NATURAL RESOURCES SYSTEMS PROGRAMME

FINAL TECHNICAL REPORT

DFID Project Number

R5981

Title

Estimation of rainfall in Namibia from meteosat infra-red imagery.

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Date

March 1996

NRSP Production System

High Potential

The citation for this report is:

Tucker, M.R. 1996. *Estimation of rainfallin Namibia from Meteosat infra-red imagery*. DFID NRSP Final Technical Report R5981: *Identification and monitoring of African weather regimes (Phases 1 and 2)*. Chatham, UK: Natural Resources Institute.

This is a report submitted to the UK Department for International Development's (DFID) Natural Resources Systems Programme (NRSP) to fulfil requirements under the research contract R5981. The views expressed are not necessarily those of DFID or NRSP.

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ESTIMATION OF RAINFALL IN NAMIBIA FROM METEOSAT INFRA-RED IMAGERY

(ODA funded project F0008)

A technical report by M R Tucker

March 1996

Summary

Daily rainfall and Meteosat cold-cloud duration images of Namibia were analysed for January and December 1993 and January and February 1994 to investigate the use of area-average data for estimating daily rainfall. Moderate to good correlations were obtained for area means for large regions and for Namibia as a whole. Correlations were generally much better than for individual stations averaged over time periods of up to 10-days. Correlations were lower in December than in January and February suggesting that deeper (colder) clouds are needed at the beginning of the season to produce rain. No clear pattern of spatial variation in correlation was found but calibrating individual pixels might provide an alternative to averaging to produce reasonable rainfall estimates. Some doubt is thrown on the validity of using 10-day CCD for estimating pixel rainfall values in Namibia.

Introduction

The use of Meteosat infra-red imagery to estimate rainfall over tropical land surfaces is a well established technique and the University of Reading, TAMSAT, rainfall estimation method, using 10-day cold-cloud duration, has been.the standard method used by NRI, in conjunction with LARST Meteosat receivers, for many years. Regressions of cold-cloud duration against rain-gauge data for a variety of temperature thresholds for a test period are used to select the optimum threshold and to estimate parameters for particular areas and months. These are then used to calculate 10-day rainfall for the forecast periods, the output consisting of maps showing estimated rainfall for each 5x5km Meteosat pixel (Milford & Dugdale 1989).

Some applications, such as river catchment runoff estimation, require daily rainfall estimation and ten-day totals are, therefore not suitable. The Bristol Centre for Remote Sensing use a variable threshold method to estimate daily rainfall, using climatic data, geographical coordinates and elevation to correct estimates based on daily cold-cloud duration (Todd *et al* 1995) .

As much of the Meteosat imagery being captured for rainfall estimation is being archived for a single cold-cloud temperature threshold, a need was identified to assess the value of single threshold estimates for daily rainfall estimation using area averages for regions of countries and individual river catchments. Walker *et al* (1995) compared daily cold-cloud duration images with daily raingauge rainfall for Namibia for the 1994-95 rainy season and for January to February 1994. The country was divided into five latitudinally-based regions. Correlation coefficients of CCD against rainfall generally decreased from north to south, from 0.86 for the northern border to 0.27 for the southern border. Means for smaller areas corresponding to individual river catchments were also compared and regression correlation coefficients of about 0.75 were obtained. It was concluded, from the limited sample, that estimates of mean river catchment rainfall, from Meteosat imagery had potential for managing water supplies.

The present work extends these analyses to include both 1993 and 1994 rainy seasons in Namibia. It compares rainfall/CCD relationships between months and seasons and for different methods of spatial and temporal averaging.

Data

Meteosat 24 hour cold cloud duration imagery covering the whole of Namibia was available for January 1993 and December 1993-March 1994. Images for 1992-1993 covered only the easternmost part of Namibia and were, therefore, not used. Most images were in IDA format and for a threshold of -40^{0}C. This threshold has been found to be best for the rainy season in Namibia and was used in Walker et al (1995). Images for February and March 1994 were in Autosat format. Problems were encountered in converting back from 8-bit IDA format to 16-bit Autosat format (because some of the header had been lost in the original Autosat to IDA conversion). As there was no problem converting Autosat images to IDA, it was decided to carry out all analyses in the IDA image processing package. Daily rainfall data for 99 rain gauge stations for the same months were available from the Namibia Meteorological Service,.as Lotus 123.format files. These were imported into an Excel 5 spreadsheet for comparison with CCD data.

Methods

Cold-cloud duration images were imported into IDA and were overlayed with a map file of Namibia raingauge stations. Within this file, rain gauge latitudes and longitudes were corrected to allow for parallax between high cloud tops and the ground caused by the slightly oblique Meteosat view angle using a formula provided by Dugdale (unpublished).

The statistics option in IDA was then used to create a file of mean pixel values for blocks of 1, 3x3 and 5x5 pixels around the corrected rain gauge location for 27 January 1993. As there was very little difference
between the 3 values for each station, it was decided to standardise on 3x3 pixels as used by Walker *et a1* (1995).For each image, statistic files were then calculated giving the mean of 9 pixels centred on the location of each raingauge. This allows for slight

location errors which might not have been covered by the parallax correction.

These files were converted to Excel format within the Excel spreadsheet and were compared with daily rainfall data using scatter plots and the correlation coefficient (R) and, if R was above 0.5, linear regression analysis, for a number of datasets.

The following datasets were compared to test what areal averaging would be necessary to obtain reasonable estimates of daily rainfall and to compare areal against temporal averaging:

a) January monthly rainfall data were compared for three years to enable results of comparisons between rainfall and CCD data to be assessed for both monthly and yearly variations.

b) Mean daily rainfall against mean daily CCD for the whole of Namibia to see if broad-scale changes in rainfall from day-to-day were reflected in CCD images.

c) Mean daily rainfall against mean daily CCD for five Namibian regions, as defined by Walker et *a1* (1995). These were:

i)	northern border	(17.0-18.5^{0}S) -	11 stations
ii)	north-central	(18.5-20.5^{0}S) - .30	"
iii)	central	(20.5-23.0^{o}S) - 34	"
iv)	south-central	(23.0-25.5^{0}S) - 12	"
v)	southern border	(25.5-28.5^{0}S) - 11	"

Given the small number of stations available for the southern areas and the low correlations found by Walker, south-central and southern border areas were combined for most analyses.

d) Daily rainfall against CCD for area averages broadly corresponding to river catchments. A methodology was available to average all pixels within defined polygons (or 'catchment areas') but it was decided to use the mean of the 3x3-pixel station values of raingauges within the catchment to provide data of the same kind as the rainfall, which was based on the mean of the same raingauges.

e) Individual station rainfall against 3x3-pixel CCD means for the same location for 1, 3,
5 and 10-day

periods for a sample of months. This was to compare area averaging against temporal averaging techniques.

NB As one of the main aims of Meteosat imagery was to distinguish raining from non-raining cloud, zero rainfall values were included in the analysis.

Results

Mean monthly rainfall for January in Namibia is about 88mm when averaged over all rain gauges, but data for 1993,1994 and 1995 show that there are very large variations between stations and between years with 1995 being extremely dry (mean monthly rainfall 8mm), 1994 wet (164mm) and 1993 intermediate (59mm) (Fig 1). In 1994 there was a significant decrease in rainfall towards the south but there was no apparent latitudinal trend in the other two years. Significant variations in the relationship between rainfall and CCD might, therefore be expected to occur between seasons. No analysis was carried out for January 1995 in this study and, in any case, the very low rainfall would make valid statistical analysis very difficult.

In January 1993 there was a good correlation of R=0.88 (N=31) between mean daily rainfall and mean daily CCb for all stations indicating a correspondence between days with rain and cold cloud for the whole of Namibia(Fig 2). The corresponding regression was RN = 1.1C + 0.54 (where RN is rainfall and C cold-cloud duration). However for forecasts to be useful it is necessary to define much smaller areas and Figures 3-8 show scatter plots and correlation coefficients for regions, as defined above, and for an area called 'Calibration 5' covering four small catchment areas in central Namibia. Surprisingly the highest correlation (R=0.92, N=31, RN = 2.6C + 0.8) was for the combined southern border and south-central area (the opposite result to that found by Walker for 1995). Other correlations were from 0.49 for the North Border to 0.78 for north-central Namibia (RN = 0.82C + 0.65). The correlation for the northern border increased to 0.6 when areas east of 20^0E (the Caprivi strip) were excluded. The Calibration5 area was very similar to the Central area both in the stations included and in the regression results (R=0.55, N=31., RN = 0.43C + 1.2). Area means, therefore, gave moderate prediction of daily rainfall from CCD but there was considerable variation in the slope of the regression line for different areas.

When plotted over time, January 1993 rainfall showed three distinct periods. From 2-10 January there were isolated heavy rainstorms but most stations were dry. From 11-22 January there was very little rain but from 25-31 January there was widespread heavy rain. CCD data were missing for 22-24 January. Monthly rainfall against monthly total CCD for each rain-gauge (N=99) produced no correlation (Fig 9) and nor did the period 2-10 January (Fig 10). There was a slight correlation for the wetter period, 25-31 January (R=0.48)(Fig 11) and this was increased by considering north-central Namibia only (R=0.57, N= 30) (Fig 12).

A similar range of correlations were obtained for the wetter January 1994 (Figs 13-20). In that year daily correlations were highest for central Namibia (and Calibration5) areas (R=0.82, N=31,.RN = 3.2C + 0.5)(Figs 15,19) and lowest for north-central Namibia (R=0.48, N=31, RN= 0.9C + 3.3)(Fig 14). The correlation for all Namibia stations was lower than 1993 (R=0.66, N=31, RN = 1.6C + 1.7) (Fig 17), apparently reflecting a wider scatter of daily rainfall totals in a wetter month. The facility within IDA to calculate area averages was tested (Fig 20). The results were very similar to those based on averages of 3-pixel means around stations but the rounding to whole CCD hours reduces the correlation slightly (R=0.80). A.ten-day total, for 21-31 January, for all Namibia stations gave a moderate correlation of R=0.8, N=99 (R N = 1.3C + 5.0)(Fig 18), much higher than. for a similar period in 1993.

Walker et a1 (1995) found poorer correlations between rainfall and CCD at the beginning of the rainy season. In the present study, correlations for area means for December 1993 were slightly lower than in the following January but, probably, not significantly so (Figs 21-24). The largest drop was for Central Namibia (from R=0.82 to R=0.62). The regression lines were very different with slopes ranging from 0.25 to 0.78, showing a gradual increase in rainfall with increasing cold cloud.When CCD and rainfall were compared for individual stations using 3-day means and 5 and 10-day totals there was no correlation whatever (Figs 25,26). This suggests that at the beginning of the rainy season cold cloud is frequently present in areas where there is little or no rain. However, over time, the variation in rainfall and cold cloud over the whole of Namibia follows a similar pattern (Fig 27).

In February 1994, mean area correlations between daily rainfall and CCD were high for 'all Namibia' means (R=0.86, N=28, RN = 1.89C + 0.79) and for north-central Namibia (R=0.85, N=28, RN = 1.26C + 0.86)(Figs 28,29) but very low for southern border/south-central Namibia (R=0.14). Central Namibia (R=0.75, N=28, RN = 2.46C + 1.18)(Fig 31) and northern border (R=0.57, N=28, RN = 0.57C + 1.85)(Fig 30) were intermediate. Again, correlations for ten-day periods were low varying from R=0.09 for 21-28 February to R=0.45 for 11-20 February.

March 1994 was very dry with a mean monthly rainfall of 13.4mm compared with a mean of 70.3mm. This was reflected in the daily cold-cloud duration images which showed very little cold cloud. The association of lack of rain with lack of cold-cloud was therefore good but did not provide a valid sample for parametric statistics. No further analysis was done on this month.

Discussion

Meteosat cold cloud duration using a single temperature threshold (-40^{0}C) has forecasting potential for estimating mean daily rainfall in Namibia for large areas (eg large river basins) but very little for precise point rainfall estimates even when 10-day periods are considered. Estimates for early in the rainy season (December) would probably be improved by using a -50^{0}C temperature threshold and this could be investigated for available data for December 1993. No systematic trend in correlations was found across Namibia and the decrease in correlation towards the southern border found by Walker et al (1995) was only found in one month.

The results throw some doubts on the accuracy of using the TAMSAT methodology for rainfall estimation in Namibia. The modified TAMSAT method for area averages (ARCS) is very similar to the area-averaging method used here, so is likely to be a major improvement over point estimation. Flitcroft et *al* (1989) have discussed the problems of relating point rainfall data to area estimations from satellite data.

The `Bristol' method, of using variable thresholds and calibrating each pixel separately using a multiple regression model, could be used to improve correlations with rainfall. However, considerably more information is must be included i.e. mean rain per rainday, latitude, longitude and elevation. The latter requires a digital elevation model. The amount of computer time needed would probably mean that for real time processing it would only be feasible to capture 2-hourly data and separate capturing and processing computers would be needed (as used by Bristol CRS).

S Walker has suggested (personal communication) that variations in correlation between different areas of Namibia are likely to reflect the relative importance of convective and frontal rainfall, with the latter occuring mainly in the south (but in the southern hemisphere winter). Investigation of synoptic weather regimes could explain some of the variability found over space and time. Further work using the southern Africa weather regimes database of Meteosat and weather forecasting model analyses might,therefore, enable methods for better estimation of rainfall in Namibia to be developed.

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Milford, J.R. & Dugdale G. (1989) Estimation of rainfall using geostationary satellite data. *In: Applications of Remote Sensing in Agriculture. Proceedings of the 48th easter Scholl in Agricultural Science, University of Nottingham, July 1989.* Butterworth, London.

Todd, M.C, Barrett,E.C. & Beaumont, M.J. (1995) Satellite identification of rain days over the upper Nile river basin using an optimum infrred rain/no-rain threshold temperature model. *Journal of Applied Meteorology* ***34:*** 2600-2611.

Walker,S, Dirske,S, van Langenhove,G, Sear,C. & Williams,J.(1995) Use of Meteosat cold cloud duration to improve water resource management in Namibia.

Figures

Fig.1. Monthly rainfall January 1993, January 1994, January 1995.

Fig.2. Mean daily rainfall v CCD Namibia, January 1993.

Fig.3. Mean daily rainfall v CCD, Calibration 5 area, central Namibia.

Fig.4. Mean daily rainfall v CCD, N border Namibia W of 20E, January 1993.

Fig-5. Mean daily rainfall v CCD, N border Namibia, January 1993.

Fig.6. Mean daily rainfall v CCD, N-central Namibia, January 1993.

Fig.7. Mean daily rainfall v CCD, central Namibia, January 1993.

Fig.8. Mean daily rainfall v CCD, S-S-Central Namibia, January 1993.

Fig.9e Monthly rainfall v total CCD for all Namibia stations, January 1993.

Fig.10. Namibia rainfall v CCD, 2-10 January 1993. Fig-11. Namibia rainfall v CCD, 25-31 January 1993. Fig.12. N-central Namibia rainfall v CCD, January 1993.

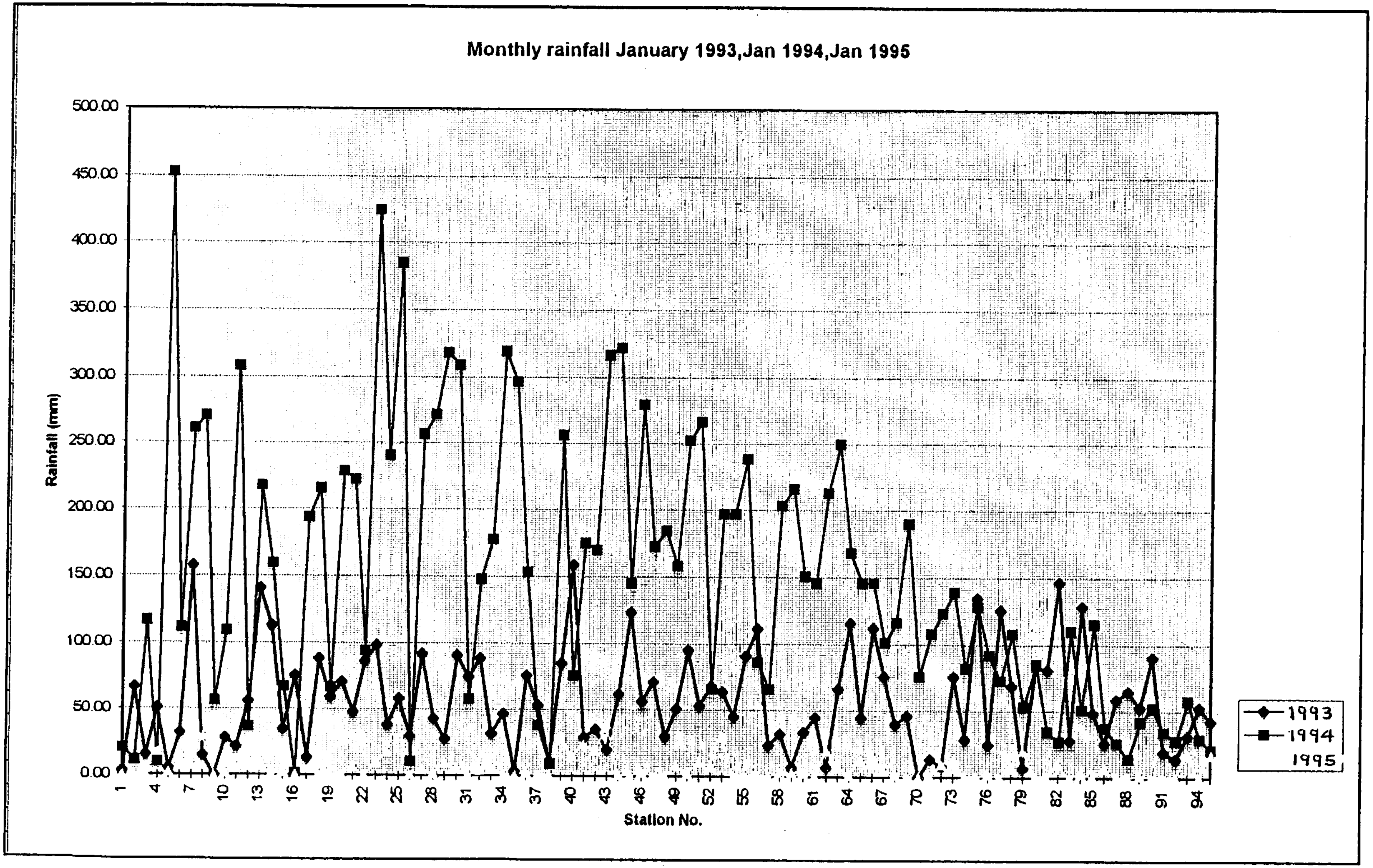
Fig.13. Mean daily rainfall v CCD, N border Namibia, January 1994.

Fig.14. Mean daily rainfall v CCD, N-central Namibia, January 1994.

Fig.15. Mean daily rainfall v CCD, central Namibia, January 1994.

Fig.16. Mean daily rainfall v CCD, S-central Namibia, January 1994.

Fig.17. Mean daily rainfall v CCD, Namibia, January 1994.


Monthly rainfall January 1993,Jan 1994,Jan 1995
Rainfall (mm)
500.00
450.00
400.00
350.00
300.00
250.00
200.00
150.00
100.00
50.00
0.00
1
4
7
10
13
16
19
22
25
28
31
34
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43
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55
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61
64
67
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73
76
79
82
85
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91
94
Station No.
1993
1994
1995

Fig.2. Mean daily rainfall v CCD Namibia Jan 1993 (R=0.88)

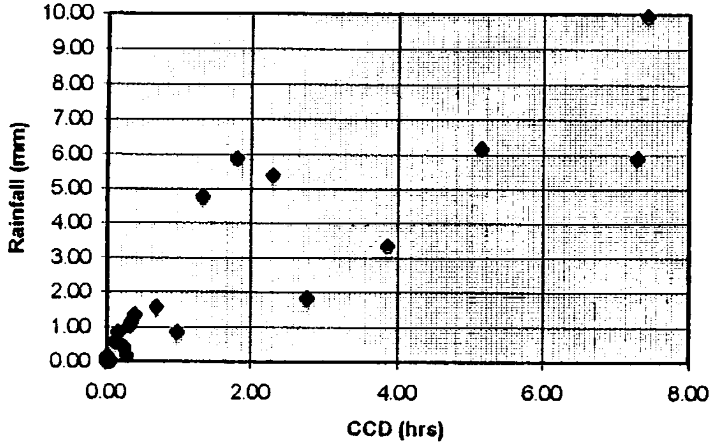


Fig. 3. Mean Daily rain v CCD Calibration5 area Central Namibia January 1993 (R=0.55)

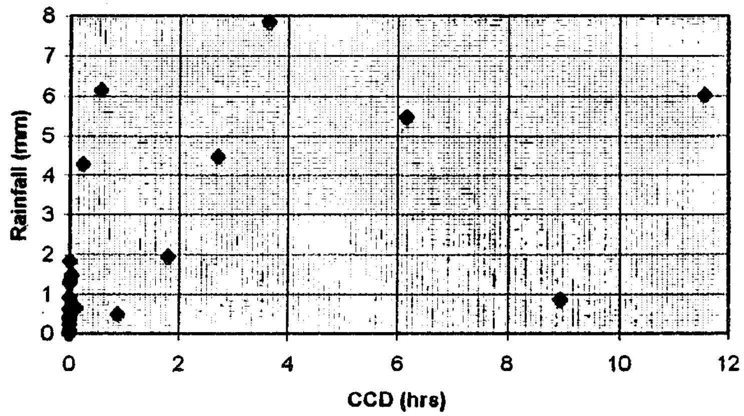


Fig.4. Mean daily rainfall v CCD N Border Namibia W of 20E Jan 1993 (R=0.6)

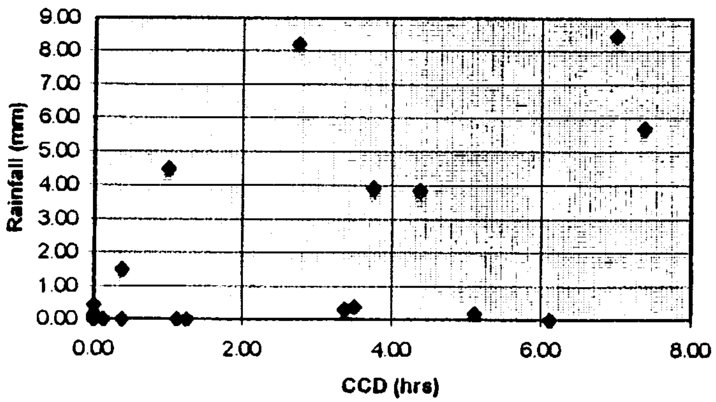


Fig. 5. Mean daily rainfall v CCD, N Border Namibia. January 1993 (R=0.49)

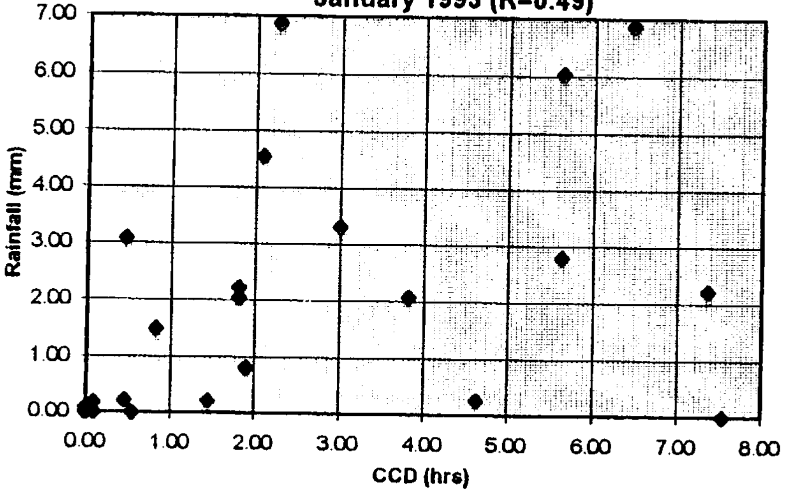


Fig. 6. Mean daily rainfall v CCD N-Central Namibia January 1993 (R=0.78)

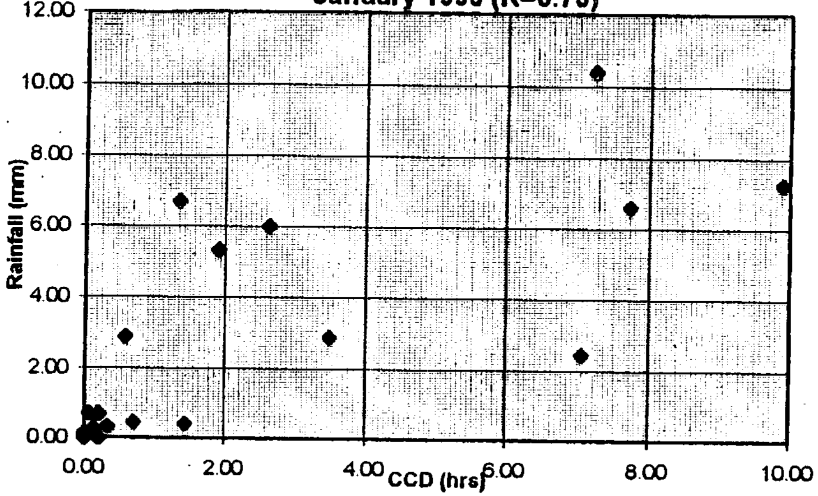


Fig.7. Mean daily rainfall v CCD Central Namibia January 1993 (R=0.65)

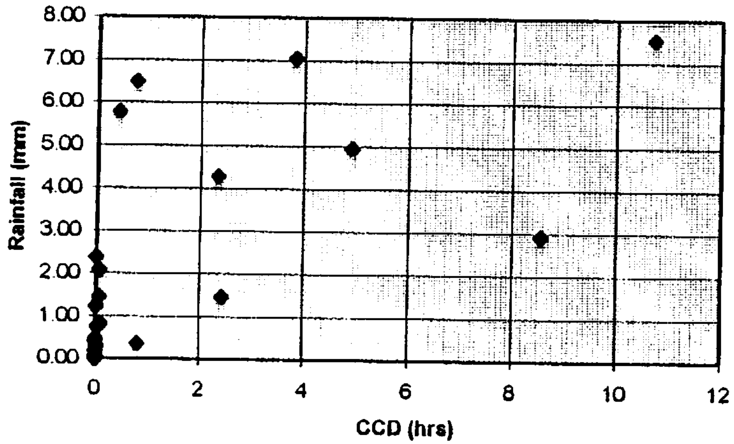


Fig. 8. Mean daily rainfall V CCD, S,S-Central Namibia January 1993 (r=0.92)

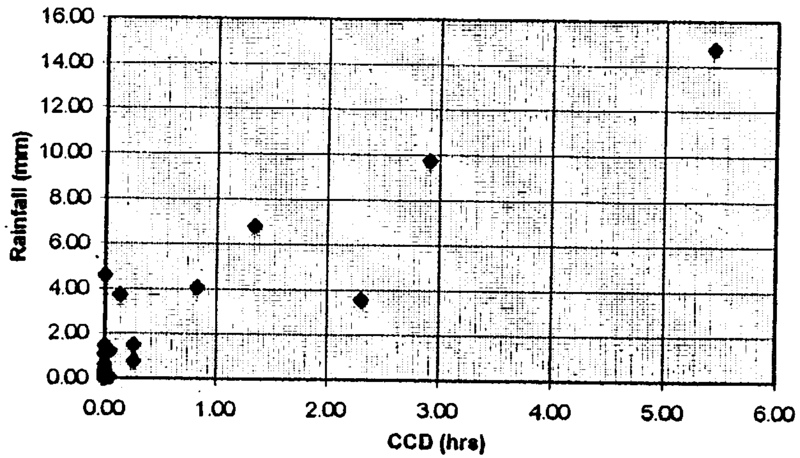


Fig.9. Monthly Rainfall v Total CCD for Namibia stations January 1993 (R=0.06)

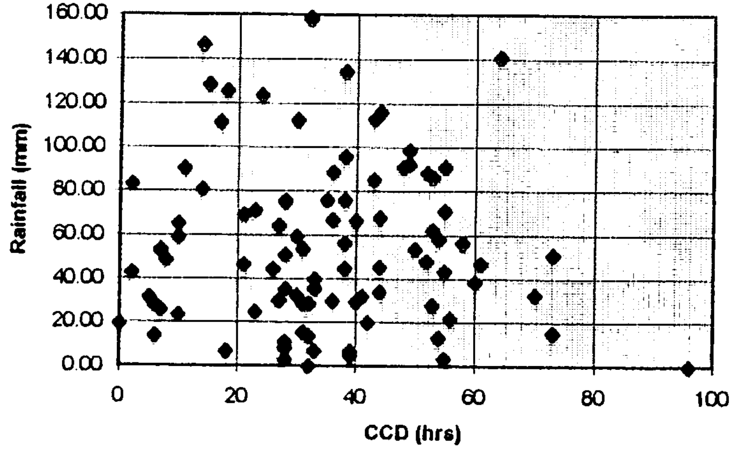


Fig. 10. 2-10 Jan 1993 Namibia Rainfall v CCD (R=0.18)

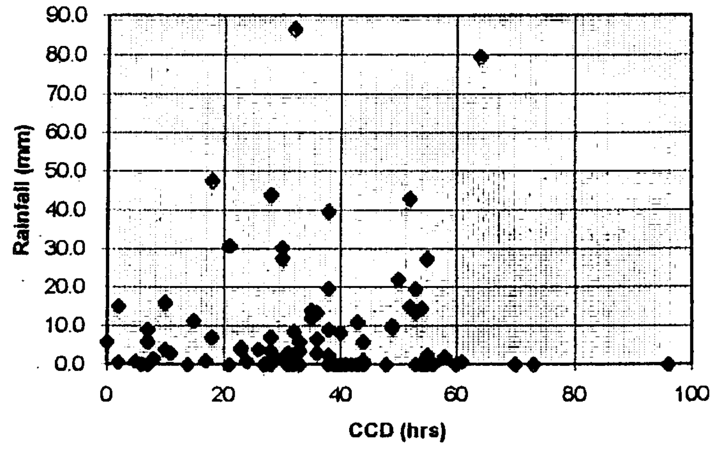


Fig.11. Namibia Rainfall v CCD, 25-31 January 1993 (R=0.48)

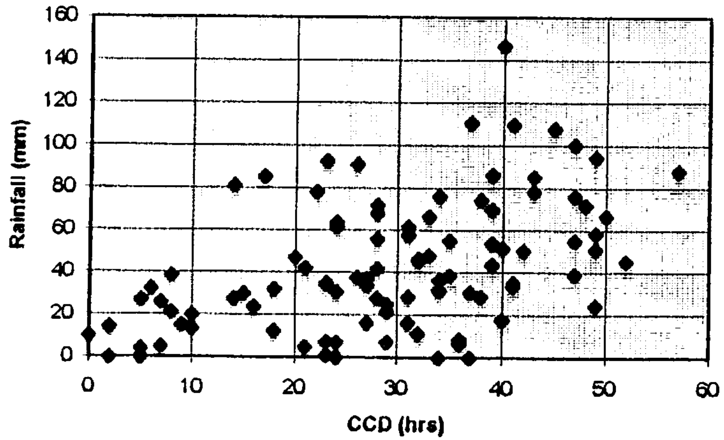


Fig. 12. N Central Namibia 25-31 January 1993 (R=0.57)

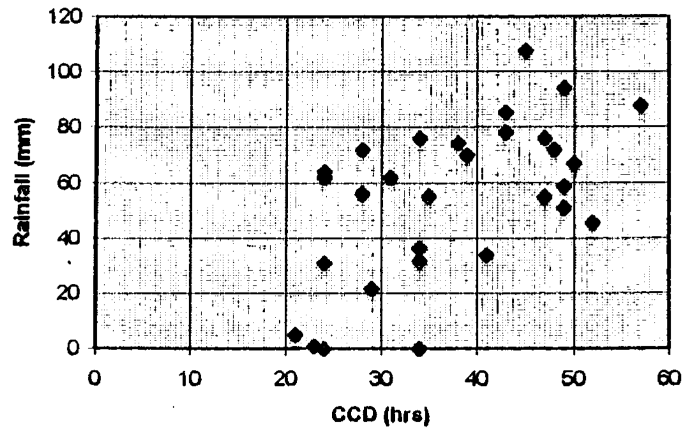


Fig. 13. Mean daily rainfall v CCD N Border Namibia January 1994 (R=0.62)

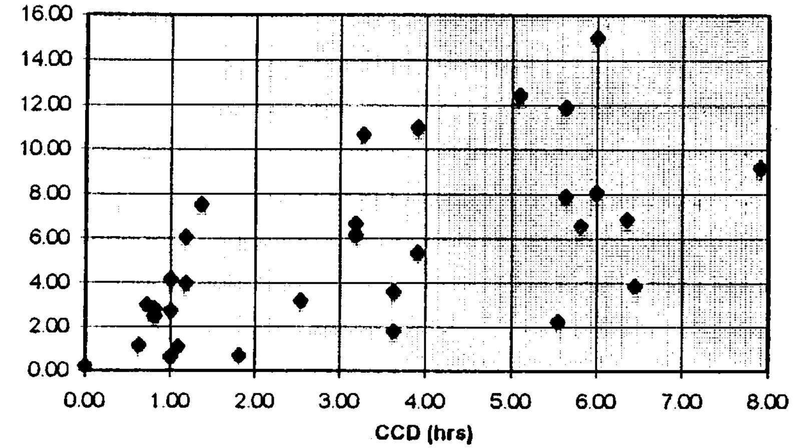


Fig. 14. Mean daily Rainfall v CCD, N-Central Namibia January 1994 (R=0.48)

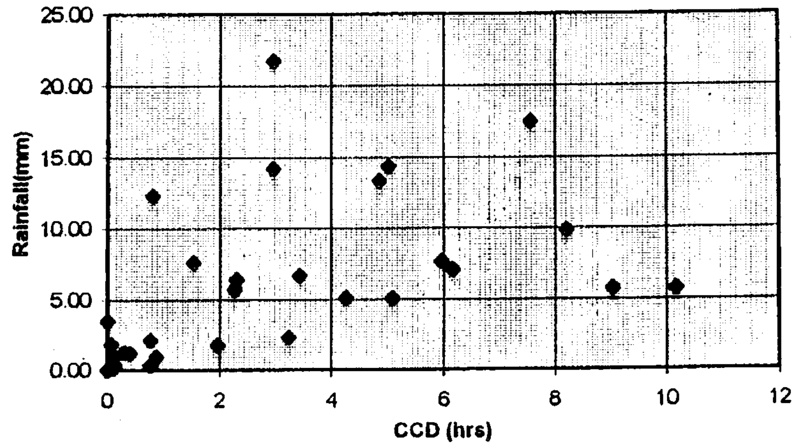


Fig. 15. Mean daily rainfall v CCD Central Namibia January 1994 (R=0.82)

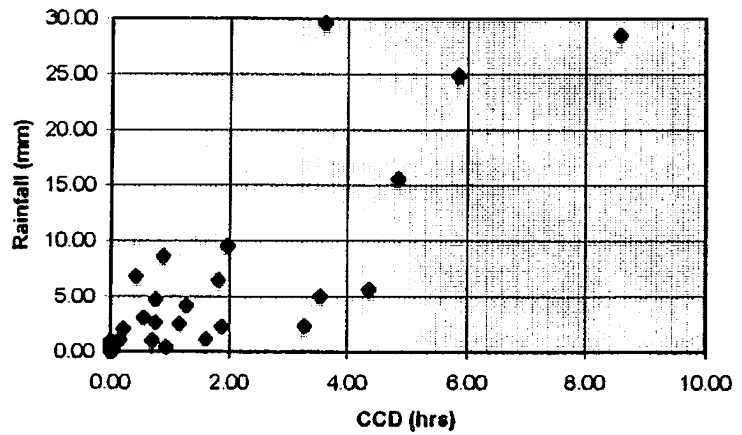


Fig. 16 Mean daily rainfall v CCD, S-Central Namibia January 1994 (R=0.73)

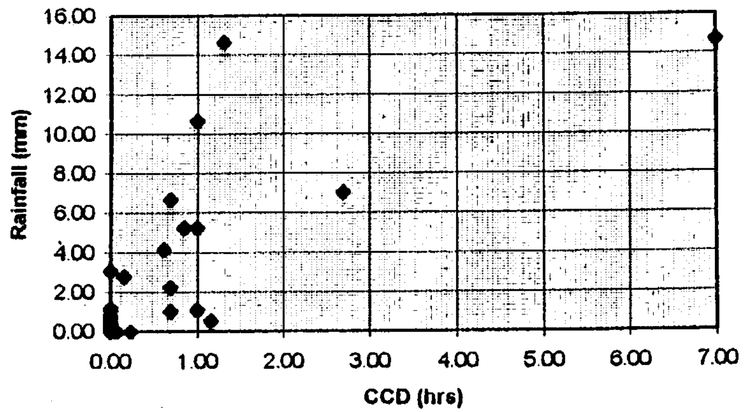


Fig. 17. Mean Daily Rainfall v CCD All Namibia, January 1994 (R=0.66)

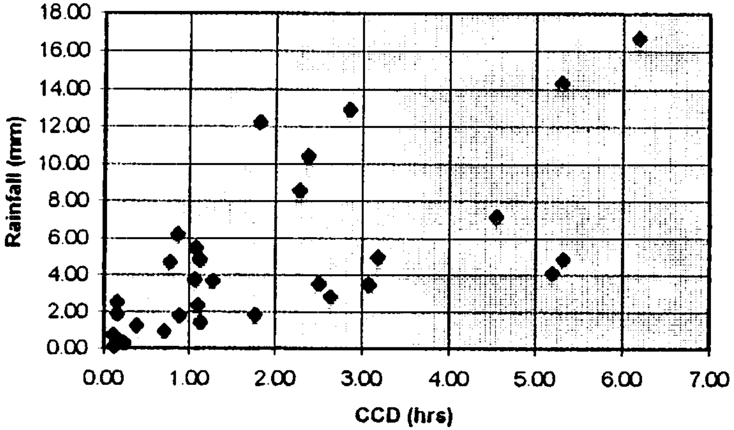


Fig.18. Mean Rainfall v CCD 21-31 January 1994 All Namibia (R=0.80)

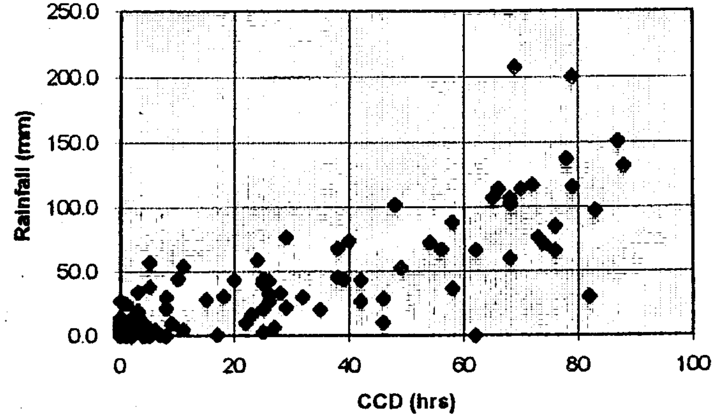


Fig. 19. Mean Daily Rain v CCD, Calibration 5 area, January 1994

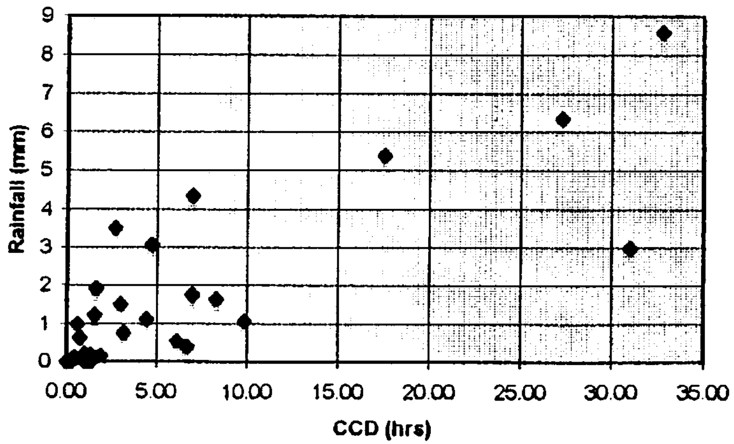


Fig.20. Mean daily rainfall v CCD, Calibration 5 area (IDA mean), January 1994 (R=0.80)

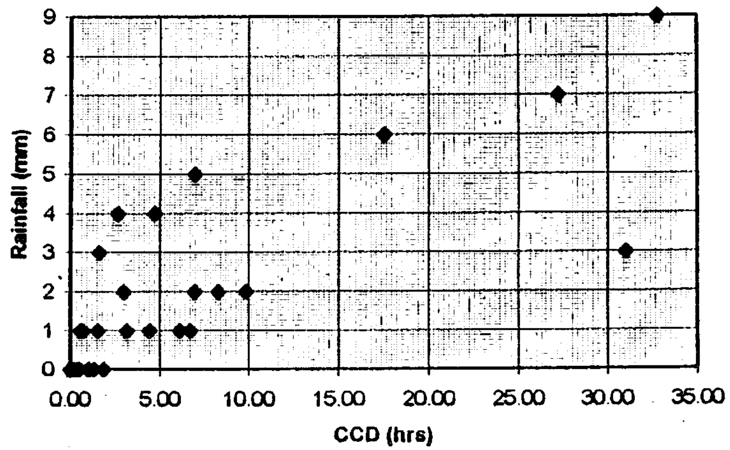


Fig 21. Mean Daily Rainfall v CCD, N Border Namibia December 1993 (R=0.57)

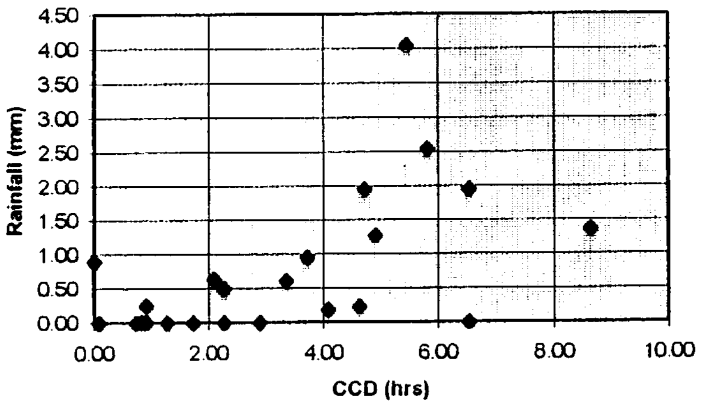


Fig.22. Daily Rainfall v CCD, N Central Namibia December 1993 (R=0.43)

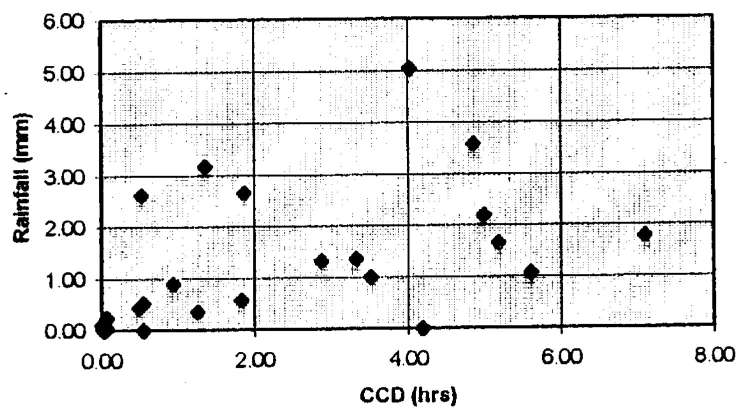


Fig.23. Daily rainfall v CCD, Central Namibia December 1993 (R=0.62)

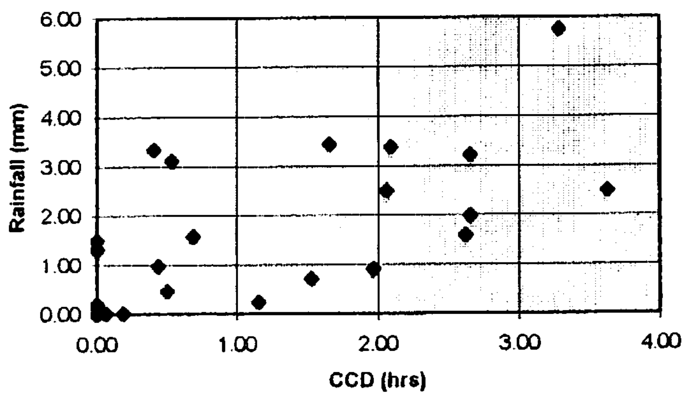


Fig. 24. Daily Rainfall v CCD All Namibia, December 1993 (R=0.61)

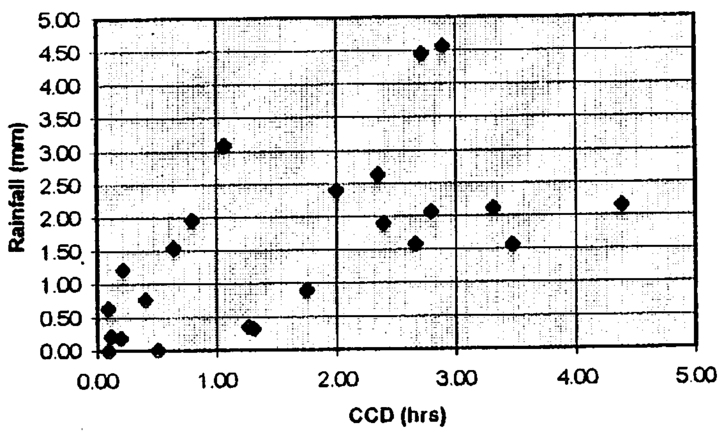


Fig.25. Total Rainfall v CCD 10-20/12/93, All Namibia (R=- 0.08)

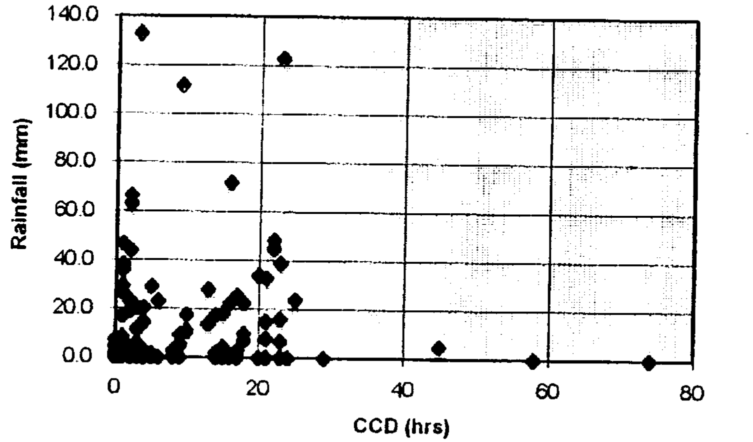


Fig. 27. Variation in Daily Rainfall and Daily CCD, All Namibia during December 1993

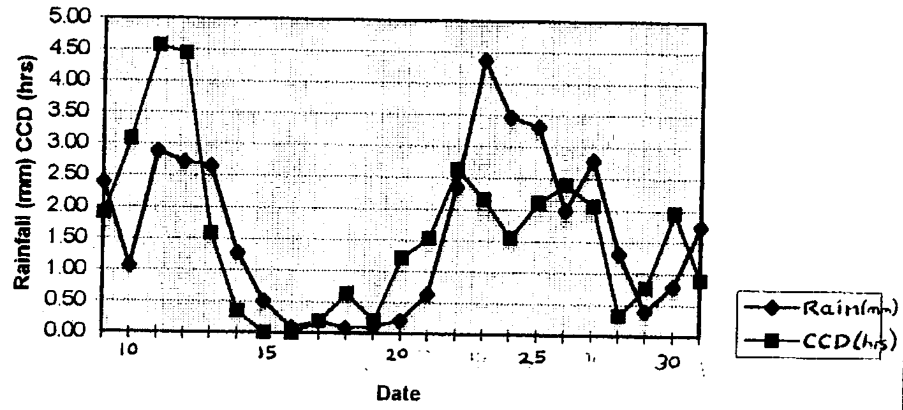
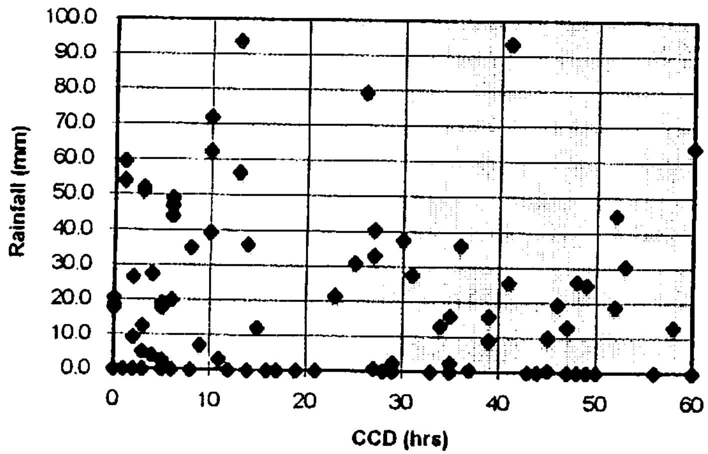


Fig.26. Total Rainfall v CCD 21-31/12/93, All Namibia (R= - 0.12)



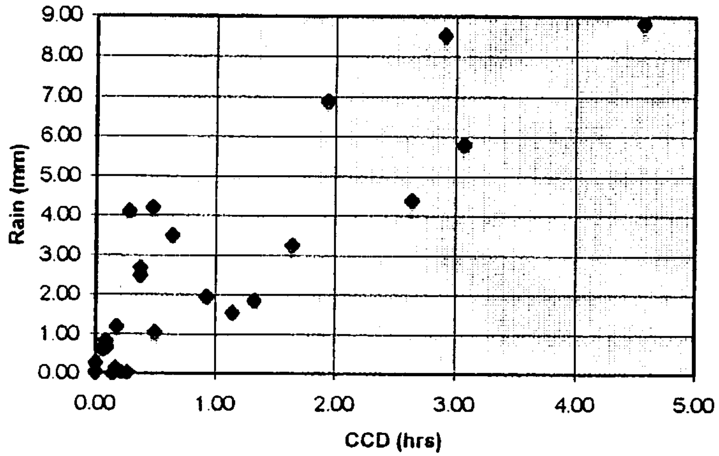


Fig.28. Mean Daily Rainfall v CCD, All Namibia February 1994 (R=0.86)

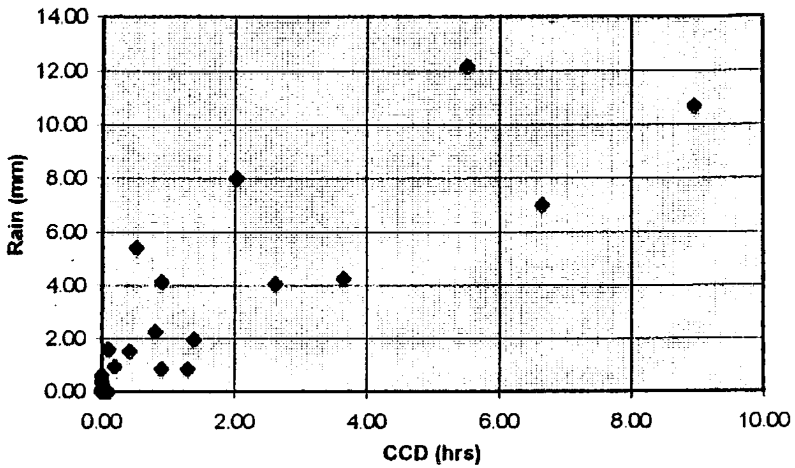


Fig.29. Mean Daily Rainfall v CCD, N Central Namibia February 1994 (R=0.85)

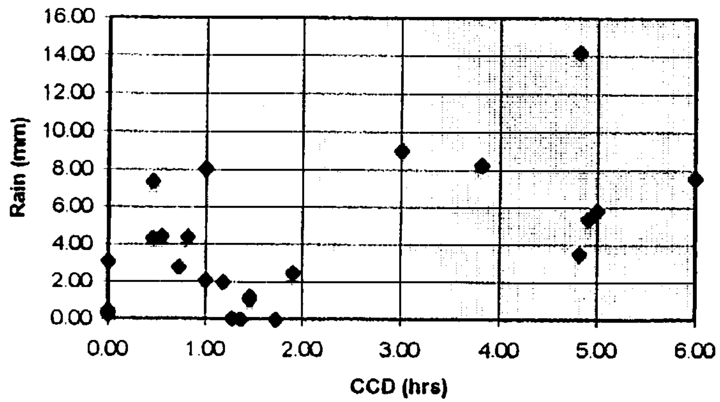


Fig. 30. Mean Daily Rainfall v CCD, N Border Namibia February 1994 (R=0.57)

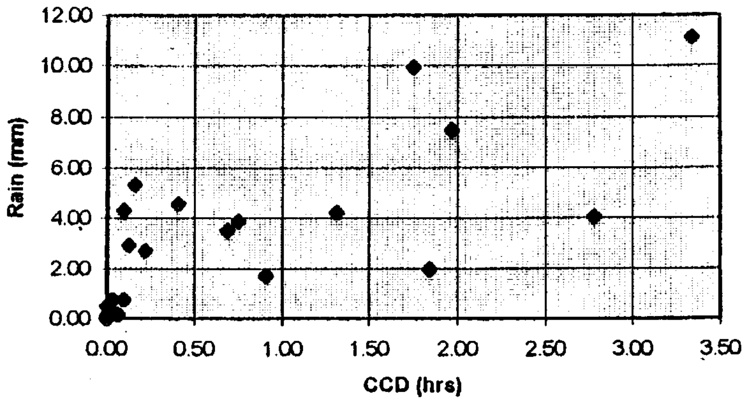


Fig.31. Mean Daily Rainfall v CCD, Central Namibia February 1994 (R=0.75)