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Changes in Rainfall Extremes in Ontario

Rudra, R.P., Dickinson, W.T., Ahmed, S. I.*, Patel, P., Zhou, J., Gharabaghi, B. and Khan, A.A.

School of Engineering, University of Guelph, Guelph, Ontario Canada N1G2W1

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ABSTRACT: There is a general consensus that climate change has impact on the intensity and frequency of rainfall events. However, very little research is available about the changes in short term rainfall extremes. The focus of this paper has been on the change in annual and monthly rainfall extremes in Ontario. The results indicate a greater variability (increase and decrease) among stations for shorter durations (15-min, 30-min, and 60-min). There is no obvious regional pattern with possible exception of increasing trends at north-western locations. The monthly rainfall extremes for the months of April and May in the Northwest region are decreasing, for May and October extremes in the southwest region and for April and May extremes in the southeast region are increasing. The August extremes for the southwest and southeast regions are decreasing, and the magnitude of decrease in the southwest region is almost double the magnitude in the southeast region. The decrease in August extremes seems to have a significant impact on the annual extremes in the southwest and southeast regions.

Key words: Precipitation, Climate change, Variability, Intensity of rainfall

INTRODUCTION

Comprehensive information on the amount and frequency of rainfall extremes is of the utmost importance for a precise design of water resources systems. Therefore, researchers and engineers involving in the process of designing and/or analyzing such systems must remain alert to the possibility of changes in the occurrence of extreme rainfalls. Recent reports on climate change have highlighted the likelihood of a general increase in rainfall amounts in various regions, and are prompting to clarify the evidence for the need for more research studies on determining the extent of changes in rainfall extremes in local areas. Rainfall extremes have generally revealed mixed results. The Intergovernmental Panel on Climate Change (IPCC) Working Group (2001) stated that an increase in the amounts of precipitation has been observed worldwide, that much of this increase has been in the form of heavy precipitation events; moreover, the recent reports and studies including model simulations and/or data analyses of climate models predict a continued increase in intense precipitation events over the 21st century. Kharin and Zwiers (2005) used simulation results generated from a climate model to reveal that changes in 24-hour extremes were larger than changes in annual mean precipitation. On the other hand, Kharin and Zwiers (2000) added that there is limited confidence in the results of simulated precipitation extremes, and that changes in simulated extremes under transient climate change should not be considered as a reliable projections of the future conditions. Michael et al. (2005) acknowledged that the available global climate change models are able to reliably produce the best mean daily precipitation data. Even though the frequency and intensity of extreme rainfall events are expected to increase in some regions, no prognostic data for such events is available.

Few research studies have focused on evaluating the effect of climate change on intensity and frequency of daily rainfall events (Brunetti et al., 2004); however, none to very limited attempts have been made to study short duration rainfall extremes. Davis et al. (2006) studied the magnitude and frequency of extreme precipitation in the Midwest region of USA and concluded that the rainfall depth of 100-year 24-hour events has significantly increased since 1961. Ntegeka and Willems (2009) studied the long term trends in rainfall extremes using 100 years of data in Belgium. They observed significant deviations in the rainfall amount with a 10 to 15 years period. The highest extremes for the winter and summer seasons were clustered in 1910s, 1920s, 1960s and 1990's. Toffol et al. (2008) investigated the changes in rainfall extremes in the urban drainage sys-

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*Corresponding author E-mail: sahmed@uoguelph.ca tems in Austrian Alpine region. They did not observe any significant trend for the total rainfall amount for the extreme events. However, the results of the deviation analysis indicated a change due to cyclic changes of the rainfall pattern in short duration rainfall intensities.

A study in Southwest China by Qin et al. (2010) for daily temperature and precipitation data (1960 to 2007) to evaluate spatial and temporal trends shows a non-significant increase in annual precipitation with a significant increasing trend during the winter season. Pal and Al-Tabbaa (2011) studied the changes in extreme rainfall events in Kerala, India, and found an increasing trend in precipitation intensity in winter and negative trends in the frequency of dry days in most northern regions. They also analyzed the annual and seasonal precipitation trends of 41 stations in Iran (1966-2005) and reported a decreasing trend in annual precipitation for more than the half of the stations.

Zhang et al. (2000) observed an average 12% increase in the annual amount of precipitation in southern Ontario from 1900 to 1998. The range of increases was from 5 to 30% with the steadiest amount of increase occurring between the '20s and the '70s. A substantial spatial variability of change in the amount of precipitation was also observed for that period of time in southern Ontario. A study by Solaiman and Somonovic (2011) evaluated the methods available for quantifying uncertainties from different climate models for the extreme precipitation events over the next century for the upper Thames Basin, Ontario, Canada, and found an increase in the probability of extreme rainfall events for summer and winter seasons in future. In a recent study Peck et al. (2012) evaluated the change in future and existing Intensity-Duration-Frequency (IDF) curves for London, Ontario, using nine durations as inputs to a weather generator. The comparison of IDF curves showed an increasing trend for maximum rainfall intensities and magnitudes. Shook and Pomeroy (2012) analyzed the historical precipitation data (1901-2000 and 1951-2000) and found statistically significant increasing trends at many locations in the Canadian prairies; however, these trends were strongly dependent on the month of the year. Also, the summer months' analysis has depicted that the temporal uniformity of rainfall has increased over the study periods. Analyses of the ratios of rainfall over multiple days indicated the general tendency to temporal uniformity in the range of 1 to 32 days. In addition, longer duration rainfall events have tendency for floods and storm as recorded in 2011 in the study area.

Recognizing the need to track changes in rainfall extremes for water resources management and design purposes, in addition to the variability existing in research results regarding possible changes in precipitation extremes, it is appropriate to precisely explore the available records relating to rainfall extremes. The purpose of this study is to reveal the results obtained from analyses of the trends and changes in short and long duration, annual, and monthly rainfall extremes which occurred during the last half of the 1900s at selected stations across Ontario.

The focus of this study is on extreme rainfall events, with particular attention given to the short duration events. The previous study by Dickinson (1977) reveals that monthly rainfall extremes exhibit significantly variability from month to month; therefore, attention was also paid to monthly as well as annual extremes. The monthly and annual rainfall extreme values were explored for 15 and 60 minutes, and 1, 6 and 12 and 24 hour durations.

MATERIAL & METHODS

Rainfall records of 15 recording rainfall stations, having reasonably long period (in the order of 50 or more years), of extreme rainfall record, across Ontario, were selected for analysis in the current research study. Table 1 and Fig. 1 identify the stations, their location and period of record, and their relative location in the province. It should be noted that 5 stations (Kenora, Sioux Lookout, Thunder Bay, Sault Ste. Marie, and North Bay) are located in the large portion of the province, north 46o N, with 10 stations located in the southern portion of the province. It is clear from the map that the density of selected stations is greater for southern Ontario; however, the locations were deemed to give a representative spatial sample of rainfall extremes in the province.

The analysis was performed in multi stages. First stage focused on trend analysis using Mann Kandell test and linear regression. Man-Kandell test is a non-parametric approach (Goosens and Berger, 1986), and is widely used in hydrology. The linear regression, a parametric approach, also widely used in hydrology was used to estimate trend slopes.

The Mann-Kendall, a non-parametric statistical test, is less powerful than the parametric tests; however, it has the capability to handle outliers. This test can be used for populations with no trend or serial correlation. The Mann-Kendall test uses the following equations outlined by Sneyers (1990) to test the significance of a trend:

$$E(d_n) = \frac{n(n-1)}{4} \tag{1}$$

$$\operatorname{var}(d_n) = \frac{n(n-1)(2n+5)}{72} \tag{2}$$

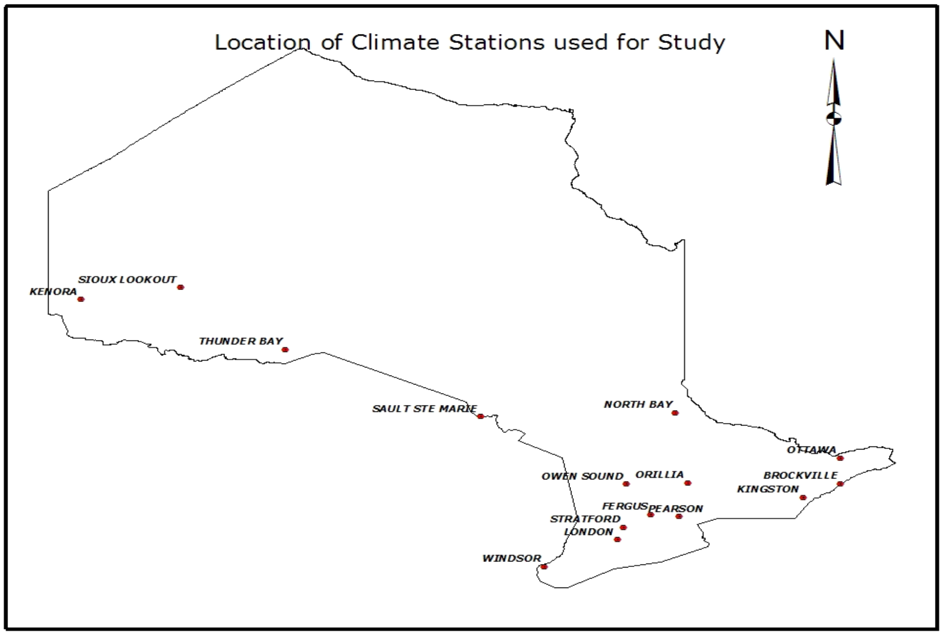

Fig. 1. Location of climatic stations used in the analysis of changes in rainfall extremes in Ontario

Table 1. Geographical coordinates and periods of record for stations used in the study

Stations	Latitude	Longitude	Altitude	Record	
				Period	Length Years
Sioux Lookout	50.12	-91.9	383.4	1939-2008	70
Kenora	49.79	-94.37	409.7	1939-2008	70
Thunder Bay	48.37	-89.33	199	1942-1992	50
North Bay	46.36	-79.42	370.3	1940-2008	70
Ottawa	45.38	-75.72	79.2	1939-2006	68
Brockville	44.6	-75.67	96	1966-2006	41
Owen Sound	44.58	-80.93	178.9	1965-2006	42
Kingston	44.24	-76.48	76.5	1978-2006	29
Fergus	43.73	-80.33	417.6	1940-2006	67
Toronto	43.68	-79.63	173.4	1940-2008	69
Stratford	43.37	-81	345	1960-2006	47
London	43.03	-81.15	278	1941-2001	61
Windsor	42.28	-82.96	189.6	1941-2008	68

$$U(d_n) = \frac{d_n - E(d_n)}{\sqrt{\mathrm{var}(d_n)}} \tag{3}$$

Where, dn is the sum of the number of observations for which the difference between the observation and the reference observation is +ve, E(dn) is the expected value of dn, and U(dn) is a statistics test value that measures whether a trend is increasing, decreasing, or trend-less.

Onoz and Bayazit (2003) also proposed the following relationship for U:

$$U = \frac{S - 1}{\sigma_s} \tag{4}$$

, for S > 0

Where, S is sum of the number of observations for which their values are greater than the starting value minus sum of the number of observations which have values smaller than the starting value, U is the standard normal distribution, s is the standard deviation for the number (n) of observations and is expressed as follows:

$$\sigma_s = \sqrt{\frac{n(n-1)(2n+5)}{18}} \tag{5}$$

An increasing or decreasing trend can be identified using the calculated value of U(dn). The trend is considered significant at 95% confidence limit (5% level of significance) if the value of U(dn) is greater than 1.65. The +ve values of U(dn) indicate a trend is increasing and the -ve values show a decreasing trend. In this study, the trend analysis was performed using Eqs. 3 and 4, and the significance level were tested at 95% confidence limit (5% levels of significance).

Linear regression analyzes the relationship between dependent variable (Y) and independent variable (X) in terms of a trend line.

$$Y = A + BX \tag{6}$$

Where, A is the intercept and B is the slope of the trend line.

The trend line tells whether a particular data set (e.g. short duration rainfall extremes) has increasing or decreasing trend over the period of time. The position and slope of the trend line is calculated using linear regression techniques. Trend line, typically a straight line, is a simple technique, and does not require experimental design, or a sophisticated technique. However, it suffers from lack of scientific validity in cases where other potential changes can affect the data.

The significance of the slope is tested by computing t-score (t) defined by the following equation.

$$t = \frac{B}{SE} \tag{7}$$

Where B is the slope of the trend line, and SE is the standard error of the slope.

The Mann-Kendall test was applied to time series of annual extremes for all variables at all stations, and the linear regression was applied to time series of annual and monthly extremes for all variables at all stations.

The annual rainfall extremes for the period of 1960 to 2003 and the monthly rainfall extreme values for the months of April through November for the same years were extracted from the selected station records for durations of 15, 30 and 60 minutes (shorter duration), and 6, 12, and 24 hours (longer duration). The trend analyses were performed on 75 annual extremal data sets (i.e. 5 durations at 15 stations), and on the corresponding 600 monthly sets of extreme values for the interval between 1970 and 2003 (i.e. the period designated as the prime interest with respect to climate change).

The analyses of the raw extremal data sets were characterized by relatively large variances, leading to a very small percent of the trend slopes to be significantly different from zero. Therefore, the trend analyses were repeated on time series of values determined from application of a 3-point moving average scheme to the series of extreme values. This scheme was applied to smooth the data sets without biasing the trend slopes, and allowed the identification of a greater percent of significant slopes. Further, the trend analysis also focused on the change rainfall extremes per decade for all duration and at all stations.

RESULTS & DISCUSSION

An example of the annual variations in 30-min rainfall extremes, obtained using raw data and the three years moving average, at Stratford and Windsor station are presented in Figs 2 and 3, respectively.

These data show large variability in the extremal values of rainfall; however, the magnitude of the variability at all of the selected stations is more or less similar. These values also reveal that the coefficient of variations for all the stations varies from a minimum

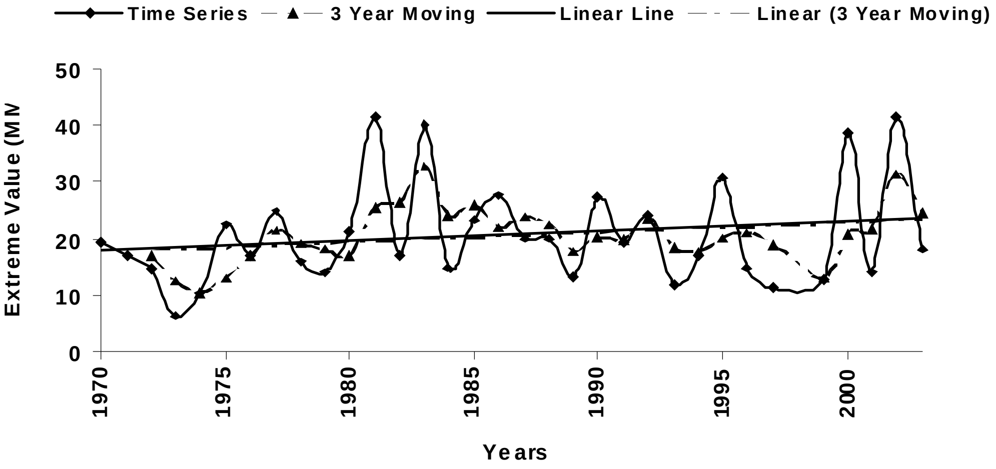

Fig. 2. Annual variations in 30 minute rainfall intensity at Stratford, Ontario

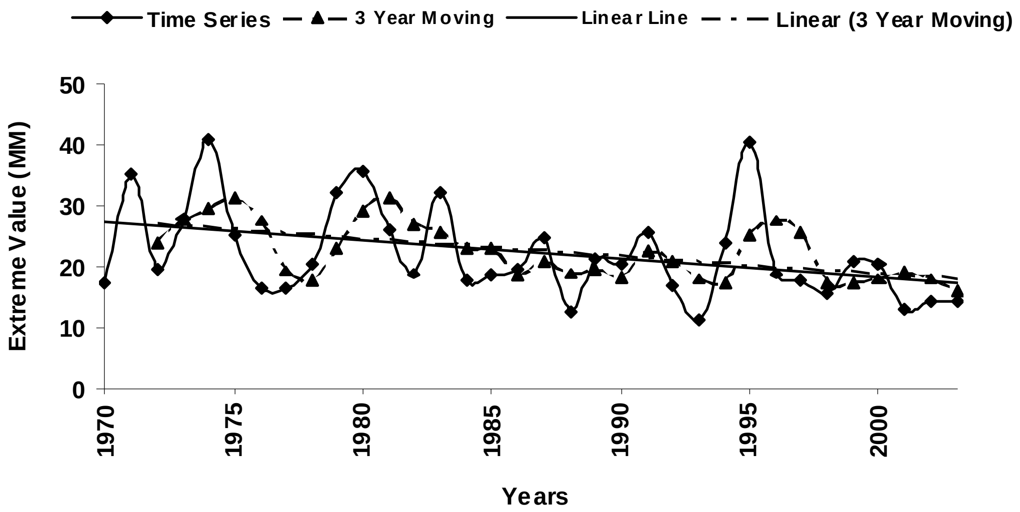

Fig. 3. Annual variations in 30-minute rainfall intensity at Windsor, Ontario

value of 0.26 at Ottawa for 720-min extremes to a maximum value of 0.60 at Stratford for 240-min extremes; however, there was no consistent relationship with the duration of extremes. The slope of the regression line calculated using raw data and the three-year moving average indicates an increasing trend at Stratford and a decreasing trend at Windsor.

Among the 15 selected stations, while the largest variability for the northwest and southwest stations was observed for 60-min duration, the largest variability for the southeast stations was observed for 30-min duration. With respect to the smallest variability, different pattern was observed for the selected stations; while the smallest variability for the northwest stations was observed for 240-min duration, the smallest variability for the southwest and the southeast stations was observed for 15-min duration and 720-min duration, respectively.

For the northwest stations the average variability was more for Kenora, followed by Sault Ste. Mary, and Sioux Lookout. The least variability was for North Bay. The variability pattern for the southwest and southeast stations is similar to the northwest stations; however, the magnitude of variability was more than that of the northwest stations. For the southwest stations the largest and smallest variability was for 240-min duration at Stratford and Windsor, respectively. In this region while the average variability was the highest at Stratford followed by Owen Sound and Fergus with similar variability, it was the lowest at Windsor and London with similar variability. The average variability for the southeast stations was the largest at Pearson and Orillia, followed by Brockville, Kingston, and Ottawa.

These data show an increasing or decreasing pattern with respect to location (station) and duration. For the northwest stations 68% of trends were positive (increasing) and 32% were negative (decreasing). However, out of 25 trends only 7 were significant, with 5 increasing and 2 decreasing trends. The trend pattern for the southwest and southeast regions was more or less similar to the northwest region; nevertheless, the number of increasing and decreasing trends was different. In the southwest region 32 % of the trends were positive, and 68% were negative. In this region while no significant increasing trend was observed, 32 percent of the trends were significantly decreasing trends. In the southeast region, the pattern of positive and negative trends was similar; 44% were increasing trends and 56% were decreasing trends. For this region, out of 28% significant trends only 12% were positive and 16% were negative.

The results of analysis of the changes in trend slope obtained using regression analysis are shown in Table 2. The slope values and trends determined to be different from zero at the 5% level of significance are noted with an asterisk. Overall, the results obtained by this analysis are similar to the results obtained from the Mann-Kendall test. Again there is no clear increasing or decreasing trend for all selected durations and for all selected stations. For the northwest stations the regression approach also generated results similar to the Mann-Kendall test. For the southwest stations regression analysis identified 40% +ve trends, 52% -ve trends, and 8% no trend. These results are slightly different from the results obtained from the Man-Kandell analysis. These differences are due to the fact that about 16% of the computed trend slopes by regression analy-

Table 2. Change in trend slope for various duration of rainfall events for three various geographic regions of Ontario

Station/Duration	15-min	30-min.	60-min.	240-min	720-min.
	Trend Slope, mm/yr				
Northwest Ontario					
Kenora	0.05	0.1	0.03	0.54*	0.74*
Sioux Lookout	-0.04	0.02	0.12	0.56*	0.59*
Thunder Bay	0.1	0.12	-0.07	-0.56*	-0.85*
Sault Ste. Marie	0.06	0.16	0.18	0.18	0.3
North Bay	-0.03	-0.07*	-0.14	-0.15	-0.14
Southwest Ontario					
Windsor	-0.30*	-0.31*	-0.35	-0.09	0.02
London	-0.19*	-0.16*	-0.11	-0.02	0.04
Stratford	0.12	0.18	0.28*	0.27*	0.24
Owen Sound	-0.14	-0.11	-0.01	0.02	0
Fergus	0.04	0.05	0	-0.09	-0.11
Southeast Ontario					
Pearson	-0.24*	-0.37*	-0.34*	-0.26	-0.22
Orillia	0.32*	0.27*	0.23*	0	-0.06
Kingston	-0.01	0.04	0.01	(-0.32)	(-0.27)
Brockville	-0.23*	-0.33*	-0.39*	-0.24	-0.1
Ottawa	-0.25*	-0.33*	-0.37*	-0.23*	-0.11

*Significant at 95% level

sis were small, and very close to zero. For the southeast stations the Mann-Kendall test identified more +ve trends and less -ve trends than the regression method.

In summary, these results reveal that both methods show similar pattern of +ve, trends. However, there was some difference between the regions and between the numbers of significant trends. The regression analysis yielded more significant events (9 +ve and 20 -ve) than the Mann-Kendall test (8 +ve and 14 -ve). The most of the difference was for the southeast stations followed by southwest stations. For the northwest stations both methods estimated almost similar trends. The regression analysis results also revealed that for the time period of analysis (1970 to 2003), there is about 30% chance of having a significant increasing or decreasing trend in rainfall extremes in Ontario. Overall, about 41% of the trend slopes are +ve and 55% -ve; 39% are significantly different from zero at 95% level, and 31 % of the significant slopes are +ve and 69 % are -ve.

In general, for the entire province the identified +ve and -ve trends are more or less similar to the Mann-Kendall analysis. However, the Mann-Kendall test identified less number of significant trends than the regression analysis. The regression method identified 46% with a +ve trend, 64% with a -ve trend where 28% had significant trends (29% of the significant trends were +ve and the remaining 71% were -ve). For the southeast stations about 20% of the trend slopes were +ve, 76% were -ve, and 4% were zero. In this case only 25% of the significant trends were +ve, and the remaining 75% were -ve. For the northern stations both the methods predicted similar numbers of +ve and -ve as well as significant +ve and -ve trends. For this region there were about 64% with +ve slopes, 36% -ve slopes, and 28% significant slopes at 95% level of significance. In addition, for the occasions where there appear to have a significant trend slope, it is equally likely that the slope could be +ve or -ve.

The analysis of variance results did not show any linkage between the sign of the significant slopes and the spatial location or the storm duration; however, it is instructive to explore the trend slopes with respect to each duration station location and duration plus location independently. Furthermore, the analysis of variance revealed no significant effect of duration, region and interaction of duration and region on trend slopes, but the regions seem to be the most dominant factor. The results obtained by Duncan multi-range test confirmed the dominant effect of the location on trend slopes. The mean value of the change in trend slopes for the northwest region was similar to the southwest region. Also the mean change in trend slopes for the southeast region was similar to the southwest region; however, the mean change in trend slopes for the northwest region was different from the mean change in slopes for the southeast region.

In order to determine the possible relationship between the trend slope values and the location of stations, the results given in Table 2 were analyzed with respect to each region. (i.e. northwest, southwest, and southeast). For the north stations, the likelihood of the existence of a trend in rainfall extremes between 1970 and 2003 is relatively small; only 7 of the 25 slope values (i.e.28%) were found to be significant. Four out of the 7 significant slope values are +ve and 3 are -ve. For the southwest stations, the likelihood of the existence of a trend in rainfall extremes during the chosen period is similar to northern stations; however, that likelihood is still less than 50% (6 of the 25 slope values being significant), and again the chances of +ve and -ve slope values are about equal (12 +ve, 13 -ve). The southeast stations have slightly different. Eight out of 25 trend slopes were -ve, 6 +ve and one no change. Fifteen out of 25 slope values were significant and 12 out of 15 significant slope values are -ve and 3 +ve.

With respect to the factor of rainfall duration (Table 2), there are greater numbers of significant slopes for the shorter durations of 15, 30, and 60 minutes (i.e. 17 of 45, or 38%) than for the longer durations of 6 and 12 hours (i.e. 9 of 30, or 30%). Furthermore, the shorter duration significant slope values revealed a greater number of -ve or decreasing trends (i.e. 14 of 17, or 82%), and the longer duration cases indicated a greater number of +ve values (i.e. 6 of 13, or 46%). The trend results are not consistent within or among the rainfall durations considered in this analysis; moreover, there is no obvious rationale either for the shorter duration slopes to more likely be significant or for those slopes to more likely be -ve.

It is perhaps most enlightening to explore the occurrences and signs of significant trend slopes with regard to the interaction between rainfall duration and storm location. Although there are relatively few significant slope values for the northwest stations, virtually all these values (i.e. 6 of 7) occur for the longer durations of 6 and 12 hours (Table 2). These results also reveal that 20% of the trend slopes determined for the longer durations at the northwest locations are significant, while only 1 slope value (i.e. 4%) is significant for the northwest shorter durations. For the southwest stations about 56% of the trend slopes were observed to be significant; seventy nine percent (11 of 14) of the significant slopes are linked to shorter durations, and 82% (9 of 11) of the significant shorter duration slopes are -ve. With respect to the southeast stations, most of the significant slope values calculated for this region (i.e. 6 of 7 or 86%) are linked to the shorter durations of 15, 30 and 60 minutes. Moreover, about half of the slope values determined for the southeast shorter durations are significant (i.e. 7 of 15 or 47%); 6 of these 7 shorter duration significant slopes at the southeast stations (i.e. 86%) are -ve.

Therefore, there seem to be slight concentrations of significant trend slope values for both the longer durations at the northwest stations and the shorter durations at the southwest and southeast stations. Also, there is a slight tendency for the northwest concentration to have +ve values and for the southwest concentration to have -ve values.

The average trend slope results for the shorter durations (15 min, 30 min, and 60 min) and the longer durations (6 hours and 12 hours) were calculated in terms of the equivalent percent changes per decade (a variable used frequently in climate change literature).The percent change per decade in extreme rainfall amounts was computed on the basis of the slope of the trend line and the mean extreme value for the period of each trend line (i.e. 1970 through 2003) for each of the 5 rainfall durations at each of the 15 stations. The two-way analysis of variance as given in Table 8 indicates that there is no significant effect of duration, and interaction of region and duration on the changes in rainfall per decade. However, once more the regions were found to be the most dominant factor. This fact was also identified and supported by the result of the Duncan multi-range test. The mean change in rainfall per decade was similar for the southwest and southeast regions, but different from the northwest region at 95% confidence level; The +ve or -ve sign associated with each plotted point is; therefore, identical with the sign of the average of the duration slope computed from the raw data (not shown) but has some dissimilarity to the trend slope from the three years moving average presented in Table 2.

Fig. 4 presents the results obtained from fitting trend lines to the three years moving average series of monthly rainfall extremes for the period from 1970 to 2003, for both the shorter and longer durations, and for the three selected regions across Ontario. The percentage change per decade values were computed on the basis of the mean of the slopes and the mean of the mean extremes (for the 5 stations) for each duration, month, and for the annual values. It should be noted that the mean monthly extremes used for the determination for short and long durations exhibit a strong seasonal pattern for all regions (Dickinson, 1977). As spring (April and May) and fall (October and Septem-

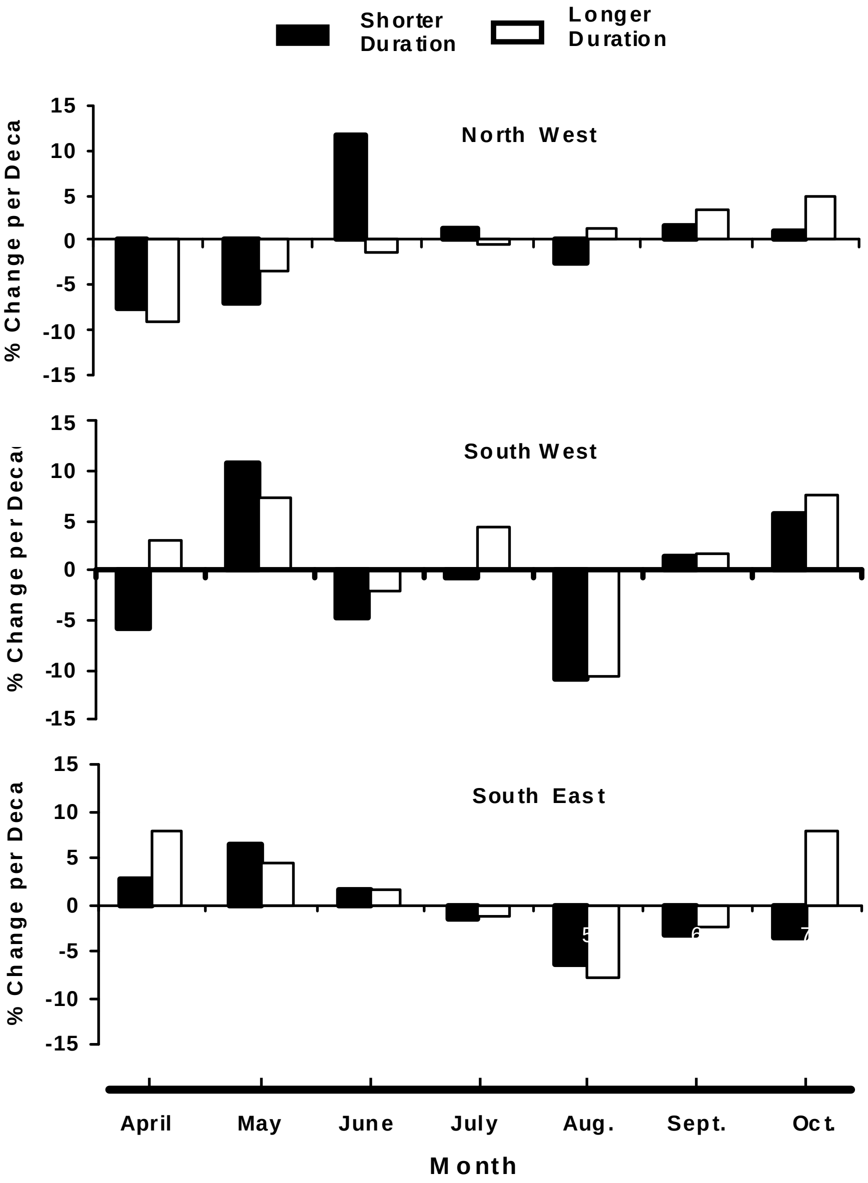

Fig.4. Monthly change in short and long duration rainfall extremes in three regions of Ontario

ber) means are only about 50% of the summer means (June, July, August, and September), particularly for the shorter durations (Dickinson, 1977); therefore, it must be kept in mind that the monthly percentage change values have been calculated on the basis of the seasonally varying mean rainfall extremes.

The results presented in Fig. 4 are once again widely scattered; however, the scatter in these diagrams is somewhat less than that shown in Table 2. This is probably due to averaging of the several station values for determination of each point. Also, as noted earlier, there is no obvious pattern associated with the shorter and longer durations. Similarities and differences between results for the northwest, southwest, and southeast stations are not particularly obvious at first glance, and may not be significant. However, it seems worthwhile to explore these data further. The range of the percentage change values for each month is about equally wide and includes both +ve and -ve values for all months except June and September, in which case the range is narrower.

While most of the data for the month of April show -ve change for the southwestern region, and all of the data for the month of May show +ve changes for the southwest and southeast regions, there is a -ve change for both the shorter and longer durations for the same period of time (April and May) in the northwest region (Fig. 4). Most of the data for the month of August for all regions and for all durations indicate -ve change per decade. During the months of June and July there are mixed but small changes (except shorter duration in the northwest region). For the month of September the changes per decade are both +ve and -ve and are smaller in magnitude. For the months of May and August, a number of the points were determined from a considerable number of significant trend slopes. Furthermore, most of the points for the month of August are -ve, and once again a number of these points are among many significant trend slopes. The corresponding points for the annual extremes are also virtually -ve, and were determined from many significant trend slopes.

The question arises: Do these results indicate any significant changes in monthly rainfall extremes? The answer to this question clearly depends on the criterion established to ascertain significance. For example, the criterion could be set that most if not all the percentage change values determined for the selected month are either +ve or -ve, and that many of those values for the rainfall extremes for that month are also determined from a majority of significant trend slopes to be considered as significant changes. Given such a criterion, the shorter and longer durations extremes for the month of May in the southwest and southeast regions, and the shorter durations extremes in the northwest region could be considered to have an increased between 1970 and 2003 (Fig. 4). However, with that same criterion, the extremes in August in the southwest and southeast regions would also have to be considered to have changed, but in these cases the changes would be -ve.

To explore the monthly changes in the rainfall extremes, the data for the month of May and August for all the 15 selected stations were analyzed in detail and the results are presented in Figs 5 and 6, respectively. These data reveal that for the southwest and southeast regions for most of the stations, the increase in the shorter duration extremes ranges from 7.9 to 26.7 %, and for the longer durations the increase ranges from 0.6 to 18.5 %. Only one station showed a decrease in both short and long term rainfall extremes, and the decrease was less than half of the increase in this region. In the northwest region the pattern of percent change is mixed, with both +ve and -ve changes.

The results in Fig. 5 show a dominant -ve change for both (shorter and longer) durations and for all stations for the month of August. Only Orillia in southeast region (for both the (shorter and longer durations), and Sioux Lookout in the northwest region (for only the longer durations), show a positive change greater than 4%. For the other southwest stations the +ve changes per decade is less than 3 percent.

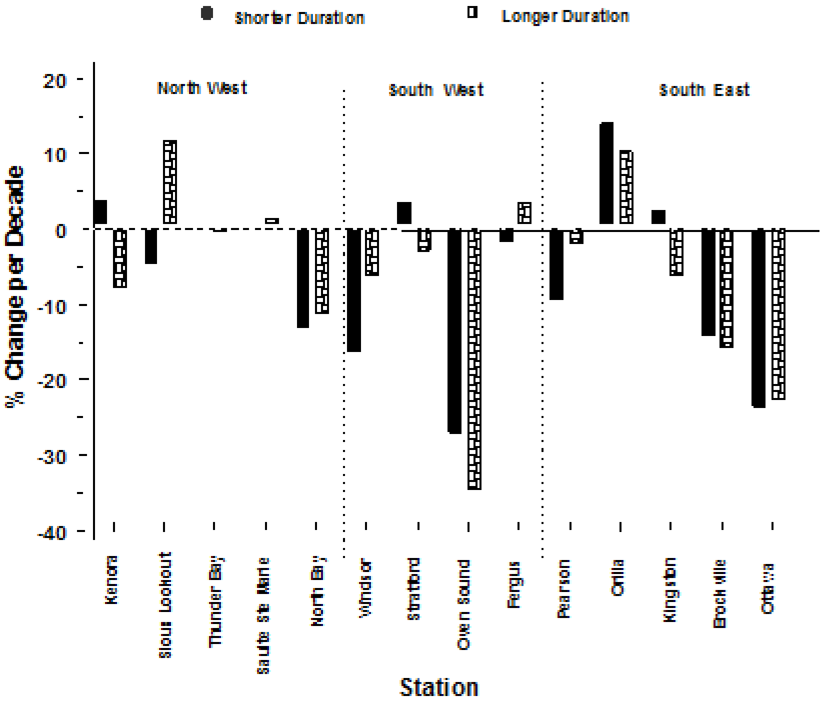

Fig. 5. Changes in short and long duration rainfall extremes for the month of August at fifteen stations in Ontario

CONCLUSIONS

The results of this study indicate that the +ve and -ve changes in annual rainfall extremes are similar in the order of magnitude. There is a greater variability among stations for shorter durations. The change in trends between shorter duration and longer duration are similar; however, the change in trends among the shorter and longer durations is different. There is no obvious spatial pattern with possible exception of +ve trends at north-western locations.While the changes in monthly extremes for the months of April and May in the Northwest region tend to be negative; the May and October extremes in the southwest region and the April and May extremes in the southeast region tend to be positive. The change in August extremes for the southwest and southeast regions is negative, and the magnitude of change in the southwest region is almost double the magnitude in the southeast region. The negative change in August trend seems to have a significant impact on the annual extremes in the southwest and southeast regions. Overall analysis shows that there is change in monthly extremes in short and long duration rainfall; however, the decrease and increase in rainfall varies spatially across Ontario.

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