ISSN 2309-3218

THE EFFECT OF TEMPERATURE AND RELATIVE HUMIDITY ON RAINFALL IN GOKWE REGION, ZIMBABWE: A FACTORIAL DESIGN PERSPECTIVE

Romeo Mawonike
Department of Mathematics and Computer Science, Great Zimbabwe University
ZIMBABWE

Godcares Mandonga
Department of Mathematics and Computer Science, Great Zimbabwe University
ZIMBABWE

ABSTRACT

The study of weather parameters is paramount in this era of climate change. Temperature, relative humidity, amount of sunshine and wind speed among others; are weather parameters which play a role to determine the amount of rainfall received on land. In this research, the effect temperature and relative humidity on rainfall was studied. The study reveals that both temperature and relative humidity have a positive significant effect on rainfall. Results show that rainfall is maximised when temperature and relative humidity are at high levels and few rainfall is expected when both these parameters are at low levels. It is also observed that temperature contributes about 50% to change in rainfall while relative humidity contributes about 80% to change in rainfall. It has been found that the interaction of temperature and relative humidity has little meaning or insignificant to change in rainfall received.

Keywords: Factorial design; rainfall; temperature; relative humidity; weather.

INTRODUCTION

Gokwe area is located in the north-western part of Zimbabwe. It is found in agro-ecological region IV of Zimbabwe (also known as natural regions (NR)) (Mugandani et al, 2012; Vincent and Thomas, 1960). This region is located in the low lying areas in the north and south of the country. The characteristics of the region are: annual rainfall of 450-650mm, average annual temperature vacillates at 22 degrees celcius, severe dry spells during the rainy season and frequent seasonal droughts (Mugandani et al. 2012). On average, the warmest month(s) are September, October and November. The most rainfall (rain season) is seen in January, February, October, November and December. Gokwe has dry periods in May, June, July and August with mean monthly relative humidity ranging from 38% (September) to 75% (January, February and December) (Weather and Climate for Gokwe 2017) (The average rainfall received in this area makes the region generally suitable for livestock rearing and for major drought tolerant crop types. Local residents in Gokwe are rearing mainly cattle and goats as well as growing some crops like cotton and maize for income generating and consumption respectively. Non-arable land is used for grazing under communal tenure. Rainfall is the backbone of Agricultural Sector and Water Resources Management. Prior to this notion studies concerning rainfall has become an area of interest globally. Agriculture continues and still remains the key sector that contributes significantly to the Gross Domestic Product (GDP), employment and foreign exchange earnings in the economy of many countries.

Historically, Gokwe used to be recognized for cotton (at large) and maize production as adequate rains were being received and the environment was said to be stable. We have observed economic and social developments in the area which have brought by successful agriculture. Foreign and local companies like Olam, Cotton Company of Zimbabwe, Grafax, Cargill, Grain Marketing Board and many others were attracted in Gokwe for buying and marketing agricultural products. Most recently, the nature in which rainfall occur has completely changed as a result of climate change (Zambuko, 2011). Variations in the rainfall patterns has completely brought significant change of life in Gokwe as evidenced by poor living standards. The maize and sorghum production has become too low to sustain farmers in terms of consumption. The change in rainfall patterns has caused deteriorating infrastructure such as roads and telecommunications, as well as overall production capacity (Moyo et.al, 2009). The amount and pattern of rainfall are among the most important factors that affect agricultural systems of a region (Nkuna and Odiyo, 2016). Weather conditions can have a significant impact on the amount of rainfall received and therefore cannot be ignored. Thus the ambient temperature and humidity variations have both diurnal and seasonal variation. While changes in weather conditions are inevitable and may have significant effects, they are usually measurable and could be mitigated based on experimental measurements. Hence, it is essential to investigate weather-related factors affecting the amount of rainfall received in order to be aware of their impact and to adapt to varying conditions.

LITERATURE REVIEW

We experience weather every day in all its wonderful variety. Most of the time it is familiar, yet it never repeats exactly (Trenberth et al., 2000). We also experience the changing seasons and associated changes in the kinds of weather. In summer, fine sunny days are interrupted by outbreaks of thunderstorms, which can be violent. When winter approaches, the days get shorter, colder and the weather typically fluctuates from warm, fine spells to cooler and snowy conditions. We expect these conditions each time and again and plan accordingly. Here in Zimbabwe, it has become a norm that towards November, farmers start to prepare for seeds and clearance of the land to make use of the expected rains usually received from November to March. Consequently, there are typical activities done in winter (indoors) as the temperatures drop even to freezing point in some of low lying regions. In this regard, the summer season bring about hot weather which necessitates outings as well as adaptions. Weather conditions change from time to time and these variations sometime become hazardous to human and animal life hence need good climatic models for predictive purposes. Nowadays it has become difficult to plan in accordance to weather conditions we used to have some years ago due to a drift in climate (climate change). We now succumbing to very hot temperatures and prolonged dry spells which are uninhabitable (Trenberth et al., 2000). Continuing climate changes are likely to have considerable negative consequences for livelihoods in many developing countries because it is expected to be very harsh with extreme conditions in future (Mertz et al 2009; Trenberth, 2012). Society and ecosystem and human activities will also be affected directly and indirectly by changes in temperature, affecting the timing and duration of plant growth, as well as hydrology (Dai, 2013).

Atmospheric models wishing to represent partially cloudy conditions must implicitly or explicitly take into account temperature and humidity variability (Tompkins, 2003). Some researchers base cloud cover on relative humidity (RH) using a monotonic increasing function (Sundqvist 1978; Slingo 1980) that increases from zero at a specified critical RH, to overcast conditions when RH reaches 100%. The serious RH for cloud formation is thus a deputation for the assumed variance of humidity and/or temperature, but the exact distribution for these quantities is not necessarily known (Tompkins, 2003). It is noted that correlated temperature and humidity fluctuations has influence on the cloud cover (Mahrt, 1991; Tompkins, 2003; Price and Wood, 2002). It is apparent that the temperature variability has less impact on cloud clover than humidity variability but the first is not insignificant (Tompkins, 2003; Price and Wood, 2002). From the investigations done by Tompkins, (2003), temperature variability has a half effect to cloud cover as compared to humidity fluctuations. Increased heating leads to greater evaporation and thus surface drying, thereby increasing the intensity and duration of drought. Droughts are associated with a lack of precipitation and often extremely high temperatures that contribute to drying (Trenberth, 2011a).

Precipitation

Precipitation is intermittent, and the character of the precipitation when it occurs depends greatly on temperature and the weather situation (Trenberth, 2003; 2005; 2011a). The latter determines the storms and supply of moisture through winds and surface evaporation, and how it is gathered together to form clouds. Precipitation forms as water vapour is condensed, usually in rising air that expands and hence cools. As air warms above the freezing point, precipitation turns to rain. As air rises into regions of lower pressure, it expands and cools, and that cooling causes water vapour to condense and precipitation to form. Consequently, changes in temperature through the Clausius-Clapeyron (C-C) relationship provide a very fundamental constraint on the amount and type of precipitation through the water vapour content of the air.

Temperature

Temperature is a measure of the warmth or coldness of an object or substance with reference to a standard value (Canada's Weather Office 2010). Temperature influences rainfall in many ways; high temperatures may result in exceedingly high rates of potential evaporation and low precipitation. This results in an area being dominated by an arid or semi-arid landscape. In other cases, high temperatures lead to more evaporation and consequently increased condensation leading to high rainfall (Buishand and Brandsma 1999; Nkuna and Odiyo 2016).

Relative Humidity

Humidity is the amount of water vapour, the gaseous state of water, in the air, and is usually invisible (Jari, 2015). This is produced by the evaporation of water from oceans, lakes, rivers, wetlands and plants. The maximum amount of water vapour in the air depends on air temperature. Relative humidity (RH) defined in percentage as, how much water vapour (absolute humidity) is in the air relative to the maximum amount of water vapour (saturated humidity) at the same temperature and pressure.

Temperature and Humidity

There is a relationship between relative humidity and temperature. It has been found from the work done by Ajadi & Sanusi (2013) that the higher the temperature the lower the relative humidity and hence the faster the drying rate of any material and Humid air slows down evaporation. Although the relationship of temperature variations and humidity variations differ from region to region, generally the variations of specific humidity correlates positively at all levels of humidity with temperature variations at the same level (Sun and Oort, 1995). However, they found out that the strength of the correlation between specific humidity variations and the temperature variations at the same level appears to be strongly height dependent. They concluded from their study contacted in tropical troposphere that statistically, water vapour increases with temperature in both upper and lower troposphere.

METHODOLOGY

Our research is based on data collected from Gokwe weather station for the period January 2000 to December 2015. Our data is monthly considering three weather parameters namely: rainfall, temperature and relative humidity. Average maximum temperatures were coded "high" or "+" and average monthly minimum temperatures were coded "low" or "-". This also applies to average monthly maximum and minimum relative humidity. Our sample considers 20 years (180 months) to adequately investigate the effect of change in temperatures and humidity variability to rainfall received. Due to the nature of our data, we explored a 2^k factorial model ($k = 2$) because it takes into consideration two different parameters together with their two levels of measurement having an effect on the response parameter. In our model, the response variable is rainfall and the independent variables are temperature and relative humidity. In the context of the design, independent variables are regarded as factors and two different measurements (max or low) are factor levels, that is, temperature and relative humidity have each two factor levels. In our research, we consider monthly average temperature of 16^0C and below as "low" and temperature of 27^0C and above as "high". On another hand, relative humidity of 75% and above is considered "high" and 40% and below is regarded as "low". We model the design using a statistical model in equation 1.

$$y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + e_{ijk} \quad (1)$$

Where y_{ijk} are observations, τ_i is the effect of the ith level of factor A, β_j is the effect of the jth level of factor B, $(\tau\beta)_{ij}$ is the effect of the interaction between τ_i and β_j. e_{ijk} is a random error component which follows a normal distribution with mean 0 and variance σ^2. Let denote temperature by "Factor A" and average maximum and average minimum temperatures be the factor levels of factor A. Again let denote relative humidity by "Factor B" and average maximum and minimum humidity be the factor levels. Let small a represents the treatment combination of A at high level and low level of B. Let small b represents the treatment combination of B high and low level of A. Let ab denote the treatment combination of both A and B being high. Finally, let (I) denote the treatment combination of both A and B being low. Each treatment combination is replicated n times. Table 1 shows the research design layout of our model taking into consideration all treatment combinations as well as replicates.

Table 1: Layout of 2^2 Factorial Design. (Montgomery 2013)

Treatment combination		**Main Effects**			**Response Replication**	
	A	B	AB	1	2 …	n
(I)	-	-	+	Y_{11}	Y_{12} …	Y_{1n}
a	+	-	-	Y_{21}	Y_{22} …	Y_{2n}
b	-	+	-	Y_{31}	Y_{32} …	Y_{3n}
ab	+	+	+	Y_{41}	Y_{42} …	Y_{4n}

We are interested in testing three hypotheses. Firstly, we test the significance of change in temperature to rainfall. Secondly, test the significance of variability in relative humidity to rainfall. Lastly, test the significance of the interaction between change in temperature and variability in relative humidity. Symbolically, we can represent the above hypotheses in their order as follows:

$$H_0: \tau_i = 0, \quad for\ all\ i$$
$$H_1: \tau_i \neq 0\ \ for\ at\ least\ one\ \tau_i$$

$$H_0: \beta_j = 0, \qquad for\ all\ j$$
$$H_1: \beta_j \neq 0\ \ for\ at\ least\ one\ \beta_j$$

$$(\tau\beta)_{ij} = 0, \qquad for\ all\ i\ and\ j$$
$$(\tau\beta)_{ij} \neq 0, \qquad for\ at\ least\ one\ (\tau\beta)_{ij}$$

H_0 is the null hypothesis which states that there is insignificance effect to the response variable brought about the change of a factor level. While the alternative hypothesis H_1 states that there is significance effect. Statistical analysis of the model is fixed effects because all treatment combinations and experimental units of interest are considered. We may define the average effect of a factor as the change in response produced by a change in the level of that factor averaged over the levels of the other factor (Montgomery, 2001). To estimate an effect or to compute the sum of squares for an effect, we must first determine the contrast associated with that effect. If we let, the symbols (I), $a, b,$ and ab (Table 1) now represent the total of the response observation at all n replicates taken at the treatment combination (Montgomery, 2013), then the main effects of factors as well as the interaction are given as follows:

$$A = \frac{1}{2n}[ab + a - b - (I)] \tag{2}$$
$$B = \frac{1}{2n}[ab + b - a - (I)] \tag{3}$$
$$AB = \frac{1}{2n}[ab + (I) - a - b] \tag{4}$$

The sum of squares of the model is given in equations (5-9).

$$SS_A = \frac{1}{4n}[ab + a - b - (I)]^2 \tag{5}$$
$$SS_B = \frac{1}{4n}[ab + b - a - (I)]^2 \tag{6}$$
$$SS_{AB} = \frac{1}{4n}[ab + (I) - a - b]^2 \tag{7}$$
$$SS_T = \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{n} y_{ijk}^2 - \frac{y_{\dots}^2}{4n} \tag{8}$$
$$SS_E = SS_T - SS_A - SS_B - SS_{AB} \tag{9}$$

Where SS_T and SS_E are total sum of squares and error sum of squares respectively. The Analysis of variance (ANOVA) was generally used to confirm and interpret the magnitude and direction of the factor effects to determine which variables are likely to be important (Montgomery 2013).

In order to do some forecasts, model diagnostic and validation, we developed a regression model for this factorial design (eqn. 10).

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \epsilon \tag{10}$$

where y is the response variable that represents the amount of rainfall received, x_1 is a variable that represents the amount of temperature, x_2 is a variable that represents the amount of relative humidity and x_1x_2 represent the interaction of temperature and relative humidity. β_0 represents the mean response $E(y)$, the parameter β_1 indicates the change in the mean response y per unit increase in x_1 when x_2 is held constant. Likewise, β_2 indicates the change in the mean response per unit increase in x_2 when x_1 is held constant. β_{12} indicates the change in the mean response per unit increase in both x_1 and x_2. ϵ is a random error term that accounts for the experimental error in the model. The estimates $\hat{\beta}_0$, $\hat{\beta}_1$, $\hat{\beta}_2$ and $\hat{\beta}_{12}$are the overall mean, one-half the factor A effect estimate, one-half the factor B effect estimate and one-half the interaction AB effect estimate respectively.

RESULTS AND DISCUSSION

The rainfall pattern is clearly seen that it is seasonal (Figure 1) with months receiving absolutely zero mm and some receiving at least 200 mm. Statistics shows that show that rainfall was at its peak when it reached 416 mm in December 2007 while the driest months are June, July and August. Monthly average temperature in Gokwe shows a clear seasonal cycle with hottest months being September, October, November, December and January. The average monthly temperature recorded its peak at a maximum of 27.7^{0}C and average minimum of 15.4^{0}C.

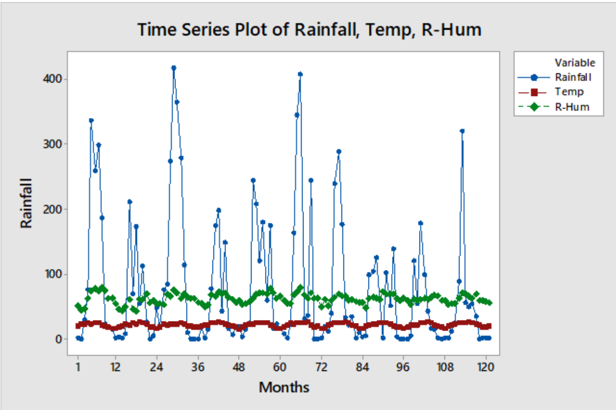


Figure 1: Time series plot of monthly average rainfall, temperature and relative humidity

Monthly average percentage of relative humidity recorded fluctuates between 42% and 80% despite other daily percentages reach as high as 100%.

Table 2: ANOVA Table for Rainfall

Source of Variation	SS	D.F	M.S	F-Value	P-Value
Temperature	181400	1	181400	26.01	0.000
R-Humidity	100505	1	100505	14.41	0.000
Temperature*R-Humidity	16528	1	16528	2.37	0.126
Error	816086	117	6975		
Total	1252085	120			

The p-values for temperature and relative humidity are respectively less than the significance level 0.05 (table 2). This indicates that we reject the null hypothesis for factor A and factor B. Therefore, conclude that the levels of temperature and levels of relative humidity have different strengths. It shows that there is statistical enough evidence to support that both temperature and relative humidity have effects on rainfall. The increase or decrease in temperature or relative humidity cause an increase or decrease in rainfall received. On another note, we accept the null hypothesis on the interaction of temperature and relative humidity since its p-value (table 2) is greater than the significant level 0.05. This means that the interaction of temperature and relative humidity has statistically insignificant effect on the amount of rainfall received.

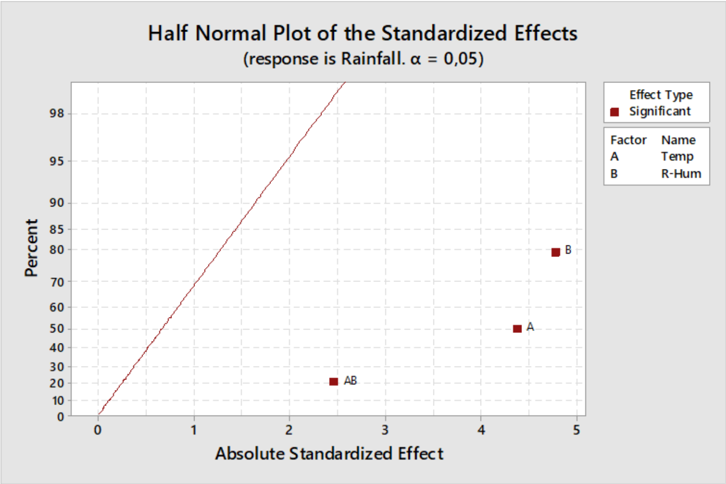
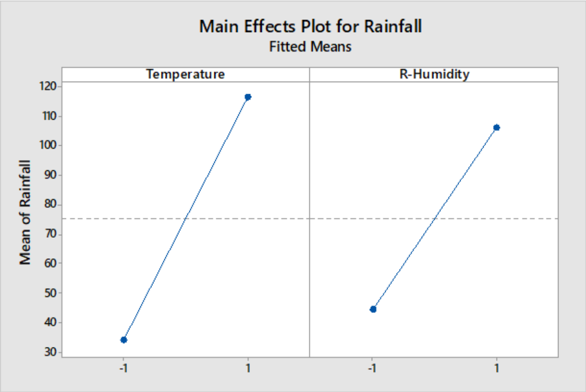


Figure 2: Normal plot of Standardized effects



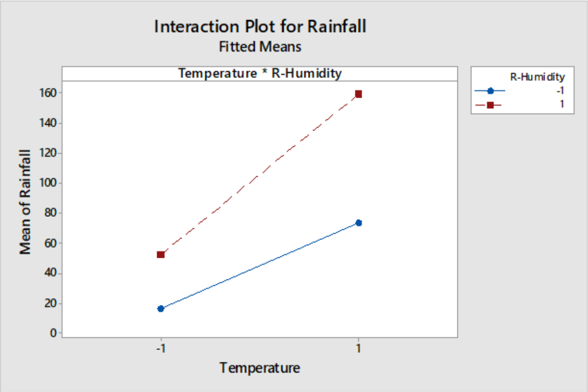
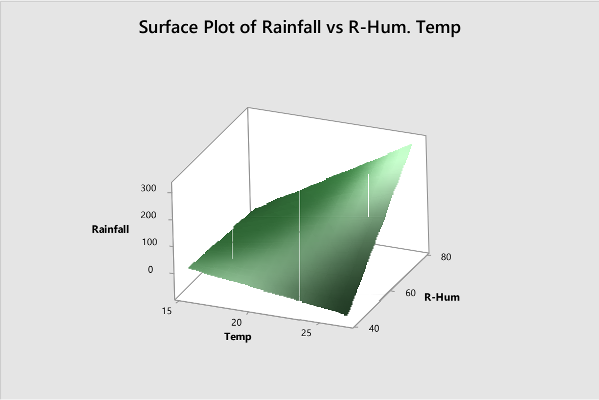


Figure 3: Main Effect plot

Figure 4: Interaction plots



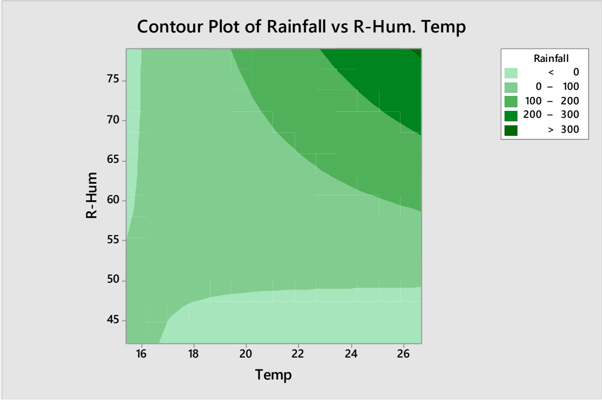


Figure 5: Surface plot of rainfall

Figure 6: Contour plot of rainfall

The normal plot of the standardized effects in figure 2 shows that temperature (A) and relative humidity (B) have significant effects on rainfall indicated by red squares. Temperature contributes about 50% to the model and relative humidity contributes about 80% to the model. This means that change in temperature has 50% effect on the amount of rainfall received. On the other hand, relative humidity variability has 80% effect on rainfall. On the same figure (figure 2), the interaction of temperature and relative humidity has a low contribution (20%) to the model, that is statistically insignificant. All two main effects are positive, which means that if we would to maximise rainfall both factors will be high.

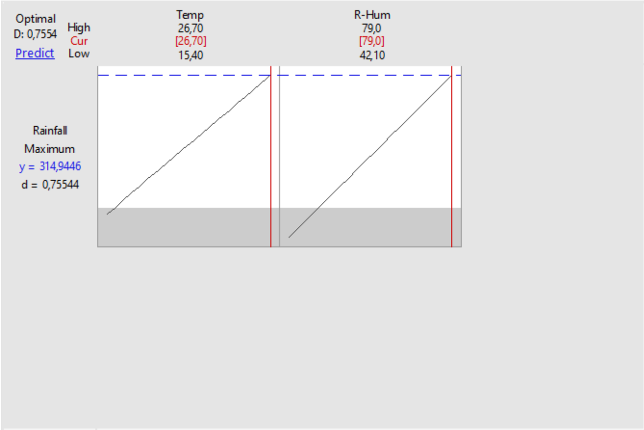


Figure 7: Optimization of rainfall

The main effect plot in figure 3 shows that rainfall is maximised when temperature and humidity are independently high. The interaction plot in figure 4, shows that interaction between temperature and relative humidity has very low contribution to rainfall, thus why the plot doesn't even show the interaction. In other words, these two parameters are independent; the interaction has less meaning as far as rainfall is received. Figure 4, 5 and 7 also show that rainfall can be maximised to over 300 mm when temperature is above 27^0C and relative humidity is above 80%.

The main effects of the factors and the coefficient estimates of the regression model were obtained using Minitab statistical package (table 3). The regression coefficient is one-half the effect estimate because a regression coefficient measures the effect of a one unit change in x on the mean of y, and the effect estimate is based on a two-unit change (from -1 to +1).

Table 3: Main effects and coefficient estimates

Term	Effect	Coefficient
Constant	-	75.43
Temperature	62.4	41.20
R-Humidity	90.4	30.67
Temperature*R-Humidity	24.87	12.44

Therefore the regression equation connecting rainfall and two independent parameters is given in (equation 11).

$$Rainfall = 75.43 + 62.4 * Temperature + 90.4 * RHumidity \qquad (11)$$

We used the regression equation to calculate residuals of the model so that model adequacy checking could be performed. We can also use the regression equation for forecasting average monthly rainfall for example:

a) In the first run (I) both temperature and relative humidity are low, that is "-" and "-" then our rainfall forecast becomes;

$$Rainfall = 75.43 + 62.4 * (-) + 90.4 * (-) \qquad (12)$$
$$Rainfall = 0mm$$

b) Second run when temperature is high and relative humidity low, our rainfall forecast becomes;

$$Rainfall = 75.43 + 62.4 * (+) + 90.4 * (-) \qquad (13)$$
$$Rainfall = 47.43mm$$

c) Third run when temperature is low and relative humidity is high, we have

$$Rainfall = 75.43 + 62.4 * (-) + 90.4 * (+) \quad (13)$$
$$Rainfall = 103.43mm$$

d) Fourth run when both temperature and relative humidity are high, we expect monthly average amount of rainfall to be

$$Rainfall = 75.43 + 62.4 * (+) + 90.4 * (+) \quad (14)$$
$$Rainfall = 228.23mm$$

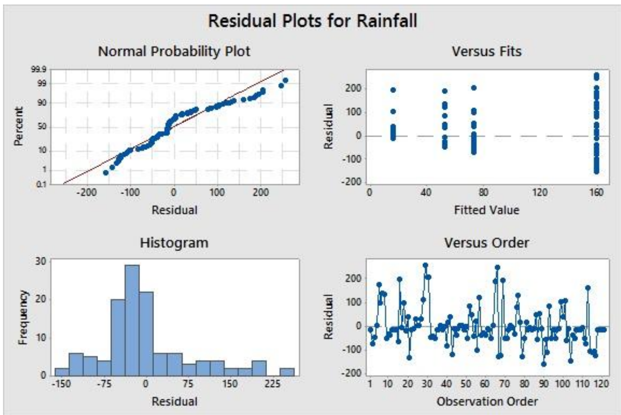


Figure 8: Residual plot

The residual plots in figure 8 show that the model adequately analyses the data. All four plots indicate normal distribution of residuals and constant variance (homogeneous).

CONCLUSIONS

A 2^2 factorial model adequately analyse rainfall data considering two factors (temperature and relative humidity) playing a pivotal role. In our research we defined "high" average temperature as 27^0C or above and "low" average temperature as 16^0C and below. We also defined "low" average relative humidity as 40% or below and "high" average relative humidity as 75% or above. The definitions may vary from researcher to researcher. Results obtained show that change in temperature affects the amount of rainfall received. It is clearly seen that rainfall can only be maximised when temperature is high (above 27^0C). Furthermore, variability in relative humidity also affect the amount of rainfall received, rainfall is also maximised when relative humidity is high (above 80%). Consequently, the interaction of temperature and relative humidity seems to have an insignificant effect on the amount of rainfall received, about 20% of it is accountable for change in rainfall. The positive coefficients of the regression model show that temperature and relative humidity have each positive correlation with rainfall even though the degree of association between these parameters is not much.

We recommend the use of 2^k factorial designs on weather parameters especially on the determination of the strength and effectiveness of independent parameters to response parameters. Again we also recommend a further analysis of these designs by incorporating the response surface methodology. In our next research, we would need to take into consideration other factors like wind speed and amount of sunshine.

ACKNOWLEDGEMENTS

We would like to thank the Meteorological Department of Gokwe station for supporting us with weather data for this research.

REFERENCES

Ajadi, D. A., & Sanusi, Y. K. (2013) Effect of Relative Humidity on Oven Temperature of Locally Design Solar Carbinet Dryer. *Global Journals Inc. (USA)* ISSN: 2249-4626. Vol 13(1).

Buishand, T. A., & Brandsma T. (1999) Dependence of precipitation on temperature at Florence and Livorno (Italy). *Climate Research*, Vol. 12.

Canada Weather Office (2013) A dictionary of weather, climate and environment.

Dai, A. (2013) Increasing drought under global warming in observations and models. *Nature Climate Change* 3, 52-58.

Gokwe (2017) Weather and Climate, average and monthly rainfall. [Accessed 20th June 2017] Available from World Wide Web: https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Gokwe,Zimbabwe

Jari, L., & Hakala I. (2015) Effects of Temperature and Humidity on Radio Signal Strength in Outdoor Wireless Sensor Networks. *ACSIS*, Vol. 5.

Mahrt, L. (1991) Boundary-layer moisture regimes. *Q. J. R. Meteorol. Soc.*, 117, 151–176.

Mertz, O., Mbow, C., & Reenberg, A. (2009) Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel. *Environmental Management* 43: 804-816.

Montgomery, D. C. (2013) *Design and Analysis of Experiments, 8th Edition*. John Wiley Sons. New York. USA.

Montgomery, D.C. (2001) *Design and Analysis of Experiments*, *5th Edition*. John Wiley & Sons. New York. USA.

Moyo, S., & Yeros, P. (2009) Zimbabwe ten years on: Results and prospects. Livelihoods and land reform: The poverty impacts of land re-distribution in southern Africa.

Mugandani, R., Wuta, M., Makarau, A., & Chipindu, B. (2012) Re-classification of agro-ecological regions of Zimbabwe in conformity with climate variability and change. *African Crop Science Journal*, Vol. 20, Issue Supplement s2, pp. 361 – 369.

Nkuna, T. R., & Odiyo, J. O. (2016) The relationship between temperature and rainfall variability in the Levubu sub-catchment, South Africa. *International Journal of Environmental Science.* Vol 1.

Price, J. D., & Wood, R. (2002) Comparison of probability density functions for total specific humidity and saturation deficit humidity, and consequences for cloud parametrization. *Q. J. R. Meteorol. Soc.*, 128, 2059–2072.

Slingo, J. M. (1980) A cloud parametrization scheme derived from GATE data for use with a numerical model. *Q. J. R. Meteorol. Soc.*, 106, 747–770.

Sun, D. Z., & Oort, A. H. (1995) Humidity-Temperature Relationships in the Tropical Troposphere. *Journal of Climate*, Vol 8. Pp. 1974-1987.

Sundqvist, H. (1978) A parametrization scheme for non-convective condensation including prediction of cloud water content. *Q. J. R. Meteorol. Soc.*, 104, 677–690.

Tompkins, A.M. (2003) Impact of temperature and humidity variability on cloud cover assessed using aircraft data. *Q. J. R. Meteorol. Soc*. 129, pp. 2151–2170.

Trenberth, K. E. (2011a) Changes in precipitation with climate change. *Climate Research* 47:123–138.

Trenberth, K. E. (2012) Framing the way to relate climate extremes to climate change. *Climatic Change*, 115: 283.

Trenberth, K. E., Dai, A., Rasmussen, R. M., & Parsons, D. B. (2003) The changing character of precipitation, Bull. Am. *Meteorol. Soc.*, 84, 1205–1217.

Trenberth, K. E., & Caron, J. M. (2000) The Southern Oscillation revisited: Sea level pressures, surface temperatures and precipitation. *J. Climate*, 13, 4358-4365.

Trenberth, K. E., Fasullo, J., & Smith, L., (2005) Trends and variability in column-integrated water vapor. *Clim. Dyn.*, doi:10.1007/s00382-005-0017-4, in press.

Vincent, V., & Thomas, R. G. (1960) An agro ecological Survey of Southern Rhodesia Part 1: Agro-ecological Survey: *Government Printers. Salisbury*. Pp. 1-217.

Zambuko, Z. (2011) Climate Issues and Facts - Zimbabwe. *Department of Meteorology*.