Detailed delimitation of rainfall regions in southern Africa†

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Abstract

The concept of a homogeneous rainfall region is particularly useful for hydrological studies in the fields of agriculture and engineering. The study described in this paper identified 712 homogeneous rainfall regions.

Regions were delimited according to the following criteria:
- mean annual precipitation (MAP);
- altitude;
- aspect;
- topographic complexity; and
- agricultural population distribution.

A data base of altitude points spaced at one minute of a degree and over 5 000 rainfall stations with more than 10 years of record was used. A digital, classified image of altitude upon which was superimposed the MAP at each station, provided the basis for a careful manual pattern recognition exercise, to delimit the rainfall regions.

The boundary points of the 712 regions have been digitised and are stored in coordinates of latitude and longitude. It is therefore possible to plot maps of any scale and projection. The results of this comprehensive study are already proving valuable in a wide range of applications.

Introduction

The term homogeneous is a relative one and therefore it is particularly difficult to define, especially in the context of rainfall regions.

A broader understanding of the context in which the term was used in this paper may be gained following a description of the methodology used to delimit such regions. In addition it is necessary to view the term homogeneous in the context of the scale at which the regions are delimited, the intended use of the regions as well as the complex nature of the rainfall regimes.

Nevertheless, despite the above-mentioned difficulties the concept of a region of homogeneous rainfall is particularly useful for hydrological studies in the fields of agriculture and engineering. Consequently the delimitation of rainfall regions in South Africa has been the subject of several previous studies.

The most notable of these regionalisations have been the South African Weather Bureau (SAWB) (1960 and 1972) classifications and that by Welding and Havenga (1974). The techniques employed in the aforementioned classifications were sound and the delimitation were comprehensive, considering the data sets and computers of the day. However, with the enhancement of computer power, digitisers and considerably enlarged data sets it has become both desireable and possible to delimit rainfall regions with greater detail and accuracy.

A data set consisting of a grid of altitudes at a spacing of 1 min of a degree and covering southern Africa, was extracted from maps and also collated from various sources. These data, combined with the mean annual precipitation (MAP) at approximately 5 000 rainfall stations, provided the foundation upon which the delimitation was based. The stage was thus set for a patient and careful manual exercise in pattern recognition. Constant reference was made to the 1:250 000 topographic maps during this procedure.

Comparison of previous rainfall regions

The Welding and Havenga (1974) regions were considered to be an improvement on those of the SAWB (1960, 1972) for several reasons. Firstly, the Welding and Havenga (1974) regional classification used 1 549 stations for the period 1931 to 1966, which is more than double the number used by the SAWB (1972) for the same period. Secondly, Welding and Havenga (1974) used monthly data in a correlation procedure which was followed by the hierarchical classification technique of McQuitty (1960). This technique is considered to be statistically more sensitive than that of the SAWB (1972), which used the distribution of mean monthly rainfall. Welding and Havenga (1974) took cognisance of topographic features, as did SAWB (1972). Welding and Havenga (1974) delimit 114 regions compared to the 34 of the SAWB (1972) and in Natal the Welding and Havenga (1974) regions show reasonable agreement with those proposed by Schulze (1983). The overall goal of the Welding and Havenga (1974) classification was to identify similar rainfall regions for agricultural purposes. It is therefore reasonable to assume that cognisance was taken of the situation "on the ground", as it were, and that it was not purely an exercise in which the correlations between monthly precipitations were the sole criterion in the delimitation. The statistics presented by Welding and Havenga (1974) did, however, reveal that the stations whose monthly rainfall is well correlated, tend to be clustered together in proximity to one another.

Unfortunately the Welding and Havenga (1974) regionalisation did not take cognisance of the mean annual precipitation (MAP) at

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stations. In addition the only map depicting the Welding and Havenga (1974) regions is that which appears in their publication and it is at a scale of 1:5 000 000 which is considered inadequate for many applications.

Technique used to delimit rainfall regions

The influence of physiography and in particular altitude on the spatial distribution of long-term average rainfall has been well known for a long time. A plethora of studies in southern Africa, *inter alia,* by Whitmore (1968), Torrance (1973), Schulze (1976), Schulze (1979), Alexander (1980), De Villiers and Bond (1982), Hughes (1982, Schulze (1983), London and Emmitt (1986) and Dent *et al.* (1989) support this hypothesis.

It was evident on examination of the above-mentioned research that any delimitation of relatively homogeneous rainfall regions would have to be based on altitude, primarily. This study was conducted concurrently with a major analysis of the spatial distribution of MAP and other statistics of precipitation in southern Africa by Dent *et al.* (1989). The latter project had established the location and altitude of the rainfall stations in southern Africa on maps of scale 1:50 000 and had prepared an altitude data set on a grid of size 1 min by 1 min of a degree for the entire southern Africa as defined for this study. The classified digital image of this altitude data set and the location, MAP and length of record of all rainfall stations with more than 10 years daily record formed the basis for the selection of "key" long-term daily rainfall stations and the delimitation of relatively homogeneous rainfall regions surrounding these stations.

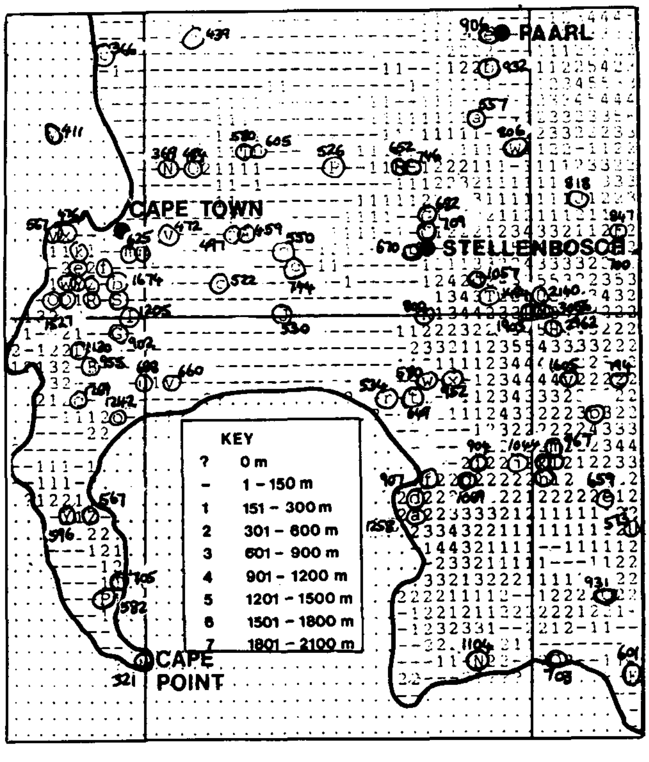

Figure 1
Classified image of altitude, for part of the south-western Cape, showing MAP at rainfall stations with >10 years of record.

A classified image of altitude covering southern Africa was printed. The locations of all stations with 10 or more years of record were superimposed on this image. The MAP and length of record at each station were noted at the station point, as shown by the example, from the south-western Cape, in Fig. 1. Thereafter followed the careful, patient and very time-consuming process of delimiting the relatively homogeneous rainfall regions based, *inter alia,* on MAP, altitude and aspect, whilst keeping the regions reasonably small and referring to the 1:250 000 topographic maps in order to provide a more detailed interpretation of the classified altitude map. Human judgement was used in the delimitation of the regions, since such judgement was considered to be more flexible and skilful than delimitations based upon a set of rigorous, computerised rules. The following criteria were employed as a guide in the delimitation:

Mean annual precipitation (MAP)

Stations with 10 or more years of rainfall record were plotted along with their MAP. Boundaries were drawn so as to group stations of similar MAP and since regions were made reasonably small these were likely to have similar weather patterns and strong interstation monthly rainfall correlations (Welding and Havenga, 1974 and Dent *et al.,* 1989). Most of the regions which were delimited, have a range in MAP of less than 100 mm, except in the mountainous areas where rainfall gradients are known to be steep (Dent *et al.,* 1989).

Altitude

Since rainfall varies with altitude an effort was made to restrict the range of altitudes covered by any one region. Consequently, many of the regional boundary lines were drawn to follow the breaks in "contours" of the classified image of altitude.

Aspect

The direction of movement of weather systems can have a marked influence on rainfall amounts, especially in mountainous areas. An attempt was made therefore to limit regions to the same side of mountain ranges and allowances were made for rain shadows.

Topographic complexity

In mountainous areas, regions were reduced in size to allow for more rapid spatial variations in rainfall and aspect. Regions tended to be larger in flat areas. The lack of rainfall stations in Lesotho made it an exception to this tendency.

Agricultural population distribution

In areas where the agricultural population is more dense and in which the diversity of arable agricultural practices is likely to be greater, the climate zones were kept smaller than in the drier more sparsely populated areas in which farming activities and climate are more uniform.

In this manner, 712 regions were delineated. The boundaries of these regions were digitised to a resolution of 1 min of a degree and stored for computerised plotting. An example of this detailed regionalisation is presented in Fig. 2 and the complete map of regions in southern Africa appears in Fig. 3.

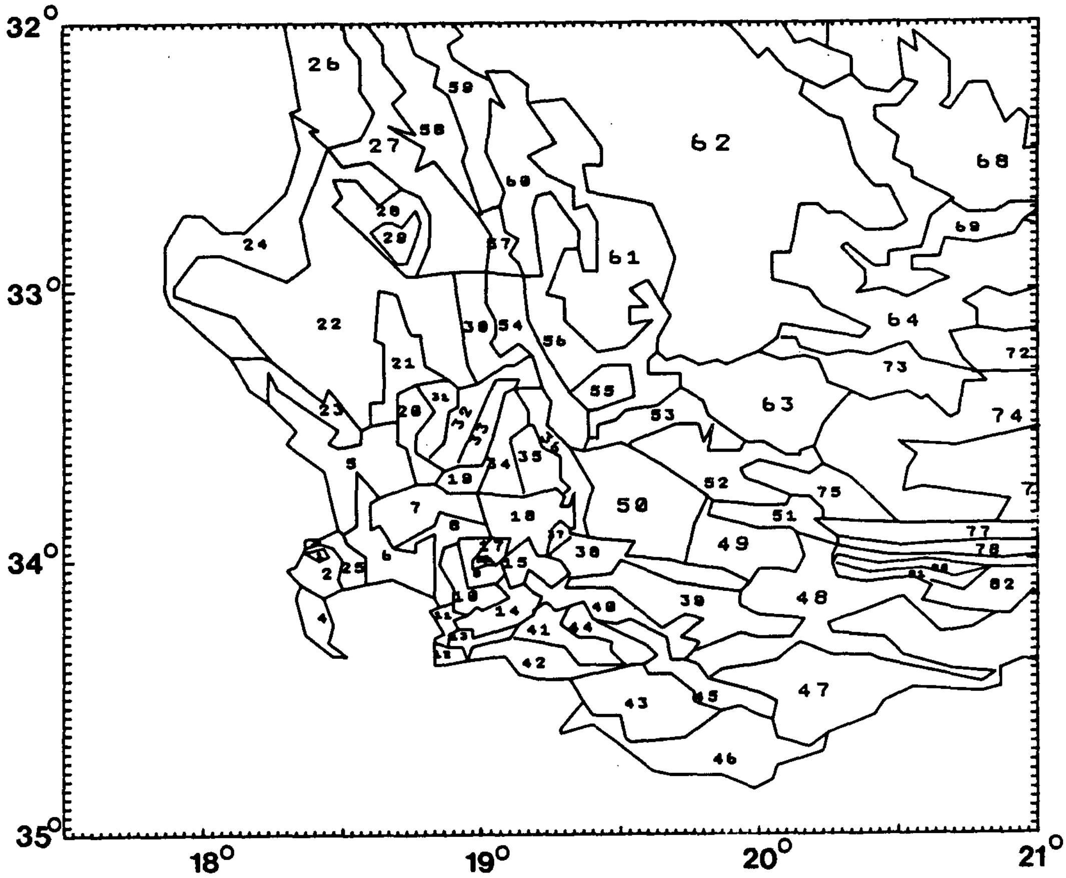

Figure 2
Delimitation of relatively homogeneous rainfall regions in the south-western Cape.

Discussion

It may be argued that 712 regions is too fine a delimitation. However, it was decided to proceed with the process of human pattern recognition based on the above criteria. Regions may always be grouped subsequently by the user, for specific tasks.

Subsequent to the original study and following the founding of the Computing Centre for Water Research it has been possible to plot the regions as overlays at 1:250 000 scale. The regional boundaries were then revised and redigitised at 1:250 000 scale. This exercise showed that the original delimitation based on the procedures described above had been good.

A study by Dent *et al.* (1989) has provided estimates of MAP at each 1 min grid point described earlier. The results of this study were used to perform the investigation described below, two years after the rainfall regions were first delimited. An algorithm was produced to classify these grid point estimates of MAP into the 712 rainfall regions. The coefficient of variability (CV) of the estimated MAP was then determined for each region. This analysis revealed that in 381 regions the CV of the MAP was less than 10 per cent. In 219 regions the CV of the MAP was between 10 and 20 per cent and in 112 regions greater than 20 per cent. These latter regions are primarily the mountainous regions of the Cape, Lesotho, the Eastern Transvaal Drakensberg and the Soutpansberg.

The boundary points of the 712 regions have been digitised and are stored in coordinates in latitude and longitude. It is therefore possible to plot maps of any scale and projection. Routines have been developed which delineate into the above regions, any points in the grid system of altitudes mentioned above. It is thus possible to provide digital images in raster form, for these regions. This form of the map has and will find many applications in overlays and geographic information systems. The results of analyses conducted at representative rainfall stations within these regions may now attain a spatial significance and shape.

The rainfall regions which were delimited in this study have already been used for two studies in southern Africa by Dent *et al.* (1988) and Schmidt and Schulze (1987). The former study involved a detailed analysis of soil moisture deficit for irrigation planning in southern Africa and for the latter a regionalisation of potential runoff depths and peak discharges for small catchments in southern Africa. In these two studies long-term daily soil moisture budgeting was conducted with the aim of fulfilling the above objectives.

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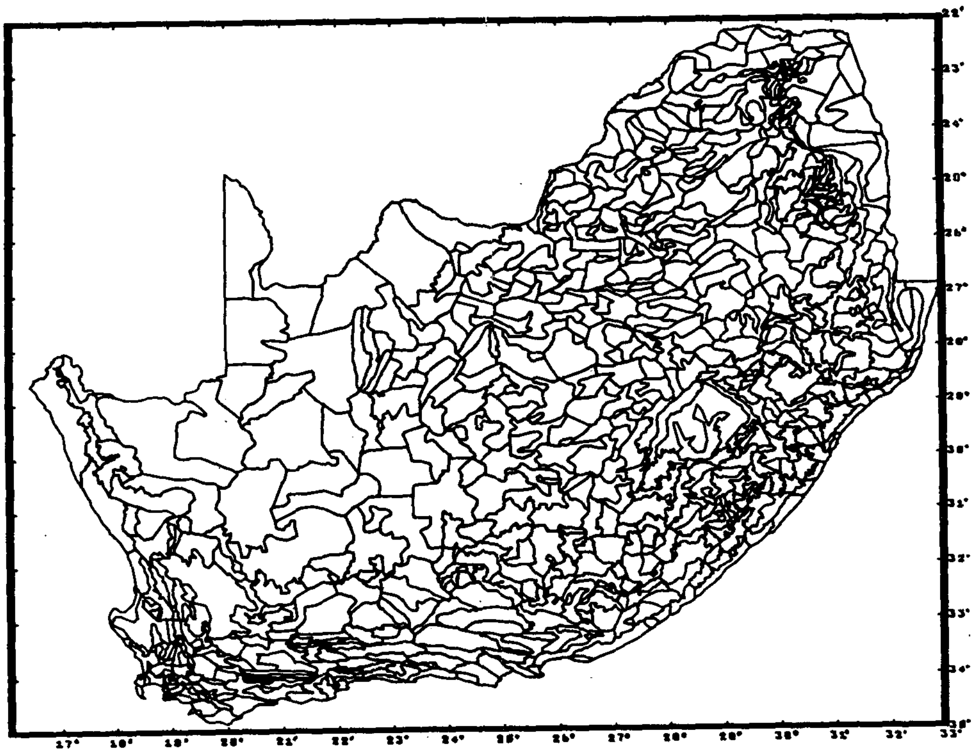

Figure 3
The 712 relatively homogeneous rainfall regions.

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