Verification of rainfall forecasts for the Vaal Dam catchment for the summer rainfall seasons of 1994 to 1998

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Abstract

Rainfall forecasts compiled by the South African Weather Service (SAWS) are used daily by agriculture, industry, sportsmen and the general public. Because of the importance of the rainfall forecast, it is of considerable interest to know how reliable these forecasts are. The SAWS evaluates the rainfall forecasts issued by the Central Forecasting Office (CFO) on a daily basis. A hit score is determined in each of 19 rainfall districts throughout South Africa. This renders a result of approximately 60% correct forecasts for all 19 districts. This paper investigates the accuracy of the predicted rainfall percentages or rainfall classes. The 24h rainfall forecasts are verified for the summer months (October to March) of 1994 to 1998 for the Vaal Dam catchment. The rainfall distribution classes were chosen to represent no-rain, isolated rain, scattered rain and widespread rain. Results indicate that the percentage of correct forecasts is less than the values obtained by using the SAWS's hit score method. The predicted widespread rain class is less than 25% correct. The tendency exists to forecast scattered rain whenever any rain event is predicted. A rain event is seldom missed (3%), but some rain is often forecast (45%) for days, which then remain dry days. A more comprehensive rainfall forecast evaluation system is recommended.

Keywords: Rainfall forecasts, verification, rainfall distribution classes, Vaal Dam catchment

Introduction

Rainfall forecasts are probably the most popular product provided by a forecasting office (Scholz, 2002). Agriculture, industry, sportsmen and the general public use the rainfall forecasts daily. The six forecasting offices of the South African Weather Service (SAWS) can receive, in total, up to 200 000 calls a month (South African Weather Service, Internal News Flashes, 2000). Many of these calls inquire about the rainfall outlook for anything from a few hours to a week ahead.

Edwards (2000) stated that the SAWS had adopted a policy, many years ago, to issue worded rainfall forecasts using the terms isolated, scattered and general rain. In a worded rainfall forecast a glossary of words and phrases is used to describe the expected rainfall. During the 1980s increasing demands were made on the Directorate of Weather Forecasting by television services in particular, as well as by the many newspapers, to produce rainfall forecasts graphically. The decision was taken to delineate areas where rainfall is predicted on a map of Southern Africa. At about this time percentages were assigned to the terms isolated, scattered and general rain. These were isolated 20% to 30%, scattered 40% to 70% and general 80% to 100%. The magnitude of these percentages assigned to the generally used verbal terms was influenced by the criteria used to issue forecasts for the aviation community. It is common practice to assign a probability, expressed as a percentage, of the occurrence of a weather event, i.e. rainfall, in the compilation of a Terminal Airdrome Forecast (TAF) (International Civil Aviation Organisation, 1998). However, a rainfall percentage forecast compiled by the SAWS for a specific area does not represent the probability of rainfall to occur, but rather the rainfall distribution over the area.

At present, rainfall forecasts, using percentages to indicate distribution, have become the norm in South Africa. Scholz (2002) stated that in a large number of the telephonic enquiries about rainfall prediction, received in the Central Forecasting Office (CFO), the enquirer often insists on getting the rainfall prediction in terms of a percentage. At present no information exists on how reliable these forecasts are. The quality of a forecast can best be determined through statistical and other verification schemes.

A detailed discussion on verification methods used in meteorology is available in Murphy and Epstein (1967), Murphy and Winkler (1984), Murphy et al. (1985), Murphy and Winkler (1987), Murphy (1995), Sanders (1963) and Stanski et al. (1989).

Verification is only useful if it leads to some decision considering the product being verified. In meteorology, verification has two goals: an administrative goal, to monitor the overall quality of a forecast and track any changes in the quality, and a scientific goal, to identify strengths and weaknesses of a forecast so as to direct research and development (Stanski et al., 1989).

The aim of this paper is to determine the accuracy of the forecast rainfall percentages subdivided into specific rainfall classes. This was achieved by using the SAWS 24 h rainfall forecasts, which are valid for the Vaal Dam catchment and for the five summer rainfall seasons (October to March) of 1994 to 1998. The rainfall forecasts are also considered subjective because no exact or reliable numerical method exists to determine rainfall distribution and depth from weather maps, actual or prognostic. It is also widely accepted within the forecasting community that rainfall predictions from general circulation models are unreliable at the spatial scale of the SAWS rainfall districts. Therefore these forecasts are subjective in the sense that they depend largely on the interpretation and experience of the individual forecaster (Sanders, 1963). The forecast and rainfall observation data are of a categorical nature and are evaluated by using the contingency tables designed by Stanski et al.

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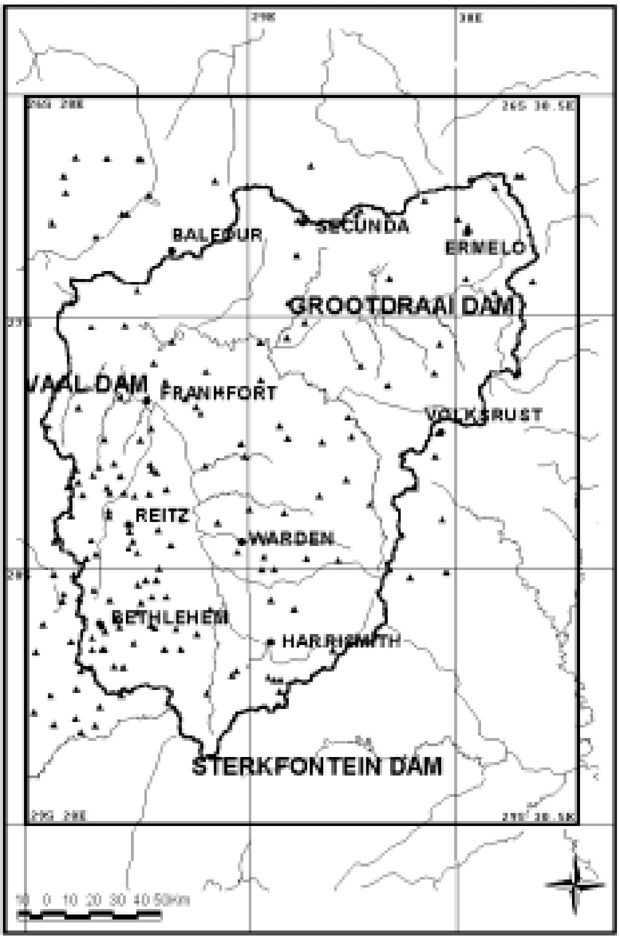

Figure 1
Rainfall stations (triangles) near and within the Vaal Dam catchment. The boundary of the Vaal Dam catchment is indicated by the solid line and the rivers by thin lines. The area where rainfall stations were isolated is indicated by the smaller rectangle.

(1989). In this paper no attempt is made to verify the depth of rain forecast, it is aimed at verifying the rainfall distribution classes.

Existing methodology

The CFO compiles the rainfall forecast during the late afternoon. This forecast is produced in the form of a map, valid for the following day. Banitz (2001) explained how the SAWS verified rainfall forecasts by using a two-way contingency (Yes/No) table, proposed by Stanski et al. (1989). From this table the hit score, skill score and the bias was calculated. The daily rainfall reports from 1702 stations are used for the verification. In this SAWS verification procedure a rainfall forecast was considered to be correct if rain occurred in the appropriate rainfall district, regardless of the percentage or depth of rainfall, which was forecast.

For the period 1998 to 2001, and considering the 19 SAWS rainfall districts together the hit rate was consistently close to or more than 60%. This high hit score indicates that the SAWS forecasters are generally very skilful in identifying areas where some rain will fall. But for the period January to December 2000, over the summer rainfall areas, the hit rate varied from less than 20% in February 2000 to better than 80% in August (Banitz, 2001). During February 2000 widespread and heavy rainfall occurred over the northern regions of South Africa (Dyson and Van Heerden, 2001) and it is interesting to note that Banitz (2001) found that despite the low hit rate obtained during February 2000 the probability of detection (POD) for the heavy rainfall was more than 80%.

Banitz (2001) also concluded that the rainfall events tended to be over-forecast with the predictions only slightly better than chance. She also concluded that the forecasts tend to improve at the time of the year without significant rainfall.

The Vaal Dam catchment

The Vaal Dam is the primary supplier of potable water to the heartland of the South African economy (Department of Water Affairs and Forestry, 1991). More than 25% of the country's people are dependent on water stored in the Vaal Dam. This dam lies in the eastern part of the much larger Vaal drainage region. Important dams in this region are the Grootdraai, Vaal, Saulspoort and Sterkfontein Dams. The rivers in this area feeding the Vaal Dam are the Vaal, Liebenbergvlei, Wilge and the Nuwejaarspruit Rivers.

The largest part of the Vaal Dam catchment lies in the Free State Province (60%) with the rest lying in Gauteng and Mpumalanga Provinces. The Vaal Dam catchment can be approximated in area by a 261km by 287km rectangle (Fig. 1). The mean annual runoff (MAR) to the Vaal Dam is approximately 8% of the annual rainfall (Department of Water Affairs and Forestry, 1991).

Figure 1 depicts the distribution of the rainfall stations in the Vaal Dam catchment.

Data and methodology

The period investigated in this paper is the summer rainfall seasons (October to March) of 1994 to 1998. Forecast rainfall data were extracted from the rainfall distribution charts generated each day by the Central Forecasting Office (CFO) of the SAWS. The rainfall predictions are in rainfall distribution classes. In other words, the percentage of rainfall stations expected to report rainfall. They are valid for a 24h period, 00:00 to 24:00 South African Standard Time (SAST). Rainfall charts for 25 February 1997 and 27 November 1998 as well as rainfall maps for the months October 1994, March 1997 and December 1998 were unavailable. The only data available for the 1998 summer season are from October to November. The other summer seasons stretch from October to March.

Actual measured gauge rainfall data were obtained for Gauteng, Free State and Mpumalanga Provinces from Climate Systems at the SAWS. Only the rainfall stations within the Vaal Dam catchment were considered in the analysis. The number of reporting rainfall stations has decreased from approximately 180 in 1994 to 118 in 1998 (Fig. 1). Rainfall depths are reported in millimetre (mm).

It is important to note that problems occur when comparing the forecasts and rainfall gauge data, referred to here as observations. The period of validity of the forecast is from 00:00 to 24:00 SAST while the daily rainfall observation is valid from 08:00 to 08:00 SAST the next day, but by convention assigned as rainfall which fell on the first (previous) day. This means that there is a 16h period in which the rainfall observational and forecast periods overlap. The rainfall forecast starts 8h before the rainfall observation and also ends 8h before the rainfall observation period ends. Fortunately during summer a large proportion of the rainfall over the Vaal catchment comes from late afternoon convective showers and thundershowers (Taljaard and Steyn, 1988).

In this paper the percentage of the stations reporting more than

TABLE 1
The rainfall class contingency table. Columns represent the number of forecasts in each class while rows list the number of observations made in each class.

	No rain	Isolated	Scattered	Wide-spread	TOT
No rain	a	b	c	D	**A**
Isolated	e	f	g	H	**B**
Scattered	i	j	k	L	**C**
General	m	n	o	P	**D**
TOT	**E**	**F**	**G**	**H**	**Z**

0.0 mm rain per day was calculated for each 24 h day. The percentages were computed using the weighted average method of Tennant (1999), where the geographical position of each station relative to the other stations is taken into consideration. The following weighting function was applied to all the stations on a daily basis:

$$Wgt = \frac{\sum_{m=1}^{N-1} r_m}{(N-1)r_{\max}}$$

where:

Wgt = weight assigned to station

$\sum_{m=1}^{N-1} r_m$ = Sum of the distance between the specific station and all other stations.

where:

$r_{\max}$ = Maximum distance between the specific station and any other station

N = Total number of stations

When rainfall stations are distributed evenly over the area, this method renders results very close to the mathematical average expressed as a percentage:

$$\frac{\text{Number of rainfall stations reporting rainfall}}{\text{Total number of rainfall stations}} \times 100$$

The use of the weighting method becomes important when the rainfall stations are not distributed evenly over an area. A rainfall station, which is geographically distant (close) to other stations will have a larger (smaller) weight factor and will therefore contribute more (less) in the computation of the percentage. The computation of the percentage of rainfall stations reporting rainfall is vital in determining the accuracy of the rainfall forecasts. For this reason two other methods in computing the weighting percentage were also investigated. However, results indicated that no significant difference in the weighting percentage existed and therefore the method adapted from Tennant (1999) was used.

Two different methods were used to perform the forecast evaluation. Contingency tables (Table 1) compare the distribution classes of the forecast and observation. The classes as classified by the authors are no-rain; isolated rain; scattered rain and widespread rain. In terms of percentages these classes are no-rain (0 to 15%); isolated rain (16 to 35%); scattered rain (36 to 75%) and widespread rain (76 to 100%). Using this classification, several skills and scores can be determined using the format depicted by Table 1. These scores include the percentage correct forecasts (PCF), the false alarm ratio, the threat score as well as the Heidke skill score as described by Stanski et al. (1989). The PCF is calculated using the following expression:

$$PCF = \frac{a+f+k+p}{Z} \times 100$$

Due to the large number of forecasts, which were classified as scattered rain, the question was raised whether it would be statistically justified to use this class without further subdivision. The decision was taken to use this class unchanged because of its common use by the South African weather forecasters and its wide acceptance by the general public. Analysis of the rainfall gauge data indicated that rainfall classified as widespread rain occurred only 8% of the time. This severely limits the significance of statistical parameters calculated for widespread rain. Because of the importance of this class (widespread rain) for hydrological forecasting it was decided to use this class without any modification.

TABLE 2
The two-way contingency table for the hit rate. Columns represent the number of forecasts in each class and the rows the number of observations in each class.

	Yes	No	Total
Yes	a	b	**A**
No	c	d	**B**
Total			**C**

The second evaluation method used in this paper is the hit rate. Eleven rainfall stations, with continuous records, within the Vaal Dam catchment area were selected. Rainfall data from the 11 stations were used to determine whether rain had occurred at the station when it was forecast but irrespective of the category (class). In order to compute the true skill score (TSS) the two-way table depicted as Table 2 and the following expression were used (Stanski et al., 1989).

$$TSS = \frac{ad-bc}{AB}$$

The TSS is a measure of the association between the forecast and observation. TSS is perfect when it is equal to +1 and at its worst when it is equal to -1. This method is similar to the one used by the SAWS, except that an observation at a specific point is used here while the SAWS does the verification for a rainfall district.

Research results

Table 3 is the contingency table for the rainfall distribution classes for the 1994 to 1998 summer rainfall season over the Vaal Dam catchment. Columns represent the number of forecasts in each class while rows list the number of observations made in each class.

Figure 2 depicts the PCF over the Vaal Dam catchment for the summer seasons 1994 to 1998. For the entire period the PCF was less than 50%. The best results were found for the 1995/1996 and 1998 summer seasons. Banitz (2001) postulated that persistence

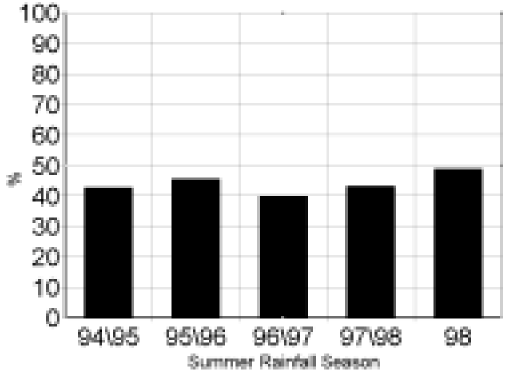

Figure 2
Percentage of correct forecasts (PCF) over the Vaal Dam catchment for the summer rainfall seasons 1994 to 1998

TABLE 3
The rainfall class contingency table for the Vaal Dam cathment for the 1994 to 1998 summer rainfall season. Columns represent the number of forecasts in each class while rows list the number of observations made in each class.

	No rain	Isolated	Scattered	Wide-spread	TOT
No Rain	228	130	101	6	**465**
Isolated	38	83	87	11	**219**
Scattered	44	75	118	17	**254**
General	3	13	55	16	**87**
TOT	**313**	**301**	**361**	**50**	**1025**

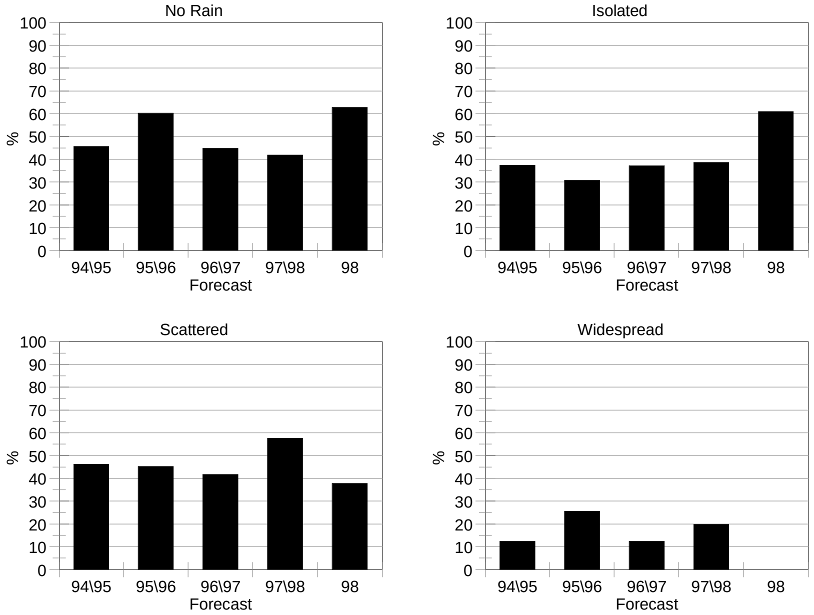

Figure 3
As Fig. 2 but for the four individual rainfall classes. The observation class is indicated at the top of each histogram.

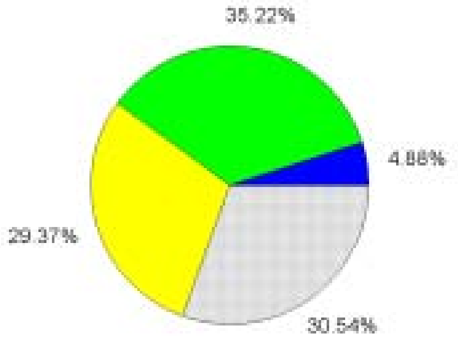

Figure 5a
The number of forecasts, expressed as a percentage, in each class over the Vaal Dam catchment for the summer rainfall seasons 1994 to 1998

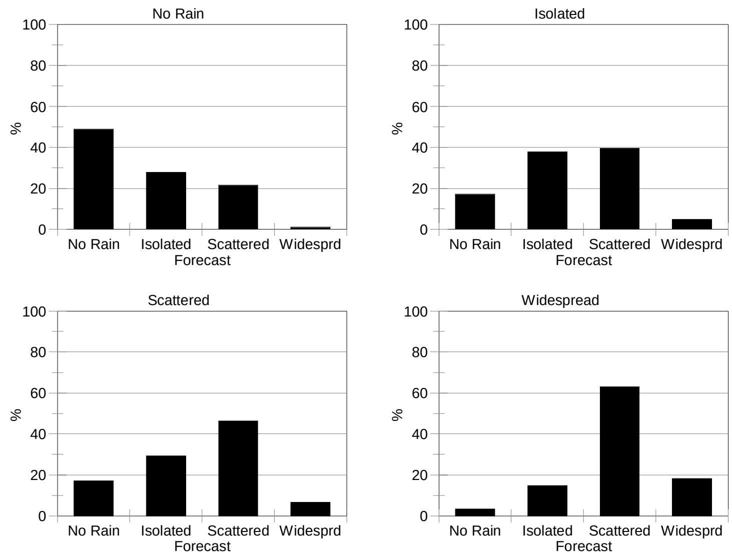

Figure 4
As Fig. 3 but for the percentages of forecasts issued in each class

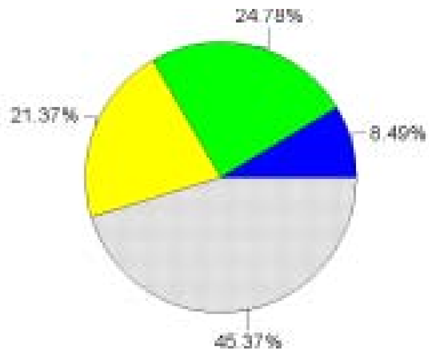

Figure 5b
As Fig. 5a but for the number of observations in each class

forecasting played a role in the forecasting skill for heavy rainfall during February 2000. It is conceivable that persistence forecasting also contributed to the higher accuracy of forecasts during the 1995/1996-rainfall season. This summer was characterised by above normal rainfall over the study area (De Coning, 1997a, b; De Coning et al., 1998 and Edwards, 1997).

Figure 3 shows the PCF but in this case considering the different classes of rainfall. Analysis of Fig. 3 indicates that the forecasts produced by the SAWS were generally less than 50% correct. Notable exceptions occurred with the 'no-rain' class during the 1995/96 and 1998 summer seasons, the 'isolated rain' class in the 1998 early summer months and the 'scattered rain' class during the 1997/98 summer season. However, when it came to 'widespread rain', the forecast accuracy for the Vaal Dam catchment was very poor. Results were less than 25% with two seasons as low as 12%.

Figure 4 indicates the percentages of what was forecast for the actual observed rainfall classes. In Fig. 4 the observed rain class is shown at the top of each histogram while the forecast for the specific class is indicated at the bottom. When 'no-rain' occurred 'no-rain' was forecast 49% of the time, 'isolated rain' was forecast 29% of the time and 'scattered rain' 21% of the time (Fig. 4a). Good forecasting is indicated by high percentages for the corresponding observation class. This was only partially achieved with the 'no-rain' and 'scattered rain' observation classes. For the 'no-rain' observation, 49% of the forecasts were 'no-rain' (Fig. 4a) while when 'scattered rain' was observed, 47% of the forecasts were 'scattered rain' (Fig. 4c). The observed 'isolated rain' class shows that the forecasters tend to predict 'scattered rain' rather than 'isolated rain' (Fig. 4b). Considering the observed 'widespread rain' class, it is also clear that the forecasters tend to be conservative and would rather predict 'scattered rain' (Fig. 4d). Figure 4 seems to indicate that for the Vaal Dam catchment region, the preferred class of rainfall forecast is 'scattered rain' whenever any rain event is expected.

Figures 5a and 5b are pie charts indicating the percentage of forecasts (observations) made in each class for the whole period. Again most rainfall forecasts (35%) fall in the 'scattered rain' class while 'scattered rain' actually occurred only 25% of the time. 'No-rain' was observed most often (45%), but it was forecast only 31% of the time. The 'isolated rain' observation, which occurred 21% of the time, was forecast 29% of the time. 'Widespread rain' occurred 8% of the time, but is only forecast 5% of the time.

Log-linear modelling (Fienberg, 1980) was also performed on the contingency table (Table 3) for the whole study period. This method was used to test the statistical association between each of the rainfall categories. Table 4 lists the results of this analysis. These values are odds-ratio values, which is a measure that describes the degree of association. Calculations showed that absolute values greater than 2.38 were significant. The ratio of the log-linear parameter estimate with its standard error indicated that a significant relationship exists between the 'no-rain' forecast and the 'no-rain' observation (9.141). An encouraging feature is that no relationship exists between the 'widespread rain' observation and the 'no-rain' forecast. This is indicated by the negative but significant value of –4.107. The relationship between the 'isolated rain' forecast and the 'isolated rain' observation is close to significant (2.141), but the 'isolated rain' forecast is also associated with the 'no-rain' observation (2.134). The 'scattered rain' forecast produced unexpected results. A very weak and negative association exists between the 'scattered rain' forecast and the 'scattered rain' observation, but a significant relationship exists between the 'scattered rain' forecast and the 'widespread rain' observation (3.431). This indicates that the 'widespread rain' observation is usually associated with the 'scattered rain' forecast. The 'widespread rain' forecast shows a significant relationship with the 'widespread rain' observation.

With respect to the hit rate at the 11 rainfall stations in the region, Table 5 indicates that a rain event was missed only 3% of the time. On average, rain was correctly predicted 52% of the time while 45% of the time rain was forecast, but did not occur. The average TSS for the 11 stations reveals a positive association between the forecasts and observations (0.2518). These results, however, are not as good as those obtained by the SAWS (Banitz, 2001) because the method used by the SAWS classifies the forecast

TABLE 4
Ratio of the log-linear parameter to its standard error for the observed and forecast rainfall classes in the Vaal Dam catchment during the summer rainfall seasons, 1994 to 1998. An asterisk marks significant values.

	No rain	Isolated	Scattered	Widespread
No Rain	9.141 *	2.134	-3.572 *	-4.869 *
Isolated	0.189	2.141	-1.061	-0.825
Scattered	-0.12	-0.345	-0.094	0.376
Widespread	-4.107 *	-2.34	3.431 *	6.144 *

TABLE 5
Hit rate for eleven rainfall stations in the Vaal Dam catchment for the summer rainfall seasons of 1994 to 1998

Stations	Latitude (°S)	Longitude (°E)	Rain observed - not forecast (%)	Correctly forecast (%)	Rain was not observed but rain was forecast (%)	True skill score (TSS)
1	27.18	29.63	4.01	50.43	45.56	**0.2252**
2	27.12	29.85	4.01	50.29	45.7	**0.2256**
3	26.85	29.15	2.44	52.01	45.56	**0.291**
4	26.77	30.12	4.76	55.41	39.83	**0.2611**
5	26.37	28.93	2.88	48.08	49.04	**0.2424**
6	26.5	29.18	3.58	57.8	38.63	**0.3117**
7	26.28	30.2	3.43	50.43	46.14	**0.246**
8	28.6	28	3.58	49.21	47.21	**0.2201**
9	27.87	28.08	3.74	52.99	43.26	**0.2575**
10	27.2	28.58	4.13	47.94	47.94	**0.1973**
11	28.12	28.35	2.39	52.62	44.99	**0.2916**
Average			**3.54**	**51.56**	**44.9**	**0.2518**

as correct if rainfall occurs anywhere in the rainfall district. In the method employed here, rainfall has to occur at the specific station before it is considered to be correct. Remembering that time discrepancies exist between the forecast and the observation times, the hit rate results suggest that the forecast of rainfall is only some 50% reliable at any specific station in the Vaal Dam catchment.

Conclusions

The SAWS evaluated rainfall forecasts for 19 districts covering most of the country and found their forecasts to be reliable (Banitz, 2001). Choosing a relatively small area, such as the Vaal Dam catchment, and verifying the rainfall distribution classes gave a PCF of less than 50%. However the statistical results are clearly dependant on the chosen verification method and it is clear that no single verification measure provides complete information about the quality of a forecast (Stanski et al., 1989).

Considering the verification of the rainfall distribution classes, the best forecasts were made during the 1995/96-summer season. The best forecast classes were 'no-rain' and 'scattered rain'. It was also found that when a rain event was expected 'scattered rain' was the preferred forecast. Log-linear modelling identified the same trends. No trend in the accuracy of the forecasts could be detected in the data over the rather short study period.

The second hit rate method indicates that although a rain event was rarely missed (3%), rain was forecast close to 45% of the time when no rain was observed.

Widespread rain was forecast poorly with the PCF ranging between 12 and 25%. Widespread rain was observed close to double the number of times it was forecast and scattered rain is often forecast when widespread rain in fact occurred. One should consider that widespread rain occurred only 8.5% of the time. On average this is only 15 d per summer rainfall season. Due to the rareness of a widespread rain event it is probable that forecasters have less skill in identifying the systems responsible and locating geographical areas where widespread rainfall is likely. Areas of widespread rain often contain regions with heavy rain, which may cause flooding. It is therefore imperative that forecasting techniques are developed to aid the forecaster in identifying and accurately predicting this rain class.

Recommendation

Considering the many discrepancies between data and forecast periods as well as the meteorological factors, the results do indicate that forecasting methods used for identifying rainfall classes need to be re-examined. It is therefore recommended that an ongoing evaluation be initiated with timely feedback to the forecasters in order to assist in the improvement of rainfall forecasts.

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