ASSESSMENT OF DIFFERENT TOOLS TO CALCULATE SPI

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ABSTRACT

Drought means a place that has less precipitation than it was normal over a certain period. Drought is considered as a natural disaster of below-average precipitation in a given region, resulting in prolonged shortages in the water supply, whether atmospheric, surface water or ground water.
The Palmer Drought Severity Index (PDSI), developed in 1965 by Palmer, is probably the first known meteorological drought indicator used in the United States and is well known internationally. In order to get a complete picture of drought conditions, an analyist should examine several drought indicators and indices. These include simple indices like the percent of normal precipitation and number of days with no precipitation, specific indices created to assess drought (such as the Palmer Drought Index and after Standardized Precipitation Index SPI). In the recent time the SPI is recommended by World Metrological Organization as the main metrological drought index that countries should use to monitor and follow drought conditions as given by Hayes, (2011). As there are several tools developed to calculate the SPI and there are no references recommended any of these tool can be used to calculate the SPI, therefore this paper develop a new tool to calculate SPI for the data obtained for four stations in Ethiopia and evaluate different tolls to calculate SPI. The authors developed a spreadsheet can be used to calculate the SPI. The results of the developed tool compared with the results from published tools by National Drought Mitigation Center (NDMC) and that published by Elkolally. The results show that in case of calculating SPI for one or three months the authors and NDMC tools are recommended as they gave close values of SPI. In case of calculation SPI for more than 3 months, any used tool among the three examined tools gave matching value, so any used tool lead to the same value of SPI.

Keywords: Drought index; Standardized Precipitation Index, Water resources, Ethiopia water resources

1 INTRODUCTION

Some meteorological drought definitions developed for application in various countries of the world include as listed by Donald, (1985):
1) Less than 2.5 mm of rainfall in forty-eight hours (United States) as by Blumenstock, G., Jr (1942),
2) Actual seasonal rainfall is deficient by more than twice the mean deviation (India). As given by Ramdas, D. A (1960),
3) When annual rainfall is less than 180 mm (Libya) as given by Hudson, H. E (1964),
4) A period of six days without rain (Bali). As given by Hudson, H. E (1964) and
5) Fifteen days, none of which received as much as 0.25 mm (Britain) as given by British Rainfall Organization, (1975).

The Standardized Precipitation Index (SPI-n) introduced by McKee et al., (1993) is a statistical indicator that compares the total precipitation received at a particular location during a period of n months with the long-term precipitation distribution for the same period of time at that location. SPI is typically calculated on a monthly basis for a moving window of n months, where n indicates the precipitation accumulation period, which would usually be 1, 3, 6, 9, 12, 24 or 48 months depending on the application.

precipitation time series over the time period of interest (i.e., 3 months for the SPI_03, 6 months for the SPI_06, 9 months for the SPI_09, 12 months for the SPI_12, and 24 months for the SPI_24) as recommended by Trambauer et al. (2014). Hence, SPI became highly associated with indices of agricultural drought, hydrological drought, and groundwater drought; whereas SPI_03 can be used as an agricultural drought index, SPI_06 is highly correlated with hydrological droughts, and SPI_12 and SPI_24 can detect ground water drought.

In this paper, the SPI is calculated from the Historical Monthly Observations Data of precipitation (P) as provided by the National Oceanic and Atmospheric Administration, National Centers for Environmental Information (2019). Four different stations are selected to be examined. These stations are: listed in table 1. The SPI is calculating for 1, 3, 6, 9, 12 and 24 month. The main aim is to calculate the SPI for the stations and comparing the obtained value with values calculated by other authors.

The results obtained by the Authors are compared by results using Elkolally program and program downloaded from NDMC. The results shows that the SPI value obtained for one and three months has an error when the precipitation containing Zero value. Using 6, 9, 12, 24 the zero value is vanished and the obtained results using the three different tools are the same.

Table 1. Selected stations location

Station Name	LATITUDE	LONGITUDE
DEBREMARCOS_Ethiopia	10.333°	37.667°
ADDIS ABABA BOLE_Ethiopia	9.033°	38.75°
GAMBELA_Ethiopia	8.25°	34.58°
GOBA_Ethiopia	7°	40°

2 LITERATURE REVIEW

Different indices have been discussed and applied for drought indicators. Among those are: Palmer Drought Severity Index (PDSI) by Palmer, W.C, (1965), Deciles as by Gibbs, W.J, (1967), Surface Water Supply Index (SWSI) as given by Shafer, B.A, (1982), Palfai Aridity Index (PAI) as given by Palfai, I., (1990), Standardized Precipitation Index (SPI) as recommended by McKee, T. B et al., (1993), Percent of Normal as recommended by Willeke, G.E et. al., (1994), and others such as Karavitis, (1999), Wilhite, D. A, (2007), and Chortaria, C et al., (2010). The nature of the indicator, local conditions, data availability and validity usually determine the indicator to be applied. Such criteria are discussed by different authors.

Research in the early 1980s uncovered more than 150 published definitions of drought. The definitions reflect differences in regions, needs, and disciplinary approaches as by Balasubramanian A., (2017).

Wilhite and Glantz, (1985) categorized the definitions in terms of four basic approaches to measuring drought: meteorological (significant negative deviation from mean precipitation), hydrological (deficit in the supply of surface and subsurface water), agricultural (deficit in soil moisture, driven by meteorological and hydrological drought, reducing the supply of moisture for vegetation), and socioeconomic (which combination of the above three types leading to undesirable social and economic impacts). The first three approaches deal with ways to measure drought as a physical phenomenon. The last deals with drought in terms of supply and demand, tracking the effects of water shortfall as it ripples through socioeconomic systems.

The Surface Water Supply Index (SWSI) was intended to be complementary to the PDSI, with the latter applying mainly to non-irrigated areas independent of mountain water supplies as given by Wilhite and Glantz, (1985).

Complex models (such as the National Land Data Assimilation System [NLDAS]) which calculate soil moisture and other hydrologic variables, indices used for water supply forecasting (such as the Surface Water Supply Index [SWSI]), and indices which reflect impacts on vegetation (such as the Vegetation Health Index [VHI] and Vegetation Drought Response Index [VegDRI]) and water availability (such as groundwater well levels and streamflow). The analyst should also examine indices at many different time scales to assess short-term to long-term drought conditions. The U.S. Drought Monitor does this by depicting drought integrated across all time scales and differentiates between agricultural and hydrological impacts.

The effect of the length of record on the standardized precipitation index (SPI) calculation was investigated by examining correlation coefficients as given by Hong, Wu et. al, (2005). He explained that the effect of the length of record used on SPI calculations was illustrated by comparing SPI values computed from different record lengths, and the reason for SPI value discrepancy was explored by investigating gamma distributions derived using different record lengths. The study shows that the SPI values derived from the different lengths of record are highly correlated for some stations
Zsolt Magyari-Sáska, (2007) Developing proper algorithm that can be adapted for different locations to calculate the SPI value, characterizing the meteorological drought and excess of humidity. The study presents that a software module, capable to create raster layers with SPI indices starting form locally measured precipitation, measure points' geographic location and altitude and digital elevation model.

Onusluel Gul et al, (2017) study, drought severity was analyzed based on the standardized precipitation index (SPI) and the standardized precipitation evapotranspiration index (SPEI) in multiple time scales in Seyhan river basin in Turkey to assess drought conditions and related hydrological impacts. He concluded that here is an increase in the drought frequency especially in recent years. Retrospective drought analysis using drought indices shows great importance as it provides substantial knowledge on drought severity, duration and frequency analysis

3 SPI CALCULATION METHOD

In order to compute the SPI value some parameters should be calculated in steps for each month through all the study period.

Cumulated precipitation

$$X = X_i = \sum_{j=i-(r-1)}^{i} p_j \quad (1)$$

Where x is the monthly precipitation and r is the timescale as in SPI_r calculated (1, 3, 6, 9, 12 and 24) for month i. Mean of the precipitation can be computed as:

$$\text{Mean} = \bar{X} = \frac{\sum X}{N} \quad (2)$$

Where N is the number of precipitation observations. The precipitation is converted to lognormal values and the statistics U, shape and scale parameters of gamma distribution are computed:

$$\text{log mean} = \bar{X}_{ln} = \ln(\bar{X}) \quad (3)$$

$$U = \bar{X}_{ln} - \frac{\sum \ln(X)}{N} \quad (4)$$

Shape parameter = $\alpha = \frac{1+\sqrt{1+\frac{4U}{3}}}{4U}$ (5)

Scale parameter = $\beta = \frac{\overline{X}}{\alpha}$ (6)

The resulting parameters are then used to find the cumulative probability of an observed precipitation event. The cumulative probability is given by:

$$G(x) = \frac{\int_0^x x^{\alpha-1} e^{\frac{-x}{\beta}} dx}{\beta^{\alpha}\Gamma(\alpha)} \quad (7)$$

Since the gamma function is undefined for x = 0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1 - q)G(x) \quad (8)$$

Where q is the probability of zero value and H (x) is the SPI value

4 RESULTS AND ANALYSIS

Figs from 1 through 6 shows the results of SPI at Debremarcos station for 1, 3, 6, 9, 12 and 24 months using the author calculation sheet for the period from 1954 till 1999. The results show that:
For Debremarcos when Appling SPI_01 one can detect the drought event (-3.33) which occurred in April 1977. In case of SPI_03 this event was not detected and conversely, -3.22 in October 1984, for SPI_06 the drought event is -3.20 in January 1985 and for SPI_09 the drought event is -3.36 in April 1985, SPI_12 the drought event is -2.33 in June 1970, finally for SPI_24 the drought event is -2.18 in June 1979.

For Addis Ababa Bole the maximum drought severity (-4.08) is for 6 months timescale in the year 1957. For 1, 3, 9, 12 and 24 month timescale the SPI value is maximum in the year 1957 (-3.56), 1957 (- 4.02), 1988 (-3.75). 1958 (-3.64) and 1966 (-2.58)

For Gambela the maximum drought severity (-4.11) is for 3 months timescale in the year 1993. For 1, 6, 9, 12 and 24 month timescale the SPI value is maximum in the year 1986 (-3.30), 1993 (-3.50), 1987 (-3.45). 1993 (-3.18) and 1988 (-2.84)

For Goba the maximum drought severity (-4.53) is for 1 months timescale in the year 1987. For 3, 6, 9, 12 and 24 month timescale the SPI value is maximum in the year 1986 (-4.15), 1986 (-4.15), 1986 (-4.36). 1987 (-4.29) and 1987 (-4.19)

As conclusion one of these timescale may detect a drought and can't be observed by another timescale and vice versa.

Debremarcos_Station

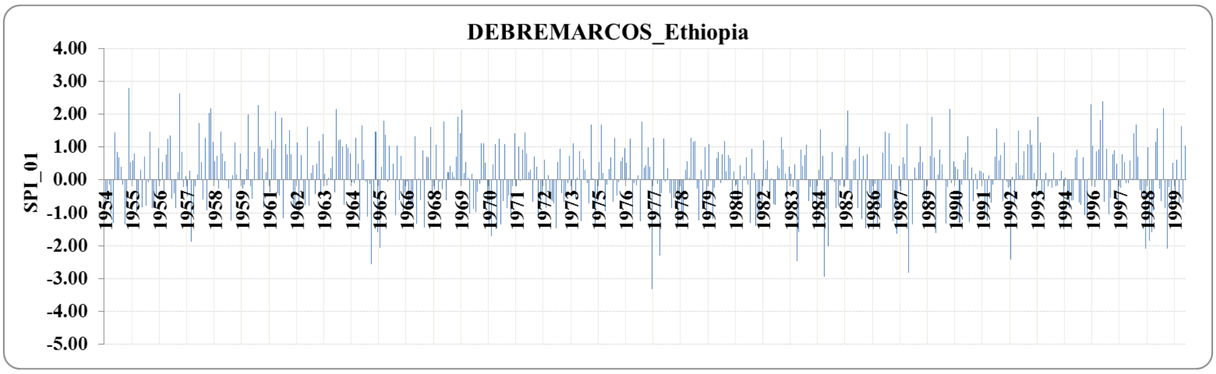

Figure 1. SPI value for one month for Debremarcos station Ethiopia

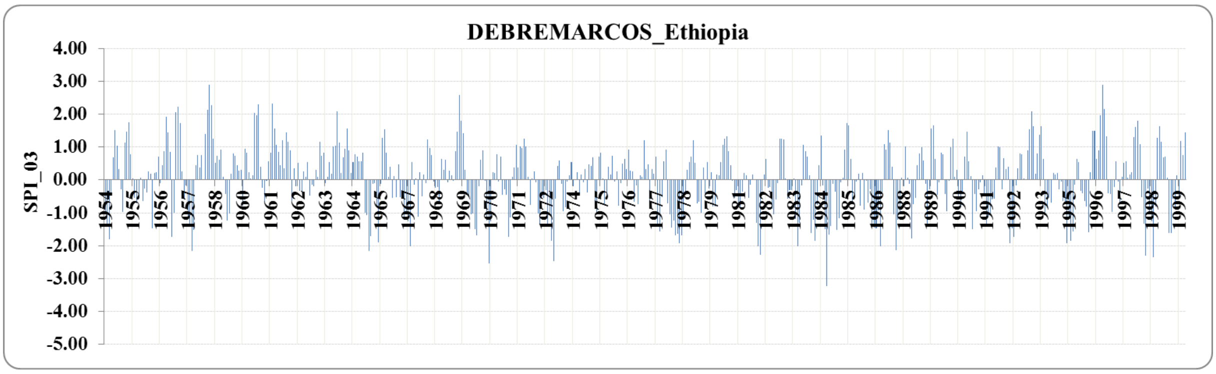

Figure 2. SPI value for three months for Debremarcos station Ethiopia

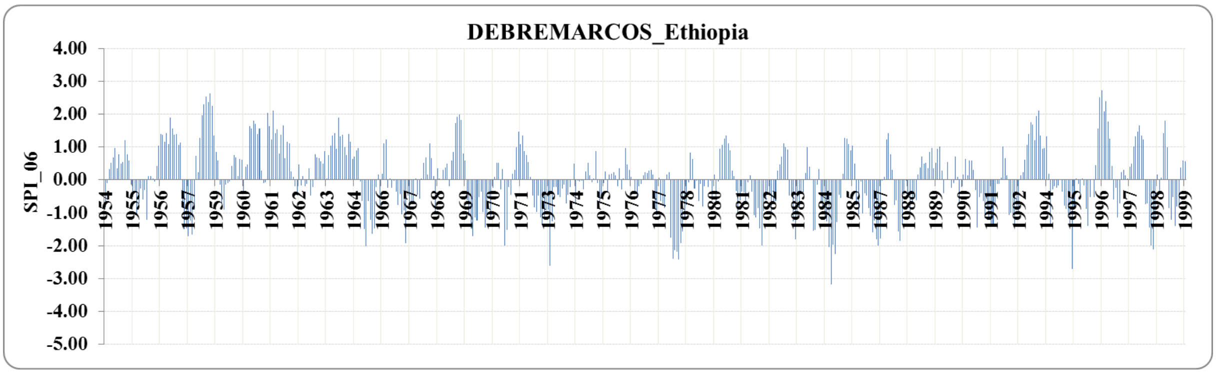

Figure 3. SPI value for six months for Debremarcos station Ethiopia

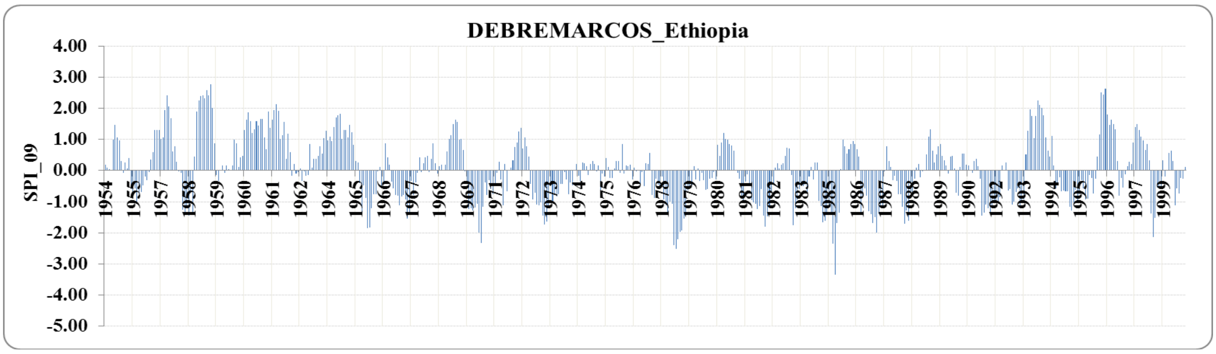

Figure 4. SPI value for nine months for Debremarcos station Ethiopia

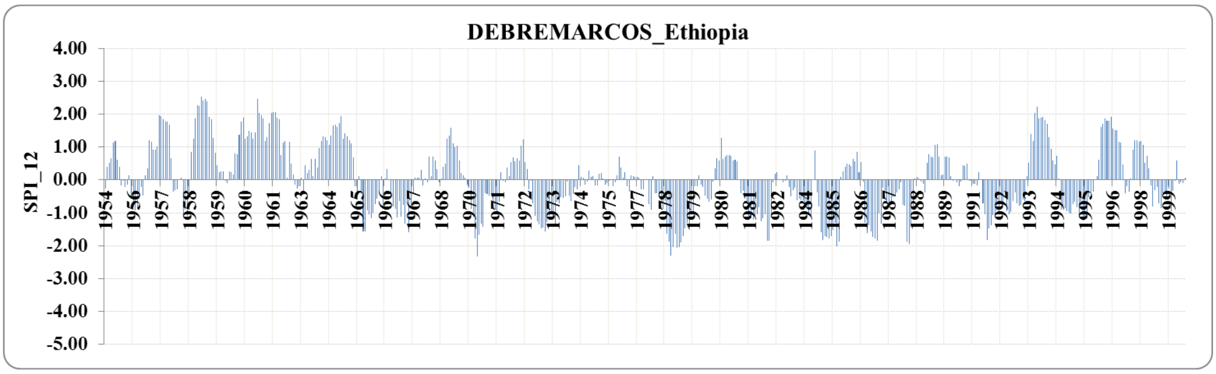

Figure 5. SPI value for twelve months for Debremarcos station Ethiopia

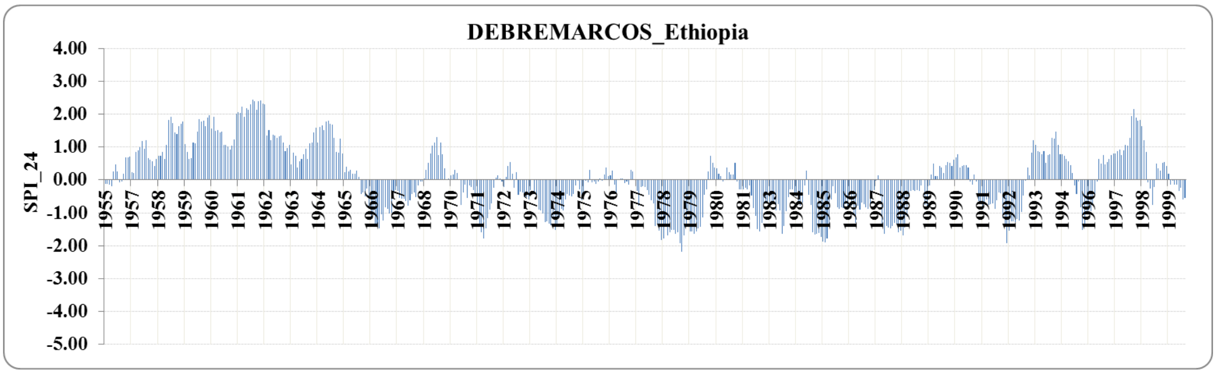

Figure 6. SPI value for twenty-four months for Debremarcos station Ethiopia

The SPI Category Yearly, SPI Category Monthly, SPI Category, Drought Category and Drought Magnitude and Duration for the whole duration are also analysed and compared with other authors.

5 COMPARISON OF DIFFERENT TOOLS TO CALCULATE SPI

In this paper three tools (Authors, Elkolally and NDMC) to calculate the standardized precipitation index (SPI) taking the 1, 3, 6, 9, 12 and 24 months results. The three different used tools are:

1- The Authors excel sheet application.
2- The SPI program, which is developed by Elkolally, (2017), using C Sharp programming language to calculate SPI. GAMMA distribution was selected to fit the precipitation series.
3- Using the SPI generator (program), provided by NDMC (National Drought Mitigation Center).

The comparison between the three different tools and as shown from figures 7 through 18 that:
By applying one and three months the zero value is appeared in some months of the accumulated precipitation calculation results, and this lead to difference in SPI calculation between the three different tools. The author and the NDMC results are match each other in case of appearing the zero value. In case of accumulated precipitation calculation results more than zero the three tools results are compatible.

In case of applying 6, 9, 12 and 24 months the chance of appearing the zero value for accumulated precipitation calculation results are disappeared, and in this cases the three tools results are matching each other.

Even the error values are small in some cases but the percentage error are big due to the small value of SPI in all cases

Debremarcos_Station

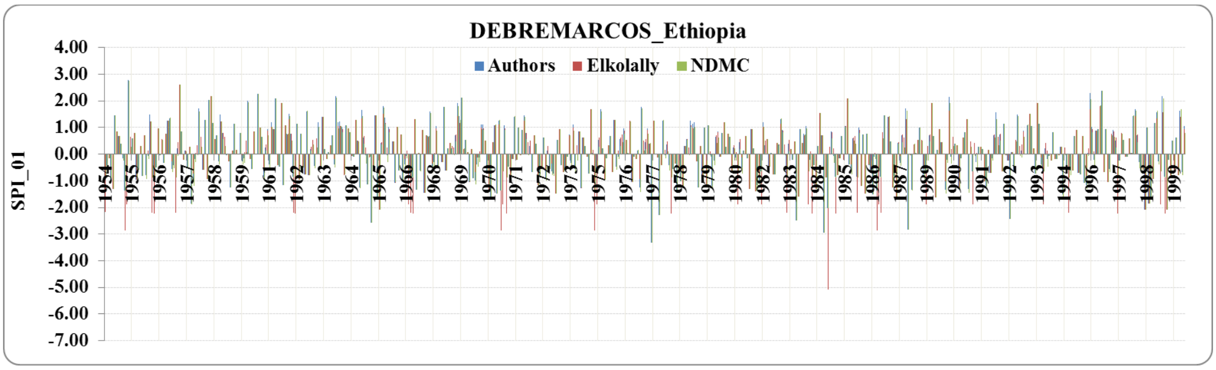

Figure 7. Comparison between the three different tools result for one month (Debremarcos station)

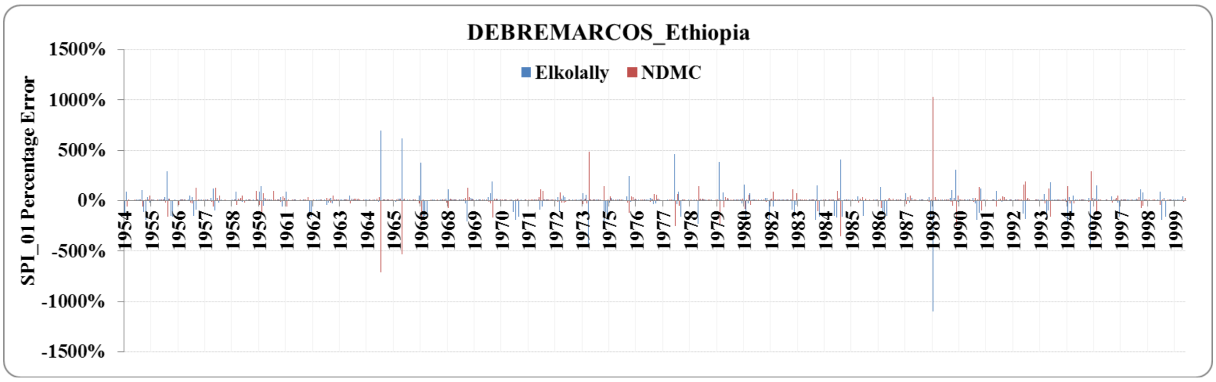

Figure 8. SPI Percentage error between the three different tools result for one month (Debremarcos station)

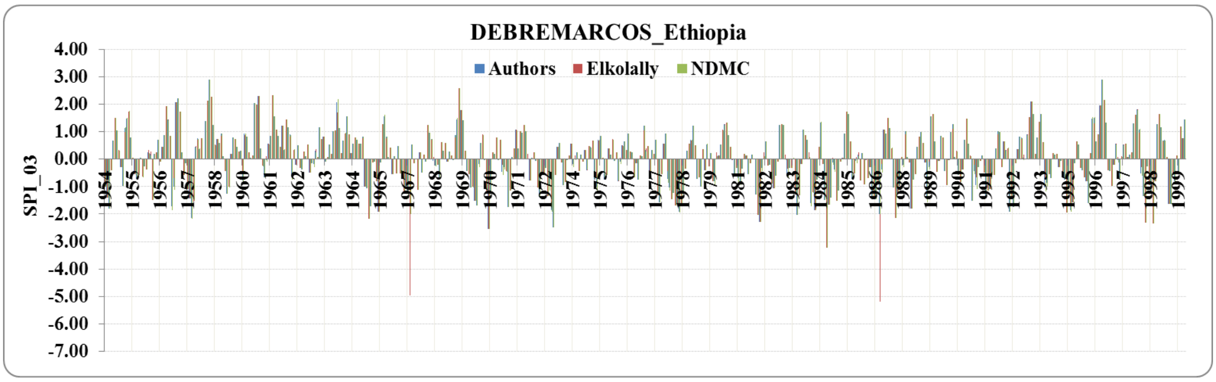

Figure 9. Comparison between the three different tools result for three months (Debremarcos station)

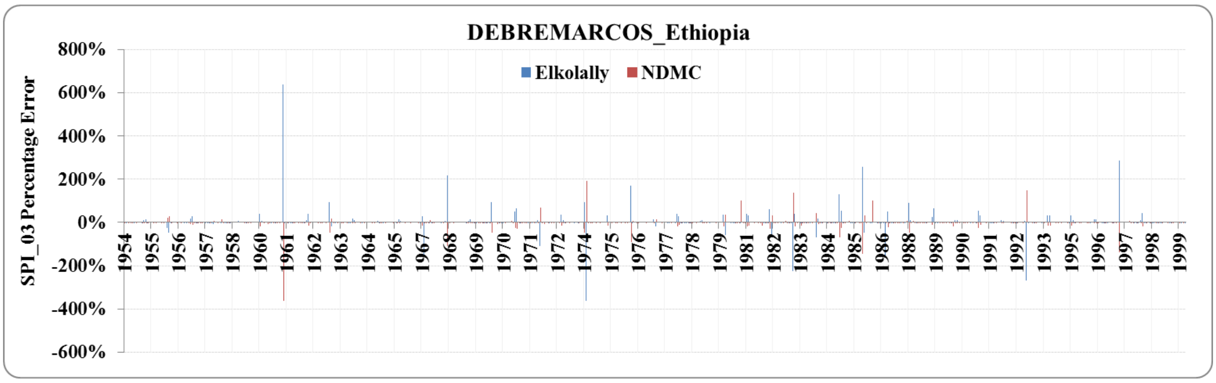

Figure 10. SPI Percentage error between the three different tools result for three months (Debremarcos station)

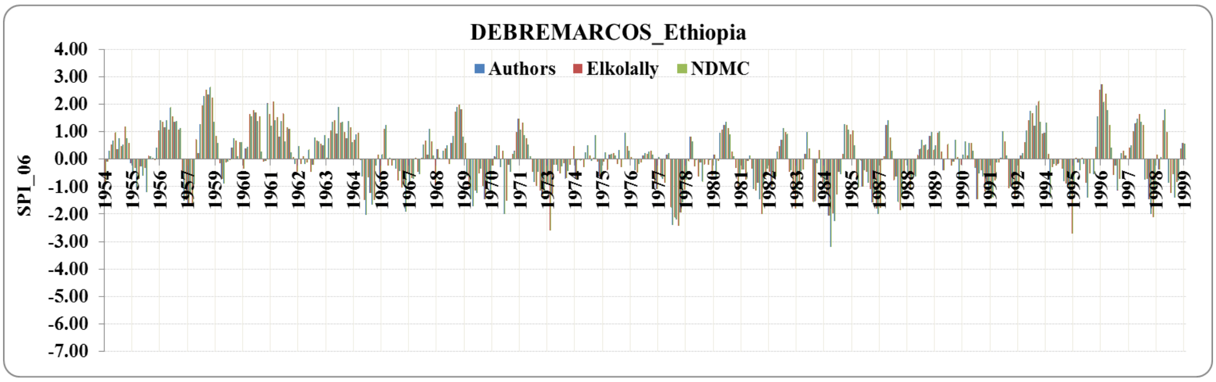

Figure 11. Comparison between the three different tools result for six months (Debremarcos station)

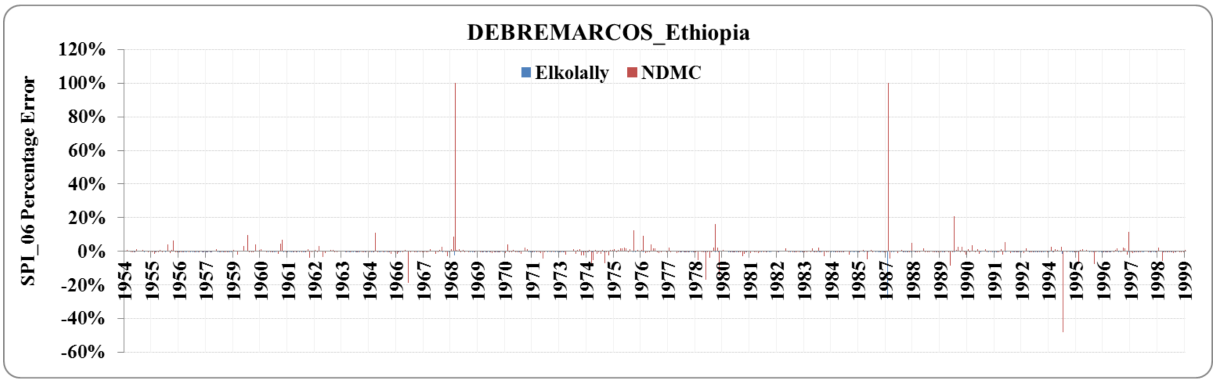

Figure 12. SPI Percentage error between the three different tools result for six months (Debremarcos station)

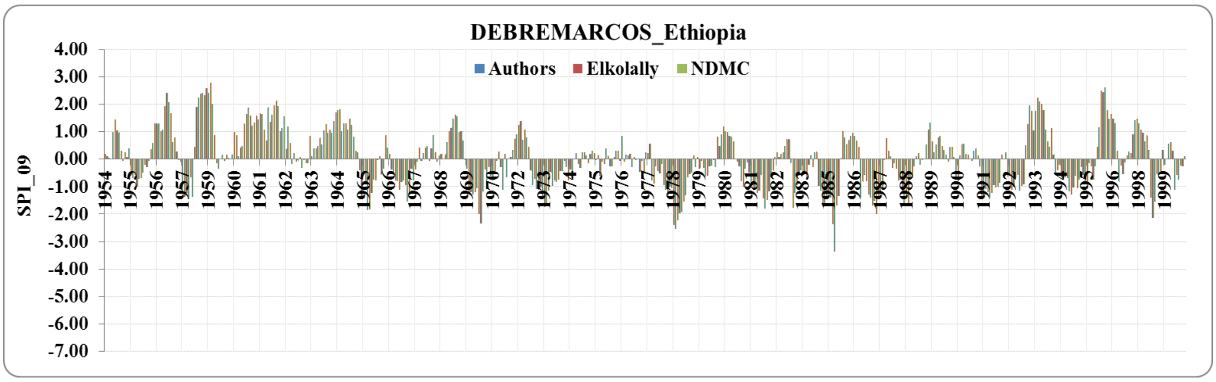

Figure 13. Comparison between the three different tools result for nine months (Debremarcos station)

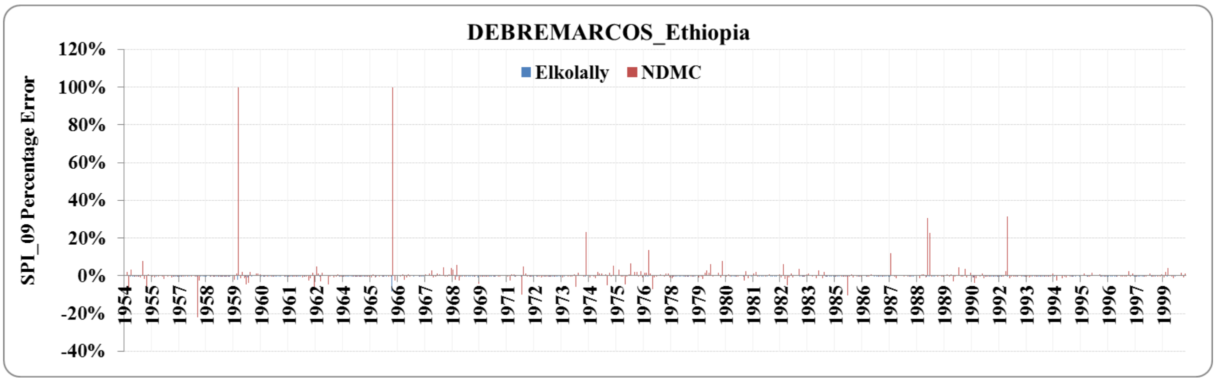

Figure 14. SPI Percentage error between the three different tools result for nine months (Debremarcos station)

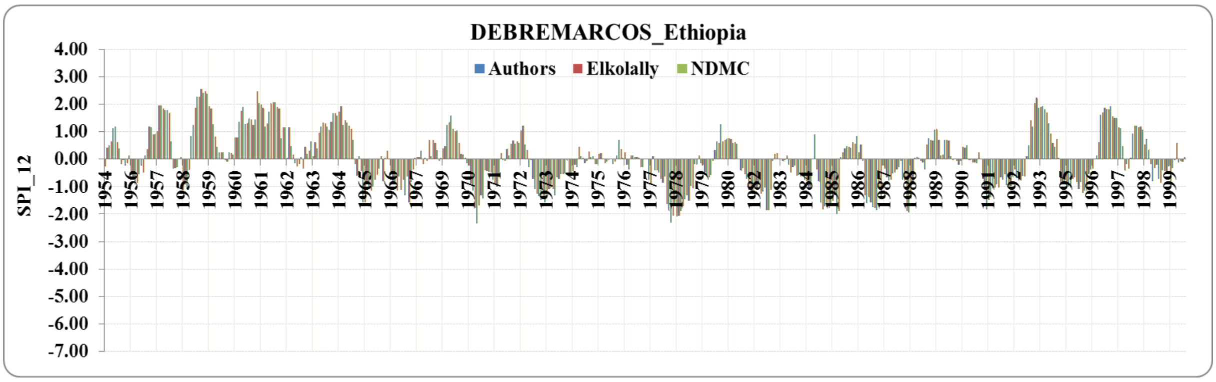

Figure 15. Comparison between the three different tools result for twelve months (Debremarcos station)

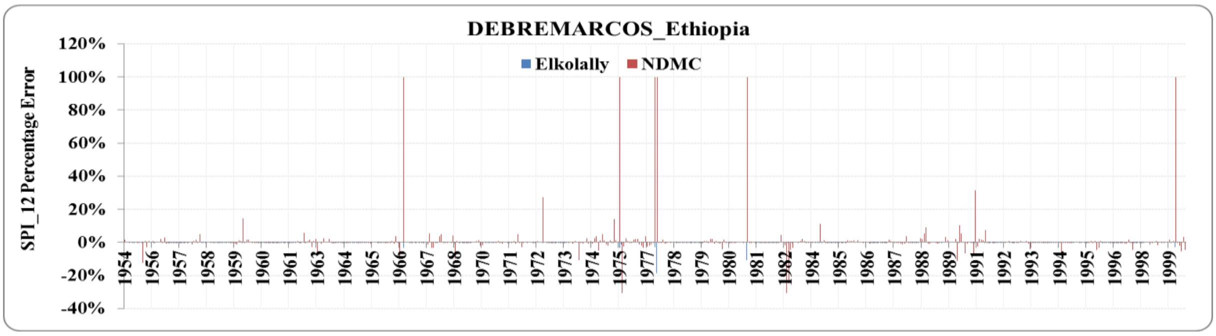

Figure 16 SPI Percentage error between the three different tools result for twelve months

(Debremarcos station)

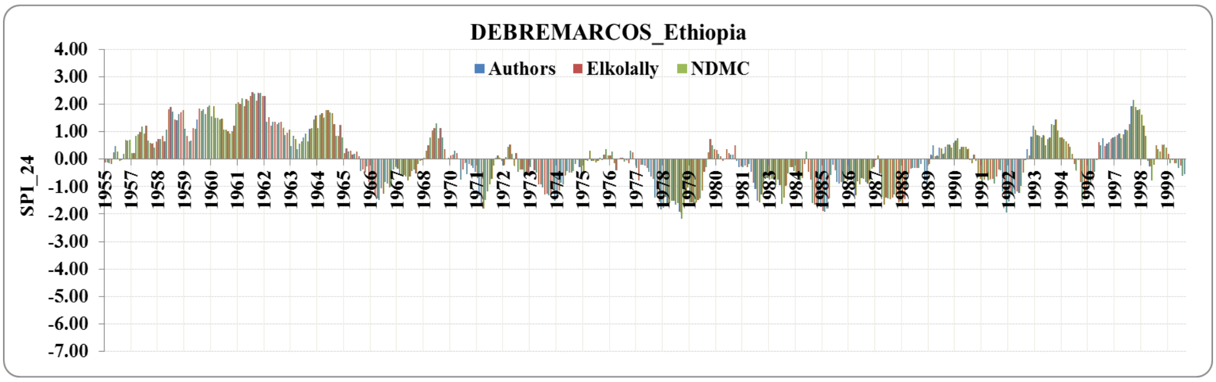

Figure 17. Comparison between the three different tools result for twenty-four months (Debremarcos station)

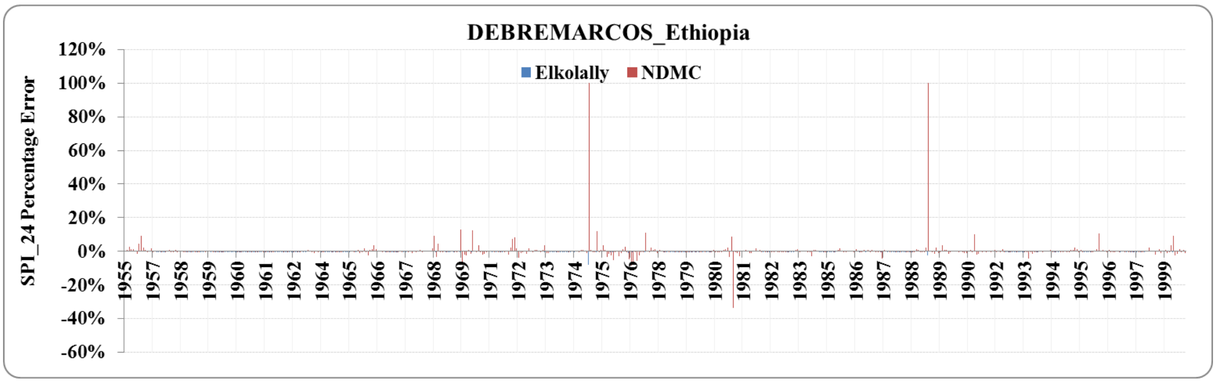

Figure 18. SPI Percentage error between the three different tools result for twenty-four months (Debremarcos station)

The value of R^2 for the results are calculated as shown in table 2. For SPI_01 and SPI_03 the calculation of R^2 between the authors and NDMC is about 0.99 to 1.00 and between the authors and Elkolally is from 0.88 to 0.96.

For SPI_06, SPI_09, SPI_12 and SPI_24 the calculation of R^2 is equal 1.00 for the relation between the authors and NDMC and the relation between the authors and Elkolally. The same results are obtained for the other stations. Figure 19 shows the R^2 for SIP_03 at Addis Ababa bole station

Table 2 R^2 for Debremarcos station

DEBREMARCOS_Ethiopia		
	Authors – Elkolally (2017)	Authors - NDMC
SPI_01	$R^2 = 0.8792$	$R^2 = 0.9914$
SPI_03	$R^2 = 0.9604$	$R^2 = 0.9991$
SPI_06	$R^2 = 1$	$R^2 = 1$
SPI_09	$R^2 = 1$	$R^2 = 1$
SPI_12	$R^2 = 1$	$R^2 = 1$
SPI_24	$R^2 = 1$	$R^2 = 1$

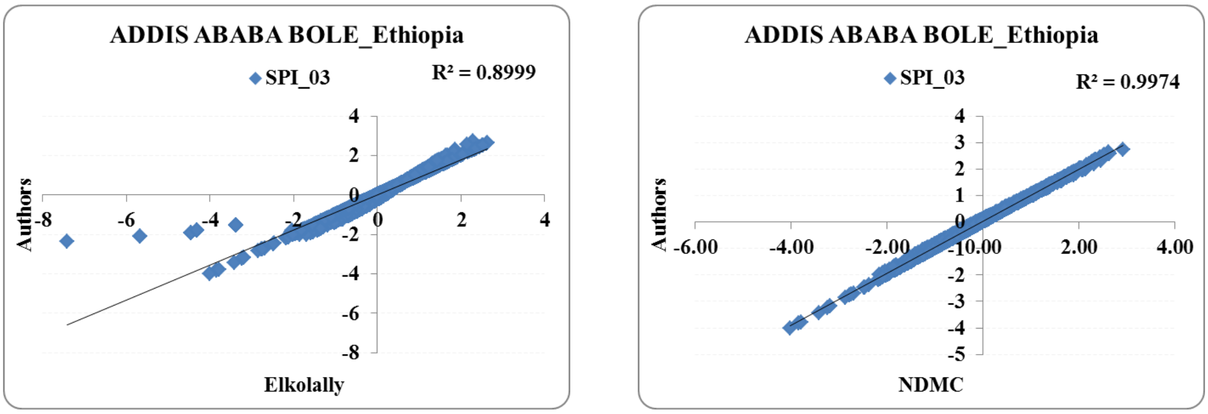

Figure 19. R^2 values for Addis Ababa Bole station

For SPI Category Yearly Max percentage of annual SPI category Moderately Dry, Severely Dry and Extremely Dry, for Debremarcos stations is:

- SPI_01 is 0.33, 0.16 and 0.16 in 1981, 1998 and 1965 respectively for the authors and NDMC but these values was 0.25, 0.25 and 0.25 in 1978, 1998 and 1984 by using Elkollaly results.
- SPI_03 is 0.33, 0.33 and 0.16 in 1978, 1978 and 1981 for the authors and NDMC but the value is 0.33, 0.33 and 0.16 in 1984, 1978 and 1981 for Elkollaly.
- SPI_06 is 0.41, 0.25 and 0.33 in 1970, 1978 and 1978 for the authors, Elkollaly and NDMC.
- SPI_09 is 0.50, 0.25 and 0.25 in 1991, 1978 and 1978 for the authors, Elkollaly and NDMC.
- SPI_12 is 0.67, 0.42 and 0.33 in 1973, 1985 and 1978 for the authors, Elkollaly and NDMC.
- SPI_24 is 0.42, 0.75 and 0.08 in 1967, 1979 and 1979 for the authors, Elkollaly and NDMC.

The same results are obtained for the other three stations but with different values.

SPI Category for the whole duration and for all stations, the percentage of SPI category Moderately Dry, Severely Dry and Extremely Dry was found as shown in figure 20 for Gambela station as:

- For SPI_01 and SPI_03 the percentage for the authors and NDMC are matched but Elkollaly is varied.
- For SPI_06, SPI_09, SPI_12 and SPI_24 the percentage for the authors and Elkollaly are equal but NDMC is slightly different.

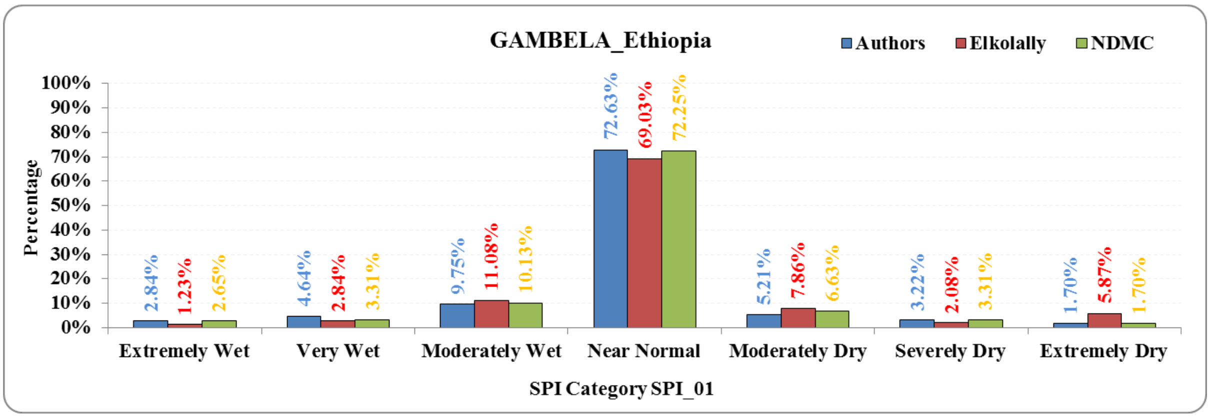

Figure 20. SPI category for one month SPI_01

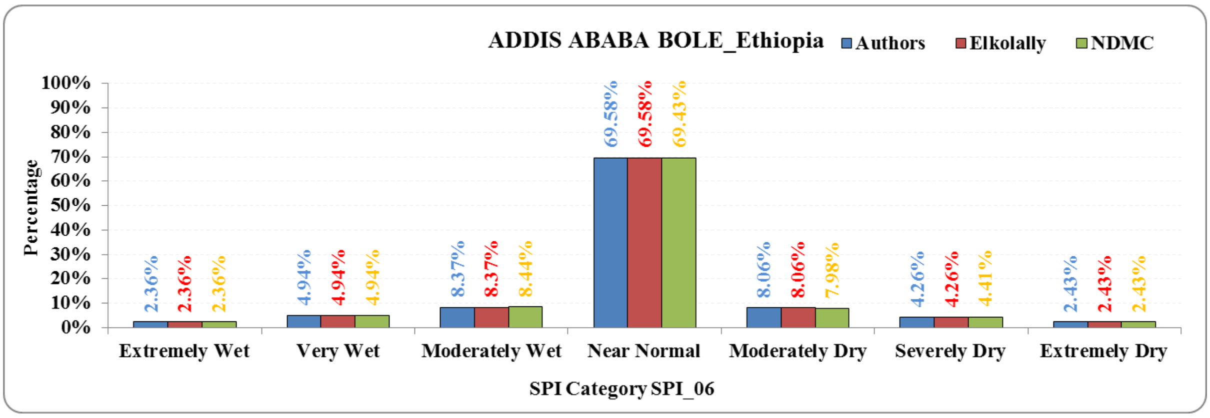

Figure 21. category for six months SPI_06

Drought Category for the whole duration and for all stations the percentage of drought category Moderately Dry, Severely Dry and Extremely Dry

- for SPI_01 and SPI_03 the percentage for the authors and NDMC are matched but Elkollaly is varied.
- For SPI_06, SPI_09, SPI_12, and SPI_24 the percentage for the authors, Elkollaly and NDMC are equal.

Drought Magnitude and Duration

Max drought magnitude and duration for Addis Ababa Bole stations as an example is:

- SPI_01 max magnitude is -3.56 in September 1957 for the authors and NDMC but -6.65 in April 1945 for Elkolally.
- SPI_03 max magnitude is -4.01 and -4.02 in October 1957 for the authors and NDMC but -7.40 in April 1945 for Elkolally.
- SPI_06 max magnitude is -4.07, -4.07 and -4.08 in December 1957 for the authors, Elkolally and NDMC.
- SPI_09 max magnitude is -3.75 in March 1988 for the authors, Elkolally and NDMC.
- SPI_12 max magnitude is -3.63, -3.63 and -3.64 in June 1958 for the authors, Elkolally and NDMC.
- SPI_24 max magnitude is -2.58 in December 1966 for the authors, Elkolally and NDMC.

The same results are obtained for the other three stations but with different values.

6 CONCLUSION AND RECOMENDATIONS

The calculated values of SPI by the authors and other tools are compared. The mean root squared values are calculated and takes as reference. It is found that in case of calculating SPI for one or three months where it is important for agriculture the authors and the NDMC tools are recommended as they gave close values in which R^2 is very close or equal one. In case of calculation of the SIP for more than 3 months the three tools gave matching values and the value of R^2 is equal one, so any used tool lead to the same calculated value of SPI.

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