Ontario

Standardized Precipitation Index

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Ministry of Natural Resources and Forestry

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Executive Summary

In 2015, the Spatial Data Infrastructure Unit (SDI) of the Ontario Ministry of Natural Resources and Forestry (MNRF) generated a Standardized Precipitation Index (SPI) for selected Environment Canada long-term climate stations located within the province of Ontario.

Standardized Precipitation Index (SPI) quantifies the precipitation deficit/surplus as an index for multiple time scales. The index is used to study the impact of dry and wet conditions to formulate sound water management approaches.

SPI is provided for 1-month, 3-month, 6-month, 9-month, 12-month and 24-month time scales in MS Access Personnel Geodatabase format.

This document details how the above indices were estimated, the structure of the final data package and considerations on appropriate data uses and limitations.

Acknowledgements

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Key Words

Standardized Precipitation Index, Precipitation, Drought

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CMI: Crop Moisture Index

LIO: Land Information Ontario

Mm: Millimetre

NMHSs: National Meteorological and Hydrological Services

PDSI: Palmer Drought Severity Index

SPI: Standardized Precipitation Index

WMO: World Meteorological Organization

1. Introduction

The Inter-Regional Workshop on Indices and Early Warning Systems for Drought was held in Lincoln, Nebraska, USA from 8 to 11 December 2009. The workshop focused on developing standards for drought indices and guidelines for a drought early warning system. The experts approved the use of the Standardized Precipitation Index (SPI) by all National Meteorological and Hydrological Services (NMHSs) around the world. Based on the recommendations, called the Lincoln Declaration on Drought, the World Meteorological Organisation (WMO) in 2012 published the "Standardized Precipitation User Guide" and the software tool.

For the present study, Standardized Precipitation Index values were estimated using the procedure and the software recommended by the WMO (2012).

2. Objective

The objective of this study is to estimate 1-month, 3-month, 6-month, 9-month, 12-month and 24-month Standardized Precipitation Index using the referenced WMO (2012) manual and software for the province of Ontario.

3. Understanding Drought

Drought is an insidious natural hazard and can affect all climatic regimes. It is defined as the deficiency of precipitation relative to what is expected or normal. In fact, when drought is extended for a season or longer period, the water quantity available to human activities and the environment can be insufficient to meet the demands. Therefore, some of the information needs for drought analysis are:

- What is the absolute amount of precipitation?
- What is the absolute/relative departure from the mean precipitation?
- How frequent are such departures?
- How can you express the departure as a single number comparable across climatic regions?

In order to understand drought severity, it is categorized based on the nature as:

- meteorological
- agricultural
- hydrological and
- socioeconomic

The origin of drought is from the deficiency of precipitation. Other types of drought cascade from this initial deficiency. Figure 1 shows the propagation of drought through the components of the hydrologic cycle and the sequence of drought. Figure 2 shows the interrelationship between the different types of drought.

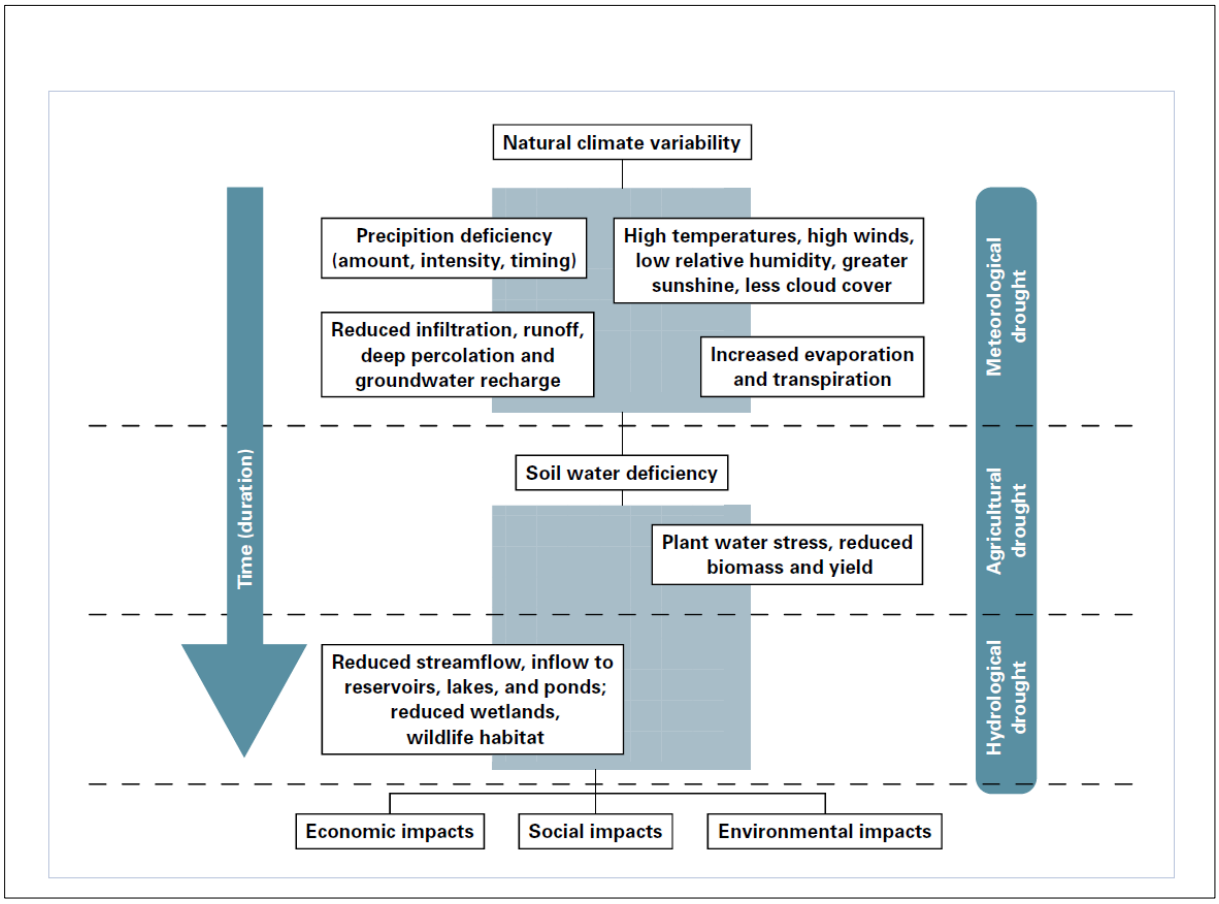

Figure 1. Propagation of drought through the hydrologic cycle and the sequence of drought (WMO, 2006).

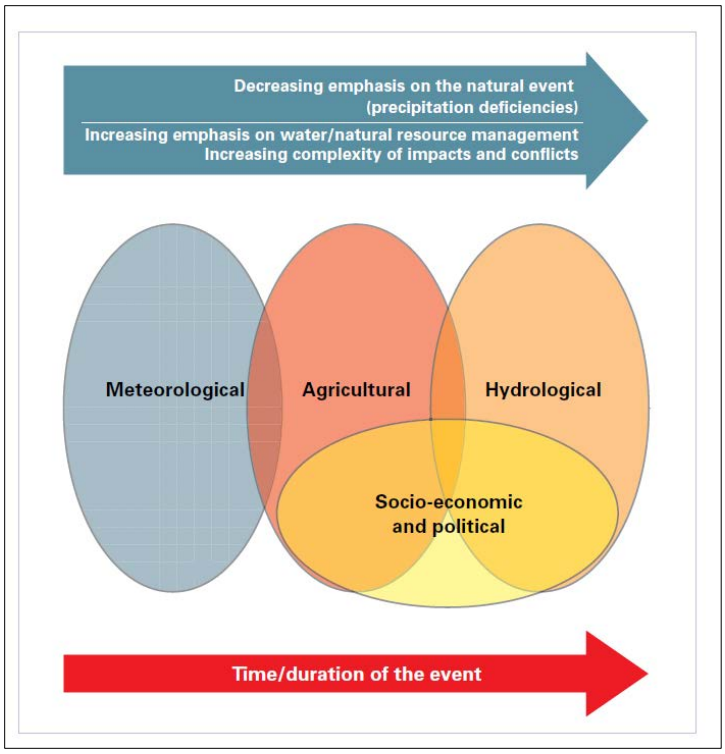

Figure 2. Interrelationship between the different types of drought (WMO, 2006).

4. Software and the Scientific Principles

The SPI program (SPI_SL_6.exe) (http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx) compiled in C++ is used for the analysis of precipitation time series data. The program calculates SPI values for up to six time windows. The time windows used for the present study are 1-month, 3-month, 6-month, 9-month, 12-month and 24-month. Year, month and the precipitation values constitute the data required for the program. A minimum of 20-30 years of monthly data is recommended for the analysis with 50-60 years or more being optimal.

McKee et al. (1993) developed the Standardized Precipitation Index (SPI). Computation of the SPI values involves fitting a gamma probability density function to a given frequency distribution of precipitation totals for a station and finding the cumulative probability. The cumulative probability is then transformed to the standard normal random variable with mean zero and variance of one, which is the value of the SPI.

With this technique, a standardized index is estimated that, in turn, can be used to combine and compare drought values across regions with markedly different climates. Further to that, as it is normalized, so both wet and dry years are represented.

Given a time series of monthly precipitation data for a location, the software calculates the SPI for any month in the record for the previous i months (where i=1, 2, 3 to 12 to 24 to 48) depending upon the time scale of interest. For example, the 3-month SPI calculated for September 2012 would have utilized the precipitation total of July 2012 through September 2012. This is usually referenced as “3-month SPI for the end of September 2012”. In other words, a 3-month SPI at the end of September compares the July-August-September precipitation total in that particular year with the July-August-September precipitation totals of all the years. The multiple time scales reflect the impact of drought on the availability of water quantity.

The classification system of the SPI values and the probability of occurrence are given in Table 1.

SPI Index	Category	Number of Times in 100 Years	Severity of Drought
Greater Than +2.0	Extremely Wet	Not Applicable	Not Applicable
+1.5 to +1.99	Very Wet	Not Applicable	Not Applicable
+1.0 to +1.49	Moderately Wet	Not Applicable	Not Applicable
-0.99 to +0.99	Near Normal	33	1 in 3 years
-1.0 to -1.49	Moderately Dry	10	1 in 10 years
-1.5 to -1.99	Severely Dry	5	1 in 20 years
Less Than -2.0	Extremely Dry	2.5	1 in 50 years

Table 1. Classification system of SPI values and the probability of occurrence.

The SPI time window will reference different types of drought, subject to the climatic region where the value is being used. Some of the general uses as given in WMO (2012) are:

- 1-month SPI application is referenced for meteorological types of drought and approximate conditions represented by Crop Moisture Index.
- 3-month SPI application is referenced for agricultural type of drought. By moving the end month, soil moisture available from germination until the maturity of the crop can be assessed.
- 6-month SPI indicates seasonal to medium term trends.
- 9-month SPI indicates the inter-seasonal precipitation patterns. The 9-month period bridges a short term and a long-term drought.
- 12 to 24-month SPI reflects long-term precipitation patterns. These values are tied to streamflows and ground water levels. 12-month SPI approximate conditions represented by the Palmer Drought Severity Index.

Note: Palmer Drought Severity Index (PDSI) index is based on the supply and demand concept of the water balance equation calibrated for homogeneous regions. Crop Moisture Index (CMI) is a Palmer derivative and reflects moisture supply in the short term across major crop-producing regions. Both indices have been used with limited success as operational drought monitoring tools and triggers for policy responses.

An elaborative description and references on drought indices are given in Zargar et al (2011)

For technical details about the methodology and the software, please refer to the WMO (2012) user manual.

5. Source of Data and Climate Stations

Published historic adjusted mean monthly precipitation data was downloaded from the Environment Canada website (http://ec.gc.ca/dccha-ahccd/default.asp?lang=en&n=2E5F8A39-1) for the province of Ontario. A total of 58 climate stations are used for the analysis and Figure 3 and Figure 4 shows the location of the climate stations and the summary of record length. All the stations had a record length of more than 40 years prior to January 2015. Table 2 shows the details of the climate stations.

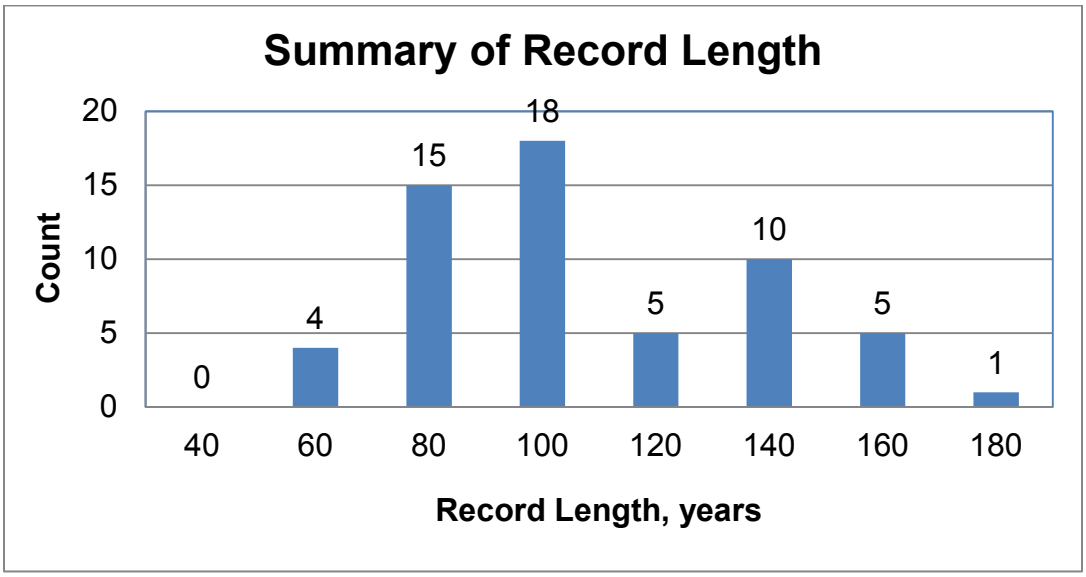

Figure 3. Summary of record length used for estimating the SPI.

Figure 4. Map showing the climate stations used for SPI analysis.

Station Name	Station ID	Start Year	End Year	Latitude Degrees	Longitude Degrees	Elevation Metres	Number of Years
AMHERSTBURG	6130257	1917	2014	42.1	-83.1	182	98
ARMSTRONG	6040330	1939	1991	50.3	-89.1	341	53
ATIKOKAN	6020384	1919	2006	48.8	-91.6	442	88
BEATRICE	6110606	1876	2008	45.1	-79.4	297	133
BELLEVILLE	6150689	1921	2014	44.2	-77.4	76	94
BIG TROUT LAKE	6010738	1939	1992	53.8	-89.9	224	54
BISCOTASING	6060773	1914	2000	47.3	-82.1	407	87
BROCKVILLE	6100971	1915	2014	44.6	-75.7	96	100
CAMERON FALLS	6041109	1924	1997	49.2	-88.3	229	74
CHAPLEAU	6061361	1914	2014	47.8	-83.3	447	101
CORNWALL	6101874	1951	2014	45.0	-74.8	64	64
DRYDEN	6032119	1914	2004	49.8	-92.8	413	91
EARLTON	6072225	1939	2004	47.7	-79.8	243	66
FORT FRANCES	6022476	1912	2010	48.7	-93.4	342	99
GERALDTON	6042716	1950	2014	49.8	-86.9	349	65
GODFREY	6102857	1924	2003	44.6	-76.6	160	80
GORE BAY	6092925	1916	1993	45.9	-82.6	194	78
HALIBURTON 3	6163171	1883	2014	45.0	-78.5	330	132
HAMILTON	6153194	1866	2011	43.2	-79.9	238	146
HORNEPAYNE	6053575	1917	1994	49.2	-84.8	335	78

Station Name	Station ID	Start Year	End Year	Latitude Degrees	Longitude Degrees	Elevation Metres	Number of Years
IROQUOIS FALLS	6073810	1913	1998	48.8	-80.7	259	86
KAPUSKASING	6073975	1918	2014	49.4	-82.5	227	97
KENORA	6034075	1900	2012	49.8	-94.4	406	113
KINGSTON	6104175	1872	2007	44.3	-76.5	77	136
LANSDOWNE HOUSE	6014350	1941	1989	52.2	-87.9	255	49
LONDON	6144475	1883	2014	43.0	-81.2	278	132
LUCKNOW	6124700	1885	1993	44.0	-81.5	290	109
MADAWASKA	6084770	1916	2000	45.5	-78.0	316	85
MINE CENTRE	6025205	1915	2014	48.8	-92.6	361	100
MOOSONEE	6075425	1892	2014	51.3	-80.7	10	123
MORRISBURG	6105460	1913	2008	44.9	-75.2	82	96
NORTH BAY	6085700	1915	2012	46.4	-79.4	370	98
ORANGEVILLE	6155790	1887	2014	43.9	-80.1	412	128
ORILLIA BRAIN	6115811	1871	2010	44.6	-79.4	250	140
OTTAWA	6105976	1890	2014	45.4	-75.7	79	125
OWEN SOUND	6116132	1879	2007	44.6	-80.9	179	129
PELEE ISLAND	6136336	1888	1994	41.8	-82.7	174	107
PETERBOROUGH	6166418	1866	2007	44.2	-78.4	191	142
PICKLE LAKE	6016527	1933	2012	51.5	-90.2	386	80
RED LAKE	6016975	1939	2011	51.1	-93.8	386	73

Station Name	Station ID	Start Year	End Year	Latitude Degrees	Longitude Degrees	Elevation Metres	Number of Years
RIDGETOWN	6137149	1883	1997	42.5	-81.9	206	115
SAULT STE MARIE	6057592	1945	2011	46.5	-84.5	192	67
SIOUX LOOKOUT	6037775	1914	2012	50.1	-91.9	383	99
SMOKY FALLS	6077845	1934	1996	50.1	-82.2	183	63
SUDBURY	6068150	1921	2012	46.6	-80.8	348	92
TERRACE BAY	6048231	1910	2007	48.8	-87.1	290	98
TIMMINS	6078285	1955	2008	48.6	-81.4	295	54
TOBERMORY	6128323	1915	1994	45.2	-81.5	190	80
TORONTO	6158350	1840	2012	43.7	-79.4	113	173
TORONTO PEARSON	6158733	1938	2012	43.7	-79.6	173	75
TRANQUILLO	6048864	1878	2007	48.2	-89.5	317	130
VINELAND	6139141	1919	2013	43.2	-79.4	110	95
WALLACEBURG	6139265	1906	1997	42.6	-82.4	177	92
WAWA	6059D09	1940	2013	48.0	-84.8	287	74
WELLAND	6139445	1873	2014	43.0	-79.3	175	142
WIARTON	6119500	1948	2014	44.8	-81.1	222	67
WINDSOR	6139525	1866	2014	42.3	-82.9	190	149
WOODSTOCK	6149625	1870	2014	43.1	-80.8	282	145

Table 2. List of climate stations with the record length and location.

6. Results and Discussions

6.1 Data Packages

The SPI estimation data package and the metadata are stored and distributed through Land Information Ontario (LIO) (https://www.ontario.ca/page/land-information-ontario). The metadata information associated with the data package can be accessed through the LIO Metadata Management Tool (https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home).

The data is stored in an ESRI 10.1 Personal Geodatabase which is entitled "StandardizedPrecipitationIndex.mdb". The database contains point feature class with 58 climate locations and the SPI values for 1-month, 3-month, 6-month, 9-month, 12-month and 24- month.

The proxy data comprising of the input files (.cor) and the output files (.dat) for the SPI program are in separate zip-file packages.

6.2 Discussion

The main features of SPI indices namely; (1) drought history of a particular station, (2) close relationship between SPI and precipitation and (3) comparison drought for two climatic regions in terms of their respective normal precipitation is highlighted through a case study (example). The example uses precipitation data from Moosonee climate station.

6.2.1 Drought History

The Moosonee station (ID 6075425) has 123 years of record from 1892-2014. The history of drought with 1-month, 2-month, 3-month, 6-month, 9-month, 12 month and 24-month SPI for the period of record is shown in Figure 5. Figure 5 gives the overall picture of the index for different time scales. It describes the variability of drought frequencies and their duration resulting from varying time windows. From the graph, it can be inferred that as the time scale progresses temporally from 1-month/3-month (within a year or seasonal) to a higher scale (1 or 2 years); the dominating climatic condition gets pronounced. For the present station, wet conditions persist; however, there are periods with less than zero as well (e.g. 1993-1996).

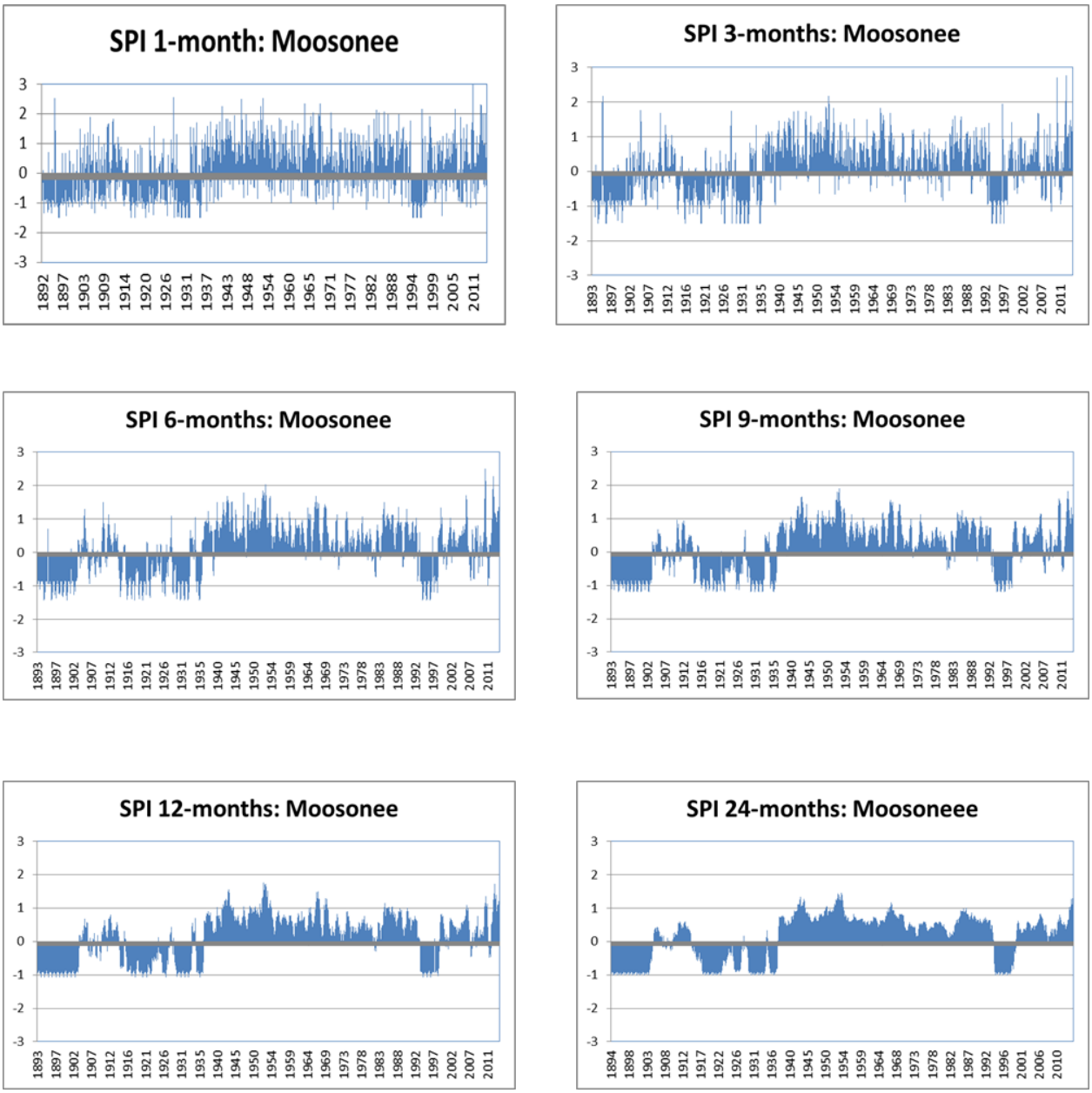

Figure 5. SPI suite (six-time scale) for Moosonee climate station.

6.2.2 Relationship between SPI and Precipitation

The following discussion describes how SPI is estimated based on the gamma distribution function fitted for data from 1892-2014 to establish an index for a short period (2000-2014) of precipitation.

A time scale of 1-month and 3-month are selected to demonstrate this feature. Table 3 shows the precipitation and the 1-month SPI values for the Moosonee Climate station for 2000-2014. The values are plotted on two separate graphs, Figures 6 and 7. From the graph, it can be seen that the annual precipitation and the SPI follow a similar trend and therefore a close relationship between the two variables exits.

Year	Month	Precipitation mm	SPI_1-month	Category
2000	8	87	0.33	Near normal
2001	8	106	0.8	Near normal
2002	8	62	-0.36	Near normal
2003	8	42	-0.97	Near normal
2004	8	96	0.56	Near normal
2005	8	97	0.59	Near normal
2006	8	116	1.03	Moderately wet
2007	8	86	0.31	Near normal
2008	8	62	-0.36	Near normal
2009	8	99	0.63	Near normal
2010	8	70	-0.13	Near normal
2011	8	67	-0.22	Near normal
2012	8	98	0.61	Near normal
2013	8	120	1.11	Moderately wet
2014	8	60	-0.42	Near normal

Table 3. SPI-1 month: Moosonee climate station.

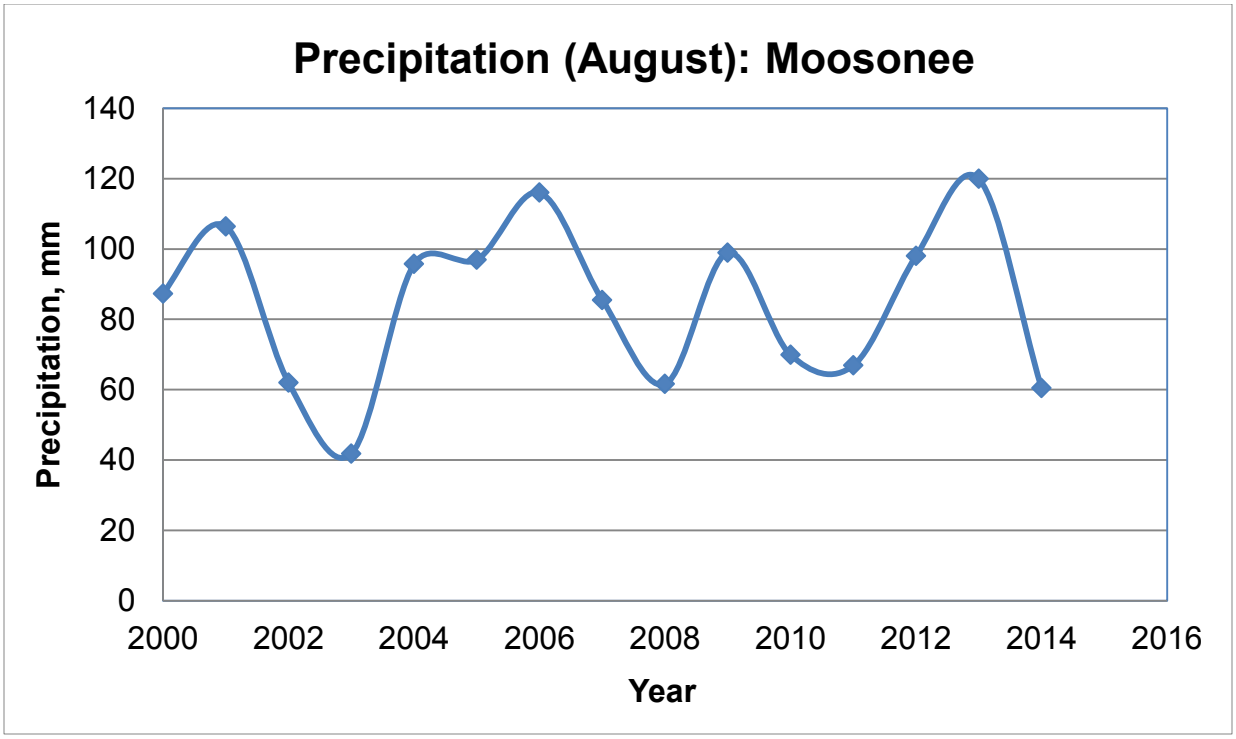

Figure 6. Precipitation (August): Moosonee climate station.

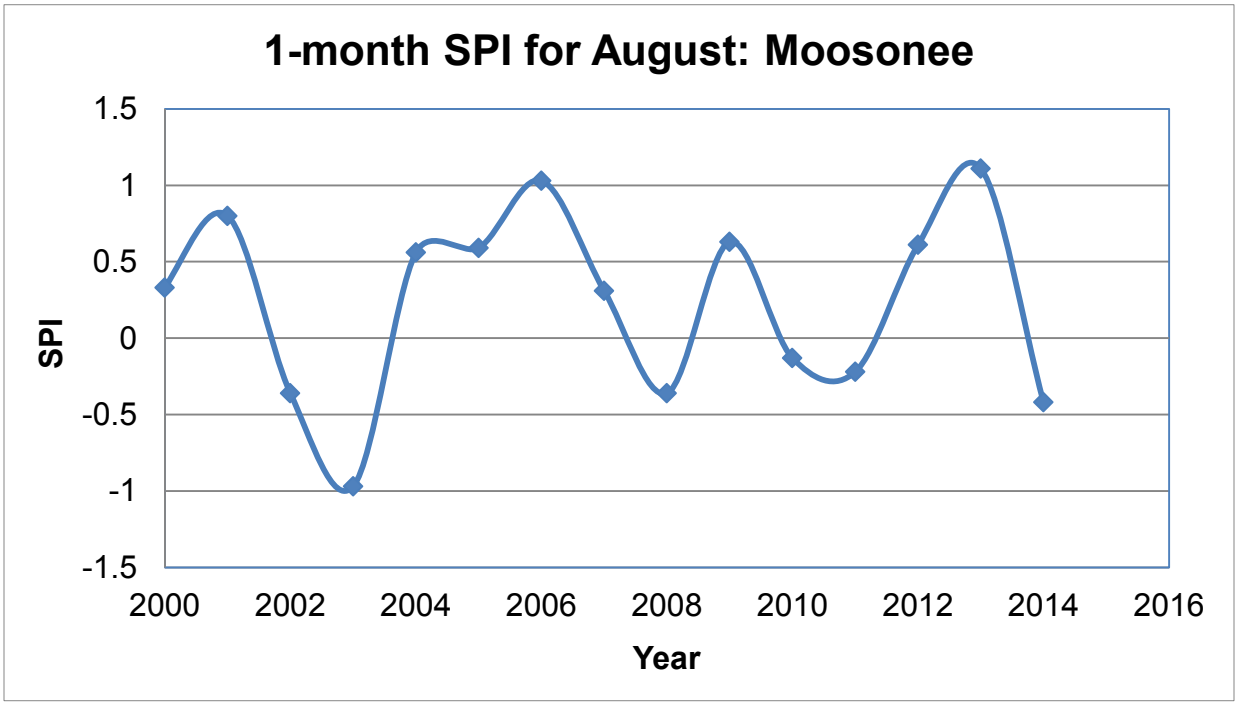

Figure 7. 1-month SPI for (August): Moosonee climate station.

Similarly, to get the 3-month SPI ending in September, the precipitation total of July-August-September is used. The relationship between the precipitation total and the SPI value is shown in Figures 9 and 10 using the data in Table 4. Both graphs show similar trends. The timing of precipitation is important for agricultural practices as well as understanding summer demand. Accumulated values (3-month) can be used to analyze the magnitude of drought. The 3-month SPI ending in the month of September tends to highlight drier conditions that are experienced in Ontario. This water deficit effects agricultural practices, water supply, hydroelectric power generation, commercial shipping, commercial fishing, probability of forest fire occurrence and recreational activities (Gabriel et.al, 1993).

Year	Month	Precipitation July, mm	Precipitation August, mm	Precipitation September, mm	Total Precipitation, mm	3-Month SPI
2000	9	41.1	87.3	67.5	195.9	-0.48
2001	9	107.7	106.4	118.3	332.4	0.96
2002	9	112.6	62	125.5	300.1	0.66
2003	9	99.1	41.8	139	279.9	0.45
2004	9	59.3	95.7	82.9	237.9	0
2005	9	65.1	96.9	53.8	215.8	-0.25
2006	9	73	116	57.2	246.2	0.09
2007	9	101.7	85.5	170.5	357.7	1.21
2008	9	117.5	61.6	92.8	271.9	0.38
2009	9	112.2	98.9	88	299.1	0.64
2010	9	154.4	69.9	97.7	322	0.87
2011	9	45.2	66.9	85.5	197.6	-0.46
2012	9	55.8	98	69.4	223.2	-0.17
2013	9	108.3	119.9	106.2	334.4	0.98
2014	9	192.1	60.4	97.8	350.3	1.13

Table 4. 3-month SPI for Moosonee climate station.

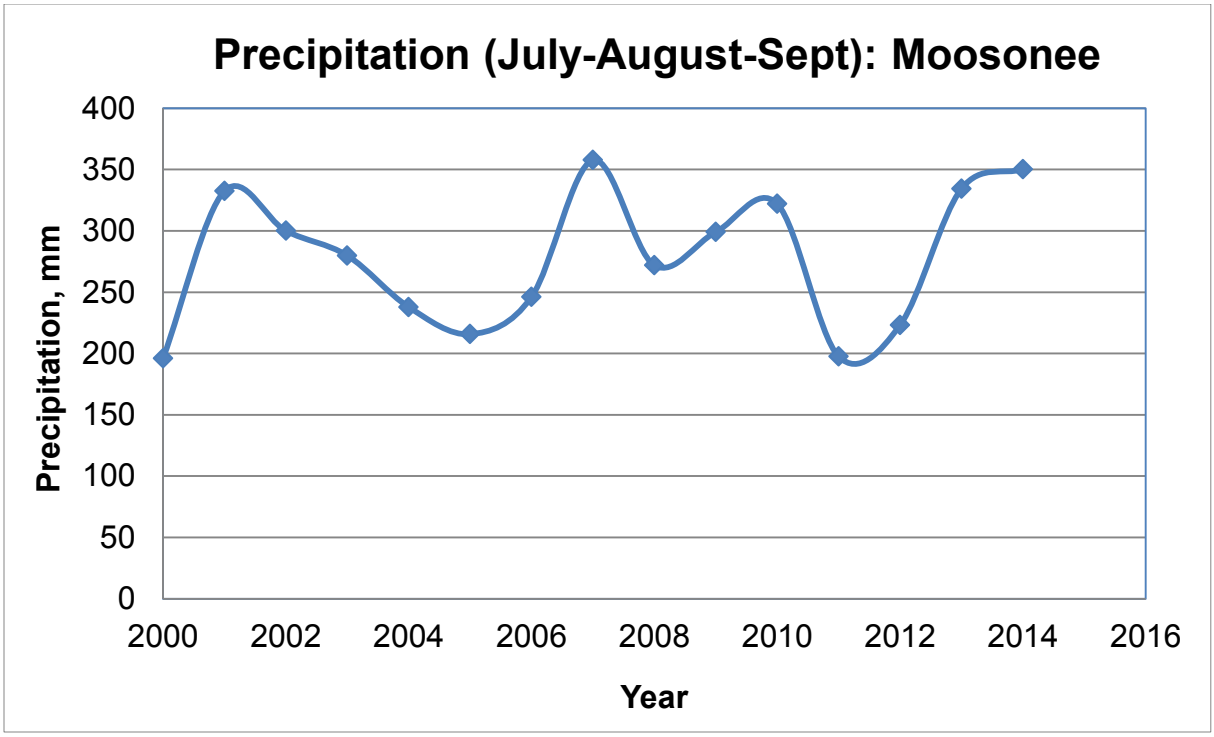

Figure 8. Total precipitation (July-Aug-Sept).

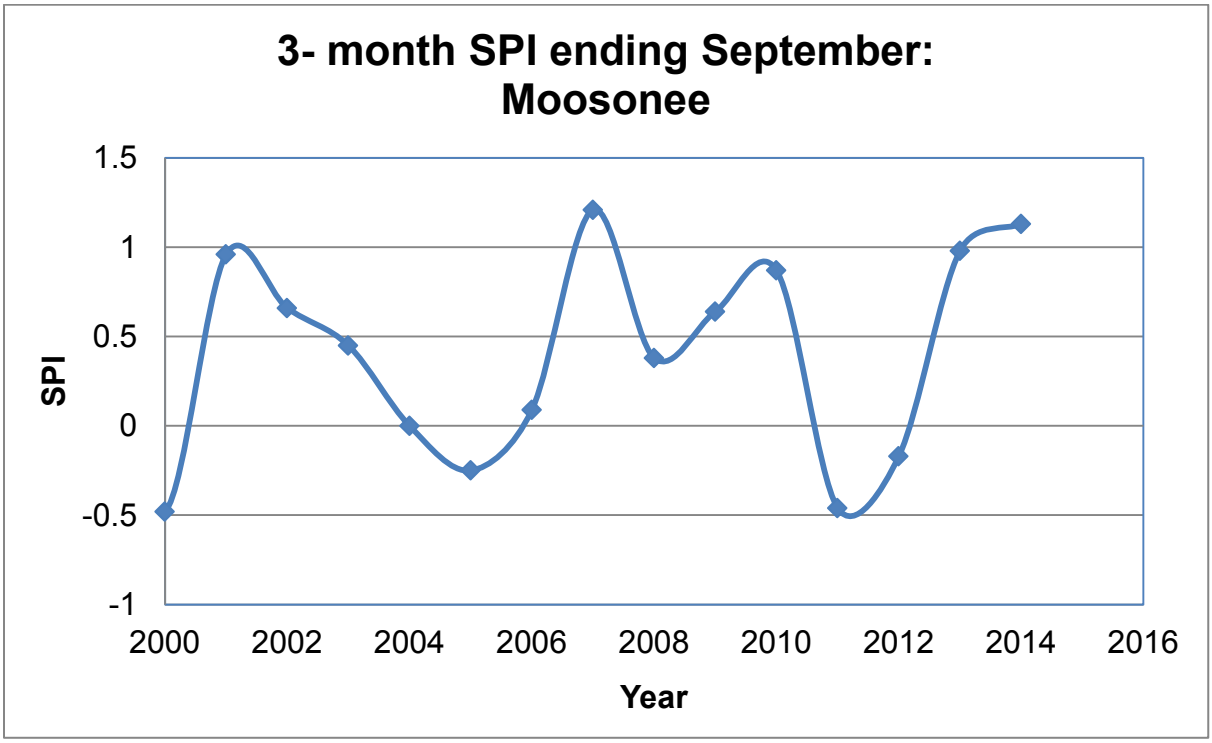

Figure 9. 3-month SPI or SPI for 3-month precipitation total.

Compare Drought of Two Climatic Regions

The SPI index is spatially invariant in its interpretation. This means the normalized value designates the drought severity on a common scale to aid in comparison. The normalized index in turn can be used to compare the drought severity in two climate regions with the respective precipitation normal. To illustrate this feature, the drought of 2001 with 1-month SPI for the month of August is shown in Figure 10. During this year, the Great Lakes region experienced record level lows in precipitation during the summer. The map shows the variability of the index with respect to the normal precipitation across climate regions of Ontario. Most of the gauges showed a normal and moderately wet condition; however, there is evidence of drought mainly in the Great Lakes watershed region. The index can be interpreted statistically for a given location and for a given time of the year.

The index is versatile in evaluating both dry (deficit) and wet (surplus) periods with spatio-temporal flexibility.

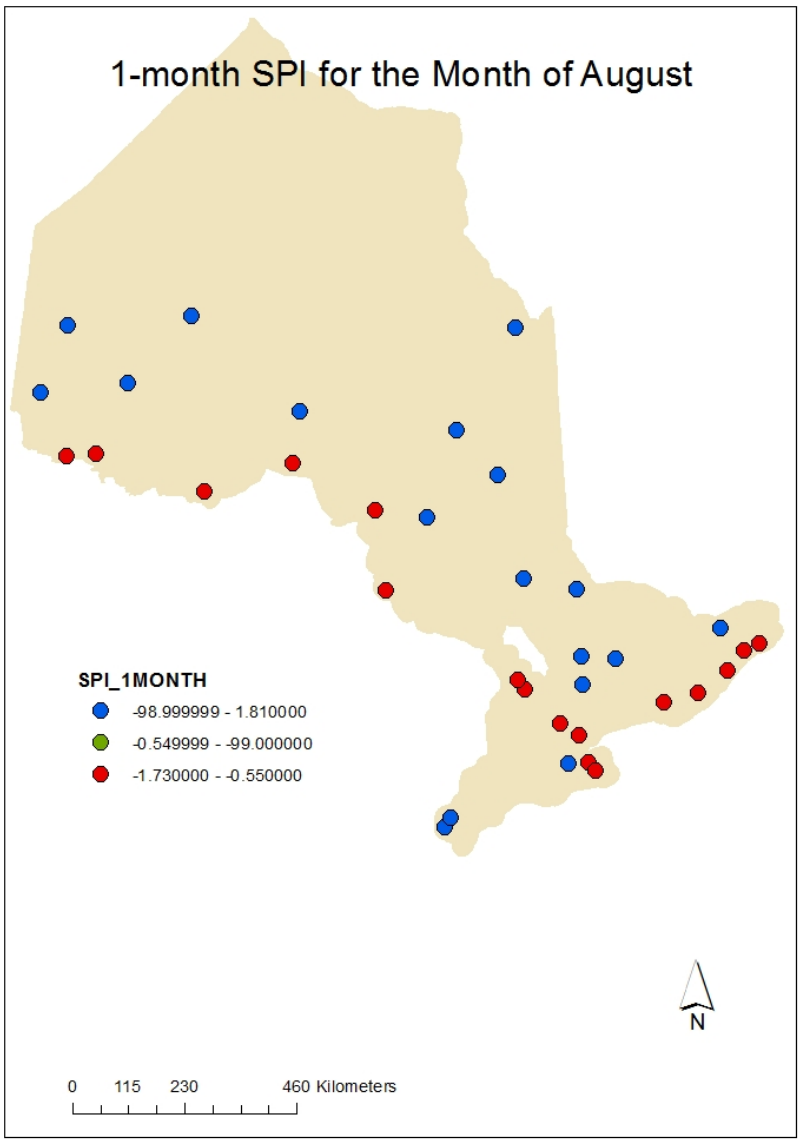

Figure 10. 1-month SPI for the month of August 2001 for all the climate stations to show the severity of drought.

7. Recommended Data Uses and Data Considerations

Plotting a time series of year against the SPI allows the drought history to be viewed for a given station. Being normalized, the SPI can be used to compare stations with different climates.

This data product gives the SPI values for the point locations of the climate stations only. No regional analysis has been carried out.

The data used is the historic adjusted data from Environment Canada. There are stations where the stations in the proximity that are joined to get longer period of record. The index estimated for the missing data should be used carefully.

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