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Climate Change

Temporal analysis of drought in Mwingi sub-county of Kitui County in Kenya using the standardized precipitation index (SPI)

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This study attempts to temporally characterize drought using Standardized Precipitation Index (SPI) over Mwingi Sub-County of Kenya. Rainfall data spanning 1961-2011 over the area of study was used to determine SPI values using quantitative techniques in R programming. The SPI values were temporally characterized using series graphs and trend analysis carried out. In order to enhance understanding of vegetative characteristics over the area of study, Vegetation Cover Index data was used to generate 3 month VCI spatial characteristics. Results of this study revealed that Mwingi region has been experiencing increasing mild to moderate drought events with occasional severe cases being reported since 1961. No extreme drought event was recorded during this period. The study noted that the drought events were increasingly varying in intensity during the period of study. The study recommends correlation analysis between all climate variables and SPI values to give direction on how they relate to each other over time. However, no extreme drought event was recorded during this period. The study recommends correlation analysis between the SPI values and all climate variables over the area of study.

INTRODUCTION

Background of the study

Kitui County is situated in the former Eastern Province of Kenya, and borders Taita Taveta County to the South, Makueni to the West, Machakos to the Northwest, Tana River to the East, Embu and Tharaka Nithi Counties to the North. The County has eight sub counties namely; Kitui Central, Kitui South, Kitui East, Kitui Rural, Kitui West, Mwingi North, Mwingi West and Mwingi Central. It is located between latitudes $0^0$10’ and $3^0$0’ South and longitudes $37^0$50’ and $39^0$0 East.

The County covers an area of 30,570.30 km^2 of which 6,369 km^2 is occupied by Tsavo East National park. The County has a total population of 1,012,709 (approx. 205,491 households) according to 2009 Kenya population census, with 2.1% growth rate. Figure 1 is the map of Kitui County classified by livelihood zones.

Socio/economic information

Kitui is among the poor Counties in Kenya with 64% of its population living below poverty line (KIHBS, 2006). Agriculture is the main economic activity particularly subsistence farming involving traditional land use systems and lowland cattle grazing (CIDP, 2014). River Athi and Tana are the only perennial rivers in the county flowing along the border with Machakos and Makueni Counties and along Tana River and Tharaka County boundaries. In addition to farming, communities practice wholesale and retail trade businesses as a livelihood in the urban areas.

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The County is primarily made up of 3 main livelihood zones (LRA, 2015) namely: Marginal mixed farming, Mixed farming and Formal employment/Peri-Urban. The bulk of the County consist of the Marginal mixed farming area where the predominant enterprise is livestock faming mainly rearing cattle, goats and sheep. Due to harsh climatic conditions, crop farming is restricted but not limited to green grams, cowpeas, maize, millet and sorghum production. In the Mixed farming livelihood zone, residents do practice cropping activities as well as keeping of livestock though at a smaller scale. The bulk of the Population (51.9%) is found in this zone which puts more pressure on land thus people occupy small pieces of land (SRA, 2015).

People living in the Marginal mixed farming livelihood zone are more exposed to risks associated with droughts owing to erratic rainfall performance which negatively affects crop and livestock farming. Quite often resource based conflicts occur in this zone due to scarcity of pasture and water resources during times of droughts.

In the Mixed farming livelihood zone, Farmers are more vulnerable to poor crop performance due to frequent poor rainfall performance. Matters are made worse by their inability to cope by insisting on planting crops such as beans and maize which are not tolerant to drought. Due to high population density, there isn’t enough space for grazing fields. However, resilience in this zone is higher due to infrastructure development over time and high education levels (NDMA, 2014).

Generally, the County has two seasons of rainfall. We have the Long rains season of March-April-May (MAM) which is less reliable for any meaningful food production while the Short rains season occurs from October-November–December (OND) period. The short rains are more

Figure 1 Map of Kitui County (Source: Google maps (2013))

Table 1 Cumulative probabilities for different spi values (Source: Dan Edwards 2001)

SPI	-3.0	-2.5	-2.0	-1.5	-1.0	-0.5	0.0	0.5	1.0
Cumulative Probability	0.0014	0.0062	0.0228	0.0668	0.1587	0.3085	0.5000	0.6915	0.8413

reliable for food production. The annual rainfall ranges from 800mm as the highest to 300mm as the lowest. The County has a temperature mean of 24 degrees Celsius with a high of 34 Celsius and a low of 14 degrees Celsius (NDMA, 2014).

As one of the 23 Arid and Semi Arid Lands (ASAL) Counties of Kenya, Kitui County has been experiencing impacts of climate change in form of frequent droughts, one of the extreme climate events associated with climate change (NDMA, 2014)). One of the major impacts of climate change in this County has been on food security sector, where all the four pillars of food security i.e. availability, access, stability and utilization are affected. Because of the nature of economic livelihoods that the local residents are involved in, i.e. farming and livestock production, the County is very vulnerable to food insecurity as these sectors are highly sensitive to climate variability and change events including drought.

Historical profile of the study area

Kitui County has a history of food insecurity. Because of reliance on rain fed agriculture (both crop and livestock production), the County is quite vulnerable to drought impacts. In the year 2004, the County was placed under Emergency Operation Food Programme (EMOP) whereby the most vulnerable populations were placed under food aid (KFSSG, 2005). Since then, the County has been on food aid with beneficiary numbers being adjusted according to recommendations of food security assessments reports. The food assessments reports are normally prepared after the end of both long rains and short rains season with the aim of finding out the impacts of the season on food security in the County. Table 1 shows a summary of beneficiary numbers of food relief interventions in the then Mwingi district of Kitui County from the year 2004 up to year 2012.

Over the last five years, successive food security assessments reports done by Kenya Food Security Steering Group (KFSSG) have consistently classified the County using the Integrated Food Security Phase Classification (IPC) as food insecure (NDMA, 2014. Mostly, the assessments have been categorizing the County at phase 2, which depicts the County as being moderately/borderline food insecure. This means that the County has a borderline adequate food access with recurrent high risk of sliding into worse food security phase due to drought hazard and high vulnerability of the residents to impacts of drought.

One of the outcomes of food insecurity in the County has been on poor food utilization specifically at the household level (ACF, 2009). Whereas most of the focus by food security stakeholders has been on impacts of drought on food availability and access, there has been little attention on the impacts of drought on food utilization. Impacts of poor food utilization by the affected population can be seen in terms of increase in prevalence of malnutrition cases and disease outbreaks among the vulnerable population. According to the Kenya Demographic Health Survey of 2014 (KDHS, 2014), approximately 46% of the children of under five years of age have stunted growth (Against a national prevalence rate of 26%). Of this number, 13% were reported to suffer from severe stunting. Stunting is a malnutrition indicator, which is a manifestation of presence of chronic food insecurity problems. Chronic food insecurity is a product of the existence of high risk recurrent food security hazards such as drought.

Problem statement

According to the recently released Intergovernmental Panel on Climate Change report (IPCC, 2013), a change in climate has been characterized by increase in the frequency and intensity of drought events. From the background information above, temporal characterization of possible drought over the area of study is important in providing information for climate monitoring and attribution.

OBJECTIVES OF STUDY

The broad objective of this study was determining temporal characteristics of drought over the area of study.

Specific objectives

In order to achieve the main objective, the following specific objectives were pursued;

1.Determine trend in SPI values over the area of study
2.Identify and Classify past drought events over the area of study
3.Determine Vegetative Cover Index over the area of study

DATA AND METHODOLOGY

Rainfall Data spanning 1961-2011 was obtained from Kenya Meteorological Department while VCI data spanning 2001-2015 was obtained from Boko University via Nation Drought Management Authority. Standardized Precipitation Indices (SPI) were generated from rainfall data over the area of study. Rainfall data quality was controlled using the single mass curve technique. Rainfall averages were calculated and standard deviation by month. Standardized Precipitation Indices (SPI) were computed using the relationship in equation (i).

$$SPI = \frac{X_{ik-\overline{xi}}}{O'_i} \ldots\ldots\ldots\ldots\ldots(i)$$

Where $O'_{i=}$ Standardized deviation for the i^{th} station
$X_{ik=}$ Precipitation for the i^{th} station and the K^{th} observation
$\overline{x}_{i=}$ *Mean precipitation for the ith station*

Using rainfall data from Mwingi station, SPI was then calculated using equation (ii) below:

$$SPI = \frac{(Rainfall\ 1961 - Rainfall\ average\ 1961-2011)}{Standard\ deviation\ of\ rainfall\ in\ 1961-2011} \ldots (ii)$$

The historic rainfall data of Mwingi station (1961-2011) was fitted to a gamma distribution, as the gamma distribution has been found to fit very well with the precipitation distribution. This was done through a process of maximum likely hood estimation of the gamma distribution parameters, α and β as shown in equation (iii).

$$g(x) = \frac{1}{\beta^{\alpha}\,T(\alpha)}\, x^{\alpha-1} e^{-x/\beta} \qquad \ldots(iii)$$

For x>0
Where
α>0 α is a shape parameter
β>0 β is a scale parameter

$$T(\alpha) = \int_0^{\infty} Y^{\alpha-1}\ e^{-y}\, dy \quad \ldots (iv)$$

Where T (α) is the gamma function

This process allowed the rainfall distribution of Mwingi station to be effectively be represented by a mathematical cumulative probability function as shown in equation (v).

$$G(x) = \int_0^x g(x)dx = \frac{1}{\hat{\beta}\ T(\hat{\alpha})} \int_0^x x^{\hat{\alpha}-1}\ e^{-x/\hat{\beta}}\, dx \ldots.(v)$$

The cumulative probability gamma functions were transformed into a standard normal random variable Z with a mean of zero and standard deviation of one. A new variation is formed, and the transformation was done in such a way that each rainfall amount in the old gamma distribution had a corresponding value in the new Z function.

The SPI is a representation of the number of standard deviation from the mean at which an event occurs, normally referred to us a "'z-score''. The SPI units are therefore considered as ''standard deviations''. Dan Edwards (Drought Network News 1994-2001) has offered the following classification of characterizing drought events based on cumulative probabilities for various SPI values.

Drought Classification

In this analysis, Mckee *et.al.* (1995) drought classification thresholds in classifying drought phases were adopted. The table 2 shows droughts classes based on SPI values.

Table 2 Drought classification thresholds Source (Mckee et.al., 1995)

Drought Class	McKee et al.(1995) SPI Value
Extreme drought	<-2
Severe drought	<-1.5
Moderate drought	<-1.0
Mild drought	<0
No drought	>0

SPI script

Standard Precipitation values were determined in R using the following script:

START OF SCRIPT

```
#load data

data(spi_data)

##write to file

write.table(spi_data,file="spi.txt",quote=FALSE,row.names=TRUE)

## Standard format with the output in the text format

spi(3,"spi.txt",1961,2011)

## A full output in graphical format

spi(7,"spi.txt",1961,2011,"Standardized Precipitation Index - mwingi",1,"years","months")
```

END OF SCRIPT

Temporal characteristics of SPI values generated were determined in R.

Vegetation Condition Index (VCI)

Processed Satellite imageries (Vegetation Condition Index) from Boko University (Via National Drought Management Authority) was used to track drought events since the year 2001.

Health vegetation has a different behavior in terms of reflection of electromagnetic radiation in the wavelength of red (R) and near-infrared (NIR). The Normalized Difference Vegetation Index (NDVI) is usually calculated on a pixed by pixel basis as picked out by satellites from space.

NDVI = (NIR-R)/(NIR+R) ……..(vi)

VCI assesses changes in the NDVI signal through time due to weather changes. It is usually calculated by the following formulae in equation (vii).

$$VCI_j = \frac{NVDI_j - NDVI_{min}}{NDVI_{max} - NDVI_{min}} * 100\% \quad \ldots\ldots\ldots(vii)$$

Where
VCI_j is the image of vegetation condition index values for date j;
$NDVI_j$ is the image of NDVI values for date j;
$NDVI_{max}$ and $NDVI_{min}$ are images of maximum and minimum NDVI values from all images within the data set;

The VCI is based on the relative NDVI change with respect to minimum and maximum historical NDVI value. The indicator is normally used to measure pastures/forage conditions and by proxy, it can tell us the drought status of a given place in a given time frame.

RESULTS AND DISCUSSIONS

Temporal Characteristics of Drought

Figure 2-6 shows temporal characteristics of drought during the June-July-August (JJA), December-January-February (DJF), March-April-May (MAM) and October-November-December (OND) seasons respectively. Drought episodes were considered every time the spi was negative. The analysis done returned three drought characteristics namely the severe, mild and moderate drought conditions classified according to the criteria outlined in Table 2. The findings reveal a seasonal trend in Drought events. Two-tail p-value t-test gave a value of p=0.0013 and t=3.2 and mean of 0.1±0.07 at 95% confidence level. The test also gave a Pearson's correlation coefficient of 0.2.

Temporal Characteristics of drought during the JJA season

Figure 2 shows the seasonal characteristics of SPI over the area of study during the JJA season. It can be seen that droughts occured in the years 1963, 1965, 1970, 1975, 1983, 1984, 1986, 1999, 2000, 2005, 2007, 2008 during the June-July-August (JJA) season, including severe cases of drought events in 1970, 1975, 1983, 1999 and 2005 respectively. This can be explained by the fact that the area of study experiences relatively lower precipitation amounts during this period.It can also be observed that drought events have been increasing both in frequency and intensity during the most recent past over the area of study. This characteristic can be attributed to increasing Climate Variability and/or change,over the area of study.

Temporal Characteristics of drought during the DJF season

Figure 3 shows the seasonal characteristics of SPI over the area of study during the DJF season. It can be seen that droughts occured in the years 1965, 1973, 1974, 1980, 1987, 1996-1999, 2005, 2009 respectively. However, the intensity of the droughts was moderate. This can be attributed to December rainfall cessation period where precipitation reduces towards January over the area of study.

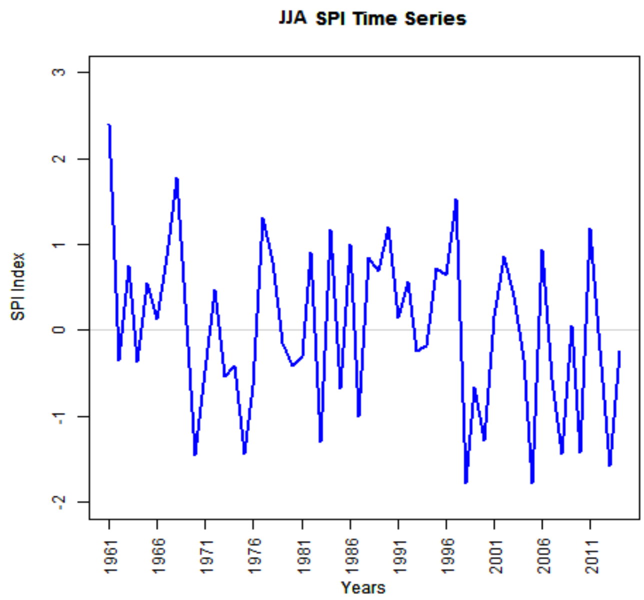

Figure 2 Temporal characteristics of SPI during the JJA season over the area of study

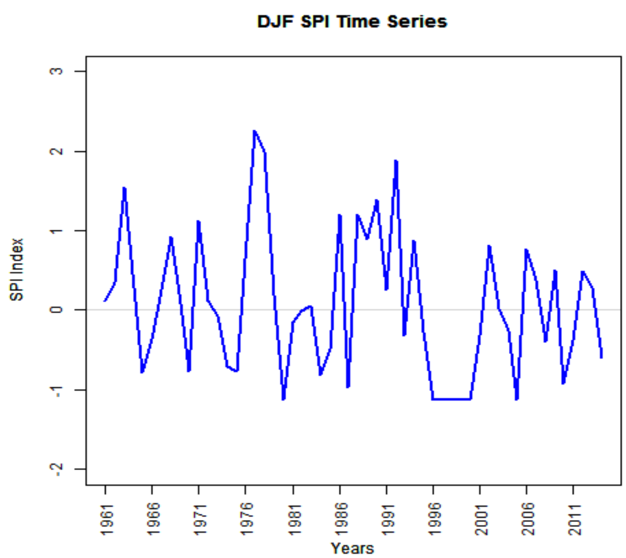

Figure 3 Temporal characteristics of SPI during the DJF season over the area of study

Temporal Characteristics of drought during the MAM season

Figure 4 shows the seasonal characteristics of SPI over the area of study during the MAM season. It can be seen that droughts occured in the years 1965, 1973, 1980, 1983, 1998, 2001, 2005-2006, 2011 respectively. It can be seen that the drought events have been increasing. This can be attributed to imvreasing climate variability and/or change of the area of study. However, the drought events in this season have been moderate, a phenomenom that can be attributed to significantly observed rainfall ammount during the months of March and April.

Temporal Characteristics of drought during the OND season

Figure 5 shows the seasonal characteristics of SPI over the area of study during the OND season. It can be seen that no drought events were observed during this period. This can be explained by relatively high precipitation levels observed during the months of November and

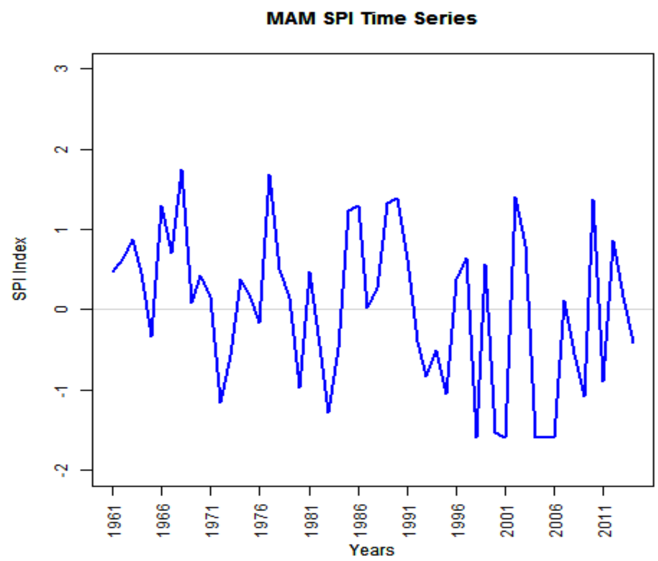

Figure 4 Temporal characteristics of SPI during the MAM season over the area of study

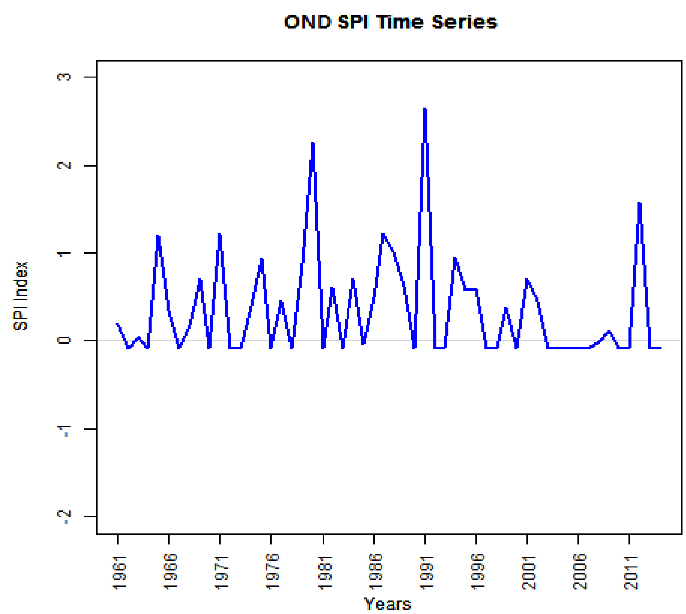

Figure 5 Temporal characteristics of SPI during the OND season over the area of study

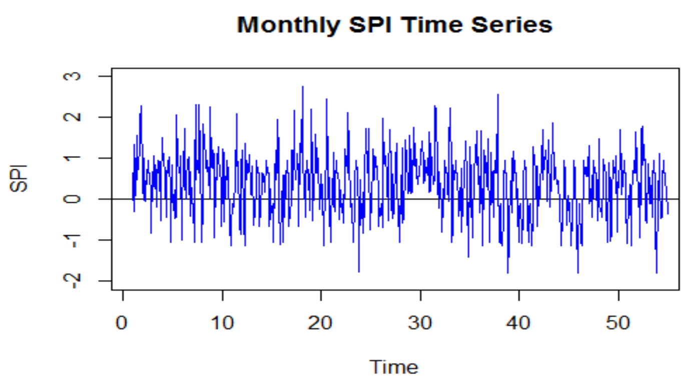

Figure 6 Monthly SPI time series data over the area of study

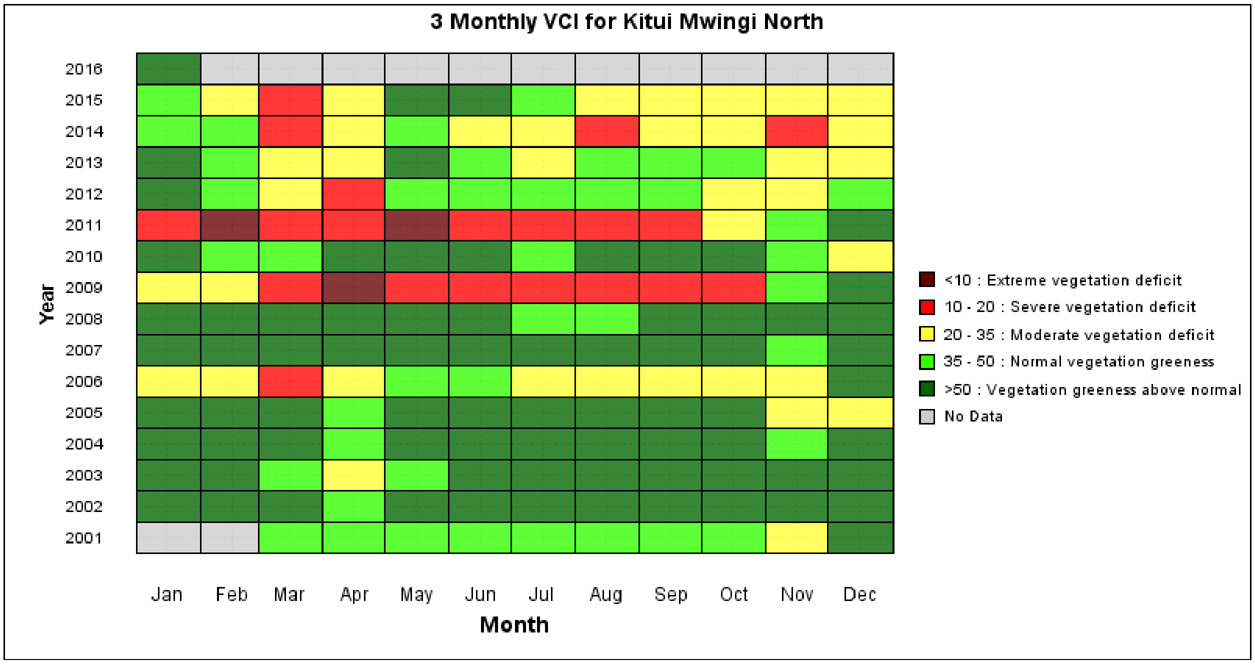

Figure 7 Vegetation condition index for Mwingi North Sub County, Kitui County (2001 to 2016); (Source: Boko University, 2015)

December over the area of study. SPI trend that is increasingly becoming irregular during the most recent period can also be attributable to increasing Climate variability and/or Change.

Monthly temporal Characteristics of drought over the area of study

Figure 6 shows a time series graph of SPI values for Mwingi synoptic station. It can be seen that droughts experience a cyclic trend with peaks during the JJA season and troughs during the OND season. Results also show that at least 11 drought events have occurred between 1961 to 2011 ranging from severe to moderate drought phases. The frequency of drought events is also becoming more regular with an interval of five to six years between them.

The matrix below (Figure 7) shows VCI results over the area of study. It can be observed that Mwingi region has had its own share of drought events ranging from moderate to severe phases since the year 2001. Drought episodes were experienced in the year 2006, 2009, 2011, 2014 and 2015.

In summary, both scenarios of using SPI and VCI indicators shows that though the region has not had an extreme drought situation, the frequency of moderate to severe drought events recurring is quite common.

CONCLUSION AND RECOMMENDATIONS

Results of this study revealed that Mwingi region has been experiencing increasing mild to moderate drought events with occasional severe cases being reported since 1961. No extreme drought event was recorded during this period. The study noted that the drought events were increasingly varying in intensity during the period of study. The study recommends correlation analysis between all climate variables and SPI values to give direction on how they relate to each other over time.

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