate change. In Climate Change 2007. The Physical Science Basis, Contribution of WG 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Solomon S, Qin D, Manning M, Chen Z, Marquis MC, Averyt KB, Tignor M, Miller HL, (Eds.), Cambridge University Press, Cambridge, New York.

Vihma T, Screen J, Brandi Tjernström M, Newton B, Zhang X, Popova V, Deser C, Holland M, Prowse T. 2016. The atmospheric role in the Arctic water cycle: A review on processes, past and future changes, and their impacts. *Journal of Geophysical Research Biogeosciences* 121(3). DOI: 10.1002/2015JG003132

Wickramagamage P. 2010. Seasonality and spatial pattern of rainfall of Sri Lanka: Explanatory factor analysis. *International Journal of Climatology* 30(8): 1235–1245. https://doi.org/10.1002/joc.1977

Wilby RL, Dawson CW, Barrow EM. 2002. SDSM – A Decision Support Tool for the Assessment of Regional Climate Change Impacts. *Environmental Modelling & Software* 17: 147-159.

Withanachchi S, Köpke S, Withanachchi CR, Pathiranage R, Ploeger A. 2014. Water Resource Management in Dry Zonal Paddy Cultivation in Mahaweli River Basin, Sri Lanka: An Analysis of Spatial and Temporal Climate Change Impacts and Traditional Knowledge. *Climate* 2(4): 329-354. doi:10.3390/cli2040329

Zhang X, Yang F. 2004. Rclimdex (1.0) User Manual. Climate Research Branch Environment Canada. Available at https://acmad.net/rcc/procedure/RClimDexUserManual.pdf