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RE-CLASSIFICATION OF AGRO-ECOLOGICAL REGIONS OF ZIMBABWE IN CONFORMITY WITH CLIMATE VARIABILITY AND CHANGE

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ABSTRACT

Zimbabwe was divided into five agro-ecological regions in the 1960s, however, the increased variability of rainfall has possibly affected the agro-ecological region boundaries. This study re-classifies the agro-ecological regions (natural regions) of Zimbabwe using soil data, mean-annual rainfall and length of growing season. Rainfall data from selected meteorological stations covered the period 1972- 2006. Soil data were obtained from the soil map of Zimbabwe, while length of growing seasons data were obtained from the FAO New Local Climate database. The simple limitation approach was used to produce a suitability zone map using all the parameters with the same weighting. The results show that the number of regions remained the same although the size of the regions had changed. The findings from this study point to an increase in the size of Natural Regions (NRs) I, IV and V by 106, 5.6 and 22.5 %, respectively. Natural Regions II and III decreased by 49 and 13.9%, respectively. The shrinking of Natural Regions II and III which are the main food producing areas in Zimbabwe, point to possible reduction in food production and thus problems of food insecurity. The shifting of the NRs boundaries observed in this study strongly points to evidence of climate variability and change.

Key Words: Natural regions, suitability classes, rainfall, soil groups

RÉSUMÉ

Le Zimbabwe était subdivisé en cinq régions agro écologiques dans les années 1960 ; par ailleurs, la variabilité accrue des précipitations aurait affecté les limites des zones agro écologiques. Cette étude ré-classifie les régions agro écologiques (régions naturelles) du Zimbabwe à l'aide de données pédologiques, la moyenne des précipitations annuelles et la durée de la saison des cultures. Les données des précipitations de stations météorologiques sélectionnées couvraient la période 1972-2006. Les données pédologiques étaient obtenues de la Nouvelle banque des données du climat Local de FAO. L'approche de simple limitation était utilisée pour produire une carte de zone d'aptitude par l'utilisation de tous les paramètres avec la même pondération. Les résultats montrent que le nombre de régions sont restées les mêmes bien que la superficie de ces régions avait changé. Les résultats de cette étude montrent une augmentation de la superficie des régions naturelles I, IV et V par 106, 5.5 et 22.5%, respectivement. Le rétrécissement des régions naturelles II et III qui sont des milieux principaux de production alimentaire au Zimbabwe, atteste une possible réduction de la production alimentaire et ainsi problèmes de l'insécurité alimentaire. Le changement observé des limites des régions naturelles dans cette étude est une preuve évidente du changement du climat et sa variabilité.

Mots Clés: Régions naturelles, classes d'aptitude, précipitations, groupes de sols

INTRODUCTION

One strategy of ensuring food security is through proper utilisation of land, which can only be achieved through land use planning in setting out the production patterns. Continuous agro-ecological zoning in this era where regions are experiencing climate variability and change has widespread applications in land use planning; design of appropriate agricultural adaptations and reducing vulnerability (Downing *et al*., 1997; Salinger *et al*., 2005). Agro-ecological zones are also used to determine crop water requirements and long-term frost protection measures (Espie *et al*., 2006).

Agro-ecological classification also known as natural region (NR) classification of Zimbabwe, divided the country into five regions based on mean annual rainfall and was done in the 1960s (Vincent and Thomas, 1960). Some weaknesses of the current agro-ecological system of land classification include little emphasis on the smallholder farming and communal areas and possibilities of boundary changes between NRs due to climate change and variability. Vincent and Thomas (1960) did not consider effective rainfall but the mean annual rainfall. Nyakanda (2005) proposed the use of rain pentads to cater for mid-season dry spells. Data from very few stations were considered and processed with no advanced processing facilities (Carter and Corbett, 1997).

There is wide variation in the length of growing periods for stations in the same NR. A 30-year rainfall data-set for one of the stations in Region V shows that only two normal growing seasons have been recorded, yet one characteristic of that NR is 1-2 normal growing seasons in 5 years, suggesting the existence of a possible sixth NR that could be more arid than NR V (Hussein, 1987). The length of growing periods for several stations on the current scheme is not available. The data on length of growing period could provide more information pertaining to cropping practice, for instance, choice of crop varieties.

The agro-ecological regions generated by Vincent and Thomas (1960) have been used for more than fifty years in Zimbabwe and their continued use can be misleading that the climate is stable, yet research points to the contrary. For example, Makarau (1999) noted increased variability of rainfall, rain days and temperature in Zimbabwe; these are possible pointers of climate change and variability. Some parts of Zimbabwe are becoming warmer and drier (Low, 2005). In fact rainfall data recorded for 100 years at Chipinge Meteorological Station in NR1 showed increased mean annual rainfall and rainy days. This contrasts with over 100 years of rainfall data from Vermont farm on the Mozambique border. Most meteorological stations in Zimbabwe showed a decline in rainfall over the same period. Given all these scenarios, Carter and Corbett (1997) noted that continued use of the system developed by Vincent and Thomas (1960) was at odds with the political, social and agrarian reform that has taken place and changes in climate being observed.

The widespread use of the NR map has been attributed to the ease of its interpretation (Carter and Murwira, 1995). However, it is so general in nature and does not consider some variations that occur within regions and, hence, has low precision (Carter and Murwira, 1995). Therefore, the use of modern approaches including interpolation of climatic data, and the combination of this with other land factors using Geographical Information systems (GIS) would allow a more detailed approach to the agro-ecological zoning also taking into account climate change and variability. GIS has the ability to capture data and to manipulate data layers, thereby providing a more systematic and dynamic approach to agro-ecological zoning than the traditional and somewhat limited approaches, for example, the use of cartography (Carter and Murwira, 1995).

Several agro-ecological zoning (AEZ) methods have been previously used to delimit land for agricultural purposes (FAO, 1977; Sys and van Ranst, 1991). The FAO method involves matching of soil and climatic requirements of the world's eleven major crops with the existing climatic and edaphic factors. Crops are chosen based on the total area planted (FAO, 1978). According to FAO, the major parameter derived from climate data is the length of growing period (LGP), defined as the number of days when precipitation (P) is greater than or equal to half of the potential evapo-transpiration (PET) (Doorenbos and Kassam, 1979). The LGP is very critical since it is a function of both moisture availability and temperature. The LGP is corrected for temperature by subtracting the period (in days) when the daily mean temperature is less than 6.5 ºC since research has shown that most plants cannot complete their phenological development during the period when 24-hr mean temperature is less than 6.5 ºC (Doorenbos and Kassam, 1979).

The AEZ methodology developed by the FAO encompasses principles of specificity of sustained suitability for a defined land use (FAO, 1977; Sys *et al.*, 1991). The evaluation also involves comparison of land use alternatives on an economic basis. This method was first used by the FAO in 1978 in land evaluation in Africa, but the FAO report was only confined to rain-fed cropping and eleven major crops at three different input levels. The major crops considered were wheat, rice, maize, pearl millet, sorghum, potatoes, sweet potatoes, cassava, soybean and *Phaseolus* bean (FAO, 1978). A crop inventory was prepared based on climatic requirements for phenology and photosynthesis of the major crops. The crop requirements were matched with the existing climatic conditions. The number of days to maturity was then used to calculate potential yield under constraint free environments. The yields of different crops were then calculated for all crops and for each of the length of growing period.

The next stage was to look at the soils and the following factors were, therefore, considered: depth, texture, salinity and structure. When a property was deemed to be outside what was required by the crop, the soil was considered unsuitable in its present state. The resultant soil suitability map was then superimposed on the climate suitability map to produce agro-ecological regions. In areas where soils were suitable for a particular crop, no change was made to the agro-climatic suitability assessment but when soils were adjudged as moderately suitable, the agro-climatic suitability was downgraded by one suitability class. As for areas in which soils had severe limitations in terms of cropping, the land was regarded as not suitable irrespective of climatic attributes. Therefore, this method is mostly referred to as the simple limitation approach (FAO, 1978; Sys and van Ranst, 1991).

The objective of this research was to reclassify the agro-ecological zones of Zimbabwe using mean-annual rainfall, soil suitability and length of growing period.

MATERIALS AND METHODS

Study area. The study was carried out in Zimbabwe, a country located between 15°37’ S to 22°24’ S and from longitudes 25°14’ E to 33° 04’E; and covering an area of 390 580 km^2. It lies entirely within the tropics but the Highveld and Eastern Highlands, have a subtropical to temperate climate. Mean annual rainfall varies from as low as 300 mm in the Limpopo Valley to a high of 3000 mm in the eastern mountainous areas. The average for the whole country is 675 mm (Department of Meteorological Services, 1981; Anderson *et al.*, 1993). The rainy season starts in November and tails off in March. There is wide spatial and temporal variation in rainfall. Its reliability increases with altitude and from south to north. High coefficients of rainfall variability (>40%) have been recorded in areas south of Bulawayo while those in the Highveld and Eastern Highlands have recorded <20% (Department of Meteorological Services, 1981).

The mean annual temperature ranges from 18-19 ºC at about 1400 m above sea level and averages 23 ºC at 450 m altitude in the Limpopo Valley. Mean maximum temperatures are low in the winter months (June-July) and highest in the month of October (Vincent and Thomas, 1960; Department of Meteorological Services, 1981; Anderson *et al.*, 1993). According to the Zimbabwe soil classification system, the soils are classified into regosol, lithosol, vertisol, siallitic, fersiallitic, paraferrallitic, orthoferrallitic and sodic groups (Nyamapfene, 1991).

Meteorological data. A total of 39 meteorological stations were selected for this study (Fig. 1). The stations were selected based on availability of meteorological data, but at the same time ensuring that the density of stations enabled precise data interpolation.

Rainfall. Daily rainfall data were obtained for the period 1972-2006 from the Department of

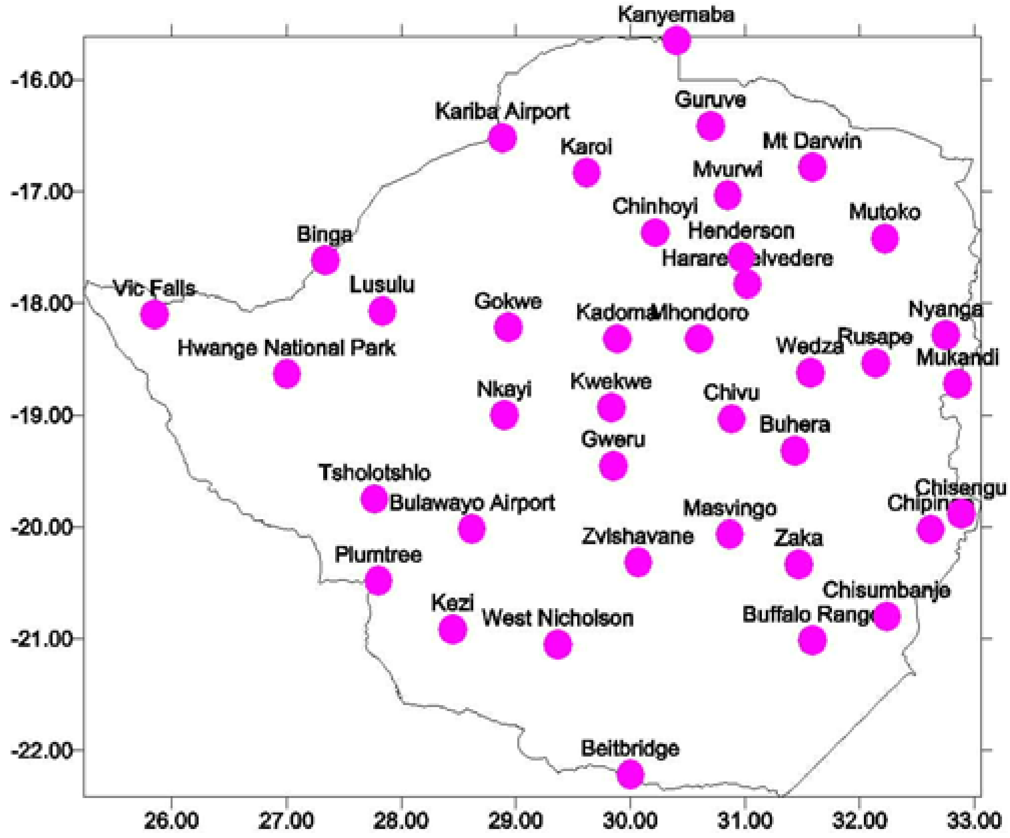

Figure 1. Location of meteorological stations in Zimbabwe used in the study.

Meteorological Services, in Harare, Zimbabwe. Monthly averages and the yearly averages for each station were then computed. From the yearly averages, the long- term mean annual rainfall was calculated. The same rainfall ranges used in the previous classification produced by Vincent and Thomas (Fig. 2) were used to describe the new regions assuming that the definition of agro-ecological regions had not changed (Table 3).

Temperature. Daily temperature records were obtained for the same period (1972-2006) also from the Department of Meteorological Services. The long-term mean averages were then computed and used to describe the temperature ranges for the new regions. Temperature was used to calculate the length of growing period and to describe the new regions, just like rainfall.

Length of cropping period. Length of growing period data were obtained from the FAO New Clim model (FAO, 2005). To obtain the length of growing period ranges (Table 1), the days to maturity and corresponding harvest index of maize varieties in Zimbabwe were analysed as adapted and modified from FAO (1978). Numerical values were allocated to the length of growing period for each meteorological station and these were used to obtain a length of growing period suitability map.

Soils. The chemical and physical properties of the soil that are relevant in crop production were used in rating of the productivity of the soils. These parameters included the basic soil requirements of major crops grown in Zimbabwe, which are water holding capacity, soil structure, the nutrient status of the soil and its depth. Soils were rated with the assumption that the productivity of certain soils can be improved if certain economically feasible improvements are made. The ratings depicted in Table 2 were then

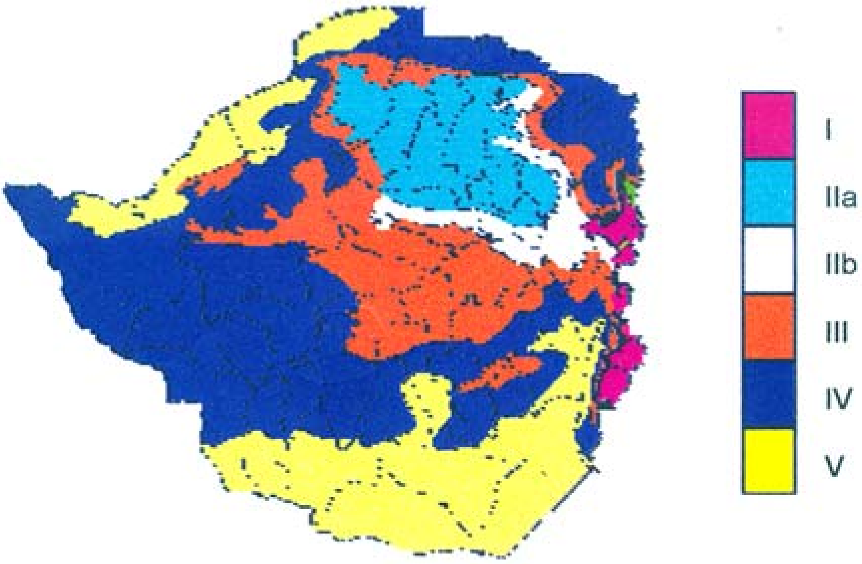

Figure 2. Map of Zimbabwe showing the current Natural Regions (Source: Surveyor General, 1984).

TABLE 1. Suitability rating of NRs based on length of growing period of maize. Suitability increases from 1 to 6 where 1 is not suitable while 6 is highly suitable

Length of growing period (days)	Rating
< 105	1
105 – 120	2
120 – 135	3
135 – 150	4
150 - 165	5
> 165	6

TABLE 2. Suitability rating of Zimbabwean soil groups generated from this study

Soil group	Rating	Suitability class
1	1	U
2	1	U
3	5	HS
4	5	HS
5	5	HS
6	5	HS
7	5	HS
8	1	U

U is unsuitable (1) HS is highly suitable (5). Soil group 1 is the regosols group, 2 is the lithosol group, 3 is the vertisols group, 4 is the siallitic group, 5 is the fersialitic group, 6 is the paraferralitic group, 7 is the orthoferralitic and 8 is the sodic group

generated. From these ratings, a soil suitability map was produced. To produce the overall suitability map, the limiting concept approach was used (FAO, 1978; Sys *et al.*, 1991). In this case, in any combination, the parameter with the worst value would take precedence over the other factors. Table 3 shows the rainfall, length of growing period and soil groups used to assign land into agro-ecological zones or NRs.

RESULTS

The new Natural Region I. Natural Region 1 was found in the eastern part of Zimbabwe. This is highly suitable for diversified cropping and covers 14, 439 km^2 and this translates to almost 4 % of the whole country. However, farmers in this NR grow crops including coffee, tea and potatoes since these are high value crops and would, therefore, translate to more income. In the previous agro-ecological classification**,** the area contributed only about 1.8% of the whole country (7024 km^2), but according to this work, the NR has moved westwards (Figs. 2 and 3). The NR has increased by 106%. In addition to factors in Table 3, mean annual temperature ranges of 15-18 ºC, mean minimum temperatures of 10-12 ºC and mean maximum temperature range of 19-23 ºC also characterise the NR. This and other factors

TABLE 3. Criteria used for the classification of Natural Regions in this study

Parameter	Natural region				
	1	2	3	4	5
Rainfall	>1000	1000-700	700-550	600-450	<500
LGP (days)	>165	150-165	135-150	105-135	<105
Soil groups	3,4,5,6,7	3,4.5,6,7	3,4,5,6,7	3,4,5	1,2,8

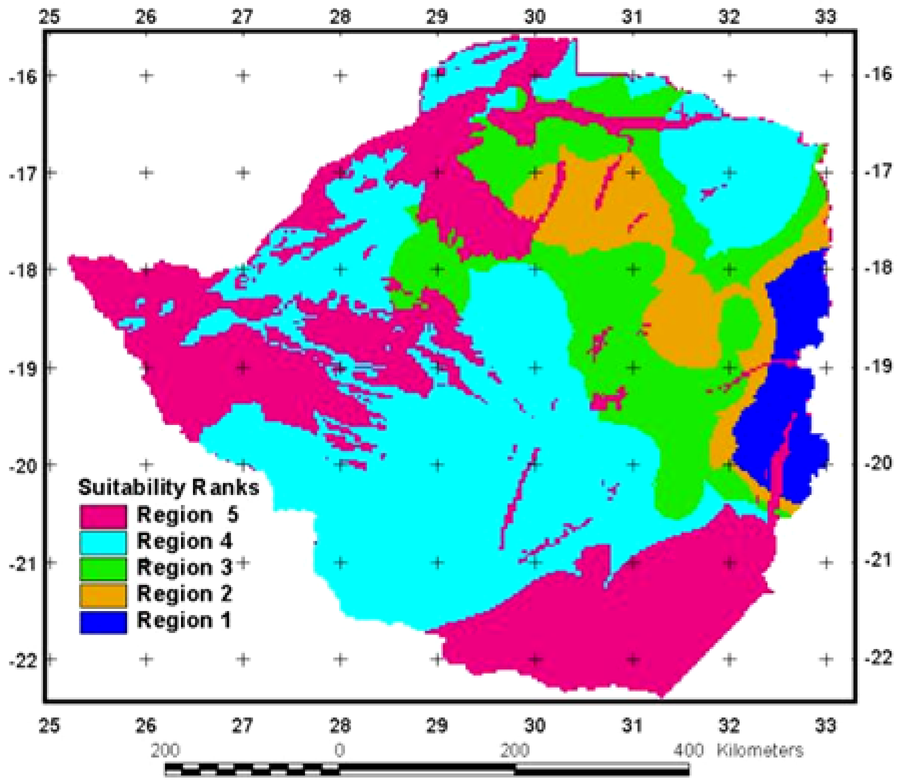

Figure 3. Map of Zimbabwe showing the new Natural Regions generated from this study.

listed in Table 3 make the NR highly suitable to cropping high value plantation crops.

The new Natural Region II. The area covers 29,658.62 km^2 translating to about 7.6% of the whole country (Fig. 3). In the previous classification, the area covered 15% (58,536 km^2) (Fig. 2) of the country. The results indicate that the NR has actually decreased by 49%. In the new classification, Mhondoro has moved from NR II to III. There is also a new narrow belt extending from Nyanga southwards, which is now part of NR II and appears to demarcate NR I from other regions. The shape of this region has also changed as part of it has been encroached by NR III. Farmers in this NR grow maize, tobacco, cotton and wheat; in addition to intensive livestock production. The new NR II is also characterised by mean maximum temperature range of 19-23 ºC, mean minimum temperature range of 10-13 ºC and mean annual temperature range of 16-19 ºC.

The new Natural Region III. The area covers 62,829 km^2 comprising of 16.1% of the whole country (Fig. 3). In the previous classification the area covered 72, 975 km^2 and this equates to 18.7% of the whole country (Fig. 2). In this new classification, NR III has been encroached by NR IV. The area now occupied by the NR has decreased by 13.9%. Farmers in this NR mainly concentrate on maize, tobacco, cotton, wheat and cattle ranching. Other characteristics of the new NR include mean maximum temperature range of 23-26 ºC; mean minimum temperature range of 11-15 ºC and mean annual temperature range of 18-22 ºC.

The new Natural Region IV. The area covers 155, 707 km^2 which translates to 39.9 % of the whole country (Fig. 3). In the previous classification, the area occupied about 37.8% of the country (Fig. 2). Other characteristics of this NR are: mean minimum temperature range of 11-20 ºC; mean maximum temperature range of 19-26 ºC and a mean annual temperature range of 18-24 ºC. The NR has increased by 5.6%, which is a result of the greater part of Gweru being downgraded from NR III to IV. However, this did not result in a significant increase since the Hwange area has been downgraded to NR V, mainly because of the new classification criteria since the greater part of that area has regosols. Natural Region IV is an extensive livestock production area with some drought tolerant crops such as sorghum and millet rapoko. Farmers also grow some short season maize varieties.

The new Natural Region V. The new Natural Region V covers about 126, 829 km^2 which is equivalent to about 32.5% of the whole country (Fig. 3). In the previous classification, the NR constituted 26.7% of Zimbabwe (Fig. 2). In the southern part of the country, the NR has extended northwards (Figs. 2 and 3). Other parameters that describe this NR are mean annual temperature range of 21-25 ºC; mean maximum temperature range of 26-32 ºC and mean minimum temperature range of 14-18 ºC.

DISCUSSION

The re-classification of the NRs resulted in changes in size of the different regions when compared with the current NRs. The shifting of the NR boundaries observed in this study strongly points to evidence of climate variability and change. Others could argue that the shift is due to the fact that Vincent and Thomas (1960) used less meteorological data points, but many researchers have observed that rainfall patterns in many different areas in Zimbabwe have progressively been changing; changes that have been attributed to climate change and variability (Unganai, 1996; Phillips *et al*., 1998).

There are many factors that have been cited to be responsible for rainfall variability over southern Africa and including Zimbabwe. *El Nino* events, involve an anomalous warming of the tropical Pacific Ocean such that sea surface temperatures over 28 ºC are experienced across the entire Ocean (Phillips *et al.*, 1998). Under normal circumstances, the eastern tropical Pacific is usually colder than the west but during an *El Nino* event, sea surface temperatures in the eastern Pacific can rise by as much as 4 ºC or more, which results in strong convection occurring over areas of warmest sea surface temperatures. Furthermore, during the *El Nino* event, the warmer sea surface temperatures shift from the western to the central Pacific resulting in an eastward shift in the location of the strong convection by more than thousands of kilometres (Mason and Jury, 1997). With this shift in the area of convection to the central Pacific during an *El Nino* event, a similar shift in the area of convection over southern Africa becomes apparent through tele-connections (Mason and Jury, 1997). The warming of the western and central tropical Indian Ocean in most cases occurs during the peak summer rainfall months of December-March when the ENSO events have reached maturity. This is also the same time when the Inter-Tropical Convergence Zone (ITCZ) is further south. *El Nino* events are frequently associated with drought over much of southern Africa (Mason and Jury, 1997).

Sea surface in other areas around southern Africa have also been associated with rainfall variability over the subcontinent (Mason and Jury, 1997). If the sea surface temperatures in the central and western tropical Indian Ocean are warmer than averages, this will in most cases bring in dry conditions over southern Africa. During the pacific *El Nino* conditions, the northern Indian Ocean will be warmer than normal and this in a way is responsible for transmitting ENSO signals to the southern Africa region. A strengthening of convection, therefore, takes place in the Oceanic areas at the expense of the inter-tropical convergence over the subcontinent (Mason, 1995; Jury, 1996). While dry conditions are frequently associated with warmer sea surface temperature in the tropical Indian Ocean, this is also an important source of atmospheric moisture throughout the summer rainfall season and, therefore, it becomes a dominant source in summer (D'Abreton and Tyson, 1995). Therefore, an increase in sea surface temperatures could actually enhance rainfall over southern Africa by increasing evaporation if and only if the warming does not result in a shift in convection (Hulme., 1996)

The study also points to the fact that re-classification of the NRs of Zimbabwe can be used to analyse the impacts of climate change on agriculture. A statistical analysis of the mean rainfall was carried out to assess if mean annual rainfall has changed (Fig. 3). It was observed that the difference in mean seasonal rainfall of the old and new NRs was not statistically significant ($p<0.05$). However, the other characteristics like occurrence of dry spells, dates of onset and cessation of rainfall and number of rainy pentads were not analysed in the research. These could also be used as indicators of climate change and variability.

The results showed that the impacts of climate change and variability vary tremendously across Zimbabwe. The impacts are both negative and positive in the highly productive zones and for the marginal areas, with significant reduction in areal extent of NR II and III, which are key cereal production regions. This has serious implications on food security. The main crops grown in NRs 11 and 111 are maize, tobacco, soyabean and wheat and these make a significant contribution to the economy of the country. Therefore a decrease in the area suitable for growing these crops will result in low production levels of the same. Farmers therefore need to adopt climate change and variability mitigation strategies.

CONCLUSION

The number of NRs in Zimbabwe has not changed based on average climatic conditions of 1972 – 2006. The mean annual rainfall for the new zones were also not significantly different ($p<0.05$) from the current zones. What has, however changed is the sizes of the NRs with NRs 1,1V and V increasing by 106, 5.6 and 22.5 % respectively, while NRs 11 and 111 decreased by 49 and 13 % respectively. The shift in the size and positions of the Natural Regions could be attributed to the impact of climate variability and change. The implication of the shifts in NRs is that the area suitable for cash plantation cropping in NR 1 is now bigger but marginal areas in NRs 1V and V have also increased in extent. Natural Regions II and III which are the main food producing areas in Zimbabwe have shrunk, pointing to possible reduction in food production and thus problems of food insecurity.

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