Access International Journal of Agricultural Sciences
Monthly peer-reviewed open access journal
Vol. 2(2), pp.18-28, June 2014
Available online at http://www.accessinterjournals.org/aijas
ISSN 2354-2446

Full Length Research Paper

The influence of El-niño Southern Oscillation on seasonal rainfall over the 47 counties of Kenya

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Accepted 24 March, 2014

The influence of the El-Nino Southern Oscillation (ENSO) evolution phases and monthly precipitation over the 47 counties in Kenya is analysed using Pearson product moment correlation analysis. Anomalies of Sea Surface temperatures from the National Climate Data Centre of the National Oceanic and Atmospheric Administration are employed for the periods 1983-2012 while estimates of precipitation rate (in mm/day) are sourced from the African rainfall Climatology project version 2 of the Climate Prediction Centre. Using GrADs software, and Climate data Operators, estimates of Precipitation are extracted for each station representing each of the 47 counties of Kenya. The study has shown that El-Niño Southern Oscillation can explain as high as 50% of seasonal rainfall over the country during the season of October-December. However, the ENSO signal are found to be less influential on the March-May rainfall over the country explaining lows of 2% of the rainfall variability. Time series plots of the analysed Niño indices and rainfall anomalies are found to be in harmony during the October-December season but in complete disharmony during the March-May season on a zero lagged analysis. The study has found that, 46% of rainfall variability over Northern counties of Marsabit, Wajir, Garissa and Turkana as well as coastal counties of Mombasa, Lamu, Kilifi, Kwale and Taita-Taveta can be explained by the El-Niño Southern Oscillation evolution during the same period of occurrence. Similarly, over the Central highlands, counties of Meru, Nyeri, Laikipia and Nakuru as well as western counties of Trans-Nzoia, Bungoma, Vihiga, Kisumu, Homabay and Kisii, the El-Niño Southern Oscillation can explain highs of 36% in seasonal rainfall variance during the October-December season. The variability explained is found to decrease with increase in lag with predictability potential of rainfall over many counties confined to one month lag during the October-December season.

Key words: ENSO, seasonal precipitation rate, Pearson moment product correlation, standardized anomalies, downscaling.

INTRODUCTION

El-Niño Southern Oscillation is planetary scale dominant mode of inter-annual climate variability that has a periodicity of 2 to 7 years. It is characterized by a warming or cooling in the Pacific Ocean near the Peruvian coast. During the period when the central-eastern Pacific Ocean warms up above average, heavy rainfall is experienced over Northern Peru and Ecuador (Ropelewski and Halpert, 1987, 1989). The evolution of these warm waters is referred to as El-Niño. La-Niña is the term that corresponds to a cooling below average across the Central eastern Pacific waters. The warming or cooling of the Pacific Ocean to the East coupled with cooling or warming to the west is associated with air pressure differences between two centres, one located at Darwin (Australia) and the other at Tahiti (Central Pacific). The see-saw pressure difference is known as the Southern Oscillation. The El-Niño or La-Niña phenomenon together with the Southern Oscillation is termed the El-Niño Southern Oscillation (Nicholson and Kim, 1997).

Rainfall over Kenya is seasonal in nature occurring during the March, April, May season and the October, November, December season. Generally, the western part of the country is wet almost throughout the year due to the nearness to the Lake Victoria basin and the ascent of the moist air mass to the west of the Rift-valley (Okoola, 1999).

Several indices are used to study El Nino. *The Southern Oscillation Index (SOI)*, a measure of the difference in surface air pressure between Darwin, Australia and Tahiti, is the index of longest record, and is the oldest (IRI, 2013). It dates back to the beginning of the 20th century when it was first realized by Sir Gilbert Walker that there was a large scale pattern in surface air pressure which extended over the entire tropical Pacific region. Generally, the SOI is negative during El Nino, and positive during La Nina.

Currently, common indices in use are based on sea surface temperature anomalies (IRI, 2013). They are obtained by taking the average value over some specified region of the ocean. There are several regions of the tropical Pacific Ocean that have been highlighted as being important for monitoring and identifying El Niño and La Niña. The most common ones are the NINO regions (IRI, 2013):

(i) NINO1+2 (0-10S, 80-90W). The region that typically warms first when an El Niño event develops.
(ii) NINO3 (5S-5N; 150W-90W). The region of the tropical Pacific that has the largest variability in sea-surface temperature on El Niño time scales.
(iii) NINO3.4 (5S-5N; 170W-120W). The region that has large variability on El Niño time scales, and that is closer (than NINO3) to the region where changes in local sea-surface temperature are important for shifting the large region of rainfall typically located in the far western Pacific.
(iv) NINO4 (5S-5N: 160E-150W). The region where changes of sea-surface temperature lead to total values around 27.5C, which is thought to be an important threshold in producing rainfall.

If the concern regarding El Niño and La Niña is the subsequent effect of that tropical Pacific variability on the climate in a particular region, then one index may be more useful than the others. For widespread global climate variability, NINO3.4 is generally preferred, because the sea surface temperature variability in this region has the strongest effect on shifting rainfall in the western Pacific.

In the past two decades, climate scientists have made ground-breaking progress in dynamic and statistical seasonal prediction. The advent of dynamic climate prediction can be traced back to El Nin˜o forecast that used an intermediate complexity coupled ocean–atmosphere model (Cane et al., 1986; Wang et al., 2009). Statistical seasonal forecasting at downscaled levels has been a subject of many recent studies. The effects of ENSO on African precipitation were studied by Nicholson and Entekhabi (1986) as well as Ropelewski and Halpert (1987, 1989). The forecast have contributed to improved agricultural productivity (Muthama et al., 2003).

The predictability of rainfall over Kenya has improved over the last decade to the benefit of crop and livestock production in Kenya since rain fed agriculture is the main stay of Kenya's economy. Over the recent years El-Nino seasons have generally been associated to good rainfall performance in Kenya. Improved, downscaled information on the impacts of El-Nino and La-Nina at county level in Kenya would help in enhanced decision making at local level. This paper seeks to investigate the spatial extent to which El-Nino and La-Nina years may be attributable to good or poor rainfall performance in Kenya.

DATA AND METHODOLOGY

Data

Two types of data sets were collected, namely: rainfall and ENSO indices. The rainfall data from 47 stations were collected, such that each station represented a county. Table 1 shows the counties, their representative stations as well as their geographical location. The stations are spatially distributed as shown in Figure 1a and 1b.

The rainfall data used in the study is daily estimated precipitation rate in mm/day from the Africa Rainfall Climatology Version 2 of the National Oceanic and Atmospheric administration's (NOAA's) Climate Prediction Centre (CPC). The data covers the periods January 1983 to December 2012.

ENSO indices from Niño 1+2, Niño 3, Niño 3.4 and Niño 4 regions were extracted from the global SST dataset.

Table 1. Station with non-significant El Nino effect for at least three Nino indices.

	OND one month lag							
Station	**Nino 1+2**		**Nino 3**		**Nino 3.4**		**Nino 4**	
	1-Lag	0- Lag	1-Lag	0- Lag	1-Lag	0- Lag	1-Lag	0- Lag
Busia		✓	✓	✓	✓	✓	✓	✓
Kisii	✓	✓		✓	✓	✓	✓	✓
Kapsabet	✓	✓	✓	✓	✓	✓	✓	✓
Bungoma		✓	✓	✓	✓	✓	✓	✓
Kakamega	✓		✓	✓	✓	✓	✓	✓
Kitale	✓	✓	✓	✓	✓	✓	✓	✓
Kapenguria		✓	✓	✓	✓	✓	✓	✓
Eldoret	✓		✓	✓	✓	✓	✓	✓
Kabarnet	✓		✓		✓	✓	✓	✓
Maralal	✓	✓	✓	✓	✓	✓	✓	✓
Kajiado	✓		✓	✓	✓	✓	✓	✓

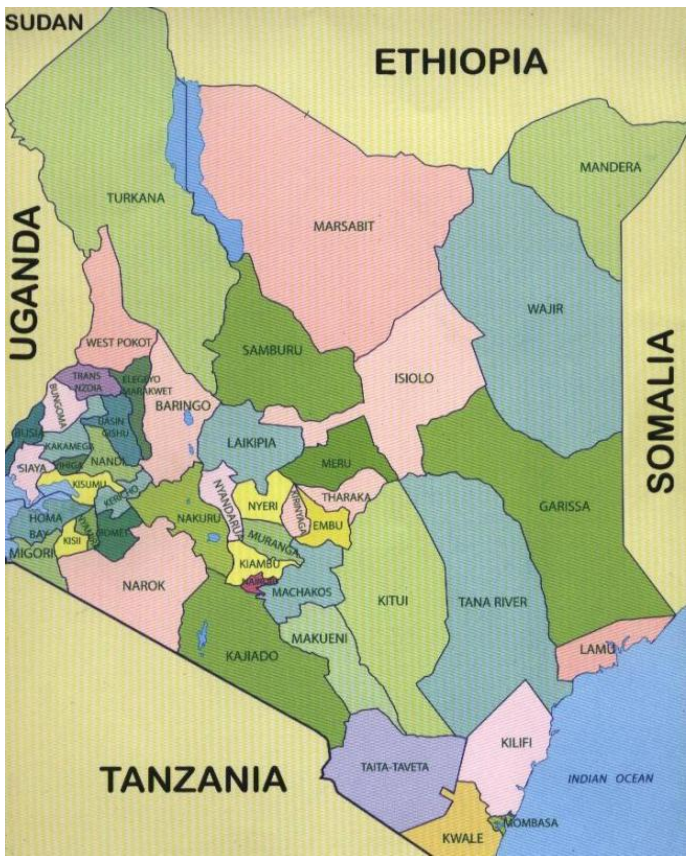

Figure 1a. A Kenyan County Map (Source Google maps).

Methodology

To answer the question whether El-Nino and La-Nina mean good or depressed rainfall in Kenya at county level, respectively, monthly precipitation anomalies were computed by subtracting the climatological means based on the 1983-2012 climatology and normalizing them by dividing the anomaly by the corresponding standard

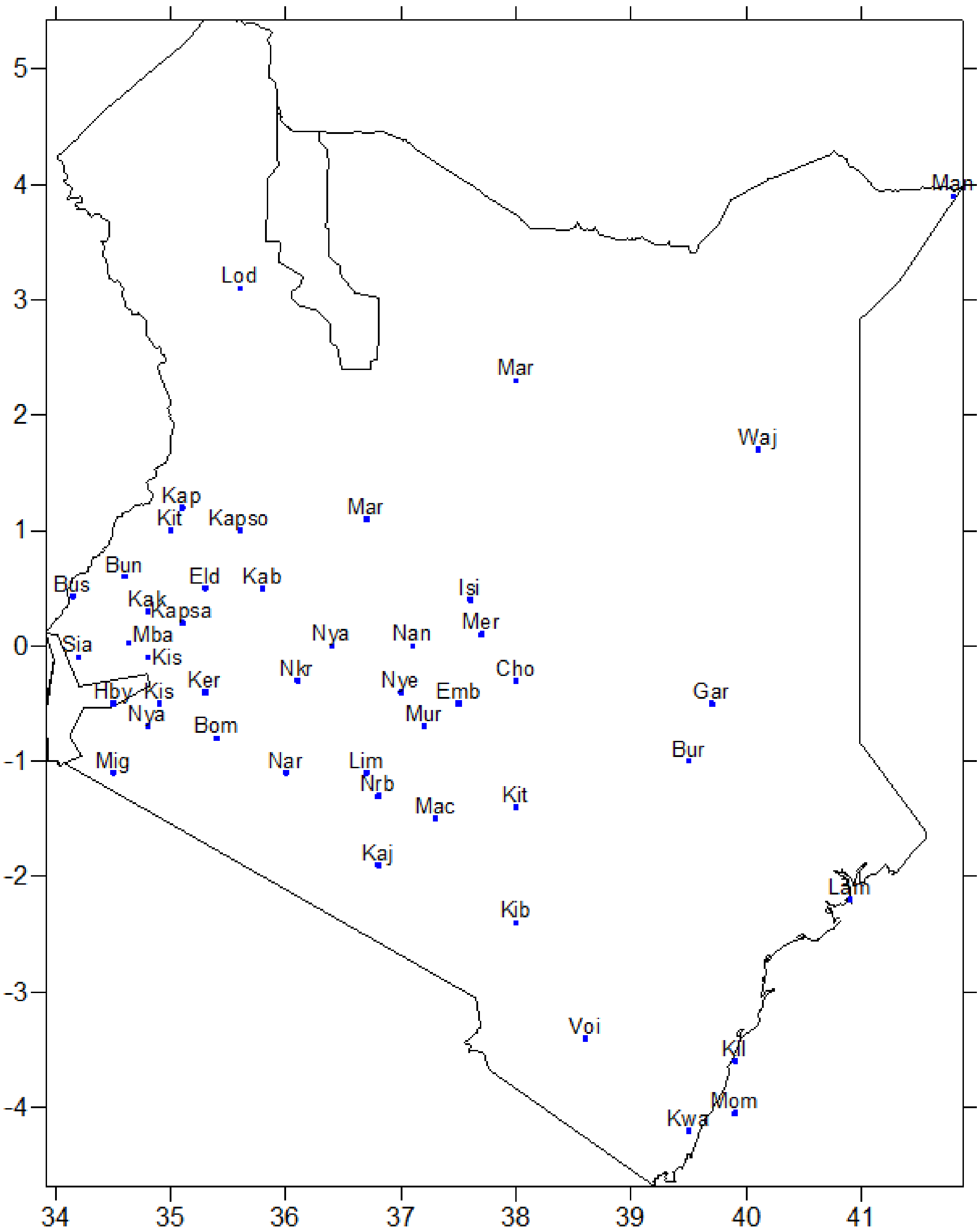

Figure 1b. Station distribution across all the counties.

deviation.

The normalized value (N) is give by:

$$N = (X - \mu)/\sigma,$$

Where X is the monthly precipitation value, μ is the climatological station mean, and σ is the 21-day running standard.

Extended Reconstructed global Sea Surface

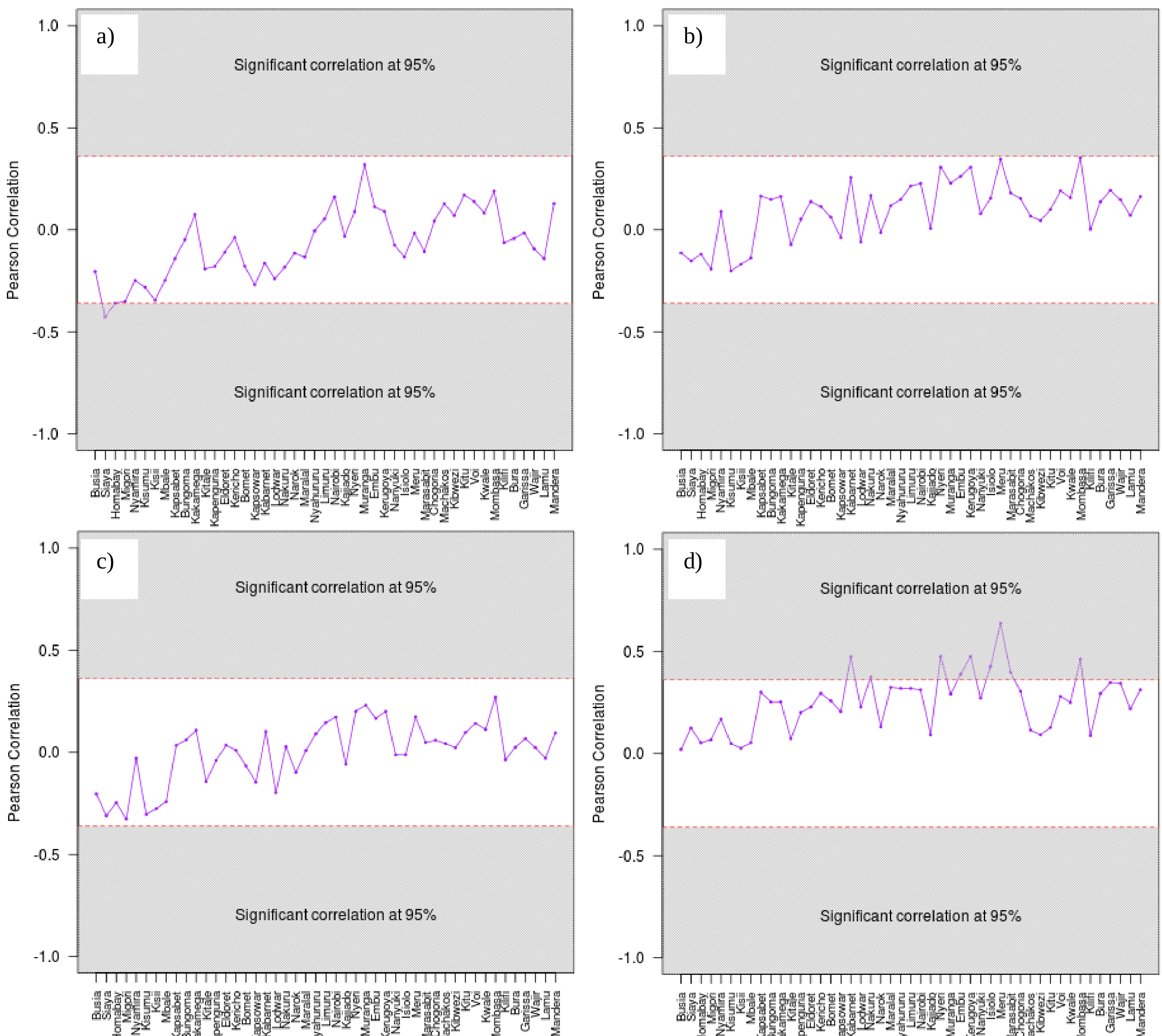

Figure 2: One month lag Pearson correlation coefficient between estimated precipitation rate anomalies and Niño indices a) 1+2 b) 3.4 c) 3 d) 4, during the season of March-April-May.

Temperature anomaly data version 3b was sourced from National Oceanic and Atmospheric Administration (NOAA's) National Climate Data Centre (NCDC) (Smith et al., 2008) through the open source International Research Institute for Climate and Society (IRI) website. The data is at a pixel resolution of 2° by 2° and covers the periods 1983-2012.

Pearson correlation analysis was used to compare ENSO evolution and seasonal rainfall over all the Kenyan counties during the season of March-April-May and October-November-December. Pearson product moment correlation was computed to find out the degree of relationship between the Niño indices and seasonal rainfall over each of the counties of Kenya.

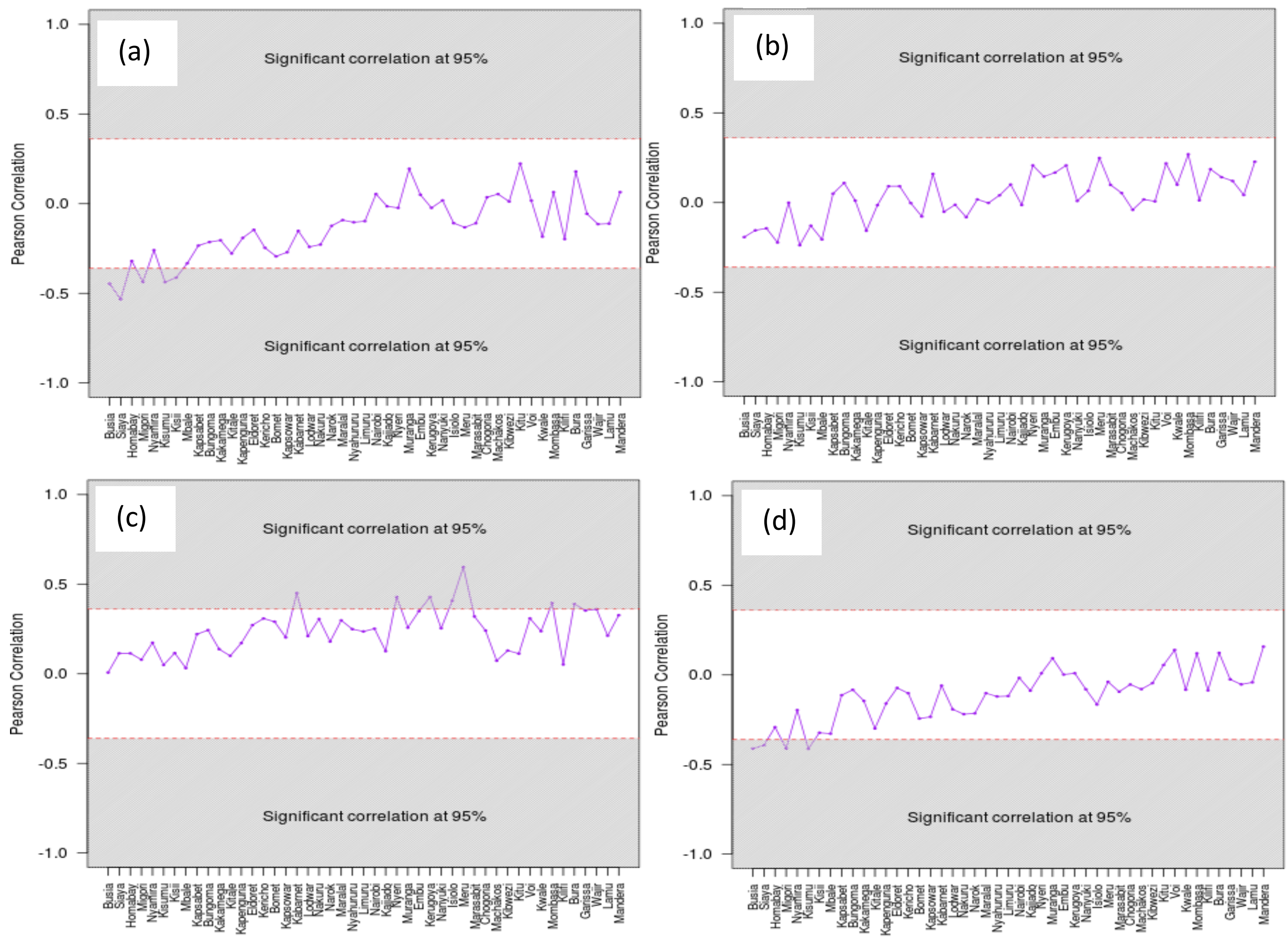

Figure 3. Zero month lag Pearson correlation coefficient between estimated precipitation rate anomalies and Niño indices a) 1+2 b) 3.4 c) 4 d) 3, during the season of March-April-May.

Pearson's correlation coefficient between two variables, defined as the covariance of the two variables divided by the product of their standard deviations. Pearson's correlation coefficient (r) was applied to a sample, and is given by:

$$r = \frac{1}{n-1}\sum_{i=1}^{n}\left(\frac{X_i-\bar{X}}{s_X}\right)\left(\frac{Y_i-\bar{Y}}{s_Y}\right)$$

Where:

$$\frac{X_i-\bar{X}}{s_X},\ \bar{X} = \frac{1}{n}\sum_{i=1}^{n}X_i,\ \text{and}\ s_X = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i-\bar{X})^2}$$

are the standard score sample mean, and sample standard deviation, respectively.

The level of significance was ascertained by using the student t-test (t) given by:

$$t = r\sqrt{\frac{n-2}{1-r^2}}$$

RESULTS AND DISCUSSION

Lag one correlation coefficients, namely, February Indices versus March –May rainfall, were computed using all the four indices. The results indicated that there was

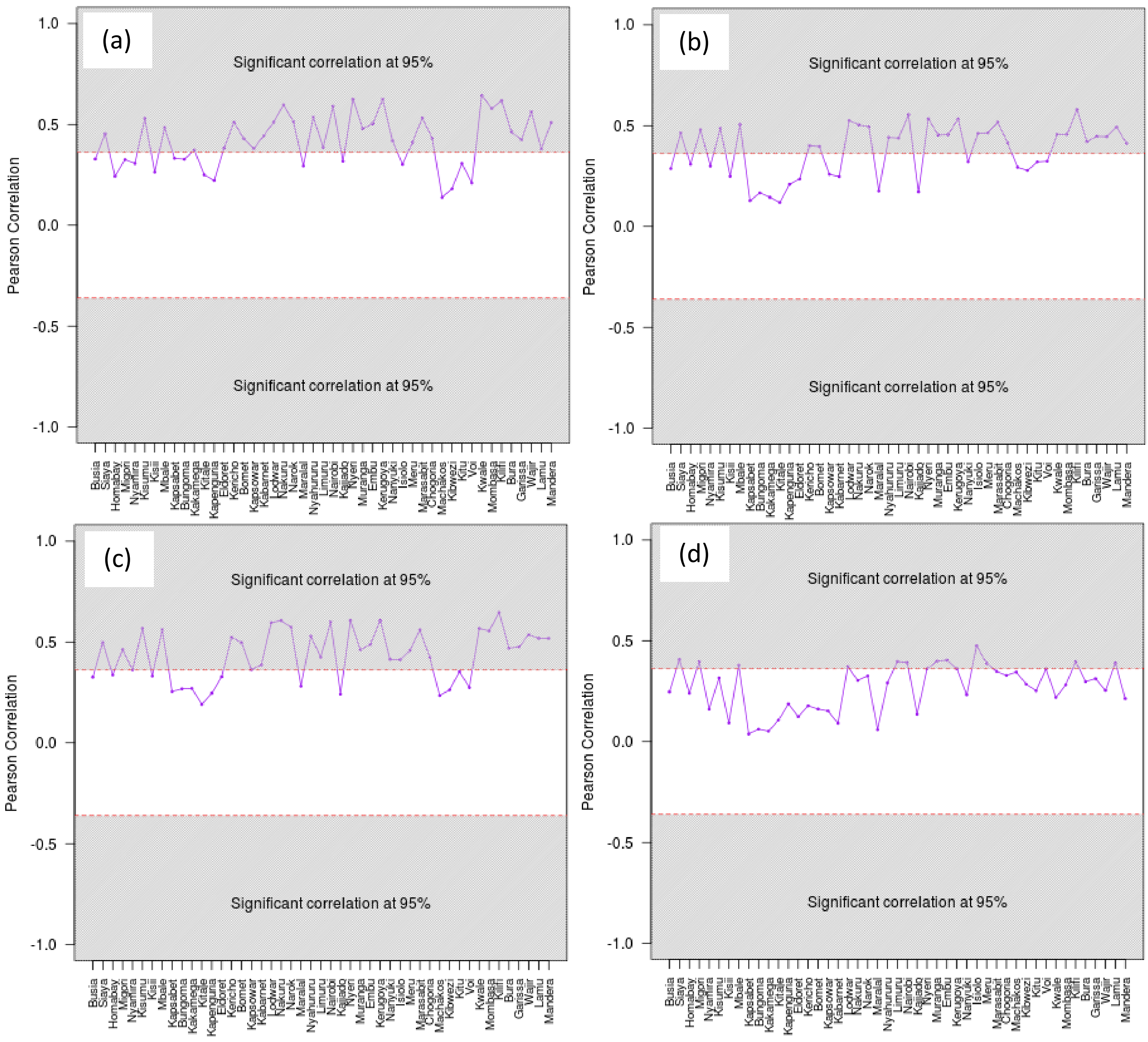

Figure 4. One month lag Pearson correlation coefficient between estimated precipitation rate anomalies and Niño indices a) 1+2 b) 3.4 c) 3 d) 4, during the season of October-November-December.

no significant correlation for all the indices (Figures 2a to 2c) except for Nino 4 where some eight stations showed significant correlation (Figure 2d). It may be observed from the analysis that El Nino effects on the March-May rainfall were experienced in the following counties: Kabarnet, Nyeri, Kerugoya, Isiolo, Meru, Mombasa, Bura and Wajir. This implies that El Nino rains are not wide spread during the long rains season contrary to the popular perception in Kenya that El Nino rains are experienced across the country during the long rains.

Lag zero correlation analysis for the March- May season indicates that between three to five station in western part of the country, namely: Busia, Siaya, Migori, Kisumu and Kisii are negatively correlated to Nino 1+2

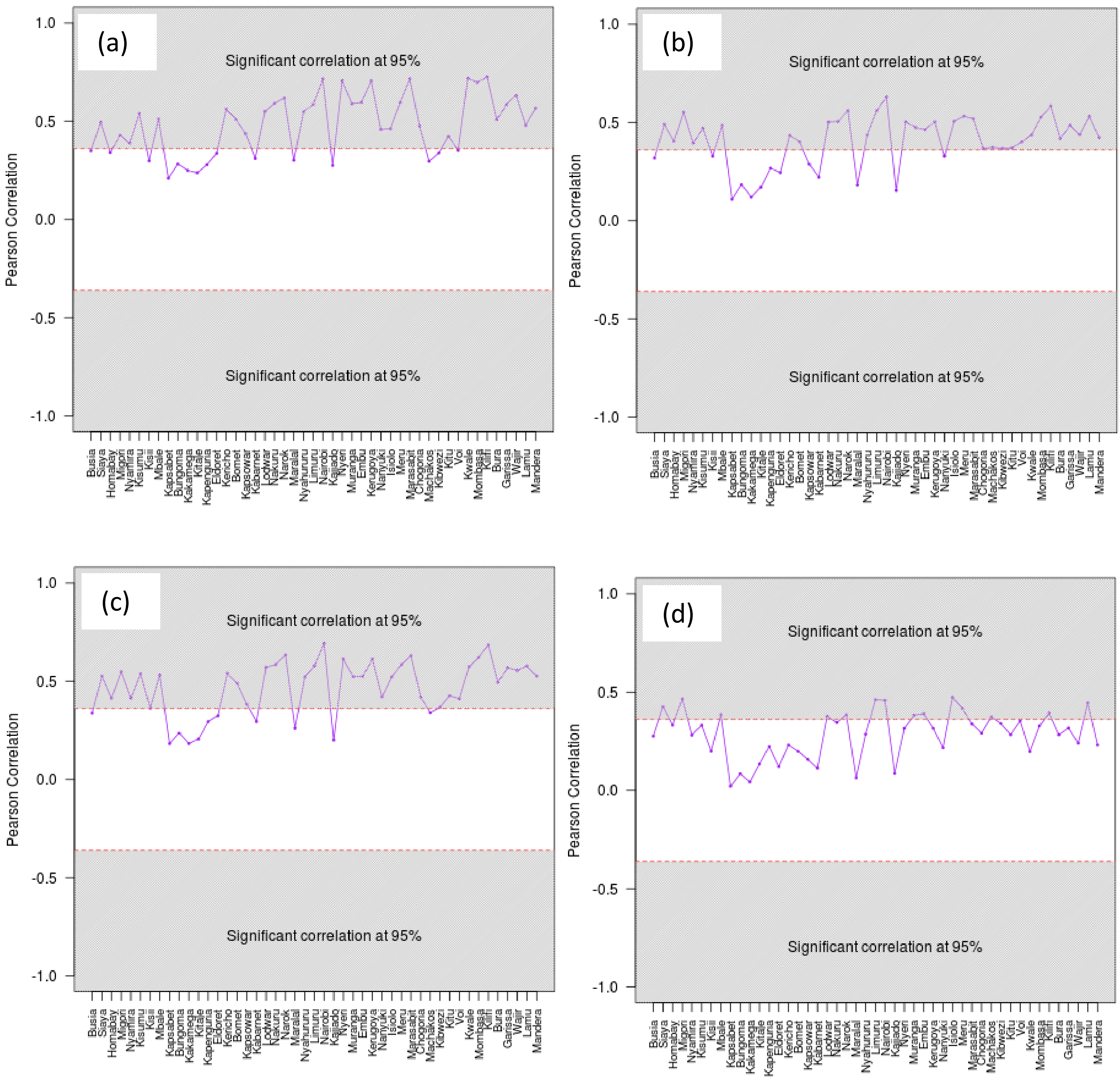

Figure 5. Zero lag Pearson correlation coefficient between estimated precipitation rate anomalies and Niño indices a) 1+2 b) 3.4 c) 3 d) 4, during the season of October-November-December.

and Nino 3 indices (Figure 3a to d). These stations are located around Lake Victoria. The atmospheric circulation effects due to the Lake may contribute to this observation. However, Nino 4 has a positive correlation with several counties in central Kenya, namely: Kabarnet, Nakuru, Nyeri, Embu, Kerugoya, Isiolo, Meru, Marsabit, Mombasa and Garissa, most of these stations showed significant lag one correlation. Further analysis may help in shedding light as to the causal relationship.

Many stations, during the Short rainfall (October to

Table 3. Pearson product moment correlation coefficients between Niño indices and estimated precipitation rate (mm/day) for each of the 47 counties of Kenya.

		Nino 1+2 Index				Nino 3.4 Index				Nino 3 Index				Nino 4 Index			
		One month lag		Zero month lag		One month lag		Zero month lag		One month lag		Zero month lag		One month lag		Zero month lag	
	County	**MAM**	**OND**	**MAM**	**OND**	**MAM**	**OND**	**MAM**	**OND**	**MAM**	**OND**	**MAM**	**OND**	**MAM**	**OND**	**MAM**	**OND**
1	Busia	-0.20	0.35	-0.45	0.33	-0.11	0.32	-0.19	0.29	-0.20	0.34	-0.41	0.33	0.02	0.28	0.01	0.25
2	Siaya	-0.43	0.50	-0.53	0.45	-0.15	0.49	-0.15	0.46	-0.31	0.53	-0.39	0.50	0.12	0.43	0.11	0.41
3	Homa-bay	-0.36	0.34	-0.32	0.24	-0.12	0.40	-0.14	0.31	-0.25	0.41	-0.29	0.34	0.05	0.33	0.11	0.24
4	Migori	-0.35	0.43	-0.44	0.33	-0.19	0.55	-0.22	0.48	-0.33	0.55	-0.41	0.46	0.07	0.47	0.08	0.40
5	Nyamira	-0.25	0.39	-0.26	0.31	0.09	0.39	0.00	0.30	-0.03	0.41	-0.20	0.36	0.17	0.28	0.17	0.16
6	Kisumu	-0.28	0.54	-0.44	0.53	-0.20	0.47	-0.24	0.49	-0.30	0.54	-0.41	0.57	0.05	0.33	0.05	0.32
7	Kisii	-0.35	0.30	-0.41	0.26	-0.17	0.33	-0.13	0.25	-0.28	0.36	-0.32	0.33	0.03	0.20	0.12	0.09
8	Mbale	-0.25	0.51	-0.33	0.49	-0.14	0.49	-0.21	0.51	-0.24	0.53	-0.33	0.56	0.05	0.39	0.03	0.38
9	Kapsabet	-0.14	0.21	-0.23	0.33	0.17	0.11	0.05	0.13	0.03	0.18	-0.11	0.25	0.30	0.02	0.22	0.04
10	Bungoma	-0.05	0.28	-0.21	0.33	0.15	0.18	0.11	0.17	0.06	0.24	-0.08	0.27	0.25	0.08	0.24	0.06
11	Kakamega	0.08	0.25	-0.20	0.37	0.16	0.12	0.01	0.14	0.11	0.18	-0.15	0.27	0.25	0.04	0.14	0.05
12	Kitale	-0.19	0.24	-0.28	0.25	-0.07	0.17	-0.16	0.12	-0.14	0.21	-0.30	0.19	0.07	0.13	0.10	0.11
13	Kapenguria	-0.18	0.28	-0.19	0.22	0.05	0.27	-0.01	0.21	-0.04	0.29	-0.16	0.25	0.20	0.22	0.17	0.19
14	Eldoret	-0.11	0.34	-0.15	0.38	0.14	0.24	0.09	0.24	0.03	0.32	-0.07	0.33	0.23	0.12	0.27	0.12
15	Kericho	-0.04	0.56	-0.25	0.51	0.11	0.43	0.09	0.40	0.01	0.54	-0.10	0.52	0.29	0.23	0.31	0.18
16	Bomet	-0.18	0.51	-0.29	0.43	0.06	0.40	0.00	0.40	-0.07	0.49	-0.24	0.50	0.26	0.20	0.29	0.16
17	Kapsowar	-0.27	0.44	-0.27	0.38	-0.04	0.29	-0.08	0.26	-0.15	0.38	-0.23	0.36	0.21	0.16	0.20	0.15
18	Kabarnet	-0.16	0.31	-0.15	0.44	0.26	0.22	0.16	0.25	0.10	0.29	-0.06	0.39	0.47	0.11	0.45	0.09
19	Lodwar	-0.24	0.55	-0.24	0.51	-0.06	0.50	-0.05	0.53	-0.20	0.57	-0.19	0.60	0.23	0.38	0.21	0.37
20	Nakuru	-0.18	0.59	-0.23	0.60	0.17	0.50	-0.01	0.50	0.03	0.59	-0.22	0.61	0.38	0.35	0.31	0.30
21	Narok	-0.11	0.62	-0.12	0.51	-0.01	0.56	-0.08	0.50	-0.10	0.63	-0.21	0.57	0.13	0.39	0.18	0.33
22	Maralal	-0.13	0.30	-0.09	0.29	0.12	0.18	0.02	0.18	0.01	0.26	-0.10	0.28	0.32	0.06	0.30	0.06
23	Nyahururu	-0.01	0.55	-0.10	0.54	0.15	0.44	0.00	0.44	0.09	0.52	-0.12	0.53	0.32	0.29	0.25	0.29
24	Limuru	0.05	0.59	-0.10	0.39	0.22	0.56	0.04	0.44	0.15	0.58	-0.12	0.42	0.32	0.46	0.24	0.40

December) season, are significantly affected by all the four El Nino indices at lag one (Figure 4a to d). The stations showing non-significant effect are varied from one index to another. However, all the stations show a positive correlation. It may be concluded that El Nino rains positively influence rainfall over many counties in Kenya during the short rains season. There seems a discernible pattern as regards the stations with non-significant relationship as shown in Table 1. Similar patterns are observed for the lag zero relationship (Figure 5a to 5).

It may be suggested that El Nino rains may not have significant impact on the counties represented by the earlier stations. It is notable

Table 3 contd. Pearson product moment correlation coefficients between Niño indices and estimated precipitation rate (mm/day) for each of the 47 counties of Kenya.

25	Nairobi	0.16	0.72	0.05	0.59	0.23	0.63	0.10	0.55	0.17	0.69	-0.02	0.60	0.31	0.46	0.25	0.39
26	Kajiado	-0.03	0.27	-0.01	0.32	0.01	0.15	-0.01	0.17	-0.06	0.20	-0.09	0.24	0.09	0.09	0.13	0.14
27	Nyeri	0.09	0.71	-0.02	0.62	0.31	0.50	0.21	0.53	0.20	0.61	0.01	0.61	0.47	0.32	0.43	0.36
28	Murang'a	0.32	0.59	0.19	0.48	0.23	0.47	0.15	0.45	0.23	0.52	0.09	0.46	0.29	0.38	0.26	0.40
29	Embu	0.11	0.60	0.05	0.50	0.26	0.46	0.17	0.46	0.17	0.52	0.00	0.49	0.39	0.39	0.35	0.40
30	Kerugoya	0.09	0.71	-0.02	0.62	0.31	0.50	0.21	0.53	0.20	0.61	0.01	0.61	0.47	0.32	0.43	0.36
31	Nanyuki	-0.07	0.46	0.02	0.42	0.08	0.33	0.01	0.32	-0.01	0.42	-0.08	0.41	0.27	0.22	0.25	0.23
32	Isiolo	-0.13	0.46	-0.11	0.30	0.15	0.51	0.07	0.46	-0.01	0.52	-0.17	0.41	0.43	0.47	0.41	0.48
33	Meru	-0.02	0.60	-0.13	0.41	0.35	0.53	0.25	0.46	0.17	0.58	-0.04	0.46	0.64	0.42	0.60	0.39
34	Marasabit	-0.11	0.72	-0.11	0.53	0.18	0.52	0.10	0.52	0.05	0.63	-0.09	0.56	0.40	0.34	0.32	0.35
35	Chogoria	0.04	0.48	0.04	0.43	0.15	0.37	0.05	0.41	0.06	0.42	-0.05	0.42	0.30	0.29	0.24	0.33
36	Machakos	0.13	0.30	0.05	0.14	0.07	0.37	-0.04	0.29	0.04	0.34	-0.08	0.23	0.11	0.37	0.07	0.34
37	Kibwezi	0.07	0.34	0.01	0.18	0.05	0.37	0.02	0.28	0.02	0.37	-0.05	0.26	0.09	0.34	0.13	0.29
38	Kitui	0.17	0.42	0.22	0.31	0.10	0.37	0.01	0.32	0.10	0.43	0.06	0.35	0.13	0.28	0.11	0.25
39	Voi	0.14	0.35	0.02	0.21	0.19	0.40	0.22	0.32	0.14	0.41	0.14	0.27	0.28	0.35	0.31	0.36
40	Kwale	0.08	0.72	-0.18	0.64	0.16	0.44	0.10	0.46	0.11	0.57	-0.08	0.57	0.25	0.20	0.24	0.22
41	Mombasa	0.19	0.70	0.06	0.58	0.35	0.53	0.27	0.46	0.27	0.62	0.12	0.56	0.46	0.33	0.39	0.28
42	Kilifi	-0.06	0.73	-0.20	0.62	0.00	0.58	0.01	0.58	-0.04	0.69	-0.09	0.65	0.09	0.39	0.05	0.40
43	Bura	-0.04	0.51	0.18	0.46	0.14	0.42	0.19	0.42	0.03	0.49	0.12	0.47	0.29	0.28	0.39	0.30
44	Garissa	-0.02	0.59	-0.06	0.42	0.19	0.49	0.14	0.45	0.07	0.57	-0.03	0.48	0.35	0.32	0.35	0.31
45	Wajir	-0.09	0.63	-0.11	0.56	0.15	0.44	0.12	0.45	0.02	0.56	-0.05	0.54	0.34	0.24	0.36	0.25
46	Lamu	-0.14	0.48	-0.11	0.38	0.07	0.53	0.04	0.49	-0.03	0.58	-0.04	0.52	0.22	0.45	0.21	0.39
47	Mandera	0.13	0.57	0.06	0.51	0.16	0.42	0.23	0.41	0.10	0.53	0.16	0.52	0.31	0.23	0.33	0.21

that three stations, namely: Kapsabet, Kitale and Maralal are not impacted at all by El-Nino effect during the short rains.

Table 2 is details on all the correlation coefficients. From the earlier analysis, we note that a few counties experience El Nino rains during both seasons of MAM and OND. On the contrary, some other stations are not affected significantly by El Nino indices. This has a bearing on the generalization of rainfall forecasts in Kenya during El Nino Periods. It is prudent to clarify the county dependency on the influence of El Nino. Therefore, downscaling of El-nino effects on rainfall in the counties of Kenya would help in improving the forecast skills at county level.

Conclusion

The El Nino system has county specific impacts in Kenya. The long rains season is least impacted by any of the four El Nino indices. However, the short rains are significantly and positively influenced by the El Nino system.

A few stations have significant negative correlation with the Nino indices during the long rains of March to May. This is very important for planning and operational purposes. It is imperative that seasonal forecast produced for the long rains season should clearly capture this finding.

El-Nino period does not necessarily translate to rainfall for the whole country. Rainfall caused by other systems may be experienced during such periods.

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