REVISION OF THE MACRO CLIMATIC REGIONS OF SOUTHERN AFRICA

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Abstract: Factors influencing pavement designs are divided into two, namely controllable and non-controllable. Controllable factors include engineering design, selection of materials, construction quality and control, standards and progress. Uncontrollable factors include climate, terrain and geological conditions such as surface and sub-surface hydrology. Therefore there are many influential factors that the engineer cannot control and hence understanding risk and reliability is a key aspect of design to cater for uncertainties. It is believed that by the year 2100, world climate will have changed in ways that are difficult to imagine - as difficult as it would have been at the end of the 19th century to imagine the changes of the 100 years since. The current heat, drought, floods and rainfall spurts are evident of the effects of climate change. The response to climate change is often seen as twofold; adaptation and disregard. Adaptation often viewed as the most essential part of the response to the threat of climate change whereas disregard comes from a poor understanding of the influential factors of the African climate. Severe lack of local weather data, particularly for central Africa is also part of the problem. This lack of knowledge makes it very difficult to predict with any degree of accuracy what will happen as a result of climate change at a country, or even sub-regional level in Africa. Extensive research has been done by climatologists on the subject of climate change. However, engineers and technologists have not yet adapted an approach that aims to address the topic within the engineering sector. Improvements ought to be made particularly on climate based parameters used in transportation engineering and designs. The Macro Climatic Regional Map of Southern Africa adopted from Weinert (1980) by Technical Recommendations for Highways (TRH4) (1994) is one of the most outdated weather based catalogues used in the industry. To date, even in light of the eminent threat of climate change, no credible advances have been made yet for any improvements on this over thirty year old design climatic regional map. Minor editions on the Weinert N-Values include up to ten percent adjustments on net cold binder whereby an increase is made on dry areas (N-value > 5) and reduction in wet/humid areas (N-value < 2). A gap therefore exists and speedy research is imperative in order to optimize our roads' serviceable life and also keep abreast with the ever changing environmental factors influencing our roads. The methodology adopted in this study included identifying and mapping areas within the Southern African region that may suffer from future increased precipitation and flash flooding among other climate based parameters. Results of preliminary analysis indicate a shift in rainfall patterns within the region where increases in rainfall per annum are expected in the central Free State and North escarpment of the Eastern Cape provinces in South Africa. In future there shall be more moderate and wet areas than when the original map was adopted. Areas characterised as dry such as the Western Cape and the Karoo shall be now described as moderate. Another visible change on the map is the increase from three different climatic regions to six.

Keywords: Weinert N-value, flooding, climatic regions, environmental factor, climate change

INTRODUCTION

One of the best-documented African climate change evidences are glacial retreats that have been witnessed on Mount Kilimanjaro. It is the tallest peak on the continent, and so, despite being located in the tropics, it is high enough so that glacial ice has been present for at least many centuries. However, over the past century, the volume of Mount Kilimanjaro's glacial ice has decreased by about 80%. If this rate of loss continues, its glaciers will likely disappear within the next decade [3].

Sea level rise is one of several lines of evidence that support the view that the climate has recently warmed [1]. According to [10][11], there are four stations recording sea level rise on the coast of Southern Africa. These are located at Lüderitz (Namibia) and in South Africa at Port Nolloth, Simon's Town and Mossel Bay. Records of the first three stations indicate a positive trend in sea-level rise (relative to the land mass) over the past three decades. For example, the trend at Port Nolloth is a 12.3 mm rise per decade. Since the west coast sea-level rise data are in agreement with the global trends, it is reasonable to accept that the predicted rates of sea level rise, modelled on the basis of global warming, are applicable to South Africa.

According to [6], current highways are designed based on typical historic climatic patterns, reflecting local climate and incorporating assumptions about a reasonable range of temperatures and precipitation levels. Given anticipated climate changes and the inherent uncertainty associated with such changes, a pavement could be subjected to very different climatic conditions over the design life and might be inadequate to withstand future climate forces that impose stresses beyond environmental factors currently considered in the design process.

It can therefore be inferred that factors influencing pavement designs are divided into two, namely controllable and non-controllable. Controllable factors include engineering design, selection of materials, construction quality and control, standards and progress. Uncontrollable factors include climate, terrain and geological conditions such as surface and sub-surface hydrology. Therefore there are many influential factors that the engineer cannot control and hence understanding risk and reliability is a key aspect of design to cater for uncertainties.

BACKGROUND

It is believed that by the year 2100, world climate will have changed in ways that are difficult to imagine - as difficult as it would have been at the end of the 19th century to imagine the changes of the 100 years since. The current heat, drought, floods and rainfall spurts are evident of the effects of climate change. The response to climate change is often seen as twofold; adaptation and disregard. Extensive research has been done by climatologists on the subject of climate change. However, engineers and technologists have not yet adapted an approach that aims to address the topic within the engineering sector.

According to [2], African continent is facing the potential of a US$183.6 billion liability to repair and maintain roads damaged from temperature and precipitation changes related to climate change through the year 2100. As detailed by [2], the central part of the continent faces the greatest impact from climate change with countries facing an average cost of US$22 million annually, if a proactive adaptation policy is adopted. However, if a reactive approach is adopted the costs will likely be US$54 million annual average, [2]. This evidence therefore suggests that urgent proactive measures in the form of improving current design parameters are required in order to curb the impacts of climate change on sub-grades.

Southern Africa can be divided into three climatic regions: (a) A large dry region (b) A moderate region (c) A small wet region.

Figure 1 is a map of southern Africa, which indicates the different climatic regions. These are macroclimates and it should be kept in mind that microclimates may occur within these regions. This is particularly important where such local microclimates have a high moisture content. This will have a direct influence on moisture-susceptible materials in basic access streets which require specific drainage considerations.

Improvements ought to be made particularly on climate based parameters used in transportation engineering and designs. The Macro Climatic Regional Map of Southern Africa adopted from Weinert (1980) by [10][11] is one of the most outdated weather based catalogues used in the industry. To date, even in light of the eminent threat of climate change, no credible advances have been made for any improvements on this over thirty year old design climatic regional map. Minor editions on the Weinert N-Values include up to ten percent adjustments on net cold binder whereby an increase is made on dry areas (N-value > 5) and reduction in wet/humid areas (N-value < 2). A gap therefore exists and speedy research is imperative in order to optimize our roads' serviceable life and also keep abreast with the ever changing environmental factors influencing our roads.

In recent years, an almost similar research was conducted by a Japanese sponsored Prediction of Climate Variations and its Application in the Southern African Region as well as the Climate Africa project which had an additional role of facilitating seasonal forecast uptake. Both these projects had the goal of making improvements to seasonal forecasting in sub-Saharan Africa. The purpose of this research was to revise the age old map of the macro climatic regions of Southern Africa as adopted from Weinert (1980) and shown in [10][11].

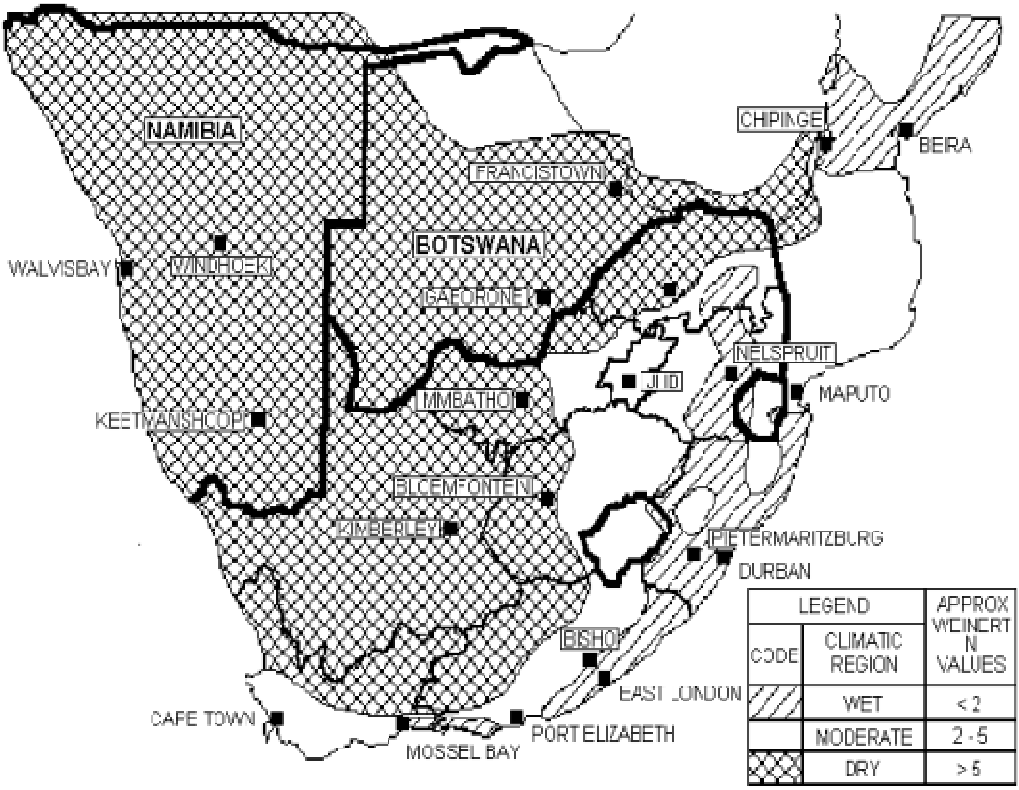

Figure 1: Macro Climatic Regions of Southern Africa (Adapted from Weinert, 1980)
Source: [10][11]

MATERIALS AND METHODS

The methodology adopted in this study included identifying and mapping areas within the Southern African region that may suffer from future increased precipitation and flash flooding among other climate based parameters.

A systematic approach was used in the process entailing; (a) Desk study (b) Data gathering (c) Calculation of Weinert N-values (d) Compilation of map

Literature review on published results of past studies in climate change formed part of the desk study. The Council for Scientific and Industrial Research (CSIR) provided climatic data for this study which has been gathered from the Southern African weather observation stations, for the period of 1960 – 2012 for use in this research. It is a requirement of climatic data collection that there should always be a human observer monitoring the weather at the station so that variables such as cloud could be available. Data gathered from the study includes annual average rainfall and evaporation. A variable-resolution atmospheric global circulation model, the Conformal-Cubic Atmospheric Model (CCAM) of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia, was used to obtain the ensemble of six regional climate projections that are analysed as part of this research.

The Weinert N-Value, initially developed by Weinert (1974) and improved in 1980 was adopted by [10][11]. It was originally developed in Southern Africa to describe different climatic environments with respect to weathereability of rocks. It is calculated using 12 times the evaporation (Ej) of the warmest month divided by the total annual precipitation (Pa) as shown in the formula;

$N = 12Ej/P_a$

where;

N = Weinert N-Value

Ej = Evaporation

P_a = Annual precipitation

The data actually needed for computation of the formula are annual average rainfall, average air temperature and average wind speed for the month concerned, and average wet bulb reading which form part of the determination of evaporation rate. Using the N value formula explained in the introduction, contoured maps of N-value were then developed for the Southern African region on a decadal basis from 1961 – 2061.

RESULTS AND DISCUSSION

Precipitation forecasts

The precipitation forecasts are given for three months lead time. Seasonal averages are given as three month rolling means which correspond to the dynamical anomalies given elsewhere. The scale on each figure is a percentage of normal (average), bluer colours indicating above normal and redder colours below normal.

Both the mean (on the left) and trimean (on the right) of the forecasts are displayed. These are both the same forecast. A forecast consists of ten separate runs with slightly different starting conditions; each of these runs is termed an ensemble member thus each forecast is run with ten ensemble members. The mean is the average of all ensemble members of the forecast. The trimean is the average ignoring the extreme ensemble members (both very wet and very dry ensemble members). The trimean therefore expresses the central tendency of the ensemble and may give a clearer indication of the forecast in regions and at times when the normal rainfall is low e.g. during winter it may be that only 1 (out of 10) ensemble members gives an abnormally high value which will skew the mean towards above normal whereas the trimean will ignore it. It is therefore advisable that both the mean and trimean are compared to see if they agree on the forecast.

On the mean forecast map (maps on the left hand side), shading has been introduced to differentiate two levels of confidence. The clear area (i.e. where there is no shading) shows where the mean of the ensemble forecasts differs from the 48-year model climatology (average climate) at the 90% significance level. It indicates where the model is more 'confident' that the forecast is different to climatology. Without any guarantees that a significant deviation will occur, a simple filter showed that the model is more likely to get the sign of the anomaly right than wrong over regions when high T-test scores are found.

Change in extreme rainfall events

The view of historical record was also investigated to get a general idea of the variability and also taking special note of the extremes. The extremes are important because recent history warns of characteristics like these; frequency, intensity and duration, to change much more quickly than the mean.

Over the whole of South Africa increases in the magnitude of extreme daily rainfall events with return periods of 10 and 30 years have been projected [7]. Noteworthy is the increase of these events even in regions where decreases in the mean annual rainfall were simulated.

In general, East Africa is projected to become generally wetter, whilst Southern Africa is projected to become generally drier with a relatively strong signal of drying projected for Zimbabwe, Zambia and Angola. The central interior of South Africa is projected to become somewhat wetter, despite the general drying signal projected for Southern Africa. At the sub-continental scale, the CCAM projected signals are consistent with those of the majority of CGCM projections described in AR4 of the Intergovernmental Panel on Climate Change (IPCC).

In light of the inconclusive preliminary results thus far, it was clear that a new approach was required. This approach involved further understanding the role of climate variability especially with regards to extreme rainfall events. According to [8], projected changes in extreme rainfall events in South Africa include wet-spells and widespread flooding over the South African Highveld and this may result from a number of different weather systems (or from a combination of different weather systems).

Figure 2 shows the ensemble-average projected change in the annual frequency of occurrence of extreme rainfall events over South Africa. Here an extreme rainfall event is defined as 20 mm of rain falling within 24 hours over an area of 0.5° x 0.5°, that is, an area of about 50x50 km². Rainfall events of this magnitude rarely occur over the South African Highveld and are likely to be associated with flooding over the region. A general, an increase in extreme rainfall events is projected for South Africa. Rainfall events are projected to increase over the mountainous regions of eastern South Africa in particular [8]. There is also a strong correspondence between the different ensemble members regarding the projected future increase in extreme rainfall events (Figure 4), which strengthens confidence in the projections.

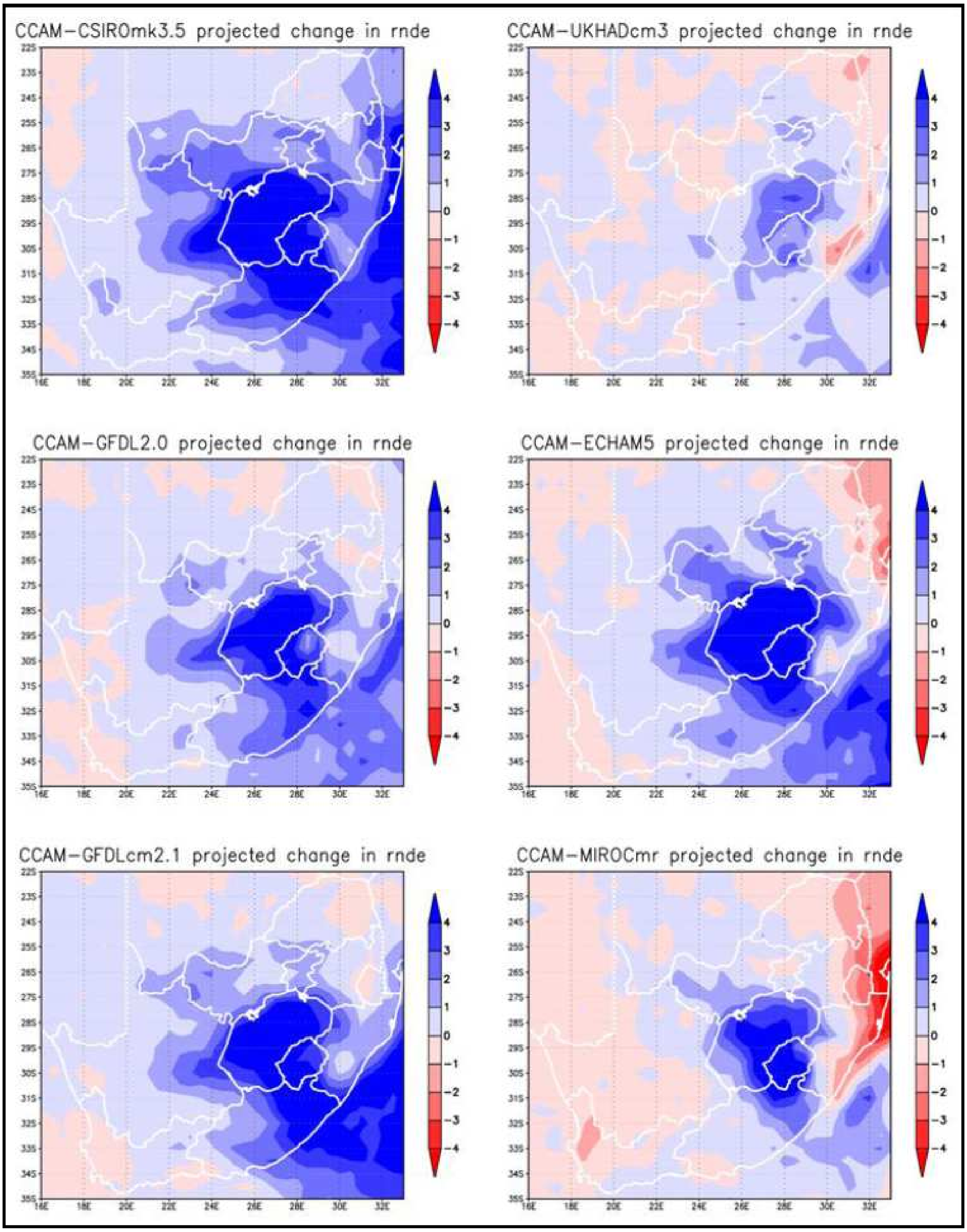

Figure 2: Decadal change in extreme rainfall
Source: [8]

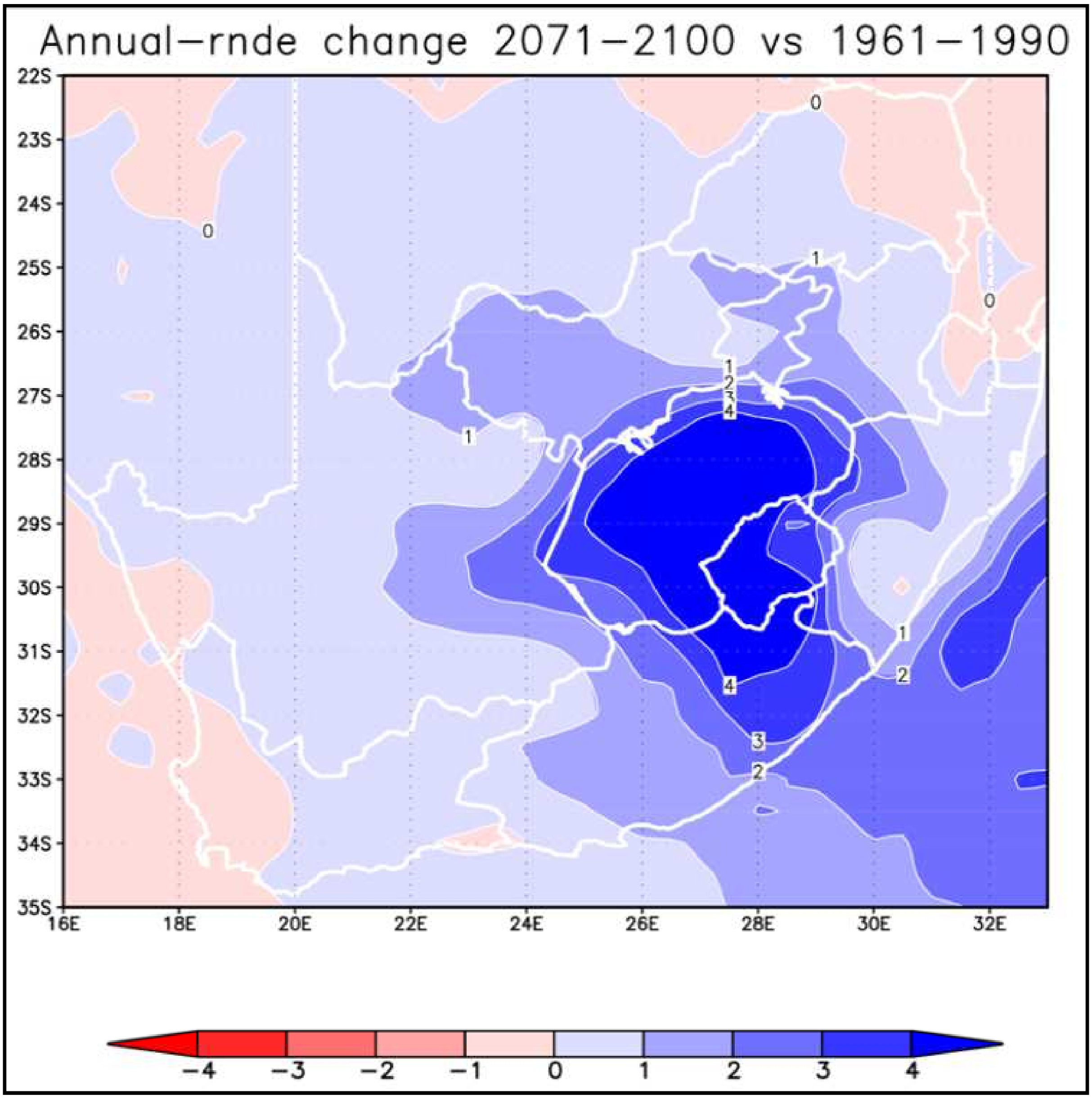

Figure 3: Projected change in the annual frequency of extreme rainfall events
Source: [8]

All the six different projections indicate an annual increase in extreme rainfall events in the chosen study area with the exception of the Model for Interdisciplinary Research On Climate (MIROCmr) portraying a reduction in the margin of -3 to -4 events per day. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) mk3.5 ensemble shows the strongest positive projected change at 3 to 4 events per day. This is at the higher end of the classification graph and hence confirms the vulnerability of the study area with regards to storm fall and possible flash flooding.

The Projected change in the annual frequency of extreme rainfall events (defined as 20 mm of rain falling within 24 hours over an area of 0.5°x0.5°) over South Africa, for the period 2071-2100 vs. 1961-1990 (units are number of events per model grid box per day). The figure shows the ensemble average of the set of downscaled projections, obtained from six Coupled General Circulation Model (CGCM) projections of AR4 of the IPCC.

CONCLUSION AND RECOMMENDATIONS

Previously, the CSIRO9 GCM was used to examine the possible changes in the frequency and intensity of extreme daily rainfall events over Southern Africa that can be expected from a doubling in atmospheric carbon dioxide. It was discovered that over the whole of South Africa increases in the magnitude of extreme daily rainfall events with return periods of 10 and 30 years were projected. Noteworthy is the increase of these events even in regions where decreases in the mean annual rainfall were simulated [4].

In general, East Africa is projected to become generally wetter, whilst Southern Africa is projected to become generally drier with a relatively strong signal of drying projected for Zimbabwe, Zambia and Angola. The central interior of South Africa is projected to become somewhat wetter, despite the general drying signal projected for Southern Africa. At the sub-continental scale, the CCAM projected signals are consistent with those of the majority of CGCM projections described in AR4 of the IPCC. Although an in-depth discussion of the CCAM projected rainfall signal falls beyond the scope of this paper, aspects of the underlying circulation dynamics are described by [5].

Rainfall simulations indicate a similar pattern to current conditions with an almost negligible decrease. The general decrease in rainfall is in the margin of 0.2% compared to present day scenarios. The winter season (May to August) is projected to have a sharper decrease in rainfall of about 5% which translates to around 80 mm. The presented maps indicate an increase in future precipitation and assume that the evaporation rate will remain the same throughout the region. Such may not be entirely true for the desired period of interest, therefore the resultant of the Weinert N-value equation will be best represented by the results as depicted in Figure 3.

It is therefore evident now that climate change will not only pose a threat in terms of temperature and rainfall changes but also in other factors that would not have ordinarily been taken into consideration will also play a major role. The ratio of evaporation to precipitation which gives us the N value as described by Weinert (1980) is clearly no longer properly represented from the then map which had a vast majority of the Southern African land classified as dry. In future there shall be more moderate and wet areas than when the map was adopted. Areas characterised as dry such as the Western Cape and the Karoo shall be now described as moderate.

Another visible change on the map is the increase from three different climatic regions to six.

Of these six climatic regions, some are considered borderline and may be interpreted as a grey area by many engineers. A number of suggestions for further study are therefore warranted; (a) Utilization of the actual evaporation rates at all southern African weather stations for the calculation of the Weinert N-Value. These must be obtained from a reputable source such as the CSIR and the Climate Systems Analysis Group (CSAG). (b) Plotting these calculated N-Values on a Southern African map (c) Re-calculation of the N-Values using the six new climatic regions

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