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# SPATIAL AND TEMPORAL VARIABILITY OF SOIL MOISTURE IN NON-FLOODED LANDSCAPE UNITS IN NAMIBIAN ZAMBEZI REGION

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## ABSTRACT

Climate variability will continue to impact the spatial and temporal variability of soil moisture in different landscapes across the world; and in turn the variability may affect crop production. Non-flood areas in the Namibian Kwalala Landscape of Zambezi (NKLOZ) region are generally relegated to second place, as somewhat marginal for the successful production of major crops such as maize (*Zea mays* L.). Even when flood water has receded, non-flooded areas which get affected during floods, are still avoided for crop production. This is because residual moisture following the rainy season, is suspected to fall far short of the longer growing duration of maize, to the extent that farmers are too apprehensive to grow maize in such areas. The objective of this study was to determine the effect of seasonal rainfall on spatial and temporal variability of soil moisture within the Namibian Kwalala Landscape of Zambezi (NKLOZ) ecology, and the extent to which soil moisture status and soil temperature patterns (STEPs) characterise soil type (STP) productive potential. Three sensors were setup up at 20, 40 and 60 cm landscape of the NKLOZ, after digging a one-metre trench at each site. Soil moisture and temperature data were retrieved and monitored using Decagon DataTrac 3 software. ANOVA multiple regressions were used to analyse the effects of soil depth, rainfall, and soil temperature on soil moisture. Seasonal rainfall in the NKLOZ during the growing period between October and April (2012-2015) significantly ($P < 0.05$) and positively affected soil moisture, both in time and space, in recharging soil moisture to sufficiently meet maize crop water requirements in the region. Although it appeared like high amounts of soil moisture sufficiency were as a result of the events of seasonal rainfall received during the growing period, anything received between mid-January and Mid-March was still below the historical minimum and maximum decadal; and in any case late for early planted maize crop. Average soil moisture data indicated for loamy soil (8.30), sandy loam (14.30) and sand at the respective sites suggested a large rainfall season-soil texture interaction. Such an interaction should inform the prudence of production of maize from the point of view of a smart or robust crop system growing planning and management.

*Key Words*: Decagon sensors, residual moisture, *Zea mays*

## RÉSUMÉ

La variabilité climatique continuera d'avoir un impact sur la variabilité spatiale et temporelle de l'humidité du sol dans différents paysages du monde; et à son tour, la variabilité peut affecter la production agricole. Les zones non inondables de la région namibienne du paysage de Kwalala du Zambèze (NKLOZ) sont généralement reléguées au deuxième rang, car elles sont quelque peu marginales pour la réussite de la production de grandes cultures telles que le maïs (Zea mays L.). Même lorsque les eaux de crue se sont retirées, les zones non inondées qui sont affectées lors des inondations sont toujours évitées pour la production agricole. En effet, l'humidité résiduelle après la saison des pluies est soupçonnée d'être bien en deçà de la durée de croissance plus longue du maïs, dans la mesure où les agriculteurs craignent trop de cultiver du maïs dans ces zones. L'objectif de cette étude était de déterminer l'effet des précipitations saisonnières sur la variabilité spatiale et temporelle de l'humidité du sol dans l'écologie du paysage namibien de Kwalala du Zambèze (NKLOZ), et dans quelle mesure l'état d'humidité du sol et les modèles de température du sol (STEP) caractérisent le sol potentiel de production de type (STP). Trois capteurs ont été installés à 20, 40 et 60 cm du paysage du NKLOZ, après avoir creusé une tranchée d'un mètre sur chaque site. Les données d'humidité et de température du sol ont été récupérées et surveillées à l'aide du logiciel Decagon DataTrac 3. Les régressions multiples de l'ANOVA ont été utilisées pour analyser les effets de la profondeur du sol, des précipitations et de la température du sol sur l'humidité du sol. Les précipitations saisonnières dans la NKLOZ pendant la période de croissance entre octobre et avril (2012-2015) de manière significative (P <0,05) et ont affecté positivement l'humidité du sol, à la fois dans le temps et dans l'espace, en rechargeant l'humidité du sol pour répondre suffisamment aux besoins en eau des cultures de maïs dans la région . Bien qu'il soit apparu que des quantités élevées d'humidité du sol étaient dues aux événements de précipitations saisonnières reçues pendant la période de croissance, tout ce qui a été reçu entre la mi-Janvier et la mi-Mars était toujours inférieur au minimum et au maximum décennaux historiques; et en tout cas en retard pour les premières cultures de maïs. Les données d'humidité moyenne du sol indiquées pour le sol limoneux (8,30), le loam sableux (14,30) et le sable sur les sites respectifs suggèrent une grande interaction saison des pluies-texture du sol. Une telle interaction devrait éclairer la prudence de la production de maïs du point de vue d'un système de culture intelligent ou robuste qui accroît la planification et la gestion.

*Mots Clés*: Capteurs Decagon, humidité résiduelle, *Zea mays*

## INTRODUCTION

Soil moisture distribution on a landscape varies by spatial differences due to evapotranspiration and rainfall as influenced by topography, soil type, soil texture, vegetation type, condition of the land and management (Gaur and Mohanty, 2013; Das and Maity, 2014). As a matter of fact, small-scale spatial variations are readily influenced by soil texture; while larger scales are influenced by precipitation and evaporation.

Wendroth *et al.* (2012) defined temporal soil (seasonality) process as a change of a soil variable or state vector observed at the same location over time, caused by underlying effects such as rainfall, evapotranspiration, drainage, tillage, cropping and management practices. Wendroth *et al.* (2012) further explained that subsequent stages of a process either in space or time do not vary randomly, but depend on each other. They argued that if later stages of the process do not depend on each other, but vary arbitrarily, the monitoring of a sequence of stages would not be amenable to deriving causal or statistical relationship between numerous ongoing changes. In other words, the spacing and time increment between observations would be inappropriate to identify the process, meaning that the process of temporal and spatial variability of soil moisture may also be a problem on non-flooded landscape units, in contrast with the problem of climate variability mainly due to seasonal rainfall variability.

Given the high rainfall seasonality of the region-in itself both spatial and temporal, both in effect aspects equally affect spatial and temporal variability of soil moisture. They in turn affect the supply of moisture to crops at different growth stages. Pandey and Pandey (2010) stated that the variability of soil moisture in space and time, coupled with insufficient water supply, leads to uneven crop yields in a given area. It is worth noting that flooded areas have flooding benefits and problems, but the former outweigh the latter. Non-flooded areas, on the other hand, encounter a myriad of confounded problems. Among the above, a soil water is of concern to bring it out of the myriad for further attention. As a result, adaptive responses and opportunities to utilise increased soil moisture levels in non-flooded landscape units brought by the seasonal rain, is critical. Knowledge of spatial and temporal variability of soil helps in the characterisation of the soil, and is also critical for understanding the land characteristics and crop water requirements (Pandey and Pandey, 2010).

Climate variability will continue to impact the spatial and temporal variability of soil moisture in different landscapes across the world. Hence, the spatial and temporal soil processes are essential to understand the variability of soil moisture in non-flooded landscape units. The ability to utilise each non-flooded landscape unit during flooded times, depends on our knowledge of spatial and temporal variability of soil moisture, since it influences yield. In the Zambezi Region in Namibia, small-scale farmers and communities have limited understanding of the spatial and temporal variability of available soil moisture on the non-flooded landscape units during flooded years. Such knowledge could assist farmers and the community to make informed decisions during planning for maize production on non-flooded landscapes.

Maize is the most predominant and most responsive to the nature of rainfall distribution of the Zambezi region. To date, the influences of climate variability on the spatial and temporal variability of soil moisture availability and sufficiency at different soil depths on non-flooded landscape units has not been studied systematically in the Zambezi (NKLOZ) landscape. At the same time, the capability of the available soil moisture (induced by the seasonal rainfall in top soil in a given season) and the timing of utilising such moisture to support maize production also remain unknown. There is still a knowledge gap as is elicited in the Namibian Kwalala Landscape of Zambezi (NKLOZ) region, on soil moisture in relation to the seasonal rain, soil temperature and soil depth on non-flooded landscape units. During flood years, even when water recedes, such areas are avoided perpetually as unsuitable for cropping. Consequently, this has led to the abandonment for agronomic production and if this state of affairs continues, NKLOZ-like areas will fail to contribute to the much-needed food security. The objective of this study was to determine effect of seasonal rainfall on spatial and temporal variability of soil moisture within the NKLOZ ecology, and the extent to which soil moisture status (SMS) and soil temperature patterns (STEPs) characterise soil type (STP) productive potential.

## METHODOLOGY

The study was conducted at Namibian Kwalala Landscape of Zambezi (NKLOZ) region (17.5000° S, 24.2667° E). The Zambezi Region of Namibia (formerly known as the Caprivi Region) covers a land surface of around 14 400 Km$^2$ and forms the north eastern part of the country. The Region may be split into two parts – the western part which constitutes the Bwabwata Game Reserve; while the eastern section is communal land. In this study, only the eastern section of the Zambezi Region was considered.

The border between the Zambezi Region and Botswana in the south is formed by the Chobe River, which contributes part of the flood waters to the flood plains in the Region. On the other hand, the Zambezi River forms the border between Namibia and Zambia, which contributes most of the flood plain's flood water. Thus, the research was undertaken at local level (i.e. Constituency level) in the Zambezi Region using the Kwalala non-flooded landscape unit in the Kabbe North Constituency as a case study area. The Kwalala non-flooded landscape unit is a 35 ha, which has been utilised for rain-fed maize production. The crop field was selected due to the willingness of the owners to avail their land for the research.

The landscape unit was surrounded by annual floods between 2004 and 2011, and the soil and temperature data were measured in the field for the purpose of the study. The 5TM decagon sensors and Em50 data loggers were used to monitor the soil moisture and temperature measurements at different soil depths between October 2012 and September 2015.

Multiple regressions (models) were applied to the data to obtain the effects of independent variables (soil depth, rainfall, and soil temperature) on the soil moisture dependant variable. Soil moisture and temperature were measured at various soil depths in space and time, at various sites characterised by loamy sand, sandy loam and sandy. Three sensors were setup at each site at 20, 40 and 60 cm soil depth; and in total nine sensors were used for the entire experiment. The sensors were setup to capture real time status of the soil moisture and temperature, in space and time, after every one hour for three years consecutively. For this analysis, the data were aggregated to achieve a monthly smoothing average.

DataTrac 3 Software was used to retrieve soil moisture and temperature data during the study period. DataTrac 3 is a programme that allows collecting, manipulating and analysing data from the Em50, Em50R, Em50G, and Em5b data loggers (DataTrac Manual, 2015). Data retrieval (downloading) and monitoring was done every three months, until the end of the experiment. DataTrac software has been used by various farmers, not in Namibia to monitor and get-up-to date hourly soil moisture and temperature status of their crop fields (DataTrac Manual, 2015).

The multiple regressions model Analysis of Variance (ANOVA) was applied to soil moisture, temperature, rainfall and soil depth data. In the research, the dependable variable was soil moisture, whereas the independent variables were soil depth, rainfall and soil temperature. Soil depth was based on the depth in which the soil sensors were setup upon (20, 40 and 60 cm, respectively).

A multiple regression equation (Cohen *et al.*, 2003) was used for predicting Y is expressed as follows:

$$Y = b_0 + b_1x_1+b_2x_2+b_3x_3 \ldots \ldots b_nx_n \text{ ....... Eq. 1}$$

As applied in Teweldemedhin (2015) to measure the magnitude and extent of elasticity of the estimated coefficient, and also to avoid problems related to normality, multicollinearity and heteroscedasticity. It was, therefore, a necessary conduction to transform the model to log-linear and in the multiplicative forms, as follows:

$$lnY = \ln(\alpha) + \beta_{0i}\, lnX_i \text{ ......................... Eq. 2}$$

Assume ln ($\alpha$) represent dummy variables for autonomous for dependant variable, which is changed $\beta_0$ becomes autonomous of Y and $X_i$ represent as main factor (determinant), and $\beta_i$ is the estimated effect.

$$lnSM = \beta_0 + \beta_i\, lnX_i \text{ ............................. Eq. 3}$$

Where:

dependent variable SM (soil moisture); and independent variable $X_i$, thus includes soil depth, soil temperature and rainfall, respectively.

The linear functions fulfil the following basic assumption of the parametric regression model: (i) significant ANOVA and $P < 0.01$, (ii) normally distributed population, and (iii) collinearity test, indicated by "tolerance" and "variance inflation factor" (VIF) of a two tailed test predicating a predictor of multicollinearity. The "tolerance" shows the degree of multicollinearity, which if it predicted a value less than 10%, would be an indication that there are redundant variables among the independent variables (i.e. collinearity among variables), in which case requiring further investigation. On the other hand, the VIF can be used to measures the degree of multicollinearity among the independent variables in a regression model analysis, although less than ten is acceptable as a rule of thumb for obviating a need to process the output/results further. When more than 10%, it requires to be investigated in detail (Teweldemedhin, 2015).

## RESULTS

Figures 1 to 3 and Table 1 show results of the spatial and temporal variability of soil moisture (volumetric water content percent, VWC%) and temperature between October 2012 and September 2015. The red line at the bottom of the graphs (P1 5TM: VWC%) represents soil moisture, and the red line at the top (P1 5TM: °C Temp) represents soil temperature at 20 cm soil depth. The blue line at the bottom (P1 5TM: VWC%) represents soil moisture and the blue line at the top (P1 5TM: °C Temp) represents the soil temperature at 40 cm soil depth. The green line at the bottom (P1 5TM: VWC%) represents the soil moisture and the green line at the top (P1 5TM: °C Temp) represents the soil temperature at 60 cm soil depth. Thus, there were variations in soil moisture and temperature in space and time between October 2012 and September 2015.

In terms of in space, both the minimum and maximum soil moisture varied between loamy sand (Site A), sandy loam (Site B) and sandy (Site C) at different soil depth levels (20, 40, and 60 cm) (Figs. 1 to 3 and Table 1), respectively. Result showed that in space at 20 cm soil depth, the minimum soil moistures were 9.7 VWC% (loamy sand - Site A), 7.9 VWC% (sandy loam - Site B) and 4.9 VWC% (sandy soil - Site C). The spatial differences in the minimum soil moisture at different soil type or sites was 23% (loamy sand – site A and sandy loam – Site B); 98% (loamy sand – site A and sandy – Site C), and 61% (sandy loam – site B and sandy – Site C), respectively. The maximum soil moisture at 20 cm soil depth logged between sites were 33 VWC% (Site A), 26.1 VWC% (Site B) and 22.9 VWC% (Site C), with soil moisture differences of 26% (loamy sand – site A and sandy loam – Site B); 44% (loamy sand – site A and sandy – Site C) and 14% (sandy loam – site B and sandy – Site C) between soil types or sites.

In terms of time, the minimum and maximum soil moisture varied between rainy seasons (October to April) in both loamy sand (Site A), sandy loam (Site B) and sandy (Site C), and at different soil depth levels (20, 40, and 60 cm) (Figs. 1 to 3 and Table 1). Results showed that in time (October 2012 to October 2015), at 20 cm soil depth level in sandy loam (Site A), the minimum soil moisture between growing seasons (October and April) were 9.5 VWC% (2012/ 2013), 9.8 VWC% (2013/ 2014) and 11 VWC% (2015/ 2016). The temporal differences of the minimum soil moisture in loamy sand soil during the growing (October and April) from season to season was 3.0% (2012/ 2013 and 2013/ 2014); 14% (2012/ 2013 and 2014/ 2015) and 12% (2013/ 2014 and 2014/ 2015), respectively. Results of temporal maximum soil moisture (October 2012 to October 2015) at 20 cm soil depth in sandy loam between growing seasons (October

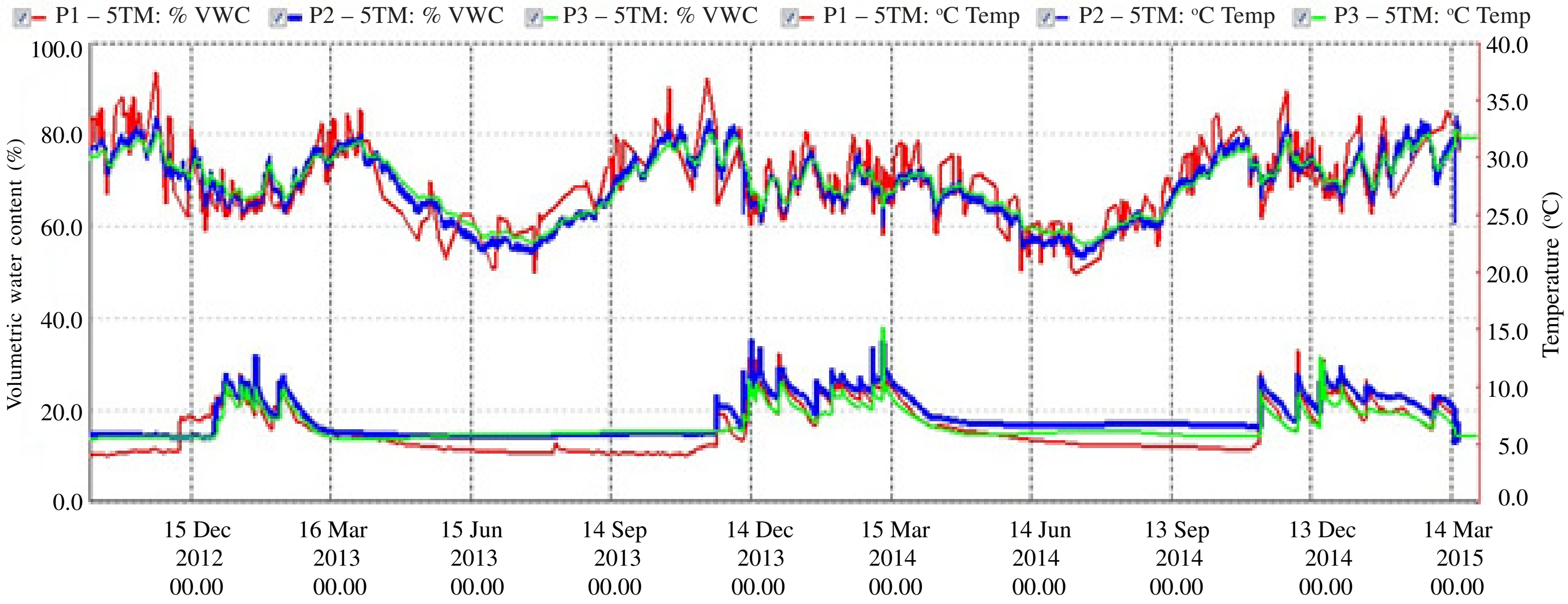

Figure 1. Temporal variability of soil moisture versus temperature trend measured in loamy sand soil over time between 10 October 2012 and 31 March 2015 at Site A of Kwalala non-flooded landscape unit.

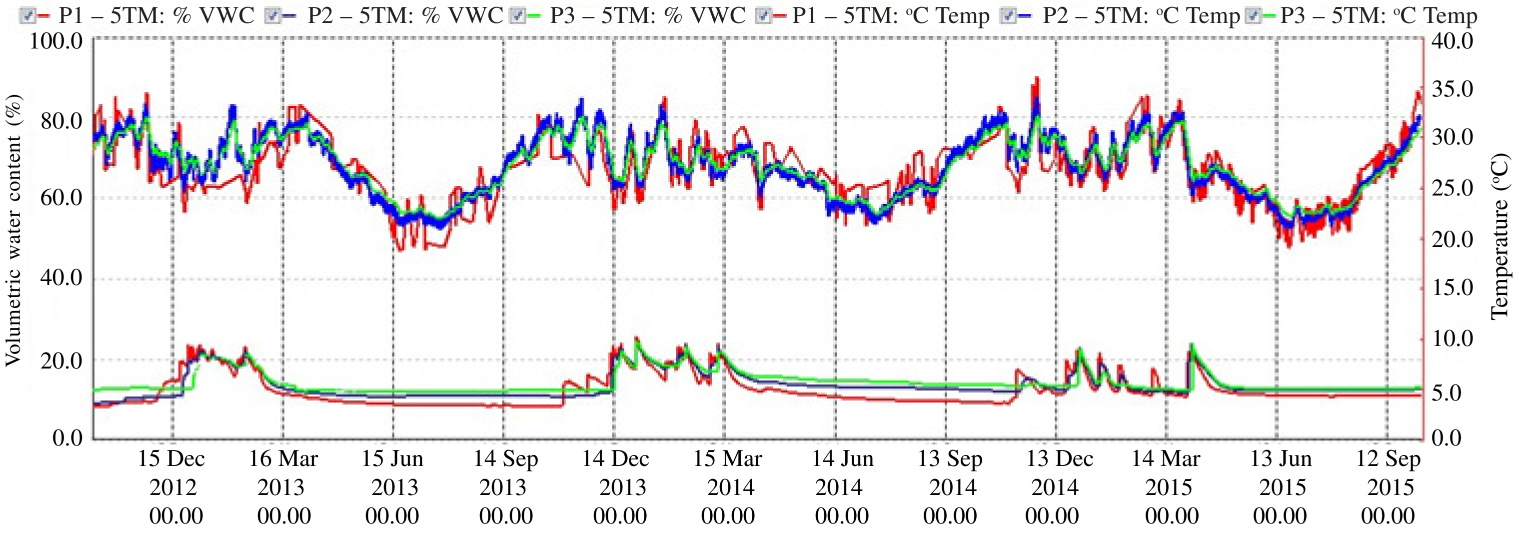

Figure 2. Temporal variability of soil moisture versus temperature trend measured in sandy loam soil over time between 10 October 2012 and 10 October 2015 at Site B of Kwalala non-flooded landscape unit.

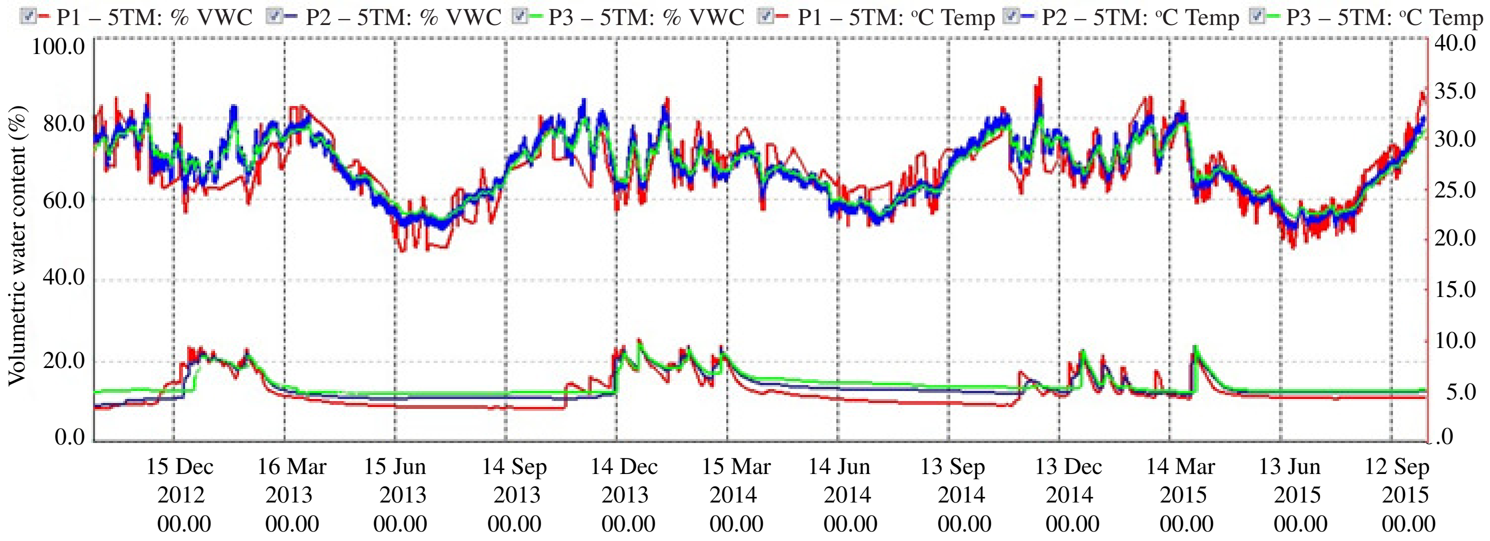

Figure 3. Temporal variability of soil moisture versus temperature trend measured in sandy soil over time between 10 October 2012 and 10 October 2015 at Site C of Kwalala non-flooded landscape unit.

TABLE 1. Descriptive statistics for soil moisture and temperature measured at Kwalala non-flooded landscape unit, Namibia (October 2012 to October 2015)

| Site and texture | Soil depth | 20 cm | | 40 cm | | 60 cm | |
|---|---|---|---|---|---|---|---|
| | Units | % VWC | °C - Temp | % VWC | °C - Temp | % VWC | °C - Temp |
| Site A (Loamy sand) | Average: | 15.50 | 27.90 | 18.30 | 27.40 | 16.60 | 27.60 |
| | Minimum: | 9.70 | 19.20 | 12.20 | 21.00 | 12.90 | 22.30 |
| | Maximum: | 33.00 | 38.00 | 36.00 | 33.70 | 39.90 | 32.50 |
| | Std. Deviation | 4.56 | 3.61 | 3.85 | 2.97 | 2.83 | 2.59 |
| | Coefficient of variation (%) | 2.13 | 5.32 | 3.17 | 7.08 | 4.55 | 8.62 |
| Site B (Sandy loam) | Average: | 12.30 | 27.20 | 13.40 | 27.10 | 14.10 | 27.10 |
| | Minimum: | 7.90 | 18.30 | 9.00 | 20.70 | 11.70 | 21.90 |
| | Maximum: | 26.10 | 37.60 | 25.10 | 34.10 | 25.00 | 32.30 |
| | Std. Deviation | 3.76 | 3.57 | 3.04 | 3.15 | 2.94 | 4.19 |
| | Coefficient of variation (%) | 2.10 | 5.12 | 2.96 | 6.57 | 3.98 | 5.23 |
| Site C (Sand) | Average: | 9.30 | 27.90 | 8.30 | 27.60 | 7.80 | 27.90 |
| | Minimum: | 4.90 | 17.90 | 4.80 | 21.00 | 5.50 | 22.40 |
| | Maximum: | 22.90 | 41.70 | 17.90 | 35.30 | 17.50 | 33.60 |
| | Std. Deviation | 4.41 | 4.16 | 2.75 | 3.09 | 4.41 | 2.84 |
| | Coefficient of variation (%) | 1.11 | 4.31 | 1.74 | 6.81 | 1.25 | 7.89 |

and April) was 32.8 VWC% (2012/ 2013); 32.3 VWC%, (2013/ 2014) and 33 VWC% (2014/ 2015). The temporal differences of the maximum soil moisture in loamy sand soil, during the growing (October and April) from season to season was 2% (2012/ 2013 and 2013/ 2014); 1 % (2012/ 2013 and 2014/ 2015) and 2% (2013/ 2014 and 2014/ 2015), respectively.

Findings suggest a high amount of soil moisture sufficiency logged mostly during the rainy seasons between October and April in a given season (Figs. 1 to 3) for both sites.

**Variability and availability of soil moisture.** Table 2 presents findings on the factors influencing soil moisture as the function of rainfall, soil depth and soil temperature of the experimental data of a cross sectional (from October 2012 to September 2015 aggregated to monthly). The $R^2$ (0.5, $P< 0.05$) shows a good fit. The good fit (equation) predicts that as soil temperature, soil depth and rainfall changes, soil moisture is likely to change with the magnitude or with the value shown in Table 2. Thus, the $R^2$ has been found to be 70.4, 72 and 55.2% for Kwalala non-flooded landscape unit's site A, B, and C respectively. However, ANOVA shows that it is significant ($P<0.05$), which accepts the alternative hypothesis that established that all the site regression output has a linear relationship. At the same time, the "tolerance test" in this study was found to be more than 10%, and shows there was no redundancy among variables. On the other hand, the VIF is less than five; that indicates there is no multicollinearity.

An F-test indicates that there is normal distribution under the null hypothesis (Fig. 4). It is often used when comparing statistical models that have been fitted to a dataset in order to identify the model that best fits the population from which the data were sampled. Under normal circumstances as a rule of thumb, more than 2 is acceptable.

In this study, it was found to be more than 34 in all sites as indicated on Table 2. Therefore, the contributions of each and every variable to the dependant variable (soil moisture) were found to be significant ($P<0.05$) with an estimated coefficient constant accounted for 3.7 for soil depth, soil temp and rain to be 0.11, -0.45 and 0.07, respectively for site-A. For example, it means that one unit increase/ decrease in the soil temperature led to a decrease/ increase in the soil moisture of 0.45 VWC%. Similarly, one unit increase/ decrease in rainfall led to an increase/ decrease of 0.07 VWC% in the soil moisture. In terms of soil depth, an increase in depth by one unit will eventually lead to an increase in soil moisture of 0.11 VWC%.

The constant error term shows 3.7 estimated coefficients. This means that there might have been some unit increase in other factors which were not captured in the model. Probable factors include condensation, evaporation, vegetation, colour of the soil, moisture content, (e.g. a soil with higher moisture content is cooler than dry soil), tillage, soil texture, organic matter content and slope of the land that led to an increase in soil moisture by 3.7 VWC%. Therefore, the above interpretation and explanation also explain the experimental sites of B and C in the same way.

## DISCUSSION

Results showing the dimension of the space and time effect on the Kwalala non-flooded landscape unit suggest that the average soil moisture sufficiency ranged between sites on sandy soil and loamy sand at various soil depths. The high amounts of soil moisture (sufficiency) were as a result of the events of rainfall received. This implies that the period between October and April is a major crop growing season. During this period the findings indicate that soil moisture varied in space and time at different soil depths at NKLOZ as a result of soil temperature and events of rainfalls. Thus, it can be interpreted that a variation of soil moisture at different soil depth levels correlate with the variation of soil

TABLE 2. Ordinary Least Square Regression analysis (for Site A, B and C) Kwalala non-flooded landscape unit, Namibia

| Model | Site-A | | | | | Site –B | | | | | Site -C | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Unstandardised coefficients | | Sig. | Collinearity statistics | | Unstandardised coefficients | | Sig. | Collinearity statistics | | Unstandardised coefficients | | Sig. | Collinearity statistics | |
| | B | Std. Error | | Tolerance | VIF | B | Std. Error | | Tolerance | VIF | B | Std. Error | | Tolerance | VIF |
| Constant | 3.71 | 0.612 | 0 | | | 3.395 | 0.588 | 0 | | | 3.183 | 0.863 | 0 | | |
| Soil depth | 0.109 | 0.035 | 0.002 | 0.999 | 1.001 | 0.157 | 0.034 | 0 | 1 | 1 | -0.115 | 0.048 | 0.02 | 1 | 1 |
| Soil temperature | -0.45 | 0.183 | 0.016 | 0.755 | 1.324 | -0.472 | 0.177 | 0.009 | 0.723 | 1.384 | -0.282 | 0.259 | 0.28 | 0.693 | 1.443 |
| Rainfall (mm) | 0.074 | 0.008 | 0 | 0.756 | 1.323 | 0.073 | 0.008 | 0 | 0.723 | 1.384 | 0.113 | 0.012 | 0 | 0.693 | 1.443 |
| R Square | | 0.704 | | | | | 0.72 | | | | | 0.552 | | | |
| Adjusted R Square | | 0.495 | | | | | 0.52 | | | | | 0.539 | | | |
| Durbin-Watson | | 1.245 | | | | | 1.00 | | | | | 1.200 | | | |
| ANOVA | | 0.00 | | | | | 0.00 | | | | | 0.00 | | | |
| F-Stat | | 34.00 | | | | | 37.00 | | | | | 42.00 | | | |

a.Not in Table! Dependent variable: Soil Moisture. b. Predicators: (constant), rainfall (mm), soil depth (cm) and soil temperature (°C)

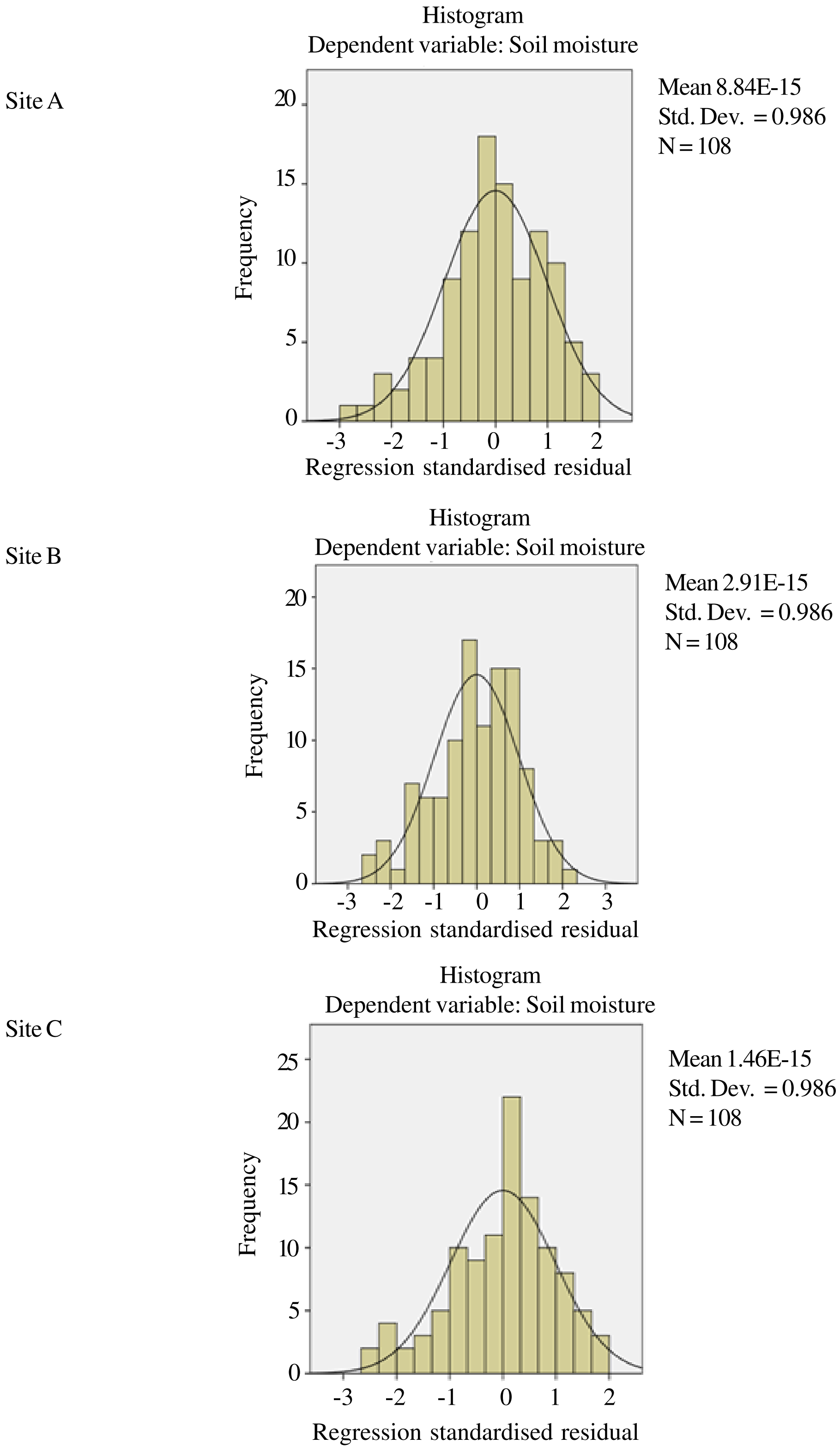

Figure 4. Normal distribution curve test of residual value.

temperature and the events of rainfall in a given season (Figs. 1 - 3). The results suggested a high possibility of soil moisture as a single exponent (a fractal dimension) and because of its nature cannot be enough to describe the spatial soil moisture dynamics. Instead, a continuous spectrum of exponents is plausible.

The spatial soil moisture variation when extreme is described as 'long distance' and 'short distance' whenever it is of less extremity. Between October and January the spatial soil moisture variation was seemingly short and also short between January and March. In the context of crop production, the findings imply that such soil moisture variations may lead to soil moisture sufficiency or insufficiency depending upon a growth stage during the growing period.

The results in this study are in agreement with the study by Skierucha *et al.* (2012) who reported that soil moisture varied according to the soil depth, as influenced by rainfall and temperature. This being so, both the nature of the soil and temperature are justifiably two important fractual dimensions. Similarly, Roxy *et al.* (2014) found soil moisture ranging between 11 and 42% at a soil depth of between 0.05m to 0.10 m, respectively. Though soil moisture varied in space and time in Kwalala non-flooded landscape unit, the minimum soil moistures logged at 20 cm soil depth, was 9.7 VWC% (loamy sand - Site A), 7.9 VWC% (sandy loam - Site B) and 4.9 VWC% (sandy soil - Site C) which was higher than the maize crop water requirement of 4.0 mm per day. Thus, findings in this study suggest that soil moisture on the non-flooded landscape unit during the growing period between October and April, despite being a long distance, was sufficient to support maize production given the prevailing climatic and soil conditions in the Zambezi Region and similar ecologies.

Results showing soil temperature and rainfall effect on the Kwalala non-flooded landscape unit that the average soil moisture varied between sites on sandy soil, sandy loam and loamy sand at various soil depths, were significant and suggest the following:

Findings suggest that soil temperature and rainfall could be the main factors that influence soil moisture to vary along the soil depths, between the growing periods at the Kwalala non-flooded landscape unit. Hence, one unit increase/decrease in the soil temperature leads to a decrease/increase in soil moisture. Similarly, results suggest that one unit increase/decrease in rainfall leads to an increase/decrease in the soil moisture.

In terms of soil depth, results suggest that an increase in the soil depth by one unit leads to an increase in soil moisture. Though it is suggested that soil moisture availability may vary along the soil depth as induced by rainfall, and influenced negatively by temperature, it has been found to be more than enough to sustain maize during the growing period. The increase in soil moisture along the soil depth suggests that such moisture could be stored in the root zones and become available to crops in space and time. These results are similar to the study by Gaur and Mohanty (2013), who examined the effects of topography vegetation, soil texture on soil moisture spatial distribution in watersheds. These findings are also in agreement with the results by Lakshmi *et al.* (2003), who found that an increase in temperature led to a decrease in soil moisture and *vice versa*. Lakshmi *et al.* (2003) further explained that temperature is crucial in determining the land surface heat and water balance in the soil, as well as estimation of evapotranspiration of crops in given climatic zones. Furthermore, results are in agreement with findings of Xu *et al.* (2011) that soil water content in soil layers significantly increases with rainfall intensity in South Western China. Similarly, the study by Lakshmi *et al.* (2003) and Xu *et al.* (2011) found that the soil moisture increased with soil depth after the events of rainfall up to a depth ranging from 0 cm - 80 cm.

Findings in this study suggest that even though soil moisture varies in space and time as influenced by soil temperature and rainfall along with soil depth, the prevailing climatic and soil conditions on the non-flooded landscape units in the Zambezi Region and similar ecologies, it is sufficient to sustain the agronomic crops during the growing period between October and April.

## CONCLUSION

This study suggests that spatial soil moisture has a short distance to assure water content sufficiency for optimising the non-flooded landscape units. Spatial and temporal data suggest that water content at all soil depth (i.e., up to 20, up to 40, up to 60 cm) were sufficient to sustain the duration of the maize and other similar growing duration. However, the challenge is to manage the events of long distance in the face of climate change.

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