EISSN: 2707-0425

East African Journal of Science, Technology and Innovation, Vol. 3 (1): December 2021

Spatiotemporal characteristics of smallholder milk production under changing climate: A case of Nandi County, Kenya

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Abstract

Milk production in Kenya is predominantly smallholder and dependent on rainfall. The study assesses spatiotemporal characteristics of smallholder milk production in Nandi County under changing climate. Climate (Rainfall and temperature), fodder availability (Normalized Difference Vegetation Index (NDVI) and soil moisture content) and milk production data were used. Methods included trend analysis, spatial plots, correlation and multi-regression analysis. Monthly NDVI and soil moisture content were high between April and November with seasonal analysis indicating highest/lowest June-August (JJA)/December-February (DJF) values. Percentage change (%Δ) for NDVI was 6.0% (DJF), 1.96% (March-May, MAM), 2.13% (JJA), 4.16% (September-November, SON) and (2.53% (Annual). Seasonal and annual %Δ for soil moisture content ranged 7.2-17.1% at 0-10cm level and 8.1-23.7% at 10-40 level. Trend analysis of milk production showed positive change from 2007 to 2016 and highest/lowest in December/April with seasonal %Δ of up to 186% (MAM), 183% (JJA), 202% (SON), 214% (DJF) and 204% (Annual). Majority of household (HH) owned between 1 and 20 acres of land with only 0.5 to 2 acres allocated to dairy farming while those allocating less than 1 acre practiced zero grazing. On average, HH had 2 lactating cows throughout the year with majority of dairy farmers (98.6%) owning improved cow breeds. Amount of milk per HH supplied to the farmer organization varied between 2.3 litres and 3.8 litres with computed daily average milk produced per HH being 18.8 litres. Active milk suppliers were highest/lowest in December/April whereas daily average milk production per HH between 2010 and 2016 was highest/lowest in January (23.7 litres)/August (15.6 litres). Lowest/highest correlation coefficients were found in precipitation/minimum temperature. Multi-regression analysis indicated that precipitation had significant contribution to dairy productivity. Given the sensitivity of milk production to climate and fodder availability, adequate adaptation and mitigation measures are necessary in order to sustainably enhance milk production.

Keywords: *Smallholder farmer; milk production; climate change; fodder availability*

Received: 13/04/21
Accepted: 12/11/21
Published: 17/12/21

Cite as: *Kirui et al., (2021)*. Spatiotemporal characteristics of smallholder milk production under changing climate: A case of Nandi County, Kenya. *East African Journal of Science, Technology and Innovation 3(1).*

Introduction

Globally livestock sector occupies 30% of free terrestrial area, uses natural resources and provides nutrition as well as income and employment (Thornton, 2010). In the rural households of developing countries livestock is a major contributor to livelihood (Herrero, *et al.*, 2009). Dairy farming and dairy industry are crucial segments of livestock farming that actively contributes to the economies of diverse communities in different countries of the world. Demand of dairy products worldwide has increased against a backdrop of a globalizing industry and a resultant intensification of the dairy trade that has increased in scope globally (International Dairy Federation, 2013). An increase in the wealth for developing countries will change the purchasing power of the 'middle class' and practically shift the predominantly grain-based diet of these individuals towards one with higher animal-based protein (Rae & Nayga, 2010). Consequently, the annual per capita milk consumption in developing countries will increase from the current 55kgs/person/year to a probable 78kgs by 2050 (Steinfeld, *et al.,* 2006).

The dairy subsector in Kenya is dominated by smallholder farmers and dependent on rain fed agriculture experiences adverse climate change related impacts (Morton, 2007, Stefanovic, 2015). It is estimated that there are 1.8 million smallholder farmer who depend on milk for their livelihood in areas that are considered dairy zone (Wanyoike *et al.*, 2005) owning 1-5 cows, with average daily production of 8-10 litres per cow (Theron and Mostert, 2008). This dairy farmers are estimated to own 4.3 million dairy cattle that are kept under free grazing, semi- zero grazing and zero grazing production systems and produce 3.43 billion litres of milk (Odero-Waitituh, 2017). The other milk is produced by 9.3 million local animals, camels (1 million) and goats (13.9 million) (FAO, 2011).

The long term impact of climate change and on dairy productivity due its undesirable influence on feed and fodder supply may severely alter the existing livestock production systems (FAO, 2004). In East Africa, the undesirable impact of climate change on agricultural productivity, forestry and fisheries will be evinced through variations of mean temperatures, rainfall patterns, availability of freshwater, occurrence of droughts and floods in terms of frequency and intensity of, a rise in sea level and increased salinization of ecosystems or perturbations that will result into enhanced variability and unpredictability of climate (Lobell, *et al.*, 2011; Beddington, *et al.*, 2012). Studies show that climate projections for the future depends on the GHG pathway chosen, and should human induced emissions continue at the current trend then more impact is expected (Hayhoe *et al,.* 2004).

Undesirable outcomes of climate change on livestock feed could be mitigated by practicing climate-smart agriculture practices (CGIAR, 2015). In retrospect, scientific innovations have enhanced adaptations for pastures and fodder species by identifying and developing certain traits to enable these crops to thrive in specific climatic conditions (Fernandez-Rivera & Weber, 2000). While considering fodder vulnerability to extreme weather conditions, it is notable that these scientific innovations vary considerably depending on crop and regional factors. An example is Lucerne, a high protein source fodder that is more drought resistant compared with grass owing to its far-reaching taproot (Wheeler & Braun, 2013). Another example under climate-smart agriculture is growth of *Brachiaria,* a type of grass native of eastern Africa. *Brachiaria* which is significantly used for carbon sequestration is used for livestock in South America and East Asia where is grown for forage extensively. It is also an important contributor to both ecological restoration and in controlling soil erosion, reducing greenhouse gases emission and in preventing loss of nutrient from vulnerable soils (BeCA, 2017).

Materials and methods

Study Area

The study was in Nandi County (Figure 1). It falls within the agro-ecological zones of Upper Highland (UH) to Upper Midland (UM) and is one of the major dairy zones in Kenya predominately smallholder dairy farming that mainly rely on rain fed fodder production. Mean rainfall is between 1,200-2,000 millimeters per year and bimodal between dry spells between December and March. Rainfall distribution varies according to topography and is influenced by south-westerly winds from Lake Victoria. Major staple crops in the area include maize, millet, sorghum, and potatoes while pyrethrum, tea and coffee are main cash crops. The farmers practice intensive and semi intensive dairy farming. Dairy farmers in Nandi grow forage crops such as Nandi *setaria* (*Setariasphacelata*), Rhodes grass (*Chloris gayana*), and Napier grass (*Pennisetum purpureum*). Smallholder farmers market their milk using different milk-marketing channels: either through an informal milk market where milk is sold to middle men or hotels or through formal market where milk is marketed through farmers' organizations' marketing channel.

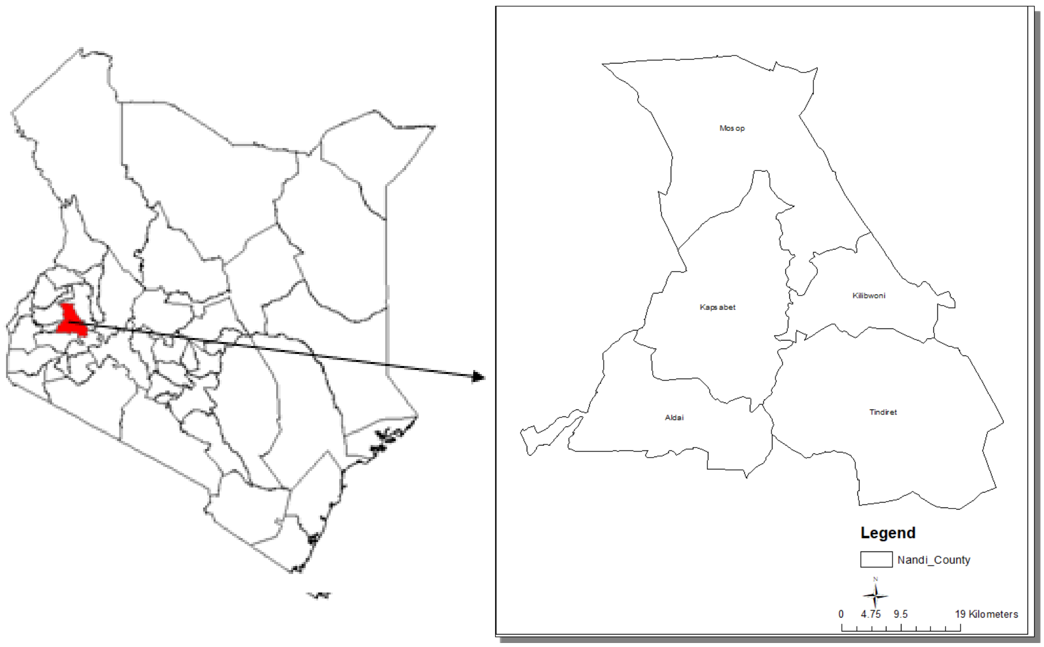

Figure 1. Map showing a) Kenya b) Nandi County

Data collection

Observed climate data which included rainfall, minimum and maximum temperature were sourced from Kenya Meteorological department for stations located in Nandi County which included Nandi hills Tea estate and Kobujoi Forest station which were mainly rainfall stations. Due to limited availability of observational stations, the study utilized both satellite derived and assimilated climate variables. This included Climate Research Unit (CRU) precipitation datasets as detailed in Harris et al. (2020). Analysis of vegetation condition as proxy for fodder availability was based on the 10-day maximum-value composite. Normalized Difference Vegetation Index (NDVI) images at 250m spatial resolution from Moderate Resolution Imaging Spectroradiometer (MODIS) instrument flown aboard the Aqua satellite. NDVI, a measure of the density of chlorophyll contained in vegetative cover, is defined as (NIR - RED) / (NIR + RED), where NIR is the near-infrared reflectance and RED is the visible-red reflectance. These vegetation products are generated from MODIS L1B Aqua surface reflectance, corrected for molecular scattering, ozone absorption, and aerosols using MODIS Science Team algorithms. The NDVI data used in the study spans the period between 2001 and 2017. Soil moisture data was retrieved from the Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS) Noah Land Surface Model L4. The source data are provided by NASA through the GES DISC site. The soil moisture data was based on two soil layer depths: 0-10 cm and 10-40 cm and spans the period between 1982 and 2017. Data on milk production was sourced from dairy farmers' organization. Milk marketed was used as proxy for milk produced. The actual milk marketed data was sourced from the farmer organization for the period between 2007 and 2016. The study also used questionnaire as the tool for data collection. Focus Group Discussions (FGD) was used to gather qualitative data from the respondents in the area of study. The sessions were guided by open ended questions that gave qualitative data. Interviews were applied in this study to gather data from the key informants. A structured interview guide was used to collect primary data from the officials. Reliability of the instruments was evaluated through a pilot study conducted in Nakuru County, a dairy production area located in rift valley with similar socioeconomic conditions to Nandi County. A reliability coefficient of the questionnaire was determined using Cronbach's coefficient alpha, and in which a threshold of 0.70 was acceptable.

Data analysis

Temporal analysis of climate and fodder availability

The presence of a monotonic increasing or decreasing trend was tested with the nonparametric Mann-Kendall test while the slope of a linear trend was estimated with the nonparametric Sen's method (Gilbert, 1987). Furthermore, the true slope of the existing trend (as change per year) was estimated using the Sen's nonparametric method. The Sen slope was then expressed as percent of the mean quantity per unit time (Salmi *et al.,* 2002; Slack *et al.,* 2003). That is:

$$\% \, trend = \frac{[Sen \; Slope \; Estimator \; Q]}{mean \; f(year)} \qquad 6$$

Temporal analysis of milk production

Temporal analysis of milk production was based on both graphical and statistical approaches. Based on review of several studies such as Omore (2004), Muriuki (2009) and Wambugu (2011), it was shown that only 55% of milk produced (MP) in Kenya is marketed (sold) either formally or informally. The remaining 45% is consumed at home and others fed to calves. Further, these studies indicate that total milk marketed formally in Kenya accounts for 20% of the total milk produced. Therefore, equation 7 was used to compute the average milk supplied per HH to farmer organization (AMSHH),

$$AMSHH = \frac{\text{TMO}}{\text{NAS}} \qquad 7$$

Where TMO is the Total Milk procured by the farmer organization and NAS is the average number of active milk suppliers. Consequently, the total milk produced per household (TMHH) was computed using equation 8

$$\text{TMHH} = \left(\frac{\text{AMSHH}}{0.2}\right) \qquad 8$$

Where AMSHH is the average milk supplied per HH to farmer organization

Spatial analysis of climate, fodder availability and milk production

To determine spatial variability of climate and fodder availability, maps were used. Plotting of maps was based on geospatial information systems tools. The analysis included plotting of both seasonal and annual maps.

Characteristic of dairy production system

The study also used a systematic random sampling technique to identified smallholder dairy farmers in the area. Household that were included in research work were those who engage in dairy production and grow fodder. A target population was defined which comprised 384 individuals drawn from farmers and government employees and experts within the Nandi County. A total of 15 respondents from Kabiyet, Lesssos, Kosirai, Kapsabet and Kaptumo Sub Counties participated.in focus group discussion (FGD)

Relationship between milk production, fodder availability and climate

In order to determine the combined effect of fodder availability and climate on milk production, Multiple Linear Regression (MLR) analysis was used. MLR is based on a least squares where the model is fit such that the sum-of-squares of differences of observed and predicted values is minimized. Milk production datasets were considered as dependent variable while fodder availability and climate data were considered as independent variable. Worth noting, all variables were re-gridded to $0.25^o \times 0.25^o$ resolution for comparison purposes. Variable collinearity was detected using Variable Inflation Factors (VIFs) which measure the impact of collinearity on the standard errors of the estimate. Collinear variables offer the same information about the predictand. The square root of VIF shows how much the standard error is inflated by the other variables in the model. Collinearity was addressed by re-specifying the model i.e. dropping one or more collinear variables. Stepwise variable selection was adopted where both the backward and forward strategies are combined until no changes occur. Model selection was based on the Akaike information criterion (AIC) which measures the relative quality of a statistical model, for a given set of data. It deals with the trade-off between the goodness of fit of the model and the complexity of the model. Durbin-Watson test-statistic was used to assess model independence i.e. the hypothesis of uncorrelated errors. It is based on differences between consecutive residuals. It is constrained to lie between 0 and 4 and values around 2 indicate independence. Small/large test statistics indicate positive/negative autocorrelation. Model's residual normality was checked visually using histograms. For normality histograms should be symmetrical (bell-shaped). Wilk-Shapiro test was used to check whether the residuals come from a normal distribution. Small/large p-values signal strong evidence against/for normality. The goodness of fit of the models was assessed using the coefficient of determination, R^2. It is a statistical measure of how well the regression line approximates the real data points. An R^2 of 1 indicates that the regression line perfectly fits the data.

Results

Spatial and temporal analysis of fodder in Nandi County

Temporal analysis NDVI

Figure 2 shows lowest NDVI value of 0.54 in February with peaks in May where NDVI value reaches 0.74 and a value of 0.65 between April and November. Table 1 indicates positive NDVI changes during DJF, MAM, JJA, SON and ANN. However, these changes were significant at α> 0.1. The slope of the line of best fit ranged between 0.0007 and 0.0023 while the mean NDVI values for DJF, MAM, JJA, SON and ANN were 0.62, 0.62, 0.71, 0.68 and 0.66 respectively. Moreover, the percentage change for NDVI values during DJF, MAM, JJA, SON and ANN were 6.0%, 1.96%, 2.13%, 4.16% and 2.53% respectively.

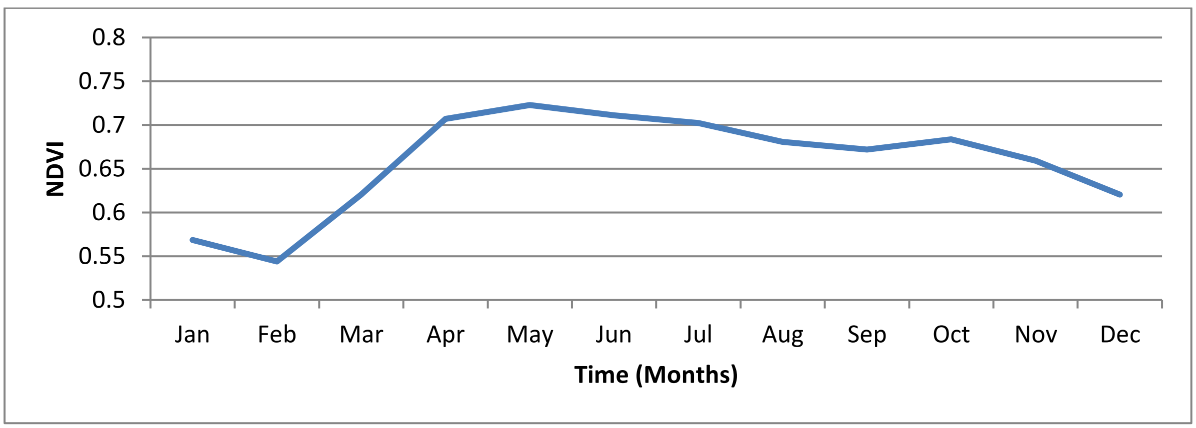

Figure 2. Climatology of NDVI over Nandi County

Temporal analysis of moisture content

Figure 3 shows annual patterns of soil moisture content at both 0-10cm and 10-40cm to be lowest in January-February-March with values < 0.20. Soil moisture content was >0.25 between April and November indicating moisture availability to support plant growth. Graphical analysis of trend (Figure 3) shows gradual increase in LTM soil moisture content between 1982 and 2016 implying sustained conditions necessary for plant growth. However, R^2 for both soil moisture content at 0-10cm and 10-40cm indicated only 24.1% and 26.1% of data could be fitted along line of best.

Table 1. Trend statistics of NDVI over Nandi County (2000 to 2016)

Season	n	Test Z	Significance level (α)	Sen Slope (Q)	Mean	%Δ
DJF	16	0.59	++	0.0023	0.62	6.00
MAM	17	0.12	++	0.0007	0.62	1.96
JJA	17	0.62	++	0.0009	0.71	2.13
SON	17	1.03	++	0.0017	0.68	4.16

Table 2. Trend statistics of soil moisture over Nandi County (1983-2016)

Variable	n	Test Z	Significance level (α)	Sen's slope (Q)	Mean	%Δ
ANN_0_10cm	34	2.55	*	0.0008	0.243	10.7
ANN_10_40cm	34	2.82	**	0.0009	0.242	12.7
DJF_0_10cm	34	1.99	*	0.0010	0.192	17.1
DJF_10_40cm	34	2.61	**	0.0014	0.195	23.7
JJA_0_10cm	34	1.81	+	0.0006	0.276	7.2
JJA_10_40cm	34	1.96	+	0.0007	0.273	8.1
MAM_0_10cm	34	1.69	+	0.0006	0.242	8.3
MAM_10_40cm	34	2.22	*	0.0007	0.235	10.2
SON_0_10cm	34	2.88	**	0.0011	0.262	14.7
SON_10_40cm	34	2.79	**	0.0013	0.261	16.5

Trend analysis (Table 2) indicated positive LTM soil moisture content changes during DJF, MAM, JJA, SON and ANN ranging between 1.69 and 2.88 for 0-10cm and between 1.96 and 2.82 for 10-40cm. These changes were significant at α≤ 0.05 for all levels except MAM (0-10cm), JJA (10-40cm) and JJA (0-10cm). The slope of the line of best fit were <0.001 while the mean NDVI values for DJF, MAM, JJA, SON and ANN ranged between 0.192 and 0.276 at 0-10cm level and between 0.195 and 0.273 at 10-40cm level. The percentage change for soil moisture content during DJF, MAM, JJA, SON and ANN ranged between 7.2% and 17.1% at 0-10cm level and between 8.1% and 23.7% at 10-40 level

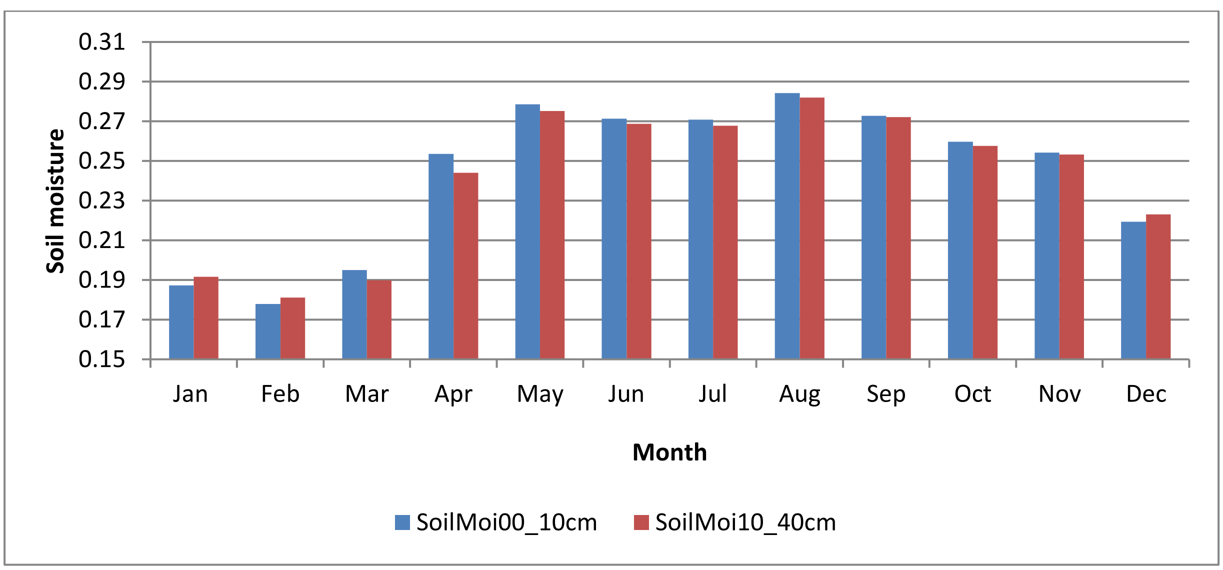

Figure 3. Climatology of soil moisture content over Nandi County

Spatial Analysis of NDVI over the Nandi county of Kenya

Figure 4 shows seasonal progression of NDVI to be lowest during the DJF over North-eastern of Nandi County and highest during JJA. Notably, NDVI values over Central of Nandi County remained high throughout the year.

Spatial analysis of soil moisture content over the Nandi county of Kenya

Figure 5 shows soil moisture at 0-10cm level to be high during JJA and low during DJF. Similarly, soil moisture content (Figure 6) was lowest during DJF and highest during JJA.

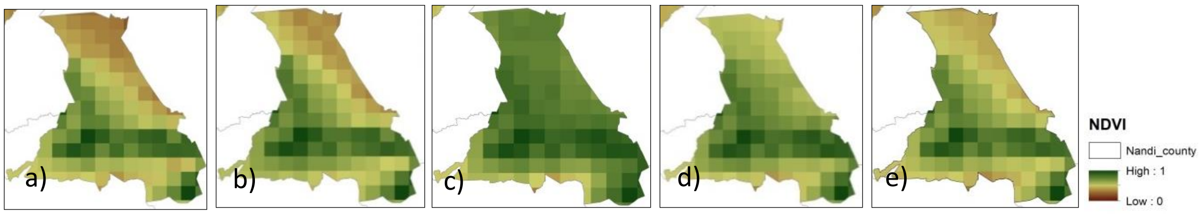

Figure 4. Spatial variability of a) DJF b) MAM c) JJA d) SON and e) ANN NDVI over Nandi County

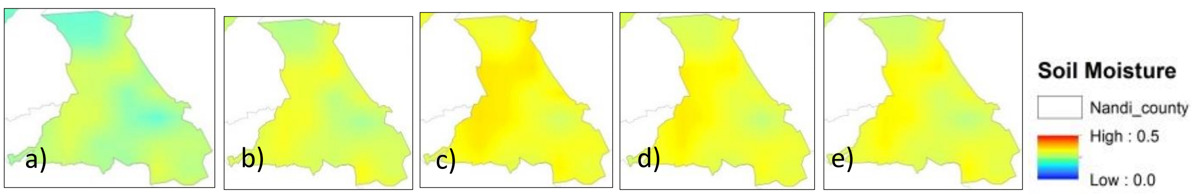

Figure 5. Spatial variability of a) DJF b) MAM c) JJA d) SON and e) ANN soil moisture content (0-10cm) over Nandi County

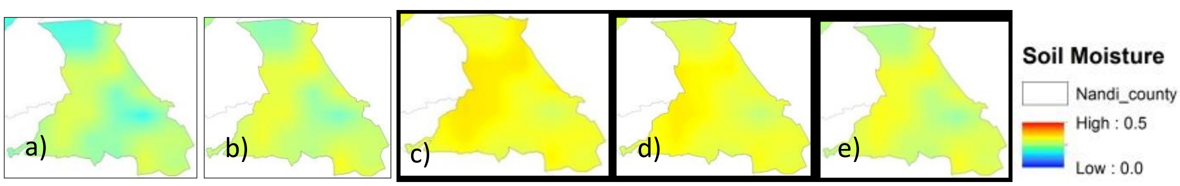

Figure 6. Spatial variability of a) DJF b) MAM c) JJA d) SON and e) ANN soil moisture content (10-40cm) over Nandi County

Temporal pattern of milk production

Graphical trend analysis of milk production

Figure 7(a) shows that trend of average daily milk procured by farmer organization increased from 2010 to 2016 with minimum of 2261.2 litres per day recorded in 2012 and maximum of 8305.5 litres per day in 2016 with average daily milk procured being 4439.5 litres. Observed increase in milk procured was attributed to the number of active milk suppliers (Figure 7 (b)) that remained highly variable suppliers with minimum (19 in 2010), maximum (69 in 2016) and average (39 between 2010 and 2016) households per day. Similarly, Figure 8 (a) shows computed average daily milk per household supplied to farmer organisation to fluctuate between 2.3 litres per household in 2012 and 4.9 litres per household in 2014 with an average of 3.8 litres per household (2010-2016). Computed milk production per household (Figure 8 b) based on the assumption that milk supplied to farmer organisation (formally marketed) only accounted for 20% of total milk produced per household indicated a minimum of 11.4 litres per household in 2012 and a maximum of 24.3 litres per household in 2014 and thus an average of 18.8 litres of daily milk produced per household (2010-2016).

Yearly statistics (Figure 9) indicate that highest monthly average milk procured (in litres) by farmer organisations in 2010 (March), 2011 (January), 2012 (December), 2013 (December), 2014 (January), 2015 (January) and 2016 (January) was 104780.8, 121106.5, 103616.0, 153547.0, 205933.0, 205933.0 and 368340.7. Yearly records (Figure 9) indicated that lowest monthly average milk procured in litres to farmer organisations in 2010 (August), 2011 (May), 2012 (April), 2013 (August), 2014 (May), 2015 (April) and 2016 (April) was

51151.0, 63047.6, 46017, 102697.3, 87303.5, 88069.0 and 195198.0. Monthly average milk procured by farmer organizations (Figure 9) was highest in January (172122.3 litres) and December (171180.7 litres) and lowest in April (105178.7 litres).

Average number of active suppliers per households in 2010, 2011 and 2012 were 584, 711 and 996 respectively (Figure 10). Computed statistics shows highest monthly average number of active milk suppliers per household in 2013 (December), 2014 (February), 2015 (December) and 2016 (December) to be 1896, 1265, 1874 and 2565 respectively. Moreover, the lowest monthly average number of active milk suppliers per household (Figure 10) in 2013 (January), 2014 (June), 2015 (April), and 2016 (February) were 1303, 792, 918, and 1734.

Monthly average milk production per HH (Figure 11) show that lowest monthly average milk production per HH in 2010 (August), 2011 (August), 2012 (April), 2013 (September), 2014 (May), 2015 (April) and 2016 (September) was 87.6, 90.3, 46.2, 60.6, 98.8, 95.9 and 89.5 litres respectively. Monthly average milk production per household (Figure 11) was lowest during the period August-September (97.0 litres) and highest in January (147.2 litres). Similarly, computed daily average milk production per household (Figure 12) in 2010 was highest/lowest in March (28.9litres)/August (14.1 litres), in 2011 was highest/lowest in January (27.5litres)/May (14.3 litres), in 2012 was highest/lowest in December (16.8 litres)/March (7.6 litres), in 2013 was highest/lowest in February (17.4 litres)/August (10.1 litres), in 2014 was highest/lowest in January (28.1 litres)/May (15.9 litres),in 2015 was highest/lowest in December (28.0 litres)/April (16.0 litres) and in 2016 was highest/lowest in February (35.7 litres)/December (15.1 litres). Figure 12 shows that the daily average milk production per household between 2010 and 2016 was highest/lowest in January (23.7 litres)/August (15.6 litres).

Statistical trend analysis of milk production

Trend analysis of seasonal and annual milk production (Table 3) were positive indicating increasing milk production throughout the year with a magnitude ranging from 3.04 (MAM) to 3.76 (JJA and DJF). Trends of milk production were all significant at α level ≤ 0.05. Sen's estimators for the true slope of linear trend were positive for MAM (50190.02), JJA (51078.07), SON (67952.45), DJF (82792.70) and ANN (260135.10). Similarly, mean values were found to be MAM (269257.5), JJA (278787.8), SON (336234.6), DJF (386095.5) and ANN (1270375). Trend of milk production showed increased of up to 186%, 183%, 202%, 214% and 204% during MAM, JJA, SON, DJF, and ANN respectively. Trend analysis of daily average milk production over Nandi County (Table 4) showed positive change and thus an indicator of increasing milk production with a magnitude 8.6, 9.2 and 1.8 for Milk procured by farmer organization, Number of Active Suppliers and Milk production per HH respectively. Sen's estimators for the true slope of linear trend were positive for Milk procured by farmer organization (75.8), Number of Active Suppliers (0.57) and Milk production per HH (0.01). Similarly, mean values were found to be Milk procured by farmer organization (4439.6), Number of Active Suppliers (39.2) and Milk production per HH (3.8). Trend of Milk procured by farmer organization, Number of Active Suppliers and Milk production per HH increased at 143.5%, 123.0% and 22.8% respectively

Characteristic of dairy production system

Land Ownership

Table 5 shows that in Aldai sub County, majority of households in Kaptumo (40.9%) and Koyo Ndurio (36.1%) owned 1 to 3 acres of land whereas majority in Kobujoi (31.3%) ward of Aldai subcounty and Chepkunyuk and Lessos ward of Nandi hills owned between 5 and 10 acres. Similarly, majority of households in Emgwen (27.1%) and Chesumei sub County in Kosirai (37.5%) and Ngechek (38.6%) owned between 1 and 3 acres of land. In Mosop Sub County, majority of households in Kabisaga

(63.2%) and Kabiyet (35.7%) owned between 10 and 20 acres of land. Generally, majority of household owned between 1 and 20 acres of land. Most of households (Table 6) in sub counties allocated between 0.5 to 2 acres of land for dairy farming except households in Lessos who allocated between 0.25 and 0.5 acres of land for dairy farming. The differences would arise from the fact that though the size of land could be the same, how the land is utilized for dairy farming results to the observed difference. Moreover, Table 7 show that majority of household had their land secured with title deed or practised farming on land secured with title deed.

but belonging to the family. Less than 1% of the household had rented land or were squatters

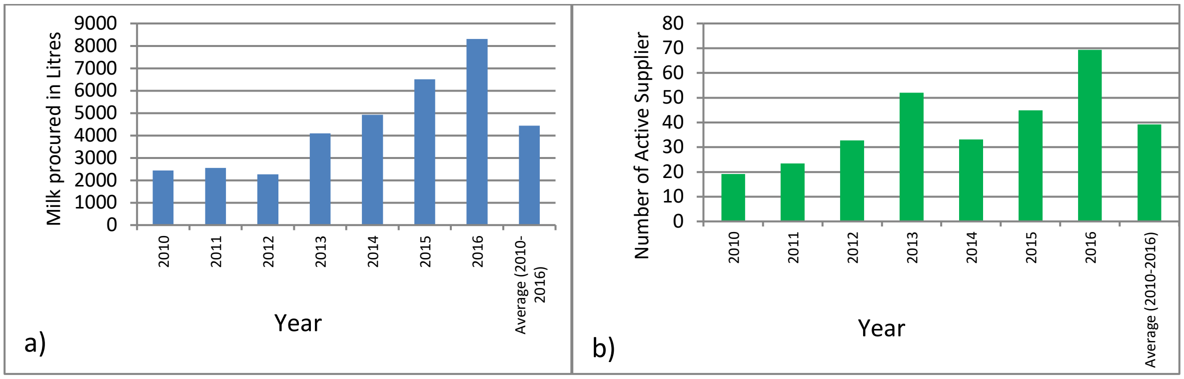

Figure 7. Mean daily a) milk procured by farmer organisations and b) number of active milk suppliers to the farmer organisation in Nandi County

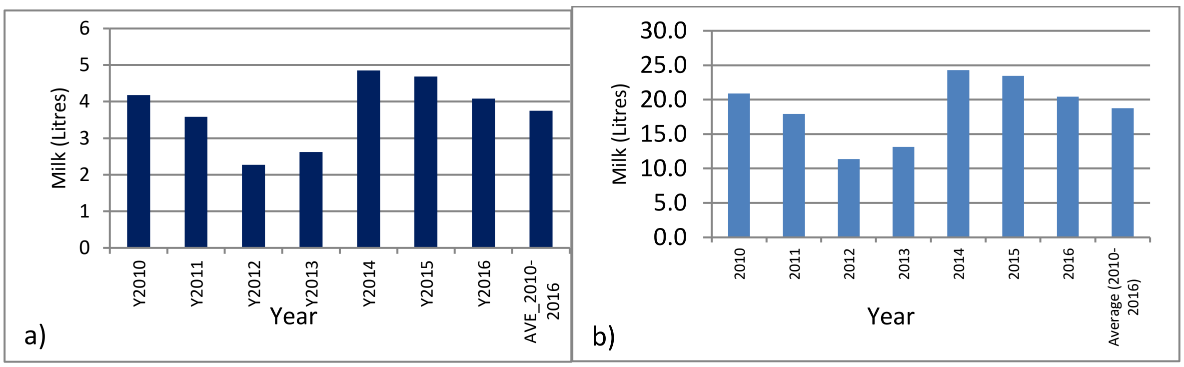

Figure 8. Mean daily milk a) supplied per household to the farmer organisation and b) production per household in Nandi County

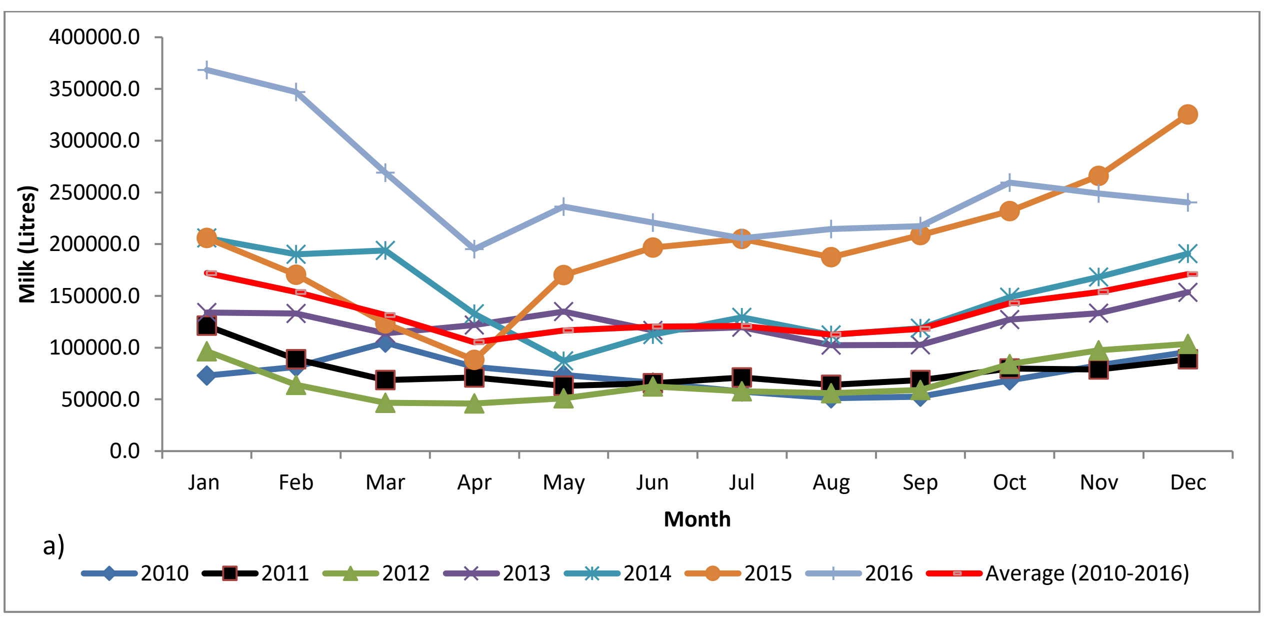

Figure 9. Monthly average milk procured by farmer organizations in Nandi County

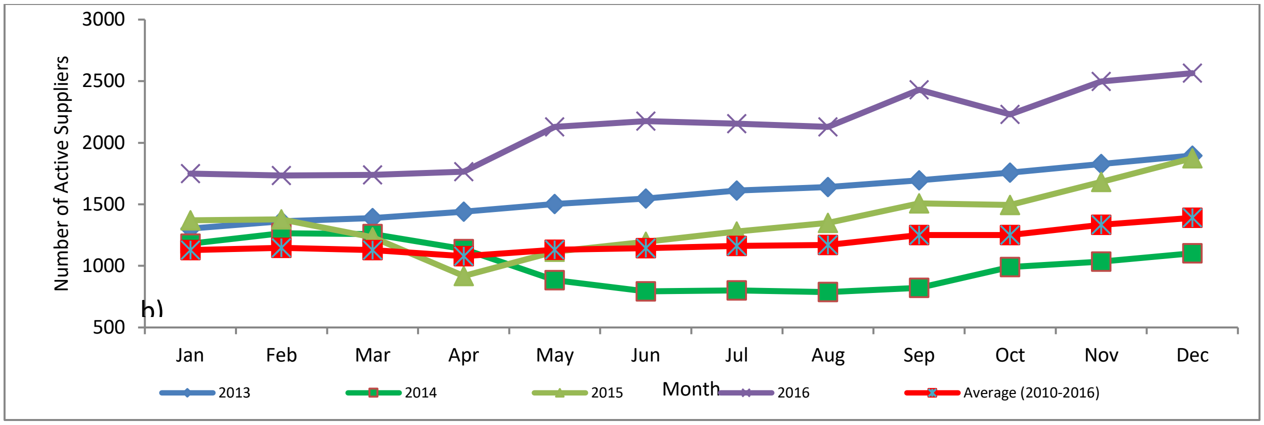

Figure 10. Monthly average number of active milk Suppliers to farmer organisation in Nandi County

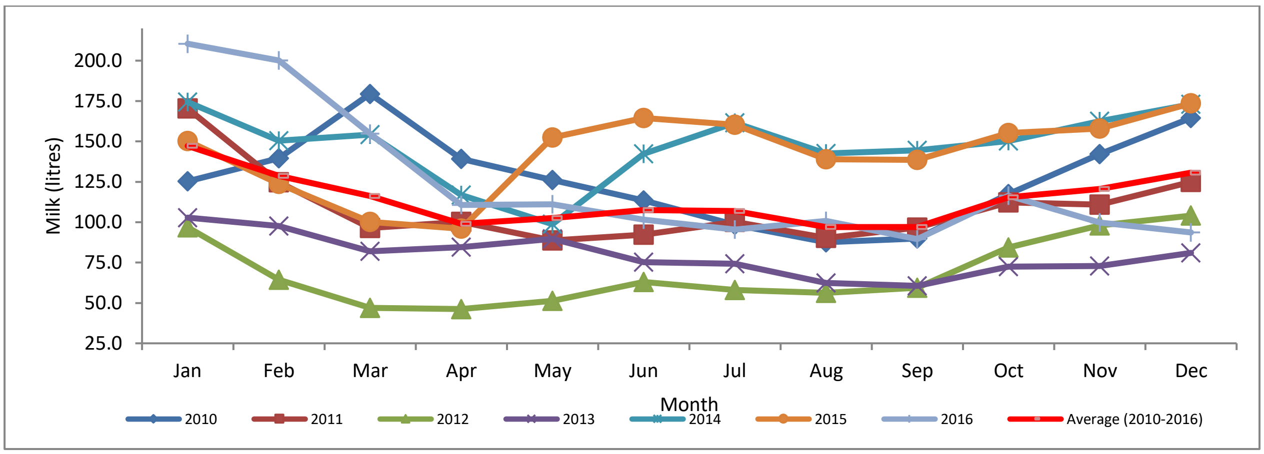

Figure 11. Monthly average milk procured per household by farmer organisation in Nandi County

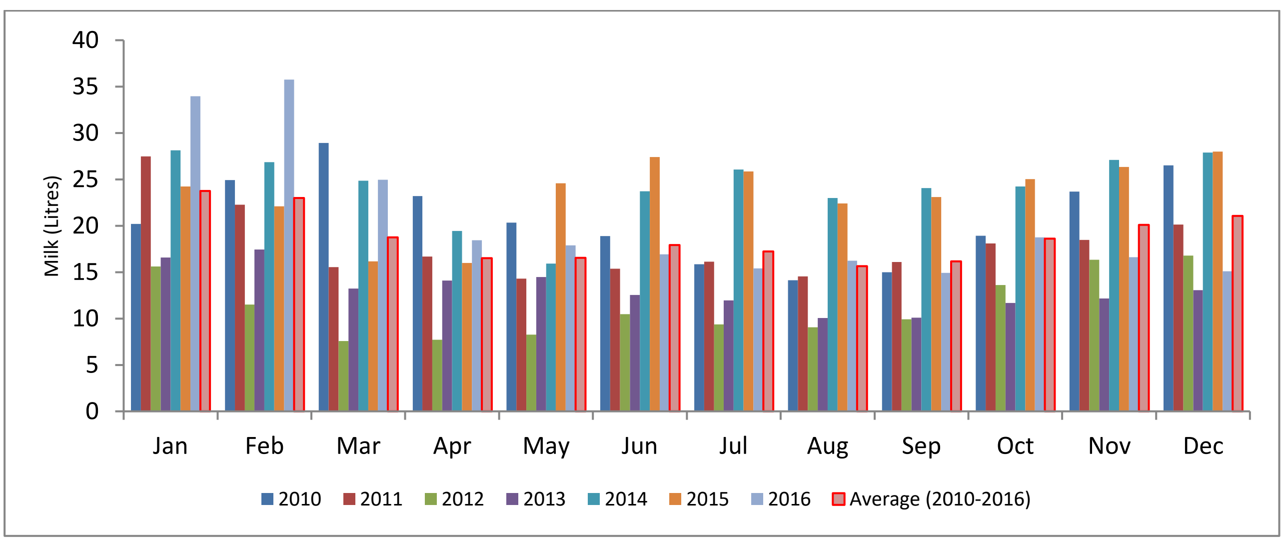

Figure 12. Daily average milk production per household in Nandi County

Dairy animals Ownership

Table 8 shows that the trend of dairy production based on livestock population, dairy cows, lactating cows and milk sales are positive with a magnitude of 3.9 with significance level (α) of 0.001 and thus an increasing trend. Sen's estimator for the true slope of linear trend for livestock population, dairy herd, lactating herd and sales were found to be 4729.7, 2838.0, 1277.3 and 1623173.7 respectively with corresponding mean values of 295160.9 (livestock population), 177096.6 (dairy cows), 79693.4 (Lactating cows) and 101292991.9 (milk sales).

Most households owned between 1 and 3 cows except in Mosop Sub County where majority in Kabisaga (44.4%) and Kabiyet (35.7%) owned between 4 to 6 cows and between 7 to 9 cows respectively (Table 9). Number of mature dairy animals (Table 10) were found to be between 1 to 3 cows except in Koyo Ndurio (49.2%) in Aldai, Kabisaga (50.0%) in Mosop and Chepkunyuk (50.0%) in Nandi Hills with 4 to 6 cows. Similarly, the numbers of young cows (Table 11) in all sub-counties were mainly between 1 and 3 cows except in Kabisaga (38.9%) which showed that majority of households had between 1 and 3 young cows. Up to 61.7% of respondents owned 1 to 3 cows (Figure 16), of which 53% of these cows were mature while 70.7% were young dairy cows.

Relationship between milk production, fodder availability and climate

Correlation analysis

At lag 0 and lag 1, there is a positive correlation between milk production and indicators of climate and fodder availability except NDVI. However, at lag 2, the correlation coefficients were all positive for climate indicators and negative for fodder availability indicators. The highest correlation coefficient was found based on minimum temperature at lag 0, 1 and 2 whereas, precipitation showed the lowest correlation coefficient for lag 0, 1 and 2.

Table 3: Trend statistics of milk production over Nandi County (2007 to 2016)

Variable	n	Test Z	Significance level (α)	Sen Slope (Q)	Mean	%Δ
MAM	10	3.04	**	50190.02	269257.5	186.40
JJA	10	3.76	***	51078.07	278787.8	183.20
SON	10	3.58	***	67952.45	336234.6	202.10
DJF	10	3.76	***	82792.70	386095.5	214.44
ANN	10	3.58	***	260135.10	1270375	204.77

Table 4. Daily average milk production

Variable	n	Test Z	Sign. level (α)	Sen Slope (Q)	Daily average	%Δ
Total Milk procured by farmer organization	84	8.6	***	75.8	4439.6	143.5
Number of Active Suppliers	84	9.2	***	0.57	39.2	123.0
Milk procured per HH by farmer organisation	84	1.8	+	0.01	3.8	22.8
Milk produced per HH	84	1.79	+	0.05	18.8	22.8

Table 5. Total Land Size of Households

Sub County	< 1 acre		1 to 3 acres		3 to 5 acres		5 to 10 acres		10 to 20 acres		> 20 acres	
	Freq (n)	Perc (%)	Freq (n)	Perc (%)	Freq (n)	Perc (%)	Freq (n)	Perc (%)	Freq (n)	Perc (%)	Freq (n)	Perc (%)
Aldai	9	7.4	44	36.4	32	26.4	26	21.5	9	7.4	1	0.8
Chesumei	10	14.7	26	38.2	14	20.6	13	19.1	5	7.4	0	0.0
Emgwen	5	8.5	16	27.1	12	20.3	14	23.7	12	20.3	0	0.0
Mosop	0	0.0	1	3.0	5	15.2	5	15.2	17	51.5	5	15.2
Nandi Hills	5	5.1	14	14.3	28	28.6	35	35.7	14	14.3	2	2.0

Table 6. Total Land Size Allocated to dairy farming

Sub County	< 0.25 acre		0.25 to 0.5 acres		0.5 to 2 acres		2 to 10 acres		> 10 acres	
	Freq (n)	Perc (%)	Freq (n)	Perc (%)	Freq (n)	Perc (%)	Freq (n)	Perc (%)	Freq (n)	Perc (%)
Aldai	9	8.3	30	27.8	46	42.6	22	20.4	1	0.9
Chesumei	6	9.0	16	23.9	28	41.8	17	25.4	0	0.0
Emgwen	6	10.5	16	28.1	23	40.4	12	21.1	0	0.0
Mosop	0	0.0	1	4.5	14	63.6	7	31.8	0	0.0
Nandi Hills	11	11.5	32	33.3	28	29.2	25	26.0	0	0.0

Multiregression analysis

Autocorrelation analysis (Table 14) shows selected models based on different predictors had positive relationship with milk production. Durbin Watson test (D-W) indicated that variables were independent as the values were distributed around 2 for different models. A comparison of selected models with at least four predictors indicated that the model with the lowest AICs value of -6.65 composed of precipitation, maximum temperature, minimum temperature and NDVI whereas the selected model with the highest AICs value composed of minimum temperature, soil moisture content (0-10cm), soil moisture content (10-40cm) and NDVI. The Value Inflation Factors of the predictor variables ranged between 1.067 and 1.226 for the selected models indicating that standard errors for coefficient of predictor variable were approximately 1.1 times as large as it would be if that predictor variable were uncorrelated with the other predictor variables. Histograms of model residual were symmetrical in shape for the selected models and thus an indication of normality in the model residuals. The results based on histograms were affirmed by the Quantile-Quantile plots for the selected stations which followed a straight line. Wilk-Shapiro test showed strong evidence against normality an indication that did not come from a normal distribution.

Discussion

Spatial and temporal analysis of fodder in Nandi County

Soil moisture content level 0-10cm and 10-40cm was lowest in the period DJF and highest in JJA season similarly the NDVI was lowest during the period DJF season and highest in the season JJA, meaning that there is a positive relationship between soil moisture content and vegetation cover. The high NDVI of above 0.65 between April and November indicates presence of good vegetation state and thus favourable condition for fodder growth and availability for livestock. In contrast, DJF season represents a period when soil moisture content at 0-10cm and 10-40cm level and vegetation cover is at its lowest status and thus limited feed resource availability. Seasonal and annual mean values of above 0.6 imply presence of good and favourable vegetation conditions throughout the year to support dairy production however this could not be realised as majority (75.9%) of smallholder farmers in Nandi allocated less than 2 acres of land to dairy farming that relied on unimproved natural pasture for feed resource (Lukuyu *et al.*, 2011) making it more vulnerable to changes in climate. The observed seasonal trend of vegetation is affirmed by studies such as Amadi et al. (2018) on sensitivity of vegetation to climate variability and its implications for malaria risk in Baringo which indicated that the annual NDVI decreased between January and March, and steadily increased between April and June whereas a decrease was observed between September and October that was followed by an increase between November and December. In addition, the positive soil moisture content affirmed presence of suitable conditions to sustain fodder production. Makoni *et al.,* (2014) linked seasonality to fodder and feed access as evidenced by lack of consistent milk supply that led to underutilization of bulking and cooling capacity in the dry season while making milk bulking and chilling capacity is insufficient during the wet season.

Temporal pattern of milk production in Nandi County of Kenya

The study found that trend of milk procured by farmer organization, number of active suppliers and milk production per HH was increasing at 143.5%, 123.0% and 22.8% respectively. Observed increased in amount of milk procured was attributed to highly variable number of active daily milk suppliers. The amount of milk per household supplied to the farmer organisation varied between 2.3 litres and 3.8 litres. Since the milk that is formally marketed accounts for only 20% of total milk produced per household (Omore, 2004; Muriuki, 2009; Wambugu, 2011), computed daily average milk produced per household in the county was 18.8 litres. Active milk suppliers were highest in December and Lowest in April. The FGD linked high milk supply and number of suppliers in December to availability of crop residues after crop harvest and availability of more land for grazing. In addition, during MAM, planting takes place and thus less land available for grazing complicating the already diminishing feeds resource because of low fodder availability. Key constraints to increased milk production have been linked to seasonality in fodder availability leading to inadequate quantity and quality of feed (Stella Wambugu, 2011). Kirui et al. (2015) found that during the wet season, the average milk production per cow ranged from 5 to 8 litres and comparatively higher than average production per cow of 2 to 5 litres during dry season. The FGD linked the observed variation in milk procured by farmer organization and the number of active milk suppliers to feed seasonality and climate that led to reduced milk production and thus increased demand for milk which meant that there was competition for the available milk from farmer organizations and other alternative markets such as informal traders who were highly competitive as they collected milk from the households and offered better prices paid on daily basis, hence reducing the amount of milk formally marketed. Corné *et al.,* (2016) acknowledged that seasonality of milk production and competition in milk procurement with informal sales, which members engaged in to diversify milk income streams to household were biggest challenges for the cooperatives. Kruse (2012) and ACET (2015) found that informal sales were made possible due to ready alternative markets available to farmers as milk traders, local markets and neighbours provided direct cash with prices being up to 70% higher under informal agreement with traders. Kruse (2012) noted that establishment of processor-owned bulking points closer to the farm also provided an incentive for farmers to sell their milk rather than to cooperatives. The FGD noted that sale of milk through informal market was common during the dry season due feed shortage and hence to supplement the available feed resource, farmers purchased feeds for the cows. Household milk demand which included milk for calves and home consumption was noted to reduce not only the amount of milk procured by farmer organizations but also the number of active milk suppliers.

Characteristic of dairy production system in Nandi County

Majority of household owned between 1 and 20 acres of land of which 0.5 to 2 acres were allocated for dairy farming Households allocating less than 1 acre of land for milk production practised zero grazing farming systems. Majority of household had their land secured with title deed or practised farming on land secured with title deed but belonging to the family and affirmed study by Makoni et al. (2014) which showed that in Eldoret and Nyahururu areas of rift-valley, dairy production was less intensive with large tracts of land available resulting in farms of 20–2,000 hectares. With majority of farmers owning improved breed dairy cows meant that they were heavy feeders with potential of producing more milk but sensitive to feed availability seasonality.

Relationship between milk production, fodder availability and climate change

Autocorrelation analysis showed that all selected models based on different predictors had positive relationship with milk production. The relationship between milk and fodder production was affirmed by a study by Kirui *et al.*, (2015) that found changes in milk and fodder production positively correlated with changes in rainfall amounts and attributed these changes to the increasing trend of extreme periods between the year 2002 and 2010. In addition, the study by Kirui *et al.*, (2015) showed that dairy production was dependent on rain-fed forages with noted increase in fodder option like Napier grass, Rhodes grass, and fodder trees.

Conclusion and recommendations

The NDVI and soil moisture content (level 0-10cm and 10-40cm) were lowest during DJF and highest during JJA season. The high NDVI (>0.65) and soil moisture content (>0.25 m^3/m^3) indicated presence suitable vegetation conditions favourable for fodder growth. Seasonal and annual mean soil moisture and NDVI indicated favourable conditions to support fodder growth. However, majority (75.9%) of smallholder farmers allocated <2 acres of land to dairy farming implying that farmers relied on unimproved natural pasture for feed resource making them more vulnerable to changes in climate. Sale of milk through informal market was common during dry season due to feed shortage necessitating farmers to purchased feeds for the cows. Household milk demand included milk for calves and home consumption decreased the amount of milk procured by farmer organizations.

Majority of household owned between 1 and 20 acres of land of which 0.5 to 2 acres were allocated for dairy farming. Households allocating <1 acre of land for milk production practised zero grazing farming systems. Majority of household had their land secured with title deed or practised farming on land secured with title deed but belonging to the family. The FGD indicated that most households had an average of 2 lactating cows throughout the year. Majority of farmers (98.6%) in all sub counties owned improved breeds of dairy cows and thus meaning heavy feeders. Milk procured by farmer organization, number of active suppliers and milk production per HH was increasing at 143.5%, 123.0% and 22.8% respectively. Trend analysis showed increasing trend in milk production throughout the season with milk procured by farmer organization, number of active suppliers and milk production per HH increasing at 143.5%, 123.0% and 22.8% respectively. Amount of milk per household supplied to the farmer organisation varied between 2.3 litres and 3.8 litres. Computed daily average milk produced per household in the county was 18.8 litres. Active milk suppliers were highest in December and Lowest in April. Daily average milk production per household between 2010 and 2016 was highest/lowest in January (23.7 litres)/August (15.6 litres). Highest correlation coefficient were found based on minimum temperature at lag 0, 1 and 2 whereas, precipitation showed the lowest correlation coefficient for lag 0, 1 and 2. Autocorrelation analysis showed that all selected models based on different predictors had positive relationship with milk production.

Therefore, milk production is highly sensitive to climate. Moreover, fodder availability which is also vulnerable to changes in climate significantly influences milk production. Given the high spatial and temporal variability in these environmental factors, it is expected that the projected change will significantly challenge future dairy productivity especially in Nandi County of Kenya. Therefore, adequate measures including adoption of climate smart technologies to mitigate and adapt the extreme climate and fodder availability are necessary in order to sustainable enhance milk production

Acknowledgement

This paper is part of the PhD Thesis presented to the University of Nairobi by Kirui JW.

The authors would like to thank Kenya Meteorology Department and dairy farmers organisations in Nandi County for providing data and the team in Nandi County for their support in data collection.

References

ACET. 2015. Promoting sustainable rural development and transformation in Africa – Kenya Country Report. Accra: African Center for Economic Transformation.

Amadi, J. A., Olago, D. O., Ong'amo, G. O., Oriaso, S. O., Nanyingi, M., Nyamongo, I. K., & Estambale, B. (2018). Sensitivity of vegetation to climate variability and its implications for malaria risk in Baringo, Kenya. PloS one, 13(7), e0199357. https://doi.org/10.1371/journal.pone.0199357

ASDSP. (2016). Nandi County. Nairobi, Kenya.

Beddington, J. R., Asaduzzaman, M., Clark, M. E., Bremauntz, A. F., Guillou, M. D., Jahn, M. M., et al. (2012). The Role for Scientists in Tackling Food Insecurity and Climate Change. Agriculture & Food Security, 10 (1), 289-290

Corné J. Rademaker, Bockline Omedo Bebe, Jan van der Lee, Catherine Kilelu and Charles Tonui, 2016. Sustainable growth of the Kenyan dairy sector; A quick scan of robustness, reliability and resilience. Report 3R Kenya/WLR 979.

CGIAR. (2015). Climate Smart Agriculture 101. Resource Library. Montpellier, France: Consultative Group for International Agricultural Research.

FAO. (2004). World agriculture: towards 2030/2050. Rome: Interim report, Global Perspective Studies Uni Food and Agriculture Organization of the United Nations.

FAO (2011). Dairy development in Kenya, by H.G. Muriuki, Rome.

Fernandez-Rivera, S., & Weber, J. (2000). Genetic variation in fodder quality traits of Combretum aculeatum foliage. Asia: Gintzburger G, Bounejmate M, Agola C, Mossi K (eds.).

Kirui JW, Muthama JN, Opere AO, Ngaina JN, 2015. Influence of climate change on smallholder dairy productivity; A case of Kosirai, Kenya, and Namayumba, Uganda. International Journal of Agricultural Science Research, Vol. 3(7), 126-135.

Hayhoe, Field, C., Frumhoff, P., & Maurer. (2004). 'Emissions pathways, climate.

International Dairy Federation. (2013). The Economic Importance of Dairying. Brussels, Belgium.

Lobell, B. D., Schlenker, W., & Costa-Roberts, J. (2011). Climate trends and global crop production since 1980.

Lukuyu B, Franzel S, Ongadi P.M. and Duncan A.J. 2011. Livestock feed resources: Current production and management practices in central and northern rift valley provinces of Kenya. Livestock Research for Rural Development. Volume 23(5), Article #112.

Kruse, G. 2012. The chilling hub model and social capital in dairy value chain development: A case of Heifer International in Kenya. Nairobi: Heifer International Kenya.

Makoni, N.F., R. Mwai, T. Redda, A. van der Zijpp, and J. van der Lee. 2014. White gold: opportunities for dairy sector development collaboration in East Africa. Report CDI- 14-006. Wageningen: Centre for Development Innovation, Wageningen UR (University & Research centre).

Morton J.F. 2007. The impact of climate change on smallholder and subsistence agriculture. Proceedings of the National Academy of Sciences Dec 2007, 104 (50) 19680-19685; DOI: 10.1073/pnas.0701855104

Muriuki, H. (2009). Smallholder dairy production and marketing in Kenya. Nairobi, Kenya, Ministry of Agriculture and Rural.

Odero-Waitituh, J. A. (2017). Smallholder dairy production in Kenya; a review. Livestock Research for Rural Development.

Omore A., S. S. (2004). Overcoming Barries to Informal Milk Trade in Kenya. EGDI-WIDER Conference on Unlocking Human Pontential Linking Informal and Formal Sector. Helsinki.

Rae, A. & R. Nayga (2010), Trends in consumption, production and trade in livestock and livestock products. pp. 11-34, in: H. Steinfeld, H.A. Mooney, F. Schneider & L.E. Neville (eds.). Livestock in a changing landscape: Drivers, consequences, and responses. Washington: Island Press

Slack, J.R., Lorenz, D.L., and others (2003) USGS library for S-PLUS for Windows. Open File Report 03-357, U.S. Geological Survey

Stefanović, J. (2015). Smallholder Farming Systems in Kenya: Climate Change Perception, Adaptation and Determinants. Zurich: Swiss Federal Institute of Aquatic.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., & De Haan, C. (2006). Livestock's long shadow. Environmental Theron and Mostert, 2008

Thornton, P. K. (2010). Livestock production Recent trends, future prospects. Philos Trans R Soc Lond B Biol Sci Biol Sci 365(1554) , 2853–2867.

Wambugu, L. K. (2011). Productivity Trends and Performance of Dairy Farming in Kenya. Nairobi.: Tegemeo Institute of Agricultural Policy and Development

Wanyoike, F. J. (2005). The Kenyan cattle population:The need for better estimation methods. Nairobi: Smallholder Dairy Project; Ministry of Livestock and Fisheries Development