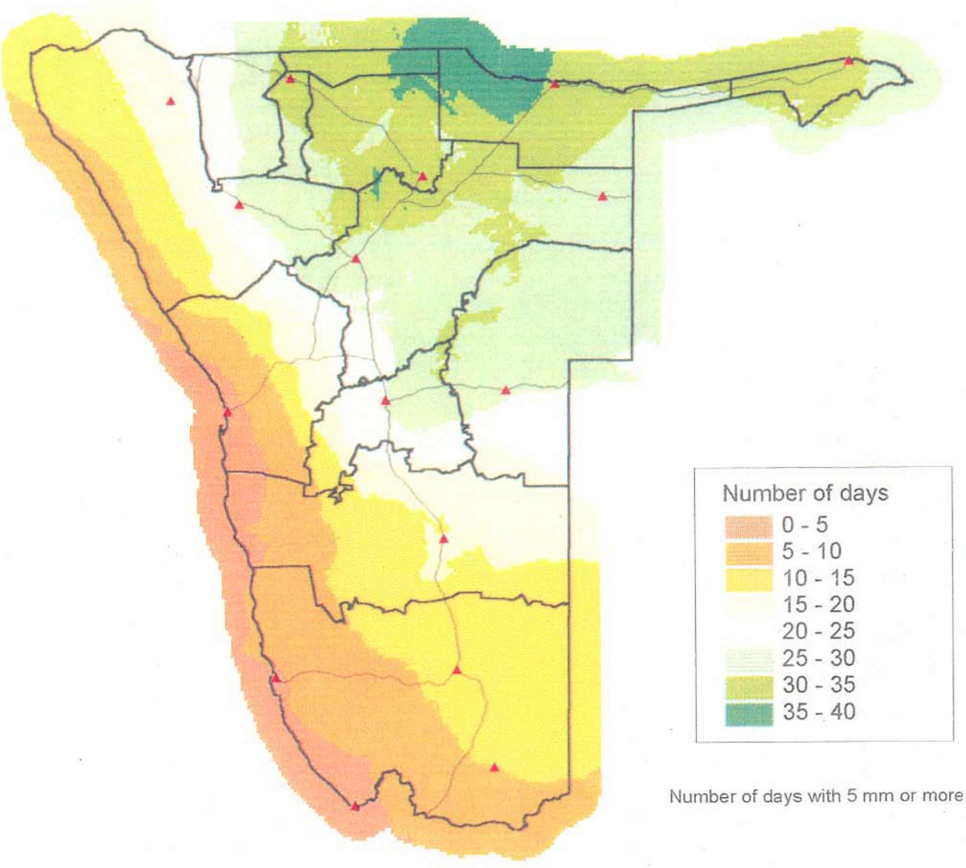
MINISTRY OF AGRICULTURE, WATER AND RURAL DEVELOPMENT

RAINFALL DISTRIBUTION IN NAMIBIA: DATA ANALYSIS AND MAPPING OF SPATIAL, TEMPORAL, AND SOUTHERN OSCILLATION INDEX ASPECTS

PHASE ONE REPORT

APRIL 1999



Number of days with 5 mm or more rain

PREPARED BY:

NAMIBIA RESOURCE CONSULTANTS
7 Hebenstreit Street
P.O. Box 11607
Klein Windhoek

Tel. 061 230679
Fax: 061 227406
E-mail: nrc@iwwn.com.na

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APPENDICES

Acknowledgements

Namibia Resource Consultants cc gratefully acknowledges the input of the following individuals and institutions towards the successful completion of this project:

- Dr. Louis du Pisani, former Chief; Namibian Meteorological Services, presently Agricultural Researcher, Directorate of Agricultural Research and Training, Ministry of Agriculture, Water & Rural Development
- Ms Marina Coetzee, Chief Agricultural Researcher, Directorate of Agricultural Research and Training, Ministry of Agriculture, Water & Rural Development
- Mr Nico de Klerk, Director; Agricultural Research and Training, Ministry of Agriculture, Water & Rural Development
- Mr Jan Brandt, Chief Research Technician, Ministry of Agriculture, Water & Rural Development

- Dr Peter Hutchinson, Head: Research & Remote Sensing Section, Namibian Meteorological Service
- Mr John Katjaita, Control Meteorological Technician, Namibian Meteorological Service
- Mr. Sepiso Mwangala, Meteorological Technician, Namibian Meteorological Service
- Mr Franz Uirab, Chief: Namibian Meteorological Service

- Mr Louis Botha, former employee of the Namibian Meteorological Service and currently Chief Technician, South African Weather Bureau
- Mr Rolf Mendelsohn, scholar son of the lead consultant

- Ministry of Agriculture, Water & Rural Development Project Steering Committee
- South African Weather Bureau
- Zambia Meteorological Office
- Botswana Meteorological Office.

Terms of Reference

The terms of reference for the project, which was awarded by the Ministry of Agriculture, Water Affairs and Rural Development (MAWRD) to Namibia Resource Consultants (NRC) in March 1998, are based on those contained in tender F1/18/1-18/97, and confirmed in a subsequent contract between the two parties.

The objectives are:

- To present rainfall data in a manner which will improve its contribution to drought policy and decision making
- To characterise the spatial and temporal variability of rainfall and how it relates to the concept of drought
- To supply a probabilistic model for forecasting rainfall based on correlations between historical rainfall and El Nino events
- To make recommendations on how rainfall data could be utilised in objective drought assessment and management
- To make recommendations on follow-up research and development work relating to –
    - (i) rainfall data
    - (ii) rangeland productivity modelling.

To achieve these objectives, the project should provide the set of statistics and maps set out in Appendix A.

The project was conceptualised in four phases over the period April 1998 to March 1999:

- Agreement between MAWRD and NRC on the Terms of Reference and methodology [phase 1a]
- Data acquisition and formatting [phase 1b]
- Rainfall characterisation and mapping [phase 1c]
- Reporting [phase 1d].

As a reliable start-up dataset was only acquired towards the end of September 1998, NRC addressed a written request in October 1998 to MAWRD to amend the due dates for deliverables relating to phases 1b, 1c and 1d. These were fixed in the contract as May 1998, November 1998, and February 1999 respectively. However, in view of MAWRD's fiscal constraints regarding financial year end, no extension was possible. NRC nevertheless undertook to use its best endeavours to deliver the product as close as possible to time deadlines.

As the project progressed, it became evident that the statistical analyses [Appendix A] envisaged in the original terms of reference did not fully reflect the outcomes expected by the various parties. A revised set of statistical analyses, and therefore also maps, was consequently agreed to at the MAWRD Project Steering Committee of 19 January 1999. These are attached as Appendix B.

Executive Summary

Background

The "Range production and drought forecasting model project - Subdivision: enumeration of rainfall data and correlation with rangeland productivity and El Nino phenomenon" was awarded to Namibia Resource Consultants (NRC) by the Ministry of Agriculture, Water Affairs and Rural Development (MAWRD) in March 1998, based on tender F1/18/1-18/97.

Objectives

The objectives of the consultancy are fully set out in the previous section on terms of reference. Essentially the emphasis in the first phase of the project was to characterise and depict the spatial and temporal distribution of rainfall in Namibia, and its relationship to the Southern Oscillation Index.

Approach and methods

(a) Acquisition of data

A large component of the project work comprised compiling a reliable and sufficiently extensive set of data on which to base the statistical analyses and mapping. This entailed gathering data from the Namibia Meteorological Service (NMS), as well as from countries bordering Namibia. It also required the purchase by MAWRD of a dataset compiled by a former employee of the NMS as part of his Master's degree research. NRC played an important role in concluding these negotiations successfully. The raw daily and monthly rainfall data gathered for the project form an important contract deliverable.

(b) Preparation of the dataset for the production of maps required

- The identification of duplicate data, and the selection of the best available data, in terms of criteria agreed on between MAWRD and NRC
- Agreement on the period of analysis, which was set at 1961 onwards

- *The interpolation of missing values, again according to criteria agreed on between MAWRD and NRC, and the de-selection of stations for which satisfactory interpolations could not be made*
- *The statistical analyses set out in Appendix B, using appropriate software*
- *Spatial interpolations using the Kriging extension for ArcView's Spatial Analyst module. All spatial data were re-projected into an Albers Equal Area metric projection with the following parameters: Bessel spheroid, standard and base parallel at 27 degrees South, 2nd parallel at 19 degrees South and the central meridian at 19 degrees East.*

The interpolated data, statistical analyses and other files used to generate the maps, together with explanations of their structure, form a second important deliverable for the contract.

c) Production of maps

ArcView was also used to generate the final maps, which form the third deliverable for the project. A variety of colour schemes and legends have been used to show how rainfall patterns vary across Namibia.

Results

The results of the statistical analyses undertaken, and the maps which reflect those results are presented as follows in the main report:

- *Introductory maps showing the spatial distribution of rainfall station records available to the project, as well as of those stations finally selected [maps 1-3]*
- *Annual rainfall [maps 4 - 9]*
- *Seasonal rainfall [maps 10 - 26]*
- *Monthly rainfall [maps 27 - 69]*
- *Daily rainfall [maps 70 - 102]*
- *Rainfall deficits [maps 103 - 107]*
- *Southern Oscillation Index relationships [maps 108 - 128].*

Explanatory text, written as far as possible in non-technical, jargon-free style to aid the possible future production of popular publications on rainfall and drought, precedes each grouping of maps, and forms the fourth deliverable.

Recommendations

This report provides a set of data, analyses and maps which can be used for many purposes.

The essential objective of the first phase, that is to characterise and depict the spatial and temporal distribution of rainfall in Namibia, and its relationship to the Southern Oscillation Index, has been achieved.

1. *Agricultural specialists should study this report, especially the statistical tables and maps, to agree on which measures of rainfall deficits would be most usefully incorporated into policies which spell out the Ministry of Agriculture, Water and Rural Development's response to the phenomenon of drought*

2. *The rainfall data assembled here should be used as one component in the production of a rangeland production model. Other components, on soils, vegetation types and vegetation structures, now need to be assembled.*

3. *NRC recommends that MAWRD proceeds with phase 2 of the project as soon as possible, as envisaged in its original call for consultancy proposals.*

4. *In Phase Two, the data compiled during this study could be used for a broad range of further analyses. For example, through popular publications, agriculturalists would gain an improved idea of when adequate rains for planting can be expected to have fallen, from*
    i. *measures of "effective rainfall", which can now be generated by calculating numbers of consecutive or closely-spaced days on which rain falls are recorded*
    ii. *cumulative total rainfalls, showing perhaps the average day of the summer by which totals of 50 or 100 mm et cetera have fallen*

iii. *measures of variation in cumulative rainfalls*

iv. *precipitation infiltration rates (i.e. effective moisture available for plant growth) and how these are affected by rate of fall and soil infiltration rate. This will in turn serve, inter alia, towards providing a better understanding of aridity and variation in rainfall, and aid officials to utilise the now available data for objective drought assessment and subsidy. It will also serve as an important parameter for the development of a predictive range production model for Namibia.*

5. *Phase Two information will further assist the MAWRD with drought policy establishment and how it should advise the Ministry of Lands, Resettlement and Rehabilitation (MLRR) regarding the proper and sustainable use of resettlement farms especially in terms of:*

   i. *dry-land arable farming*

   ii. *stocking rates*

   iii. *grazing rotations*

   iv. *dealing with endemic drought*

   v. *inter-region stock transference.*

6. *The information thus generated should be distributed (widely and gratis) to as large an audience as possible, utilising both semi-popular publications and posters. The key goal of these publications should be to provide, in a reader-friendly way, a good understanding of variation in rainfall and distribution, how little rainfall normally occurs in Namibia, and how to deal with this.*

List of acronyms

MAWRD	Ministry of Agriculture, Water and Rural Development
MLRR	Ministry of Lands, Resettlement and Rehabilitation
NMS	Namibia Meteorological Service
NRC	Namibia Resource Consultants
SOI	Southern Oscillation Index

List of maps

1. INTRODUCTION

1.1 Project Background

The "Range production and drought forecasting model project - Subdivision: enumeration of rainfall data and correlation with rangeland productivity and El Nino phenomenon" was awarded to Namibia Resource Consultants cc (NRC) by the Ministry of Agriculture, Water Affairs and Rural Development (MAWRD) in March 1998, based on tender F1/18/1-18/97.

The project is to be completed in four phases:

- Agreement between MAWRD and NRC on the Terms of Reference and methodology [phase 1a]
- Data acquisition and formatting [phase 1b]
- Rainfall characterisation and mapping [phase 1c]
- Reporting [phase 1d].

Objectives

The objectives as set out in the terms of reference are

- To present rainfall data in a manner which will improve its contribution to drought policy and decision making
- To characterise the spatial and temporal variability of rainfall and how it relates to the concept of drought
- To supply a probabilistic model for forecasting rainfall based on correlation between historical rainfall and El Nino events
- To make recommendations on how rainfall data could be utilised in objective drought assessment and management
- To make recommendations on follow-up research and development work relating to –
  (i) rainfall data
  (ii) rangeland productivity modelling.

The terms of reference and methodology were agreed between MAWRD and NRC during a meeting held for that purpose in March 1998 [phase 1a]. As the project progressed, it became evident that the statistical analyses [Appendix A] envisaged in the original terms of reference did not fully reflect the outcomes expected by the various parties. A revised set of statistical analyses, and therefore also maps, was consequently agreed to at the Project Steering Committee of 19 January 1999. These are attached as Appendix B.

The original statistical analyses and maps required from the project, and the amended list subsequently agreed on between MAWRD and NRC, are set out in Appendices A and B.

Reporting

A first report on phases 1a and 1b was submitted in January 1999, followed by the final dataset, in Excel format, of

- monthly data from 275 Namibian stations and 163 stations from neighbouring countries
- Daily data from 145 Namibian stations and 5 stations from neighbouring countries.

  (All of these data are raw, in the sense that they have not been patched by the project team. Missing values are coded as –99999; and)

- ArcView GIS database for all stations.

This present report concerns phases 1c and 1d of the project, which were in effect completed simultaneously. It also represents the completion of phase one of the project as a whole, and thus includes, and supercedes, the phase 1a and 1b report of January 1999.

1.2 Approach to the Study

The approach to, and methods used during the study are fully set out in paragraph two, and the results, their presentation and interpretation is discussed in paragraph three. Paragraph four contains recommendations arising from this report, and paragraph five considers Phase 2 of the project.

1.3 Staffing

The NRC team for the project comprised:

- Dr John Mendelsohn of RAISON, who as lead consultant, undertook client liaison on technical issues, built the datasets used in the study, undertook the statistical analyses, selected the mapping and presentation methods, interpreted the results, and provided team leadership

- Ms Sally Harper of NRC, who co-ordinated the project, undertook data acquisition and formatting, basic GIS work, report compilation and editing

- Mr Rod Davis of NRC, who undertook project administration and management

- Mr Tony Robertson, who was subcontracted to assist with statistical analyses, map layouts, supervision of GIS work and report-writing

- Dr Louis du Pisani, adviser based in South Africa, who provided advice on the design of the project, sources of data and statistical methodology.

2. METHODS

2.1 Data acquisition

2.1.1 Data from other countries

To place Namibian rainfall in a regional context, the following data from selected surrounding countries were either purchased or acquired:

- **South Africa**: monthly rainfall records from 23 stations in the northern Cape closest to the South African/Namibia border
- **Zambia**: daily rainfall records for 5 stations as supplied by the Director, Zambia Meteorological Department
- **Botswana**: monthly rainfall records for 27 stations as supplied by the Director, Botswana Meteorological Services Department
- **Angola**: As no recent data are available, data from 103 stations which are already available in Namibia from the Global Historical Climate Network database, were utilised.

2.1.2 Data from Meteorological Services, Namibia

The original assumption of both MAWRD and NRC was that rainfall data available at the Namibian Meteorological Services (NMS) of the Ministry of Works, Transport & Communication - a party external to the contract between MAWRD and NRC - would form the primary data set for the analyses and mapping required by the project. An initial examination undertaken by NRC however showed that *at that time*, the gaps in the data available were serious enough to place the required level of confidence in the analysis results in doubt. This finding was agreed to by NMS as well.

2.1.3 Data from Mr Louis Botha

As required by the contract, this potential obstacle to the successful completion of the project was reported to MAWRD in April 1998. A Project Steering Committee, comprising representatives from MAWRD, NRC, and NMS was formed both to address this problem, and oversee the project generally. It was agreed in April 1998 that MAWRD should acquire the "Botha" data set for the project. It was also agreed that the project team would assemble and analyse data for the period 1961 onwards.

The "Botha" data set was generated by a former employee of the NMS who subsequently left Namibia to take up a position in the Pretoria office of the South African Weather Bureau. All parties agreed that this dataset [used as the basis for Mr Botha's thesis] was suitable for the project because it was both relatively complete and accurate. In addition, the interpolations done by Mr Botha in cases where data were missing, added to the data set's value.

Acquisition of the data involved telephonic discussions between NRC project team members and Mr Botha, an on-site visit in May 1998 by Dr. Hutchinson and Ms. Coetzee of NMS and MAWRD respectively to view the data, and subsequent extended negotiations between MAWRD and Mr Botha as to an appropriate purchase price, conditions of purchase, and delivery format. NRC played a key role in these negotiations, the outcome of which has undoubtedly been of benefit to all parties.

The "Botha" dataset was only finally received towards the end of September 1998. It covers the period 1960/61 to 1989/90, and comprises:

- Patched monthly data for 276 stations, 1961-1990
- Corrected daily and ten-day data for 94 stations, 1961-1990.

2.1.4 The updated NMS dataset

At the time of project initiation, the NMS was already engaged in computerising the daily rainfall records of selected stations. In November 1998, NRC agreed, in the interests of the project, to make available at NRC expense, a data typist to complement this process. Much of the data typist's work consisted of adding data for the 1990's to daily data provided by Mr. Botha.

2.1.5 Summary of data sources

In summary then, the dataset with which phase 1c of the project commenced, comprised data originating from:

- Meteorological Services: daily and monthly records
- Mr. Louis Botha: daily and monthly records
- South African Weather Bureau: monthly records for stations near Namibia's southern border
- Zambia Meteorological Office: daily and monthly records
- Botswana Meteorological Office: monthly records
- Angola: monthly records.

2.2 Preparation of the final data set for statistical analyses and mapping

2.2.1 Duplicate records

Once combined, some of these records duplicated one another. In these cases, the following rules were applied by the project team, in close co-operation with MAWRD staff, to select data for the final set:

- NMS daily data were selected in preference to any other source
- Monthly totals generated from NMS daily data were selected in preference to any available monthly totals.

2.2.2 Period of analysis

It was agreed during the early stages of the project that most emphasis would be placed on collecting and analysing rainfall data that reflected the most recent climatic conditions in Namibia. In addition, rainfall records for recent years are more complete than those for earlier decades in this century. It was also agreed that the data set collected, processed and, in some cases, interpolated by L. Botha would form the basis of the data to be assembled. The set of data available from L. Botha spanned the period January 1961 to December 1990.

With the data from L. Botha as a foundation, additional rainfall data were obtained from the updating programme of the Namibian Meteorological Services described in paragraph 2.1.4. Most of these data were for the period 1991 onwards. As a result, data analysed during this study were restricted to records starting from January 1961 onwards.

While analyses were restricted to data from 1961 onwards, data for earlier years were assembled for some rainfall stations. These data are included in the files of raw data for daily and monthly rainfall records.

2.2.3 Coding of stations

Microsoft's Excel spreadsheet facility was used for raw rainfall data storage. The first column, or field, in each spreadsheet used, is called "MAIN_CODE", and lists the code unique to each station. This field is also used to link different files or sets of data together. The complete list of all main codes, station names, and latitude and longitude co-ordinates is available in the file "all stations.dbf" while the subset of main codes, station names and co-ordinated for stations used for mapped analyses is listed in "mapped stations. dbf". Both files are part of ArcView spatial datasets. The selection of stations used for mapped analyses is explained below.

2.2.4 Interpolation of missing values, and selection of stations for analyses

Discussions were held in February between members of the project team and Dr Louis du Pisani of the MAWRD to obtain agreement on how to select final data, and to deal with missing data.

The following criteria for selecting stations were agreed on

- Data prior to 1961 would not be used for analyses
- There should be 27 or more years of data for each station from 1961 onwards
- Within those two parameters, stations with 25% and more missing data were discarded, unless there were good reasons to retain them, such as that the missing data would be easy to interpolate, or the station record gave information not readily available elsewhere.

Guidelines for "patching" missing data were:

- Only data from 1961 to 1990 was patched
- Data were not to be patched for periods before or after the main period for which rainfall was recorded at a station
- Missing values in stations were patched, even if they were close to complete data stations, to obtain a more robust data set
- If interpolated values/ratios did not seem reasonable, the median was used as a last resort.

Apart from the above guidelines, project team members also applied the following rules to interpolate missing data in stations which qualified for retention in terms of the agreed-on guidelines.

(a) Selection of station from which to interpolate data for the incomplete station:

Wherever possible, the "donor" station was

- Topographically similar, and as close as possible to the station to be patched
- Had complete data for the period 1961-1990, or alternatively not less than 27 years data.

(b) Interpolation method:

- The ratio of rainfall of the "receiving" station to the "donor" station was established by calculating the average rainfall of each and then dividing the "receiving" station's average by the "donor" station average
- The ratio obtained was multiplied by the rainfall [for the relevant month] in the "donor" station to obtain an interpolated figure for the "receiving" station
- No interpolations were done from stations themselves containing interpolated data.

Some exceptions were made:

- Figures for a station were sometimes interpolated from two to three different nearby stations in order to obtain a record by which to multiply the obtained ratio, Steinkopf is an example

- If the required value was also missing in the only suitable "donor" station, the median value for the "receiving" station was substituted instead

- In some cases, the stations being patched did not themselves meet the 27 year criterion, but were retained to create a more robust data set. A further problem was that within stations covering a 27 year period, up to four monthly values were missing. This meant that in some cases, interpolations from a suitable "donor" station were done from as few as 24 monthly values. Masese interpolated values for October and November are examples, as is Oshakati, the records for which cover 1967-1990, that is 24 values. However up to 4 monthly values were missing; meaning that interpolations were done on 20 values only. Where the number of values available for interpolation fell below 20, the station was eliminated. An example is Kavimba, where available records covered 1970-1990, and within that period, one or two values were missing. Other stations eliminated because satisfactory interpolations could not be done, were Kalkfontein, Alexander Bay and Kavimba airport.

All interpolated figures have been marked in red in the data file "Agmet interpolated data.xls", which also shows the year and month, as well as the station from which the interpolated figure was obtained.

2.3 Statistical analyses

Most analyses of raw monthly and daily data were done using Microsoft Excel, such that averages, standard deviations, and totals were calculated using this programme's pivot table utility. Percentiles were calculated using SPSS, while the Visual Basic facility in Microsoft's Access was used to calculate running totals to provide measures of the frequency of "drought" months for each station. Access was also used to organise and extract the data required to assess relationships between Southern Oscillation Index (SOI) phases and rainfall during the consecutive three month periods.

Appendix D lists the files of statistical analyses produced during this study. Most of the fields were linked to spatial data files to produce interpolated patterns of rainfall variation. Some fields were not used for mapping but have been included for purposes of further analysis. Appendix D also provides explanations for all field names used in the statistical files.

2.4 Spatial interpolations

Using the 293 and 133 stations for which adequate monthly and daily data, respectively, were available, interpolations were generated using ArcView. The interpolated area was masked to a buffered zone 50 kilometres around the borders of Namibia. Cell sizes were set to 5 x 5 kilometres so as to allow reasonable resolution yet ensure that sets of data were not unnecessarily large.

Interpolations were done using the Kriging extension written by Marco Boeringa (available from www.esri.com) for ArcView's Spatial Analyst module. Various Kriging models were tested. A linear model (with sill) was adopted, using a 50 000 metre lag distance to estimate the variance for the production of semivariograms to account for the variance.

All spatial data were re-projected into an Albers Equal Area metric projection with the following parameters: Bessel spheroid, standard and base parallel at 27 degrees South, 2nd parallel at 19 degrees South and the central meridian at 19 degrees East.

The interpolated data are available in a series of ArcView grid files listed in Appendix C and provided on a compact disc.

2.5 Map production

The interpolated maps for this report were printed using ArcView on a modest ink-jet printer. The improved quality maps which would be required for publication for example, could be produced using a higher resolution printer. The digital maps could also be imported into high-quality graphics programmes (e.g. Adobe Illustrator, Corel, Freehand) which would provide better control over colours and text.

2.5.1 Legends

A variety of legends has been used to show how rainfall patterns vary across Namibia. Some colour schemes, for example, light to dark blue, were selected to show that some areas receive more rain than others. For other parameters (such as variance) colour gradations were selected to disaggregate the ranges from the lowest to the highest values.

Ranges of values were usually divided into 10 classes, with equal class intervals. For example, there are 10 classes used to show the range of rainfall values in the higher rainfall summer months: 0-15, 10-30, 30-45, ...135-150 millimetres. Each class is shown as a separate colour.

One legend with fixed class intervals and identical colour scheme was used for each group of thematically similar maps. The same legend was thus used for the seven average rainfall maps for each of the seven higher rainfall months (October-April). All 10 classes and colours are shown in the legends for those months having up to 150 millimetres, but only the lower classes of colours and intervals are shown on maps for those months having lower rainfall totals. The map for average total rainfall in October thus only shows two classes: 0-15 and 15-30 millimetres. The colours used for these two classes are the same as those appearing on other maps where a higher range of classes is shown.

The legend files used are described in paragraph 3.7.

3. RESULTS

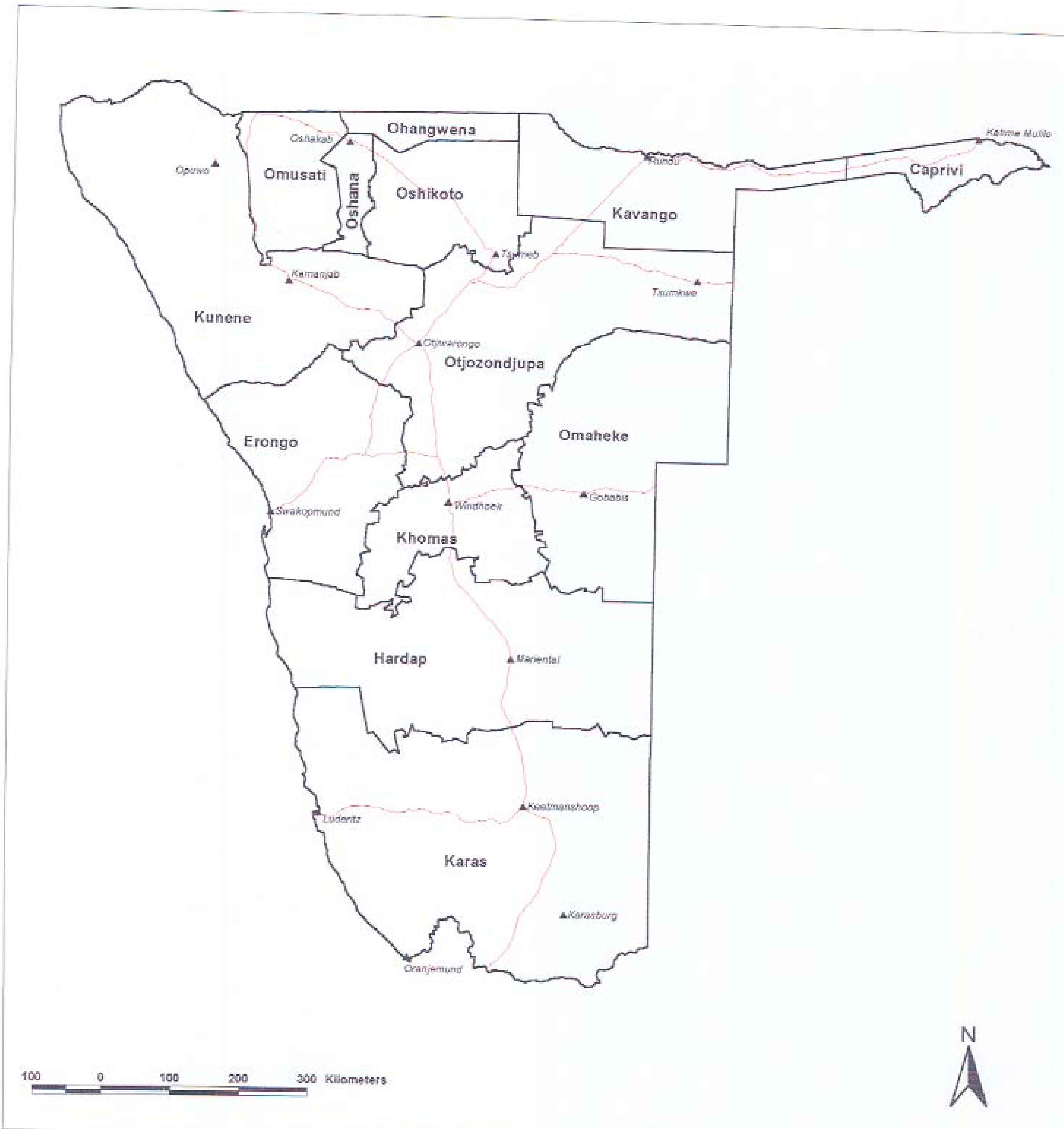
The results of the statistical analyses undertaken, and the maps which reflect those results have been grouped for presentation and discussion as follows:

- Introductory maps [maps 1-3]
- Annual rainfall [maps 4 - 9]
- Seasonal rainfall [maps 10 - 26]
- Monthly rainfall [maps 27 - 69]
- Daily rainfall [maps 70 - 102]
- Rainfall deficits [maps 103 - 107]
- Southern Oscillation Index relationships [maps 108 - 128].
- Data and production of maps

INTRODUCTORY MAPS

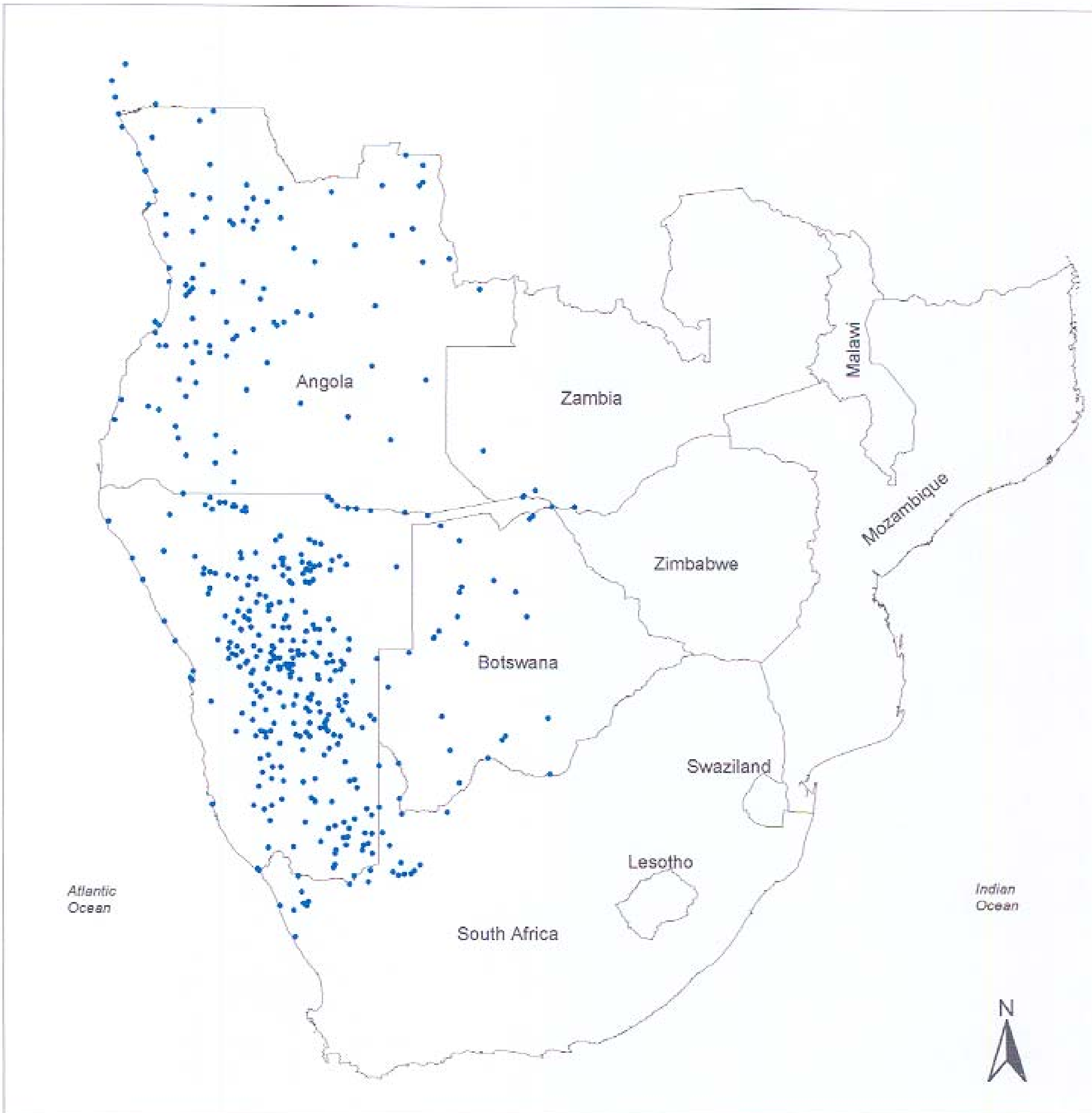
Map 1 shows Namibia's regions, major towns and major roads. **Map 2** shows the initial set of stations for which data was available (438, of which 275 are in Namibia), and **map 3** the subset of stations used for final analyses and mapping (293).

Map 1
Map of Namibia showing regions, major towns and major roads

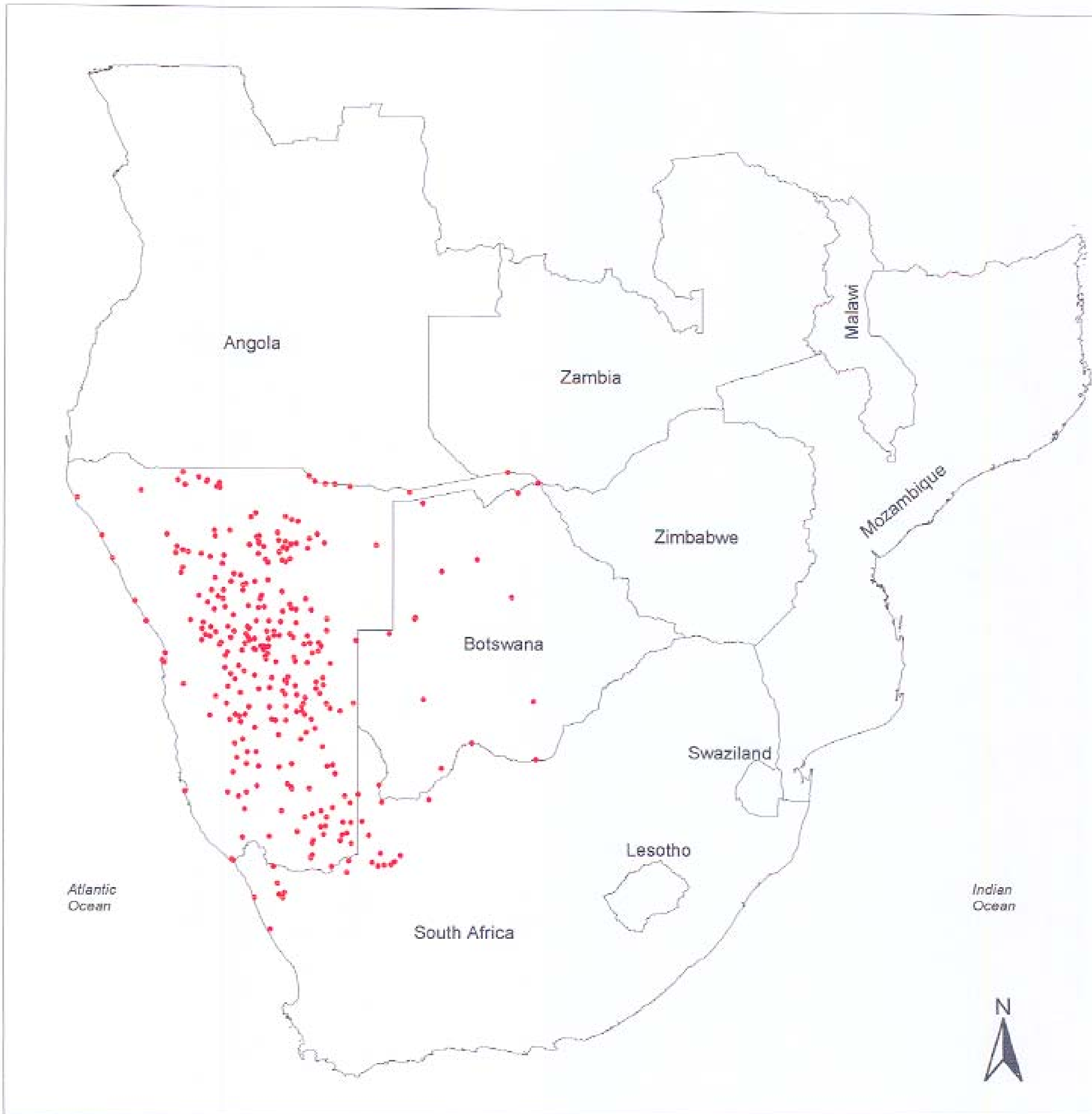


Map 2

Spatial distribution of stations for which rainfall data was available



Map 3
Spatial distribution of stations used in final analyses and mapping



3.1 ANNUAL RAINFALL (maps 4-9)

Average Rainfall

Average annual rainfall **(map 4)** is the best known measure of rainfall, one that is widely quoted and depicted on maps. The statistic is calculated by summing all the rain measured in different years and dividing that total by the number of years for which data were recorded.

The map of average annual rainfall confirms the well-known pattern in Namibia, showing that the highest total rainfalls are in the north-east, and the lowest in the west and southern third of the country. Areas in and around the Karas mountains in the south and the Otavi mountains near Tsumeb and Grootfontein receive more rain because of the higher topographic relief.

To most people, average rainfall figures are values representing those amounts of rain that can be expected in "normal" years, leading to the view that any deviation from the average represents an "abnormal" condition. However, rainfall averages are often skewed or distorted by those few years when very large amounts of rain are recorded. For example, a particular location may usually receive 300-400 mm of rain each year but the average annual rainfall will be skewed upwards by the few years in which perhaps 500, 600 or 700 mm are recorded.

Median Rainfall

Median annual rainfall **(map 5)** provides a better measure of the amount of rainfall that can be expected normally. The median is the value that represents the mid-point between the driest and wettest years. Let us assume that rainfall records exist for 30 years at a particular location. Those records can be arranged in rank order ranging from the driest year to the year with the highest recorded total. The median is that value of total annual rainfall that separates the first 15 or driest years from the remaining 15 years with higher totals.

Median total rainfall is usually somewhat lower than average annual rainfall because it is not as skewed by the effects of a few years with abnormally high falls. The degree to which average rainfall is higher than median rainfall is shown in **map 6**, where the difference is expressed as a percentage of the median. By far the greatest differences are in the central and northern coastal belt and in the Namib. This is because unusually high falls lead to distorted averages, while much lower medians reflect the almost negligible amounts of rain received in most years. Differences between averages and medians in the south of Namibia range between 15 and 30% in most areas. The north-eastern half of the country has similar average and median measures of rainfall, averages being less than 10% higher than the median.

Upper and Lower Terciles Rainfall

Following the concept that the median represents the mid-point between equal numbers of the driest and wettest years, we can also estimate the value of total annual rainfall that represents the cut-off between the driest 33% or third of all years and the remaining two-thirds having higher falls. **Map 7** shows the upper value of annual total rainfall that fell in the driest 33% of all years. By way of example, if rain has been recorded at one location for 30 years and 250 mm or less rain fell in the ten driest of those 30 years, 250 mm would be the 33rd percentile for that station. Percentiles provide a way of ranking a range of values into groups. When ranges are ranked and grouped into three groups, each group is called a tercile.

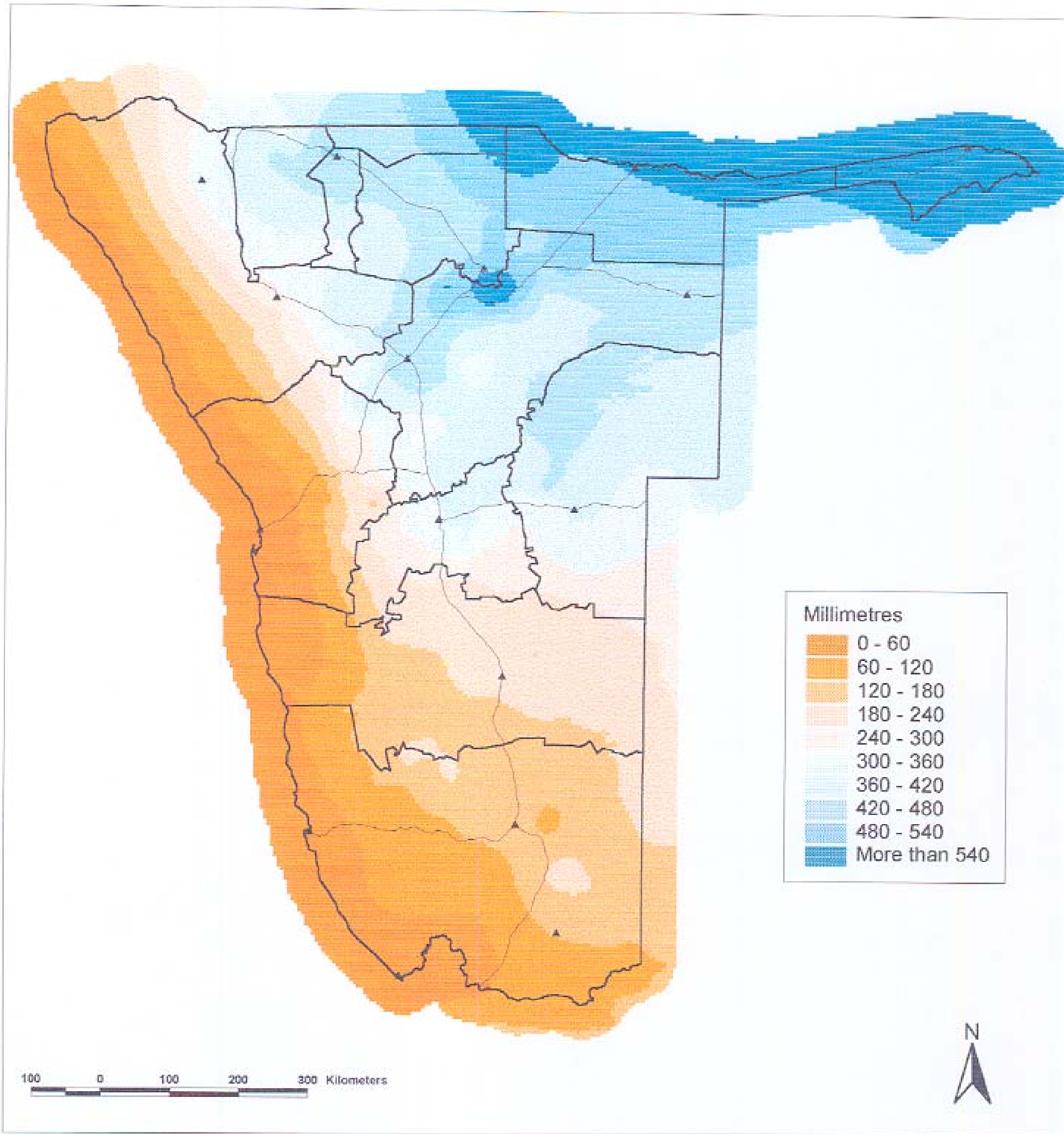
Map 8 is the converse of map 7. It shows values of total annual rainfall that form the lower limit to the wettest 33% of years. Thus, rainfalls of these values or more were recorded in the wettest third of all years. Because these values, or percentiles, are calculated by ranking total rainfalls from the lowest to the highest, the values in map 8 are the 67th percentile or the highest tercile.

Variability in Rainfall

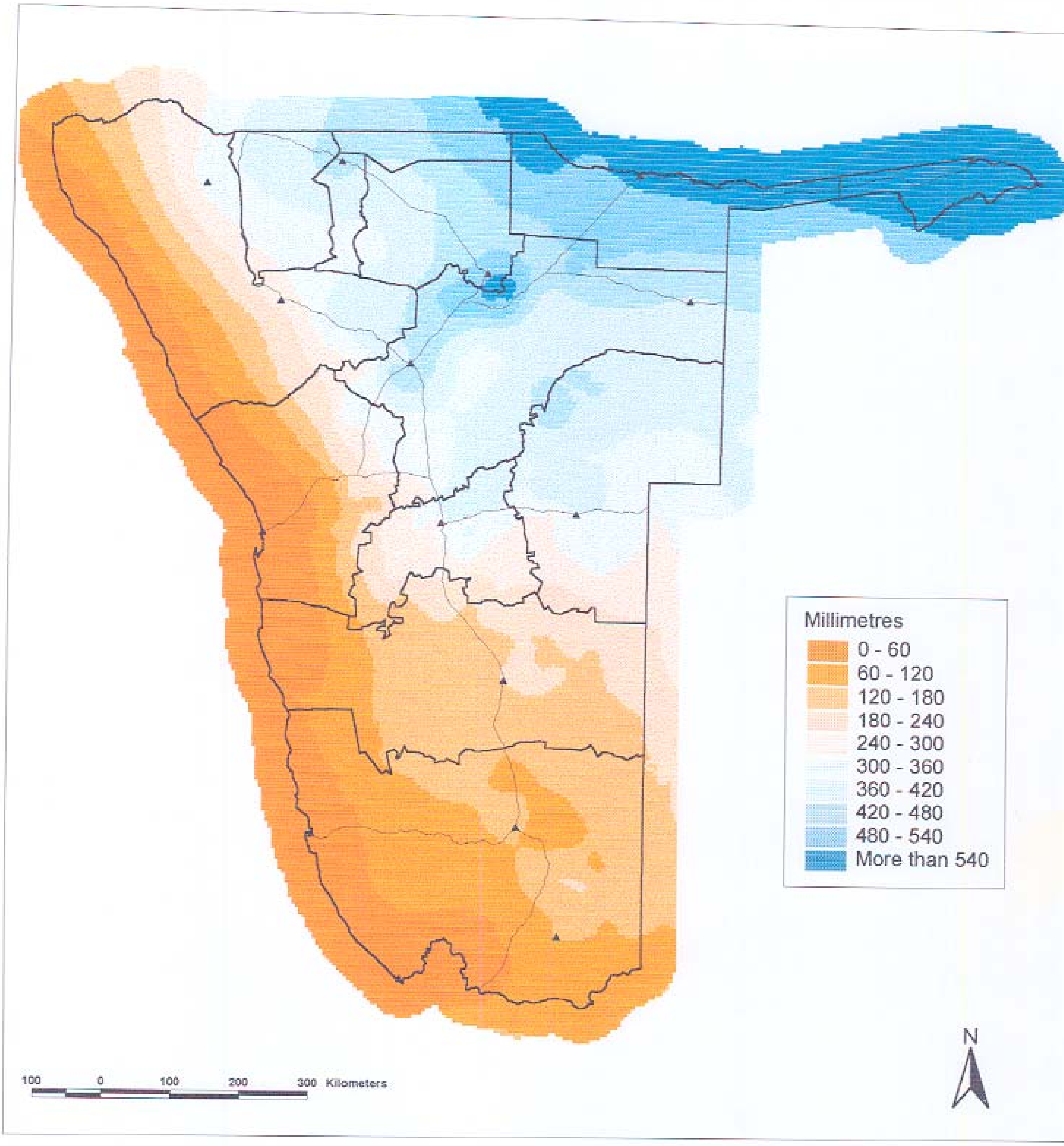
A high degree of variation characterises rainfall in Namibia more than any other feature, yet variability is one of the most difficult concepts to portray. One measure is the coefficient of variation in annual total rainfall (Map 9). The coefficient is calculated as the standard deviation as a percentage of annual average rainfall. A coefficient of variation of 50% thus means that the standard deviation is half of the annual average. But what is a standard deviation? Assume that a place has an annual average of 300 mm with a standard deviation of 150 mm, and therefore a coefficient of variation of 50%. The standard deviation is a measure that indicates that 33% of all years had a total rainfall of 300-150 mm and another 33% of years had total falls of 300+150 mm. This means that annual falls were between 150 and 450 mm in 67% or two-thirds of all years. Additional complexities arise when annual rainfalls are not distributed normally in a statistical sense, but those complexities are beyond the scope of this account.

From this example, it is easy to see that those areas with the highest coefficients of variation have the most variable rainfalls. Areas in southern and western Namibia where annual averages are 100 mm or less have coefficients of variation of 65% and more. This means that in two-thirds of all years we can expect rainfall of between 50 and 150 mm at best.

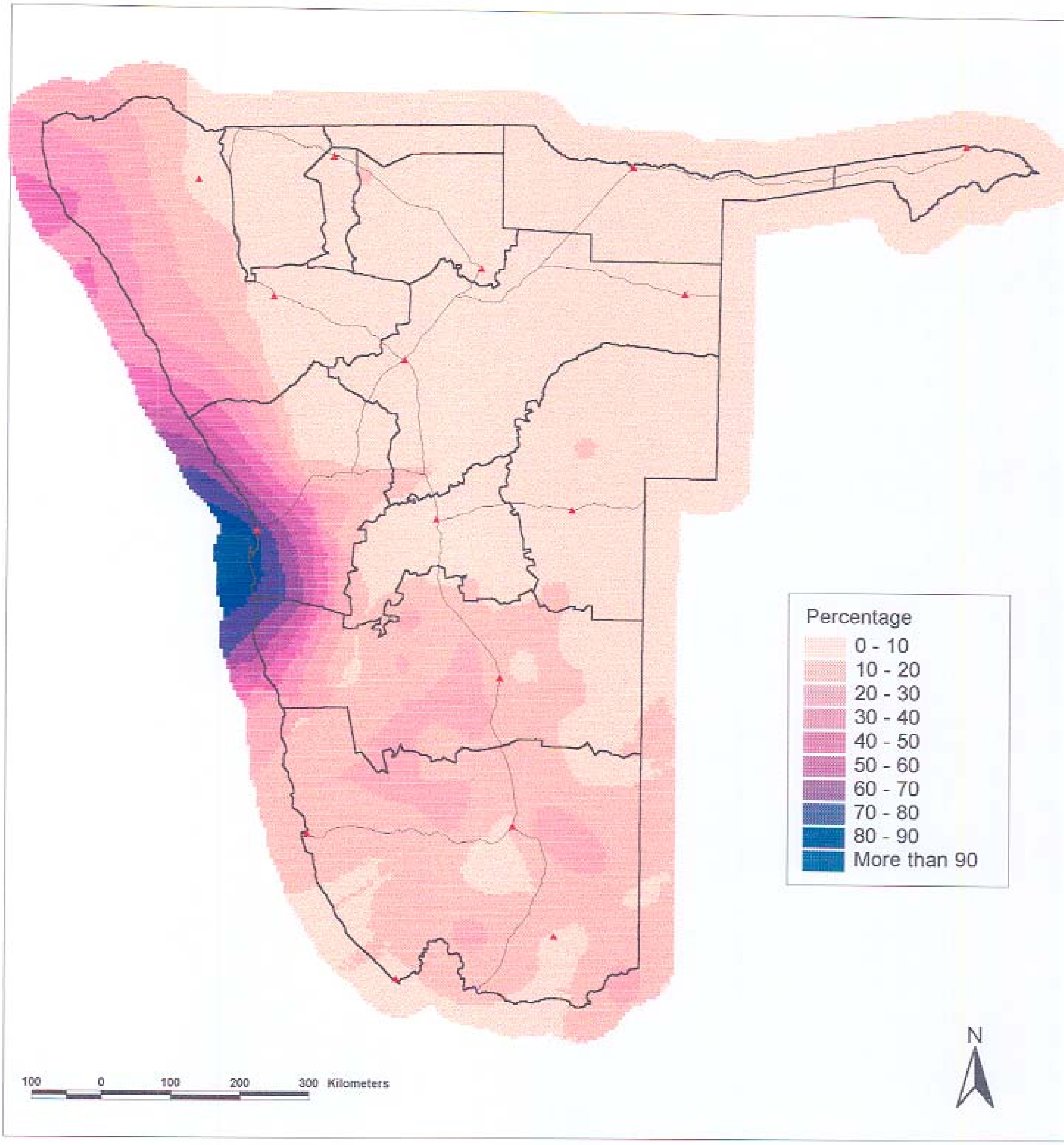
Map 4
Average annual rainfall



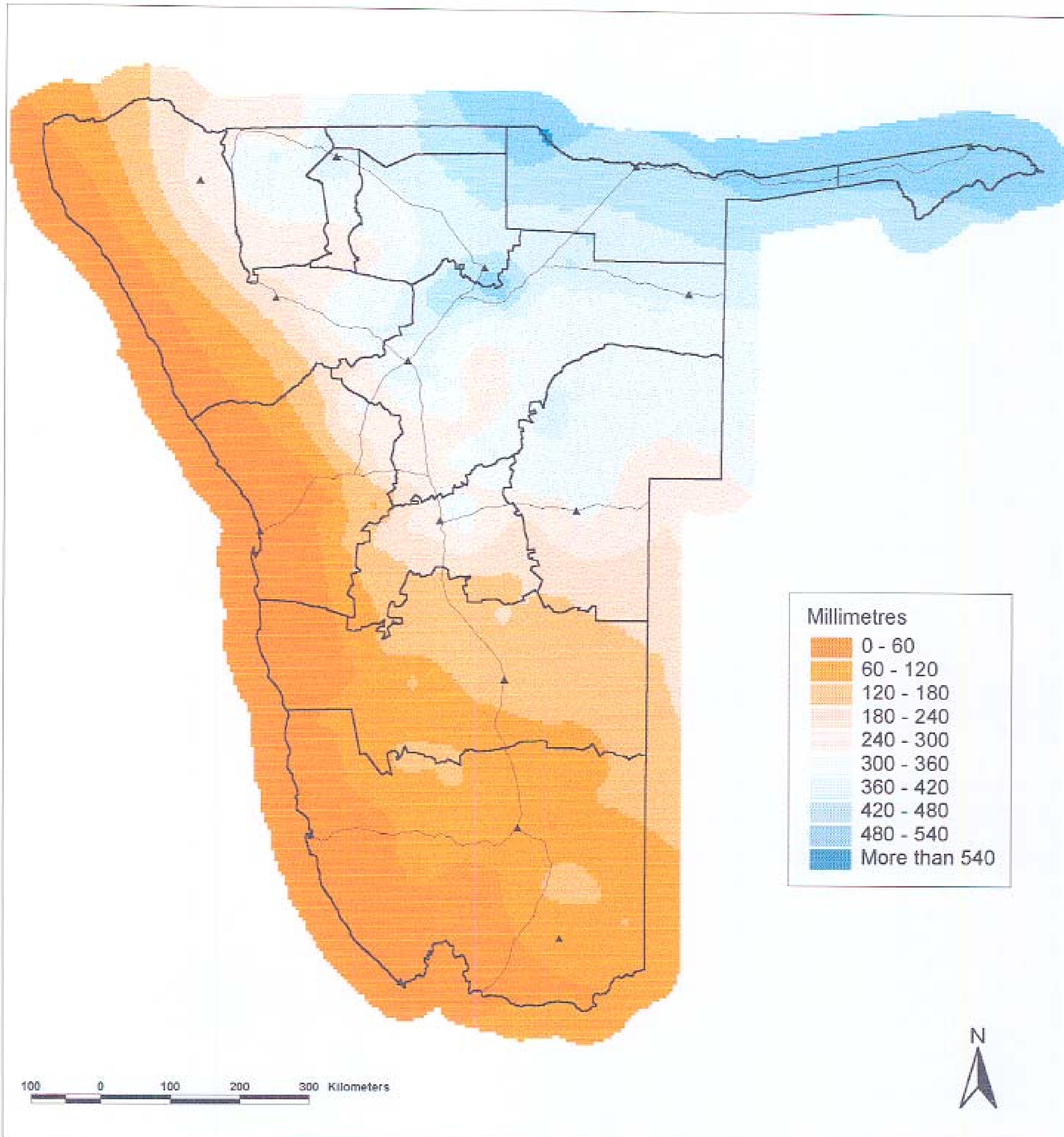
Map 5
Median annual rainfall



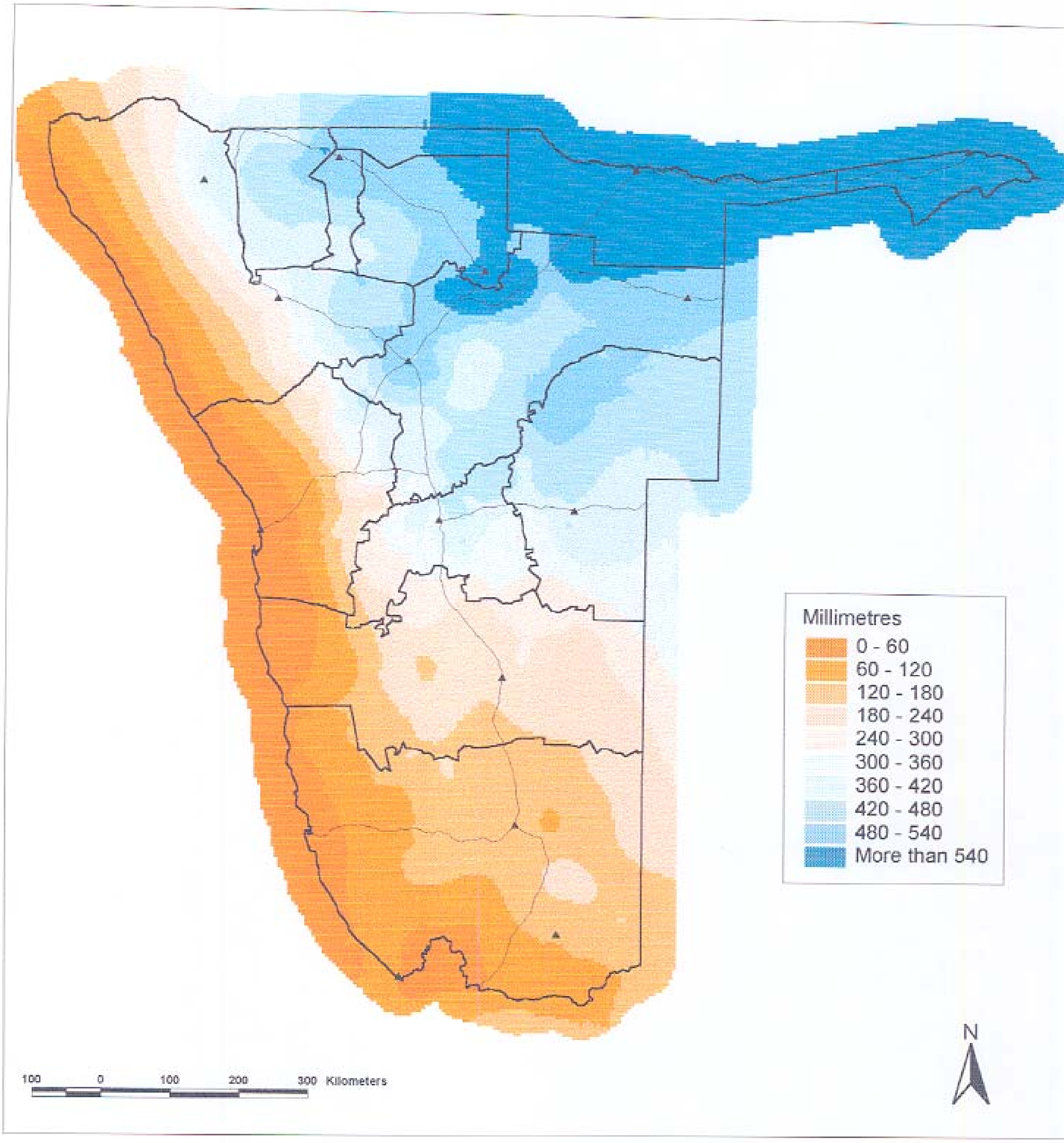
Map 6
Difference between average and median as percentage of median



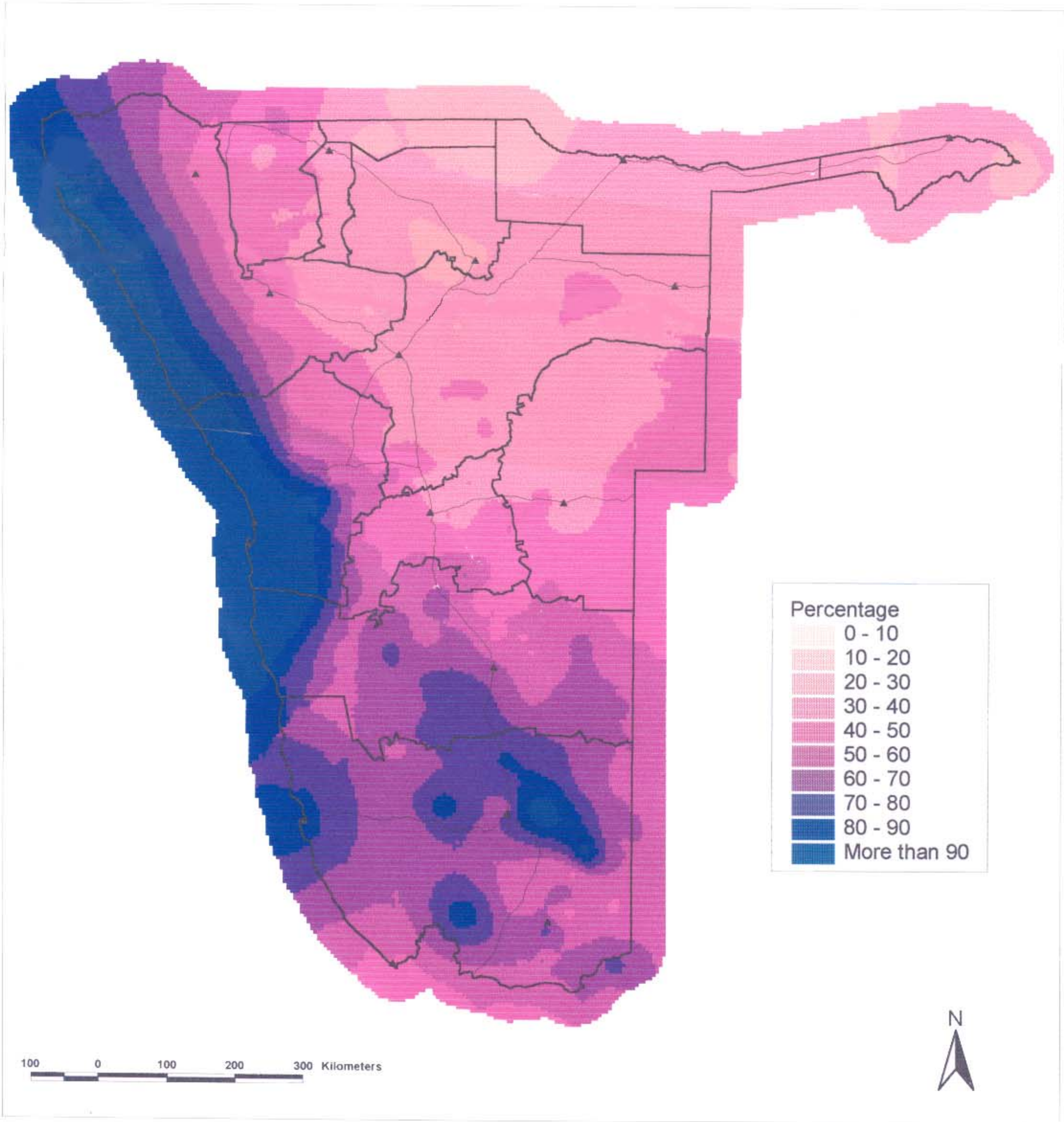
Map 7
Annual rainfall: 33rd percentile



Map 8
Annual rainfall: 67th percentile



Map 9
Coefficient of variation of annual rainfall



3.2 SEASONAL RAINFALL (maps 10-26)

Rainfall in Namibia is highly seasonal in occurrence, with the major part of the country receiving most of its rain during the summer months. The following series of maps depicts this seasonality showing the proportions of total annual rain falling within different periods and months.

<u>October to April Rainfall</u>
Ninety percent and more of all annual rains are received between October and April over most of Namibia **(map 10)**, confirming that much of the country can only expect to see rain during the warmer summer months. It is only in the extreme south-western section that a substantial proportion of annual rainfall falls during the other, winter months, as shown by the lower percentage values in Map 10.

<u>October to December Rainfall</u>
Map 11 shows the proportion of annual rain falling within the first three months of summer – October, November and December. This is the period during which most people await rain anxiously, especially those crop farmers in the northern regions who need to plant their mahangu, maize and sorghum as soon as the first substantial rains have fallen. However, most areas receive rather little of their annual quotas during these three months, especially those in the west. The south-western half of the country can expect to receive less than 20% of its total annual quotas during these first three summer months.

<u>January to April Rainfall</u>
A much higher proportion of the total annual rain falls during the second period of the summer **(map 12)**. In fact, leaving aside the south-western winter rainfall area, more than half of all the annual rain is received during the four months of January, February, March and April. The highest proportions are in the western areas, which see 80% and more of their annual rains in these months. The north and north-eastern areas of the country receive 60% and more of their rain between January and April.

<u>October to April Monthly Rainfall as Proportions of Summer Rainfall</u>
Maps 13 to 19 present information on the proportions of the summer seasonal totals that fall in October, November, December, January, February, March and April, respectively.

Very little of the summer rains falls in October. The only area where substantial proportions are received is in the extreme south-west **(map 13)**. This is because some of the remnants of the winter rains fall in October. While these are not large amounts, they are significant in representing substantial proportions of the little rain that does fall during the summer months in those areas. The only other area that receives moderate proportions of it summer rain is in the south-east, presumably as a result of moist air moving westwards over Botswana from South Africa.

Few areas of the country receive much of their summer rains in November **(map 14)**. Those that record 10-15% of their summer rains are in the north-central and the north-eastern regions.

Areas receiving 15% and more of their summer rains in December are in eastern Kavango and the whole of the Caprivi, especially the eastern Caprivi where more than 20% of the season's rain is recorded in December **(map 15)**.

January is the first of the summer months during which a large part of the country can expect to receive 25% and more of its summer rain **(map 16)**. In fact, the largest part of Namibia records 20% and more of its summer rain during this month.

A broad belt running north-south down the centre of Namibia receives 25% and more of its summer rain during February **(map 17)**. The same is true for the extreme north-western area of the country. Much of the northern part of Namibia receives between 20 and 25% of its summer rainfall in February.

The map for March illustrates the substantial contribution that March rainfall makes to total rainfall received in the dry Namib belt **(map 18)**. It shows the month's rainfall as a percentage of the summer season's total, and presents a dramatic portrayal of how a large proportion of the little rain that falls in the Namib is seen during that month. Proportions of seasonal rain decline eastwards from the western, Namib belt.

April **(map 19)** signals the end of the summer rains and the start of the winter rains in the south-west. Most of the summer-rainfall area records less than 15% of the summer rain during April. The high proportions in the south-west show that rain that does fall in April represents a large proportion of the little summer rain that ever falls in this winter rainfall area.

Dry Months

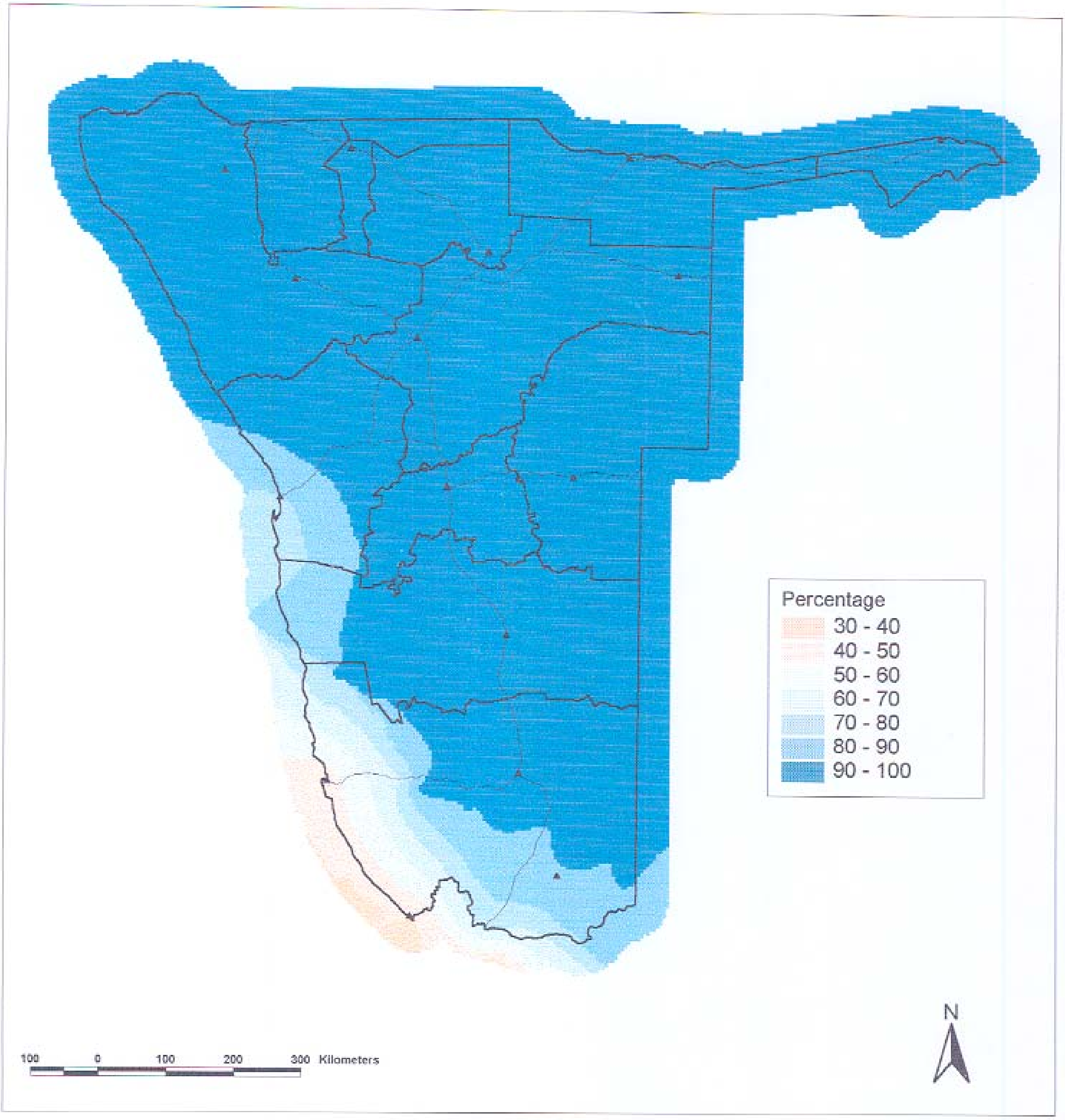
Maps 20 to 26 show the frequency with which the seven summer months have been recorded as being dry months. "Dry months" in this instance refer to months during which no rain fell. Other than the south-western extreme of Namibia, which frequently has remnants of its winter rains falling in October, in 60% and more of all years no rain falls in October **(map 20)**.

November, December, January, February and March show similar patters **(maps 21, 22, 23, 24 and 25)**, with only the extreme west and south frequently recording no rain during these months.

Only the northern Namib records dry Aprils frequently **(map 26),** with no rain being received during 60% and more of all years. This leaves most of the rest of the country with fairly high chances of receiving at least some rain during this last summer month.

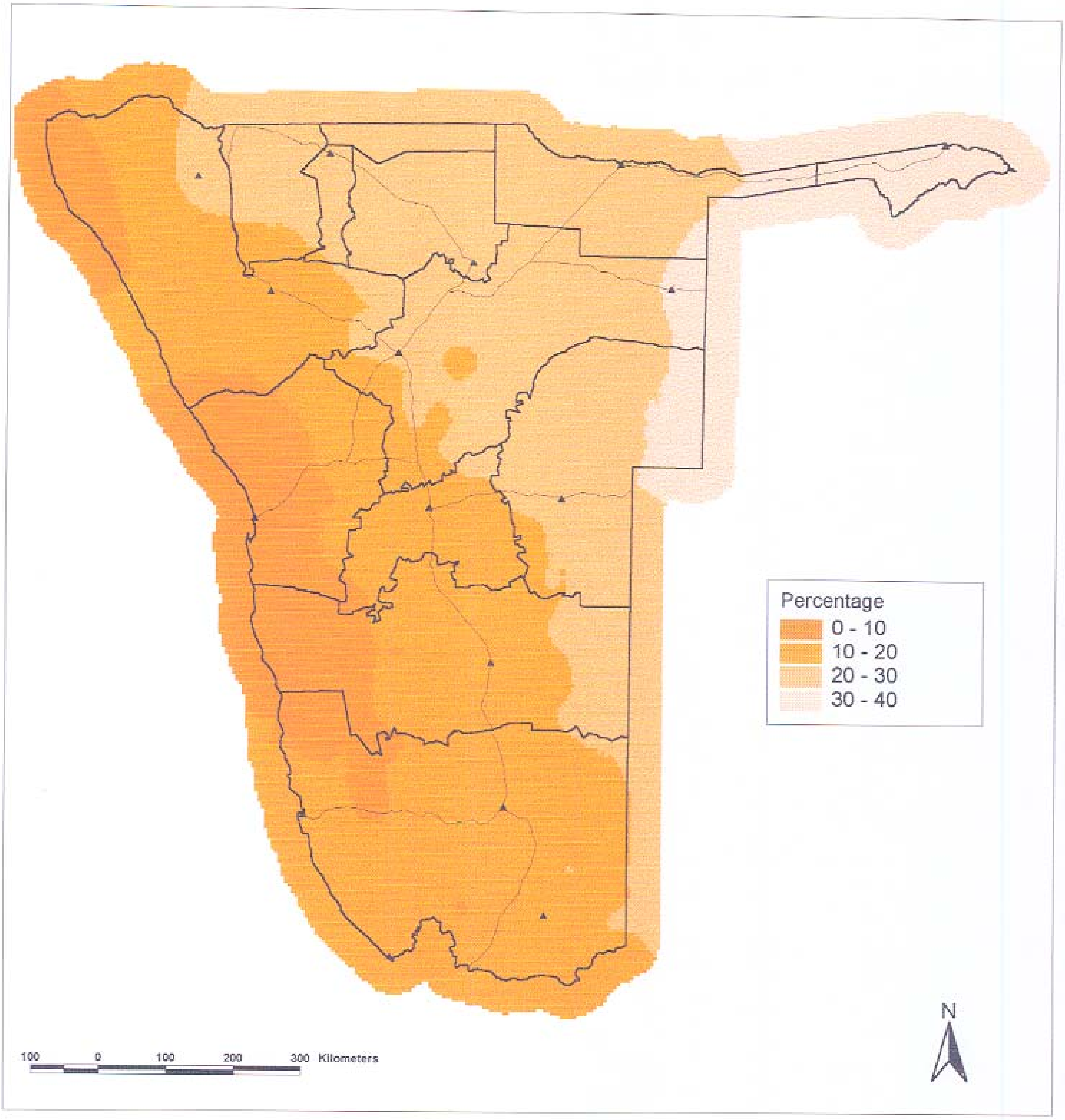
Map 10

October-April as percentage of total annual rainfall

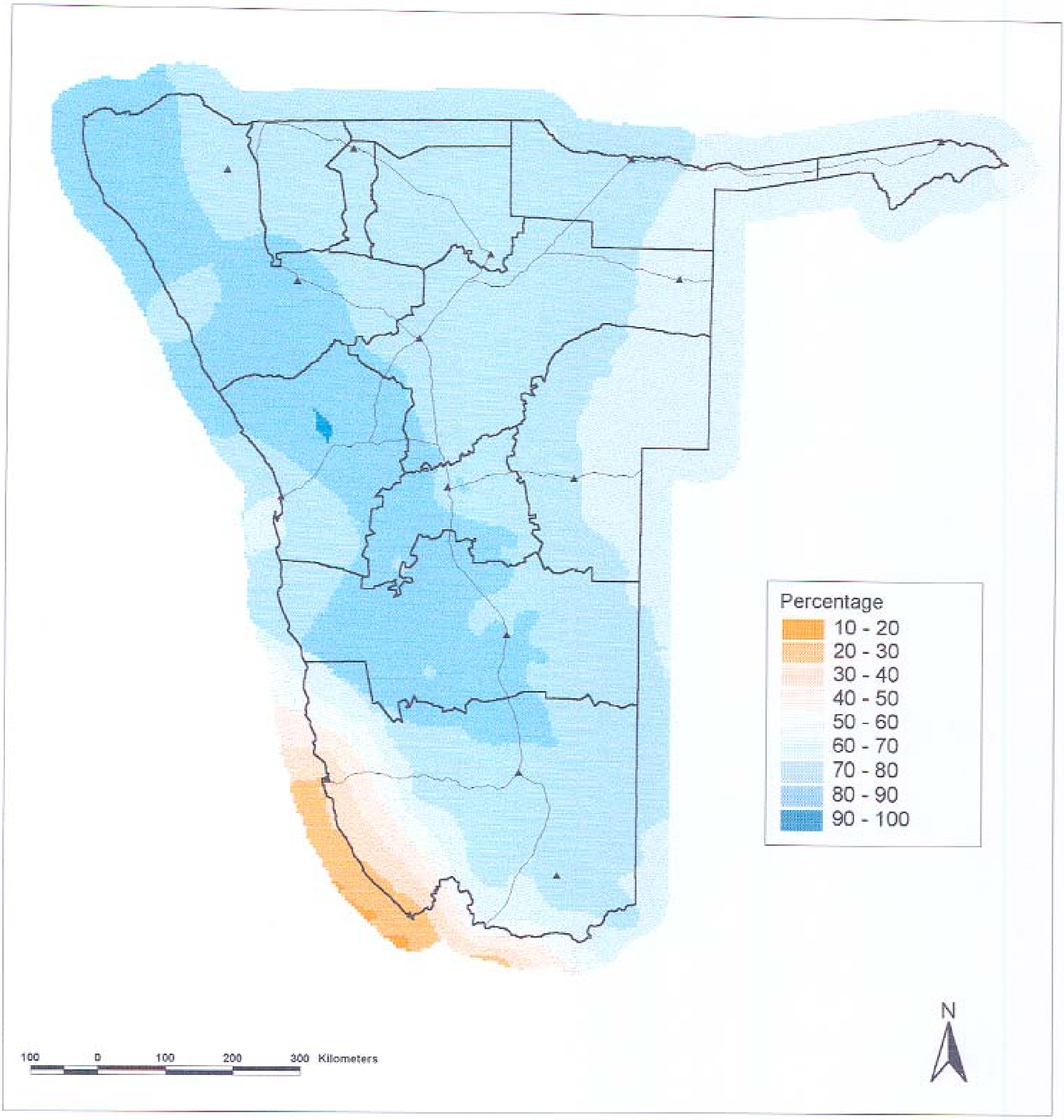


Map 11

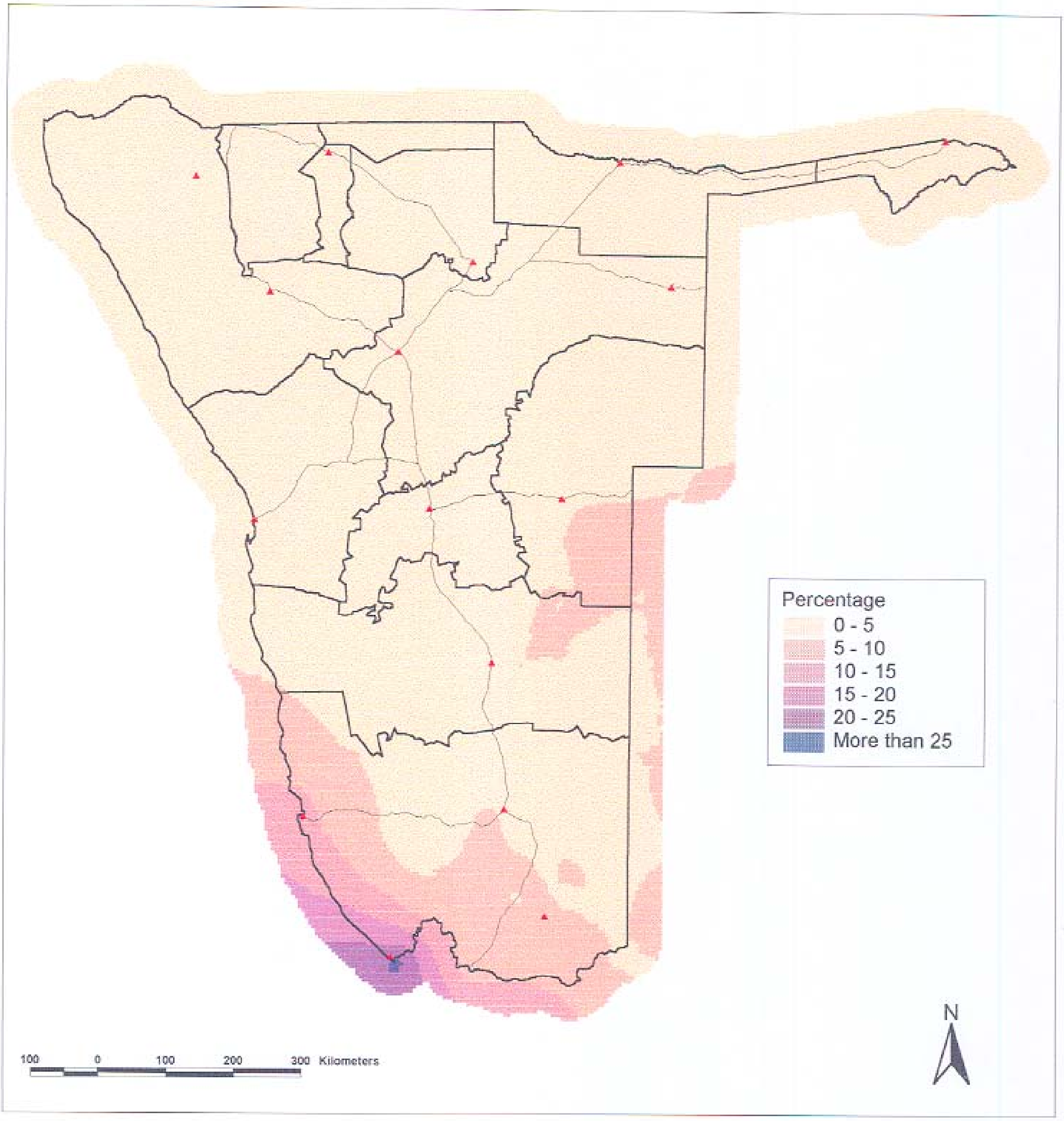
October-December as percentage of total annual rainfall



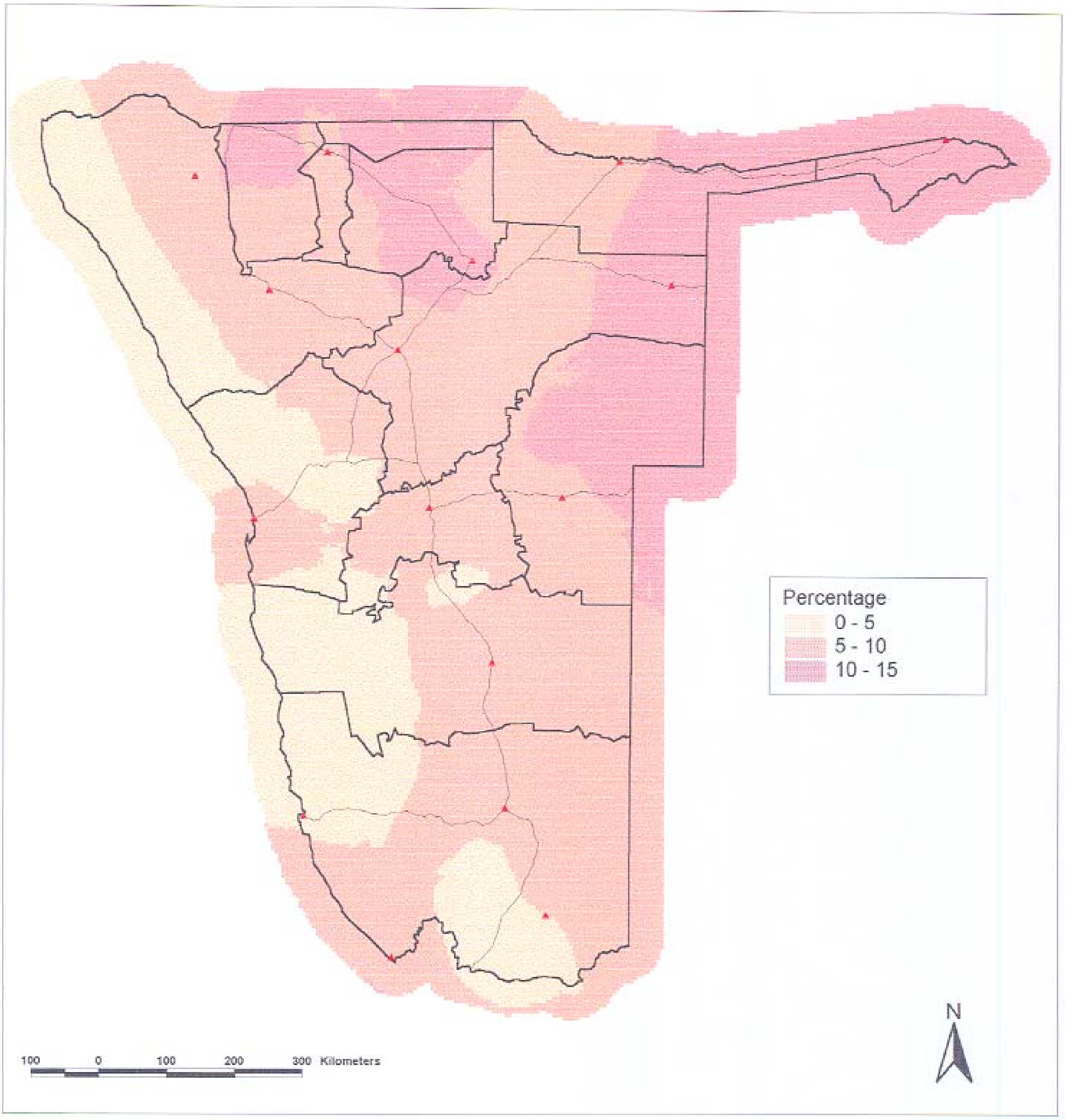
Map 12
January-April as percentage of total annual rainfall



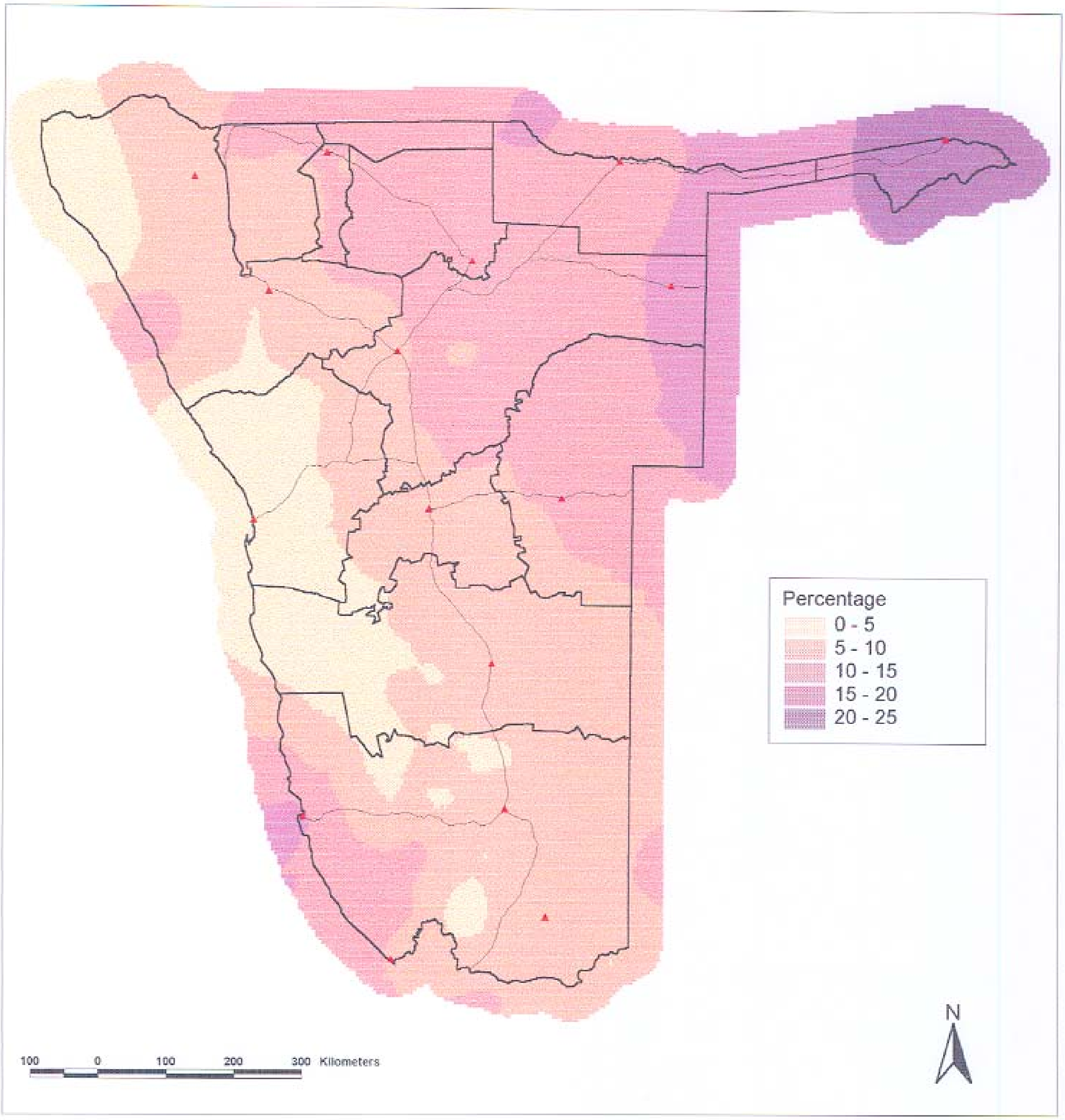
Map 13
October total as percentage of seasonal total



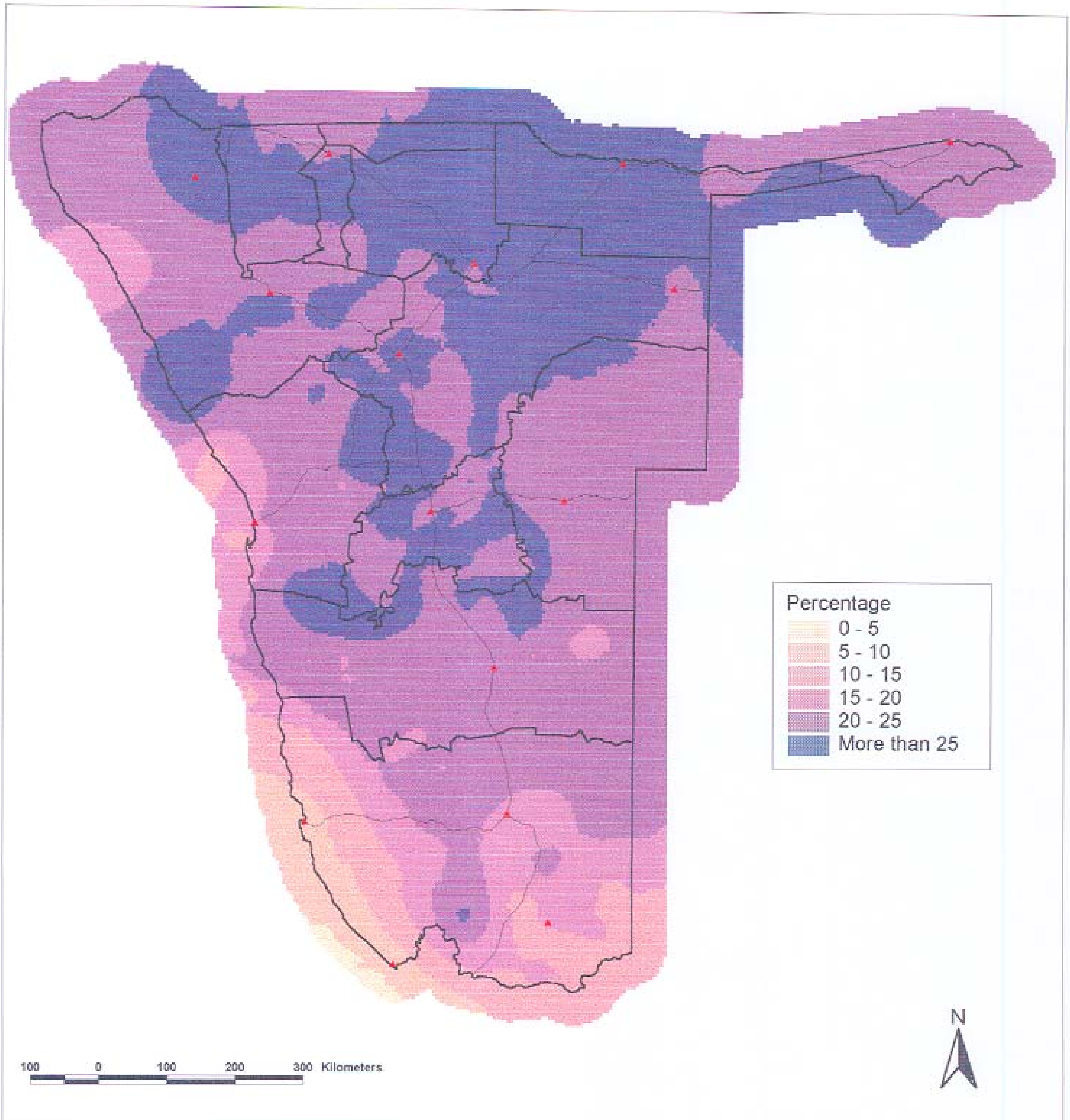
Map 14
November total as percentage of seasonal total



Map 15
December total as percentage of seasonal total

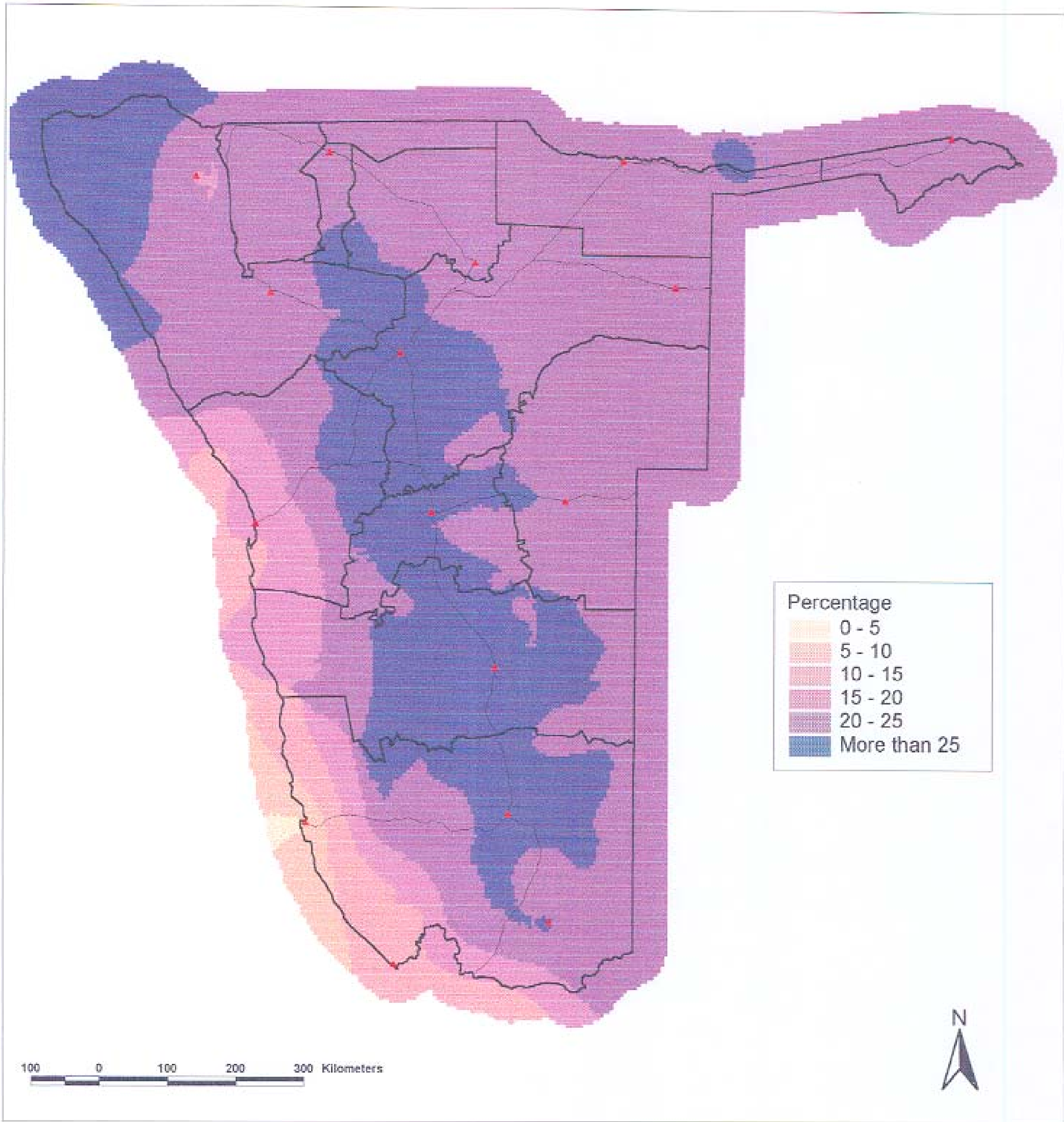


Map 16
January total as percentage of seasonal total



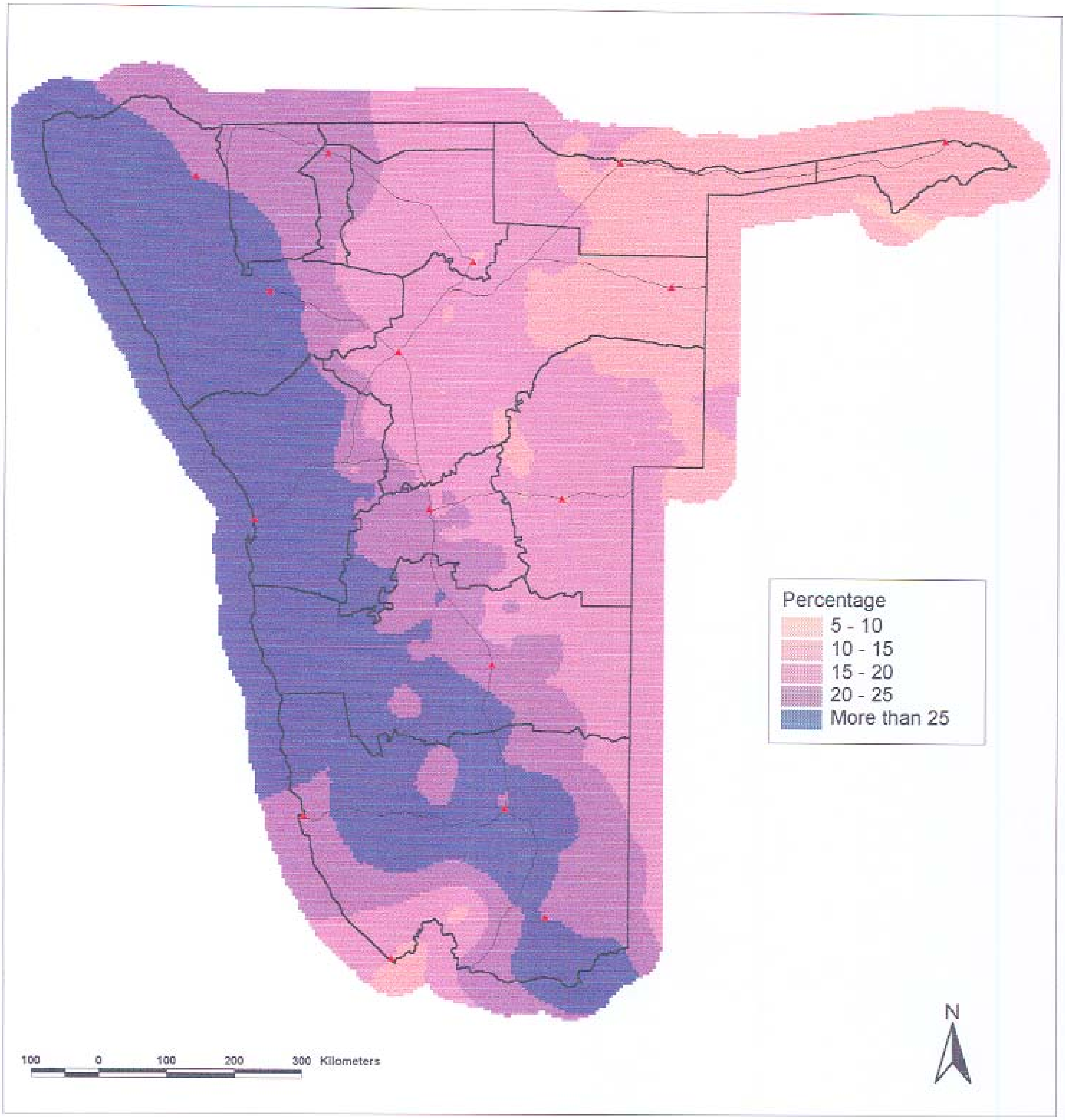
Map 17

February total as percentage of seasonal total

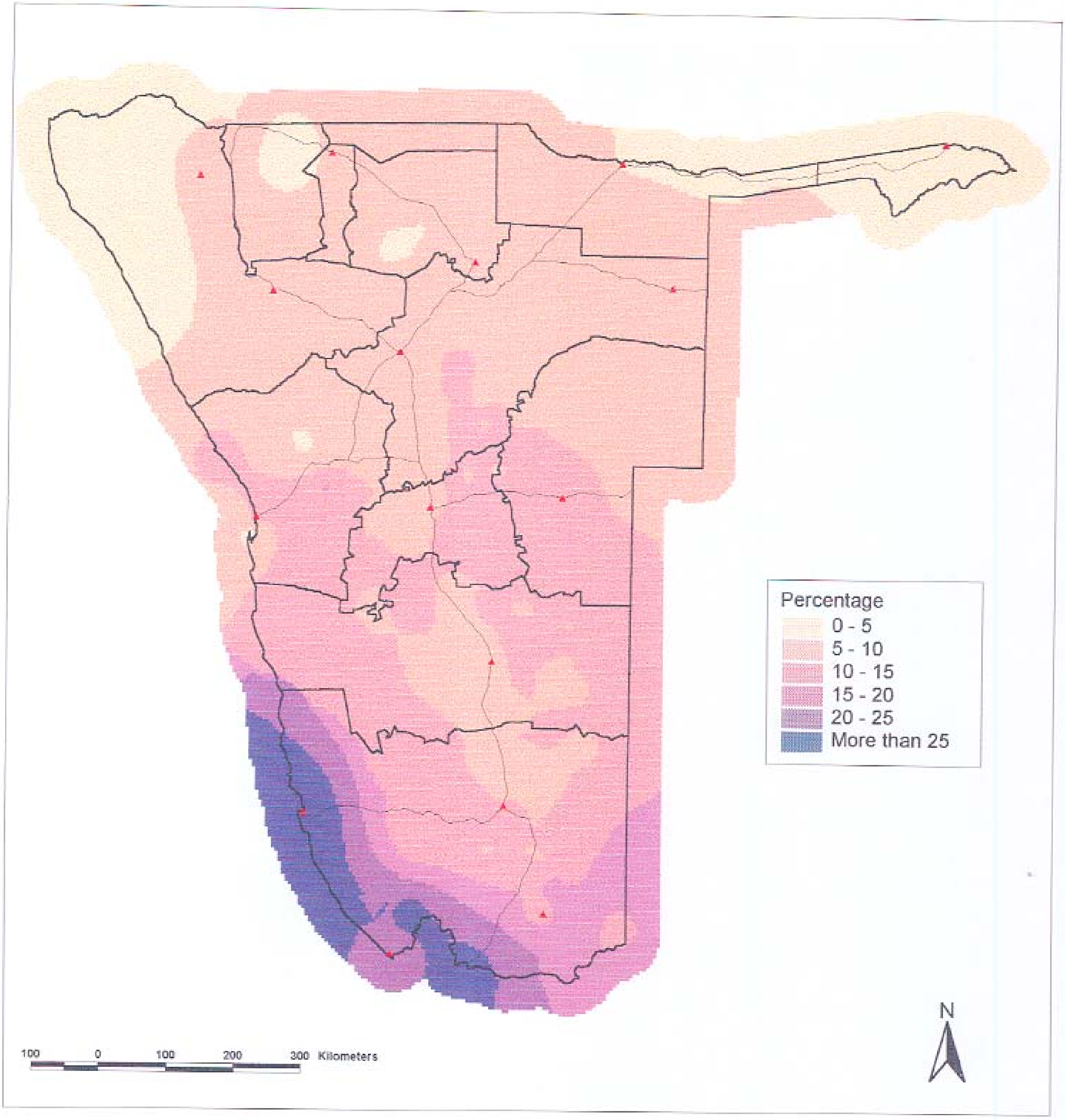


Map 18

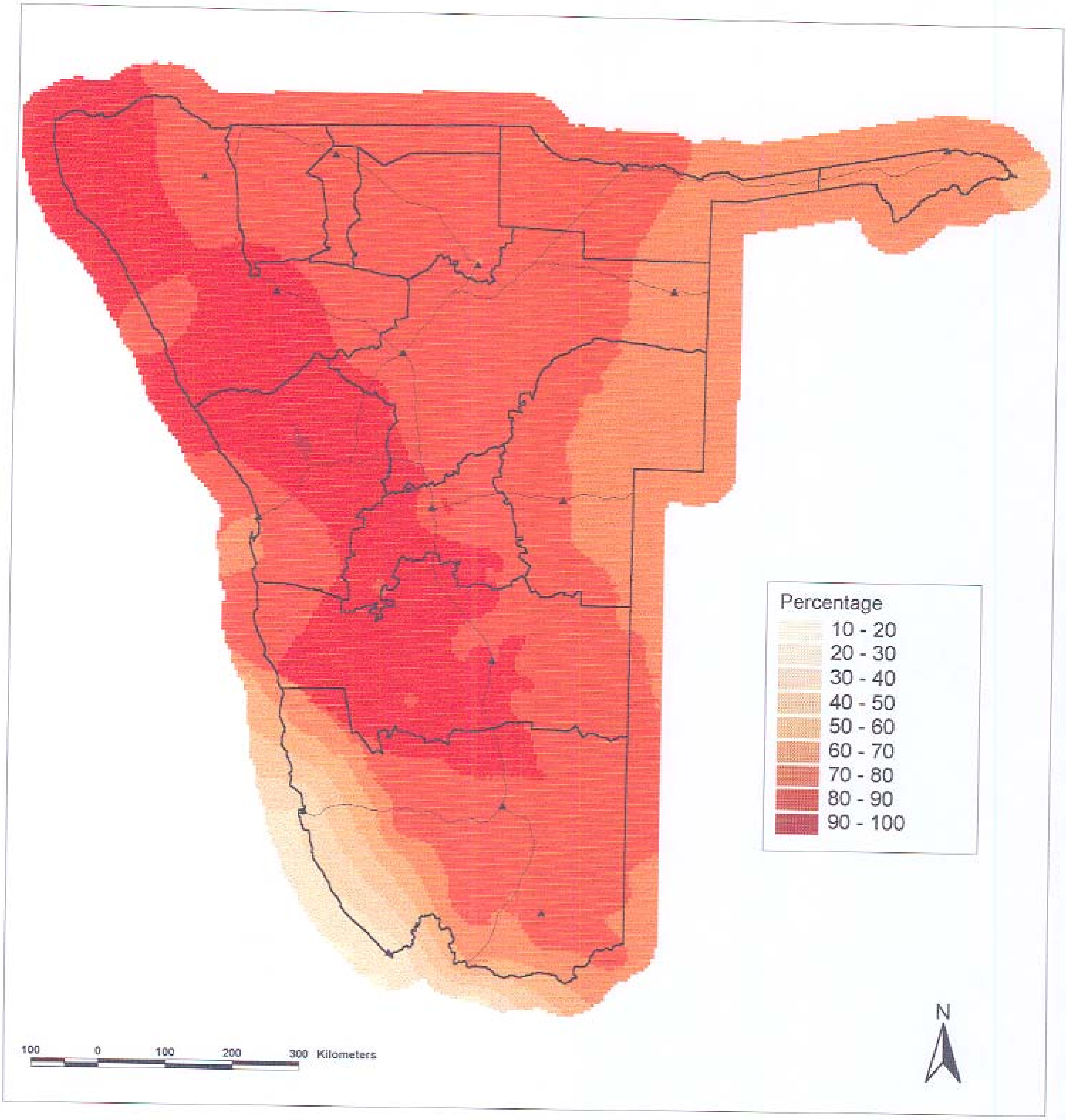
March total as percentage of seasonal total



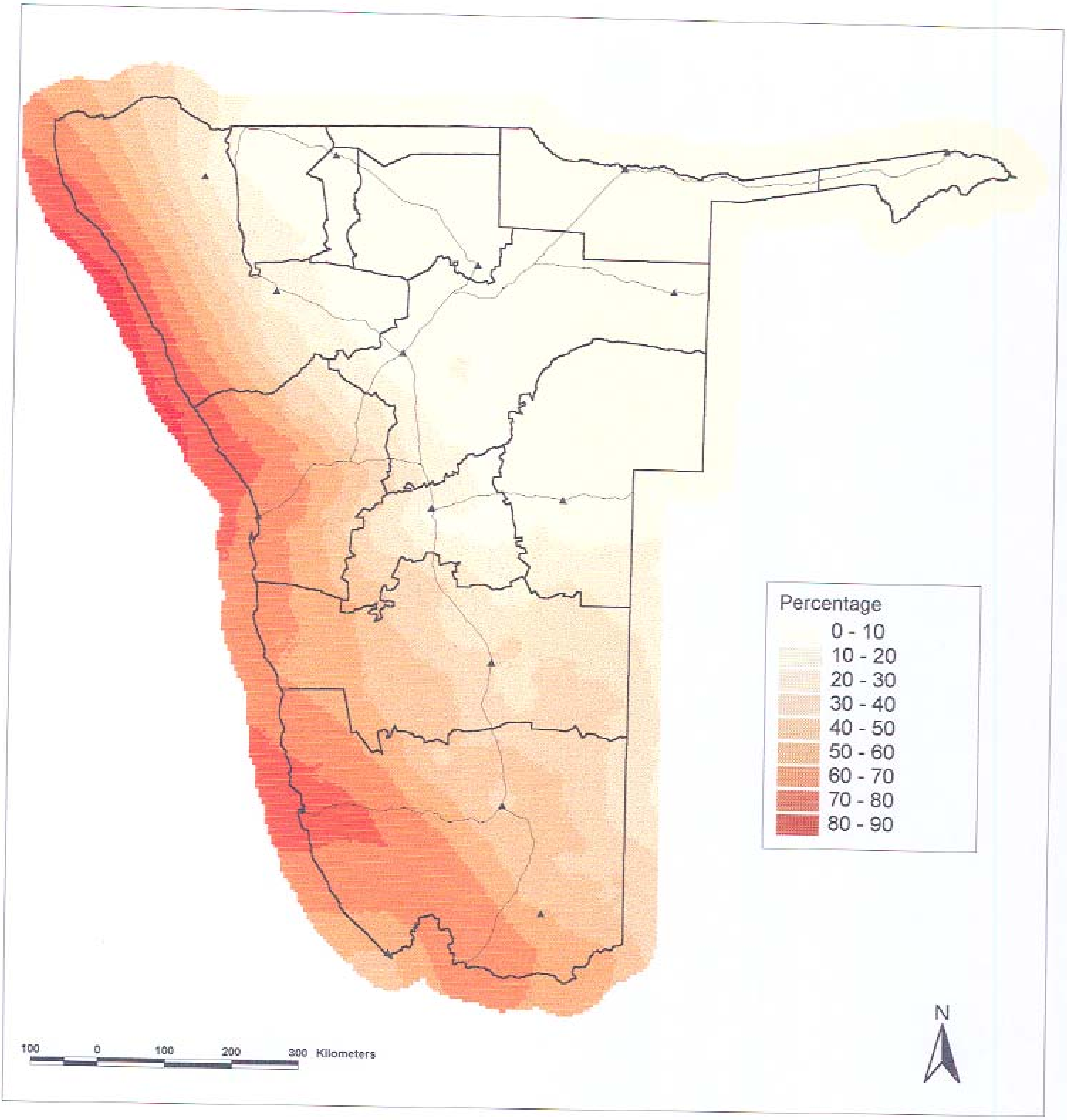
Map 19
April total as percentage of seasonal total



Map 20
Percentage frequency of October being dry

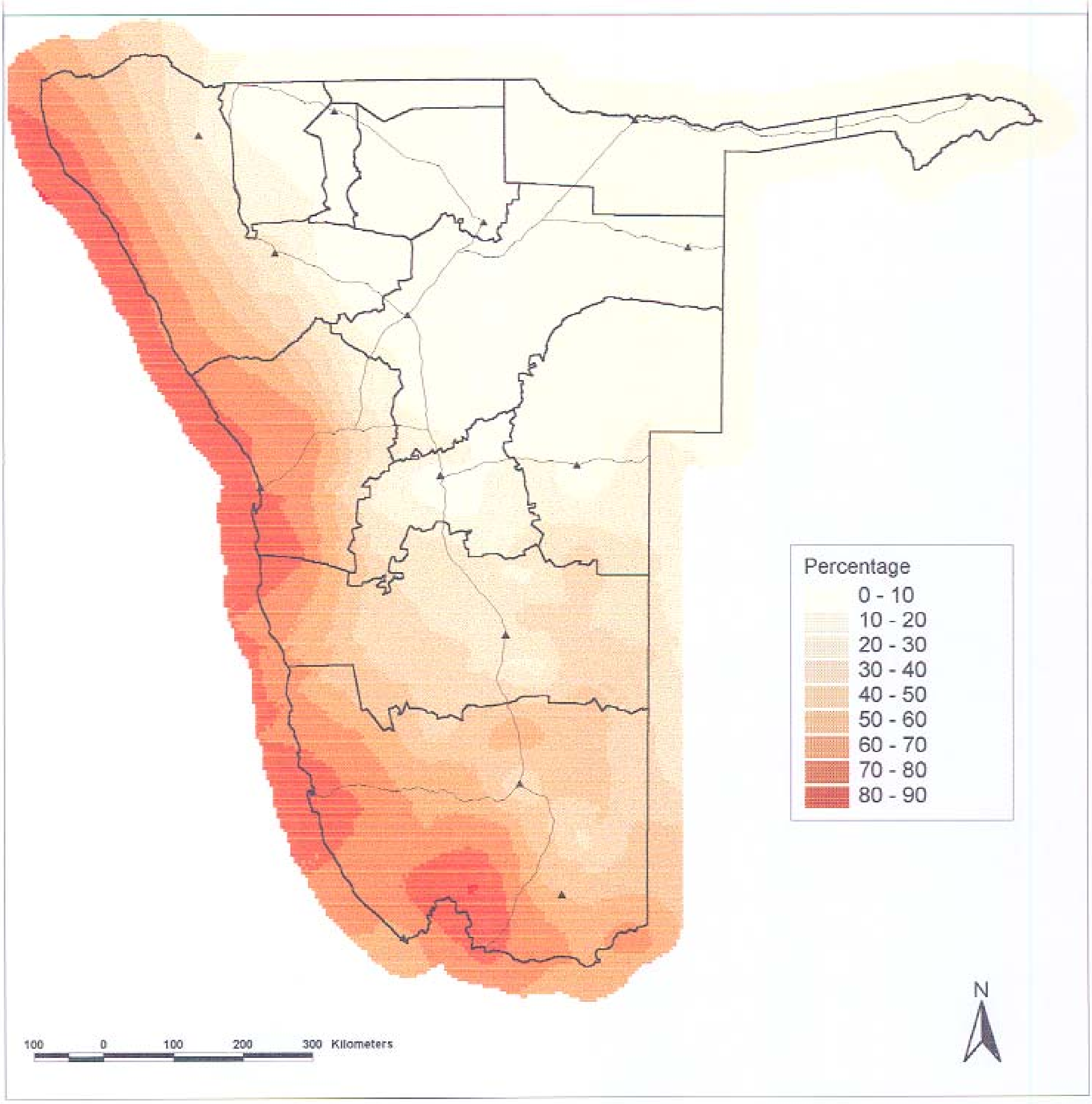


Map 21
Percentage frequency of November being dry

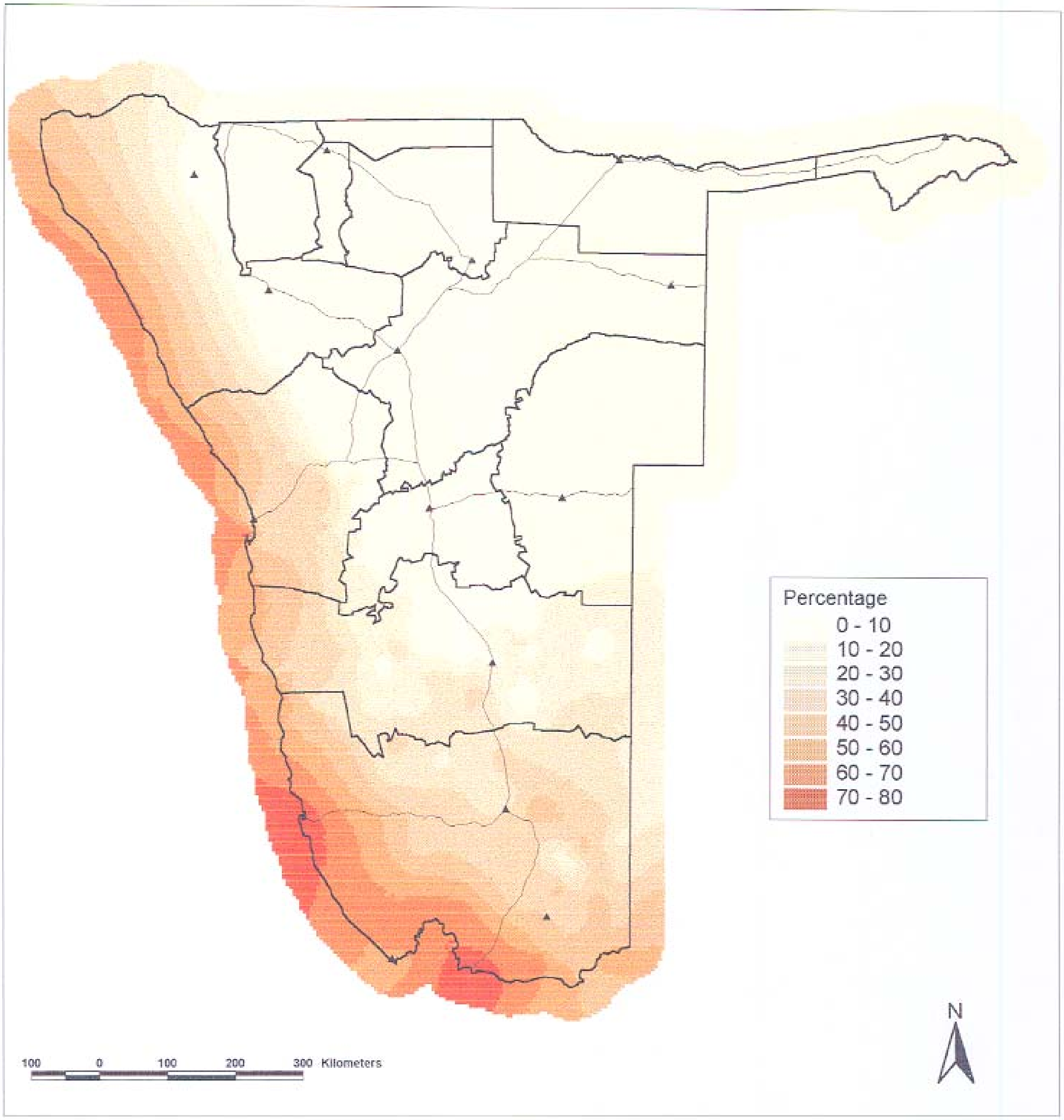


Map 22

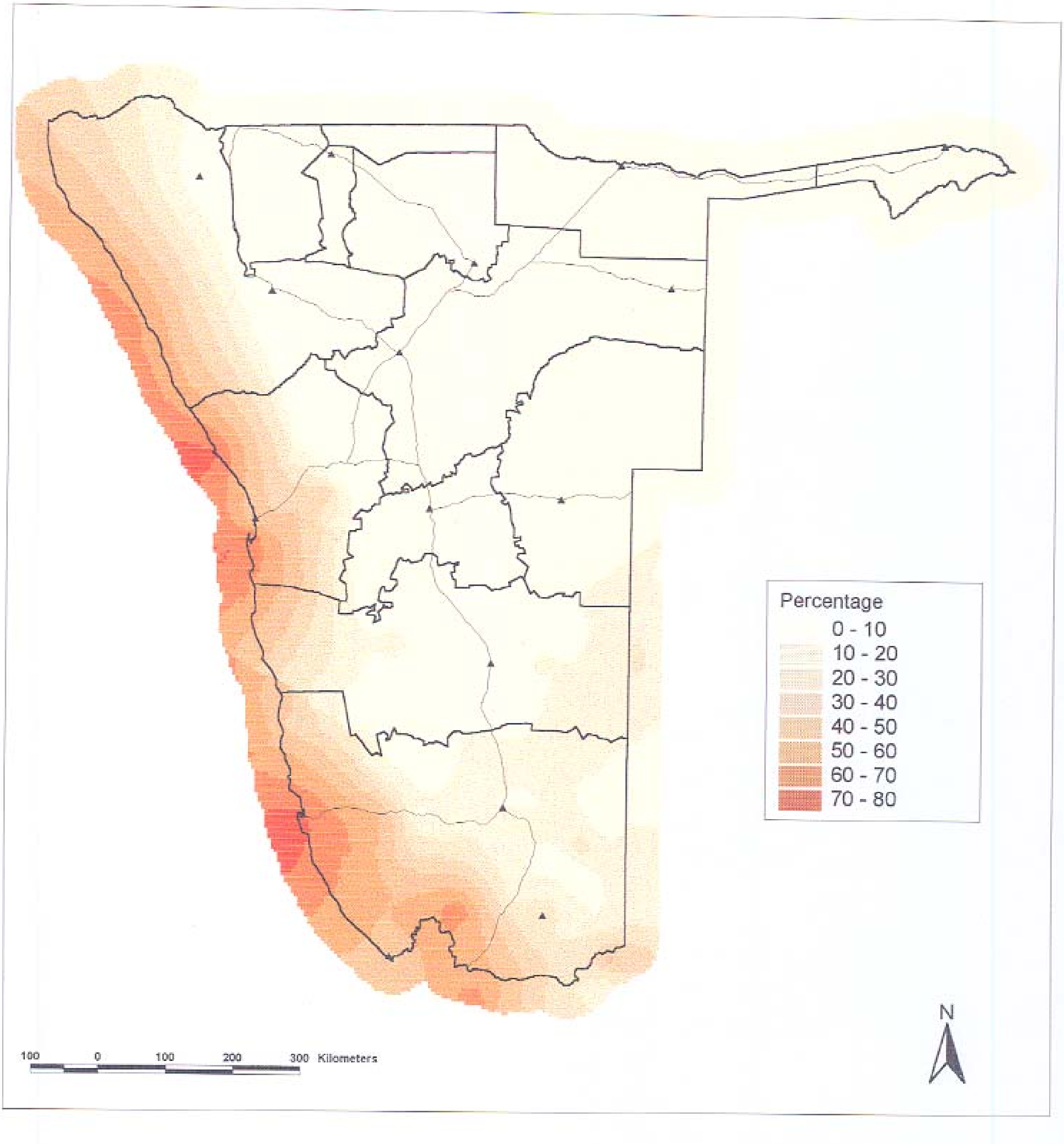
Percentage frequency of December being dry



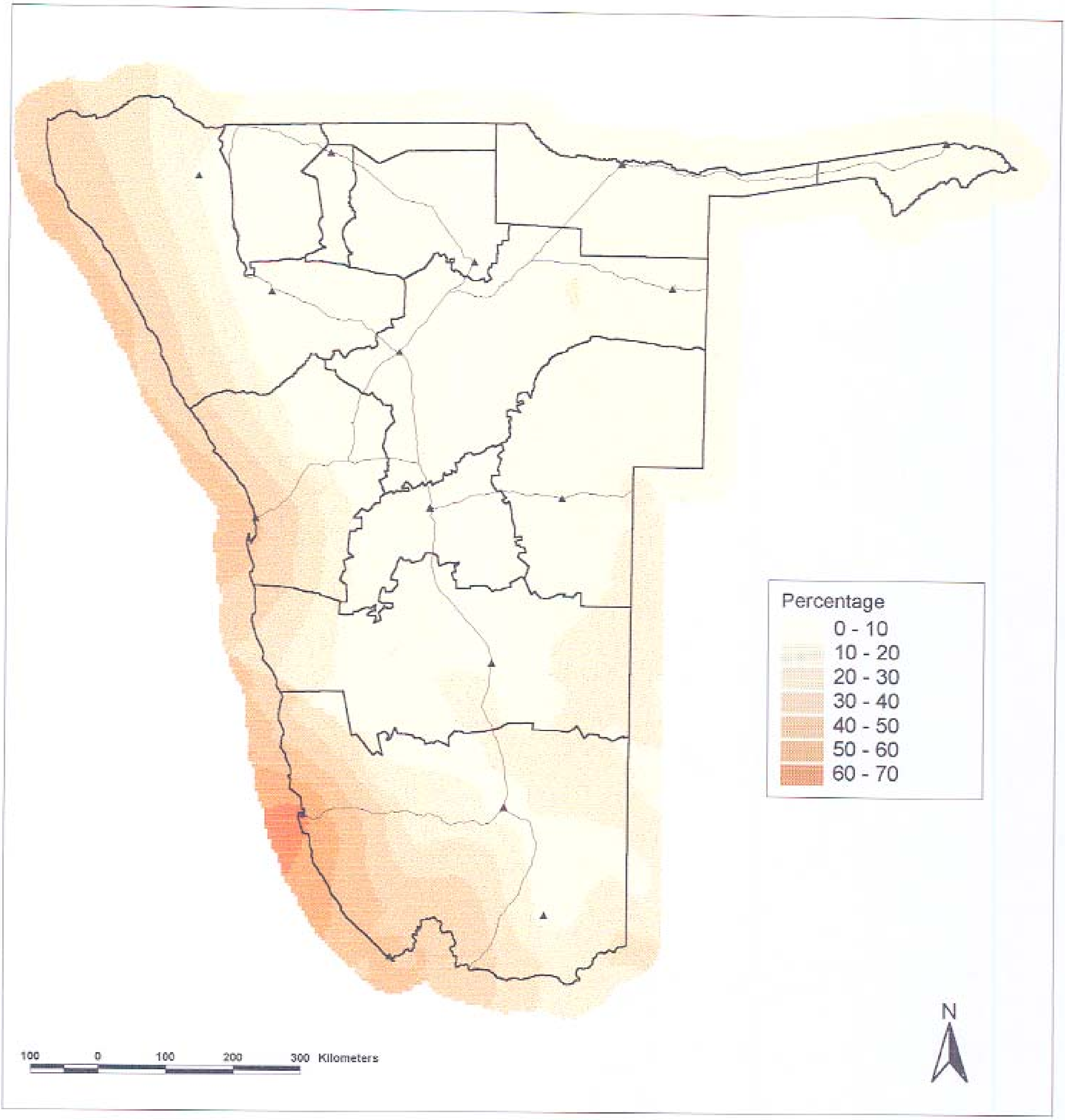
Map 23
Percentage frequency of January being dry



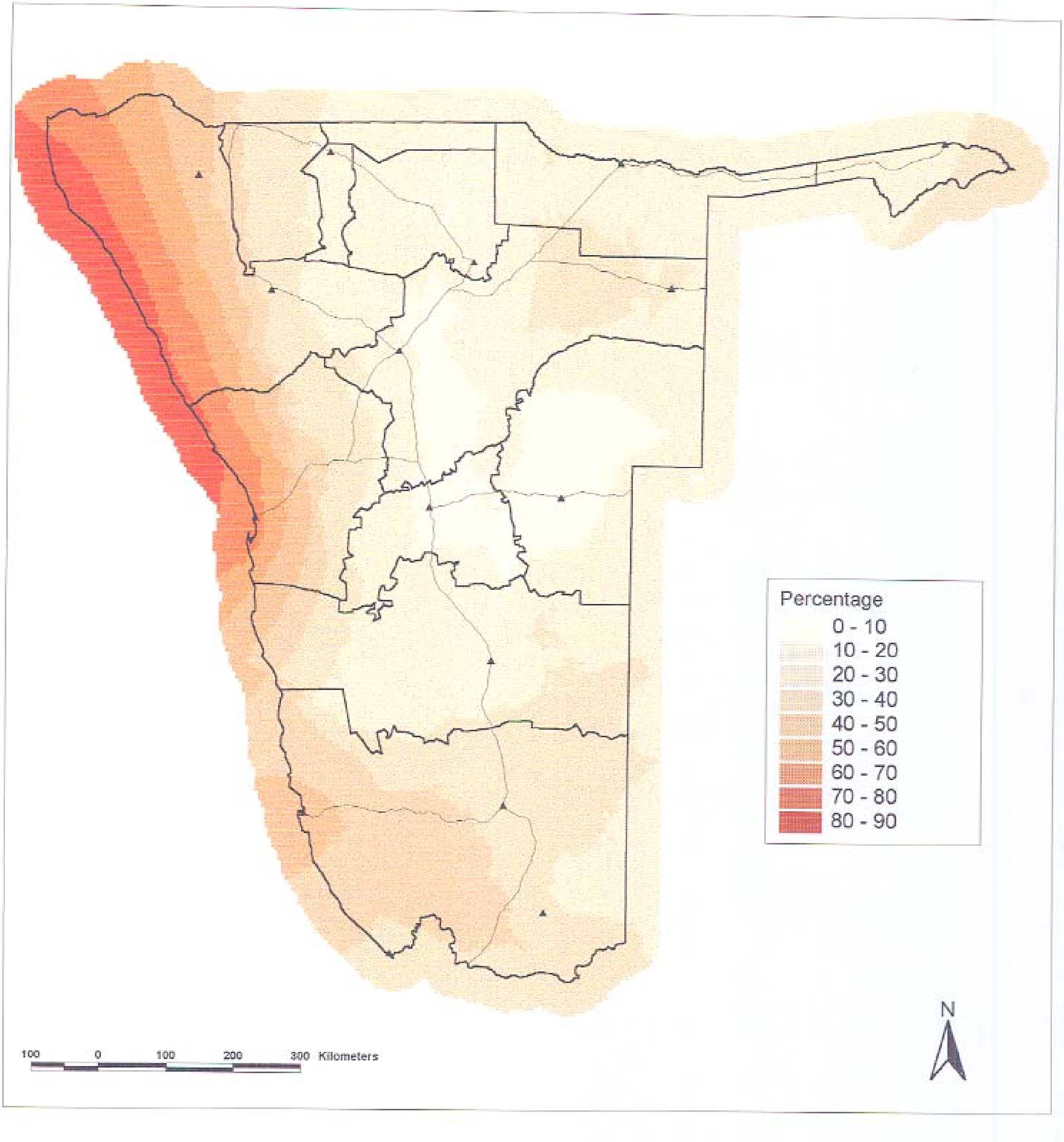
Map 24
Percentage frequency of February being dry



Map 25
Percentage frequency of March being dry



Map 26
Percentage frequency of April being dry



3.3 Monthly Rainfall (maps 27 – 69)

Average and Median Rainfall by Month

The following 24 maps (**maps 27 to 50**) depict average and median rainfall, respectively, for each of the 12 months: January to December. Two colour schemes are used for legends, each with its own class of intervals. The first, in blue tones, is for the higher rainfall summer months of January, February, March, April and then October, November and December. The second, in brown tones, is for the drier winter months lasting May to September.

Each pair of maps, showing the average and median rainfall for the month, illustrates the discrepancies between average and medians values resulting from occasional and abnormally high falls. During the summer rainfall months, the gradations in higher to lower rainfalls from the north-east to the south-west are also clear.

Maps of total rainfall during the winter months show that median rainfalls within Namibia never exceed 10 millimetres, higher totals only being recorded south of the border. In fact, average and median rainfalls along the whole Orange River valley on the border of Namibia are never more than 15 millimetres in any month, winter or summer.

Variability in Rainfall by Month

Maps 51 to 57 provide a measure of the variability of rainfall each month during the summer season from October to April. Similar maps were not produced for other months because the amounts of rain received then are so low and variable that measures of variation become absurdly high. The coefficient of variation is the standard deviation of monthly rainfall as a percentage of average monthly rainfall. A coefficient of variation of 50% thus means that the standard deviation is half of the monthly average. A coefficient of variation of 50% also means that for about two-thirds of all years total falls have been within a range, the size of which spans above and below the average by about the same value as the average itself. A place having an average of 60 mm per month would have recorded falls ranging between 30 and 90 mm in two-thirds of all years.

The degree of variation in monthly totals decreases as the summer rainfall progresses. Rainfall in October **(map 55)** is thus much more variable than in November **(map 56)** and so on. Levels of variation in February and March are roughly similar and the lowest during the summer. Rainfall abruptly becomes more variable in April **(map 54)**, with levels of variation similar to those seen in October **(map 55)** and November **(map 56)**.

Throughout the summer months the western fringe of the country has the greatest variation in monthly falls, largely because the little rain that does fall there can be expected to fall at almost any time. The north-eastern regions, by contrast, have the lowest levels of variation in most months. Areas with the lowest levels of variation also expand southwards and westwards as the summer months progress.

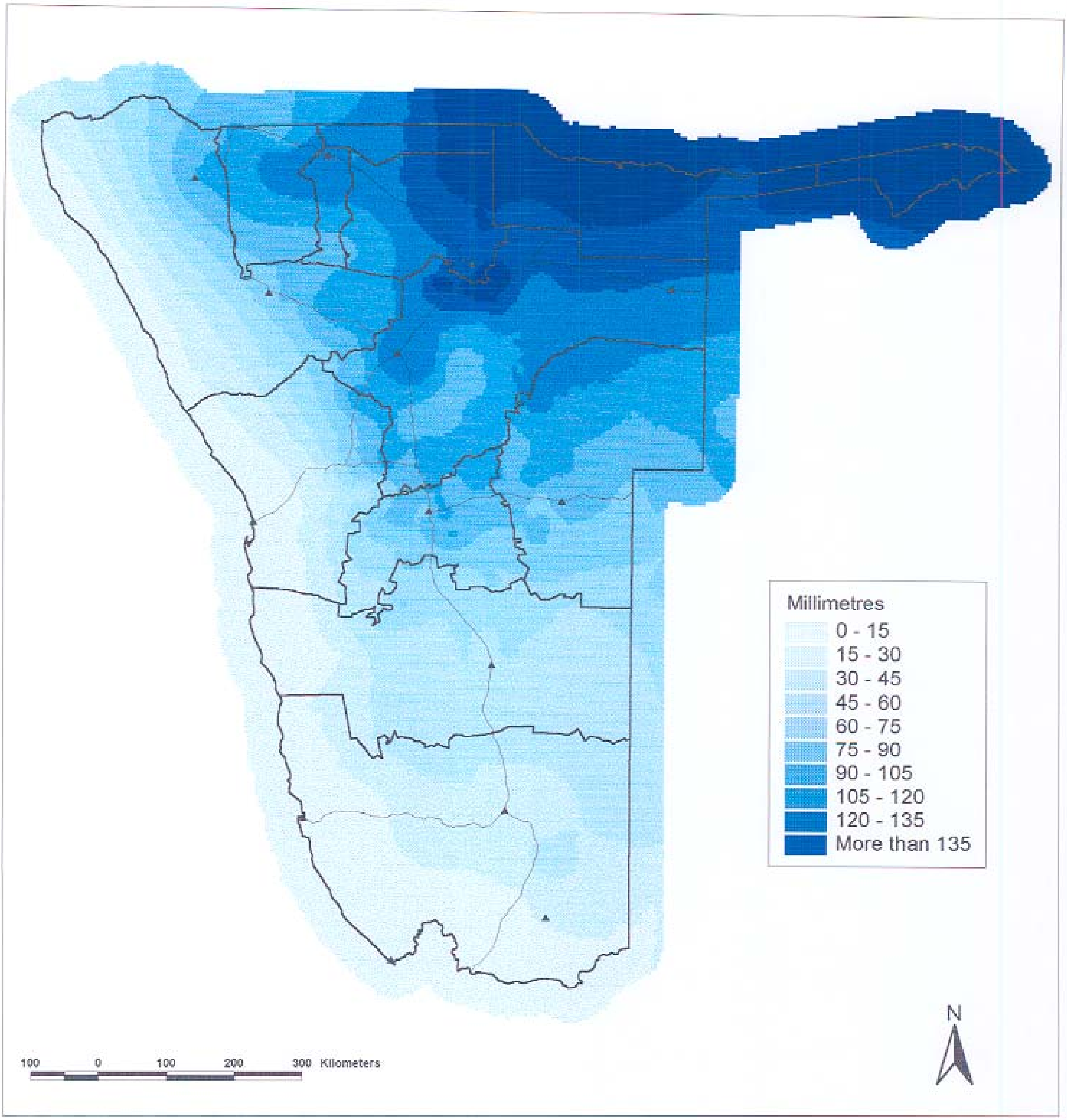
Monthly Rainfall as a Proportion of Annual Rainfall

Maps 58 to 69 show the proportions of annual rain received in each month, January to December. The maps for October to December and January to April are rather similar to those for the same months (**maps 13 to 19**) showing the proportions of total seasonal rain falling in each month. Much of the country receives about half of its total rainfall in January and February **(maps 58 and 59)**, while the map for March **(map 60)** shows that a broad swathe of Namibia, running from the north-west to the south-east, receives much of its rain in that month.

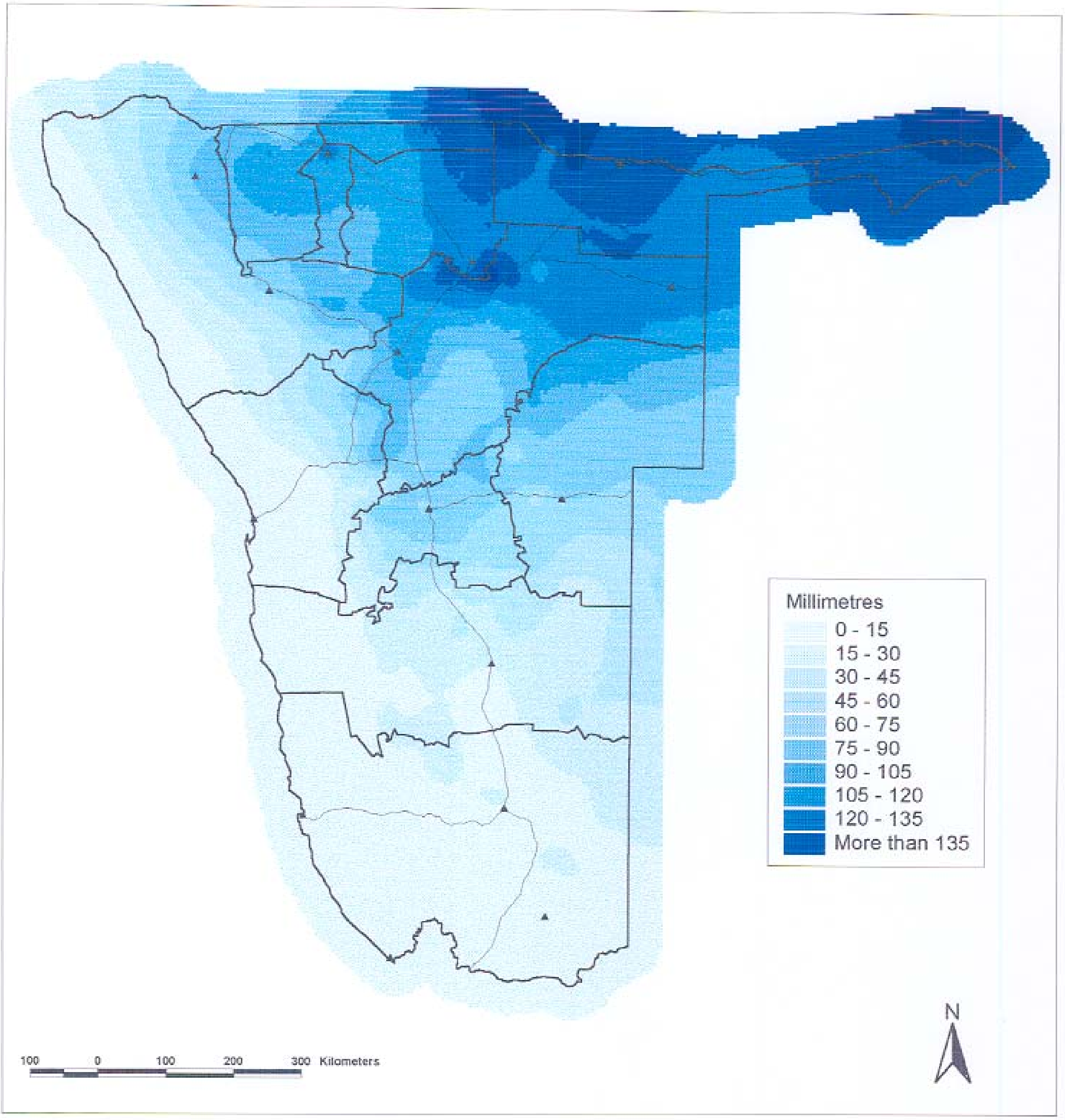
The winter rainfall areas in the south-west receive high proportions of their annual rains in April **(map 61)** and June **(map 63)** and July **(map 64)**, with surprisingly little rain falling in the intervening month of May **(map 62).**

Eastern Caprivi receives roughly equal and the highest proportions of its annual rain falling in December **(map 69)**, January **(map 58)** and February **(map 59)**.

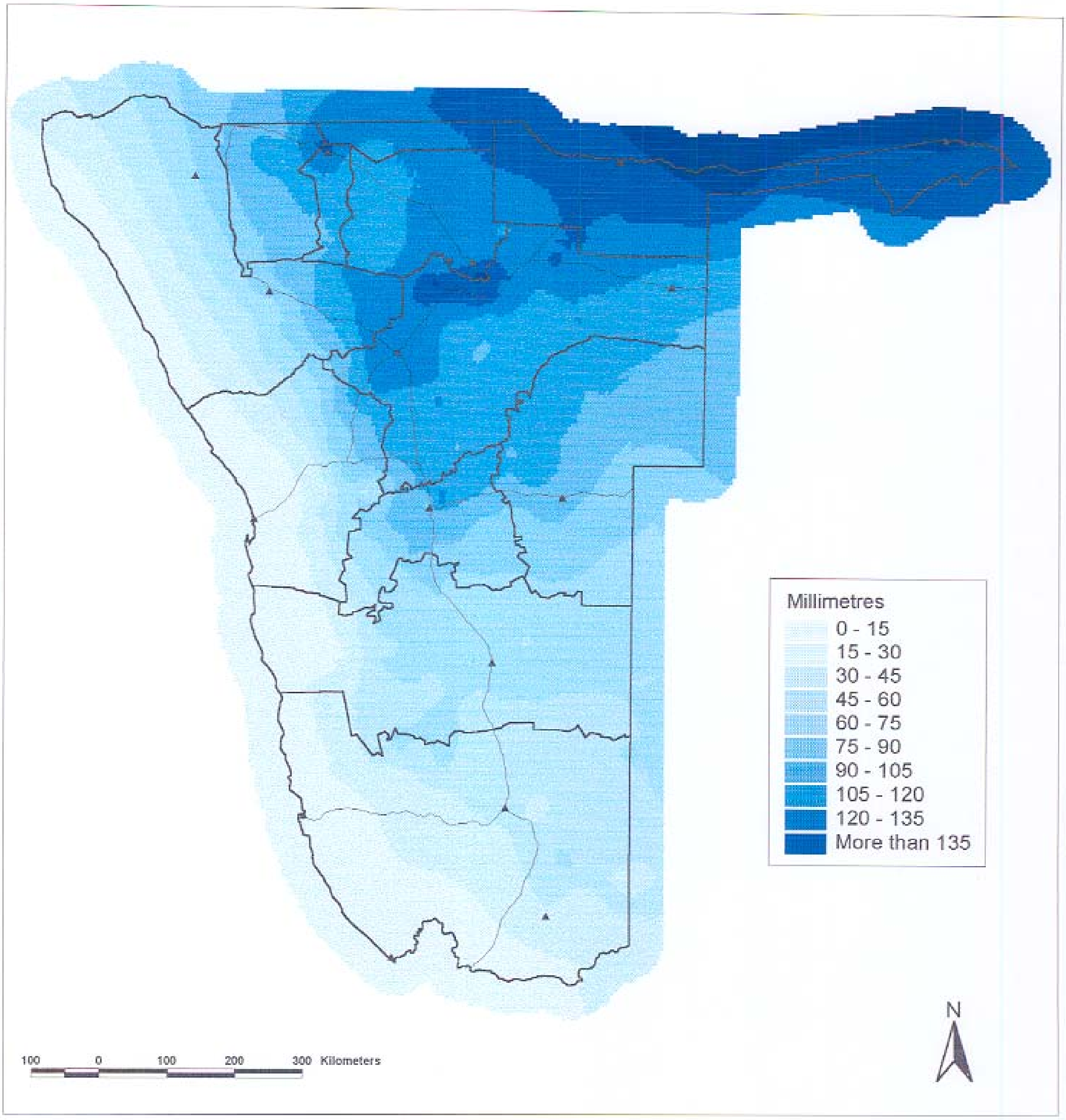
Map 27
Average January rainfall



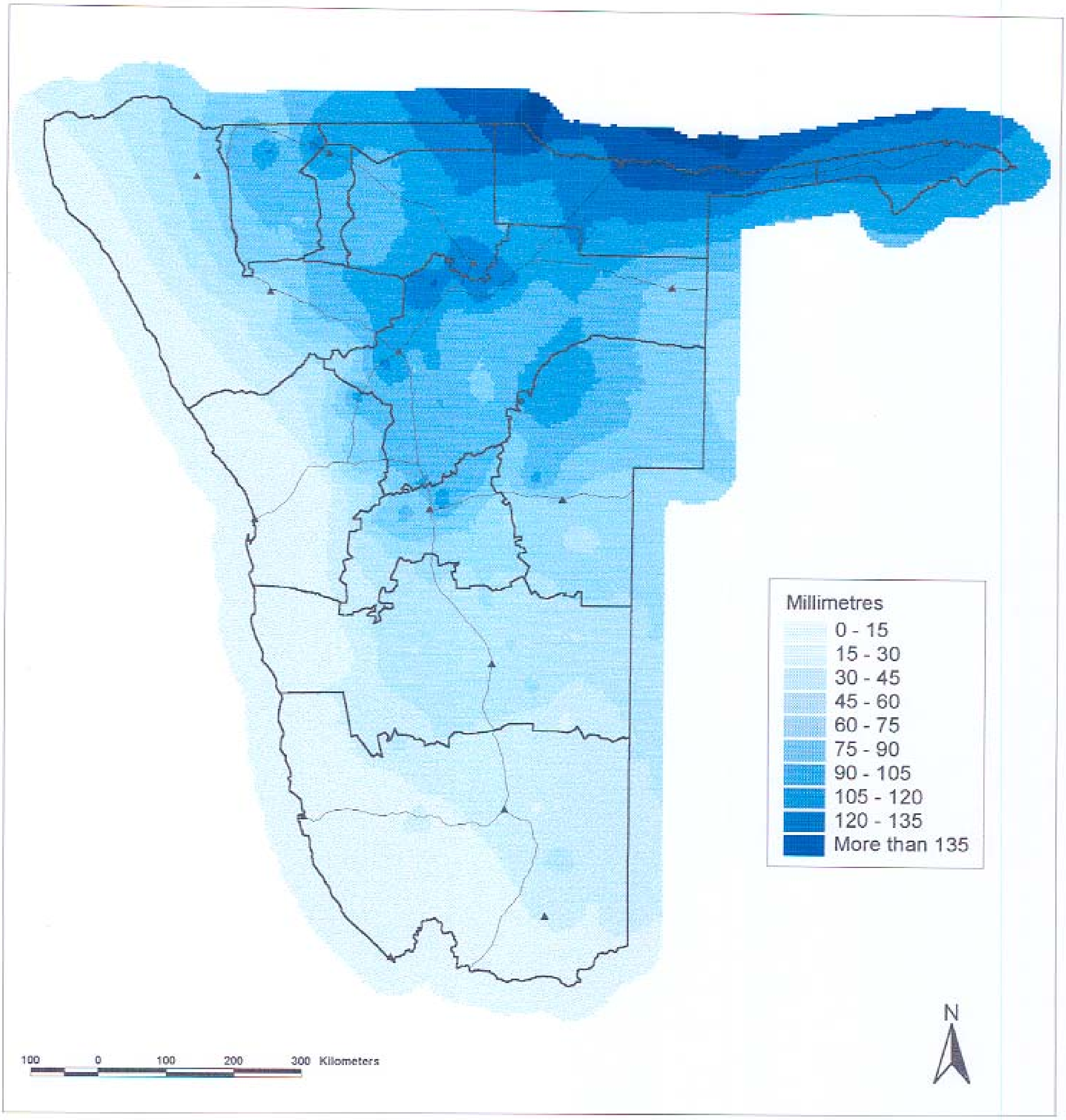
Map 28
Median January rainfall



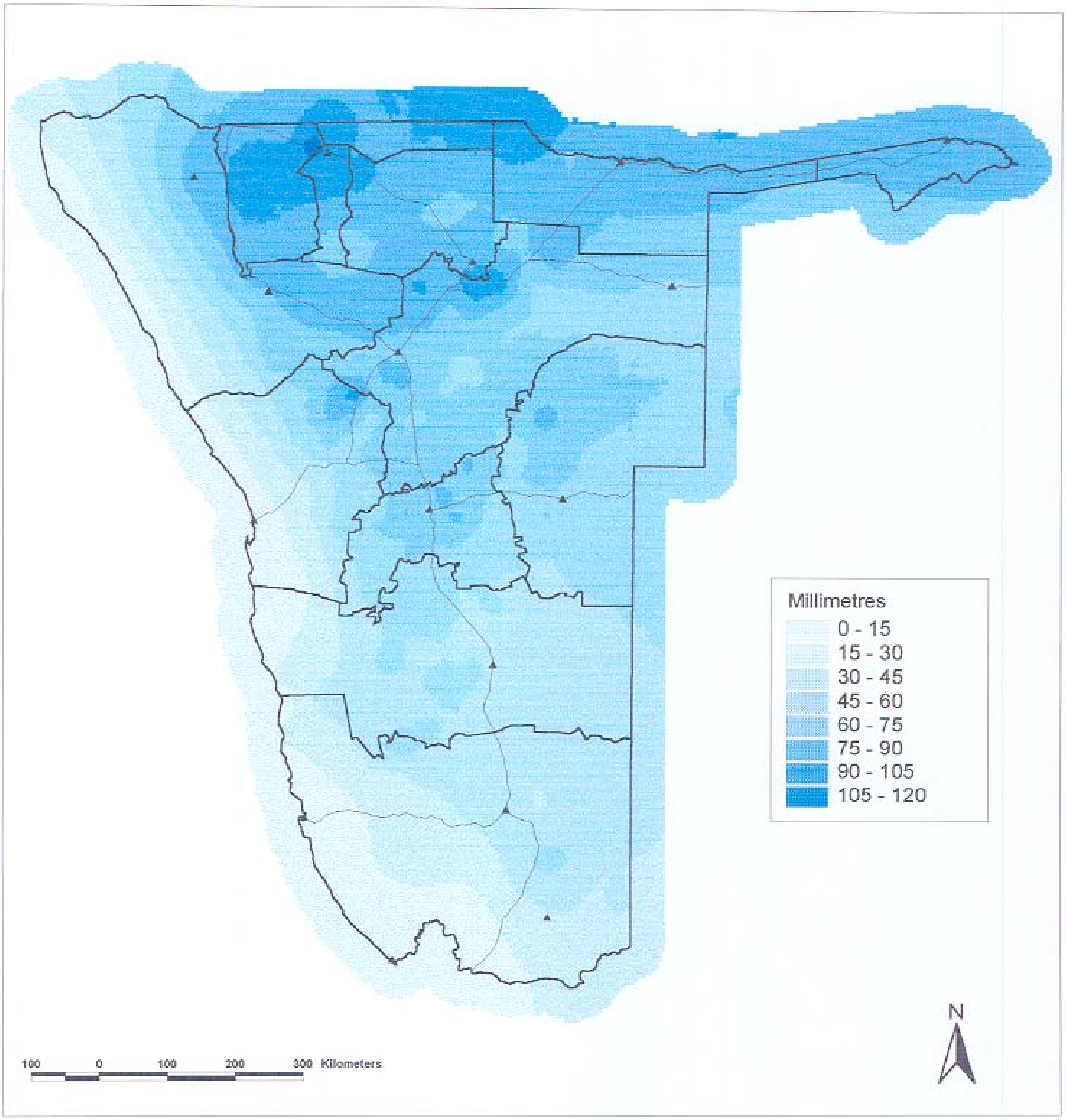
Map 29
Average February rainfall



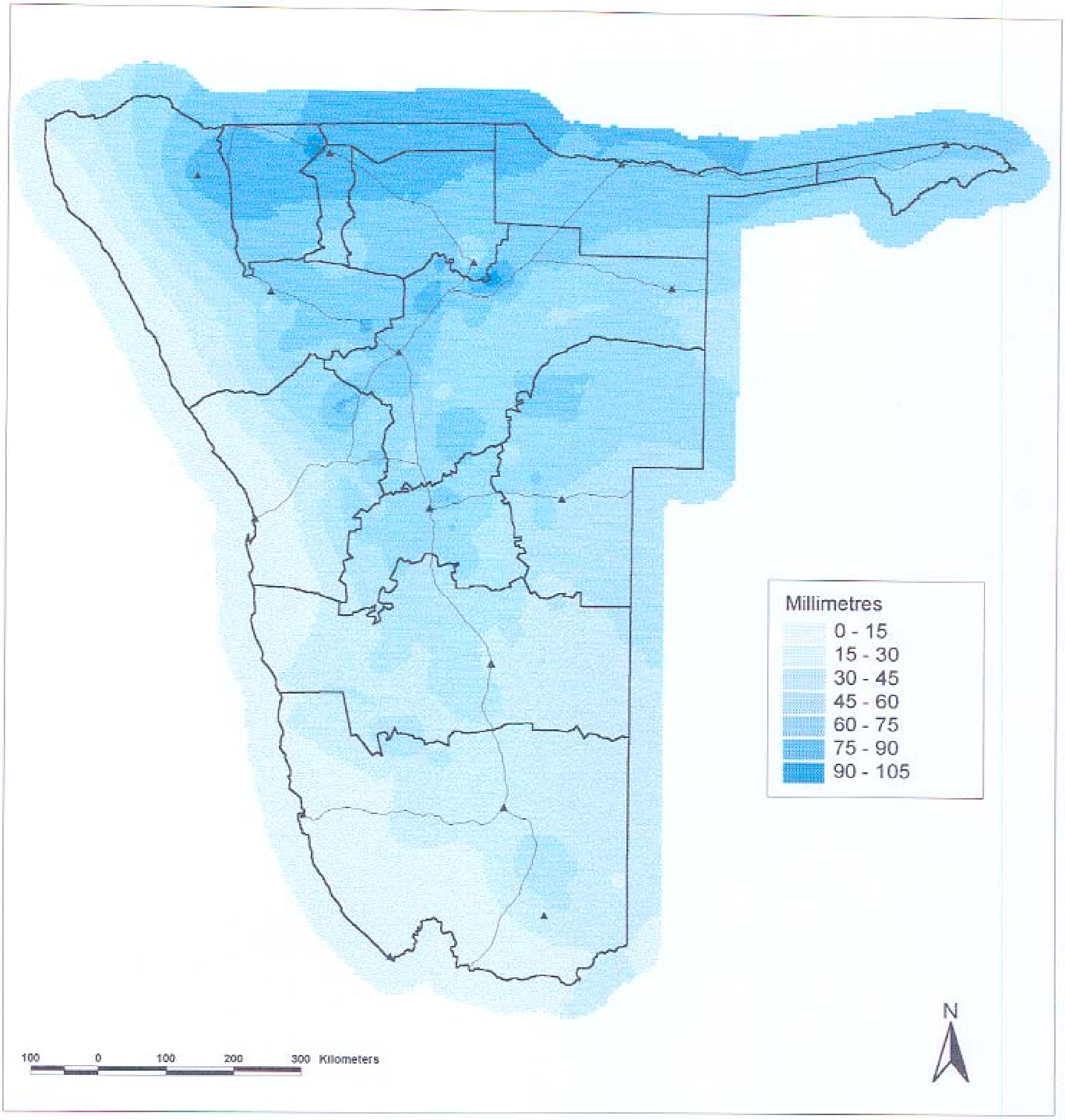
Map 30
Median February rainfall



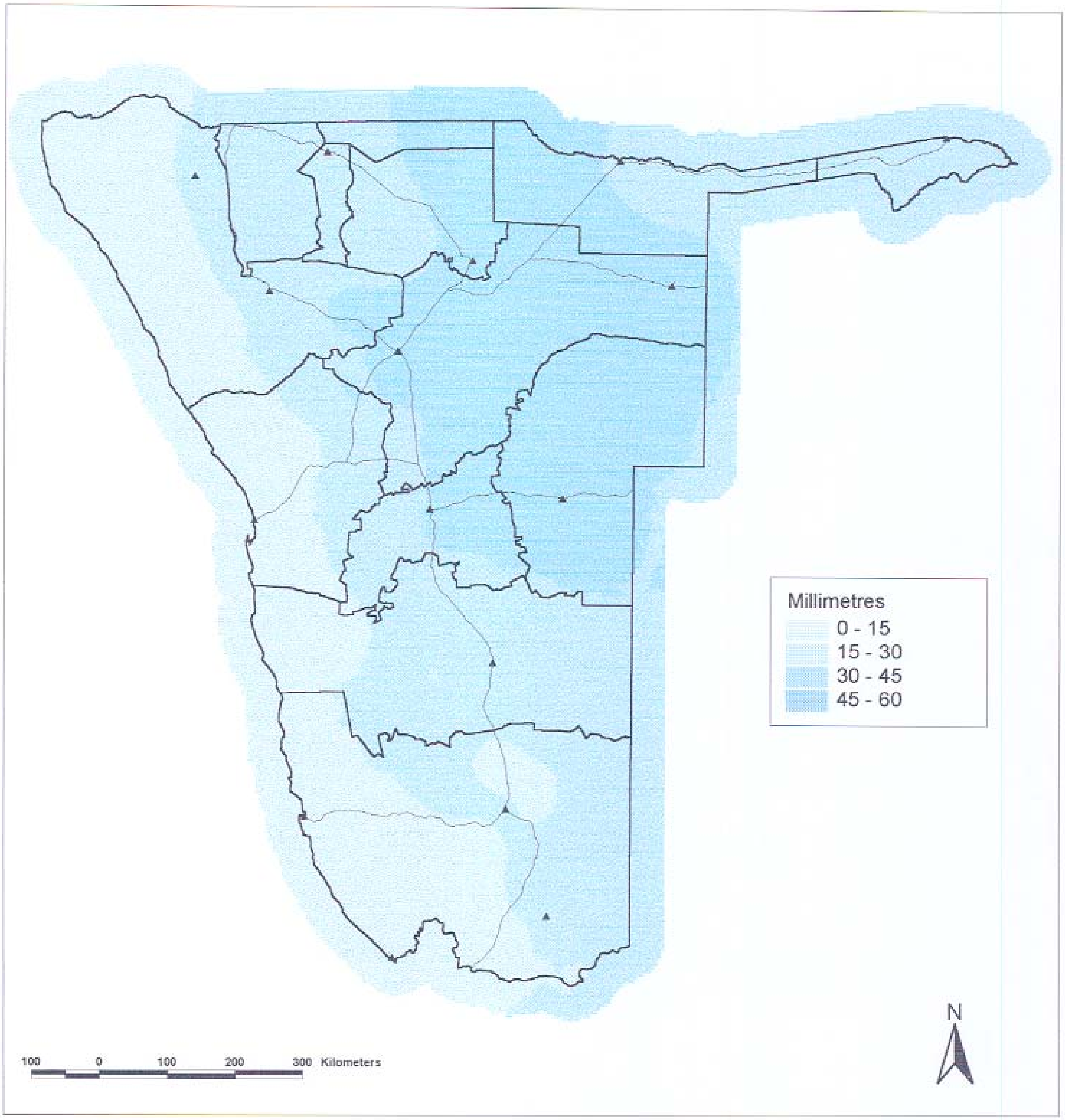
Map 31
Average March rainfall



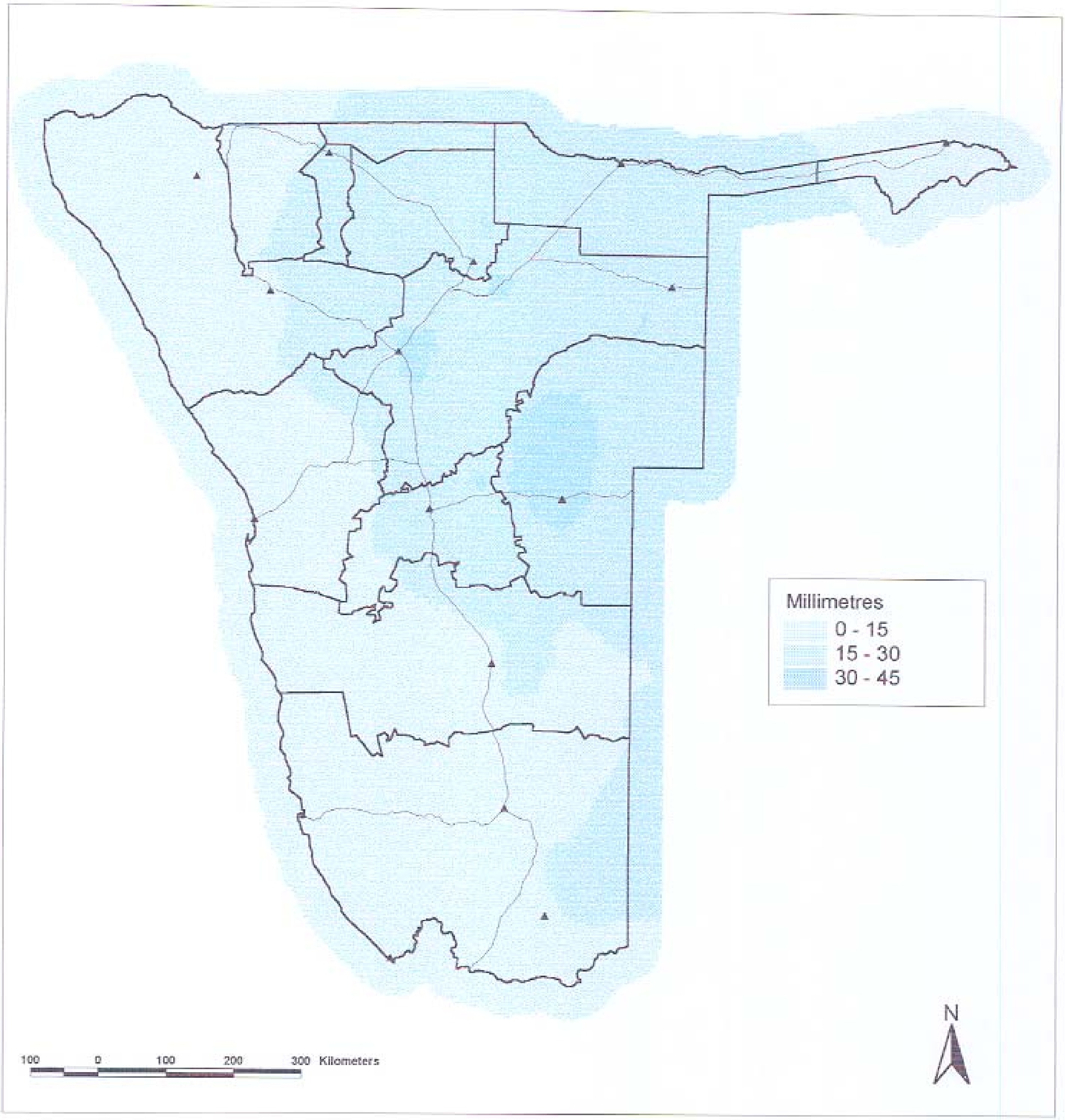
Map 32
Median March rainfall



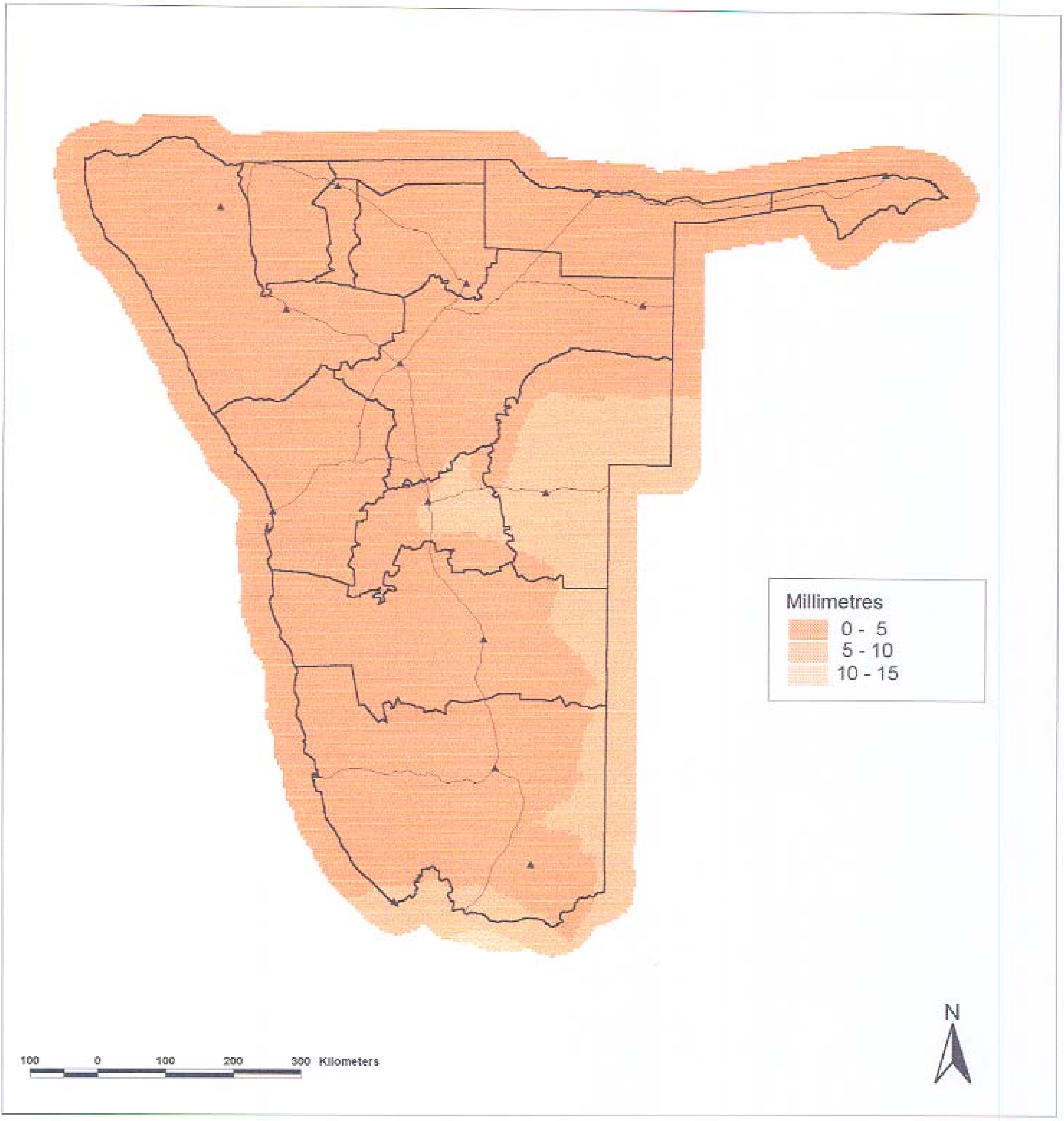
Map 33
Average April rainfall



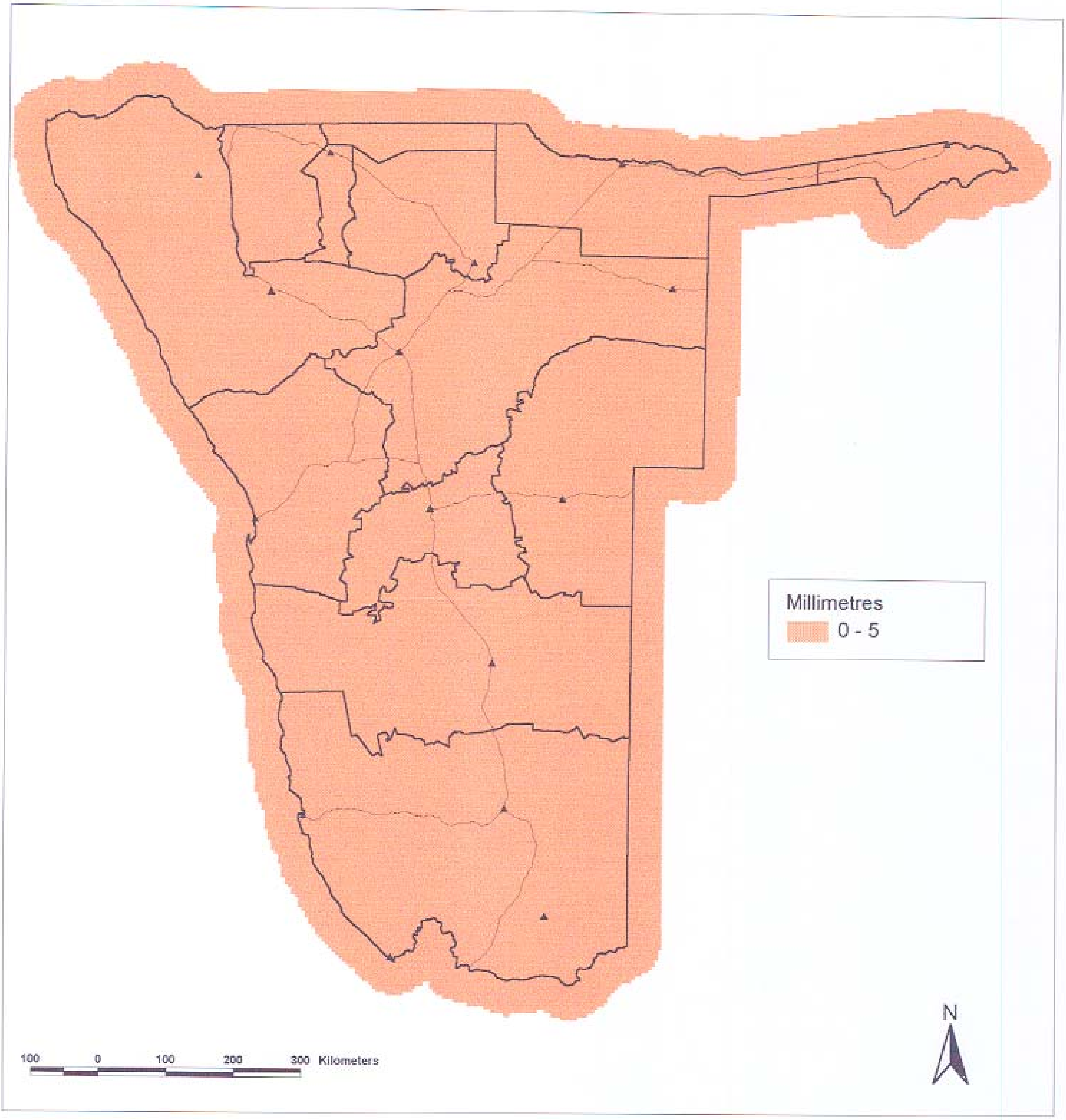
Map 34
Median April rainfall



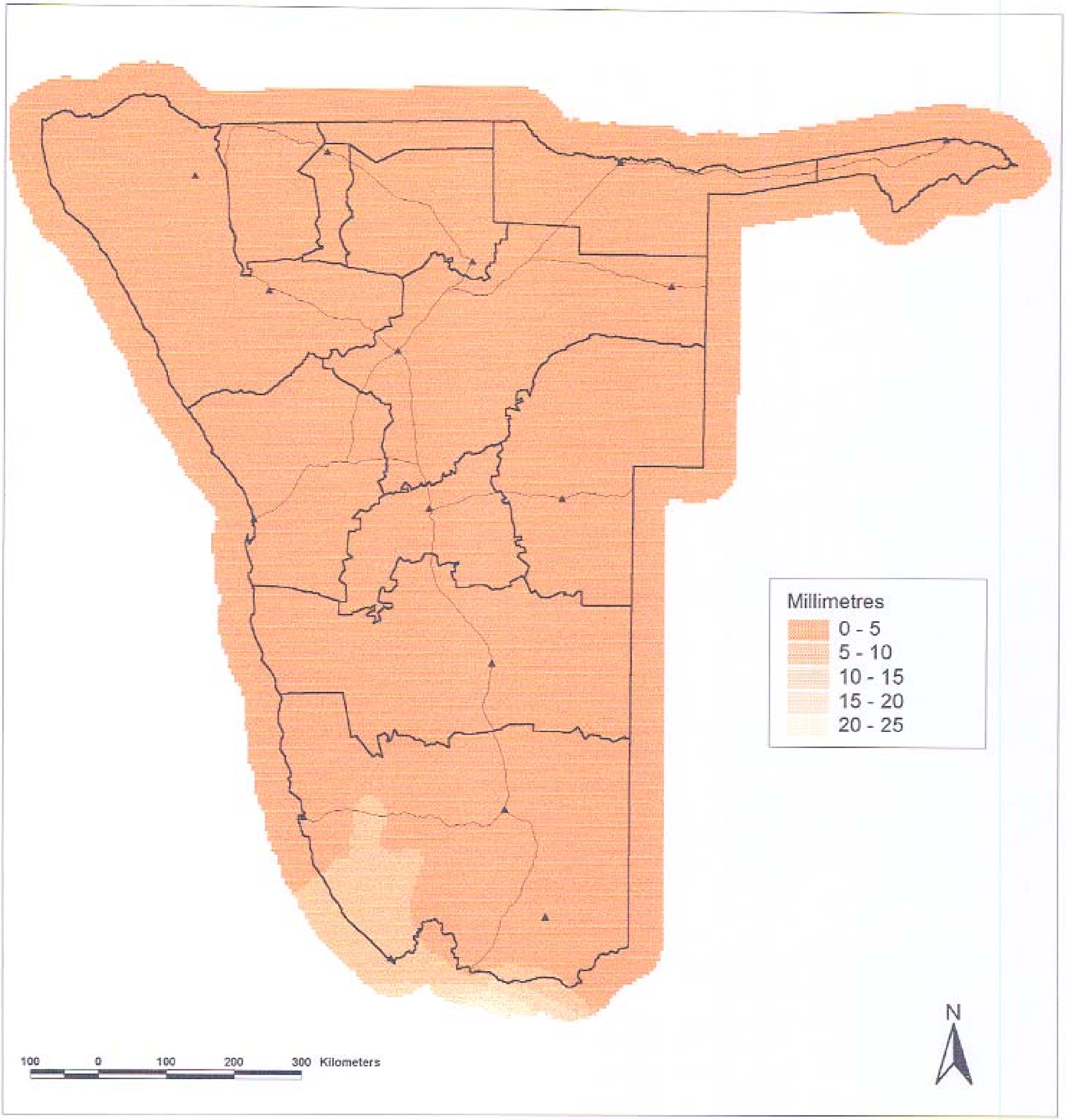
Map 35
Average May rainfall



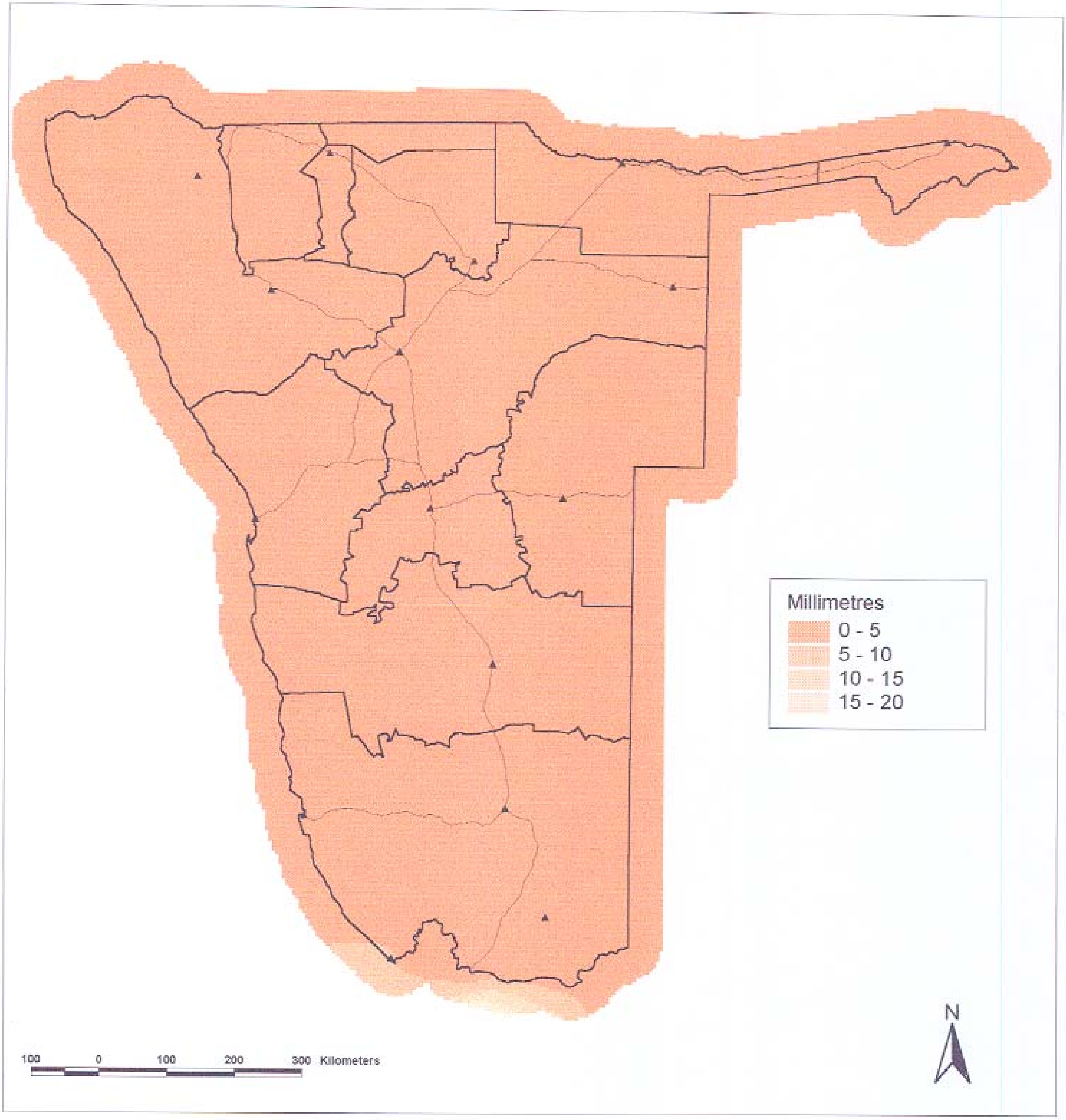
Map 36
Median May rainfall



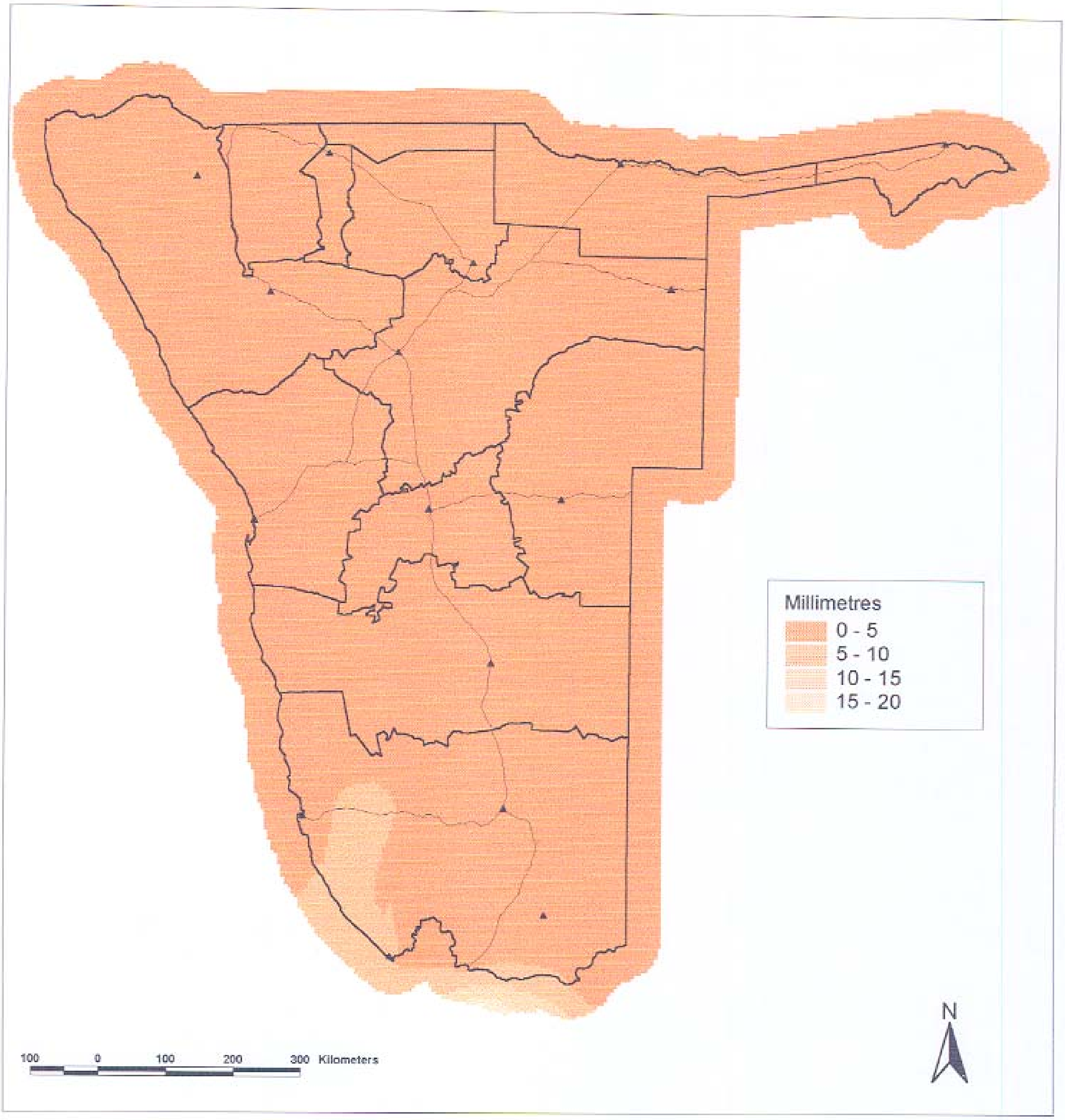
Map 37
Average June rainfall



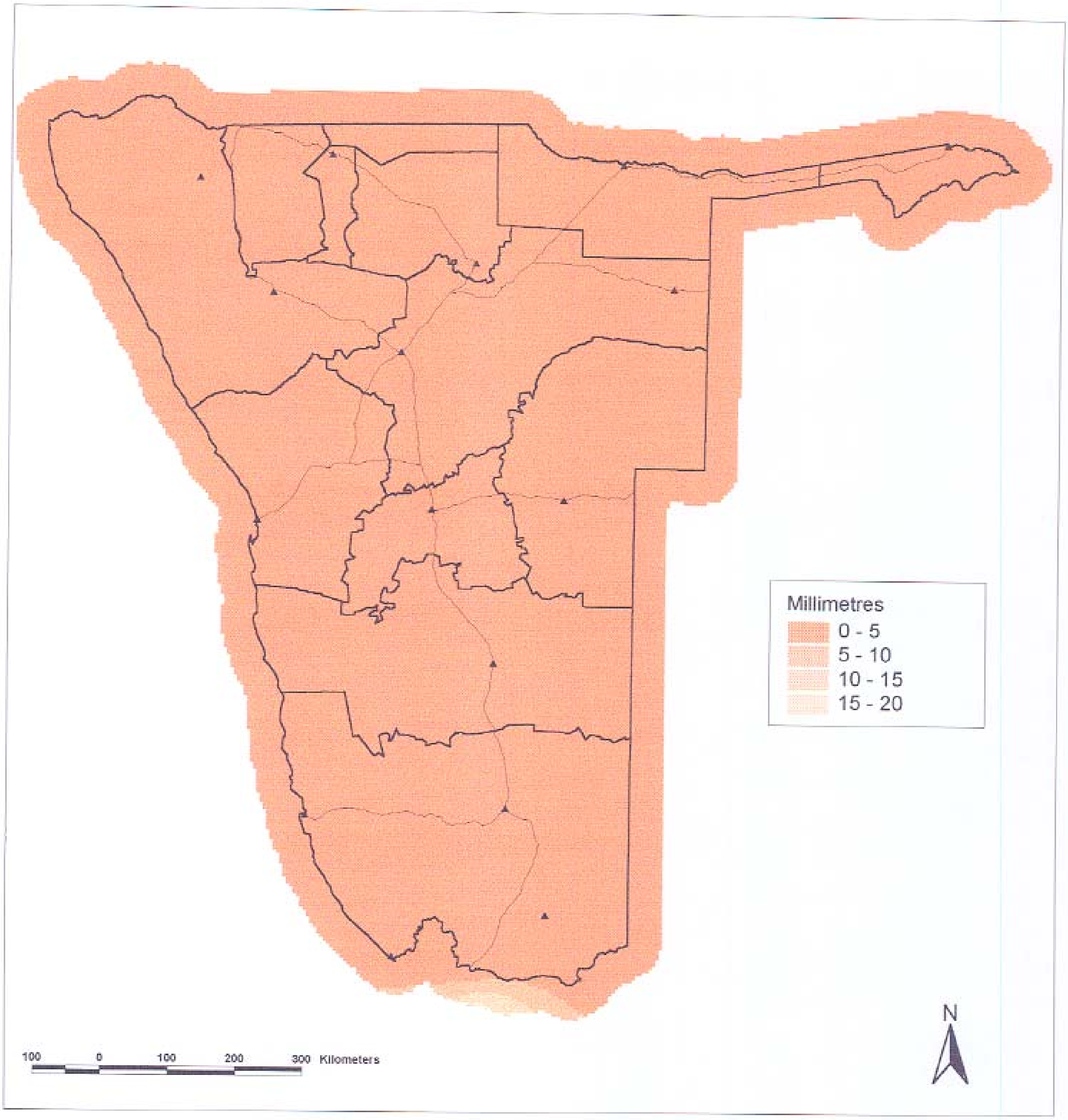
Map 38
Median June rainfall



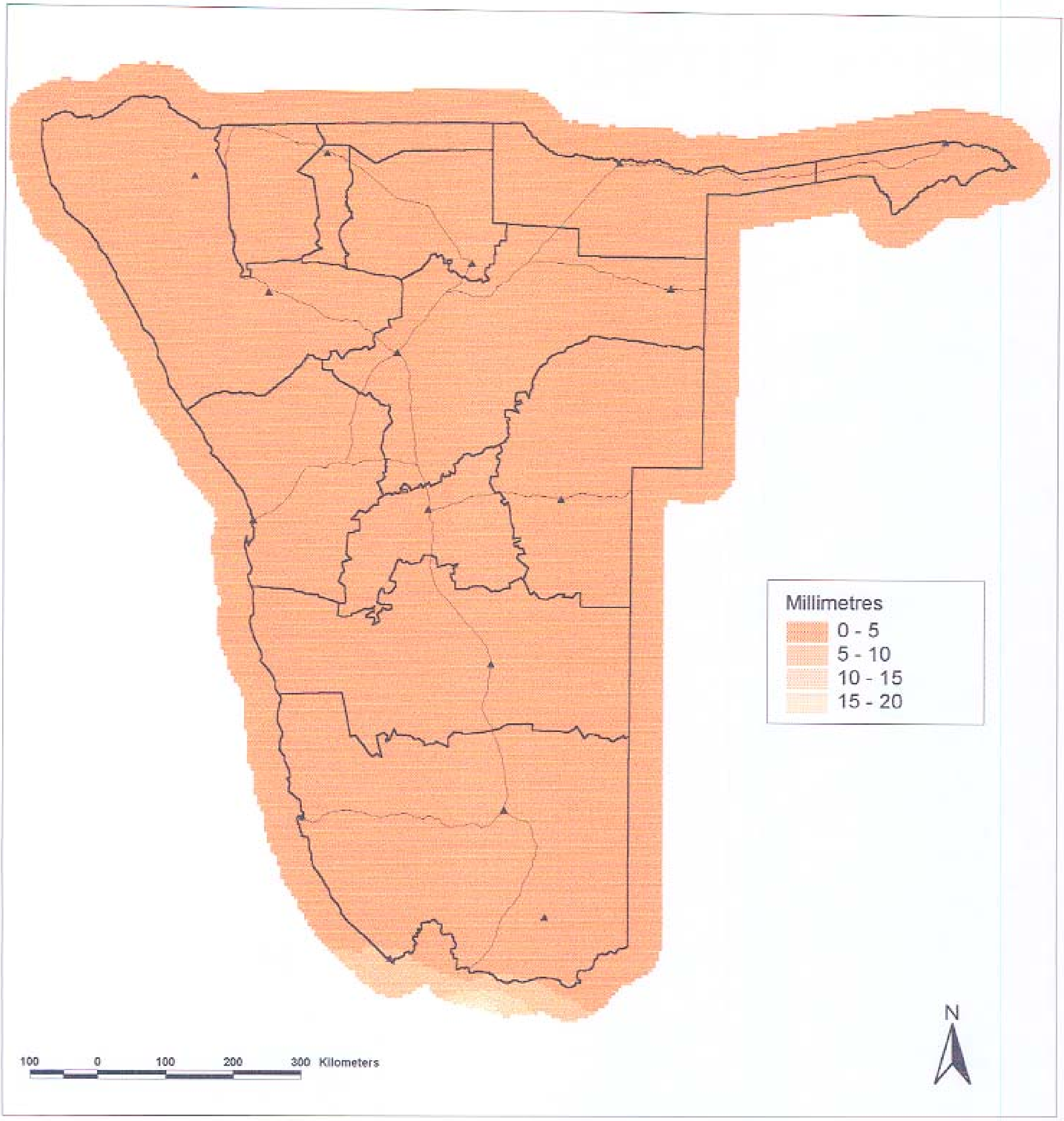
Map 39
Average July rainfall



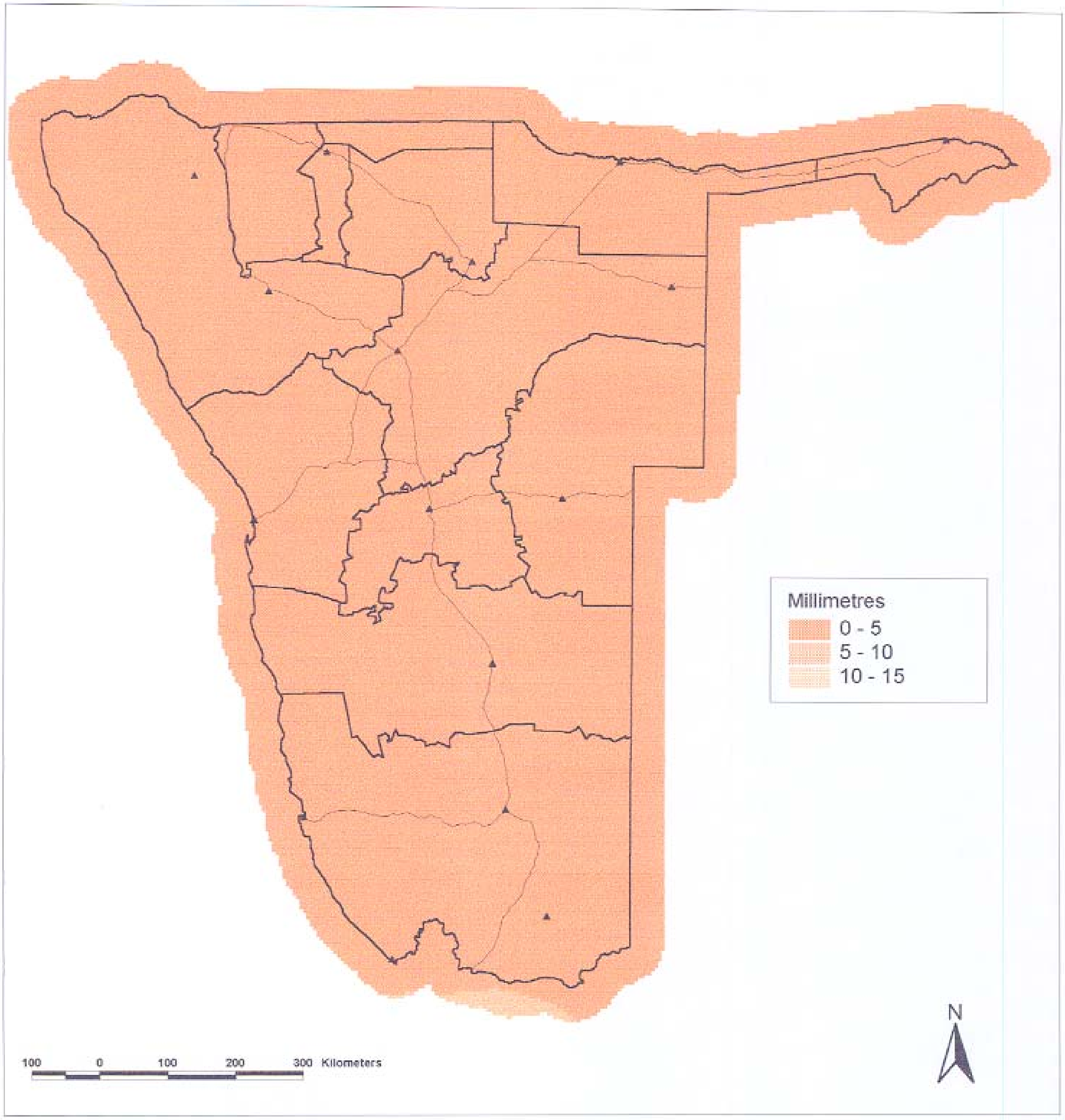
Map 40
Median July rainfall



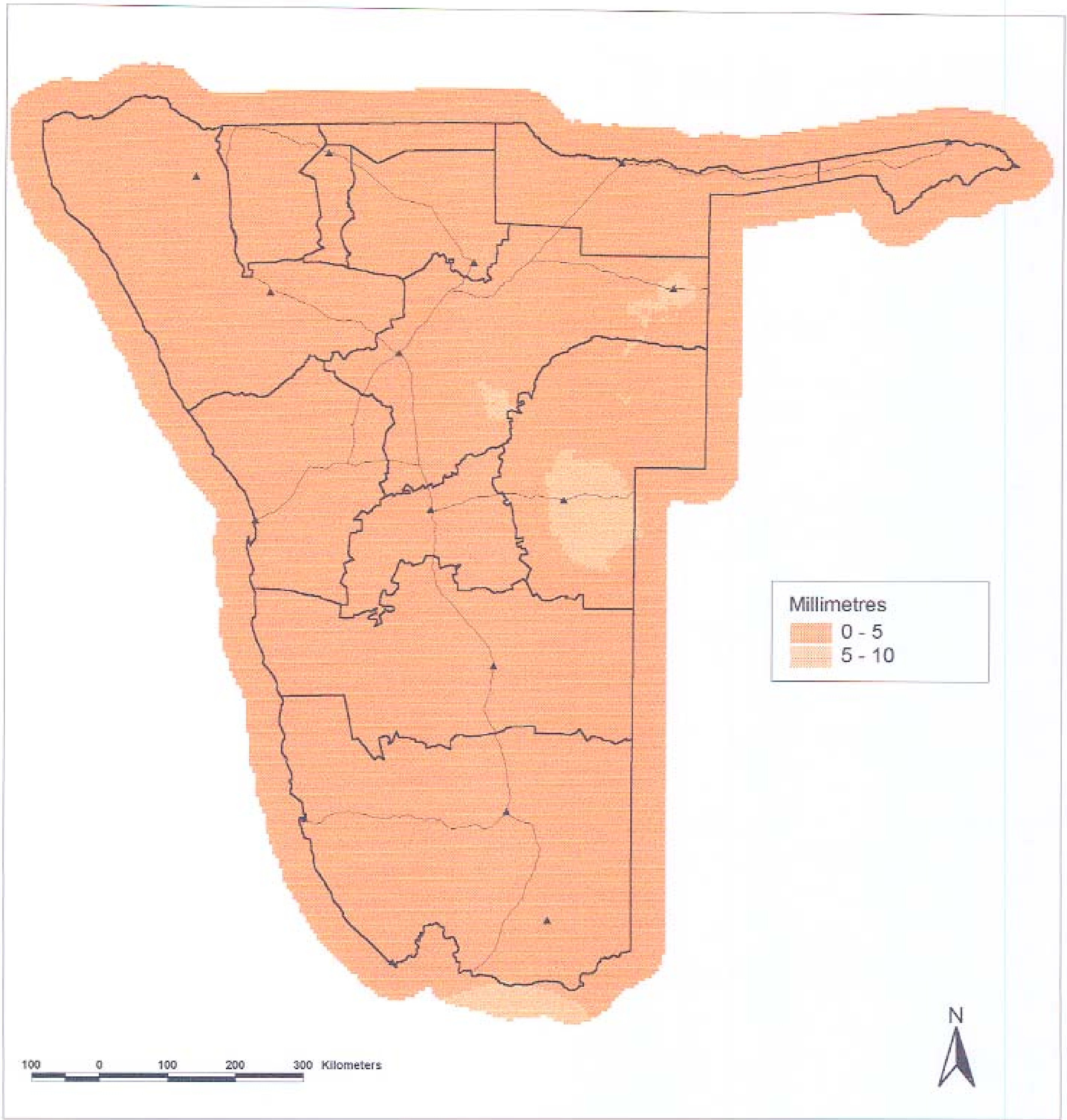
Map 41
Average August rainfall



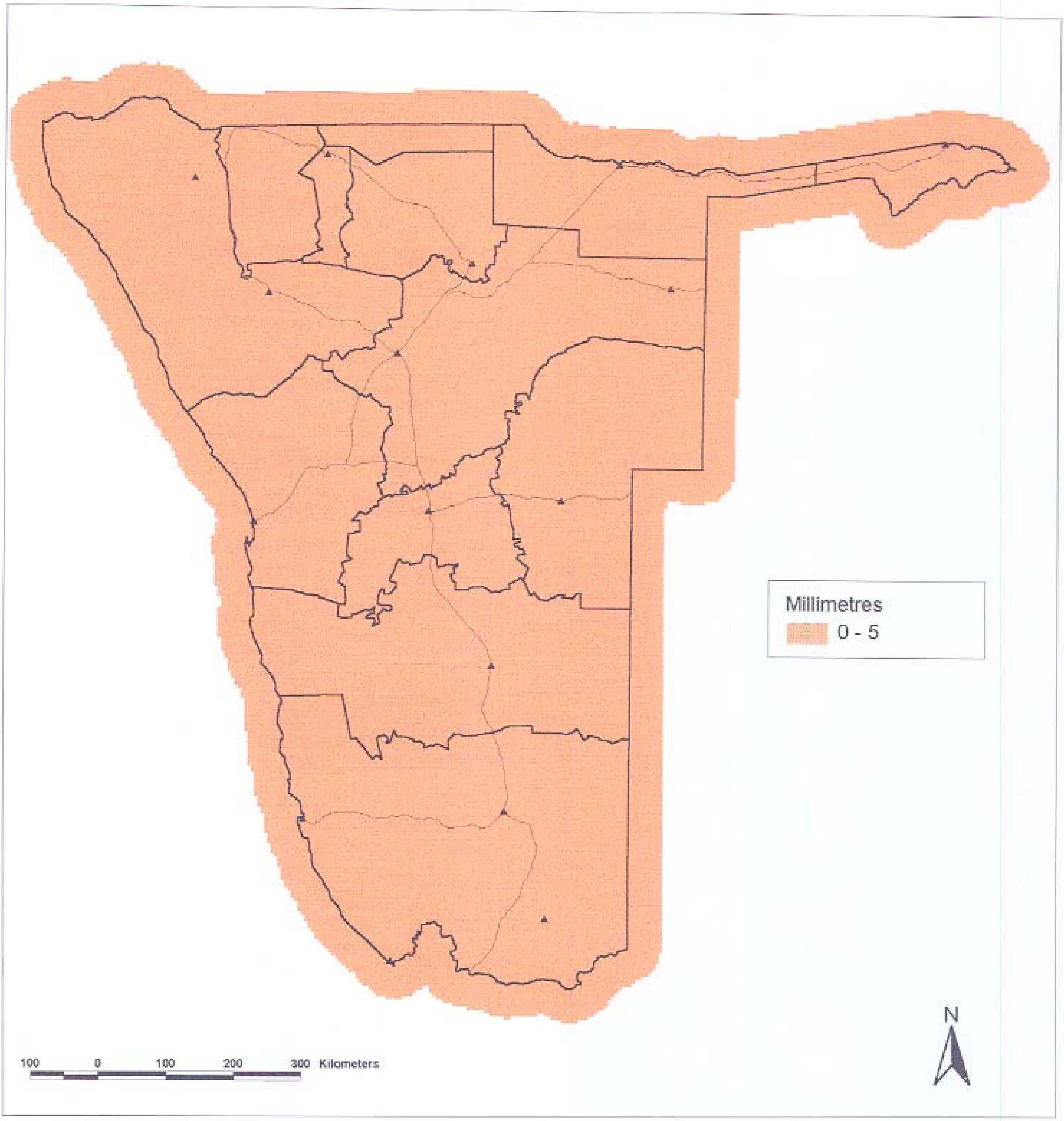
Map 42
Median August rainfall



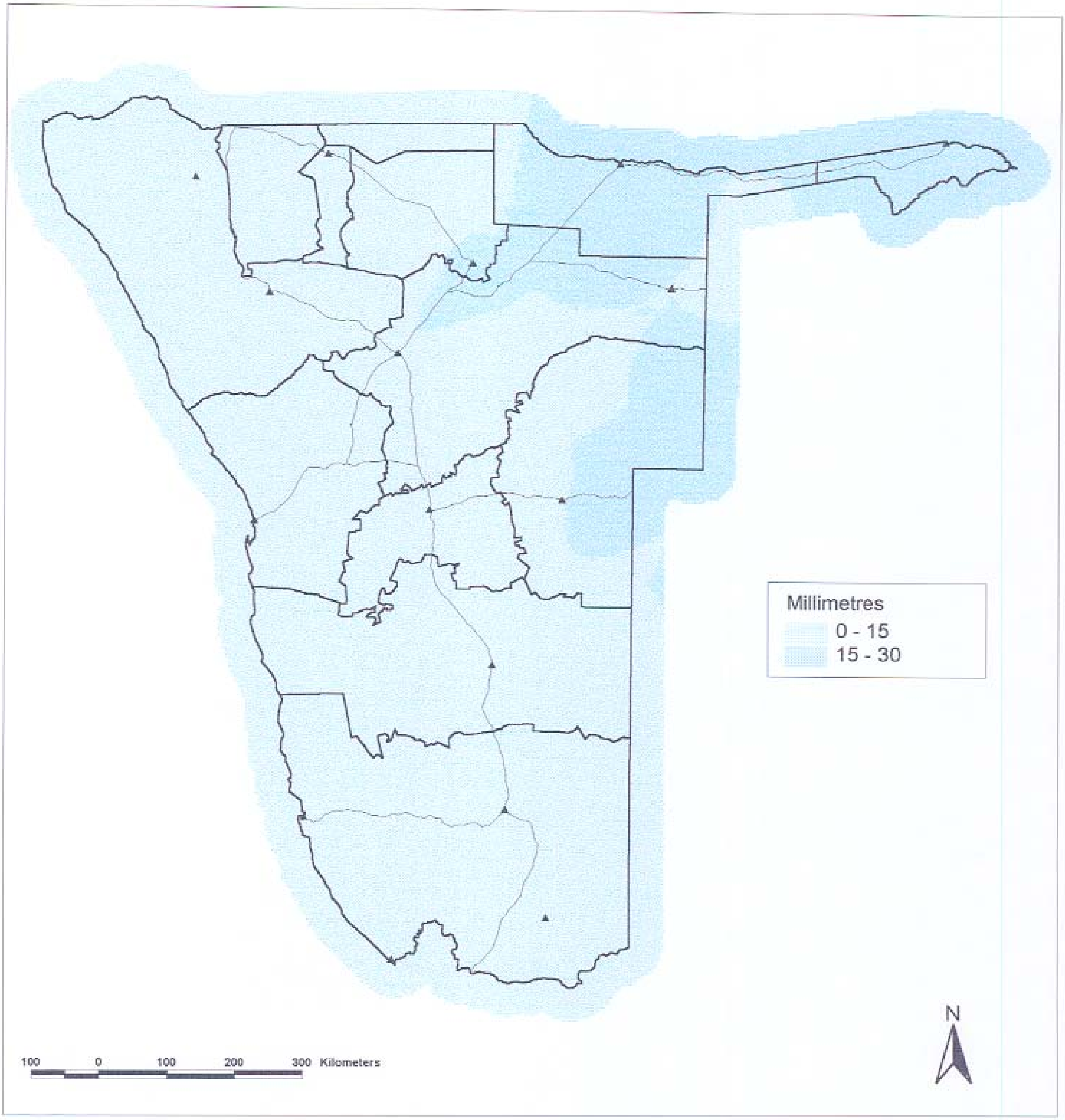
Map 43
Average September rainfall



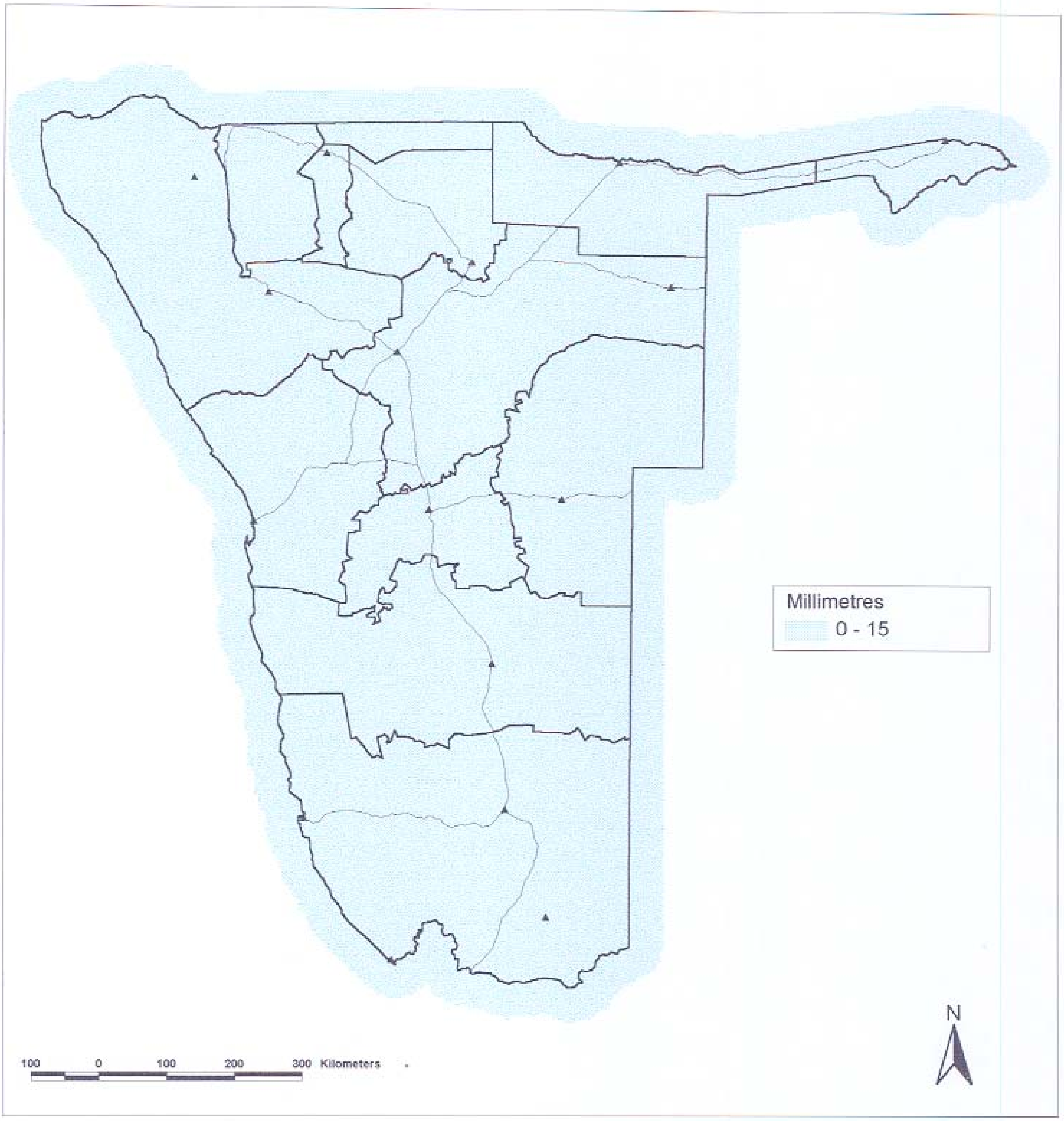
Map 44
Median September rainfall



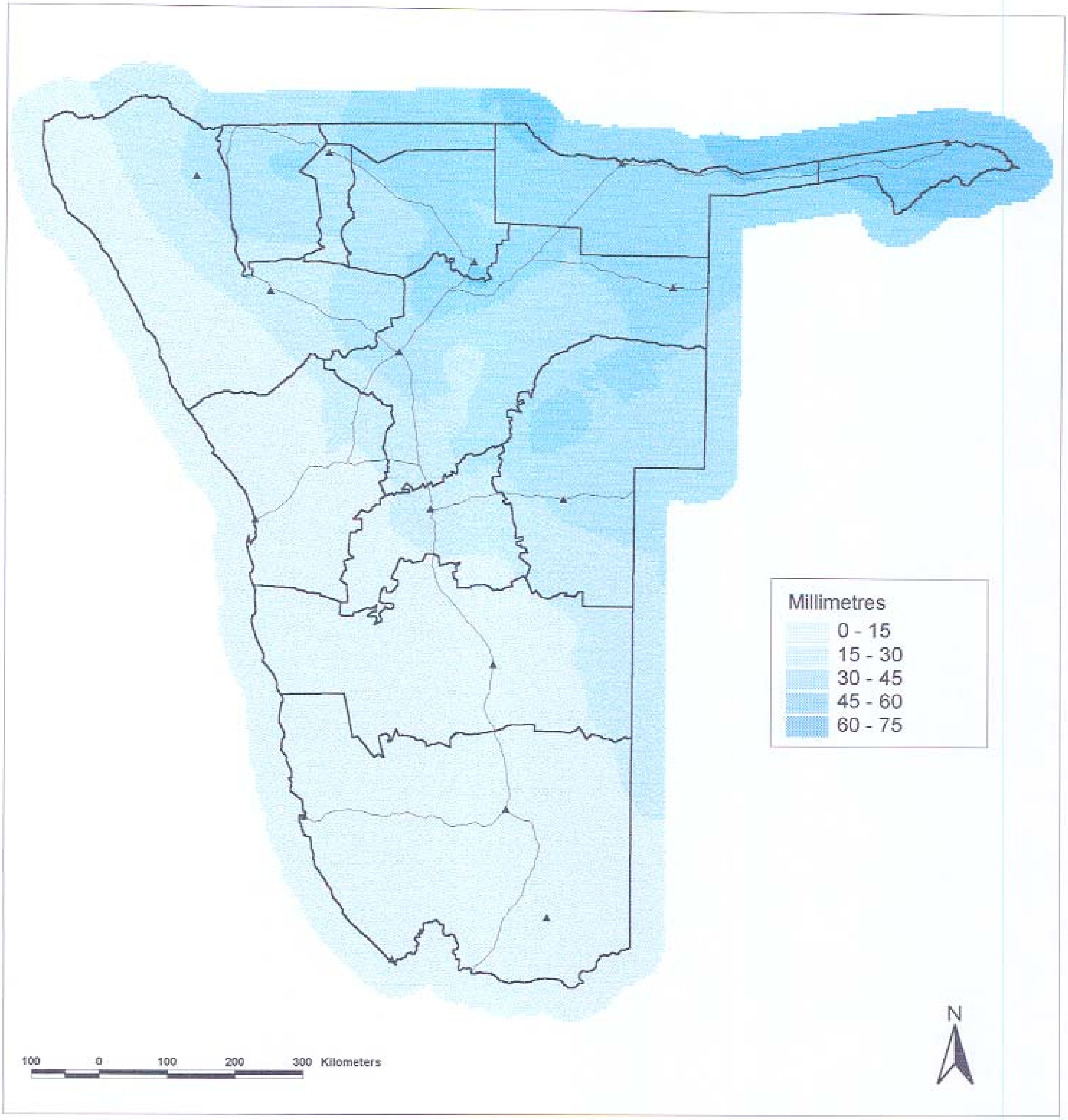
Map 45
Average October rainfall



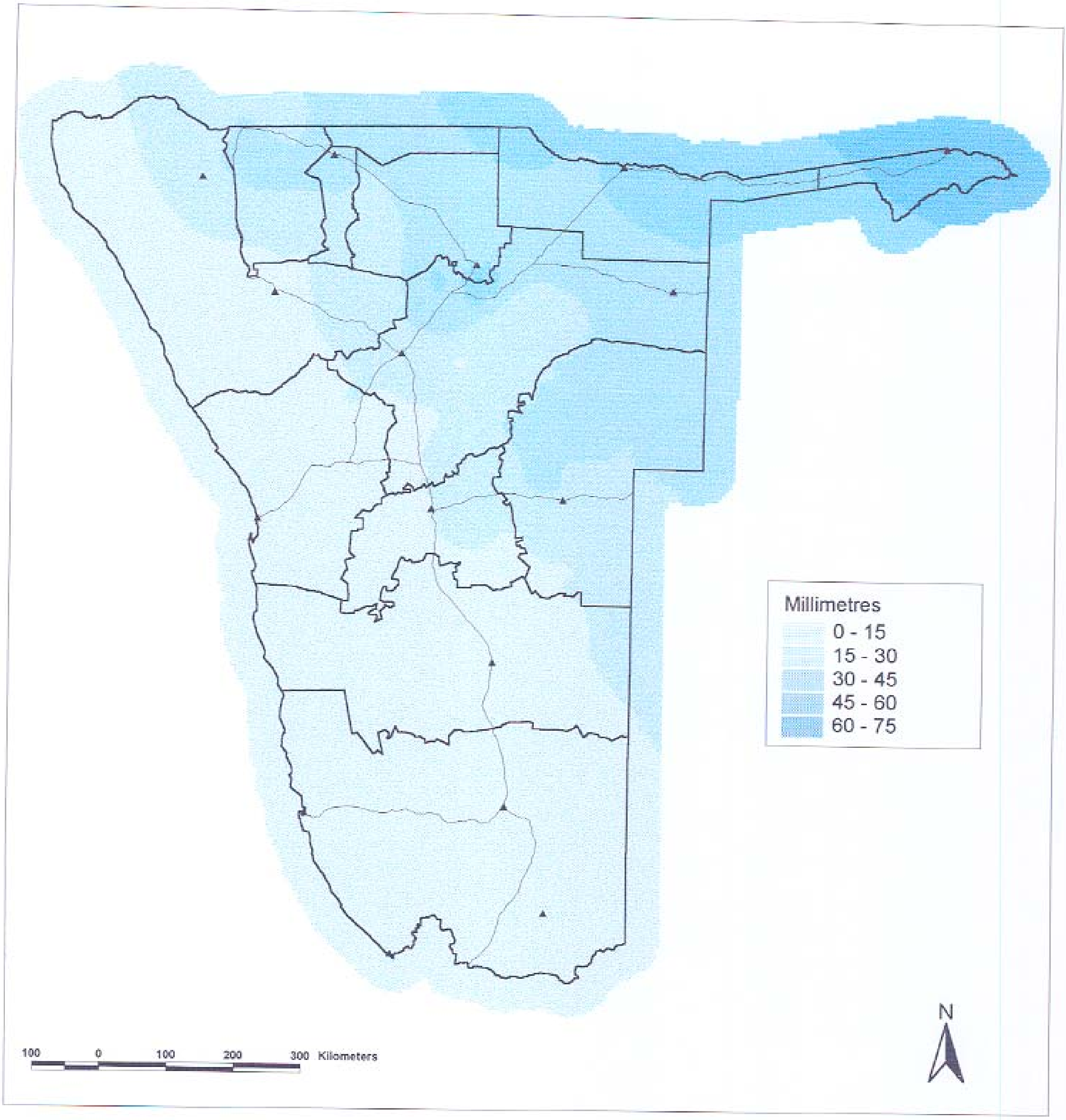
Map 46
Median October rainfall



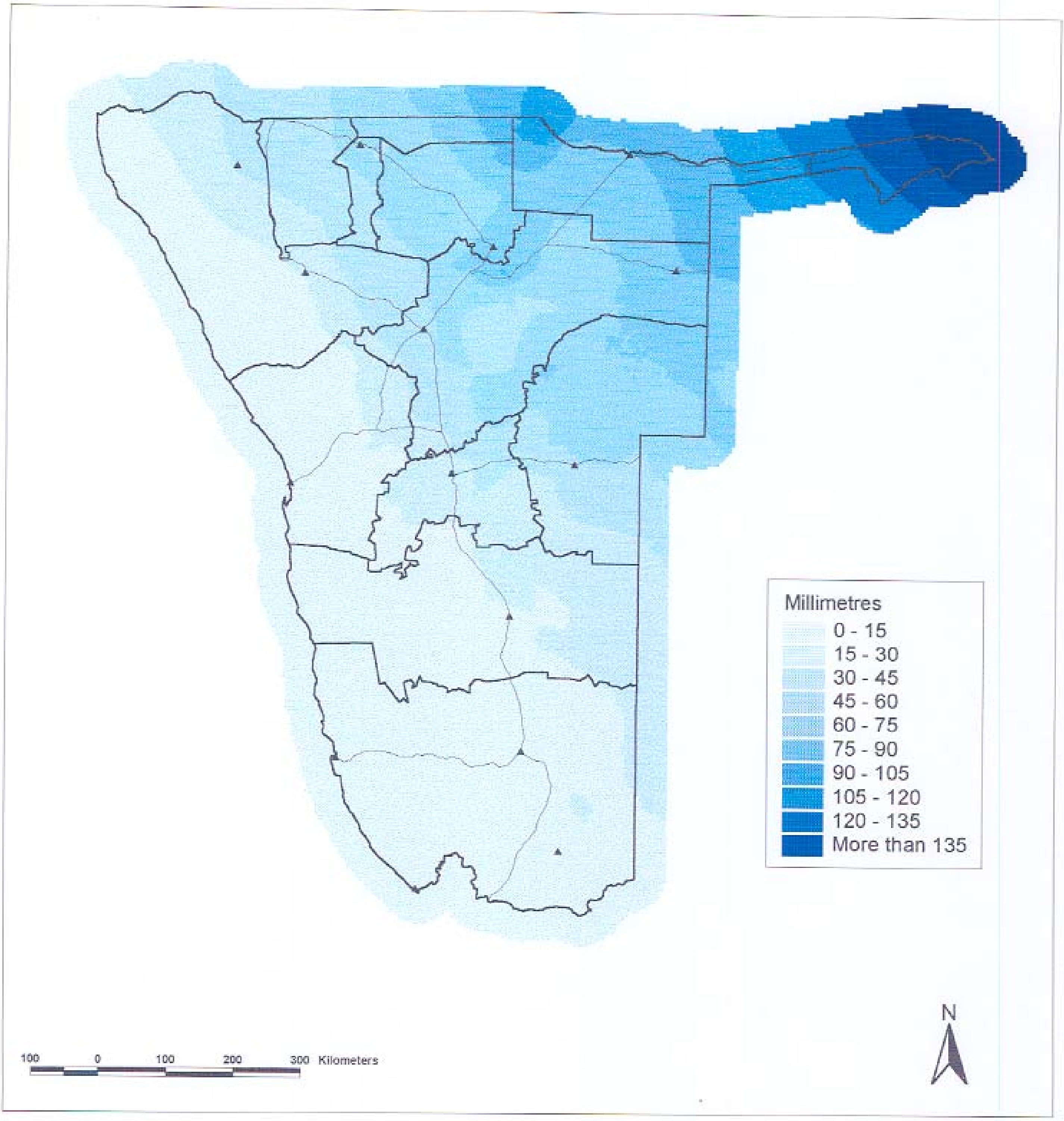
Map 47
Average November rainfall



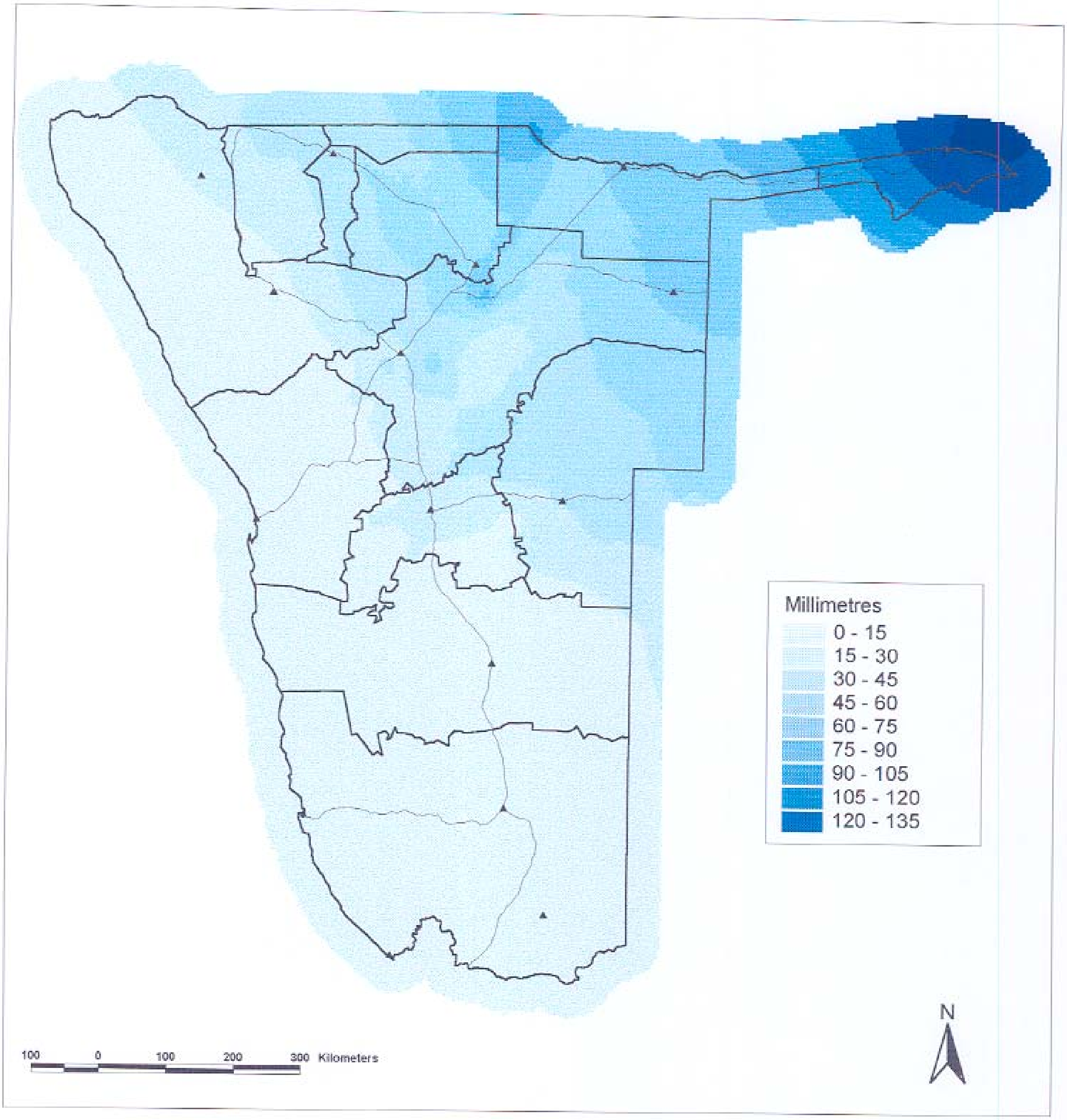
Map 48
Median November rainfall



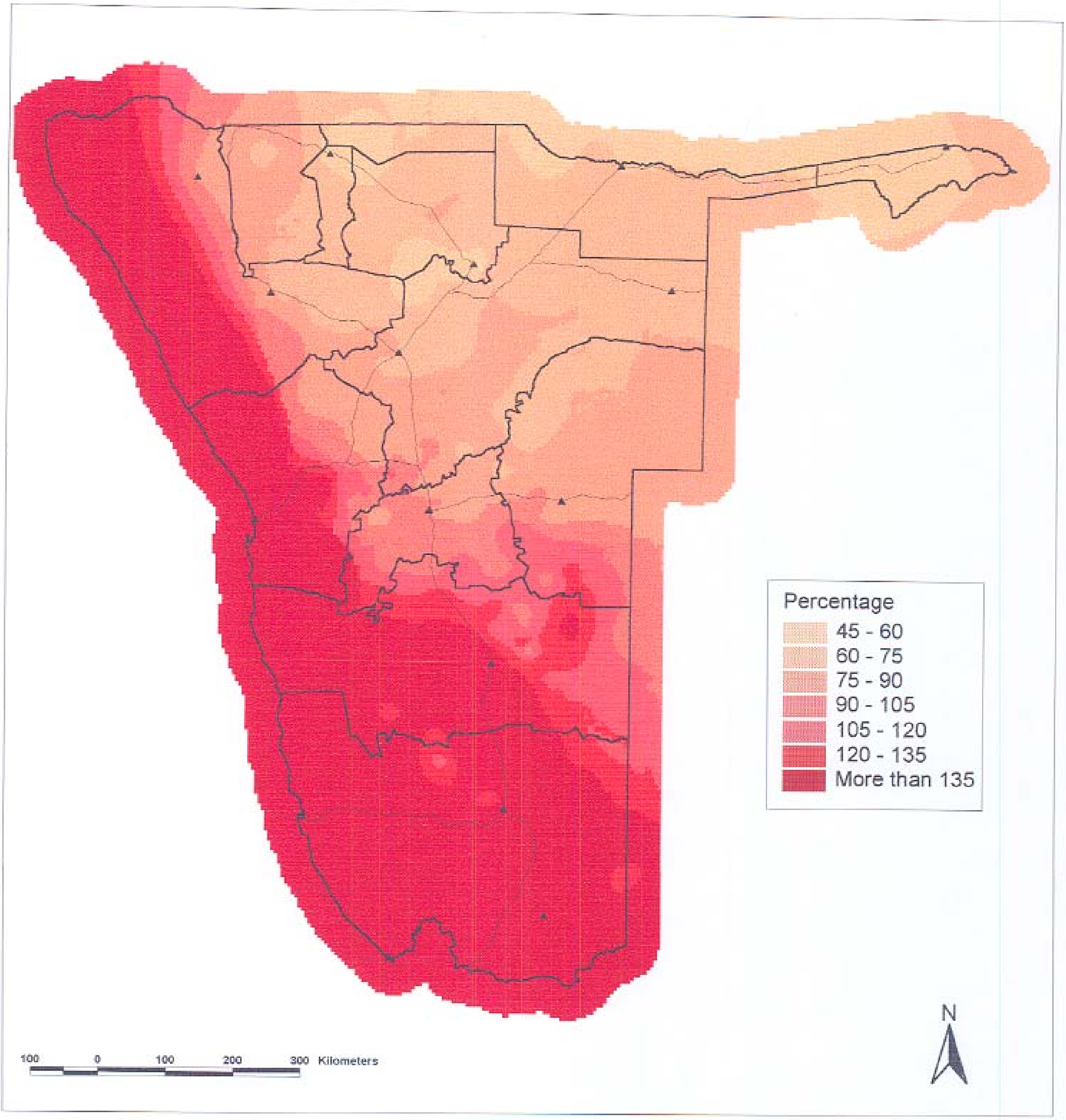
Map 49
Average December rainfall



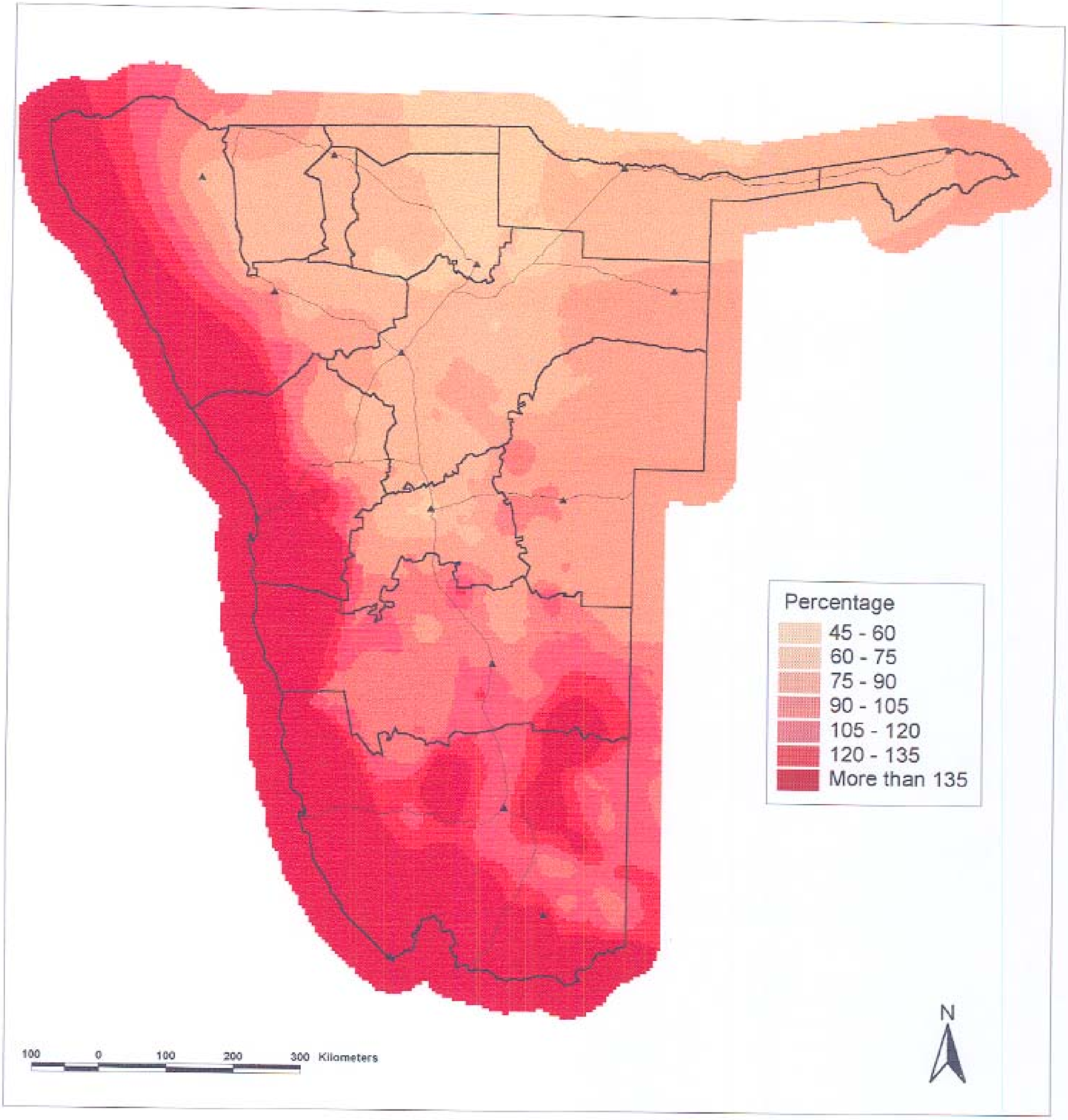
Map 50
Median December rainfall



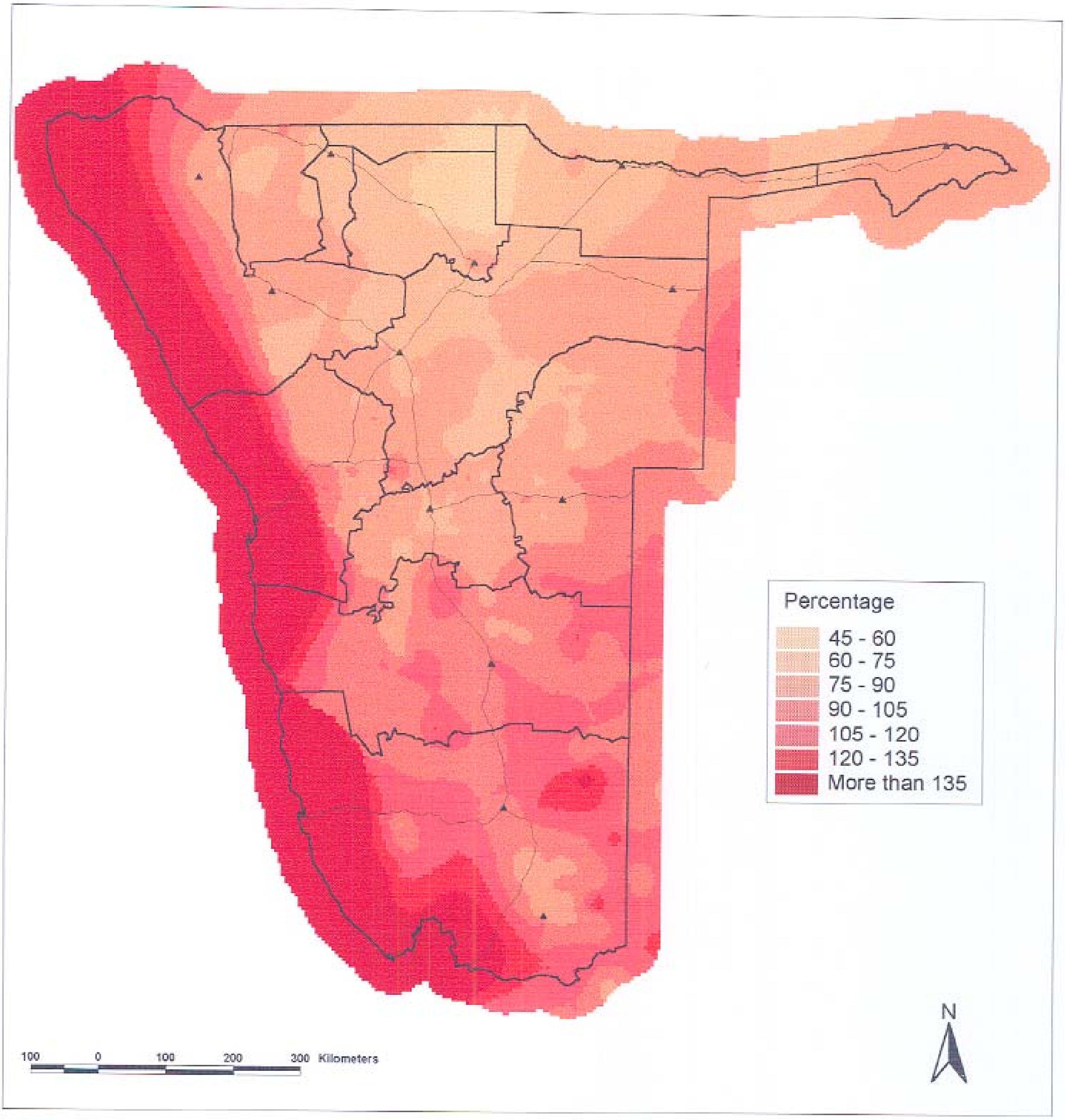
Map 51
Coefficient of variation: rainfall in January



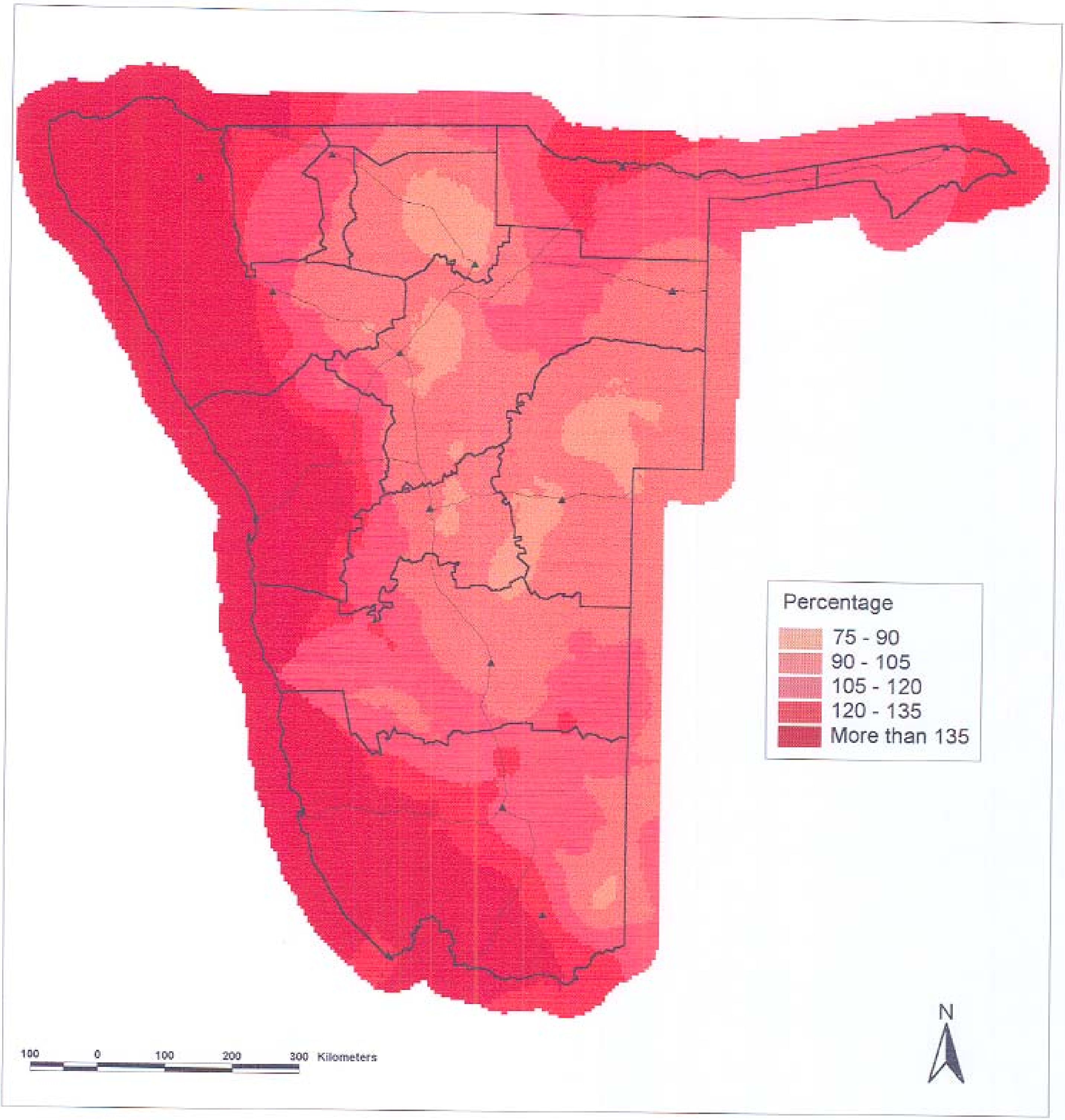
Map 52
Coefficient of variation: rainfall in February



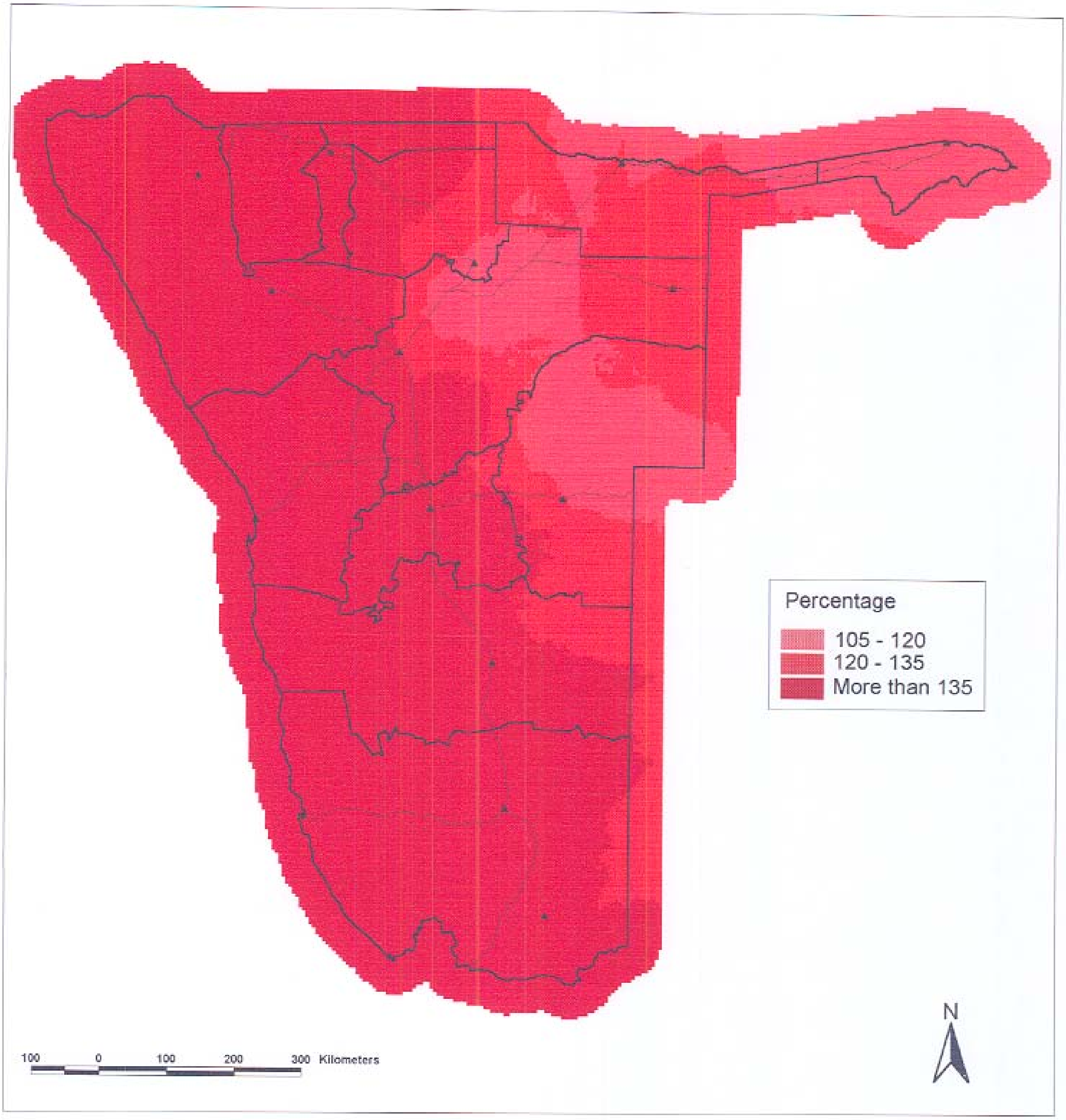
Map 53
Coefficient of variation: rainfall in March



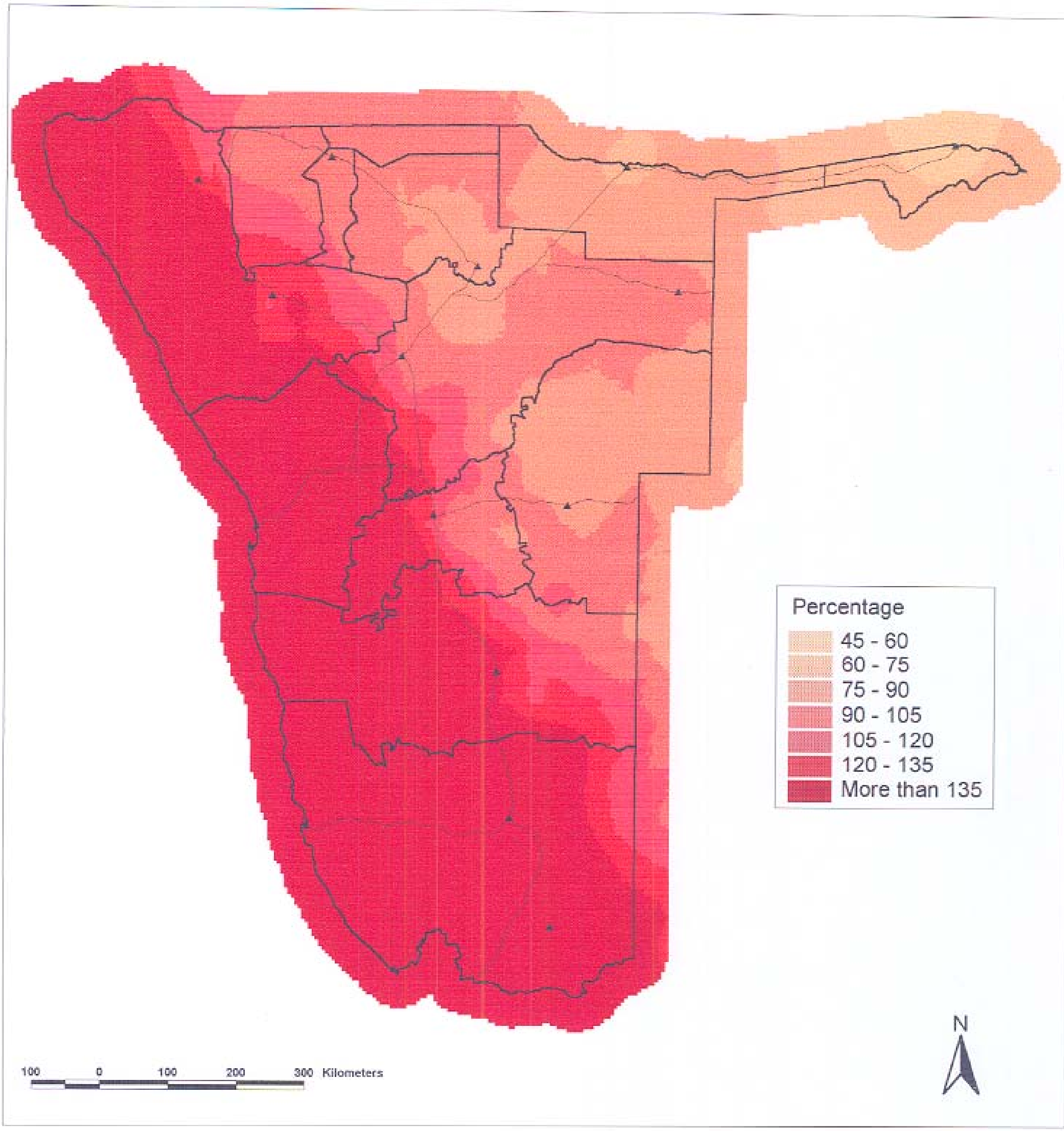
Map 54
Coefficient of variation: rainfall in April



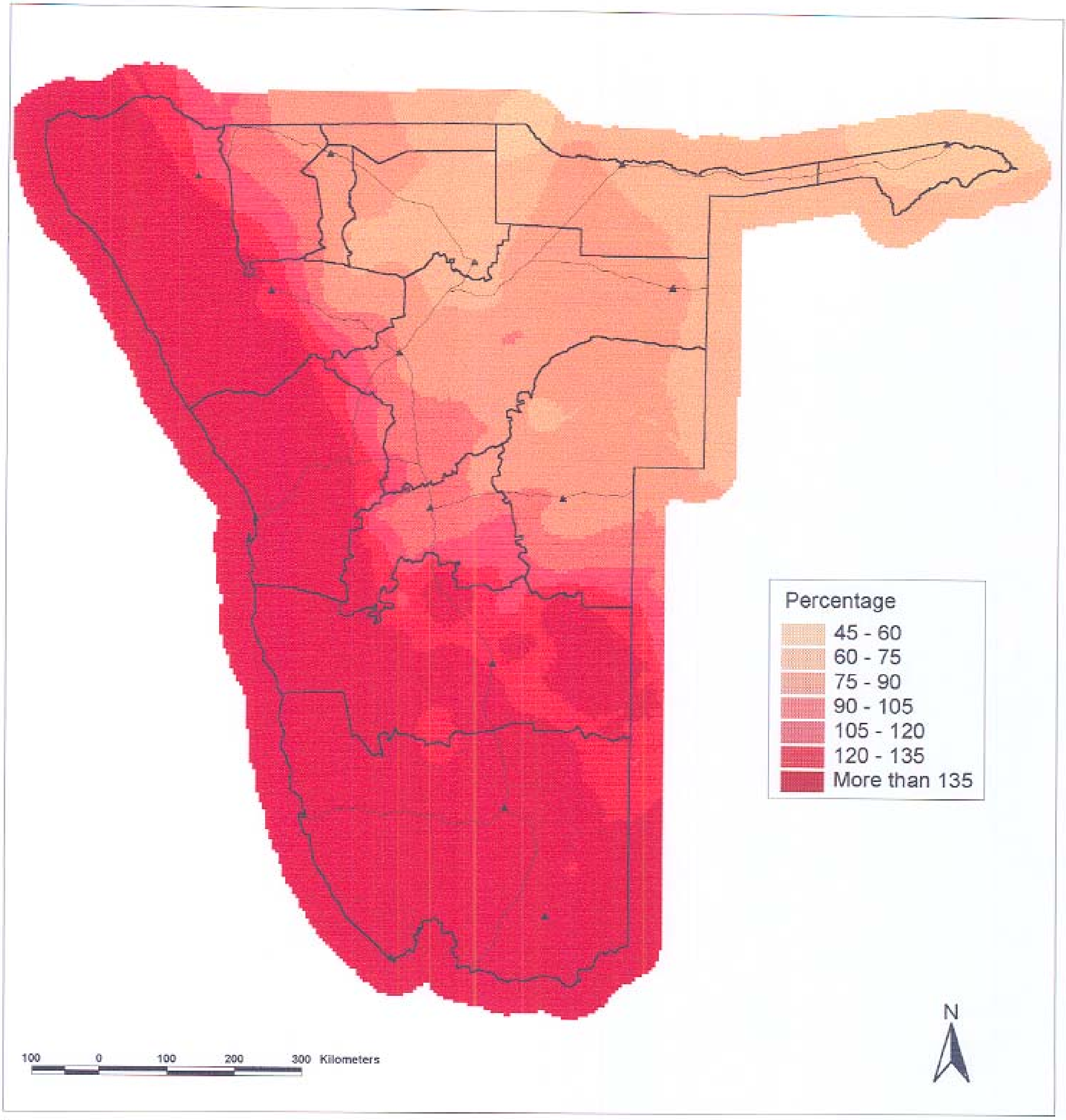
Map 55
Coefficient of variation: rainfall in October



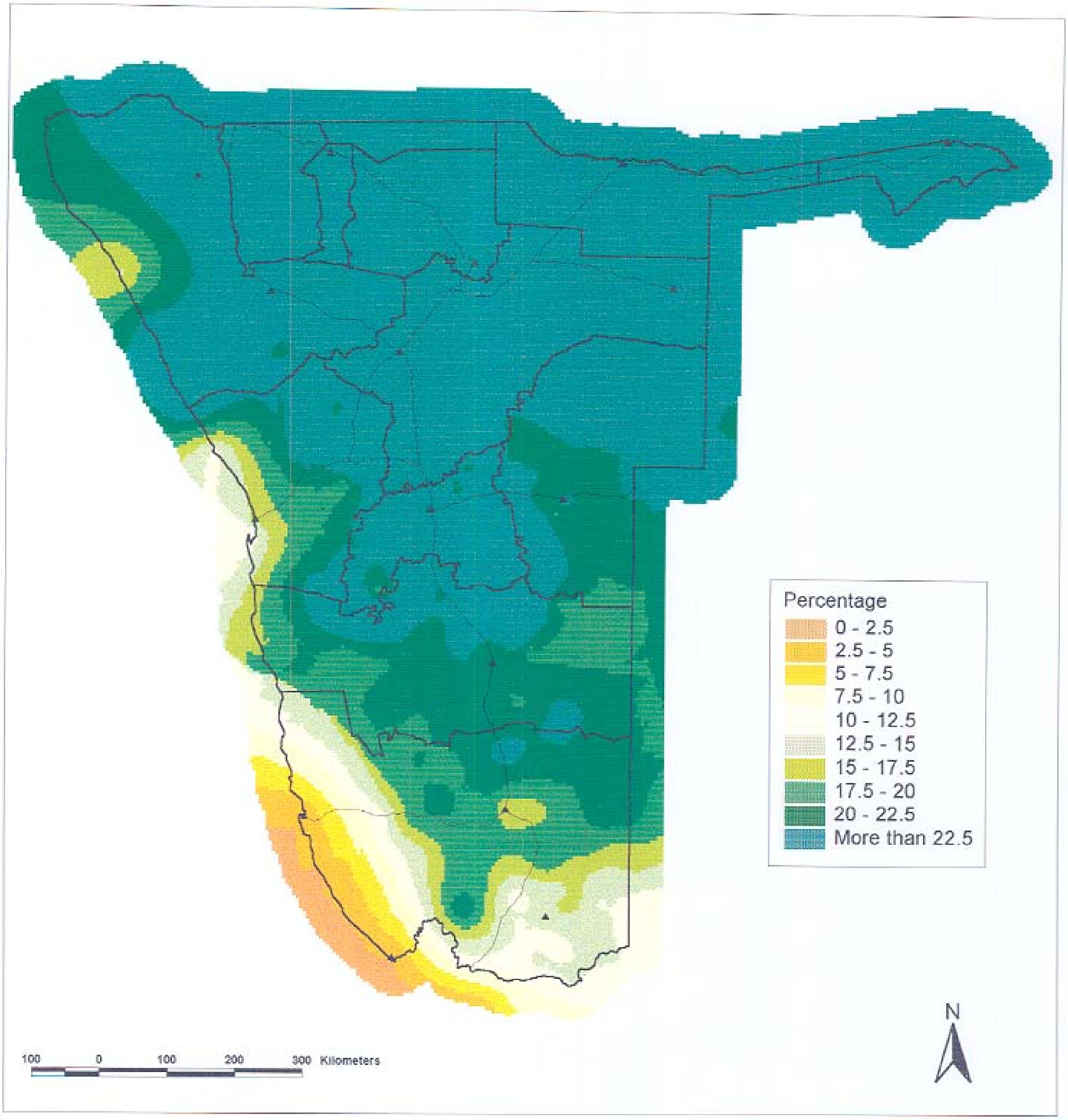
Map 56
Coefficient of variation: rainfall in November



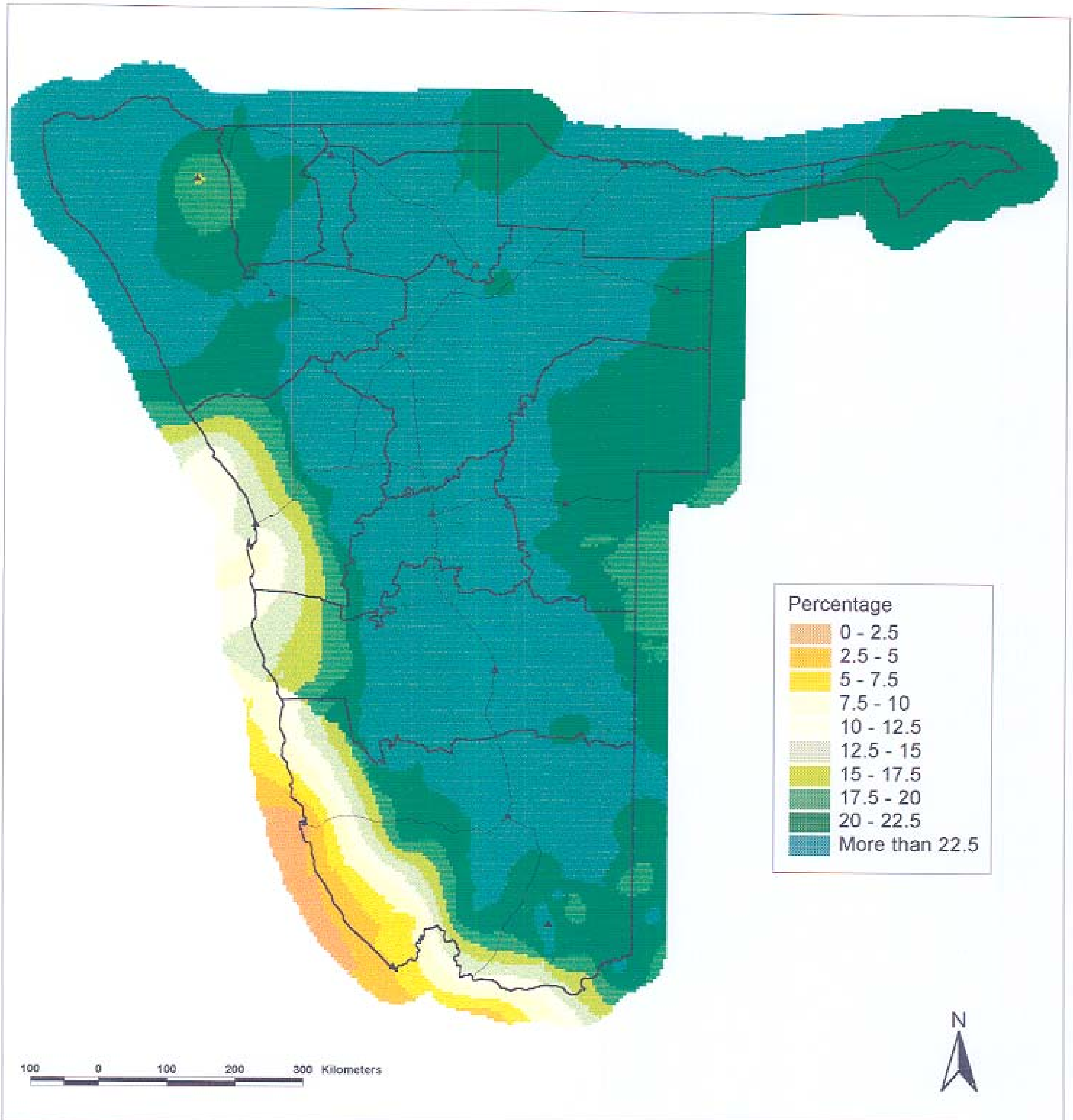
Map 57
Coefficient of variation: rainfall in December



Map 58
January rainfall as percentage of annual total

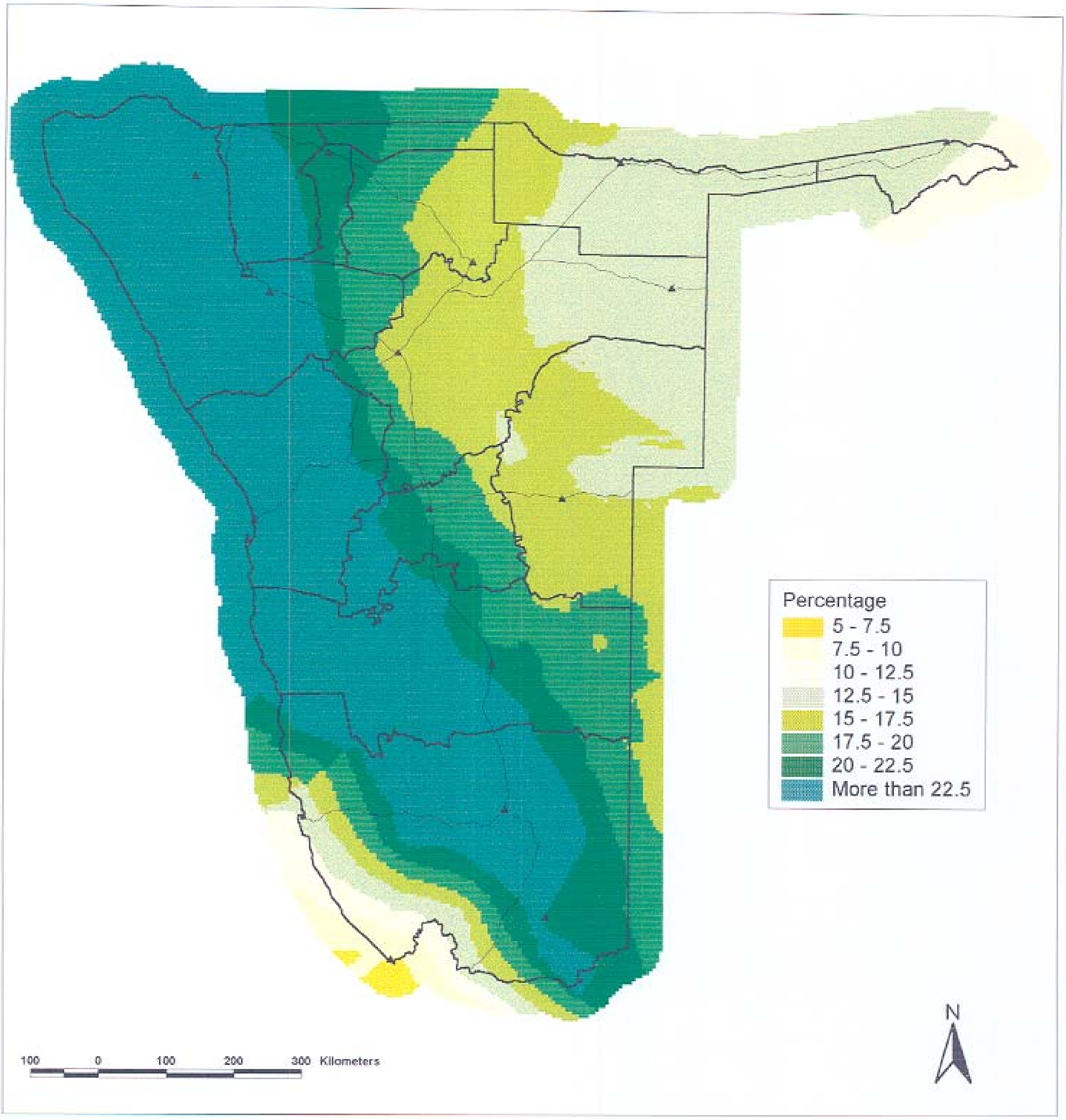


Map 59
February rainfall as percentage of annual total

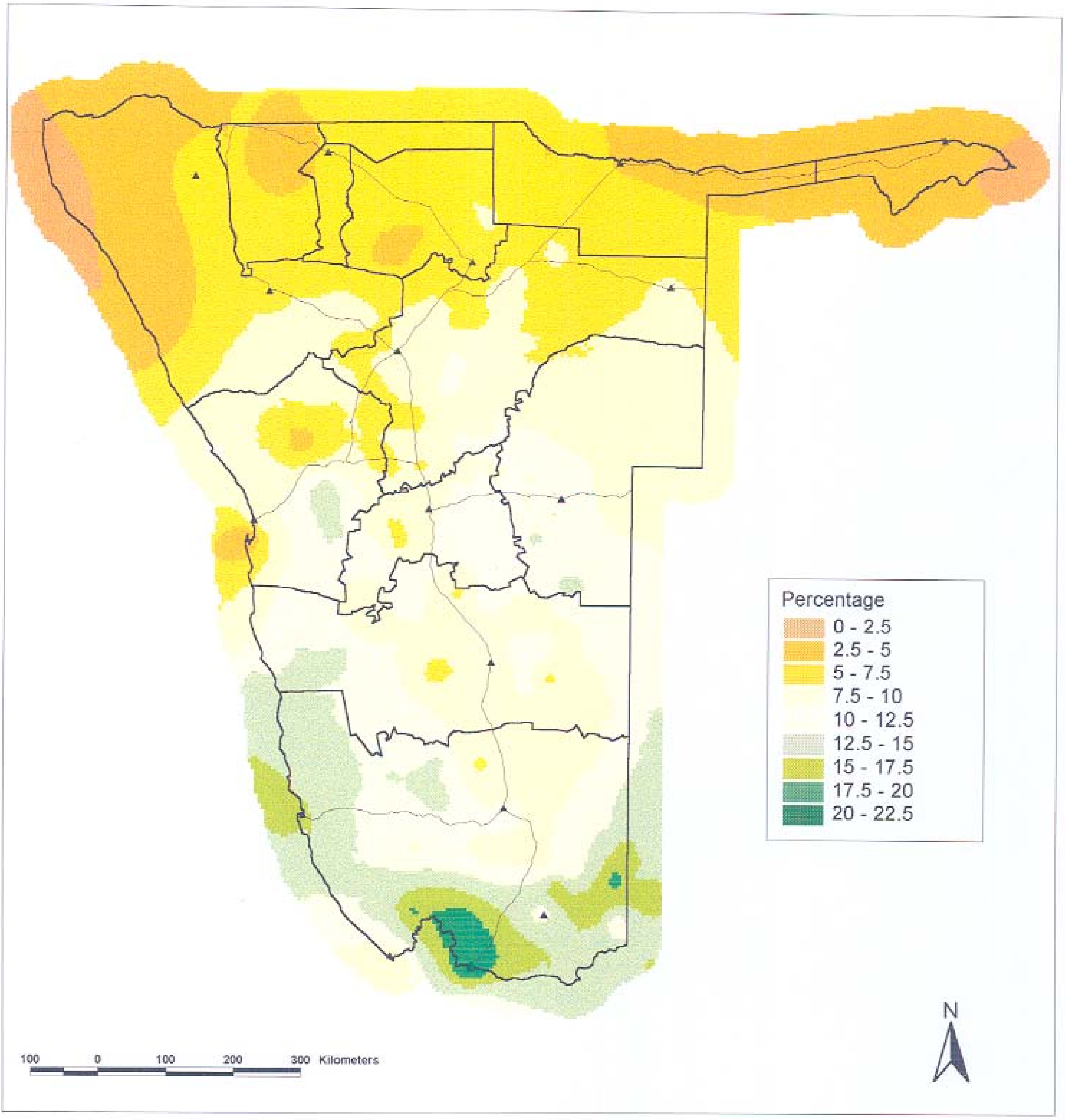


Map 60

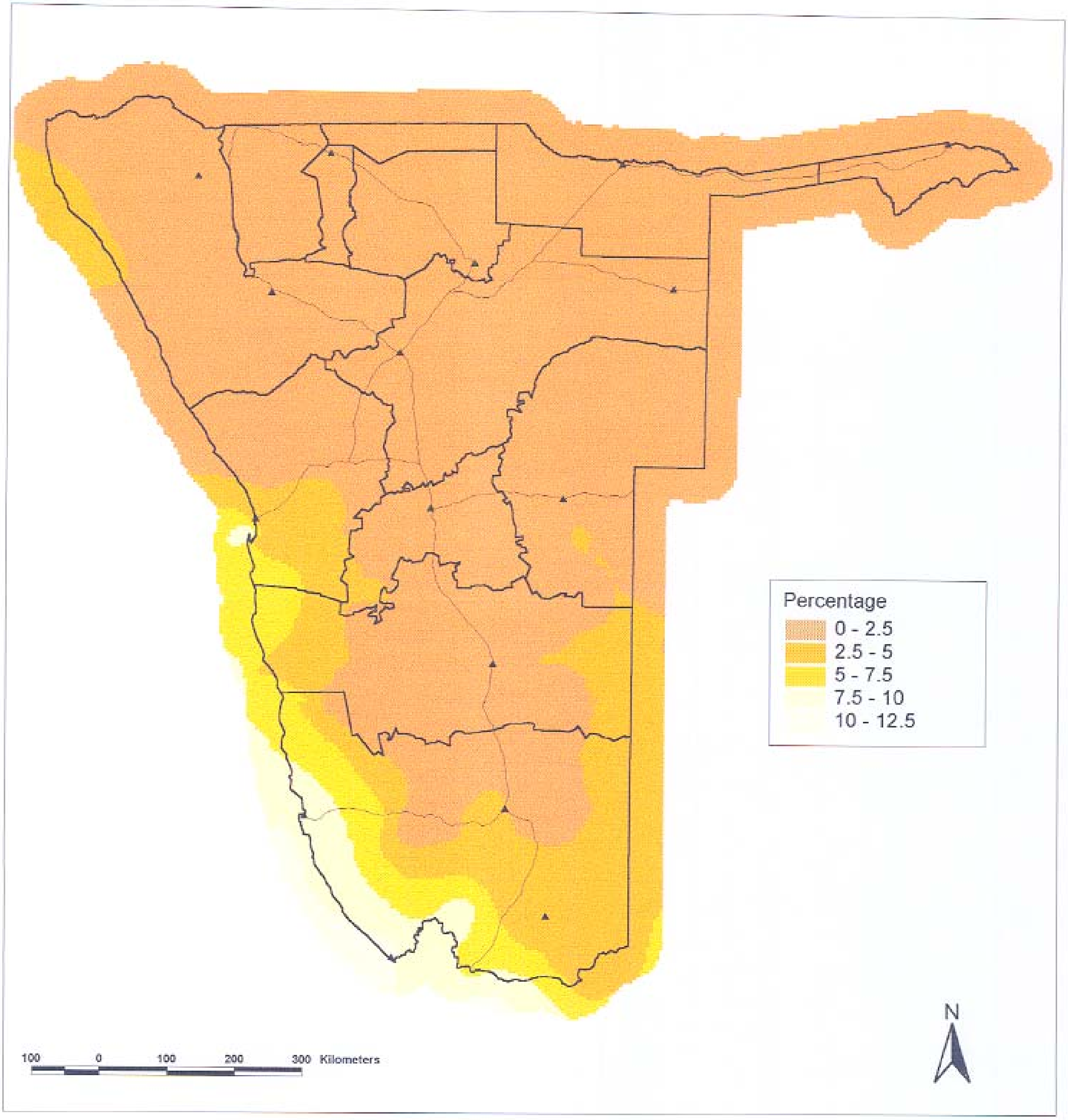
March rainfall as percentage of annual total



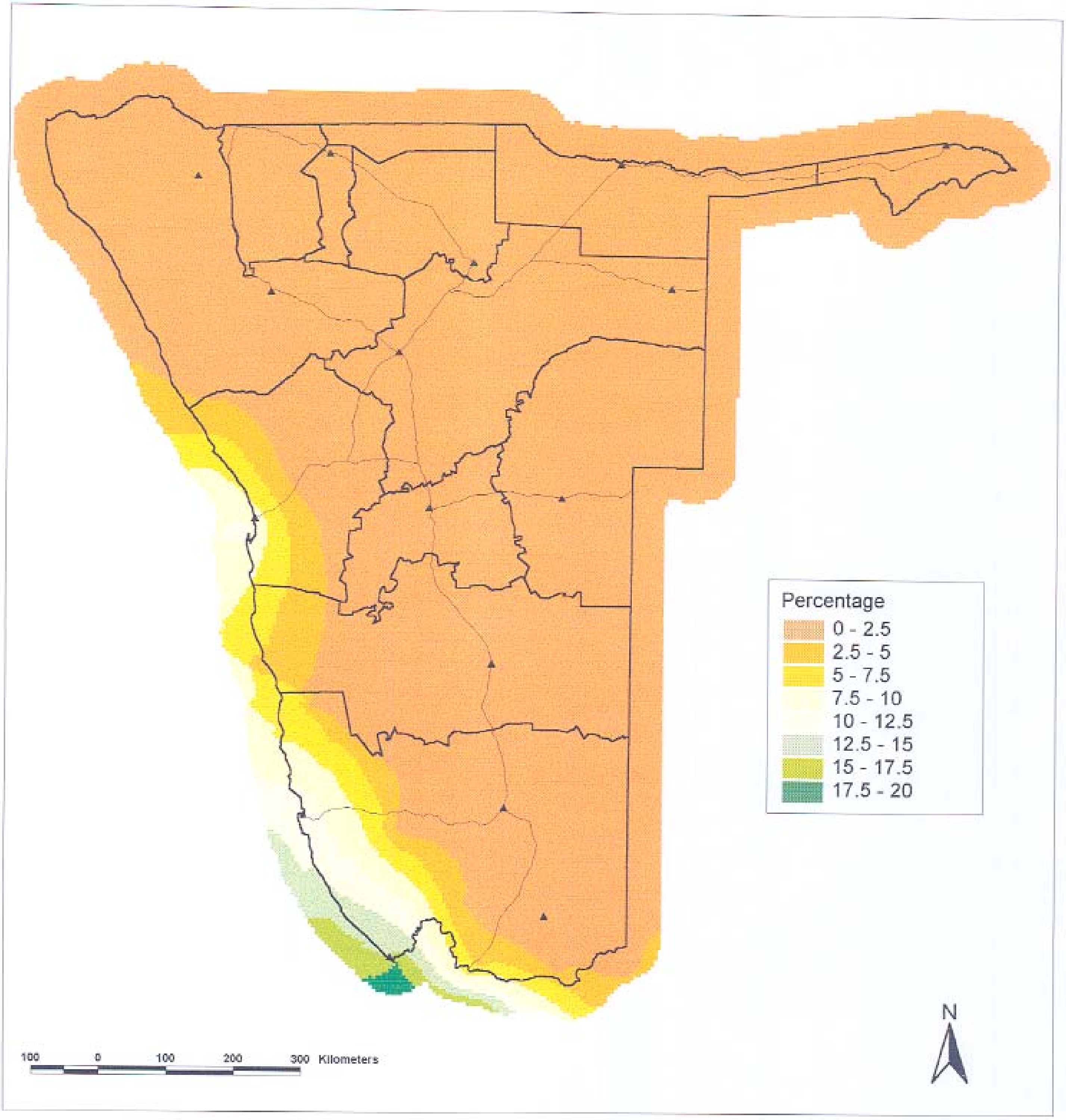
Map 61
April rainfall as percentage of annual total



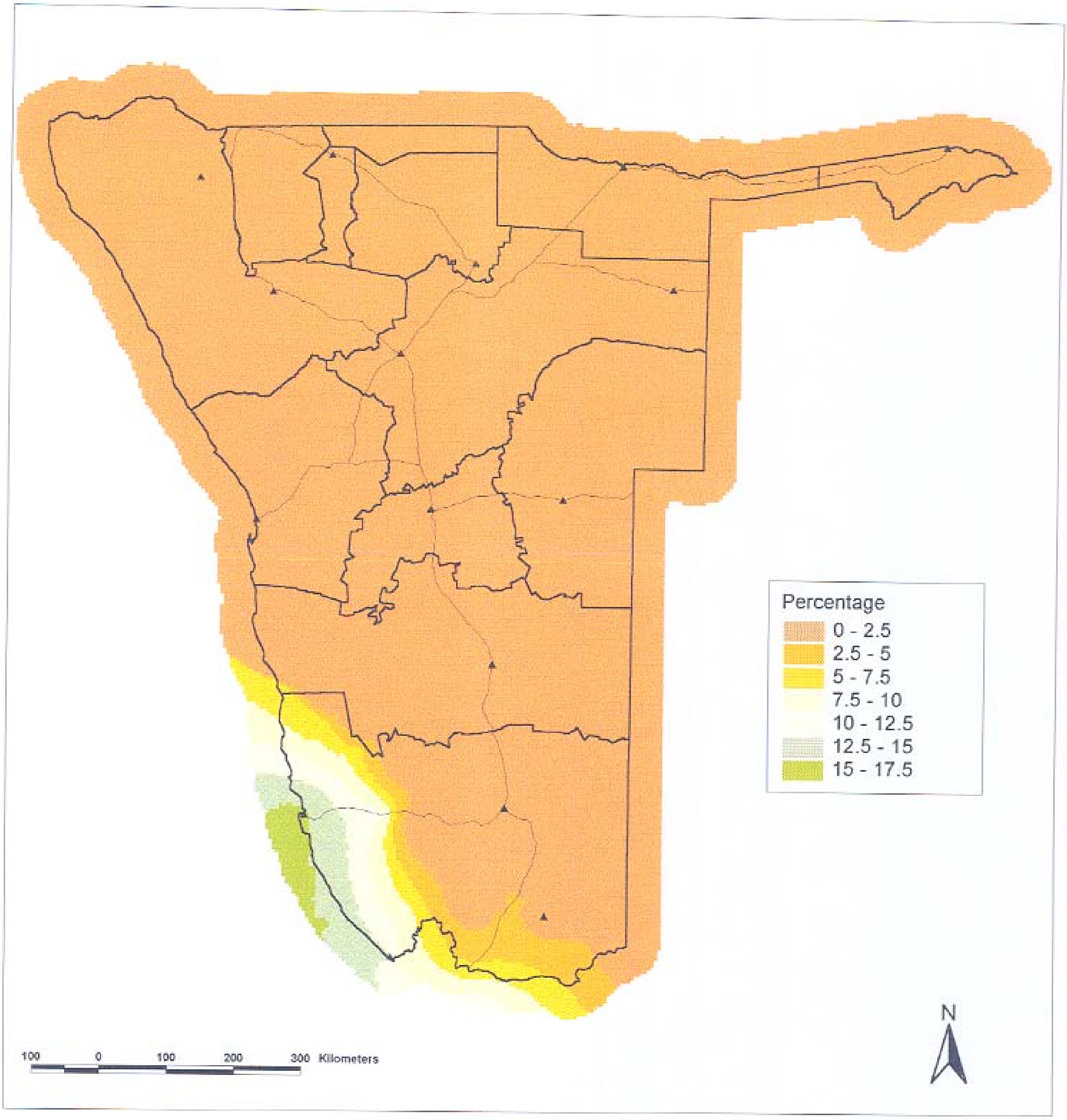
Map 62
May rainfall as percentage of annual total



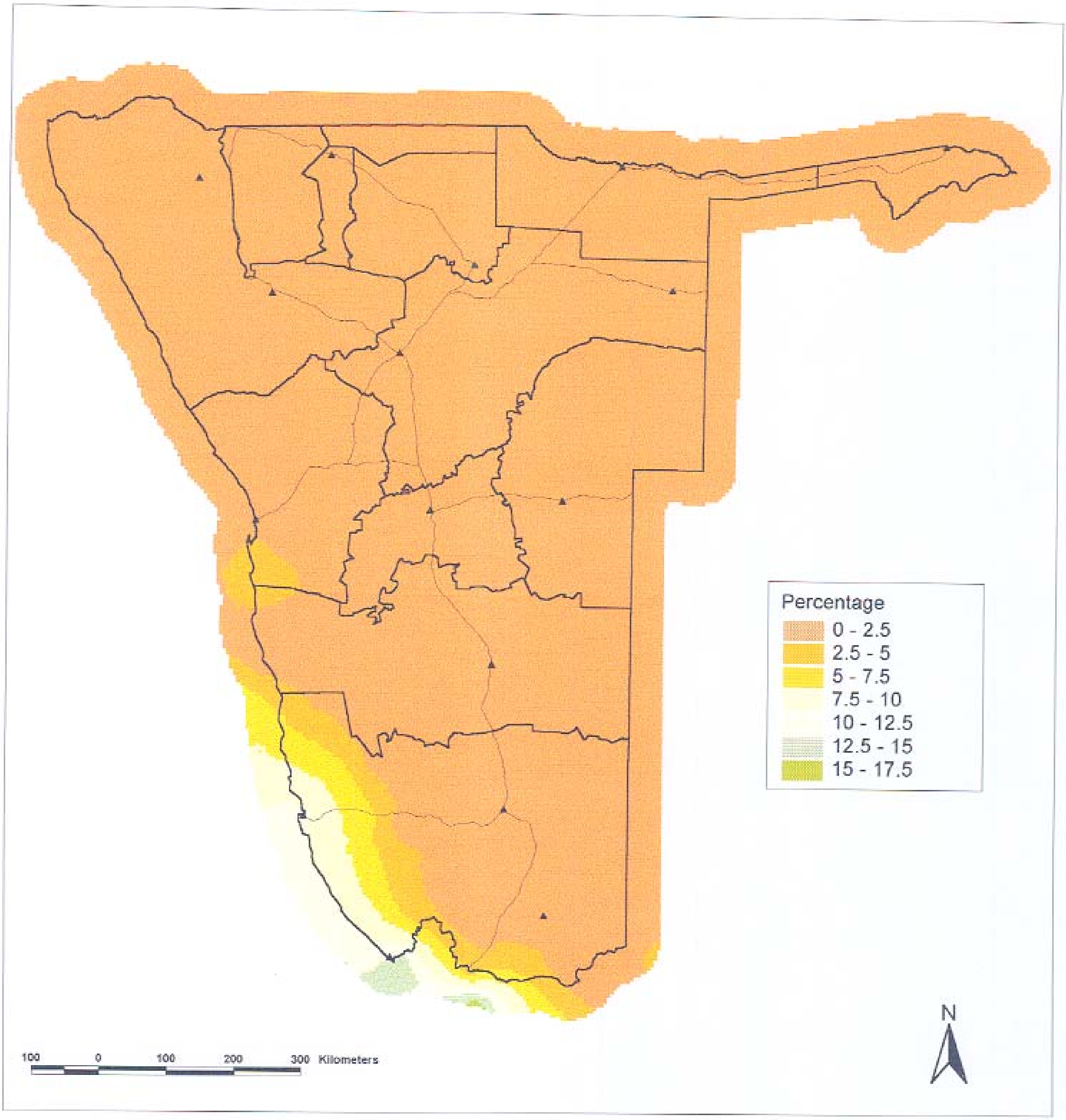
Map 63
June rainfall as percentage of annual total



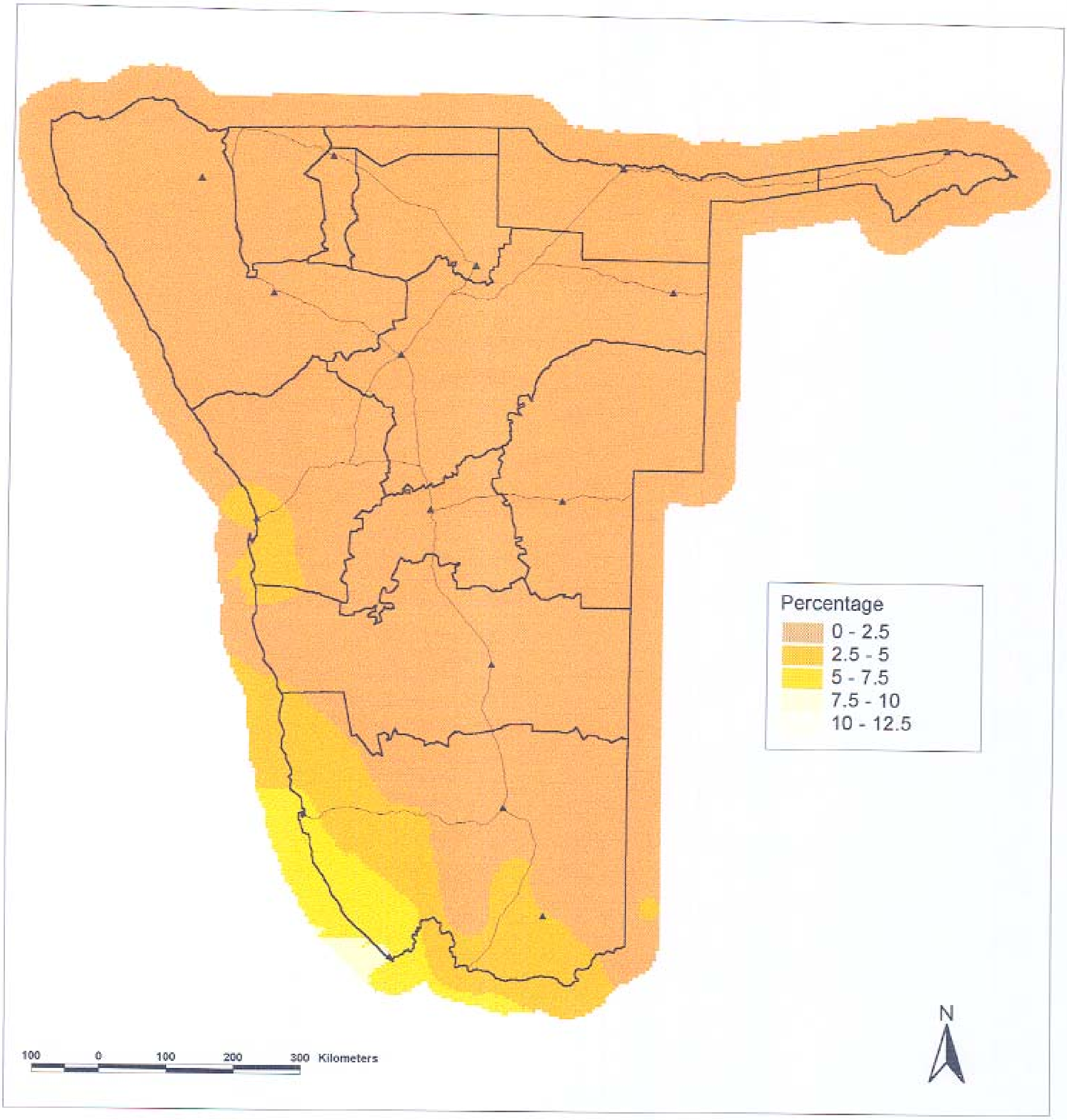
Map 64
July rainfall as percentage of annual total



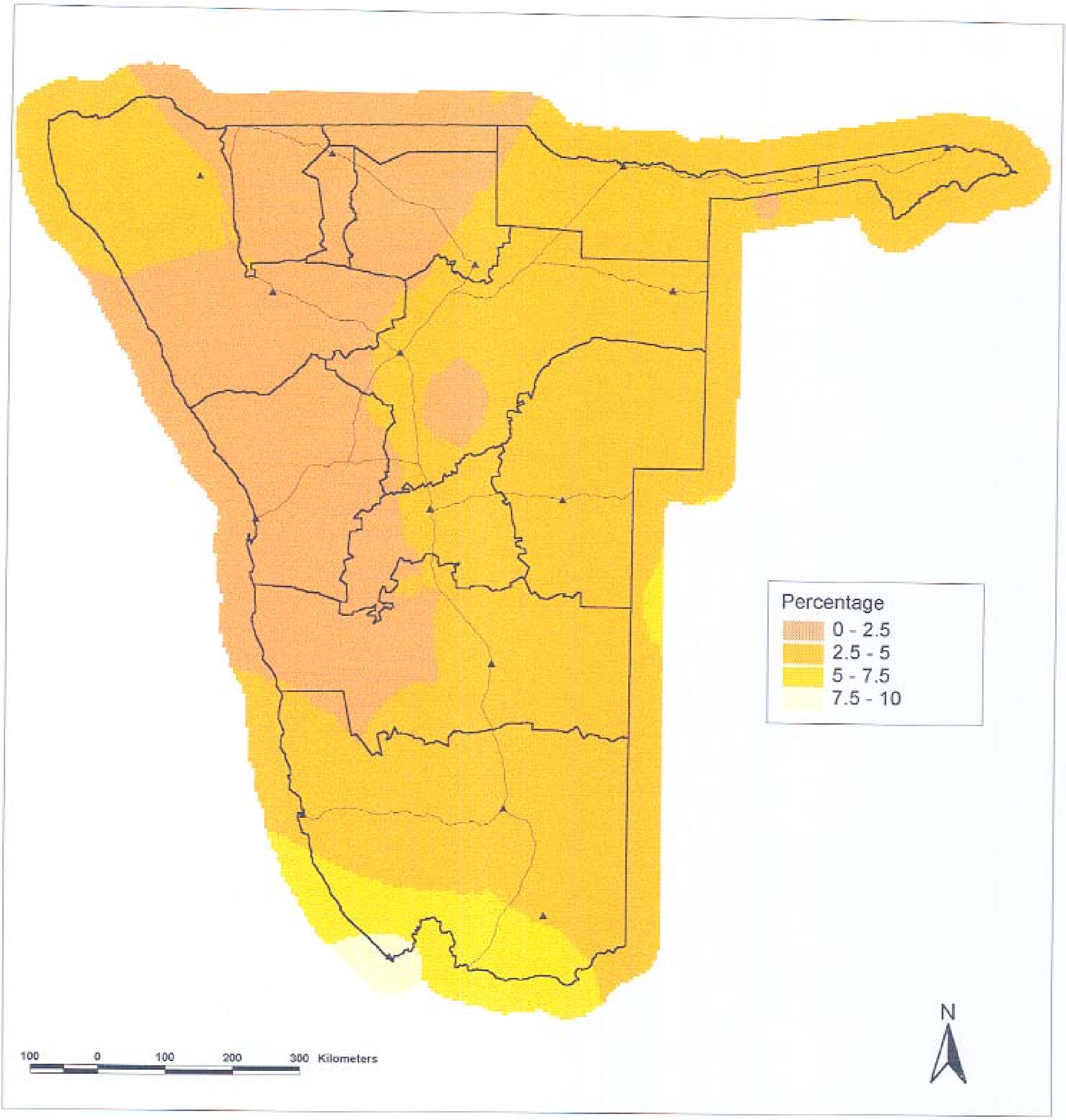
Map 65
August rainfall as percentage of annual total



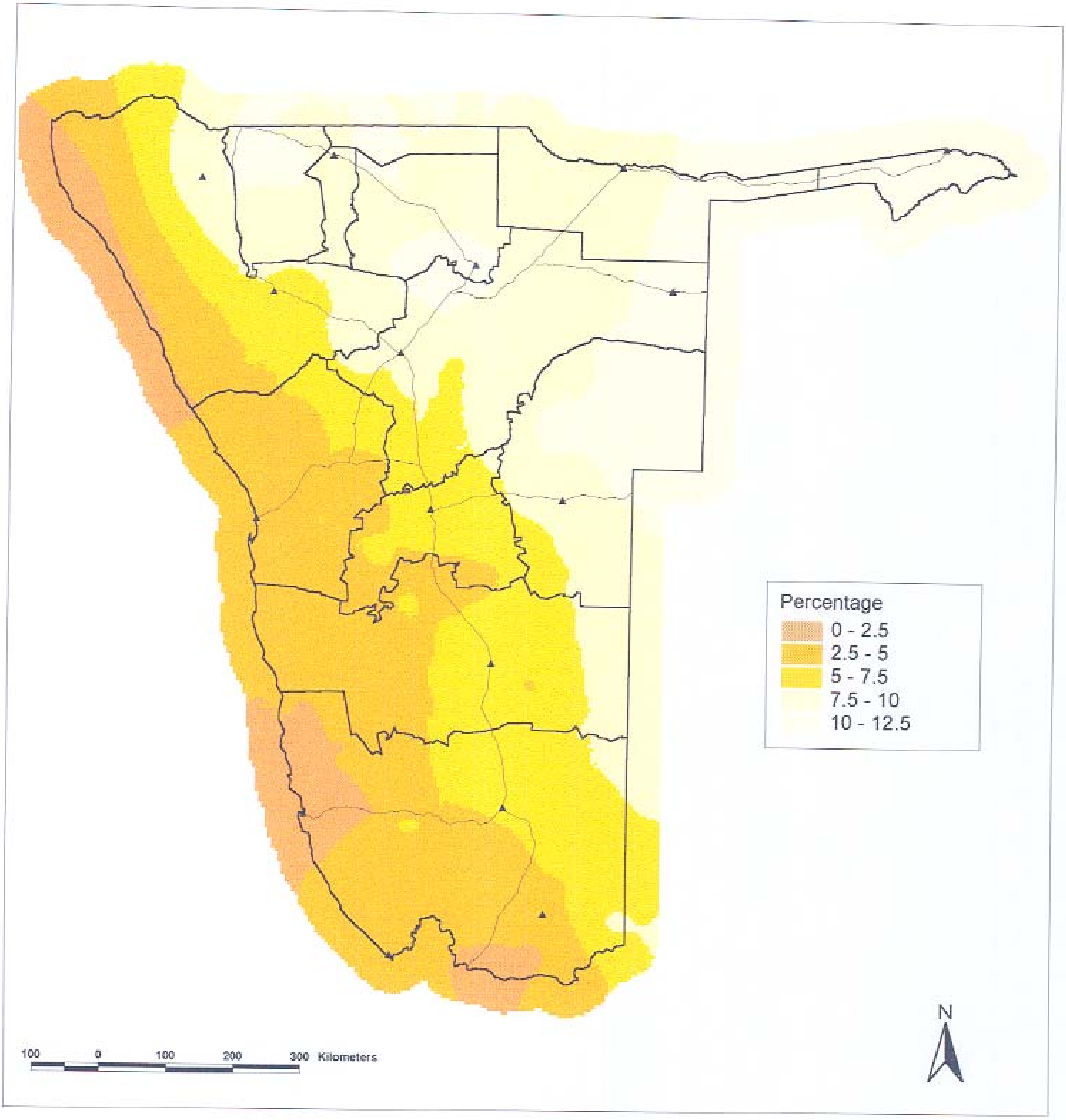
Map 66
September rainfall as percentage of annual total



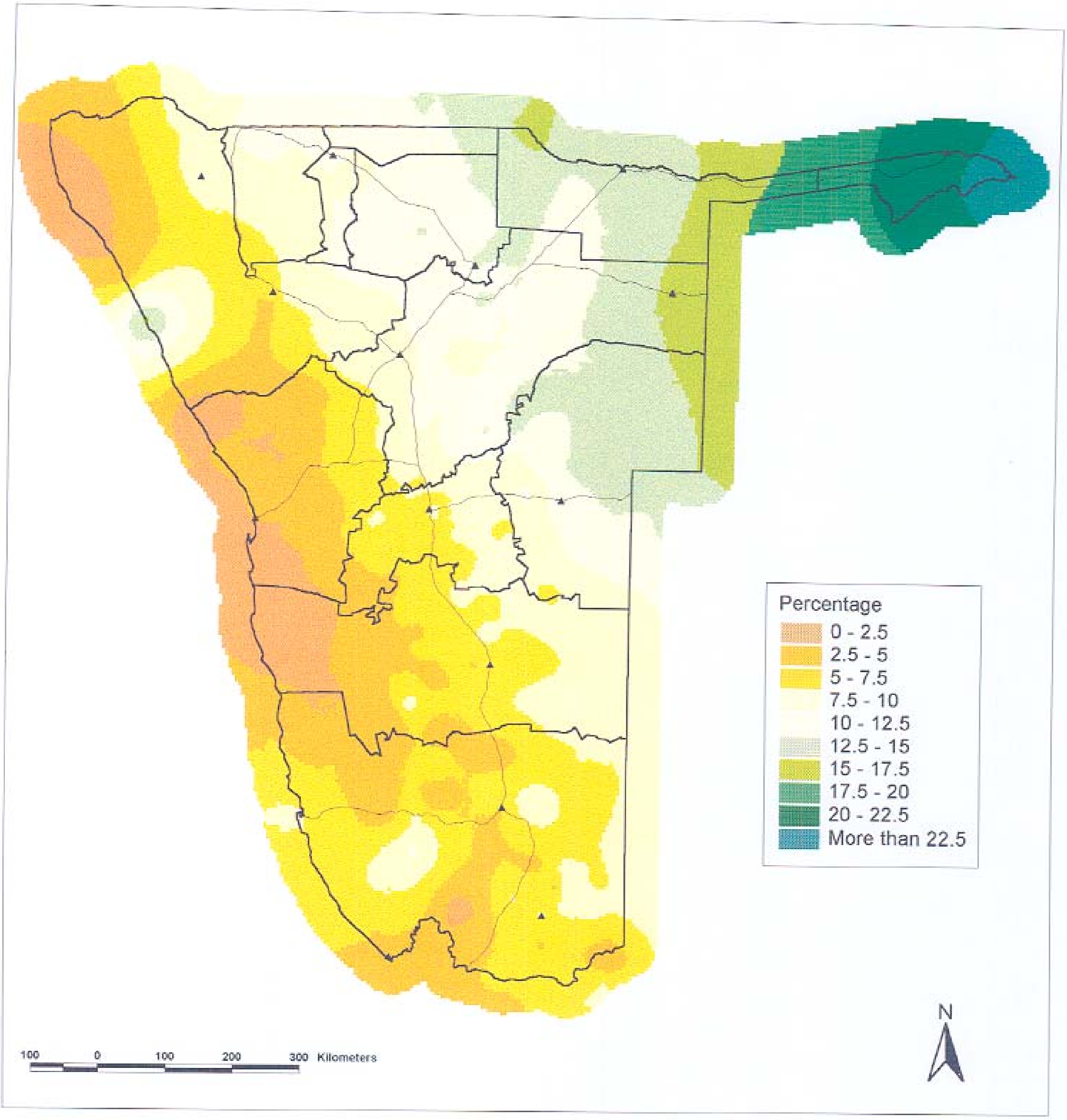
Map 67
October rainfall as percentage of annual total



Map 68
November rainfall as percentage of annual total



Map 69
December rainfall as percentage of annual total



3.4 Daily Rainfall (maps 70 – 102)

The next group of maps portrays frequencies with which rain falls on a daily basis, both for the year as a whole and for individual summer rainfall months. The first **(map 70)** shows the number of days on which any rain was recorded; "any" rain is regarded as 0.1 millimetres or more. While the north-east, and Caprivi in particular, receives more rain than the rest of the country, the highest frequencies of rainfall are actually in the north-central region and in a small area to the east of Windhoek where rain has been recorded on 60 and more days each year. By contrast, the dry Namib belt and the extreme south-west records rain on less than 10 days each year.

<u>Number of days per year</u>

Maps 71, 72, 73 and 74 show the numbers of days on which more than 1, 5, 10 and 20 millimetres, respectively, has been recorded each year. **Map 71** shows that there is a narrow and sharp transition zone from areas in the west and south to areas to the east and north. The southern and western areas receive 1 millimetre and more on less than 25 days each year, while the northern and eastern areas have these amounts falling on 40 and more days per year. The zone runs roughly from Ruacana south-eastwards to the Khomas region and then due eastwards to the Gobabis area.

Higher daily falls, of 5, 10 and 20 millimetres and more which are more significant for purposes of cultivating crops, are recorded most frequently in the north-eastern areas of Namibia **(maps 72, 73 and 74).** Each of these maps again indicates the transition zone between the west and south (where daily falls are less frequent) to the east and north (where higher falls are recorded more often).

<u>Numbers of days per month</u>

The next group of maps looks at frequencies of daily rainfalls each month. The numbers of days on which 1 millimetre or more have been recorded during each of the seven summer rainfall months are shown in **maps 75 to 81**. This sequence of maps shows how the rains start in the northeast and extend westwards and southwards as the summer months progress. December **(map 78)**, January **(map 79)** and February **(map 80)** are the only months during which falls of 1 millimetre or more are recorded on 9 days or more each month. In other words, 1 millimetre or more can be expected on about one-third of all days in a month.

Maps 82 to 88 show frequencies of 5 millimetres or more falling in each of the seven summer months. Falls of that and greater magnitudes are much less frequent than smaller ones, so the numbers of days on which these higher falls are recorded each month are often expressed as fractions. For example, a frequency of 0.5 days means that 5 millimetres or more has only been recorded once in about 60 days of a 30 day month, or only once in two years. A frequency of 0.1 days means that this amount of rain is only recorded once in ten years during that month.

The progression of summer rains from the northeast to the west and south are again portrayed in **maps 82** to **88**, with 5 millimetres or more falling on 5 and more days each month in December **(map 84)** in Caprivi, then over much of Kavango and the Otavi mountains in January **(map 85)** and February **(map 86)**.

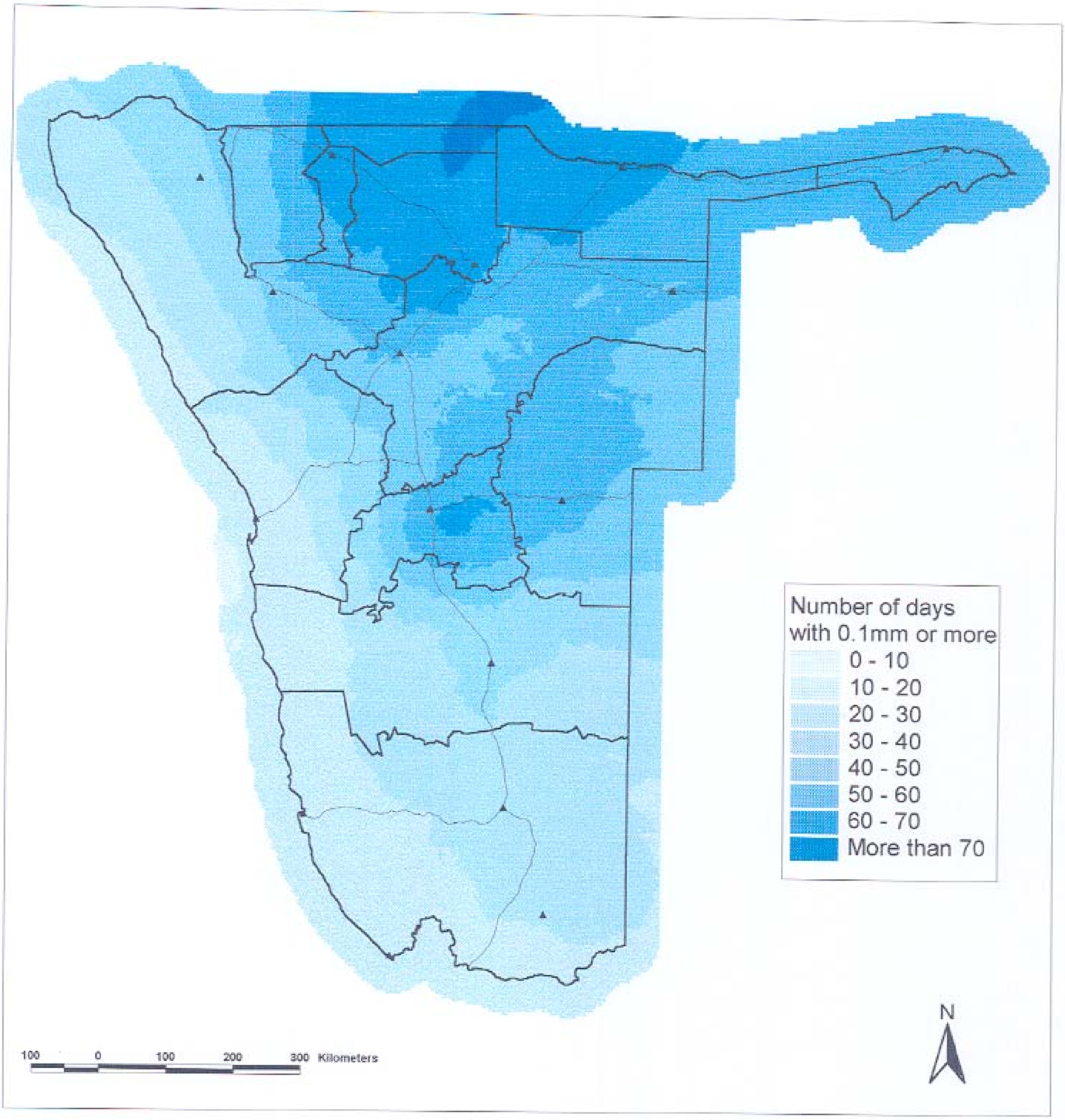
Maps 89 to 95 show the numbers of days per month on which 10 millimetres or more has been recorded. Falls of that magnitude are only regular in December, January and February in the north-eastern regions, and to a lesser extent in March in the Cuvelai basin.

The final series of maps **(maps 96 to 102)** show the numbers of days on which 20 or more millimetres has been recorded during each of the summer months. Such falls are almost never recorded in October **(map 96).** Eastern Caprivi can expect such rainfall on one day in November **(map 97)** and two days in December **(map 98)**. In January and February **(maps 99 and 100)**, 20 millimetres and more can be expected to fall twice per month over much of the north-east, while the Cuvelai basin will receive such falls once or twice per month in March **(map 101)**. These heavier rains have all but disappeared from the whole country in April **(map 102)**.

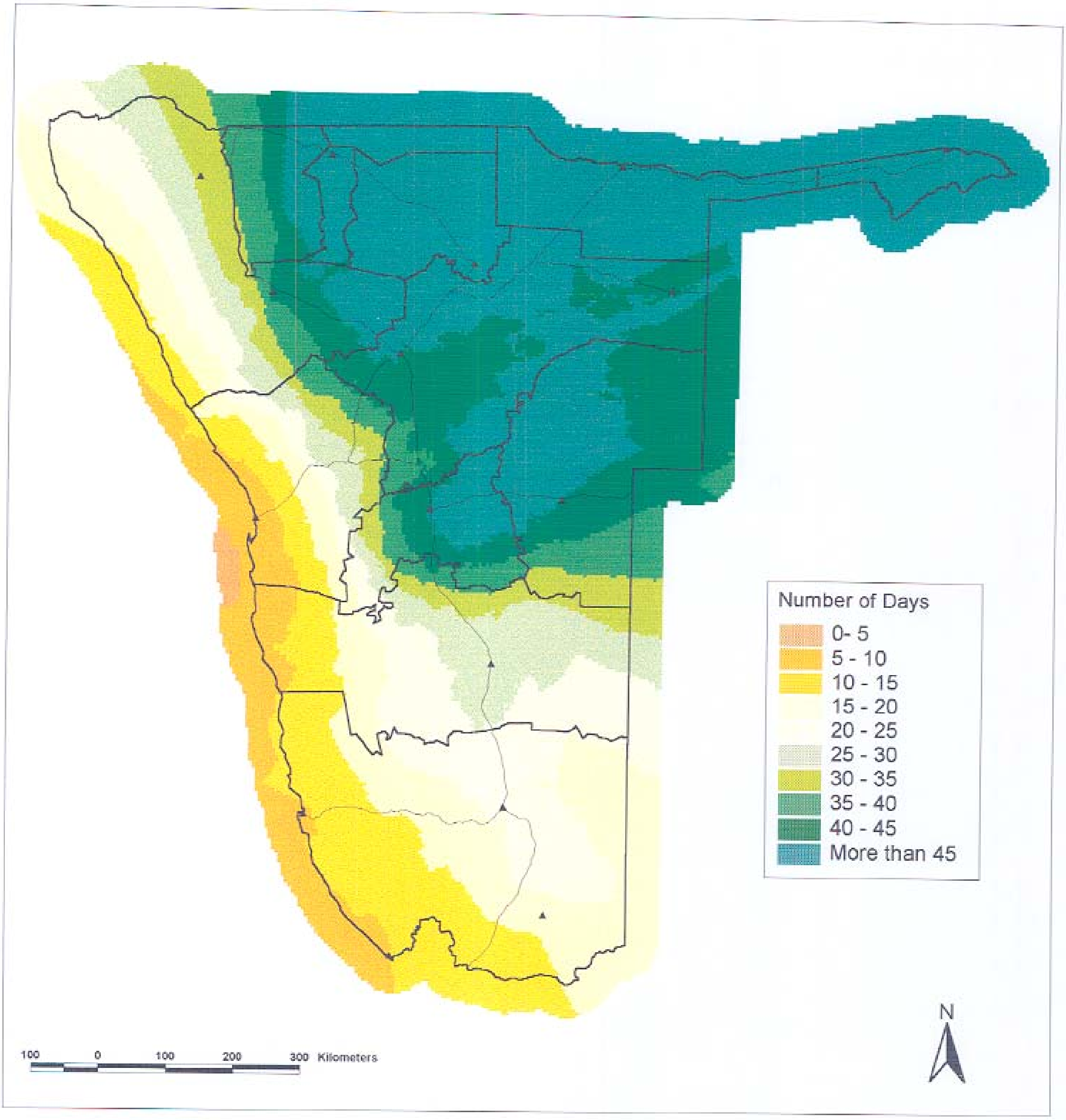
The original terms of reference indicated that analyses would be done to show geographical variation in the frequency of days with more than 50 mm. However, it became clear during the statistical analysis of the data that such events are so rare that any spatial analysis of their frequency would be meaningless.

Map 70

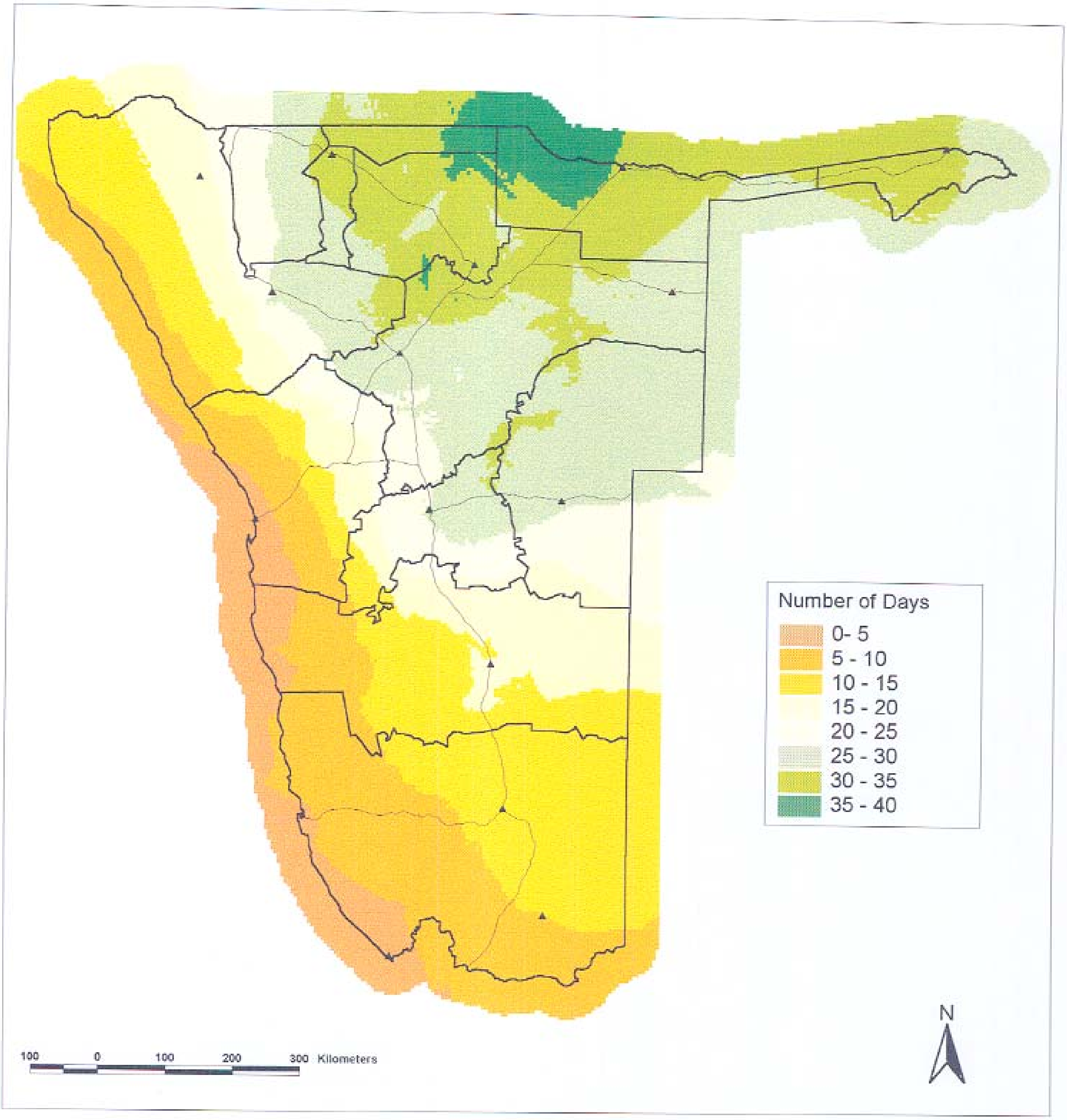
Average number of days per year with any rain



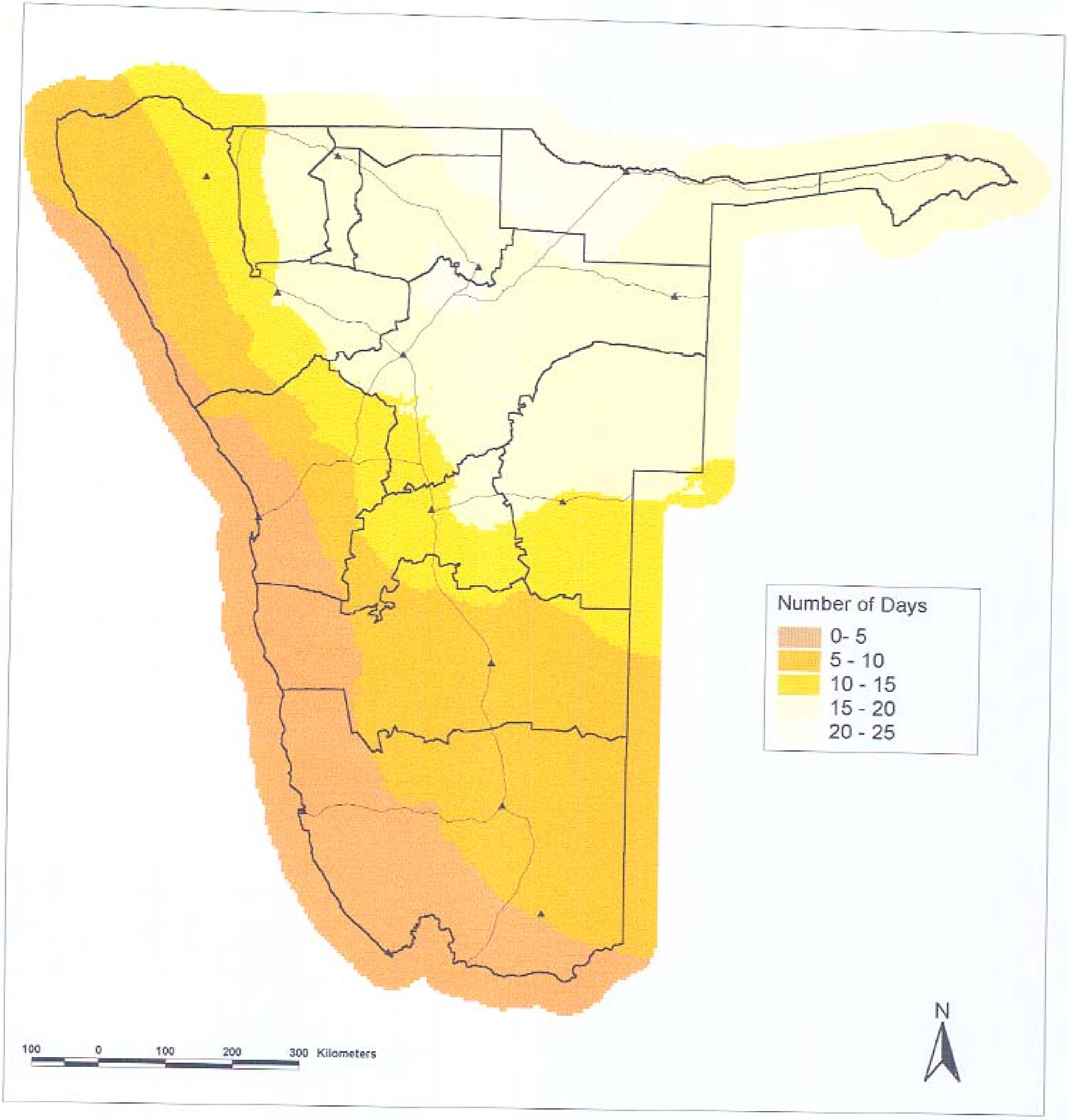
Map 71
Average number of days per year with 1 mm or more rain



Map 72
Average number of days per year with 5 mm or more rain

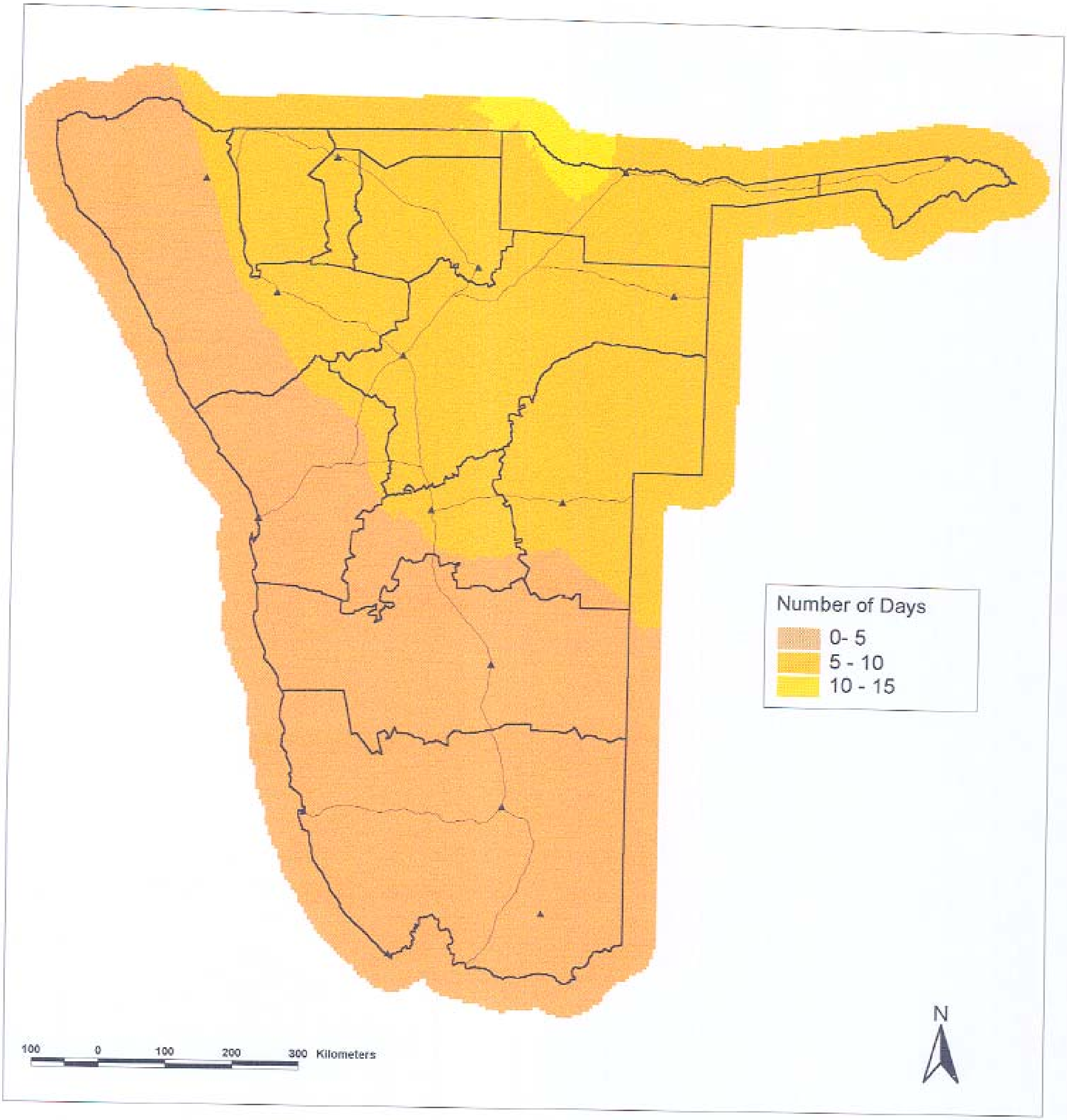


Map 73
Average number of days per year with 10 mm or more rain

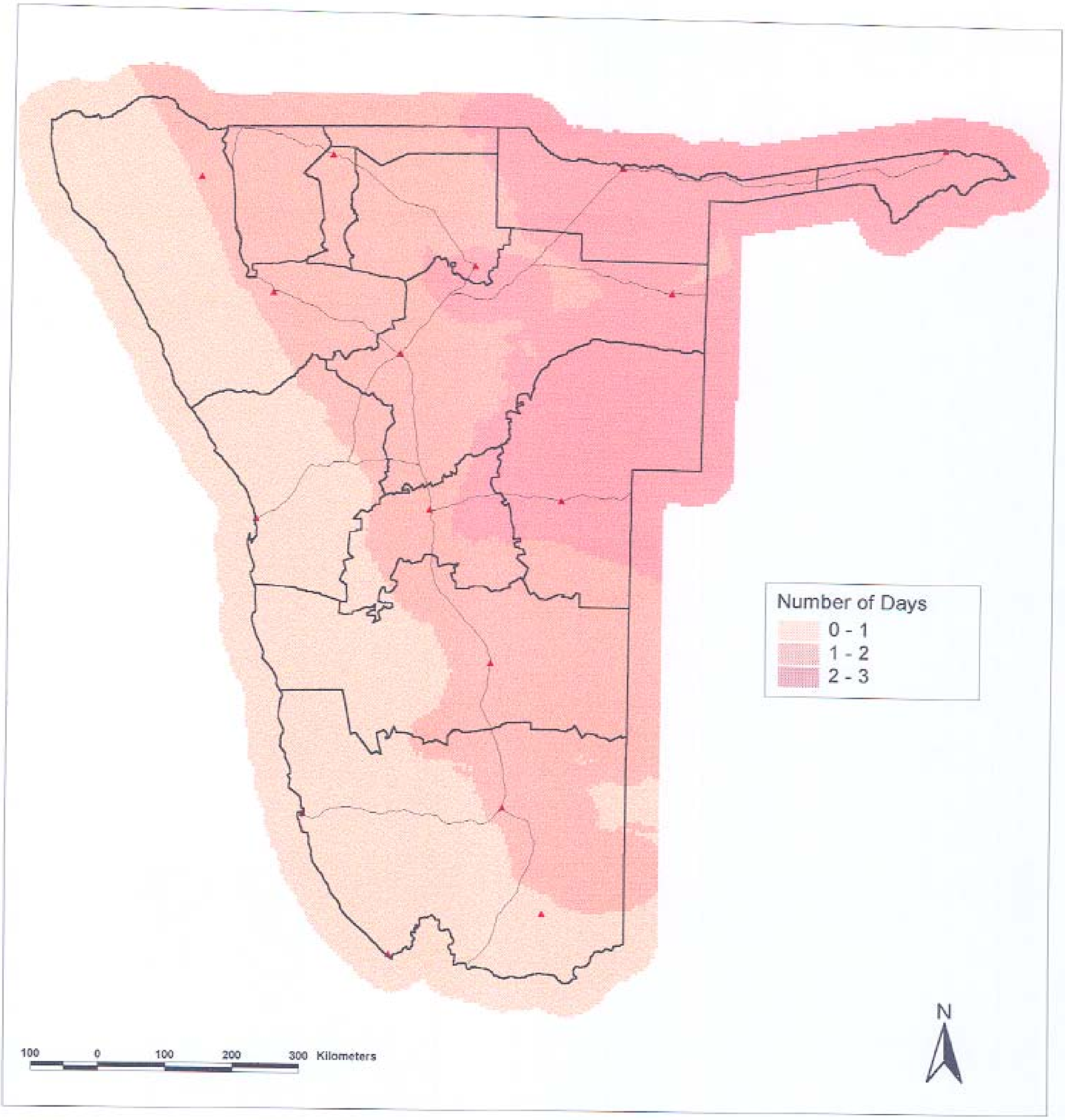


Map 74

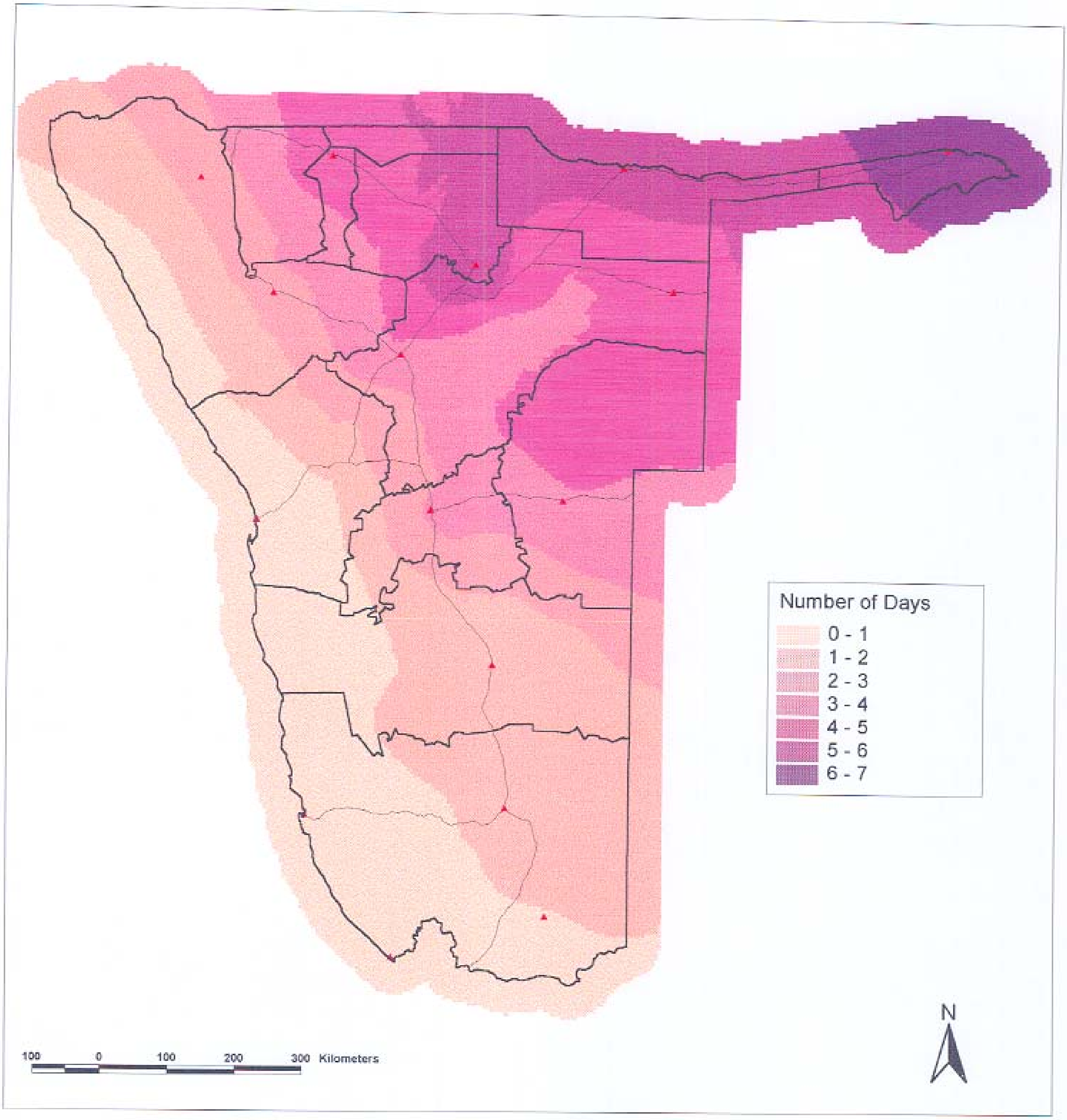
Average number of days per year with 20 mm or more rain



Map 75
Average number of days in October with 1 mm or more rain

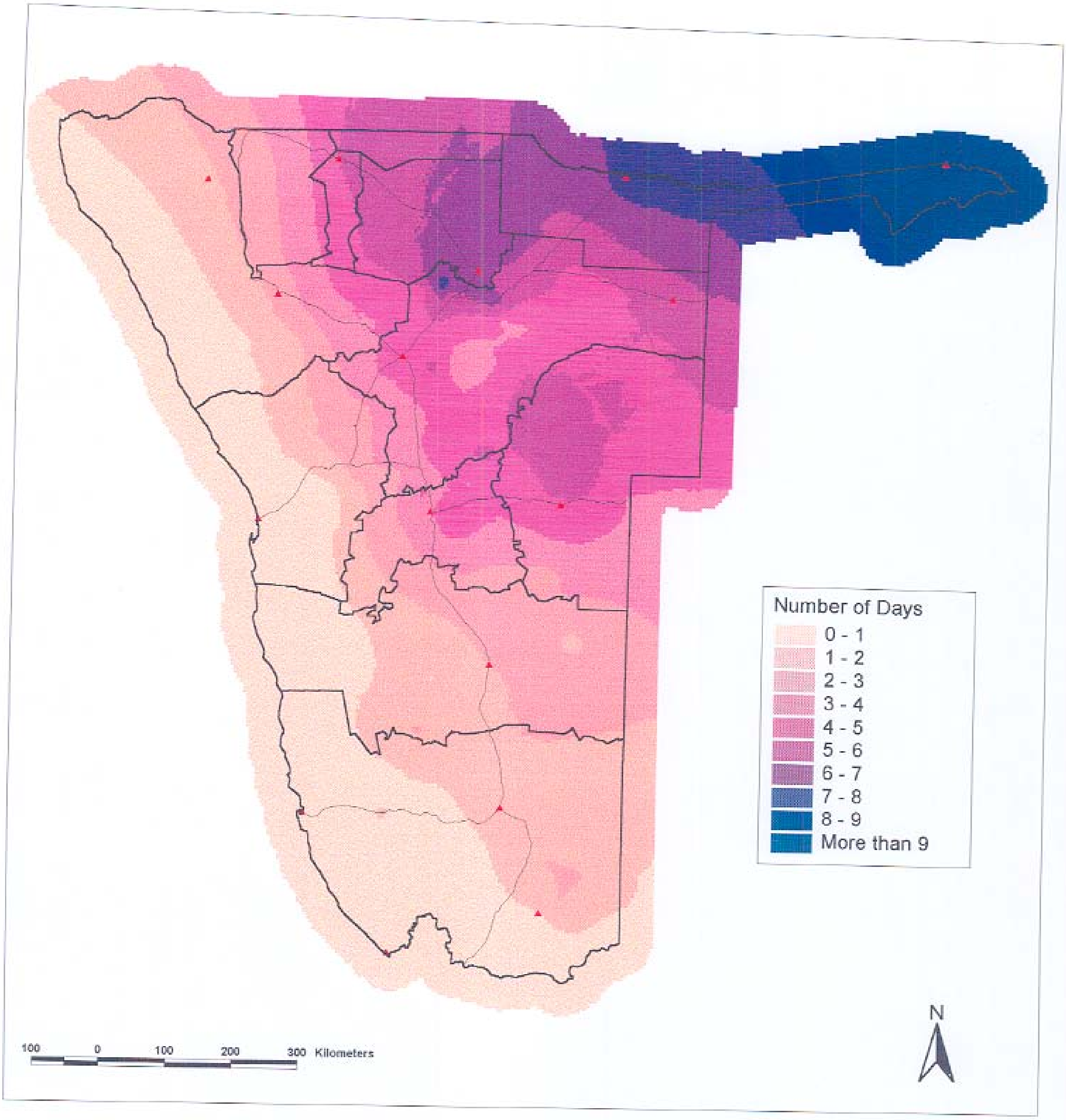


Map 76
Average number of days in November with 1 mm or more rain

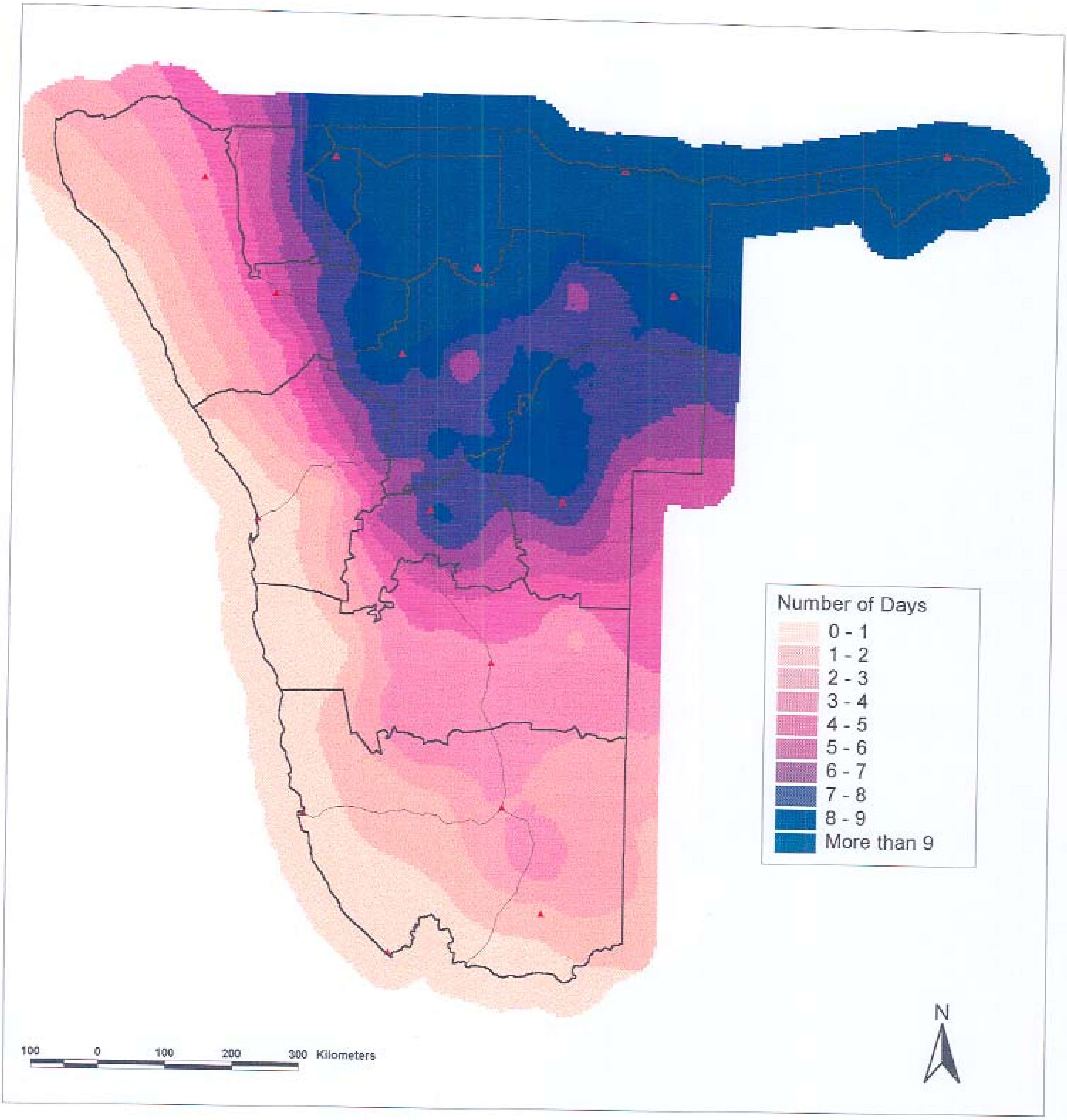


Map 77

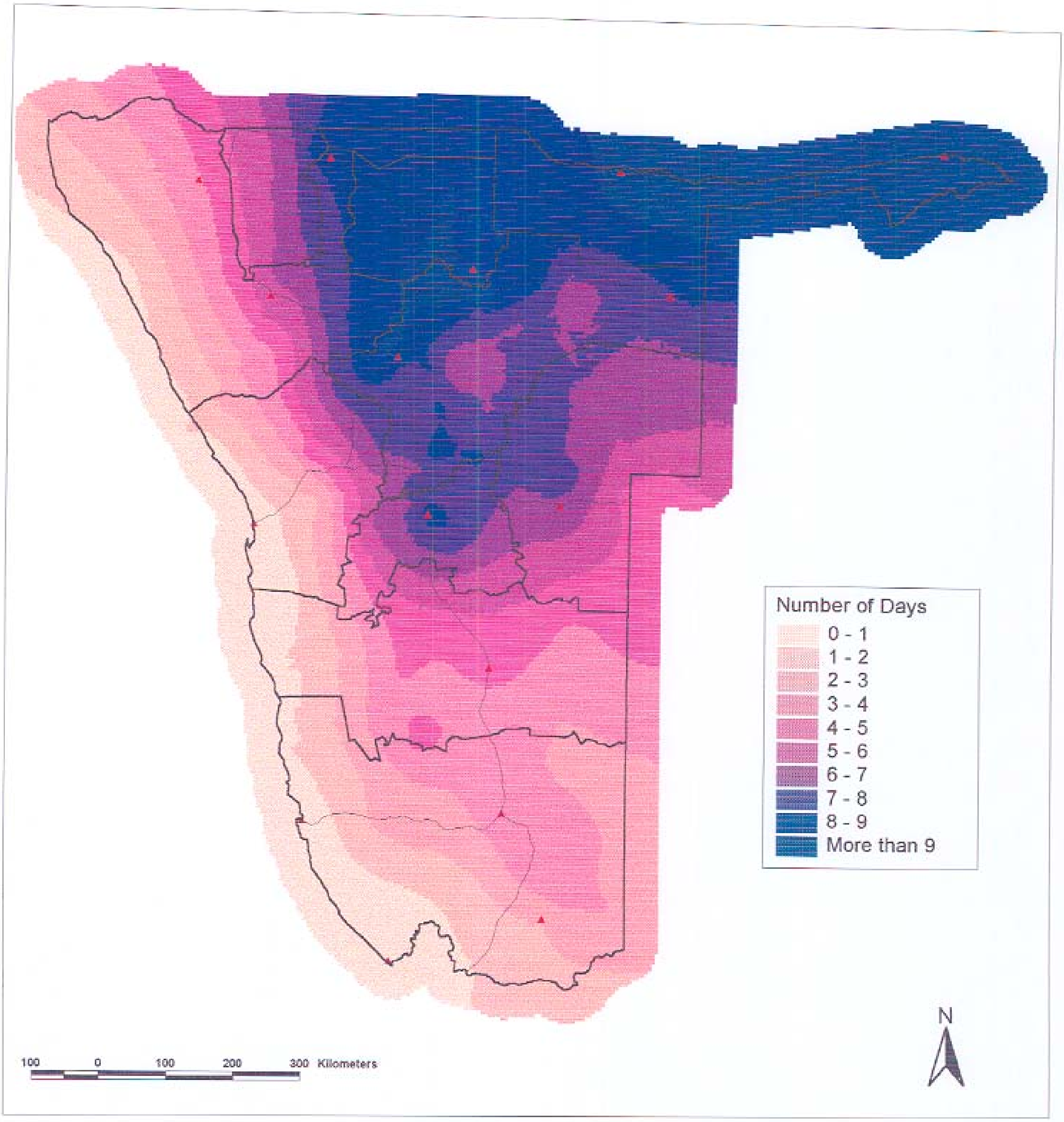
Average number of days in December with 1 mm or more rain



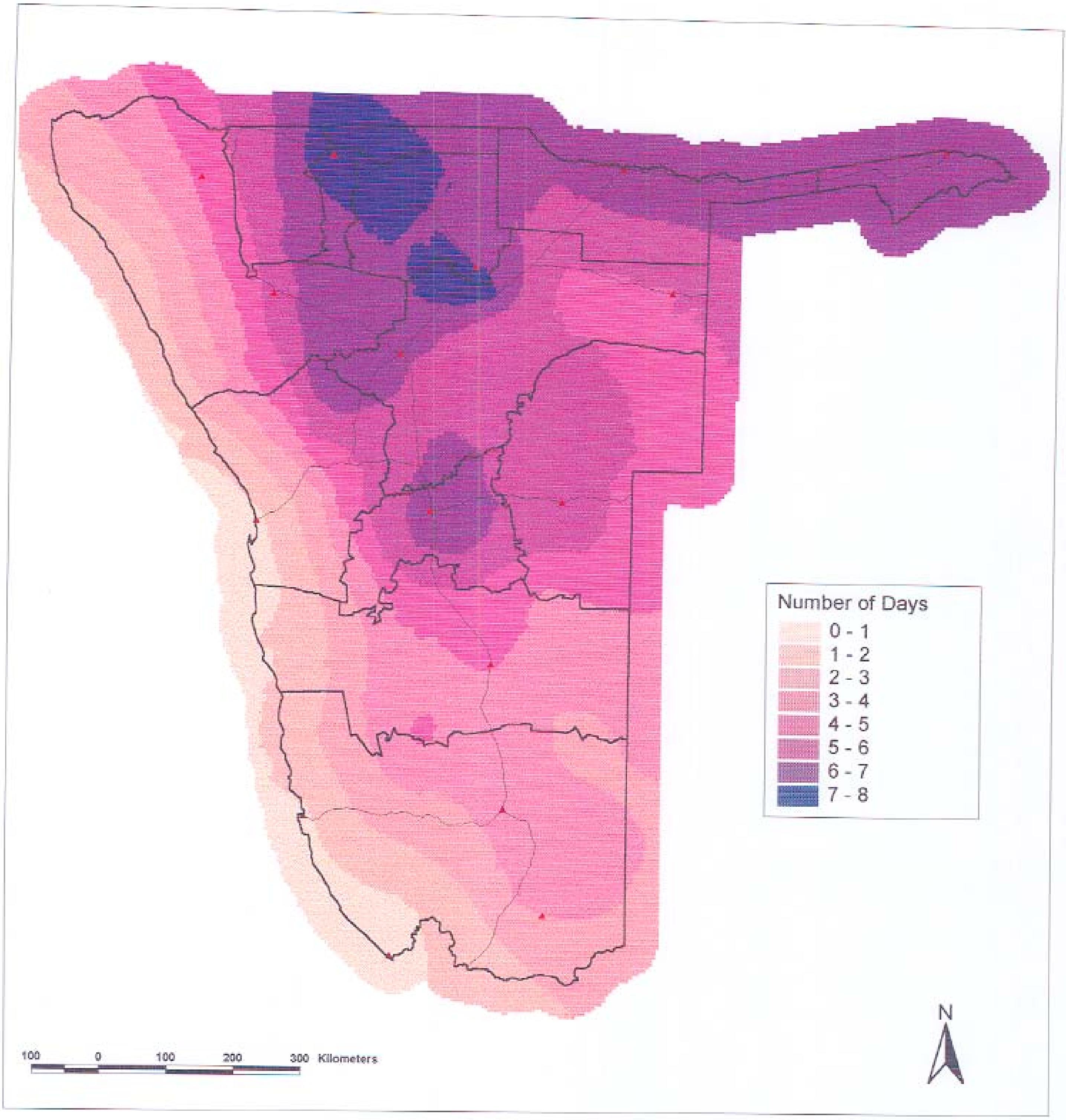
Map 78
Average number of days in January with 1 mm or more rain



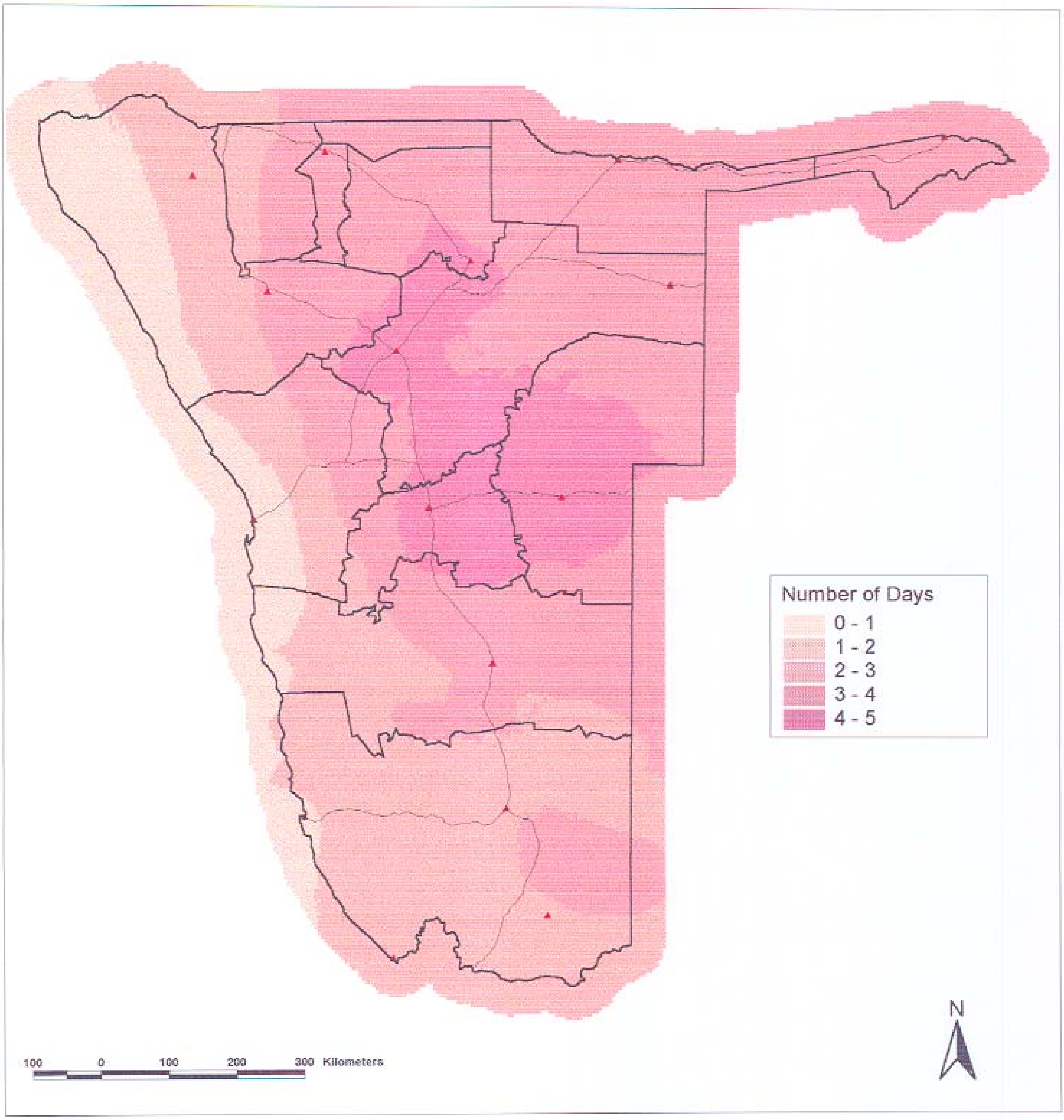
Map 79
Average number of days in February with 1 mm or more rain



Map 80
Average number of days in March with 1 mm or more rain

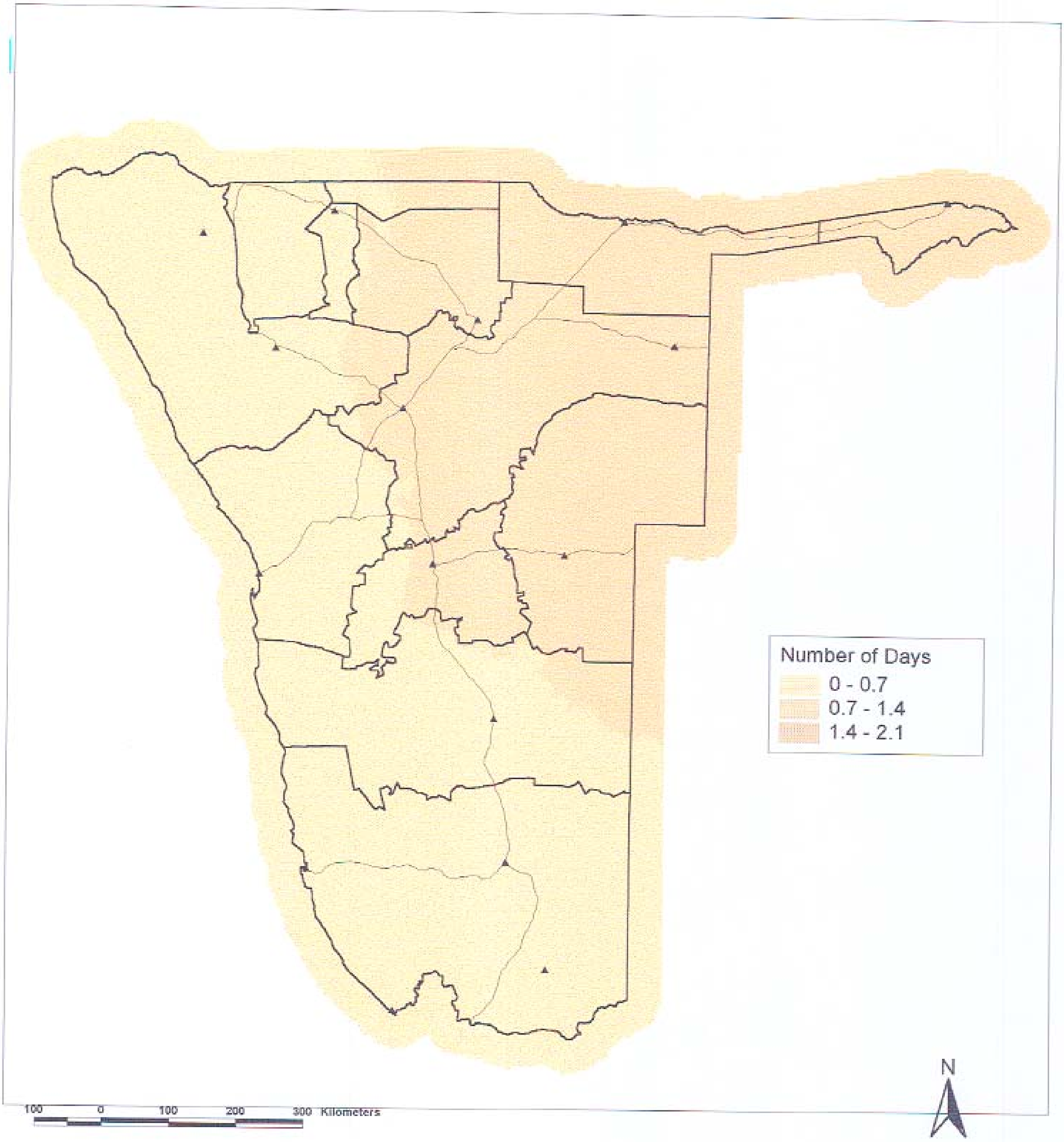


Map 81
Average number of days in April with 1 mm or more rain

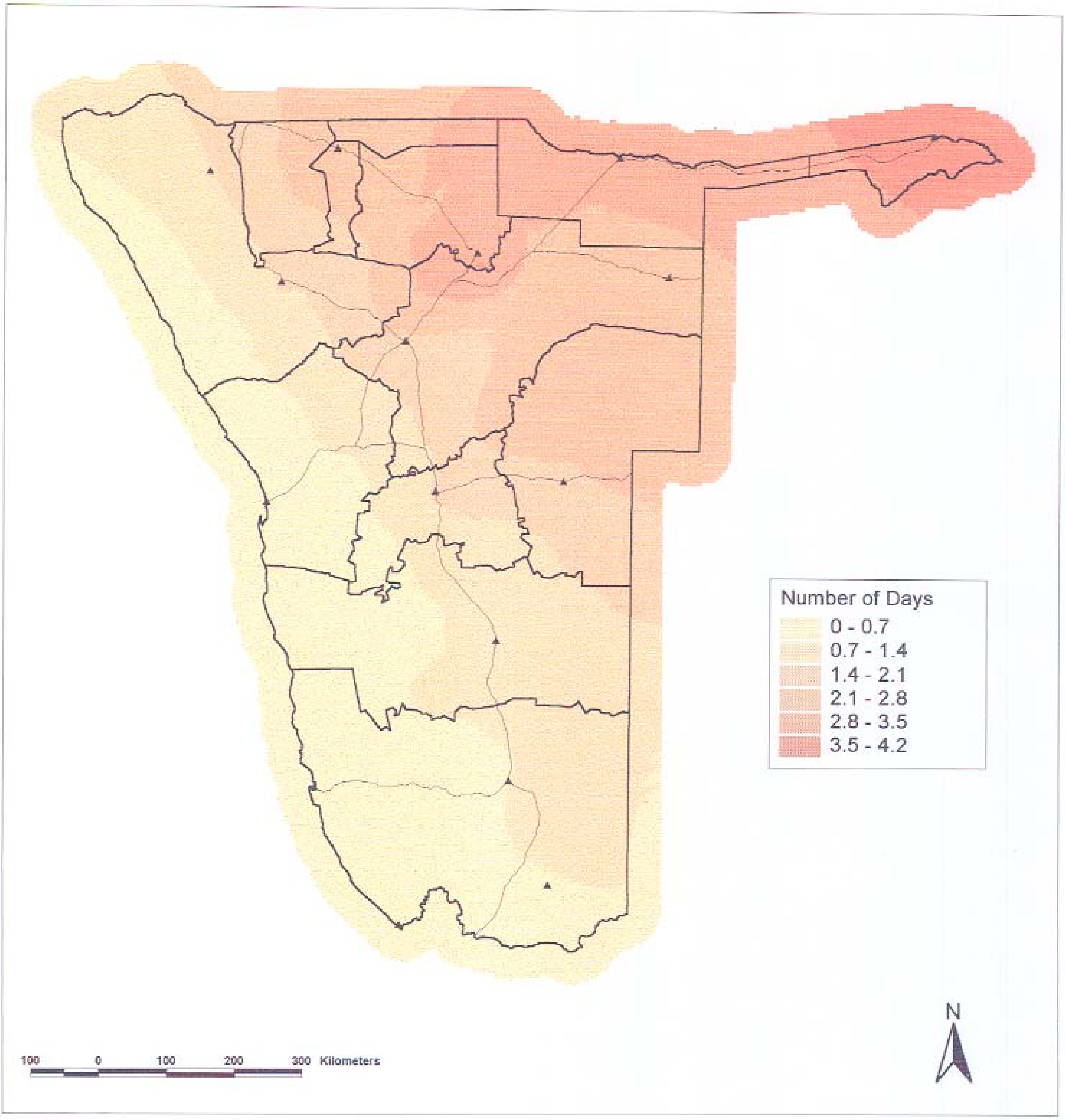


Map 82

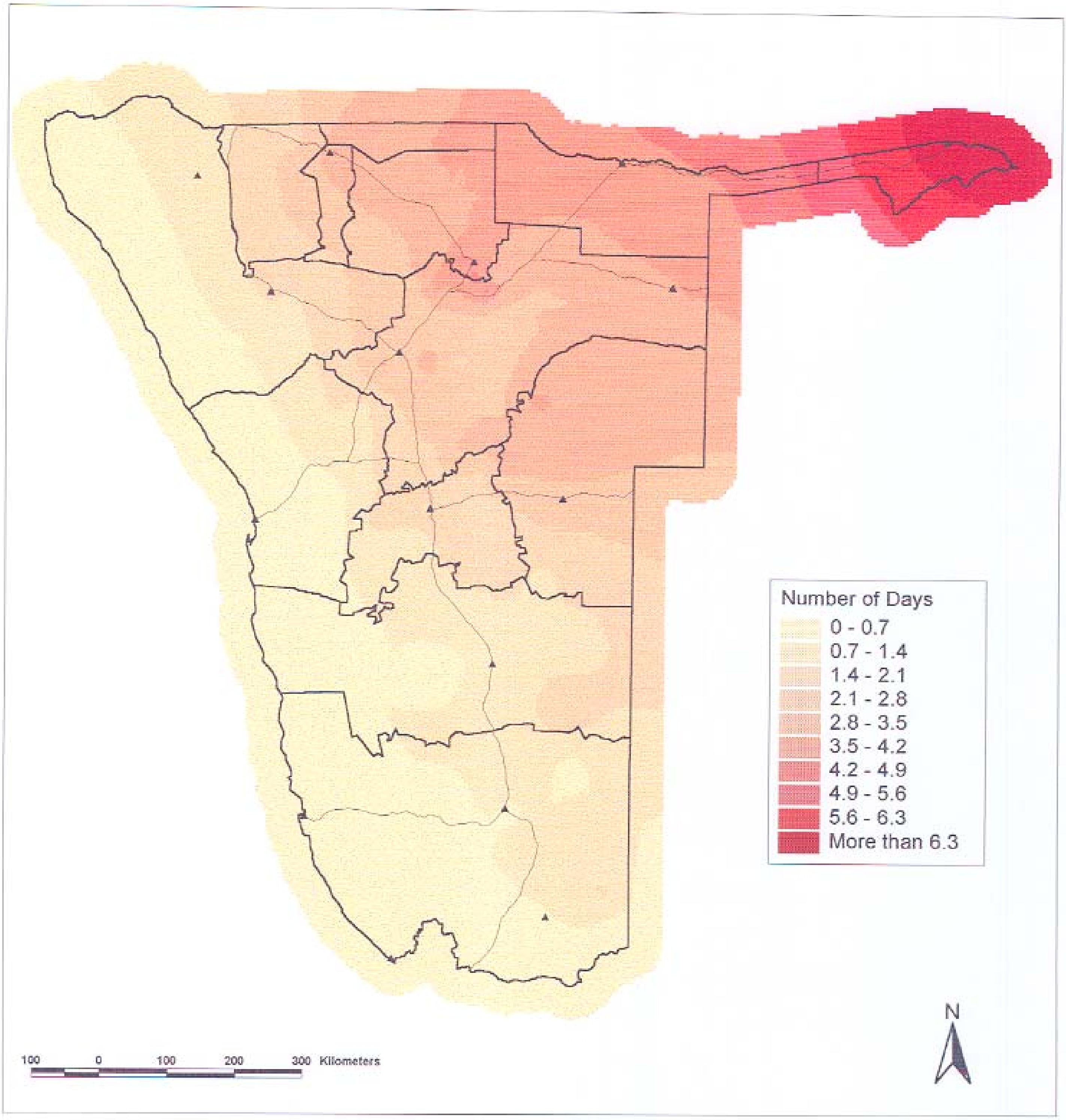
Average number of days in October with 5 mm or more rain



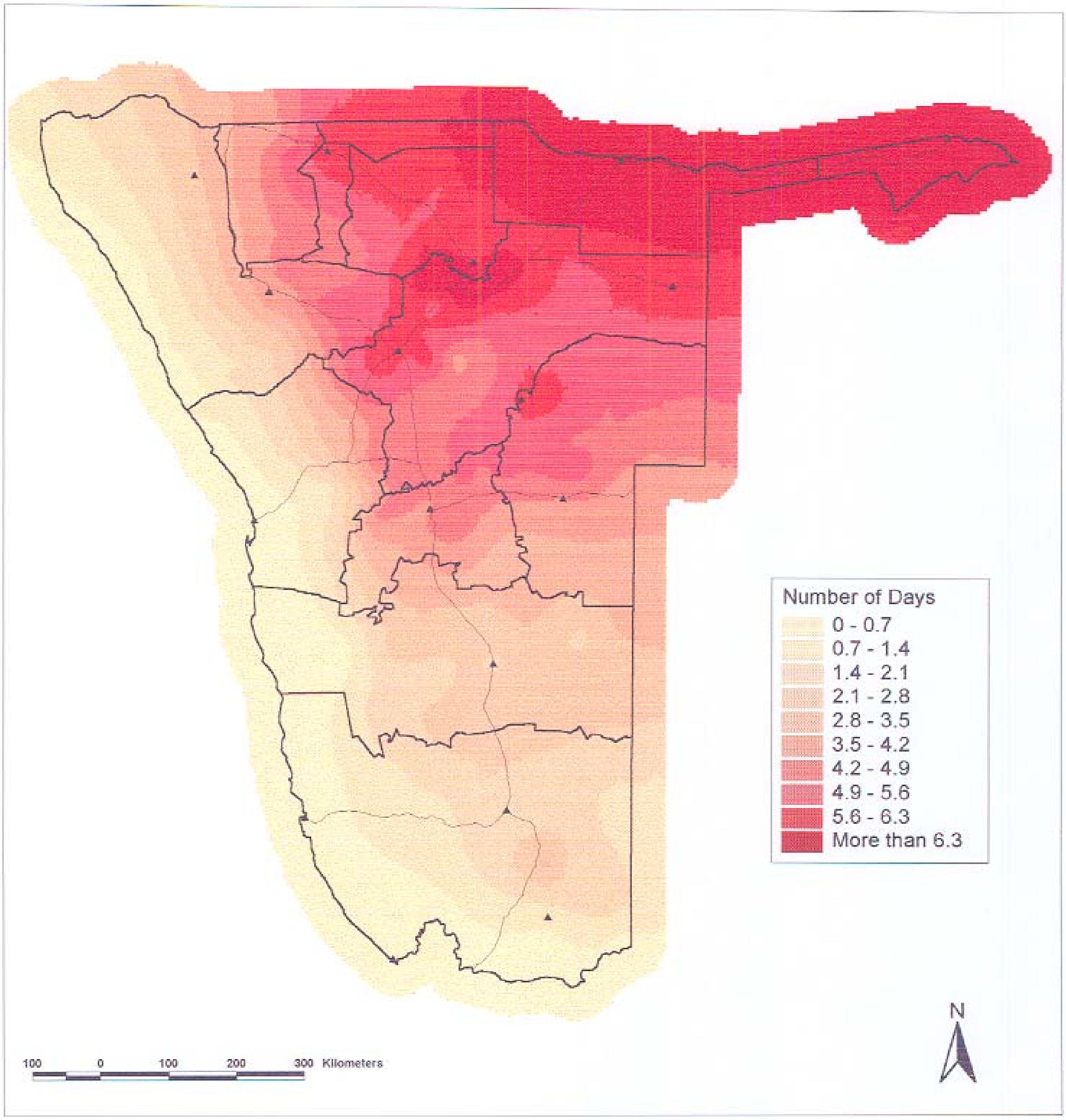
Map 83
Average number of days in November with 5 mm or more rain



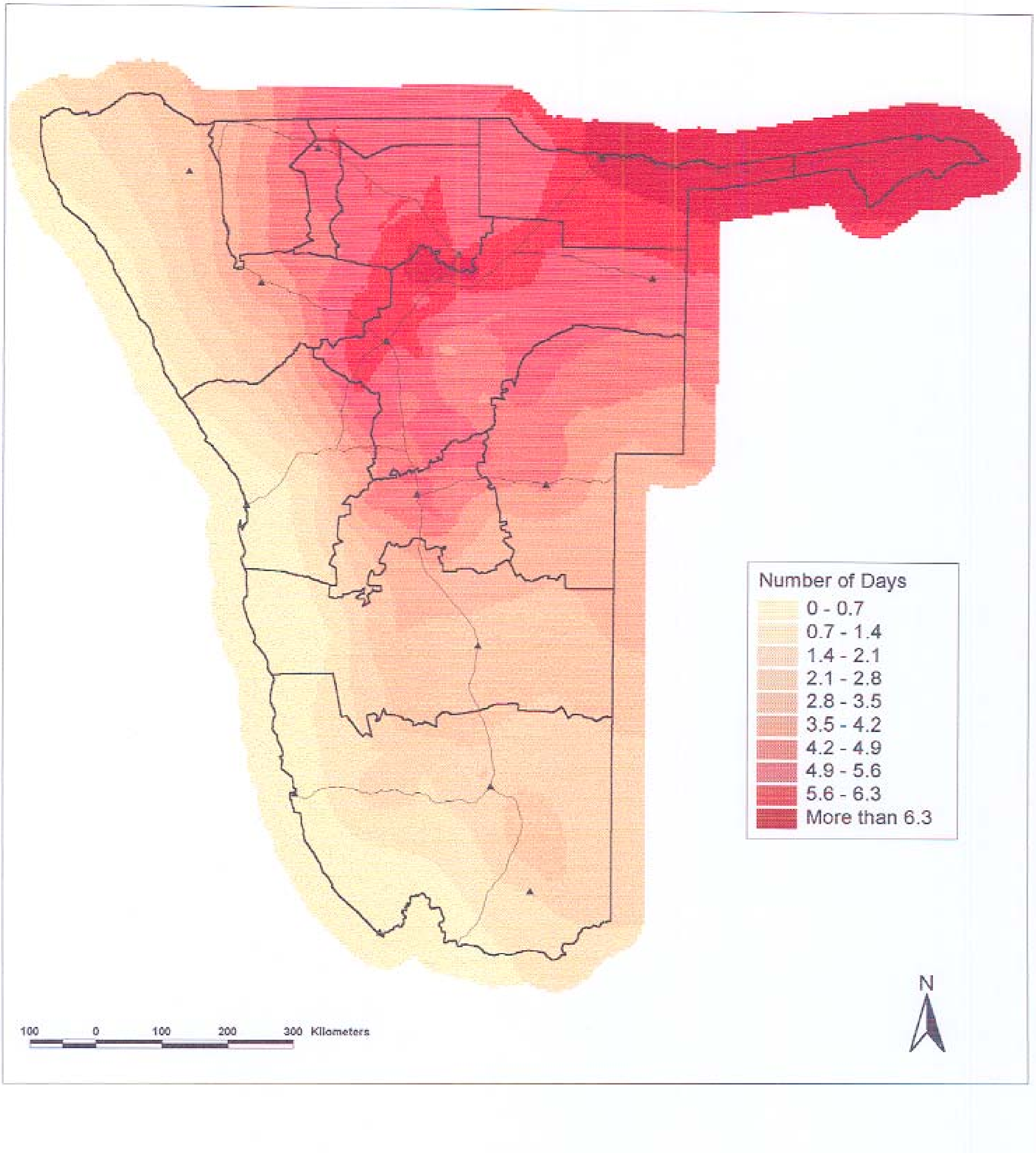
Map 84
Average number of days in December with 5 mm or more rain



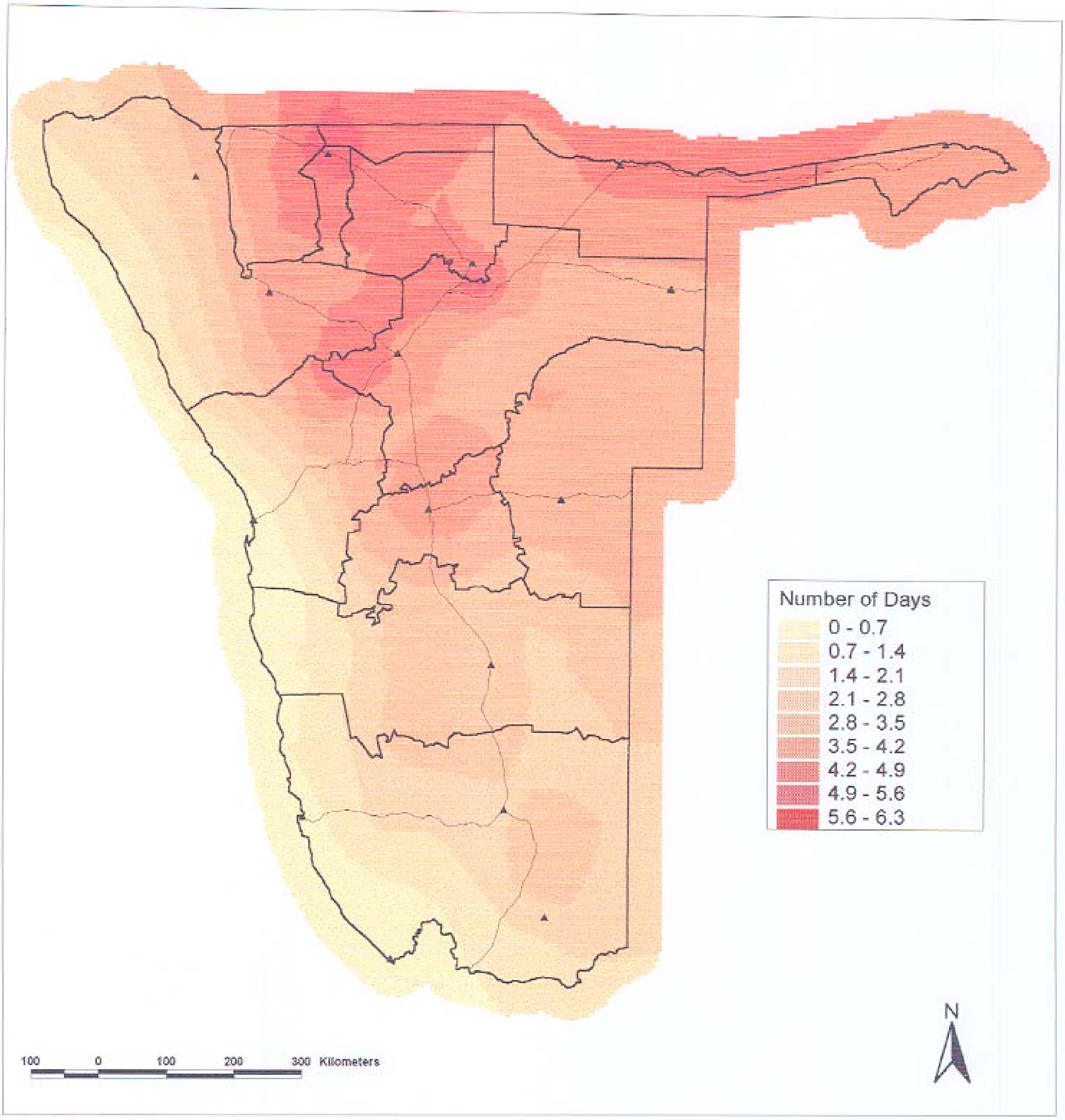
Map 85
Average number of days in January with 5 mm or more rain



Map 86
Average number of days in February with 5 mm or more rain

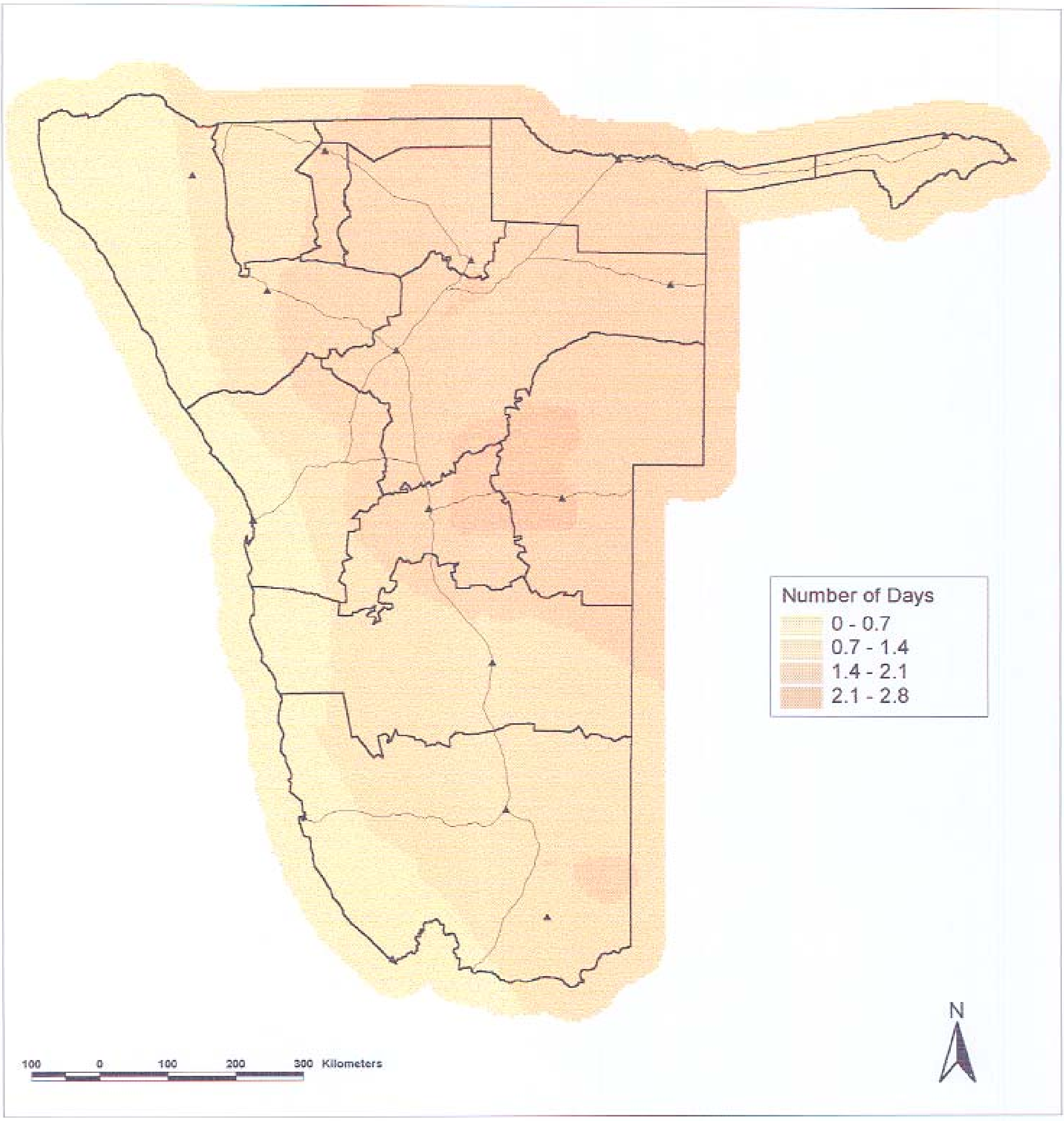


Map 87
Average number of days in March with 5 mm or more rain

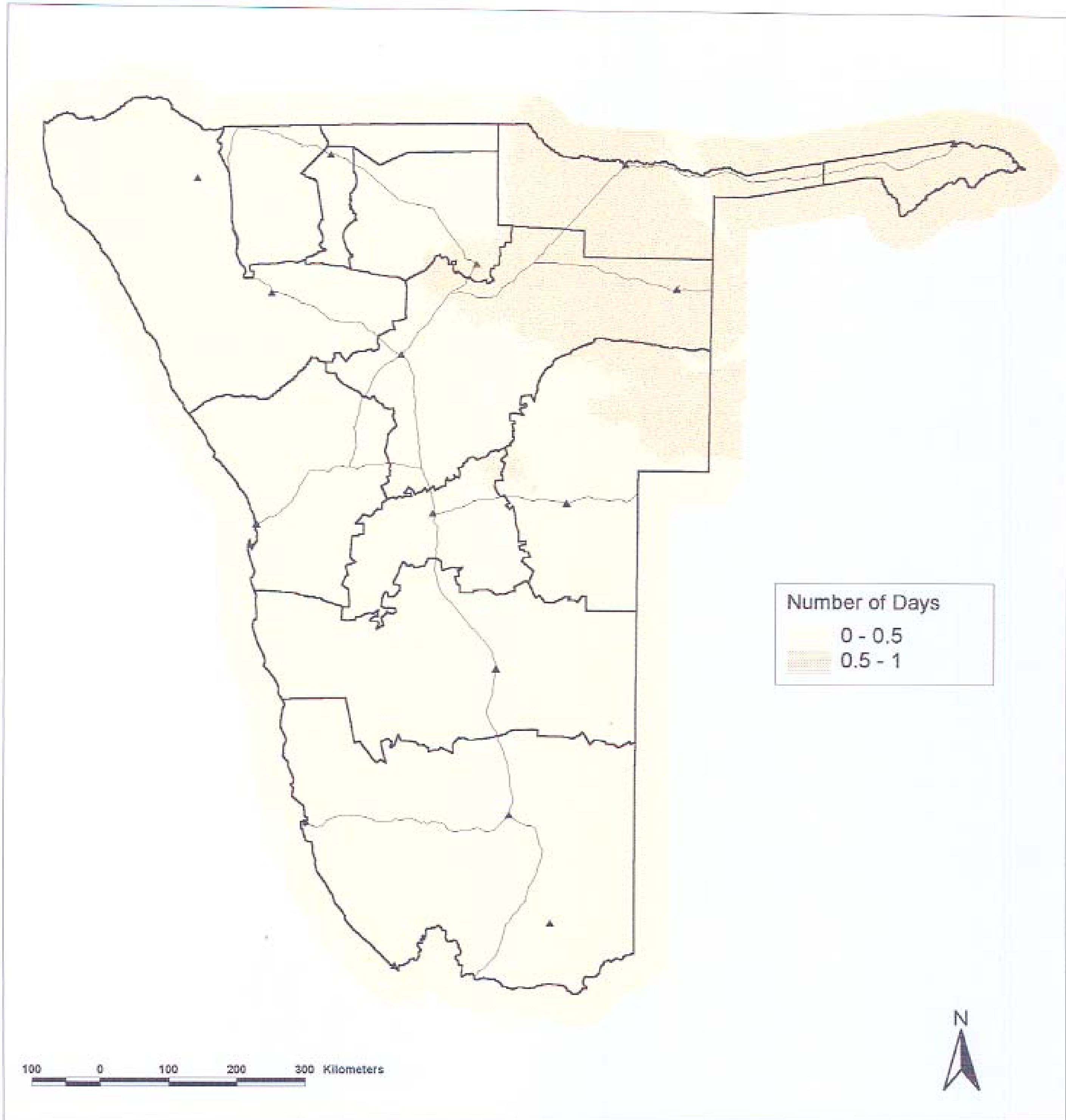


Map 88

Average number of days in April with 5 mm or more rain

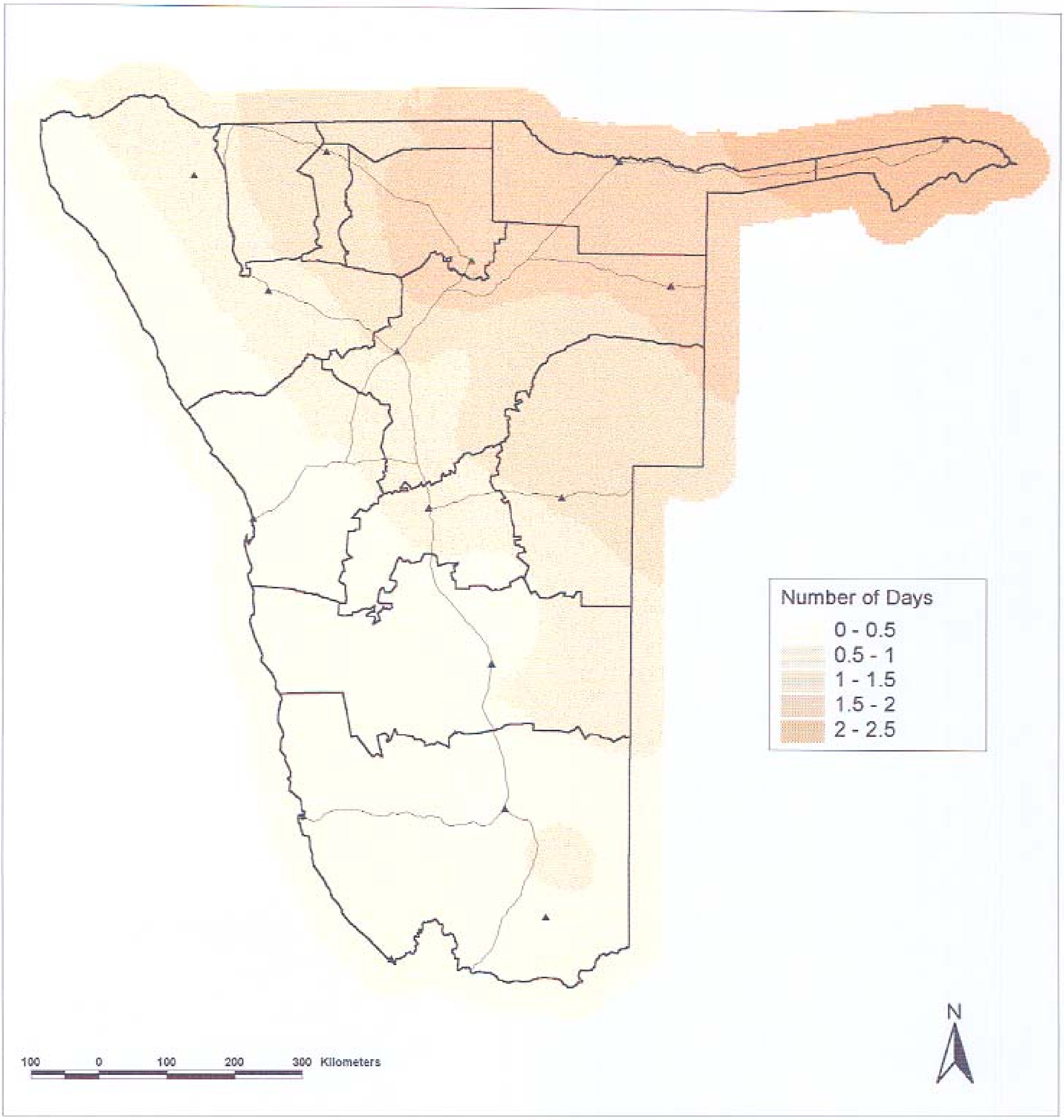


Map 89
Average number of days in October with 10 mm or more rain

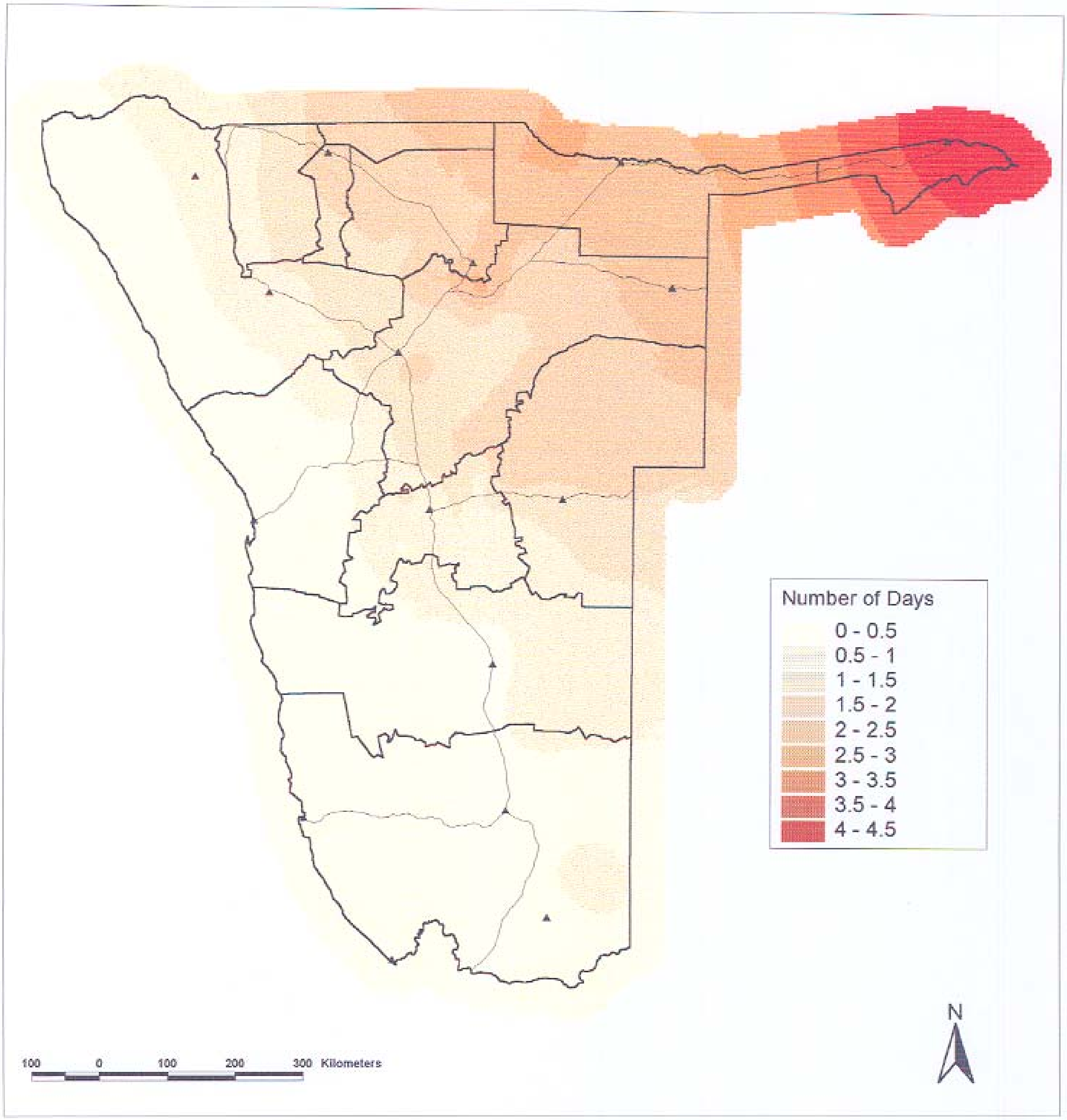


Map 90

Average number of days in November with 10 mm or more rain

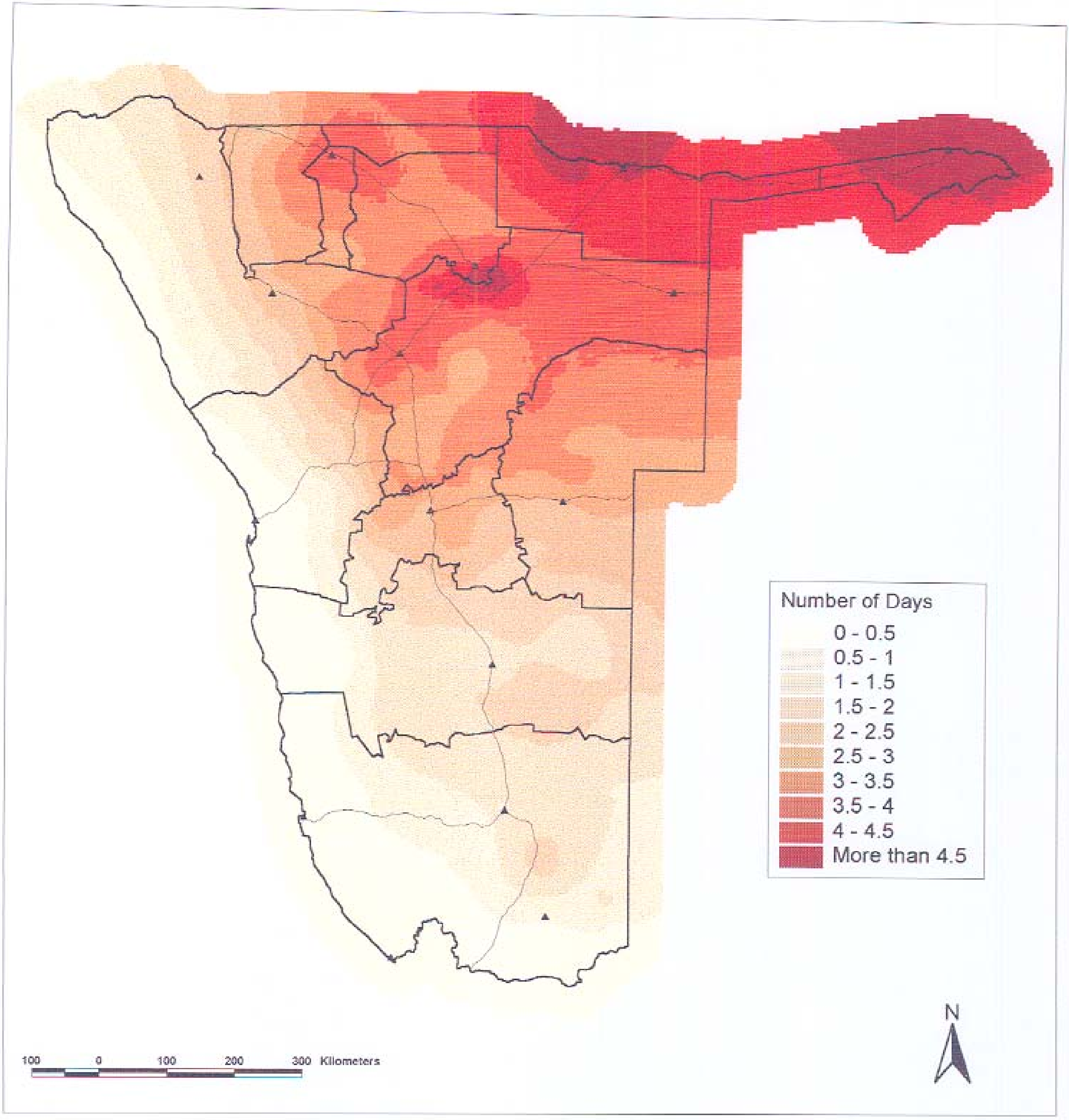


Map 91
Average number of days in December with 10 mm or more rain

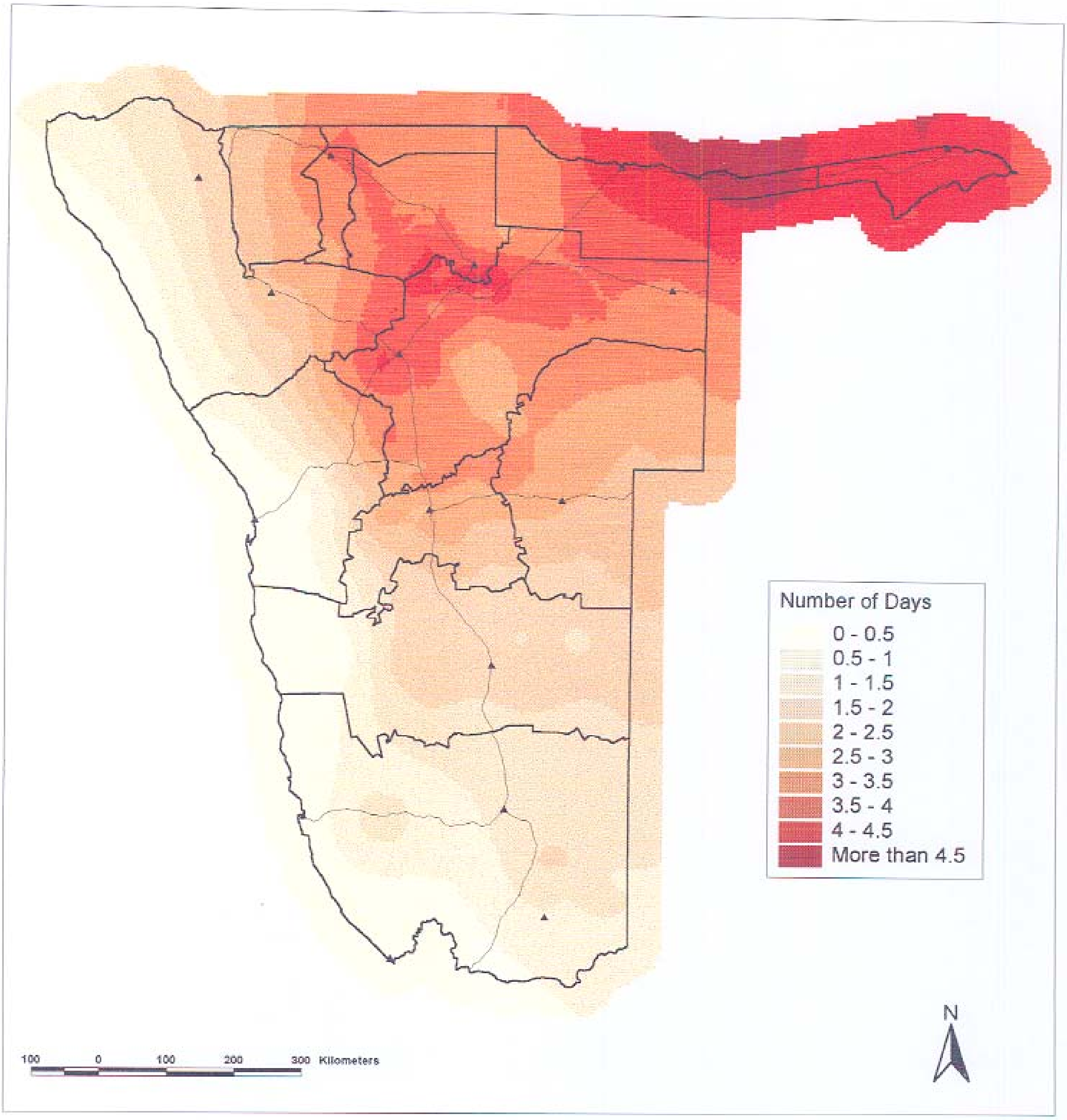


Map 92

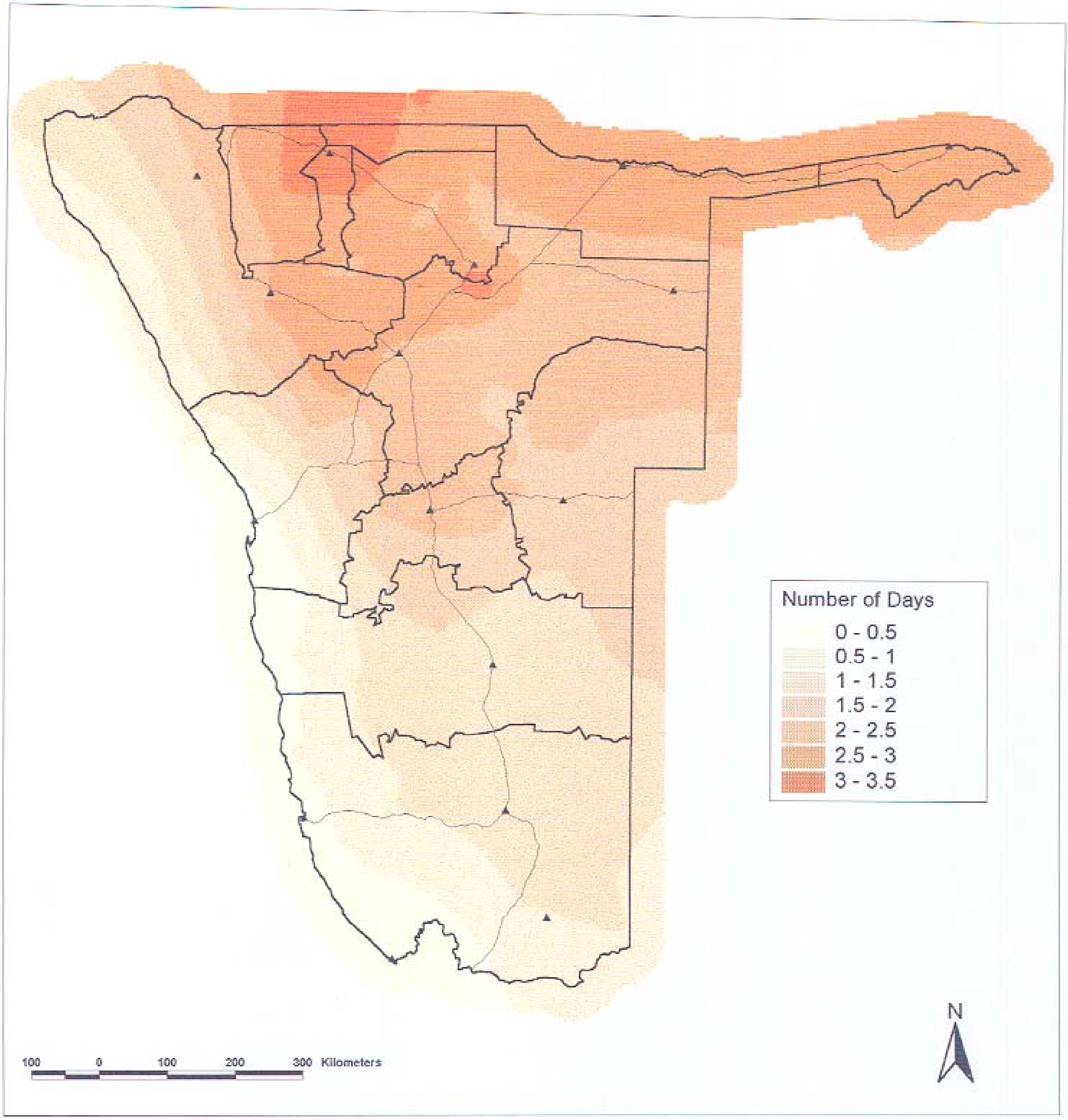
Average number of days in January with 10 mm or more rain



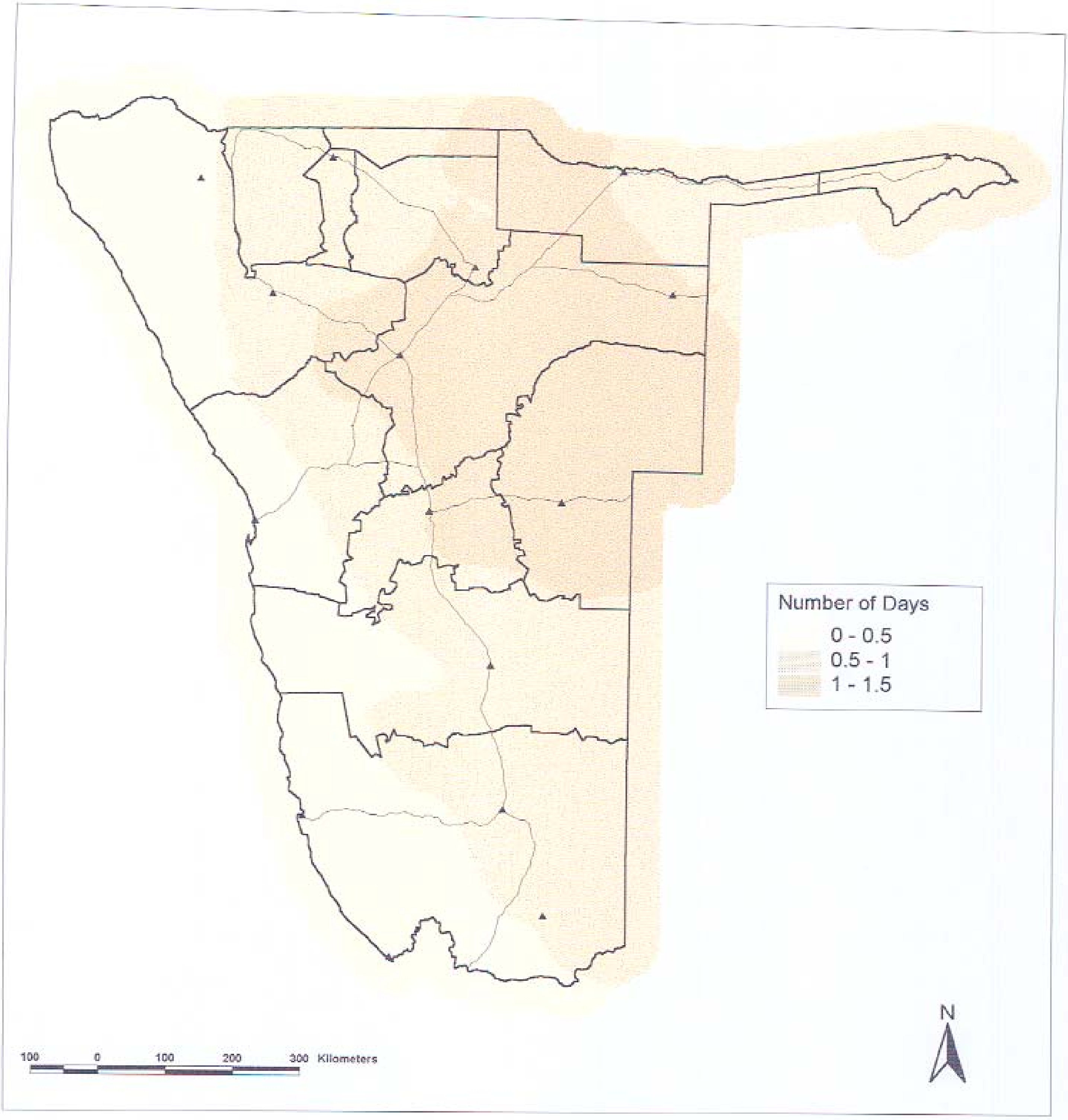
Map 93
Average number of days in February with 10 mm or more rain



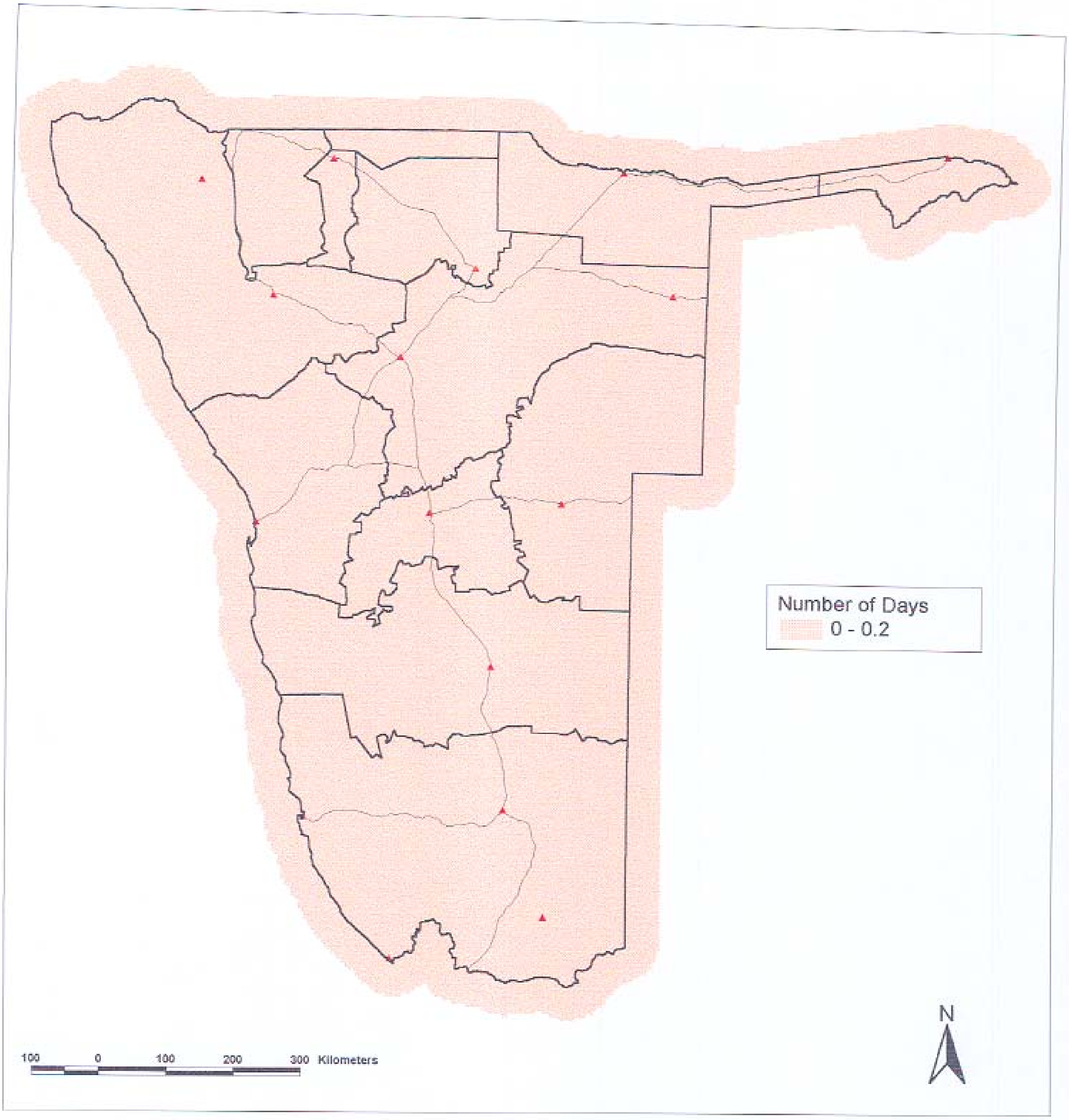
Map 94
Average number of days in March with 10 mm or more rain



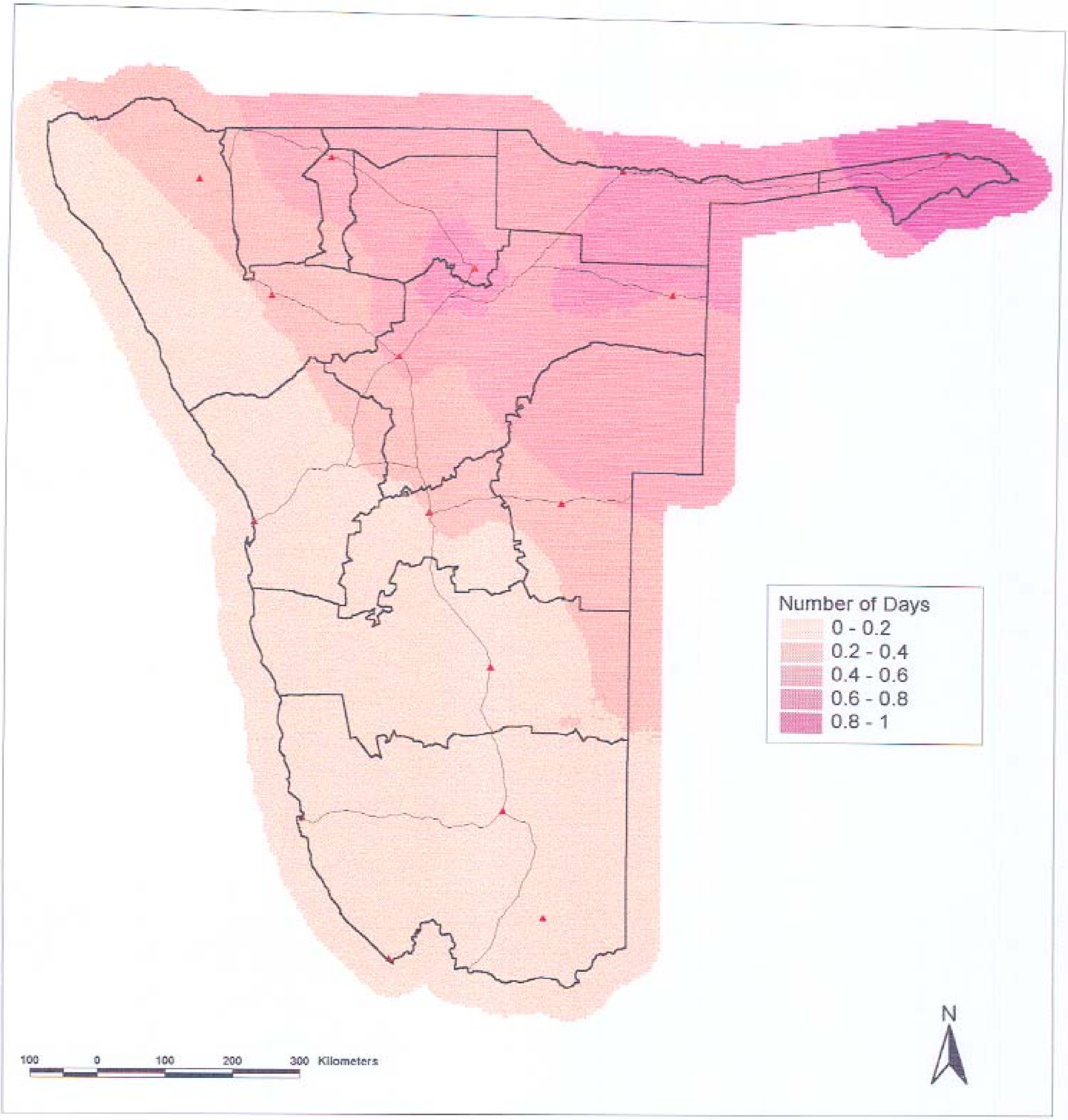
Map 95
Average number of days in April with 10 mm or more rain



Map 96
Average number of days in October with 20 mm or more rain

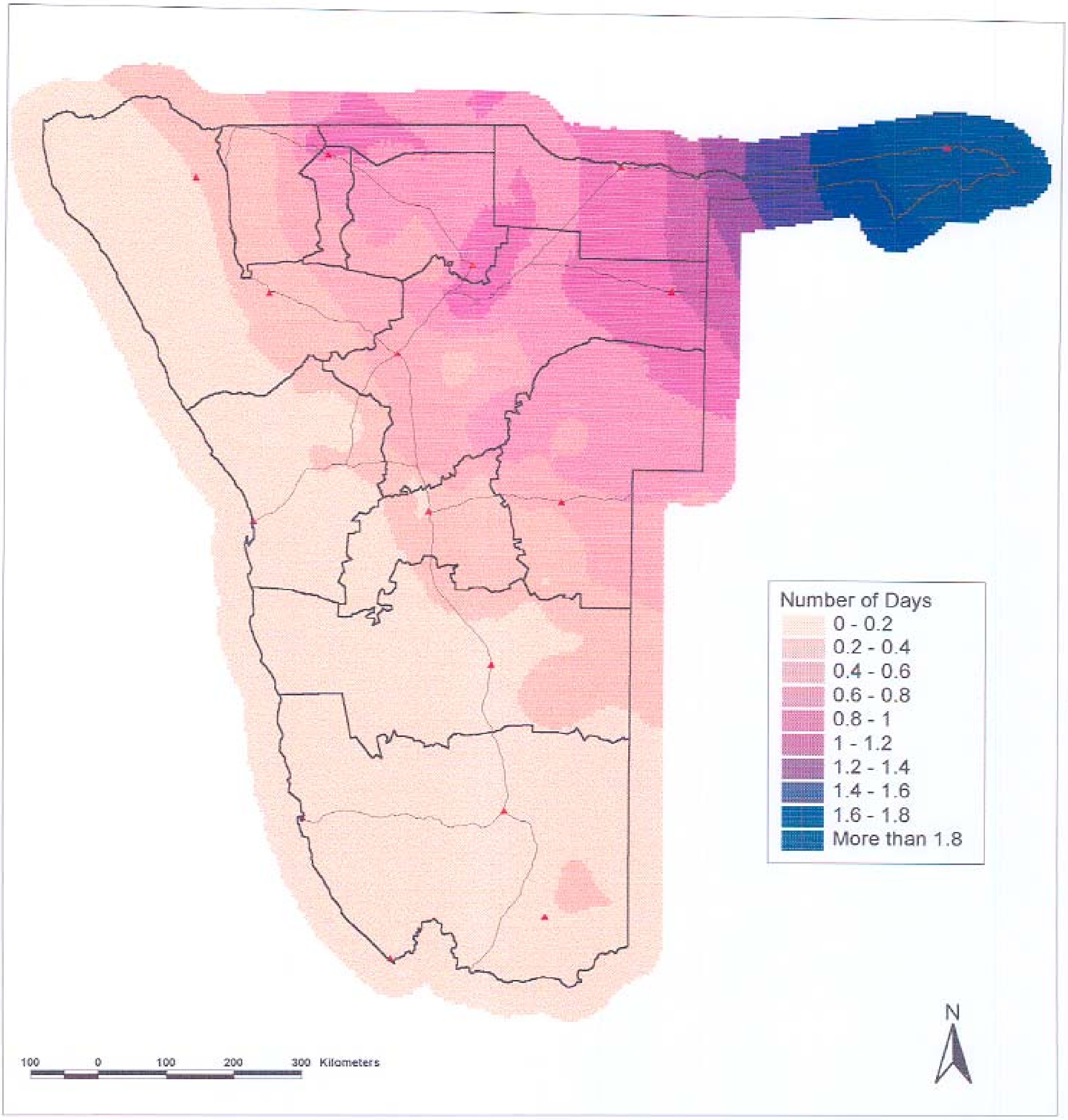


Map 97
Average number of days in November with 20 mm or more rain

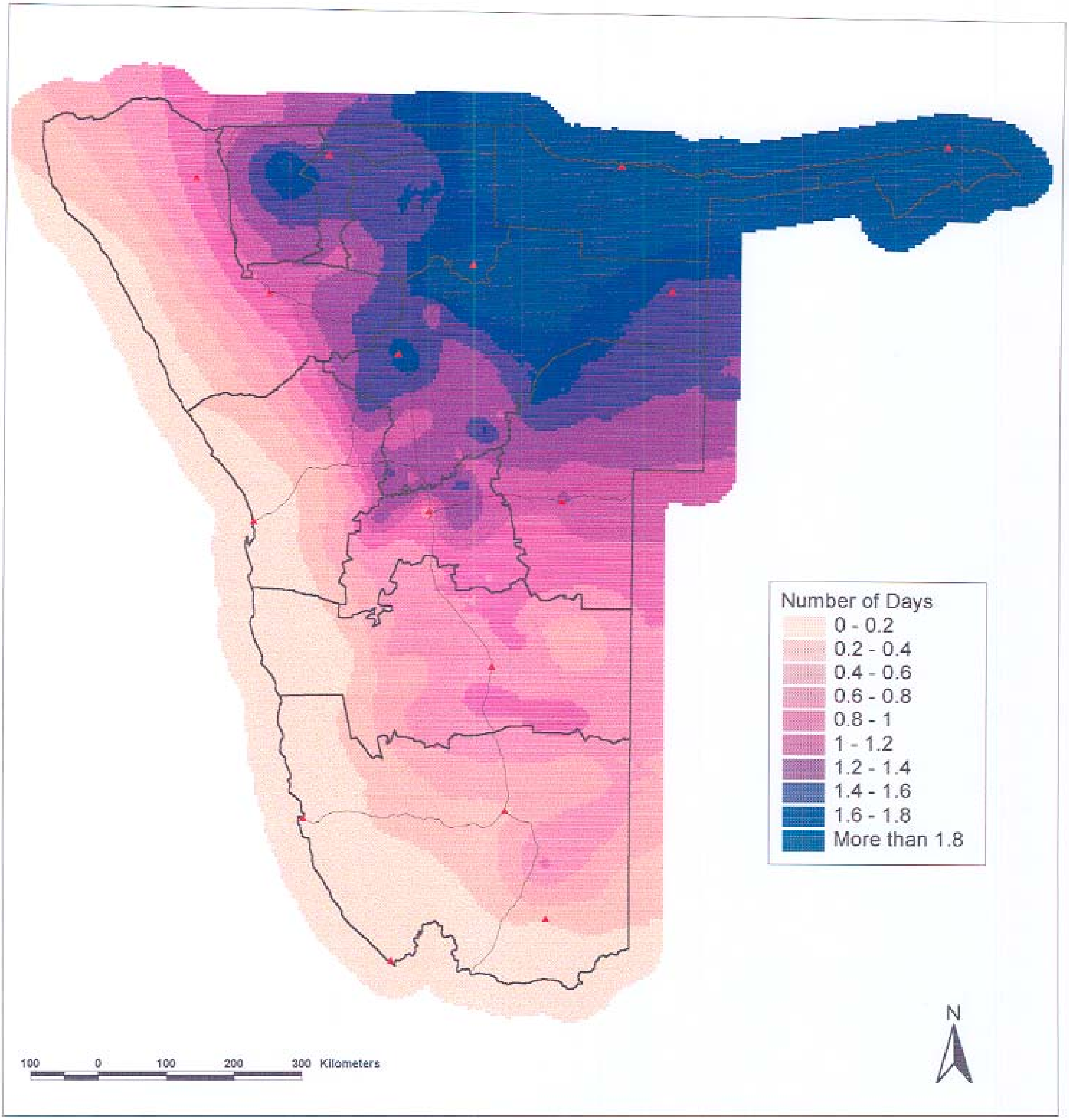


Map 96

Average number of days in December with 20 mm or more rain

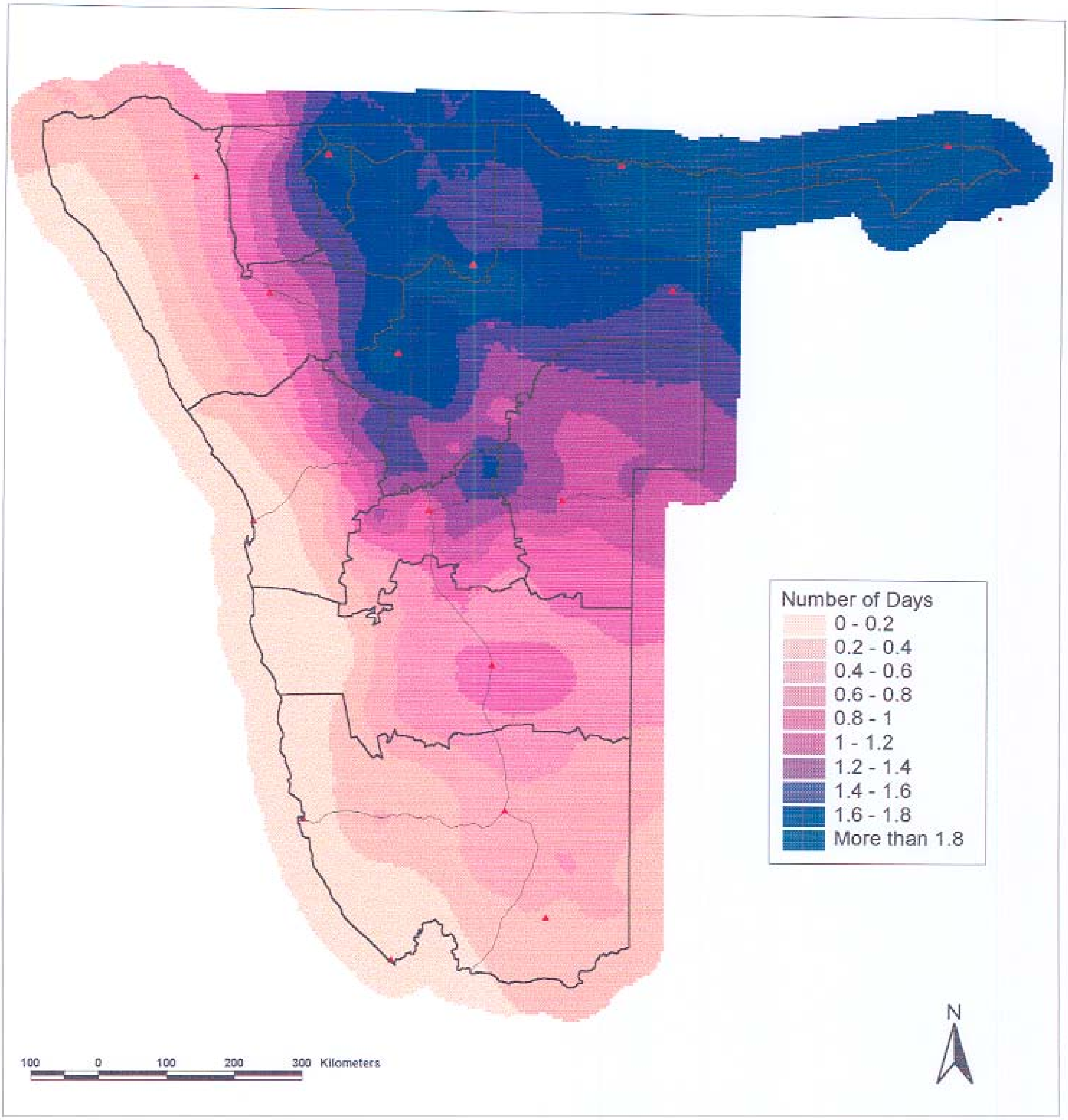


Map 99
Average number of days in January with 20 mm or more rain

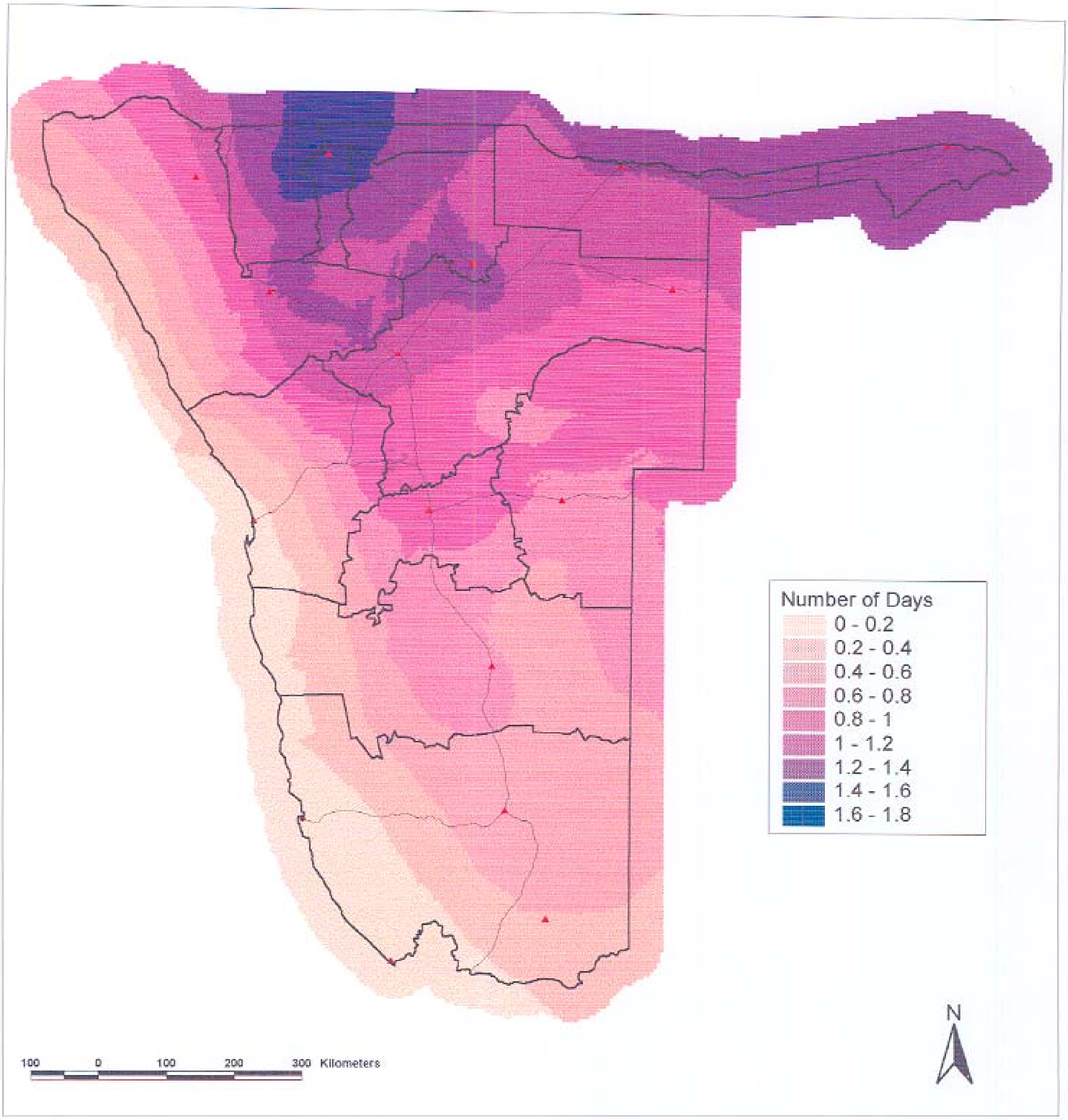


Map 100

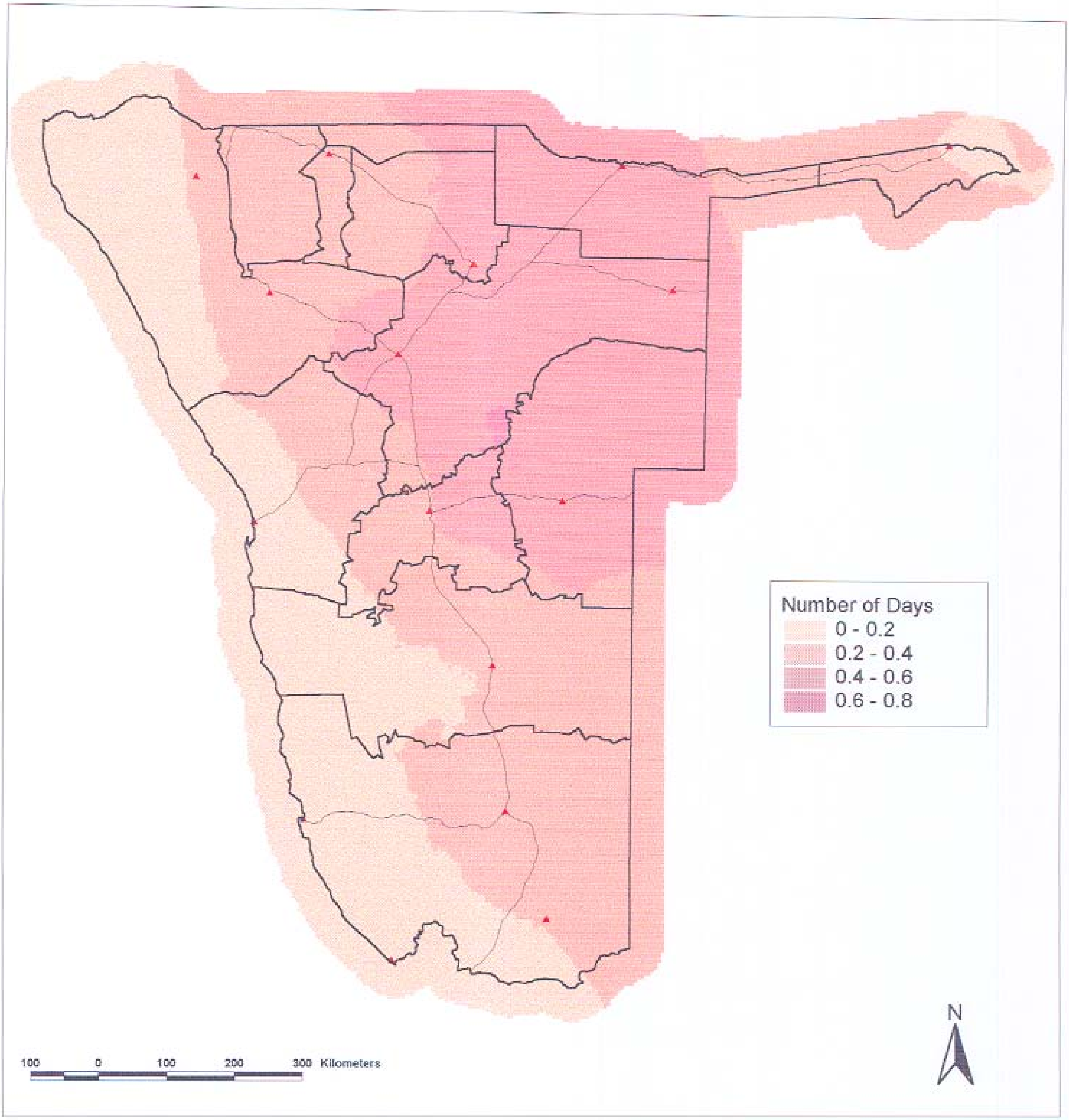
Average number of days in February with 20 mm or more rain



Map 101
Average number of days in March with 20 mm or more rain



Map 102
Average number of days in April with 20 mm or more rain



3.5 Shortages of Rain (maps 103 - 107)

There are frequent shortages of rain in a dry country where rainfall is erratic. However, there is little agreement on what constitutes a shortage. There are also very different views on what shortages are "normal" – perhaps because they can be expected to occur frequently – and which are so "abnormal" that people may expect relief assistance from government and other parties. "Drought relief" often also has political dimensions because governments are keen to assist people in politically significant constituencies who may be affected by shortages of rain.

<u>"Moving Average" as a Rainfall Deficit Indicator</u>

The following series of maps portrays a number of different measures of shortages of rain. **Map 103** shows the proportion of all months which follow 12 month periods during which less than 75% of the annual average rainfall has fallen cumulatively. This is a widely used measure of drought, although periods shorter or longer than 12 months may be used as a threshold after which "drought" conditions may be considered to have set in.

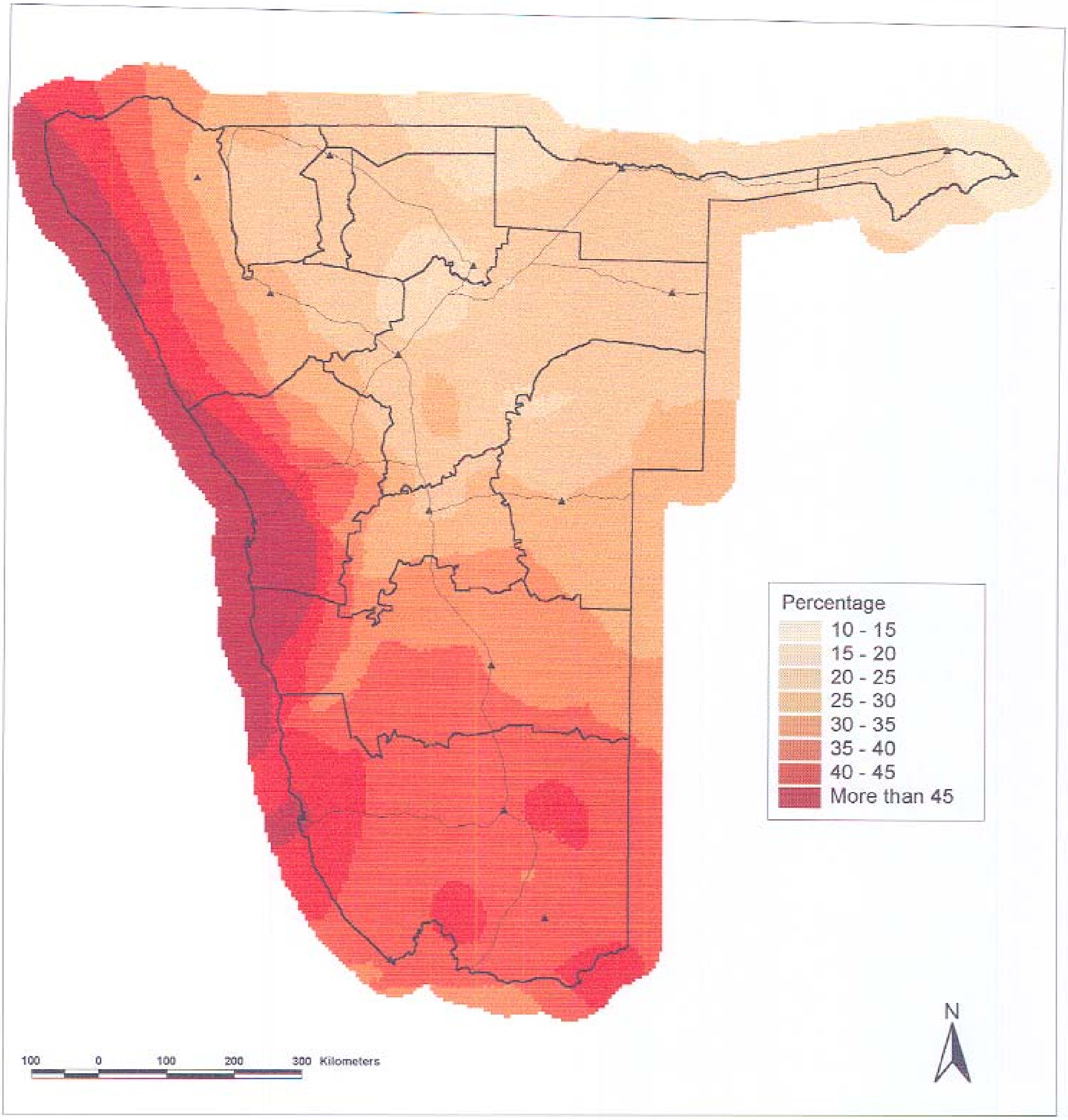
The measure is calculated by adding up the numbers of months following 12-month periods over which less than 75% of the annual average rain has fallen. The total amount of rain that has fallen over a 12-month period is calculated as a moving total over the 12 months. The total number of months following such dry 12-month periods is calculated and divided by the total number of months over which rainfall has been recorded at a station.

Map 103 shows that proportions of drought months are much higher in the western and southern regions of Namibia, where a quarter and more of all months have followed periods of 12 consecutive months during which less than 75% of average annual rainfall has fallen. The most extreme conditions are in the central and northern Namib where close to half of all months follow such dry periods.

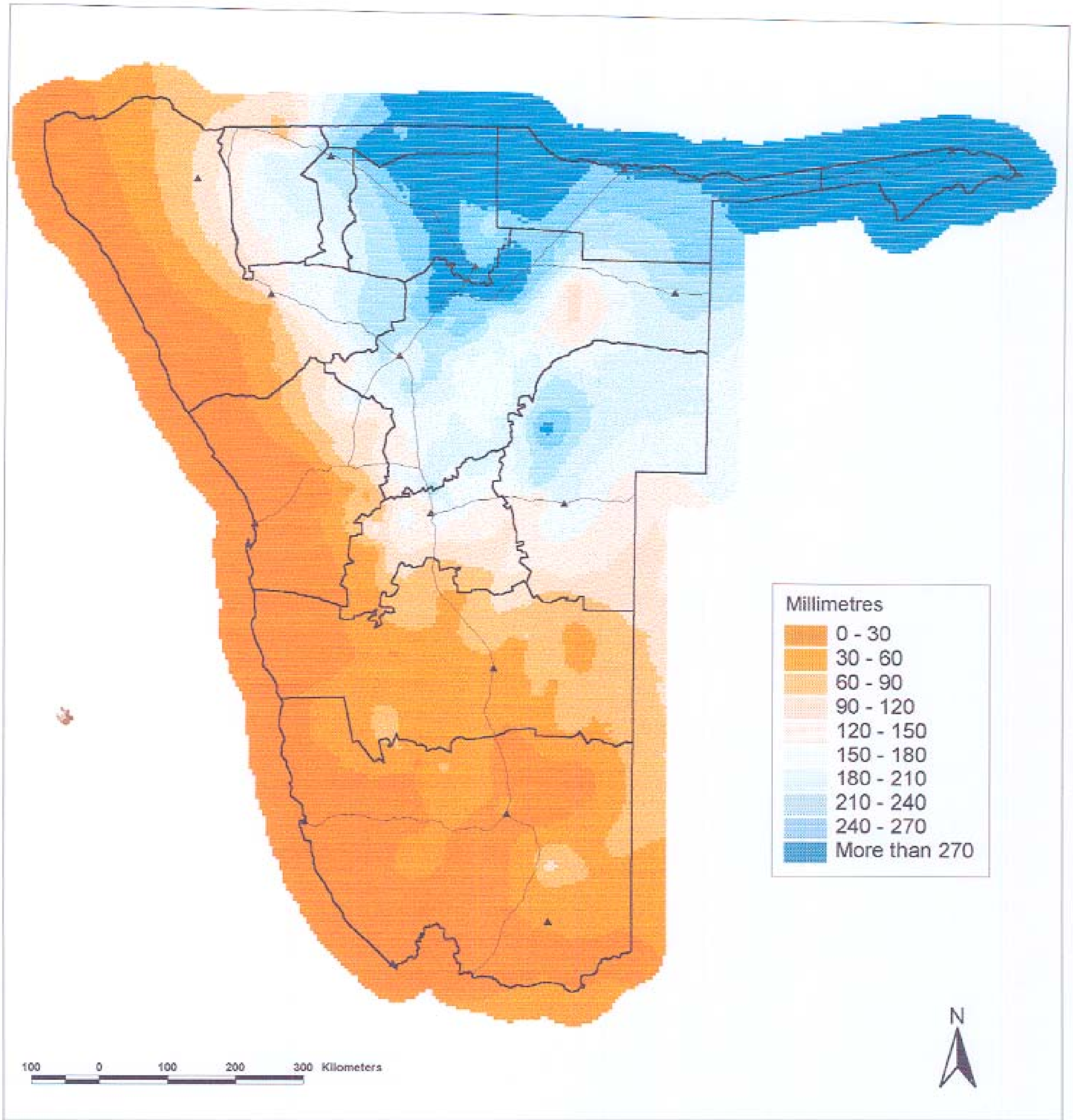
<u>Lowest Percentiles as a Rainfall Deficit Indicator</u>

The lowest percentiles of annual total rainfall provide other measures of rainfall deficits. These are the total amounts of rain recorded in the driest years, as shown here for the driest 7% of all years **(map 104),** the driest 10% **(map 105)**, the driest 20% **(map 106)** and the driest 30% **(map 107)** of all years. The differences in rainfall between these percentiles are often fairly substantial. For example, Windhoek may receive up to 120-180 millimetres per year during the driest 7% of years, but up to 250 mm in the driest 30% of years. Likewise, areas around Grootfontein can expect 250-300 mm at most during the driest 7% of years, but totals may go up to 400 mm in the driest 30% of years.

Map 103
Percentage of drought months

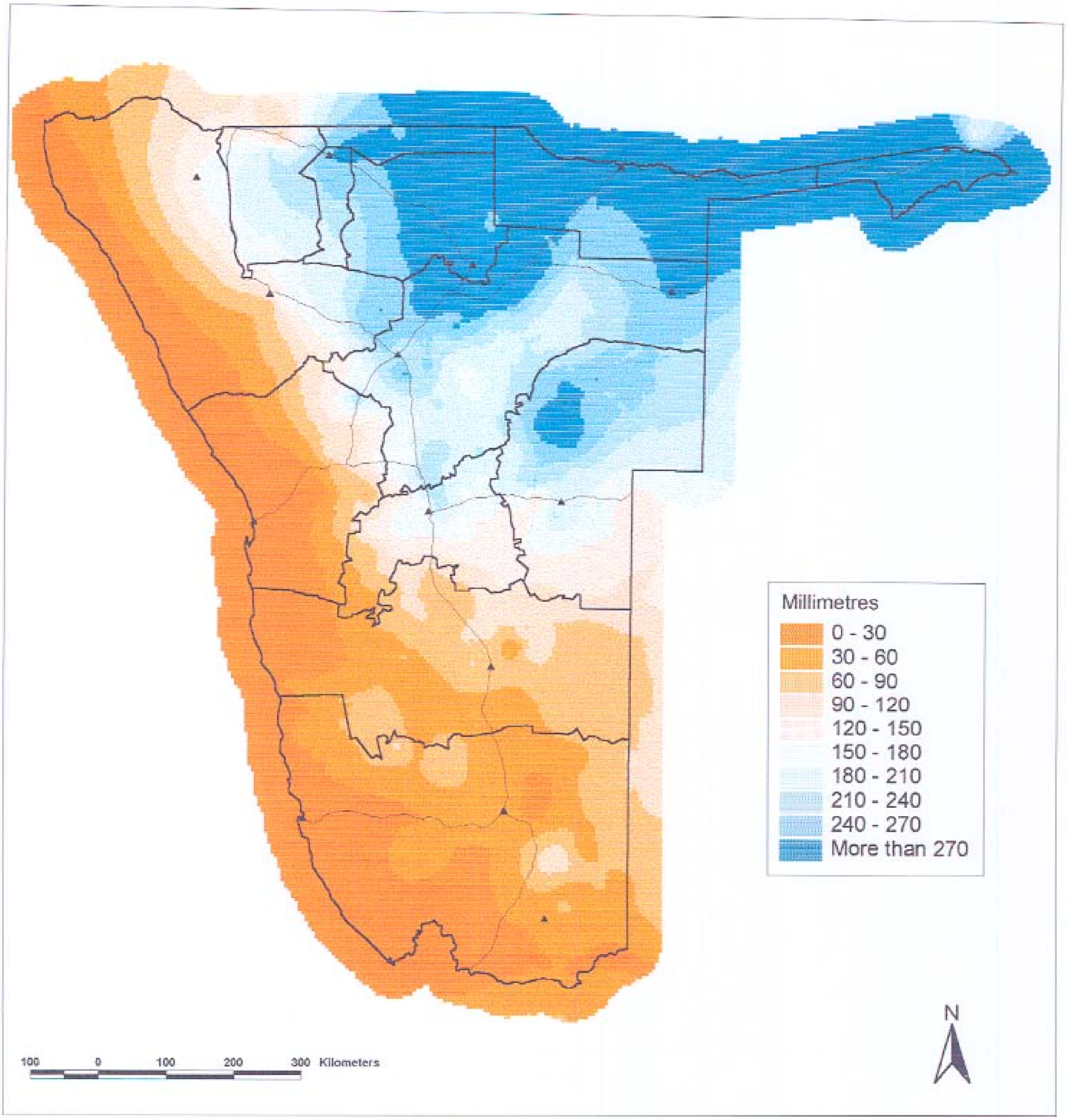


Map 104
October-April total rainfall: 7th percentile

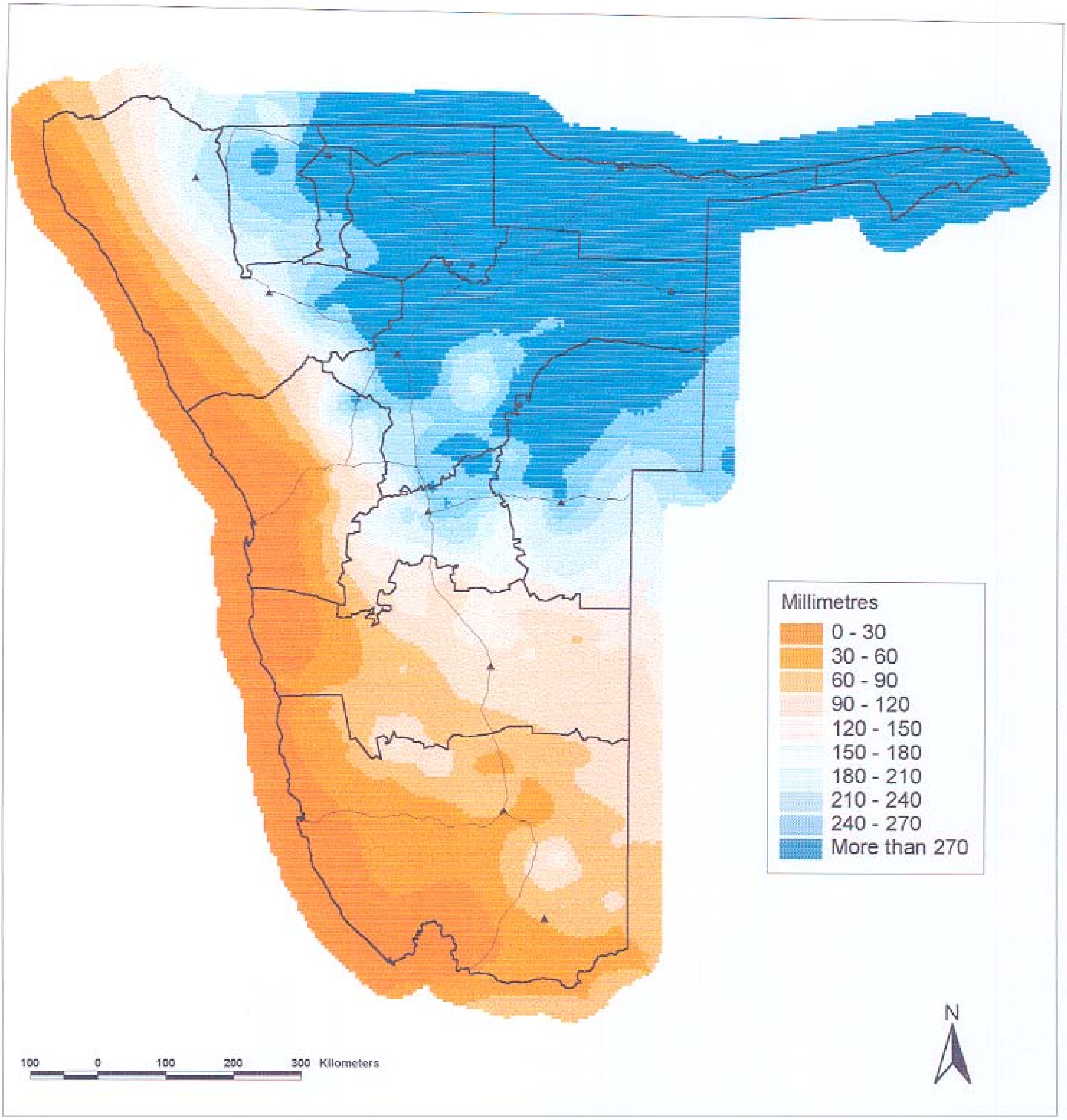


Map 105

October-April total rainfall: 10th percentile

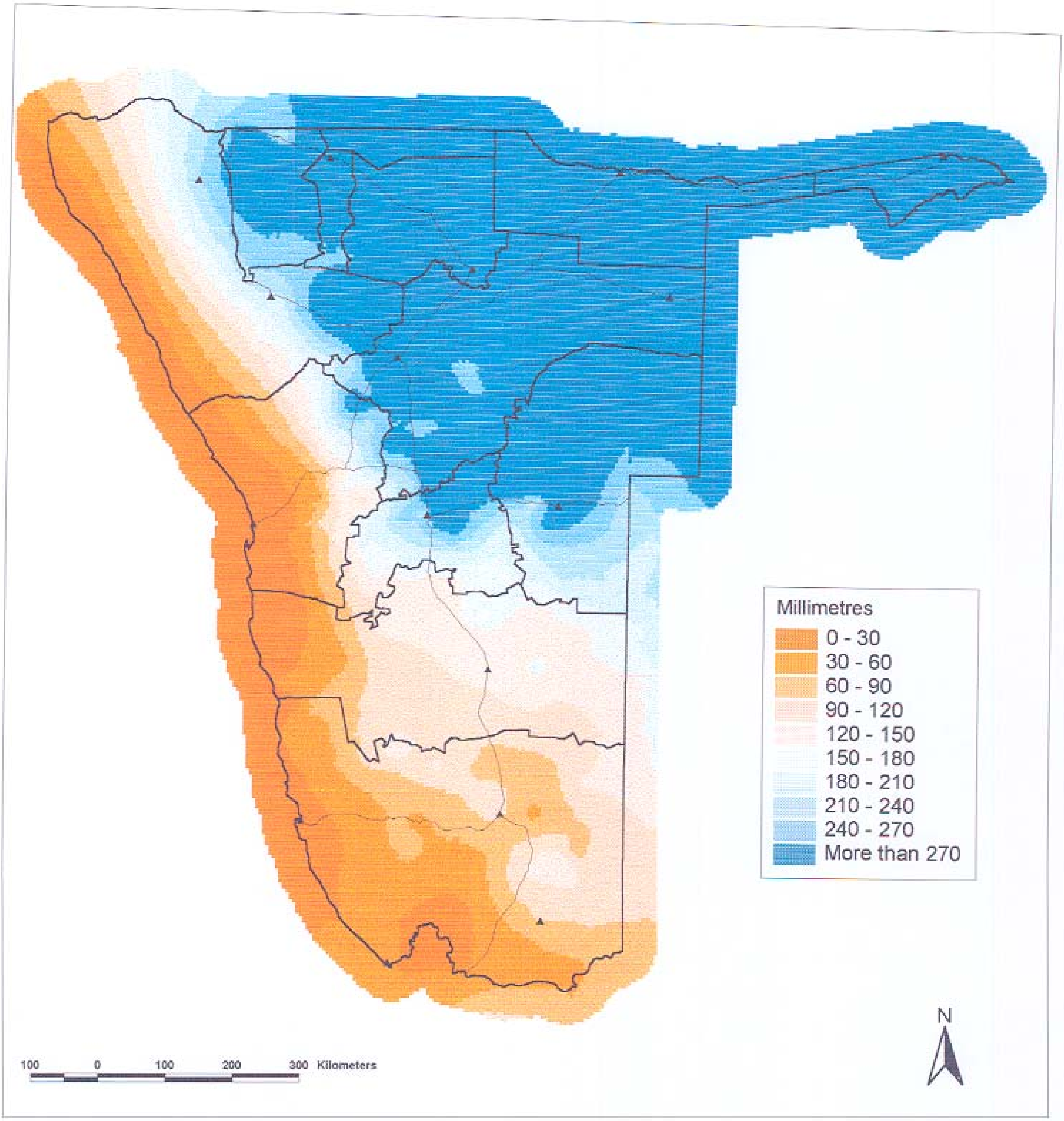


Map 106
October-April total rainfall: 20th percentile



Map 107

October-April total rainfall: 30th percentile



3.6 Southern Oscillation Indices (SOI) and Rainfall (maps 108 - 128)

The SOI and its Phases

The following sequence of maps depicts the probabilities of rainfall in Namibia exceeding medians in relation to various phases of the Southern Oscillation Index (SOI). The SOI is the difference in barometric pressure anomalies between Tahiti and Darwin, Australia. Negative values of the SOI are associated with the El Niño condition, and positive values with La Niña.

There are five phases into which SOI values fall, each phase dependent upon the value of the SOI and trends in the SOI values from month to month. Phase 5 occurs when the SOI is near normal and not changing. In Phase 4, the index rises rapidly, and in Phase 3, falls rapidly. Phase 2 represents a period when the SOI is consistently positive (La Niña) and during Phase 1 it is consistently negative (El Niño).

Since SOI values have been recorded each month over many years, it is possible to examine the relationship between the SOI phase in any one month and the amounts of rain that fall during the following three months. The maps presented here show the probabilities of rainfall exceeding long-term medians during consecutive three month periods. For example, since Phase 2 or La Niña conditions are often associated with higher rainfalls in southern Africa, we might expect that the probability of total rainfall exceeding the median for the next three months would be above 50%. Conversely, Phase 1 or El Niño phases are associated with lower rainfall and then the probabilities of median rainfall being exceeded should be lower than 50%. With a long term dataset, it follows that probability maps for each month and each phase can be produced.

Data Availability and Analyses

Because the dataset used in analyses only spans the period 1961 onwards, the number of possible SOI phases for each month was small, the maximum being 11. A summary of frequencies of SOI phases for each month is presented in table 1 below. For most phases and months the number of events was smaller than 11, and for phase 3 and 4 (rapid rises and falls) the numbers were so small that it was not possible to compare rainfall totals with medians for most of the wet season months. A study covering a much greater number of years would be required to look at relationships between these two short-lived phases and rainfall totals.

Table 1: Frequency of occurrence of each SOI phases for each month (1961 - 1997)

SOI Phase	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1	9	5	*	9	6	5	7	9	10	10	9	8
2	*	6	6	*	6	7	10	6	10	11	7	5
3	*	7	11	7	*	9	*	*	*	*	*	*
4	8	9	7	*	13	8	6	8	*	*	6	*
5	11	9	8	10	8	6	10	9	10	10	11	18

* less than 5 occurrences for most or all of the 294 rainfall stations from 1961 onwards

As in many cases, numbers of SOI phase events were so low, a cut-off criterion of five phase events was adopted. In other words, probabilities were only calculated for months which had at least 5 occurrences for each SOI phase.

For each SOI phase and month, the probabilities mapped were calculated by recording the number of times that the total rainfall that fell over the consecutive three months exceeded the median for those three months. The number of times that medians were exceeded was expressed as a percentage of the number of times the SOI phase was recorded in the month that preceded those three months. The probabilities for each station were simply the proportions of times that rainfall exceeded the three month. For example, phase 1 occurred eight times during December during the records spanned by this study (1961 to 1997). If the total rainfall in January, February and March at any particular station was above the median five times during those three months, the probability of rainfall exceeding the median at that station is 5/8 or 62.5%.

While the sample of possible SOI phases was rather small, the numbers of stations for which medians and total rainfalls were compared independently was large. The geographic patterns and trends seen on the maps where certain broad areas have much higher or lower probabilities of rainfall exceeding the medians are thus significant. This is because they represent good congruence between many stations independently showing the same patterns over the few years in which different SOI phases have been recorded.

<u>Geographic Rainfall Patterns in Relation to SOI</u>

The maps presented here **(maps 108 to 128)** are for phases 1, 2 and 5 in September to April. These are probabilities of median rainfall during the following three months being exceeded. Maps for some phases are not provided because there were only four or fewer months in which these phases were recorded during the period spanned by this study (see table 1). Maps are also not provided for the winter months of May to August because rainfall is so extremely variable in relation to the insignificant falls that occur following these months. Likewise phase 3 and 4 occurred so infrequently that analyses of rainfall patterns in relation to these phases were also excluded.

The most significant results are for phase 1 (El Niño conditions) and phase 2 (La Niña), especially following November, December, January, February and March. As expected, probabilities of higher rainfalls are greater following phase 2 months, while lower falls are would be predicted following months in which phase 1 conditions hold. A variety of geographic patterns are apparent, with separate areas of the country expecting different probabilities of higher or lower rainfall. For example, higher rainfalls are expected in the south-east following phase 2 conditions in October **(map 112)**, and November **(map 115),** but higher falls are expected in the north-east following the same phase in February **(map 123)** and March **(map 125).**

Probabilities of median rainfalls being exceeded after phase 1 (El Niño) months are usually of the order of 20-40%. This means that there is a 60-80% chance of rainfall being below median values. These patterns also hold over significant separate areas, for example, the south-east following November **(map 114)** and December

(map 117), and parts of the north-east following January **(map 120)** and February **(map 122).**

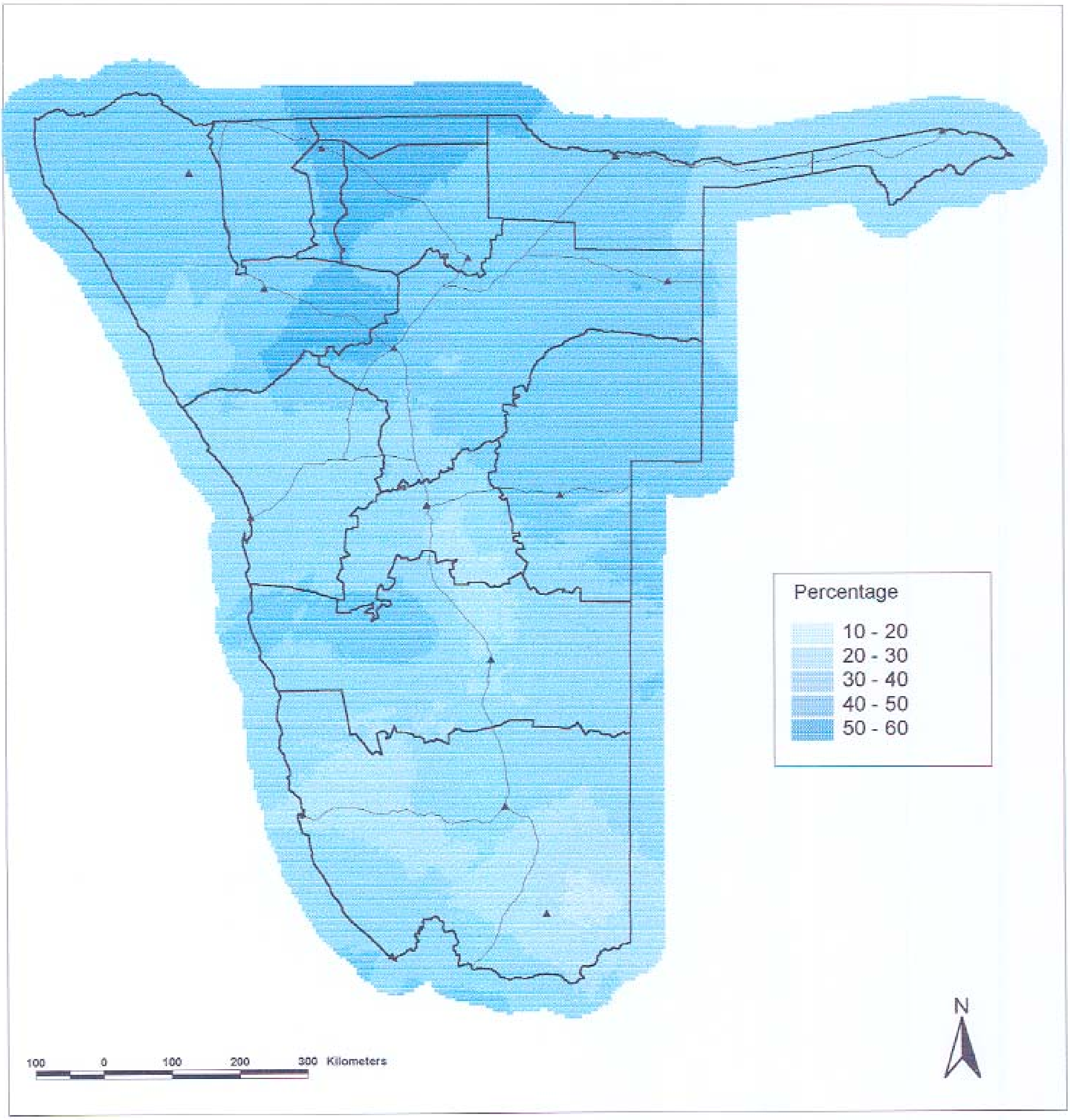
As expected, maps for phase 5 **(maps 110, 113, 116, 119, 121, 124, 126 and 128)**, when the SOI is more or less stable, provide no clear probabilities of rainfall being higher or lower than median values.

To our knowledge, these analyses represent the first attempt to explore relationships between rainfall and SOI phases in Namibia. The results appear to be significant in indicating that some confidence may be attached to predicting probabilities of higher or lower rainfall in certain areas in relation to SOI phases. The analyses were restricted to the frequency with which rainfall exceeded the median, because the limited numbers of SOI phases recorded each month within the period spanned by the data were inadequate to examine relationships between more extreme rainfalls, such as the lowest or highest terciles. However, further analyses, using data spanning longer periods, should be done to record relationships between SOI phases and these more extreme values.

Map 108

September SOI phase 1:

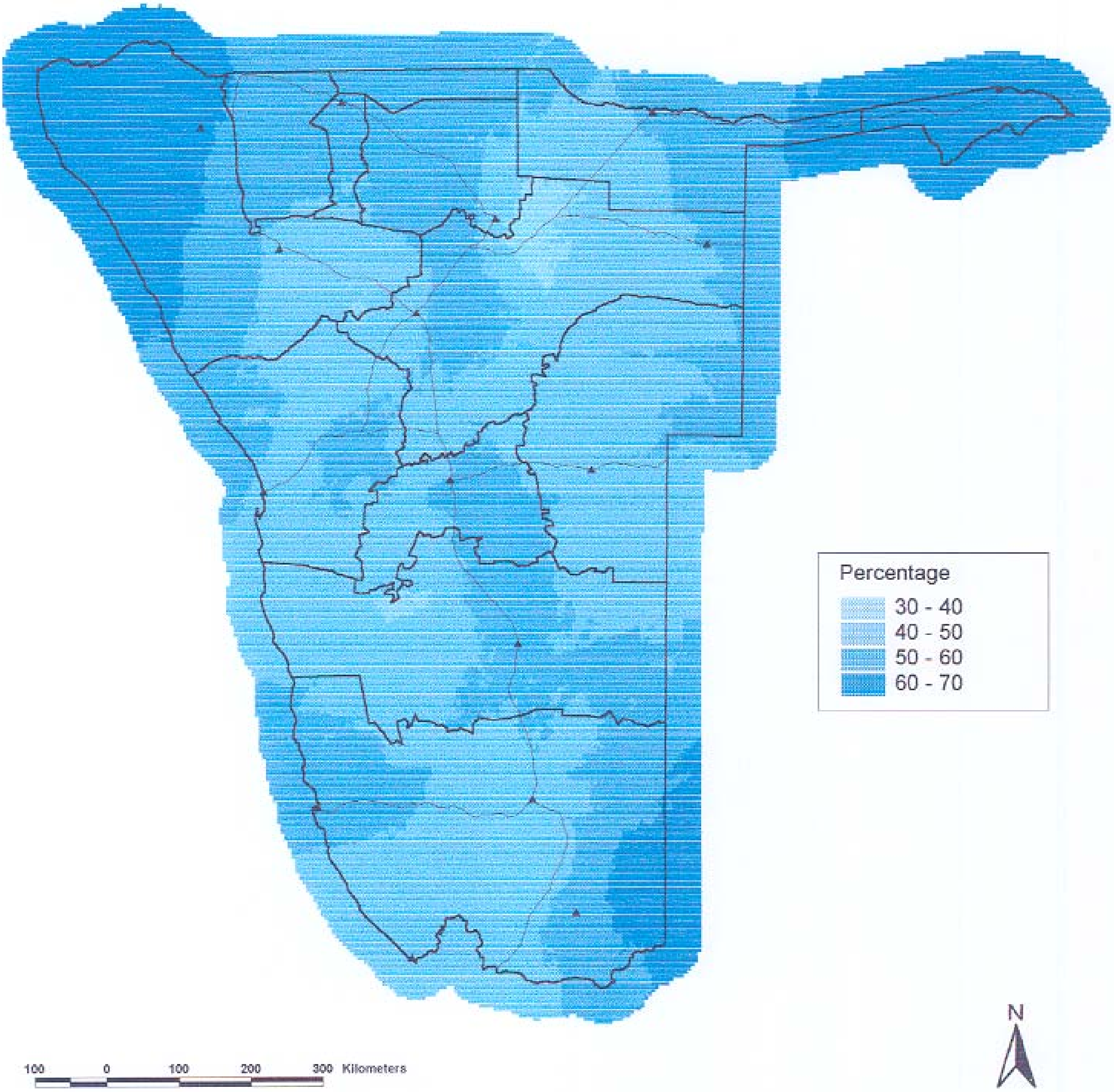
Percentage probability of exceeding median rainfall in the next three months



Map 109

September SOI phase 2

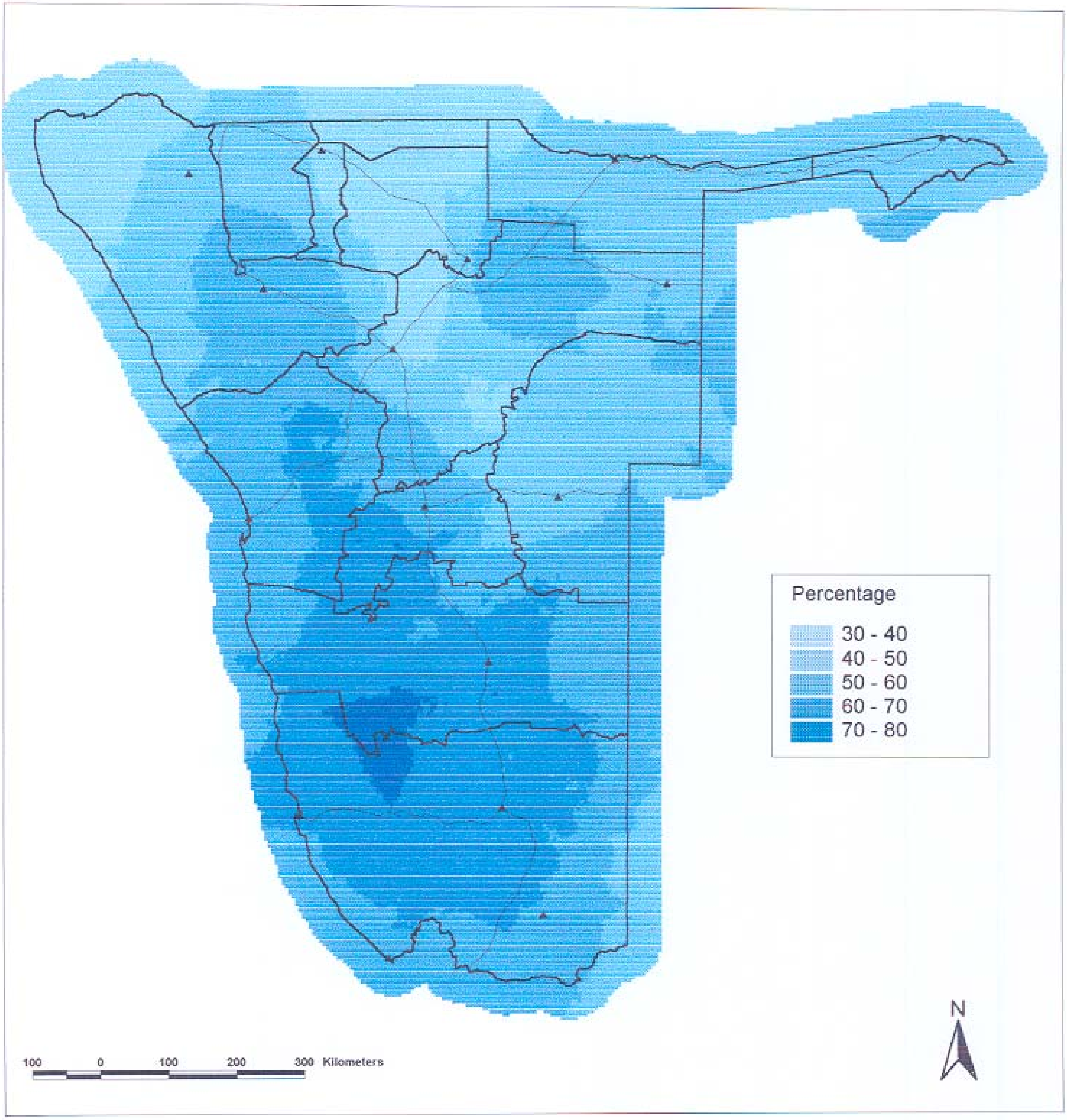
Percentage probability of exceeding median rainfall in the next three months



Map 110

September SOI phase 5

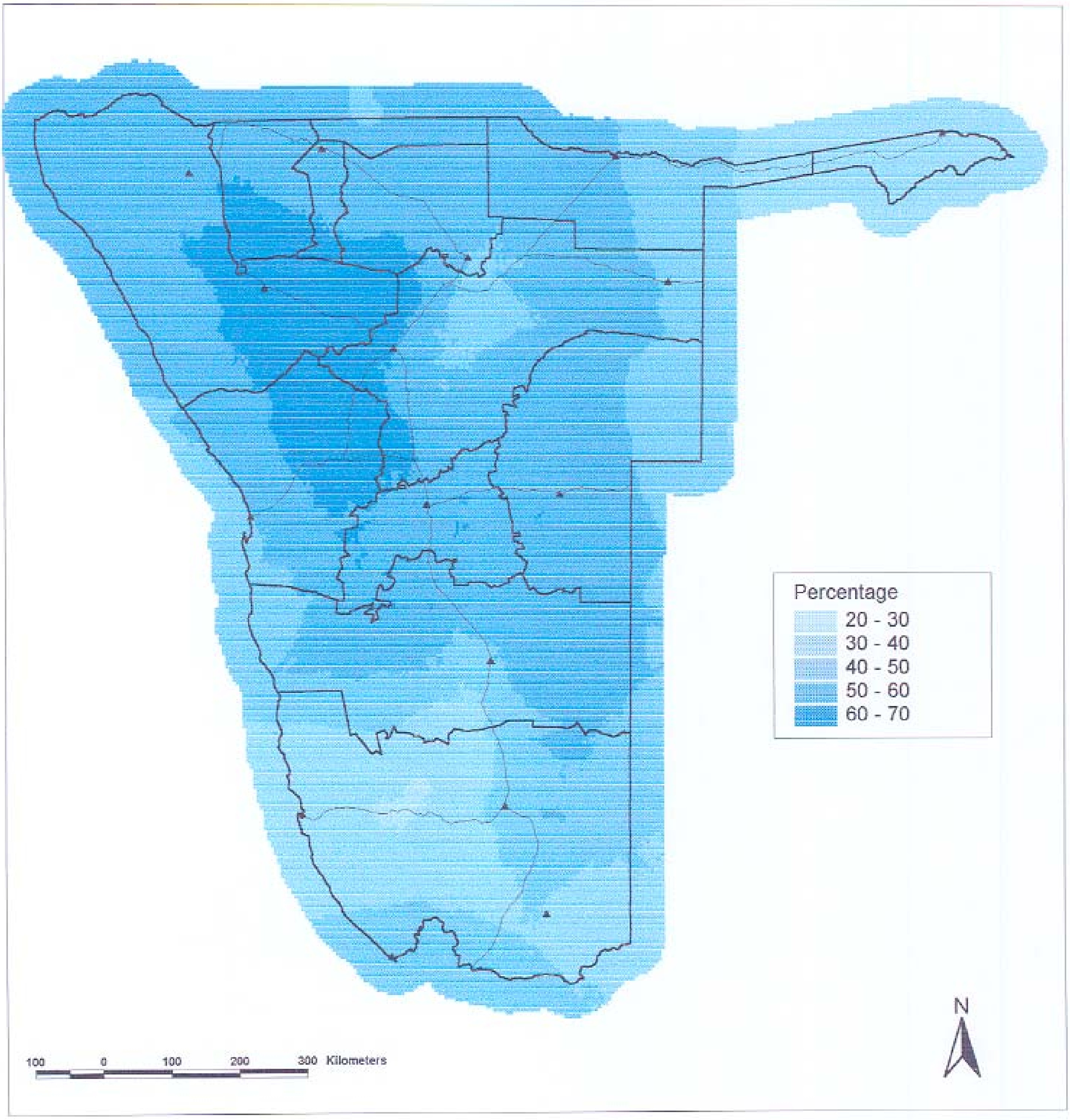
Percentage probability of exceeding median rainfall in the next three months



Map 111

October SOI phase 1

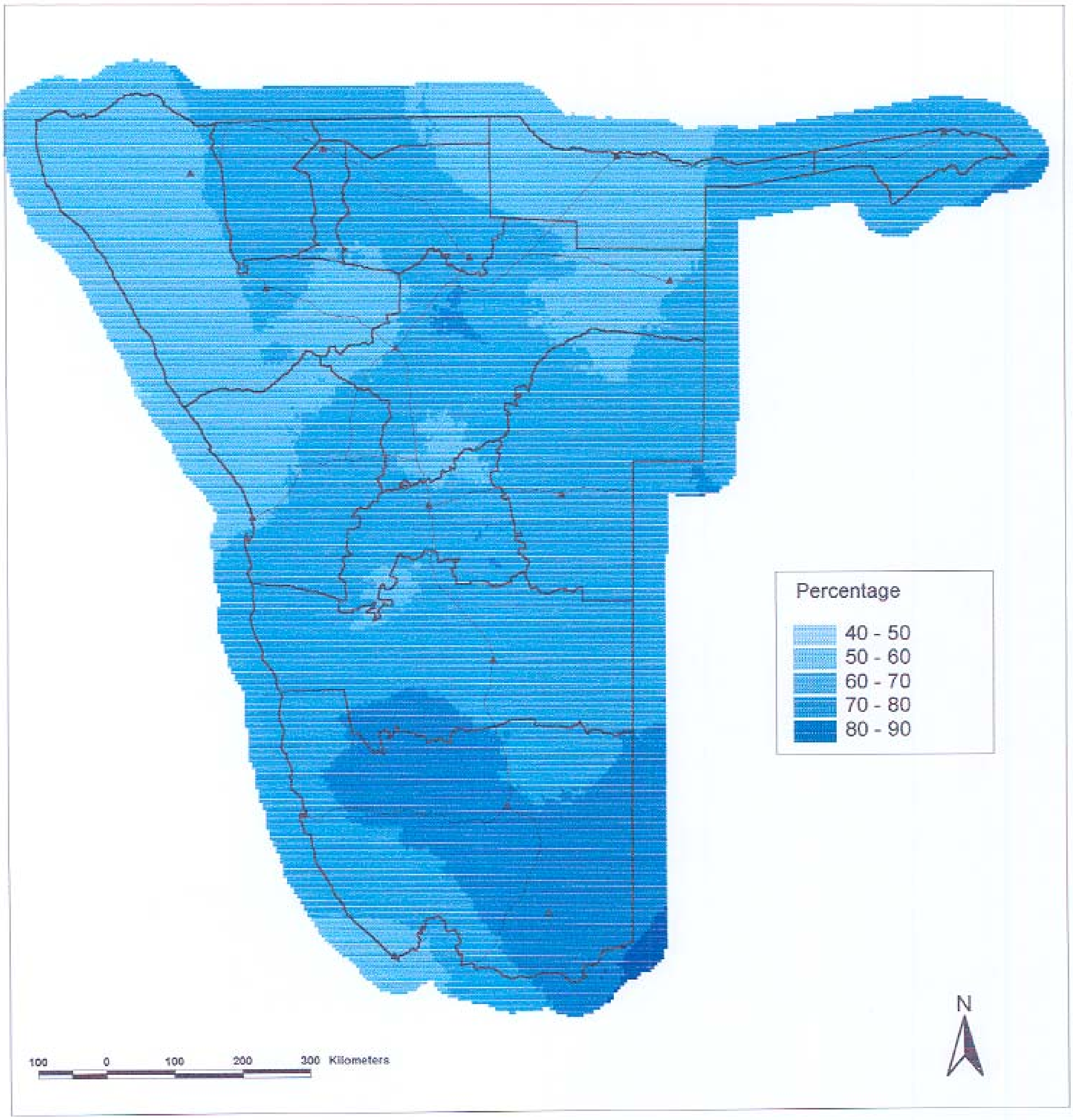
Percentage probability of exceeding median rainfall in the next three months



Map 112

October SOI phase 2

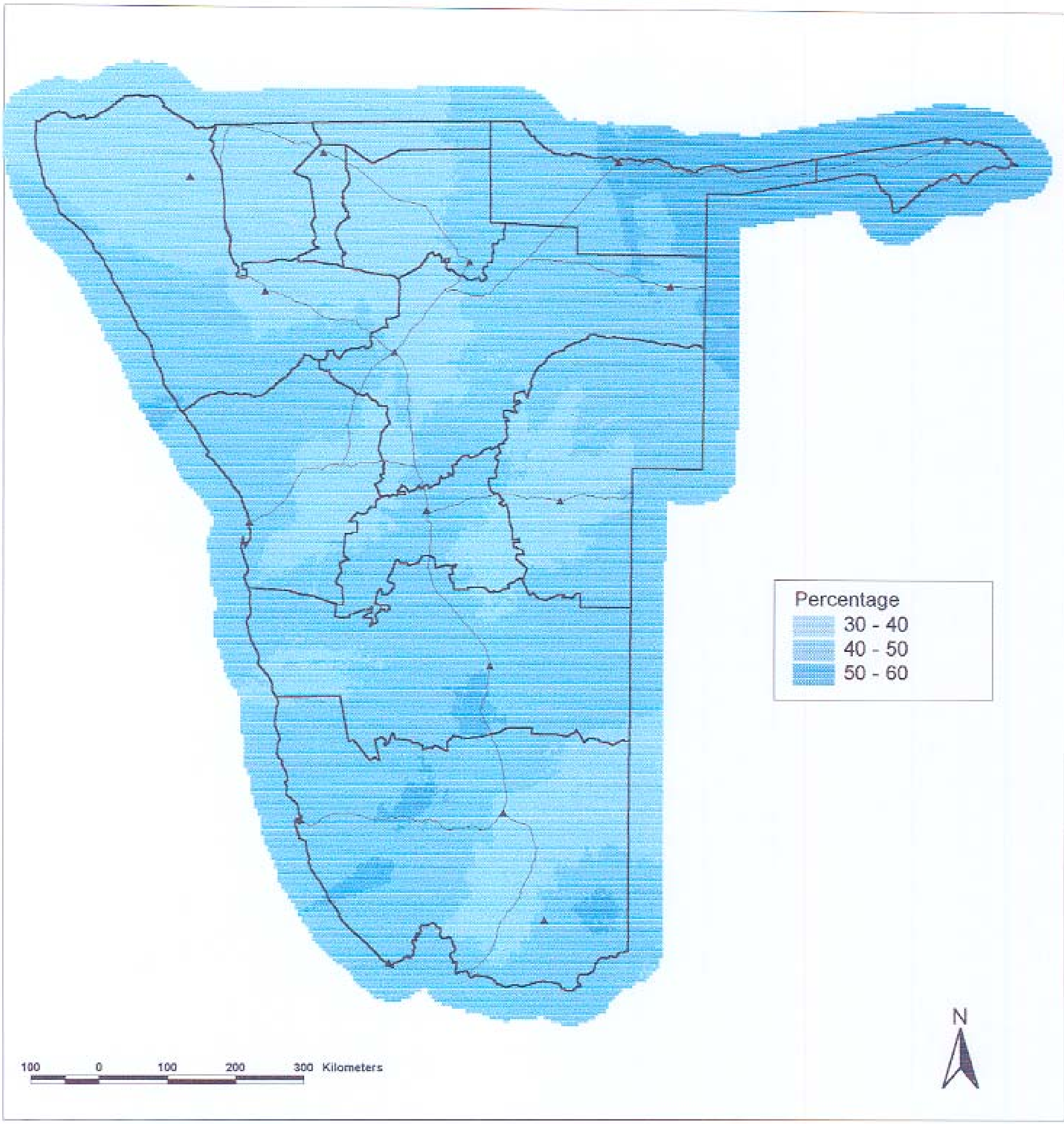
Percentage probability of exceeding median rainfall in the next three months



Map 113

October SOI phase 5

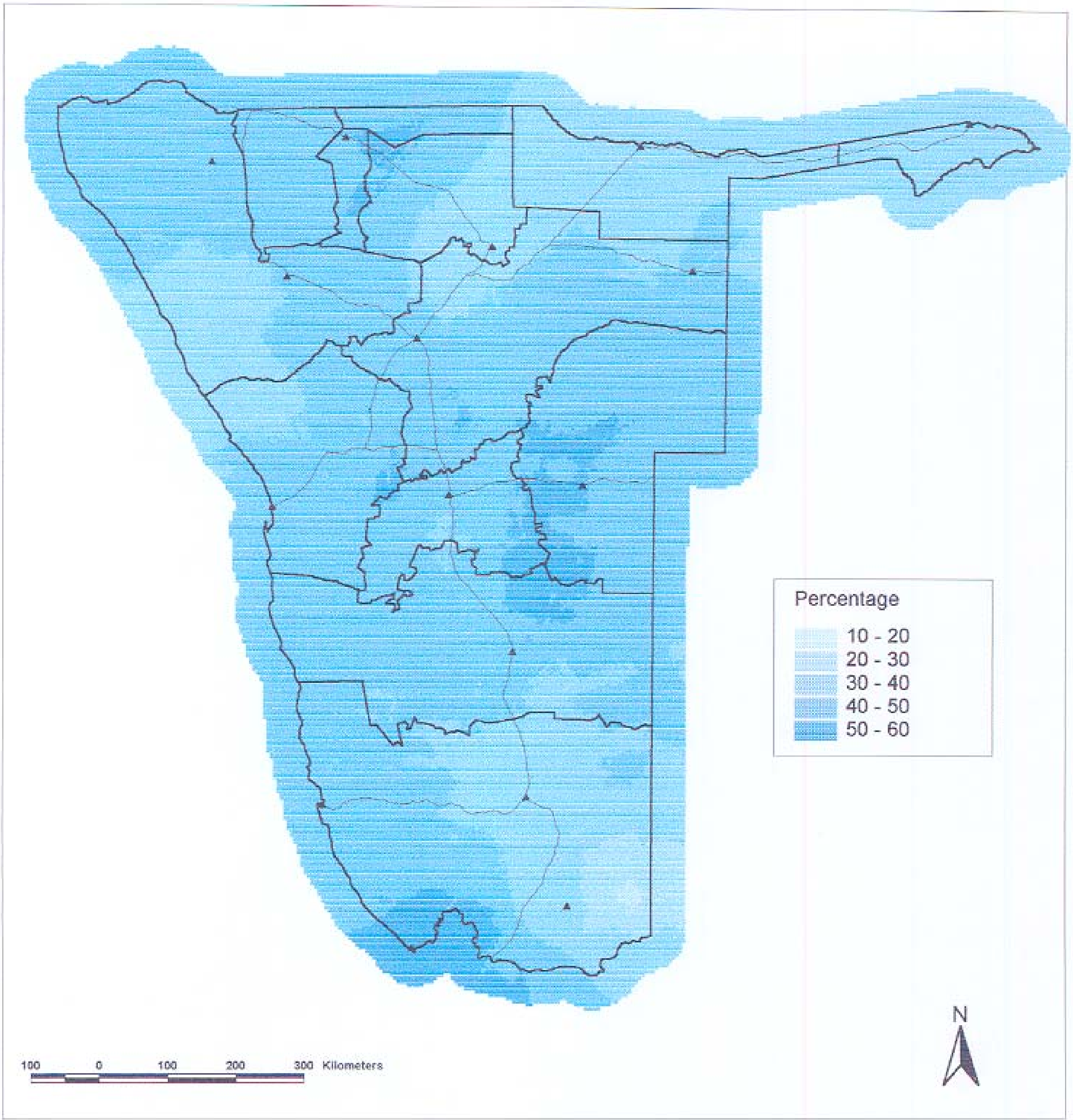
Percentage probability of exceeding median rainfall in the next three months



Map 114

November SOI phase 1

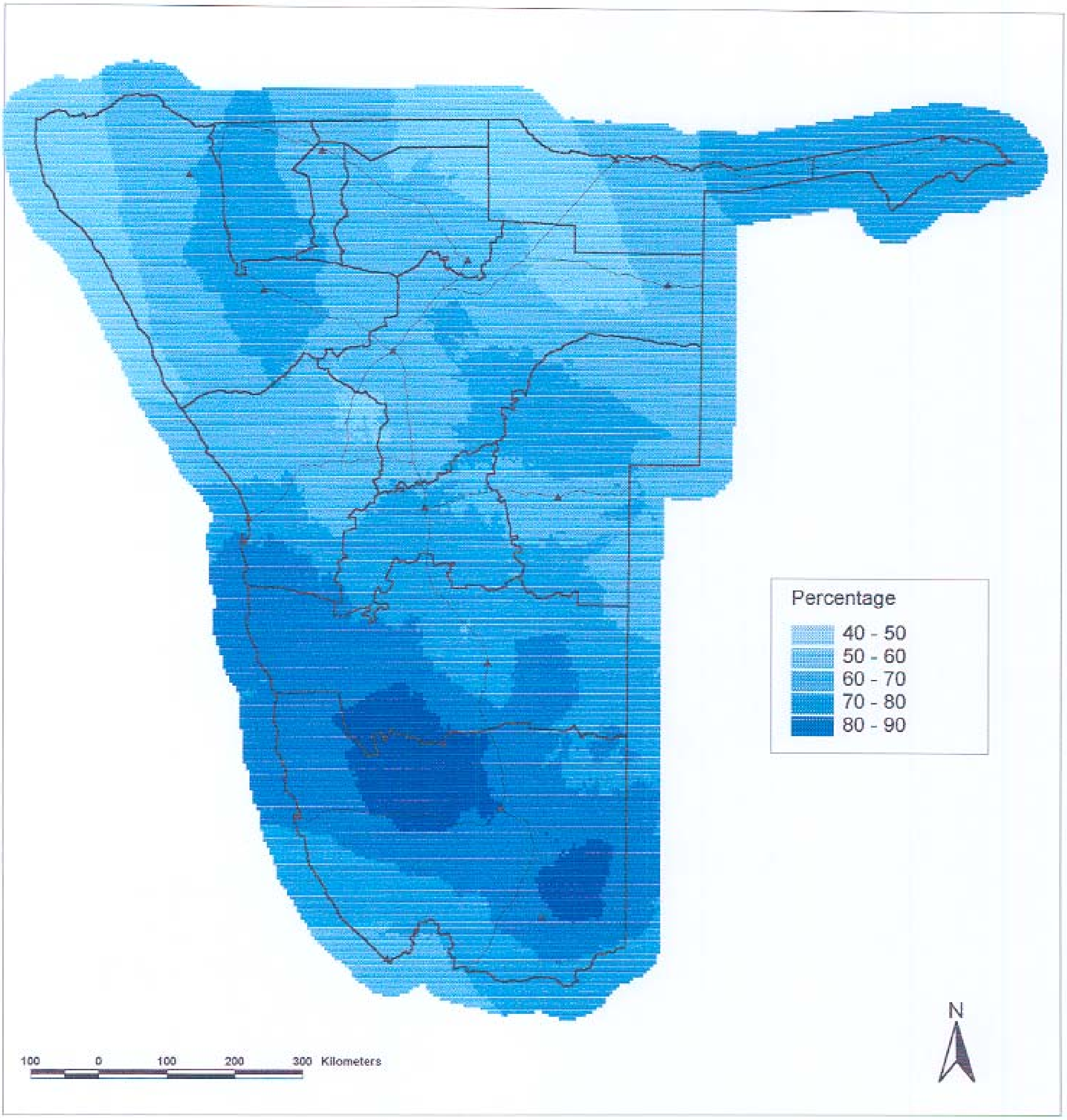
Percentage probability of exceeding median rainfall in the next three months



Map 115

November SOI phase 2

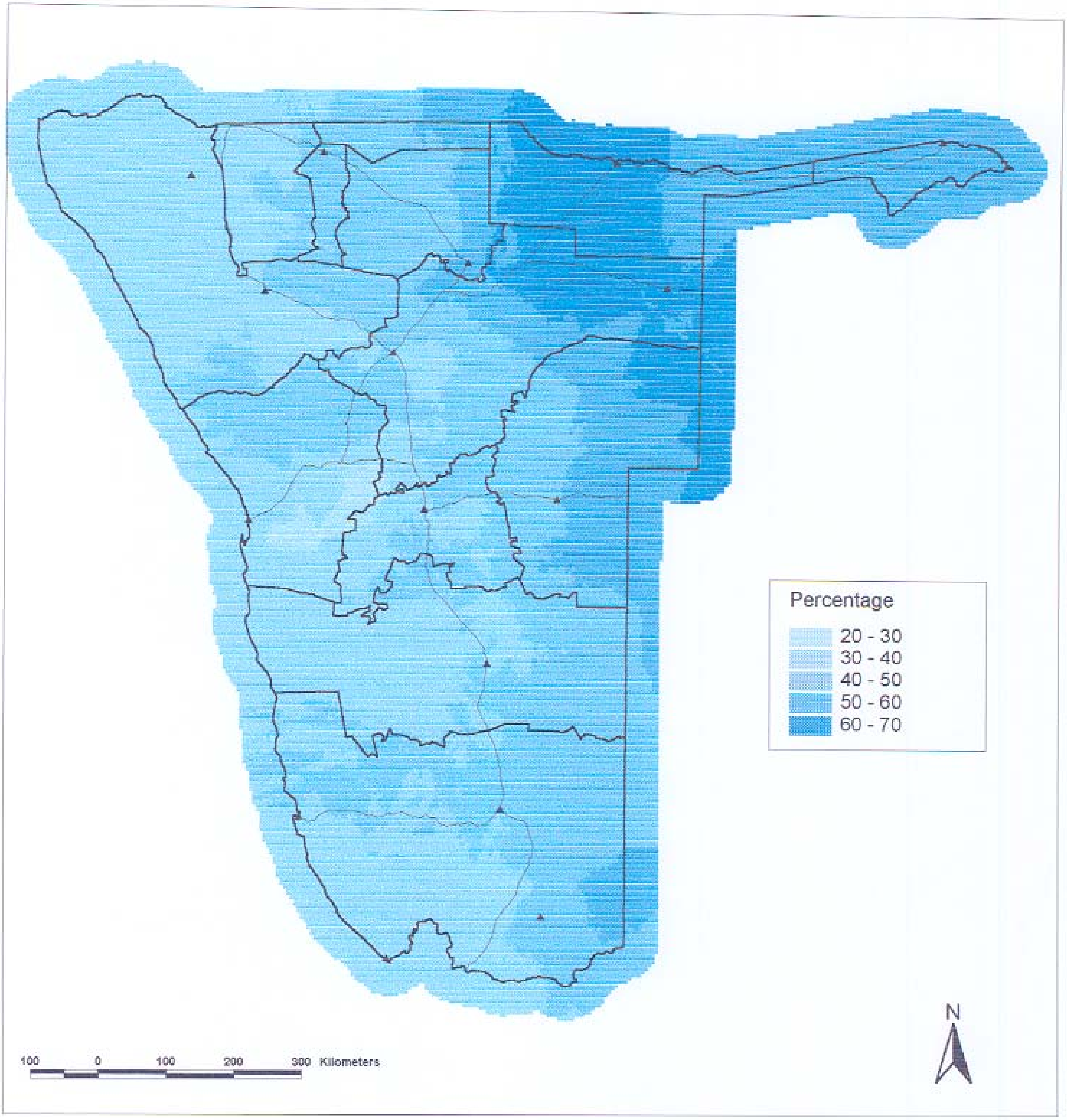
Percentage probability of exceeding median rainfall in the next three months



Map 116

November SOI phase 5

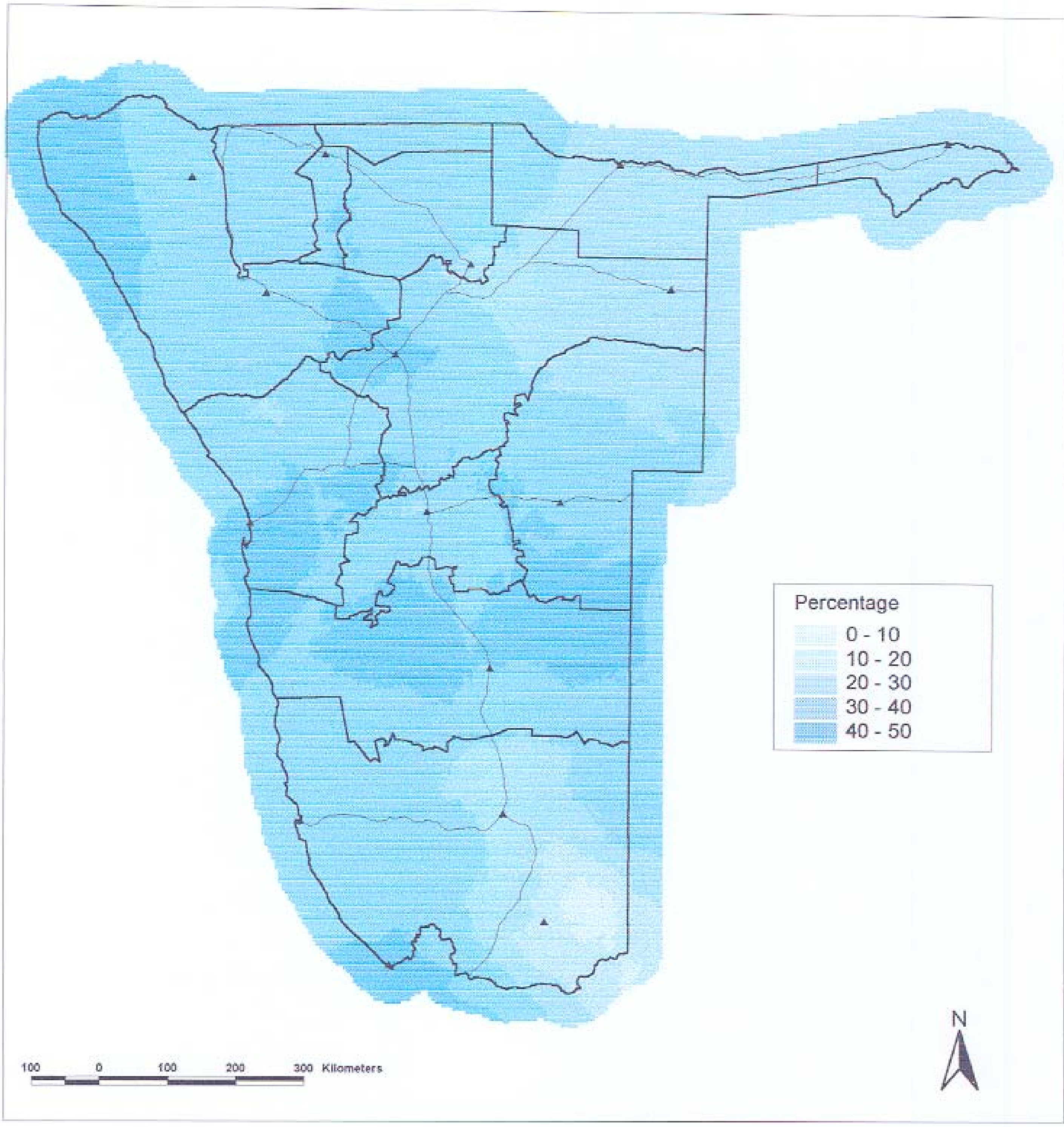
Percentage probability of exceeding median rainfall in the next three months



Map 117

December SOI phase 1

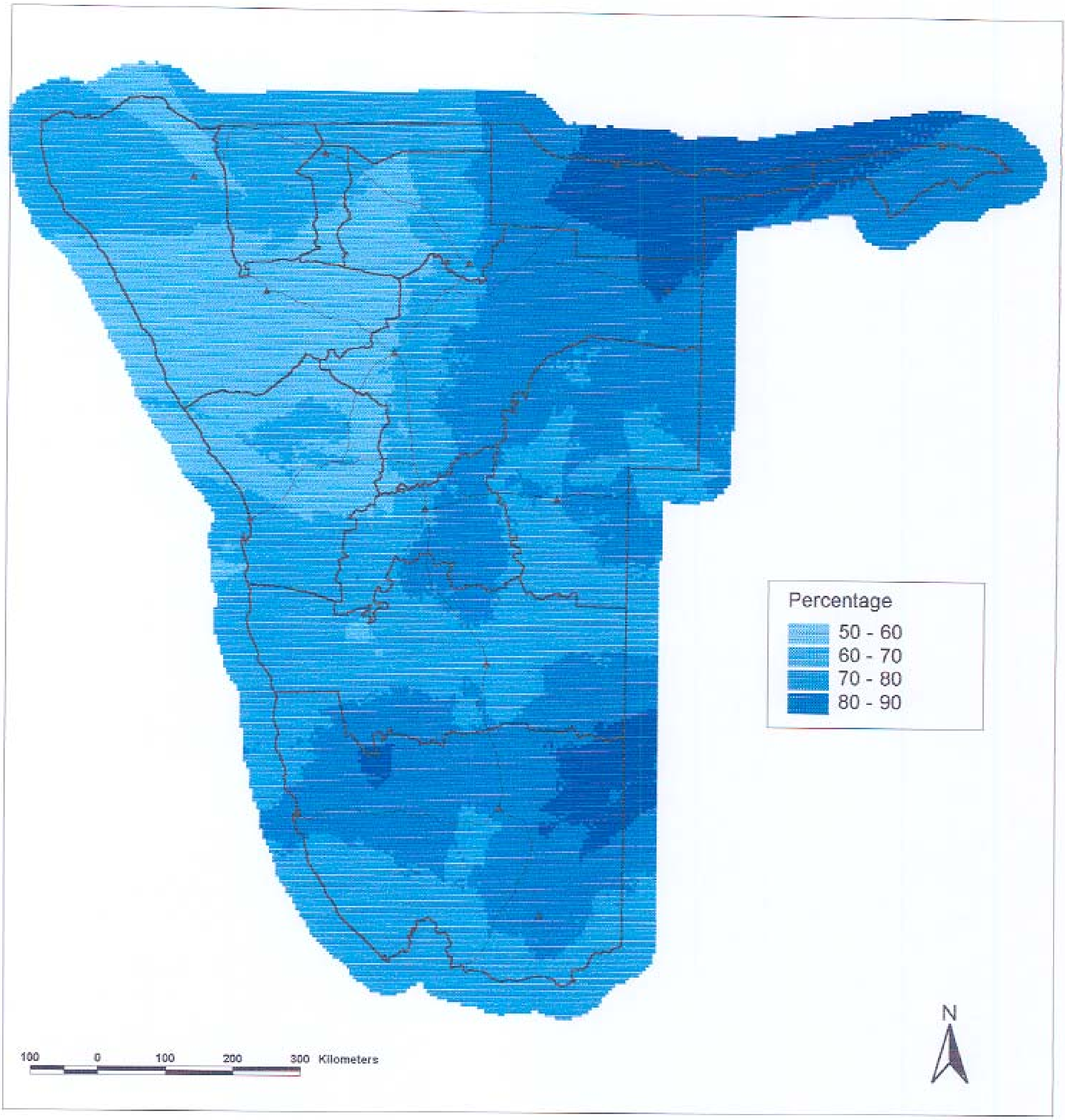
Percentage probability of exceeding median rainfall in the next three months



Map 118

December SOI phase 2

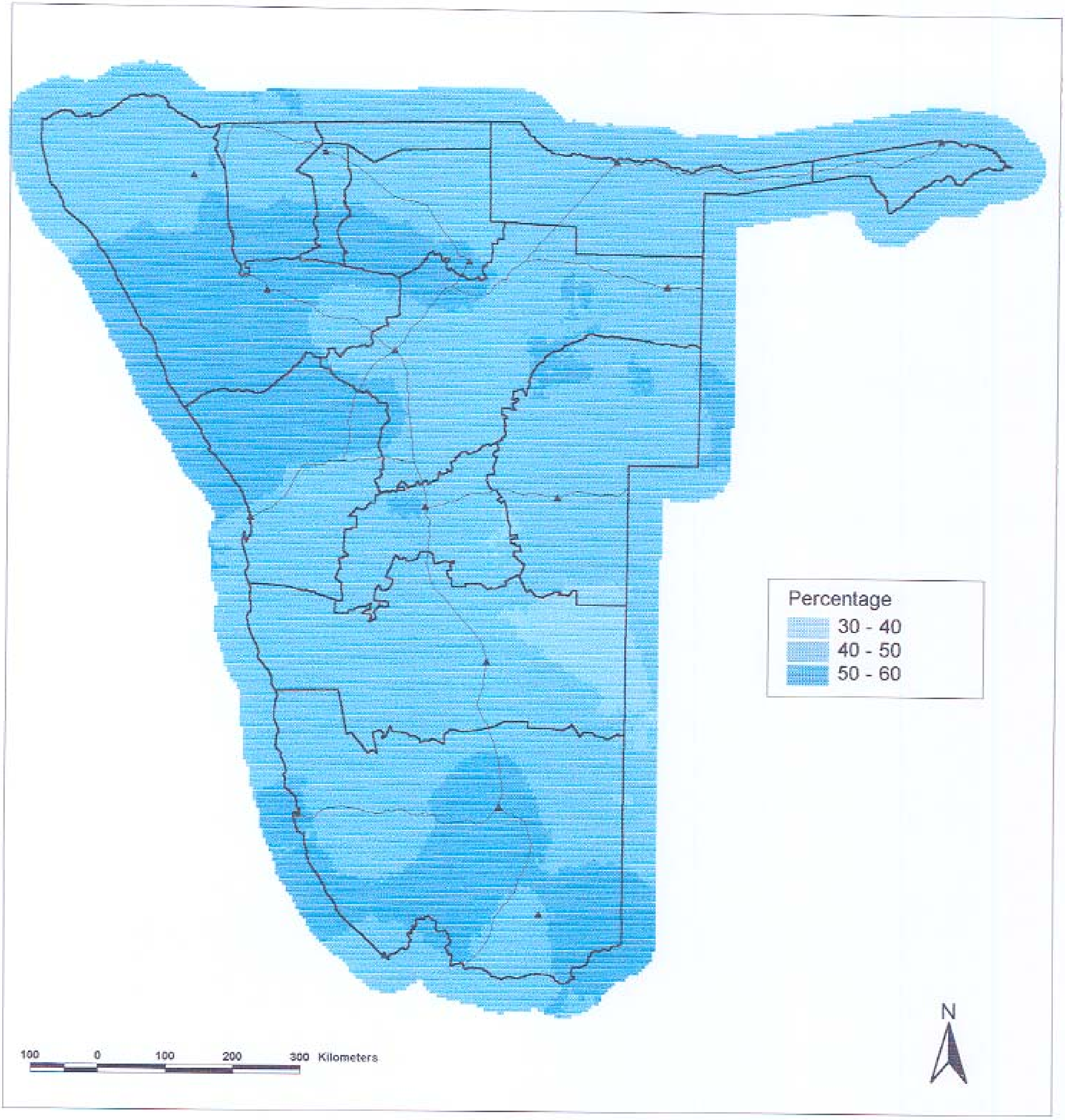
Percentage probability of exceeding median rainfall in the next three months



Map 119

December SOI phase 5

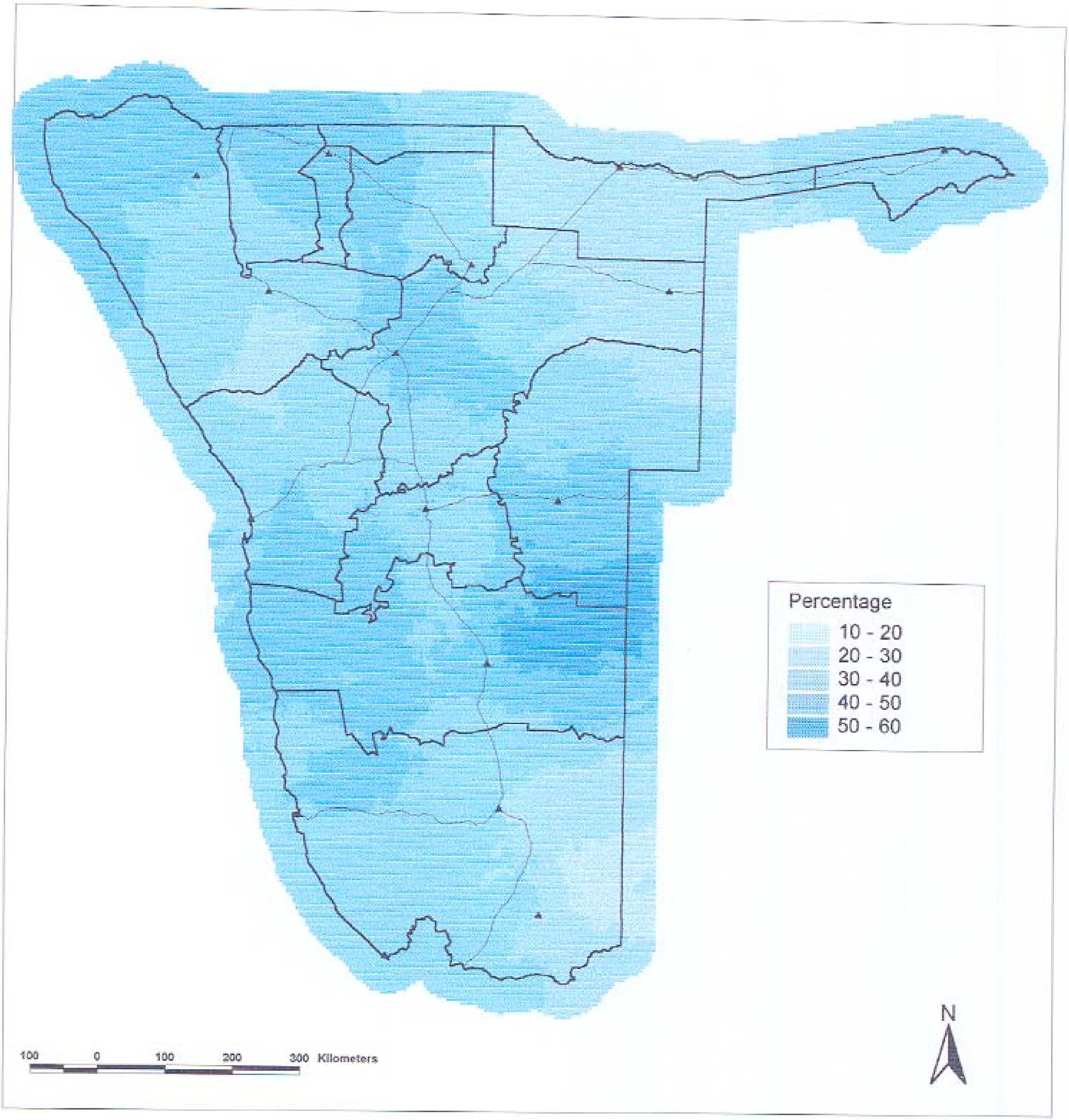
Percentage probability of exceeding median rainfall in the next three months



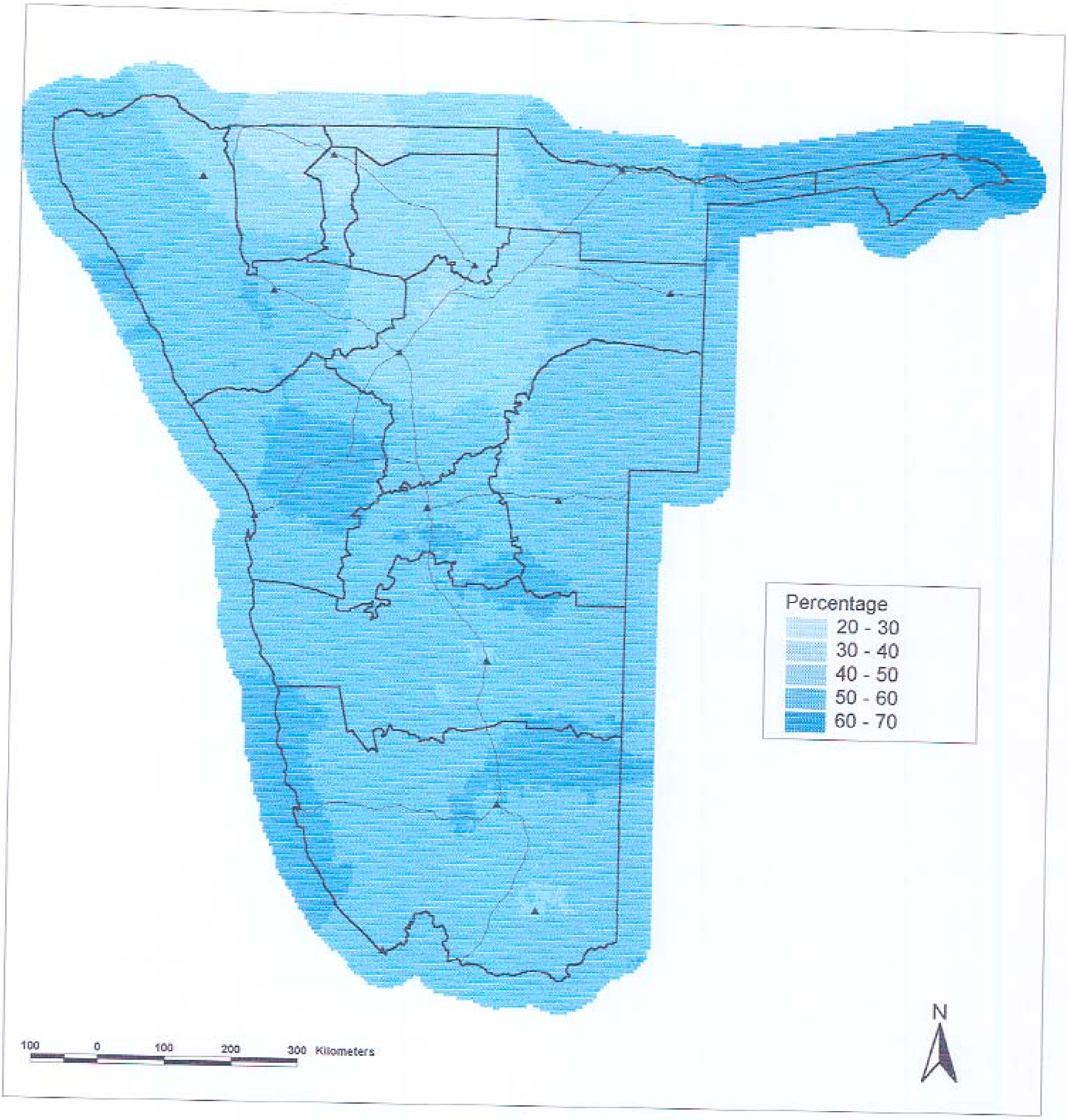
Map 120

January SOI phase 1

Percentage probability of exceeding median rainfall in the next three months



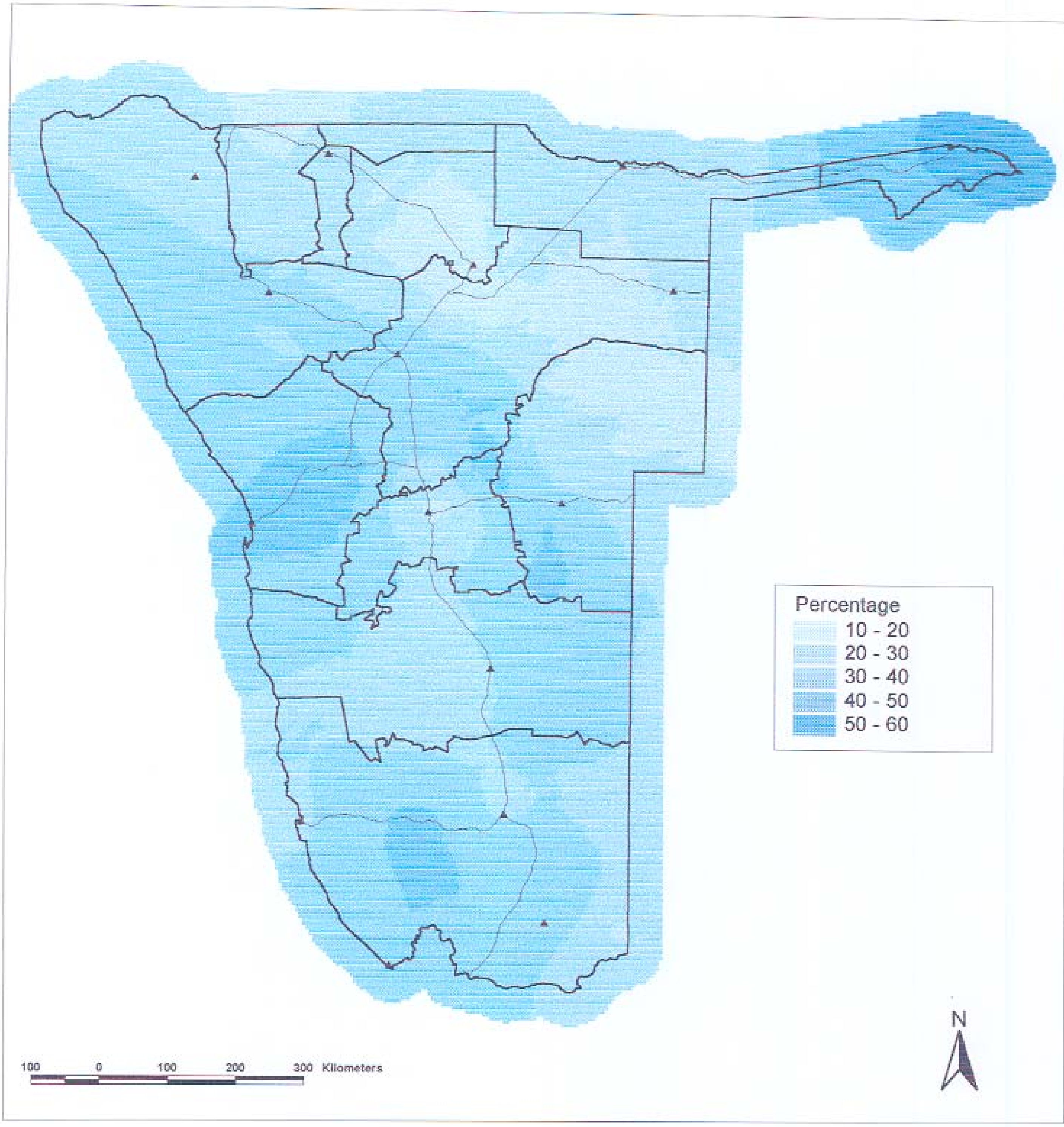
Map 121
January SOI phase 5
Percentage probability of exceeding median rainfall in the next three months



Map 122

February SOI phase 1

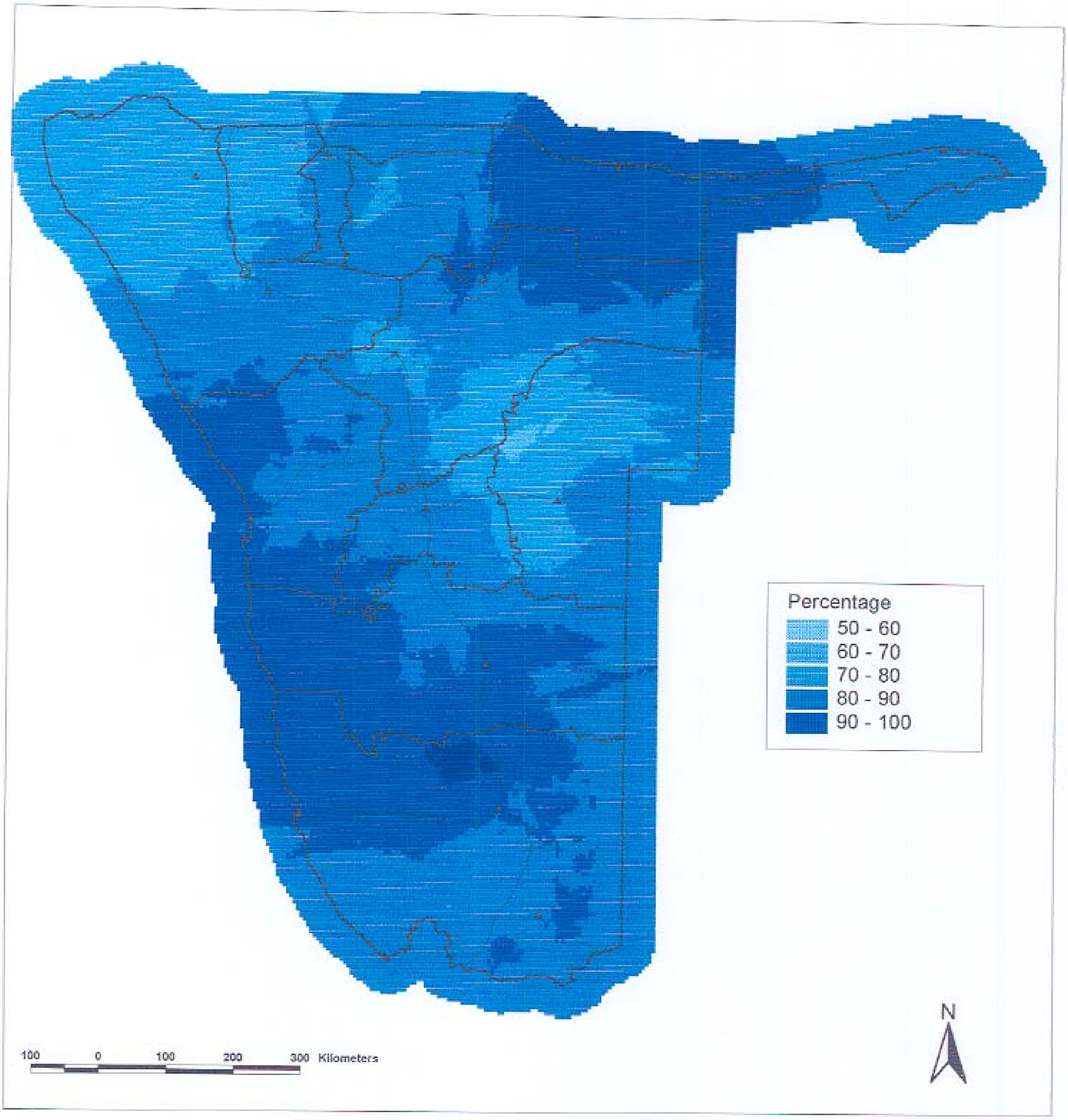
Percentage probability of exceeding median rainfall in the next three months



Map 123

February SOI phase 2

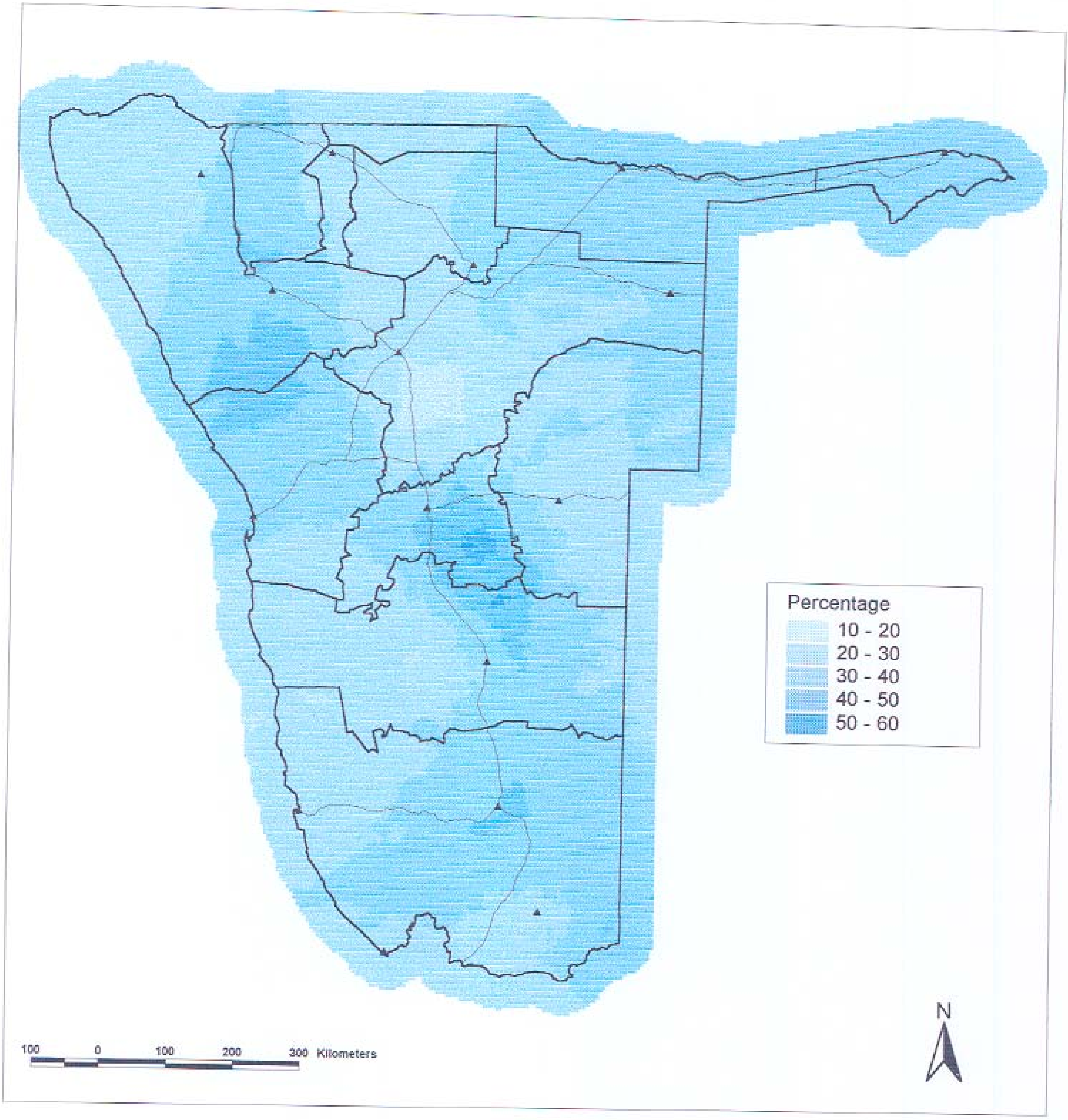
Percentage probability of exceeding median rainfall in the next three months



Map 124

February SOI phase 2

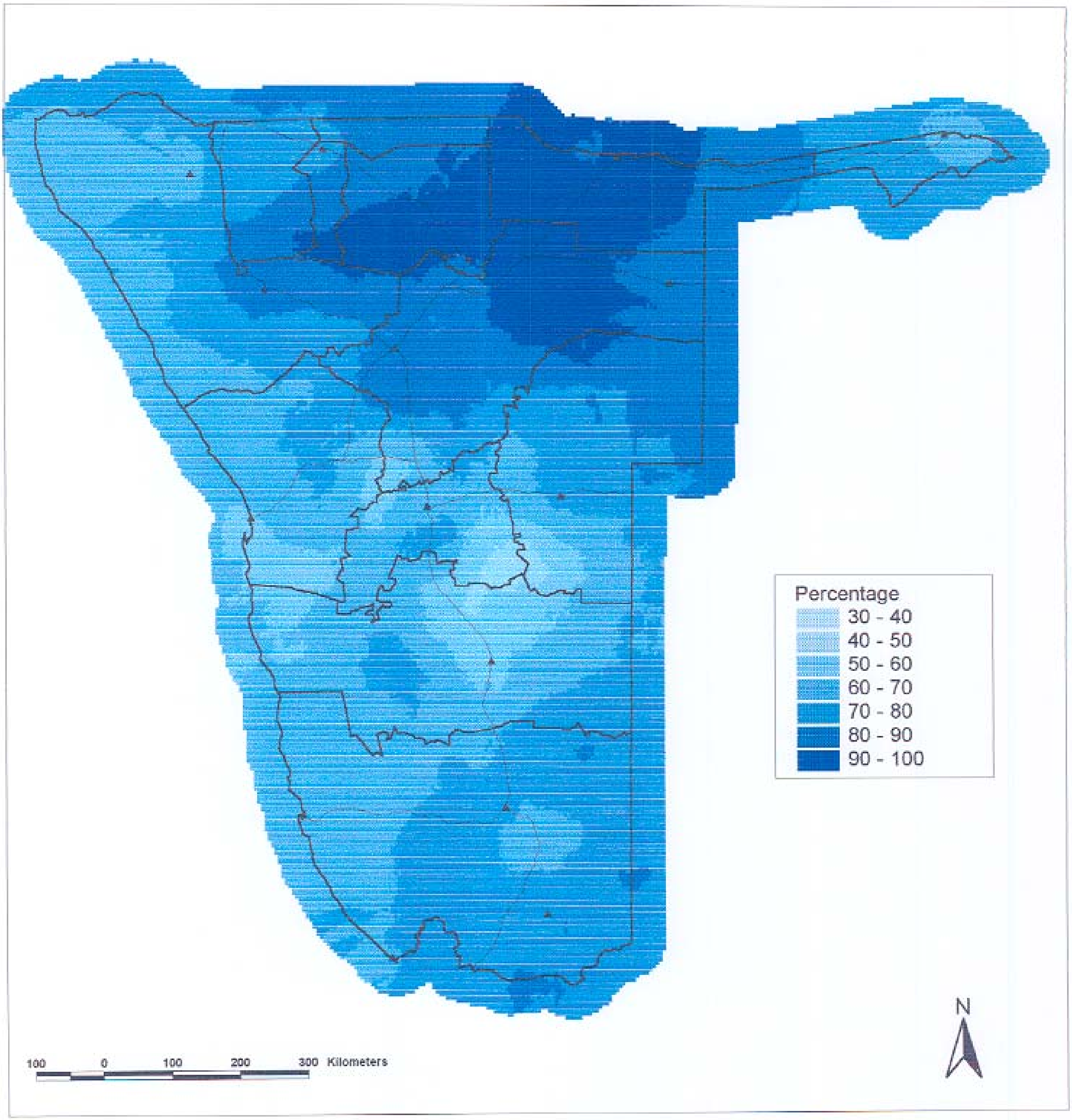
Percentage probability of exceeding median rainfall in the next three months



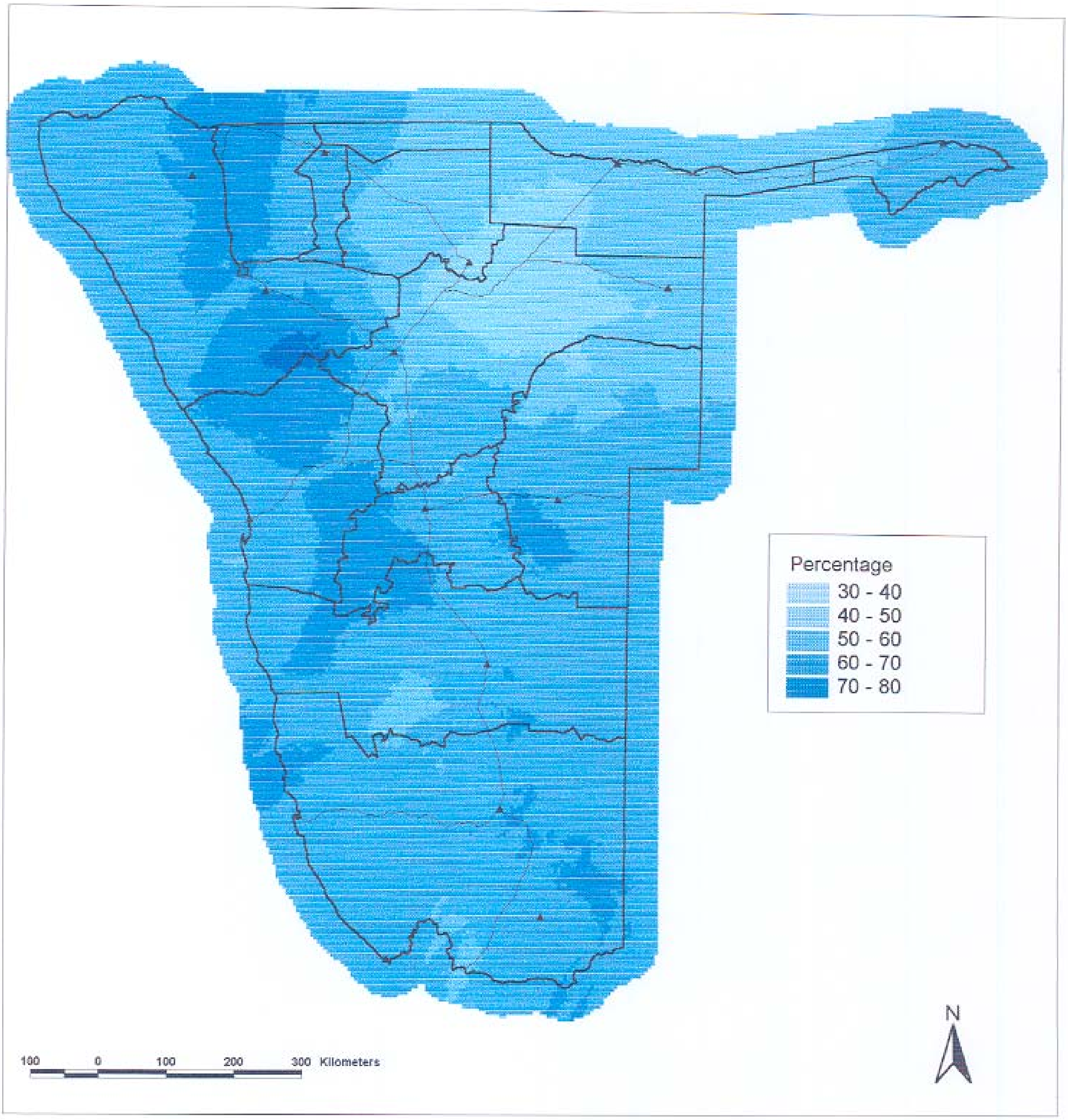
Map 125

March SOI phase 2

Percentage probability of exceeding median rainfall in the next three months



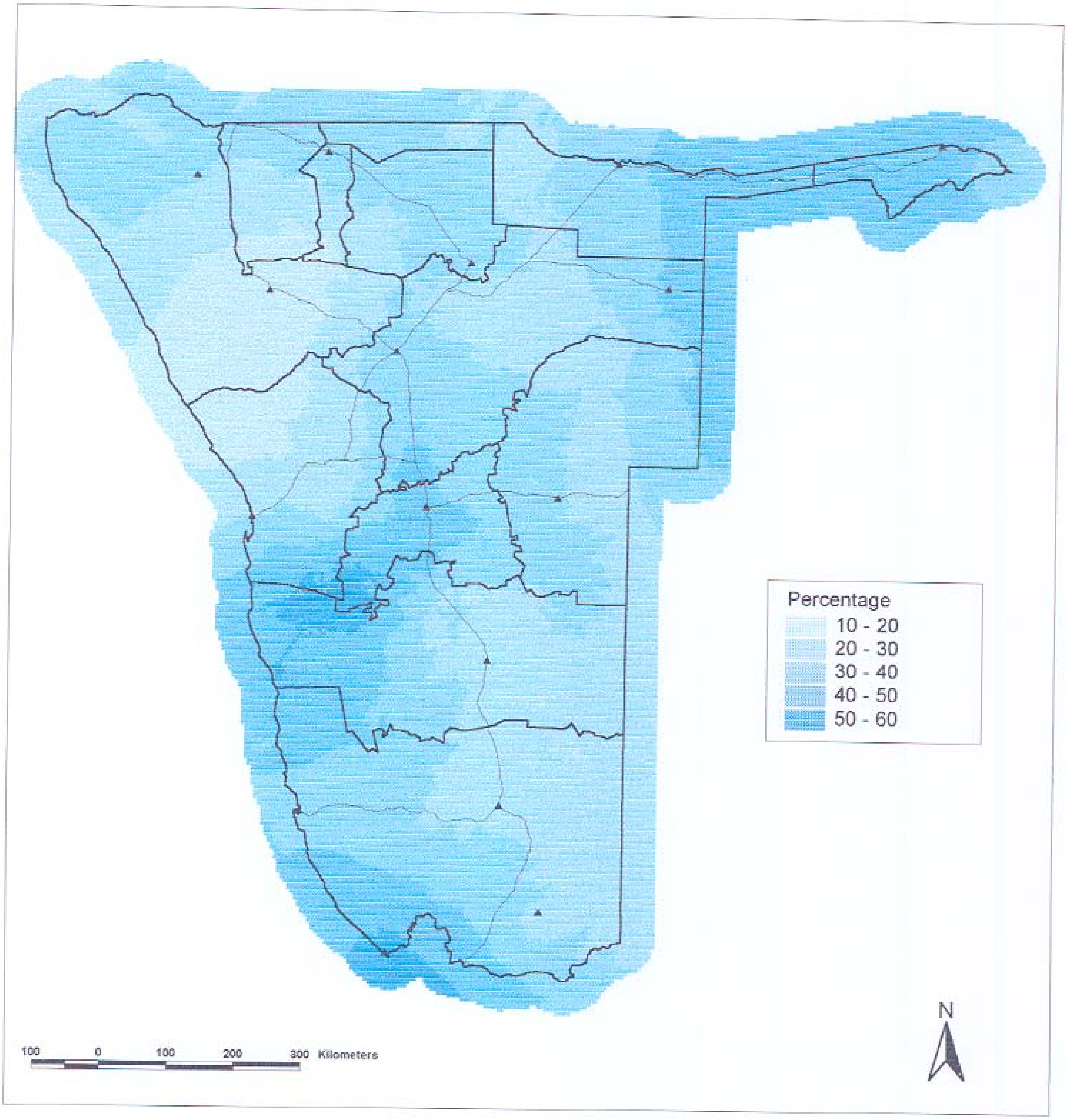
Map 126
March SOI phase 5
Percentage probability of exceeding median rainfall in the next three months



Map 127

April SOI phase 1

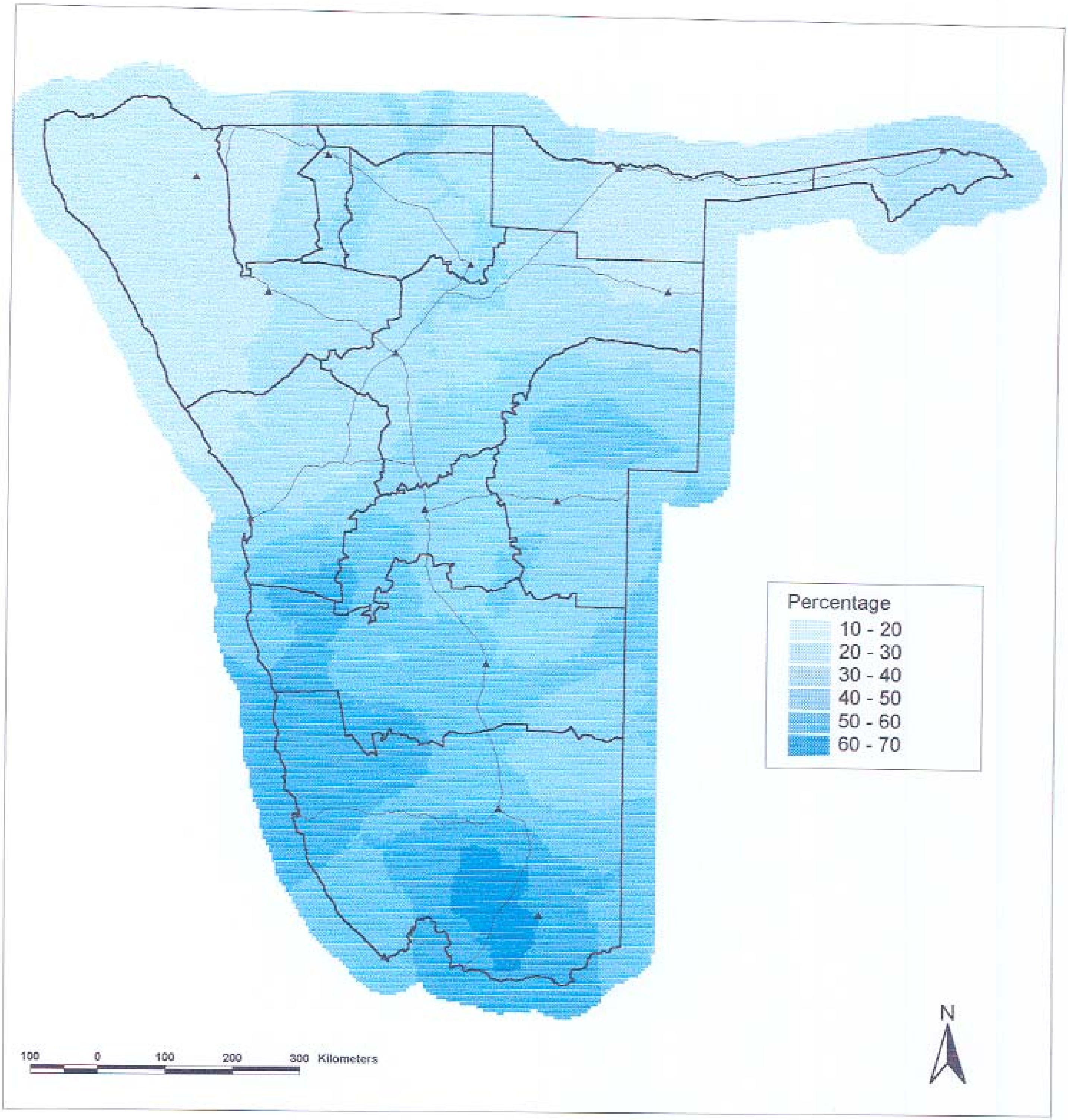
Percentage probability of exceeding median rainfall in the next three months



Map 128

April SOI phase 5

Percentage probability of exceeding median rainfall in the next three months



3.7 Data and Production of Maps

All data compiled and produced by this project are provided on a CD ROM. The data are arranged in five directories, named and containing the following files and data:

Core data directory:

1. AGMET Daily data.xls
2. AGMET Monthly data.xls
3. AGMET Interpolated.xls
4. SOI phases.xls

AV shapes directory:

All Stations.shp/shx/dbf

Mapped stations.shp/shx/dbf

Main roads.shp/shx/dbf

Border.shp/shx/dbf

Main towns.shp/shx/dbf

Monthly data.shp/shx/dbf –	The dbf file contains averages, standard deviations, minimums, maximums, coefficients of variation, and median values.
Annual data.shp/shx/dbf	The dbf file contains averages, standard deviations, minimums, maximums, coefficients of variation, medians, and 7th, 10th, 20th, 25th, 30th, 33rd, 40th, 50th, 60th, 67th, 70th, 70th, 75th, 80th and 90th percentile values for each station
SOI phases.shp/shx/dbf	The dbf file contains the percentage frequency with which rainfall exceeded medians for each SOI phase and month
Drought months.shp/shx/dbf	The dbf file contains numbers of months defined as "drought months", the numbers of years of data available, and the percentage that the "drought months" represent of all months for which data were available

Seasonal.shp/shx/dbf	The dbf file contains average totals for the periods of October to April, October to December, and January to April, and the proportions these averages constitute of annual totals. The file also contains the proportions with which each month was recorded as a dry month (no rain fell during the whole month), and the proportions that monthly average totals constitute of seasonal and annual totals.
Days of rain.shp/shx/dbf	The dbf file contains numbers of days per year on which 0.1, 1, 5, 10, 20 and 50 mm or more fell, and for each month the numbers of days on which 1, 5, 10, 20 and 50 mm or more fell.

AV Grids:

Grid files are listed in Appendix C.

Statistics:

Descriptions of these files are available in Appendix D:

Annual stats.xls
Monthly stats.xls
Monthly medians.xls
Seasonal stats.xls
Numbers of days with rain.xls
Average no. of days with rain.xls
Annual percentiles.xls
Moving totals for drought.xls
Percentage of dry months.xls
Dry_month_freq.xls

Legends:

These are the legend files created and the maps to which they were applied:

Legend Name	Maps
blue_10classes_10perc.avl	108-128
blue_10classes_15mm.avl	27-34, 45-50
blue_10classes_10days.avl	70
blue-orange_10classes_30mm.avl	104-107
blue-orange_10classes_60mm.avl	4-5,7-8
blue-orange_10classes_10perc.avl	10-12
orange-green_10classes_2.5perc.avl	58-69
orange-green_10classes_5days.avl	71-74
purples_10classes_0.2days.avl	96-102
purples_10classes_10perc.avl	6,9
purples_10classes_1day.avl	75-81
purples_6classes_5perc.avl	13-19
yellow-orange_6classes_5mm.avl	35-44
yellow-red_10classes_10perc.avl	20-26
yellow-red_10classes_0.7days.avl	82-88
orange-red_10classes_15perc.avl	51-57
yellow-brown_10classes_0.5days.avl	89-95
yellow-brown_10classes_5perc.avl	103

All the maps produced as part of this report can be generated from the data provided. After starting ArcView, the extension Spatial Analyst must be loaded to read the interpolated grid files. The ArcView background shape files for main roads, main towns and Namibia's border can be loaded from the directory "AV shapes". From that directory, the user can also load the files of rainfall stations (either "All stations" or "Mapped stations"). Apart from the Excel statistics files in the directory "Statistics", all the statistics from which interpolations were produced are available as components of ArcView shape files in the directory "AV Shapes", and can therefore be loaded into ArcView.

All the interpolated grids are stored in the directory "AV Grids" and can be loaded into Views. The legend files used for the printed maps are stored in "Legends" and can be applied as needed.

4. RECOMMENDATIONS

The essential objective of the first phase, that is to characterise and depict the spatial and temporal distribution of rainfall in Namibia, and its relationship to the Southern Oscillation Index, has now been achieved.

The datasets and maps generated by the project thus far will in turn serve, *inter alia,* towards providing a better understanding of aridity and variation in rainfall, and aid officials to utilise the now available data for objective drought assessment and subsidy. The rainfall datasets will also serve as one of several parameters for the development of a predictive range production model for Namibia.

Recommendations

1. Agricultural specialists should study this report, especially the statistical tables and maps, to agree on which measures of rainfall deficits would be most usefully incorporated into policies which spell out the Ministry of Agriculture, Water and Rural Development's response to the phenomenon of drought.

2. The rainfall data assembled here should be used as one component in the production of a rangeland production model. Other components, on soils, vegetation types and vegetation structures, now need to be assembled.

3. NRC recommends that MAWRD proceeds with phase 2 of the project as soon as possible, as envisaged in its original call for consultancy proposals.

4. In Phase Two, the data compiled during this study could be used for a broad range of further analyses. For example, through popular publications, agriculturalists would gain an improved idea of when adequate rains for planting can be expected to have fallen, from:
   - i. measures of "effective rainfall", which can now be generated by calculating numbers of consecutive or closely-spaced days on which rain falls are recorded
   - ii. cumulative total rainfalls, showing perhaps the average day of the summer by which totals of 50 or 100 mm *et cetera* have fallen
   - iii. measures of variation in cumulative rainfalls
   - iv. precipitation infiltration rates (i.e. effective moisture available for plant growth) and how these are affected by rate of fall and soil infiltration rate. This will in turn serve, *inter alia,* towards providing a better understanding of aridity and variation in rainfall, and aid officials to utilise the now available data for objective drought assessment and subsidy. It will also serve as an important parameter for the development of a predictive range production model for Namibia.

5. Phase Two information will further assist the MAWRD with drought policy establishment and how it should advise the Ministry of Lands, Resettlement and Rehabilitation (MLRR) regarding the proper and sustainable use of resettlement farms especially in terms of:

   i. dry-land arable farming
   ii. stocking rates
   iii. grazing rotations
   iv. dealing with endemic drought
   v. inter-region stock transference.

6. The information thus generated should be distributed (widely and gratis) to as large an audience as possible, utilising both semi-popular publications and posters. The key goal of these publications should be to provide, in a reader-friendly way, a good understanding of variation in rainfall and distribution, how little rainfall normally occurs in Namibia, and how to deal with this.

APPENDIX A

ANALYSES OF RAINFALL DATA AS SET OUT IN ORIGINAL TERMS OF REFERENCE

APPENDIX A

ANALYSES OF RAINFALL DATA AS SET OUT IN ORIGINAL TERMS OF REFERENCE

FACET	DELIVERABLES	
	Statistics in a GIS database	Maps
Statistical analyses and mapping of annual rainfall	Percentile ranges Decile ranges Mean/median Mean deviation Standard deviation Coefficient of Variation Relative variability Maximum Minimum	Mean/median Maximum as % of mean Minimum as % of mean Relative Variability Wet & Dry Years
Statistical analyses and mapping of monthly rainfall	Percentile ranges Decile Ranges Mean/median Mean deviation Standard deviation Coefficient of Variation Relative variability Maximum Minimum	Mean/median Extremes Relative variability
Mapping monthly rainfall distribution and seasonal rainfall indices		Monthly rainfall as % of mean annual rainfall Seasonal rainfall
Statistical analyses and mapping of daily rainfall	Rain days/annum Days with >10 mm	As per Statistics
Statistical analyses and mapping of periods of drought	Monthly deficit of rainfall % Occurrence of monthly deficits	As per Statistics
Statistical analyses of SOI phases and rainfall	Correlation between SOI and monthly rainfall	As per Statistics

APPENDIX B

REVISED LIST OF STATISTICAL ANALYSES/MAPS AS APPROVED BY THE MAWRD STEERING COMMITTEE

on 19 January 1999

APPENDIX B

REVISED ANALYSES OF RAINFALL DATA

Annual totals

Statistics:

Mean
Median – same as 50th percentile
Percentiles – deciles (10), quartiles (25), terciles (33), and 7% (as drought threshold)
Standard deviations and coefficient of variation
Maximums – only of interest to compare record falls
Minimums– only of interest to compare record falls

Maps:

Mean (1 map)
Median (1 map)
Coefficients of variation (1 map)
Map values of "wet years" – top tercile
Map values of "dry years" – bottom tercile

Monthly and seasonal totals

Statistics:

Mean
Median
Percentiles – deciles (10), quantiles (25), terciles (33), and 7% (as drought threshold)
Standard deviations and coefficient of variation for select months with reasonable levels of variation
Maximums – only of interest to compare record falls
Minimums – only of interest to compare record falls
% frequency with which each month has been "dry" = 0 rain

Maps:

Means (12 maps)
Median (12 maps:
Coefficients of variation in rain season (7 maps)
Total falls during October-April as proportion of annual rainfall
Total falls during October-December as proportion of rain season totals
Total falls during January-April as proportion of rain season totals
% frequencies of "dry" months in a rain season for each of the 7 months (7 maps)
Monthly totals as % of total annual (12 maps)
Monthly totals as % of total seasonal (7 maps)

Dekadal totals[1]

Statistics:

Mean
Median – same as 50th percentile
Percentiles – deciles (10), quantiles (25), terciles (33), and 7% (as drought threshold)
% frequency with which each dekad has been "dry" = 0 rain

Maps:

Proportions of "dry" dekads during rain season for each of the 21 dekads (21 maps)
% frequency of "dry" dekads in each month of the wet season (7 maps)

Daily falls

Statistics:

Numbers of rain days/year
Number of days with 1, 5, 10, 20, 50 mm of rain

Maps:

Number of rain days/year
Number of days with 1, 5, 10, 20, 50 mm of rain

Drought

Statistics:

Rain season totals in 7, 10, 20 and 30% percentiles for each station
Numbers of monthly "12 month-moving averages" with less than 75% of average rain for each station

Maps:

Rain season totals in 7, 10, 20 and 30% percentiles
Proportions of monthly "12 month-moving averages" with less than 75% of average rain

SOI

Statistics:

Correlations between monthly rainfall and SOI phase for each station

Maps:

Probabilities of rainfall totals being in lower, middle or upper terciles for each SOI phase

[1] These analyses and maps were offered by NRC in addition to the original terms of reference. However, they could not be delivered due to time constraints

APPENDIX C

LIST OF GRIDS FROM WHICH MAPS WERE GENERATED

APPENDIX C

LIST OF GRID FILES

Grid file name	Description
Buffer	Buffer to mask area of reported interpolation
	Annual totals
annual_avg	Annual average
Avg_median	Annual median
Median-mean	Difference between average and median as percentage of median
coeff_var	Coefficient of variation of annual average
	Monthly means
avg_may	Average May rainfall
avg_jan	Average January rainfall
avg_feb	Average February rainfall
avg_mar	Average March rainfall
avg_jun	Average June rainfall
avg_apr	Average April rainfall
avg_jul	Average July rainfall
avg_sept	Average September rainfall
avg_aug	Average August rainfall
avg_oct	Average October rainfall
avg_nov	Average November rainfall
avg_dec	Average December rainfall
	Monthly coefficient of variation
cv_jan	Coefficient of variation: January
cv_feb	Coefficient of variation: February
cv_mar	Coefficient of variation: March
cv_apr	Coefficient of variation: April
cv_may	Coefficient of variation: May
cv_june	Coefficient of variation: June
cv_july	Coefficient of variation: July
cv_aug	Coefficient of variation: August
cv_sept	Coefficient of variation: September
cv_oct	Coefficient of variation: October
cv_nov	Coefficient of variation: November
cv_dec	Coefficient of variation: December
	Seasonal proportions
prop_oct_apr	October-April rainfall as percentage of total annual rainfall
prop_oct_dec	October-December rainfall as percentage of total annual rainfall
prop_jan_apr	January-April rainfall as percentage of total annual rainfall
	Percentages of dry months
per_dry_oct	Percentage frequency of October being dry
per_dry_nov	Percentage frequency of November being dry
per_dry_dec	Percentage frequency of December being dry
per_dry_jan	Percentage frequency of January being dry
per_dry_feb	Percentage frequency of February being dry
per_dry_mar	Percentage frequency of March being dry
per_dry_apr	Percentage frequency of April being dry

	Monthly rainfall as percentage of annual total
per_jul	July rainfall as percentage of annual total
per_aug	August rainfall as percentage of annual total
per_sept	September rainfall as percentage of annual total
per_oct	October rainfall as percentage of annual total
per_nov	November rainfall as percentage of annual total
per_dec	December rainfall as percentage of annual total
per_jan	January rainfall as percentage of annual total
per_feb	February rainfall as percentage of annual total
per_mar	March rainfall as percentage of annual total
per_apr	April rainfall as percentage of annual total
per_may	May rainfall as percentage of annual total
per_jun	June rainfall as percentage of annual total
	Monthly totals as percentage of seasonal total
sper_oct	October total as percentage of seasonal total
sper_nov	November total as percentage of seasonal total
sper_dec	December total as percentage of seasonal total
sper_jan	January total as percentage of seasonal total
sper_feb	February total as percentage of seasonal total
sper_mar	March total as percentage of seasonal total
sper_apr	April total as percentage of seasonal total
	Percentiles
tot2oth	Annual rainfall: 20^{th} percentile
tot1oth	Annual rainfall: 10^{th} percentile
tot7th	Annual rainfall: 7^{th} percentile
tot30th	Annual rainfall: 30^{th} percentile
tot33rd	Annual rainfall: 33rd percentile
tot_50th	Annual rainfall: 50^{th} percentile
tot67th	Annual rainfall: 67^{th} percentile
	Annual medians
med_jan	Median January rainfall
med_feb	Median February rainfall
med_mar	Median March rainfall
med_apr	Median April rainfall
med_may	Median May rainfall
med_jun	Median June rainfall
med_jul	Median July rainfall
med_aug	Median August rainfall
med_sept	Median September rainfall
med_oct	Median October rainfall
med_nov	Median November rainfall
med_dec	Median December rainfall
moving_totals	Percentage of months following 12 months with less than 75% of annual average
	Number of days with rain
avgdays01	Number of days per year with 0.1 mm or more
avgyear1	Number of days per year with 1 or more mm
avgyear5	Number of days per year with 5 or more mm
avgyear10	Number of days per year with 10 or more mm
avgyear20	Number of days per year with 20 or more mm
Avgjan1	Number of days in January with 1 or more mm
avgfeb1	Number of days in February with 1 or more mm
avgmar1	Number of days in March with 1 or more mm

avgapr1	Number of days in April with 1 or more mm
avgoct1	Number of days in October with 1 or more mm
avgnov1	Number of days in November with 1 or more mm
avgdec1	Number of days in December with 1 or more mm
avgjan5	Number of days in January with 5 or more mm
avgfeb5	Number of days in February with 5 or more mm
avgmar5	Number of days in March with 5 or more mm
avgapr5	Number of days in April with 5 or more mm
avgoct5	Number of days in October with 5 or more mm
avgnov5	Number of days in November with 5 or more mm
avgdec5	Number of days in December with 5 or more mm
avgjan10	Number of days in January with 10 or more mm
avgfeb10	Number of days in February with 10 or more mm
avgmar10	Number of days in March with 10 or more mm
avgapr10	Number of days in April with 10 or more mm
avgoct10	Number of days in October with 10 or more mm
avgnov10	Number of days in November with 10 or more mm
avgdec10	Number of days in December with 10 or more mm
avgjan20	Number of days in January with 20 or more mm
avgfeb20	Number of days in February with 20 or more mm
avgmar20	Number of days in March with 20 or more mm
avgapr20	Number of days in April with 20 or more mm
avgoct20	Number of days in October with 20 or more mm
avgnov20	Number of days in November with 20 or more mm
avgdec20	Number of days in December with 20 or more mm
	Numbers of days per years on which rain fell
avgyear1	Number of days with 1 or more mm
avgyear5	Number of days with 5 or more mm
avgyear10	Number of days with 10 or more mm
avgyear20	Number of days with 20 or more mm
	Southern Oscillation Indices
sep1	Probability of rainfall exceeding median during 3 months after September with Phase 1 SOI
sep2	Probability of rainfall exceeding median during 3 months after September with Phase 2 SOI
sep5	Probability of rainfall exceeding median during 3 months after September with Phase 5 SOI
oct1	Probability of rainfall exceeding median during 3 months after October with Phase 1 SOI
oct2	Probability of rainfall exceeding median during 3 months after October with Phase 2 SOI
oct5	Probability of rainfall exceeding median during 3 months after October with Phase 5 SOI
nov1	Probability of rainfall exceeding median during 3 months after November with Phase 1 SOI
nov2	Probability of rainfall exceeding median during 3 months after November with Phase 2 SOI
nov5	Probability of rainfall exceeding median during 3 months after November with Phase 5 SOI
dec1	Probability of rainfall exceeding median during 3 months after December with Phase 1 SOI
dec2	Probability of rainfall exceeding median during 3 months after December with Phase 2 SOI
dec5	Probability of rainfall exceeding median during 3 months after December with Phase 5 SOI

jan1	Probability of rainfall exceeding median during 3 months after January with Phase 1 SOI
jan5	Probability of rainfall exceeding median during 3 months after January with Phase 5 SOI
feb1	Probability of rainfall exceeding median during 3 months after January with Phase 1 SOI
feb2	Probability of rainfall exceeding median during 3 months after February with Phase 2 SOI
feb5	Probability of rainfall exceeding median during 3 months after February with Phase 5 SOI
mar2	Probability of rainfall exceeding median during 3 months after March with Phase 2 SOI
mar5	Probability of rainfall exceeding median during 3 months after March with Phase 5 SOI
apr1	Probability of rainfall exceeding median during 3 months after April with Phase 1 SOI
apr5	Probability of rainfall exceeding median during 3 months after April with Phase 5 SOI

APPENDIX D

LIST OF DATAFILE STRUCTURES

APPENDIX D
LIST OF DATA FILE STRUCTURES

The following data files are presented on compact disc, and their structures listed in this appendix:

D-1 Agmet daily data.xls

D-2 Agmet monthly data.xls

D-3 Agmet interpolated data.xls

D-4 All stations dbf/shp/shx

D-5 Mapped stations dbf/shp/shx

D-6 Soi phase.xls

D-7 Annualstats.xls

D-8 Monthlystats.xls

D-9 Monthly medians.xls

D-10 Seasonalstats.xls

D-11 Number of days with rain.xls and Average number of days with rain.xls

D-12 Annual percentiles.xls

D-13 Moving totals for drought.xls

D-14 Percentage of dry months.xls

D-15 Drymthfreq.xls

ANNEXURE D-1
DATA STRUCTURE FOR ALL DAILY DATA FILE
"Agmet daily data.xls"

This file contains daily records for x stations in Namibia and x outside Namibia

Field Name	**Explanation**
main_code	Main code of station
source	Source of rainfall record
name	Name of station
month	Month indicated as 1,2,3 12
year	Year
year_month	Combination of year and month, as in 1969_01 used for sorting
missing	Used to identify missing values for later sorting
d1	Day 1 of the month
d2	Day 1 of the month
d3	Day 1 of the month
d4	Day 1 of the month
d5	Day 1 of the month
d6	Day 1 of the month
d7	Day 1 of the month
d8	Day 1 of the month
d9	Day 1 of the month
d10	Day 1 of the month
d11	Day 1 of the month
d12	Day 1 of the month
d13	Day 1 of the month
d14	Day 1 of the month
d15	Day 1 of the month
d16	Day 1 of the month
d17	Day 1 of the month
d18	Day 1 of the month
d19	Day 1 of the month
d20	Day 1 of the month
d21	Day 1 of the month
d22	Day 1 of the month
d23	Day 1 of the month
d24	Day 1 of the month
d25	Day 1 of the month
d26	Day 1 of the month
d27	Day 1 of the month
d28	Day 1 of the month
d29	Day 1 of the month
d30	Day 1 of the month
d31	Day 1 of the month

ANNEXURE D-2
DATA STRUCTURE FOR MONTHLY DATA FILE
"Agmet monthly data.xls"

Field Name	Explanation
main_code	Main code
name	Name of station
year	Year
jan	Monthly rainfall for January
feb	Monthly rainfall for February
march	Monthly rainfall for March
april	Monthly rainfall for April
may	Monthly rainfall for May
june	Monthly rainfall for June
july	Monthly rainfall for July
aug	Monthly rainfall for August
sept	Monthly rainfall for September
oct	Monthly rainfall for October
nov	Monthly rainfall for November
dec	Monthly rainfall for December
total	Total annual rainfall
comment	Here missing values were noted, or comments on interpolation recorded. Note that all interpolated records are recorded in "interpolated data.xls"
source	Source of rainfall record

ANNEXURE D-3
DATA STRUCTURE FOR INTERPOLATIONS OF MISSING DATA FILE
"Agmet interpolated data.xls"

This file provides a record of each station for which one or more monthly totals have been interpolated. Interpolated figures are provided in red font for quick identification, and an explanation of the origin of the interpolation is provided.

Field Name	Explanation
Main_code	Main code
Station name	Station name
Year	Year
Jan	Monthly total for January
Feb	Monthly total for February
Mar	Monthly total for March
Apr	Monthly total for April
May	Monthly total for May
June	Monthly total for June
July	Monthly total for July
August	Monthly total for August
Sept	Monthly total for September
Oct	Monthly total for October
Nov	Monthly total for November
Dec	Monthly total for December
Total	Total annual rainfall
Notes on how missing data was interpolated	These notes give the station or stations from which the interpolation was done
Data source	Source of rainfall record for that station

ANNEXURE D-4
DATA STRUCTURE FOR ARCVIEW FILES RELATING TO ALL RAINFALL STATIONS

"all stations dbf/shp/shx"

Field Name	Explanation
main_code	Main code for station
name	Name of station
alt	Altitude
x_coord	X co-ordianate
y_coord	Y co-ordinate

ANNEXURE D-5
DATA STRUCTURE FOR ARCVIEW FILES RELATING TO MAPPED STATIONS
"mapped stations dbf/shp/shx"

Field Name	Explanation
main_code	Main code for station
name	Name of station
x_coord	X co-ordinate
y_coord	Y co-ordinate

ANNEXURE D-6
DATA STRUCTURE FOR SOUTHERN OSCILLATION INDEX PHASES
"soi phase.xls"

Field Name	Explanation
Year	Year between 1960-1997
Jan	Soi phase (1 – 5)
Feb	Soi phase (1 – 5)
Mar	Soi phase (1 – 5)
Apr	Soi phase (1 – 5)
May	Soi phase (1 – 5)
Jun	Soi phase (1 – 5)
Jul	Soi phase (1 – 5)
Aug	Soi phase (1 – 5)
Sep	Soi phase (1 – 5)
Oct	Soi phase (1 – 5)
Nov	Soi phase (1 – 5)
Dec	Soi phase (1 – 5)

ANNEXURE D-7
DATA STRUCTURE FOR ANNUAL STATISTICS FILE
"annual stats.xls"

Field Name	Explanation
main_code	Main code
average	Mean annual rainfall
minimum	Minimum annual rainfall
maximum	Maximum annual rainfall
sdev	Standard deviation
cv	Coefficient of variation

ANNEXURE D-8
DATA STRUCTURE FOR MONTHLY STATISTICS FILE
"monthly stats.xls"

Field Name	Explanation
main_code	Main code
jan_avg	Mean rainfall for January
jan_min	Minimum rainfall for January
jan_max	Maximum rainfall for January
jan_sdev	Standard deviation of rainfall for January
jan_cv	Coefficient of variation in rainfall for January
feb_avg	Mean rainfall for February
feb_min	Minimum rainfall for February
feb_max	Maximum rainfall for February
feb_sdev	Standard deviation of rainfall for February
feb_cv	Coefficient of variation in rainfall for February
mar_avg	Mean rainfall for March
mar_min	Minimum rainfall for March
mar_max	Maximum rainfall for March
mar_sdev	Standard deviation of rainfall for March
mar_cv	Coefficient of variation in rainfall for March
apr_avg	Mean rainfall for April
apr_min	Minimum rainfall for April
apr_max	Maximum rainfall for April
apr_sdev	Standard deviation of rainfall for v
apr_cv	Coefficient of variation in rainfall for April
may_avg	Mean rainfall for May
may_min	Minimum rainfall for April
may_max	Maximum rainfall for April
may_sdev	Standard deviation of rainfall for April
may_cv	Coefficient of variation in rainfall for April
jun_avg	Mean rainfall for June
jun_min	Minimum rainfall for June
jun_max	Maximum rainfall for June
jun_sdev	Standard deviation of rainfall for June
jun_cv	Coefficient of variation in rainfall for June
jul_avg	Mean rainfall for July
jul_min	Minimum rainfall for July
jul_max	Maximum rainfall for July
jul_sdev	Standard deviation of rainfall for July
jul_cv	Coefficient of variation in rainfall for July
aug_avg	Mean rainfall for August
aug_min	Minimum rainfall for August
aug_max	Maximum rainfall for August
aug_sdev	Standard deviation of rainfall for August
aug_cv	Coefficient of variation in rainfall for August
sep_avg	Mean rainfall for September
sep_min	Minimum rainfall for September
sep_max	Maximum rainfall for September
sep_sdev	Standard deviation of rainfall for September
sep_cv	Coefficient of variation in rainfall for September

Field Name	Explanation
oct_avg	Mean rainfall for October
oct_min	Minimum rainfall for October
oct_max	Maximum rainfall for October
oct_sdev	Standard deviation of rainfall for October
oct_cv	Coefficient of variation in rainfall for October
nov_avg	Mean rainfall for November
nov_min	Minimum rainfall for November
nov_max	Maximum rainfall for November
nov_sdev	Standard deviation of rainfall for November
nov_cv	Coefficient of variation in rainfall for November
dec_avg	Mean rainfall for December
dec_min	Minimum rainfall for December
dec_max	Maximum rainfall for December
dec_sdev	Standard deviation of rainfall for December
dec_cv	Coefficient of variation in rainfall for December

ANNEXURE D-9
DATA STRUCTURE FOR MONTHLY MEDIANS FILE
"monthly medians.xls"

Field Name	Explanation
main-code	Main code for station
med_jan	Median rainfall for January
med_feb	Median rainfall for February
med_mar	Median rainfall for March
med_apr	Median rainfall for April
med_may	Median rainfall for May
med_jun	Median rainfall for June
med_jul	Median rainfall for July
med_aug	Median rainfall for August
med_sep	Median rainfall for September
med_oct	Median rainfall for October
med_nov	Median rainfall for November
med_dec	Median rainfall for December

ANNEXURE D-10
DATA STRUCTURE FOR SEASONAL STATISTICS FILE
"seasonal stats.xls"

Field Name	Explanation
main_code	Code for station
annual average	Total annual rainfall
avg_oct_apr	Average falls during October to April
prop_oct_apr	Total falls during October-April as proportion of annual rainfall
avg_oct_dec	Average falls during October to December
prop_oct_dec	Total falls during October-December as proportion of annual rainfall
avg_jan_apr	Average falls during January to April
prop_jan_apr	Total falls during January to April as proportion of annual rainfall
no_years	Number of years of data
per_dry_oct	% frequencies of "dry" Octobers in a rain season
per_dry_nov	% frequencies of "dry" Novembers in a rain season
per_ dry_dec	% frequencies of "dry" Decembers in a rain season
per_ dry_jan2	% frequencies of "dry" Januarys in a rain season
per_dry_feb	% frequencies of "dry" Februarys in a rain season
per_ per_dry_mar	% frequencies of "dry" Marches in a rain season
per_dry_apr	% frequencies of "dry" Aprils in a rain season
per_jul	Monthly total for July as % of total annual rainfall
per_aug	Monthly total for August as % of total annual rainfall
per_sep	Monthly total for September as % of total annual rainfall
per_cot	Monthly total for October as % of total annual rainfall
per_nov	Monthly total for November as % of total annual rainfall
per_dec	Monthly total for December as % of total annual rainfall
per_jan	Monthly total for January as % of total annual rainfall
per_feb	Monthly total for February as % of total annual rainfall
per_mar	Monthly total for March as % of total annual rainfall
per_apr	Monthly total for April as % of total annual rainfall
per_may	Monthly total for May as % of total annual rainfall
per_jun	Monthly total for June as % of total annual rainfall
sper_oct	Monthly total for October as % of total seasonal rainfall
sper_nov	Monthly total for November as % of total seasonal rainfall
sper_dec	Monthly total for December as % of total seasonal rainfall
sper_jan	Monthly total for January as % of total seasonal rainfall
sper_feb	Monthly total for February as % of total seasonal rainfall
sper_mar	Monthly total for March as % of total seasonal rainfall
sper_apr	Monthly total for April as % of total seasonal rainfall

ANNEXURE D-11
DATA STRUCTURE FOR STATISTICS ON NUMBERS OF DAYS WITH RAIN, "number of days with rain.xls" and AVERAGE NUMBER OF DAYS WITH RAIN FILES "average number of days with rain.xls"

There are two files: the first (number of days with rain.xls) contains counts of the number of days for each station, for each year and for each month on which more than 1, 5, 10, 20 or 50 mm of rain fell. The cell values are blank for those stations, years and months when no data were recorded. The second file (average no. of days with rain.xls) contains average numbers of days for station and month and for the whole year on which more than 1, 5, 10, 20 or 50mm of rain fell. All the fields (except avgdays0.1) in this second file were derived from the first. The field avgdays0.1 was calculated directly from the original data in Alldaily.xls

Number of days with rain.xls

Field Name	Explanation
main_code	Code for station
Year	Year of record
jan1	Number of days in January with 1mm or more
feb1	Number of days in February with 1mm or more
mar1	Number of days in March with 1mm or more
apr1	Number of days in April with 1mm or more
may1	Number of days in May with 1mm or more
jun1	Number of days in June with 1mm or more
jul1	Number of days in July with 1mm or more
aug1	Number of days in August with 1mm or more
sep1	Number of days in September with 1mm or more
oct1	Number of days in October with 1mm or more
nov1	Number of days in November with 1mm or more
dec1	Number of days in December with 1mm or more
jan5	Number of days in January with 5mm or more
feb5	Number of days in February with 5mm or more
mar5	Number of days in March with 5mm or more
apr5	Number of days in April with 5mm or more
may5	Number of days in May with 5mm or more
jun5	Number of days in June with 5mm or more
jul5	Number of days in July with 5mm or more
aug5	Number of days in August with 5mm or more
sep5	Number of days in September with 5mm or more
oct5	Number of days in October with 5mm or more
nov5	Number of days in November with 5mm or more
dec5	Number of days in December with 5mm or more
jan10	Number of days in January with 10mm or more
feb10	Number of days in February with 10mm or more
mar10	Number of days in March with 10mm or more

apr10	Number of days in April with 10mm or more
may10	Number of days in May with 10mm or more
jun10	Number of days in June with 10mm or more
jul10	Number of days in July with 10mm or more
aug10	Number of days in August with 10mm or more
sep10	Number of days in September with 10mm or more
oct10	Number of days in October with 10mm or more
nov10	Number of days in November with 10mm or more
dec10	Number of days in December with 10mm or more
jan20	Number of days in January with 20mm or more
feb20	Number of days in February with 20mm or more
mar20	Number of days in March with 20mm or more
apr20	Number of days in April with 20mm or more
may20	Number of days in May with 20mm or more
jun20	Number of days in June with 20mm or more
jul20	Number of days in July with 20mm or more
aug20	Number of days in August with 20mm or more
sep20	Number of days in September with 20mm or more
oct20	Number of days in October with 20mm or more
nov20	Number of days in November with 20mm or more
dec20	Number of days in December with 20mm or more
jan50	Number of days in January with 50mm or more
feb50	Number of days in February with 50mm or more
mar50	Number of days in March with 50mm or more
apr50	Number of days in April with 50mm or more
may50	Number of days in May with 50mm or more
jun50	Number of days in June with 50mm or more
jul50	Number of days in July with 50mm or more
aug50	Number of days in August with 50mm or more
sep50	Number of days in September with 50mm or more
oct50	Number of days in October with 50mm or more
nov50	Number of days in November with 50mm or more
dec50	Number of days in December with 50mm or more

Average No. days with rain.xls

Field Name	Explanation
main_code	Code for station
avgdays0.1	Average no. of days per year with rain of 0.1mm or more
avgjan1	Average no. of days in January with 1mm or more
avgfeb1	Average no. of days in February with 1mm or more
avgmar1	Average no. of days in March with 1mm or more
avgapr1	Average no. of days in April with 1mm or more
avgmay1	Average no. of days in May with 1mm or more
avgjun1	Average no. of days in June with 1mm or more
avgjul1	Average no. of days in July with 1mm or more
avgaug1	Average no. of days in August with 1mm or more
avgsep1	Average no. of days in September with 1mm or more
avgoct1	Average no. of days in October with 1mm or more
avgnov1	Average no. of days in November with 1mm or more
avgdec1	Average no. of days in December with 1mm or more
avgjan5	Average no. of days in January with 5mm or more
avgfeb5	Average no. of days in February with 5mm or more
avgmar5	Average no. of days in March with 5mm or more
avgapr5	Average no. of days in April with 5mm or more
avgmay5	Average no. of days in May with 5mm or more
avgjun5	Average no. of days in June with 5mm or more
avgjul5	Average no. of days in July with 5mm or more
avgaug5	Average no. of days in August with 5mm or more
avgsep5	Average no. of days in September with 5mm or more
avgoct5	Average no. of days in October with 5mm or more
avgnov5	Average no. of days in November with 5mm or more
avgdec5	Average no. of days in December with 5mm or more
avgjan10	Average no. of days in January with 10mm or more
avgfeb10	Average no. of days in February with 10mm or more
avgmar10	Average no. of days in March with 10mm or more
avgapr10	Average no. of days in April with 10mm or more
avgmay10	Average no. of days in May with 10mm or more
avgjun10	Average no. of days in June with 10mm or more
avgjul10	Average no. of days in July with 10mm or more
avgaug10	Average no. of days in August with 10mm or more
avgsep10	Average no. of days in September with 10mm or more
avgoct10	Average no. of days in October with 10mm or more
avgnov10	Average no. of days in November with 10mm or more
avgdec10	Average no. of days in December with 10mm or more
avgjan20	Average no. of days in January with 20mm or more
avgfeb20	Average no. of days in February with 20mm or more
avgmar20	Average no. of days in March with 20mm or more
avgapr20	Average no. of days in April with 20mm or more

Field Name	Explanation
avgmay20	Average no. of days in May with 20mm or more
avgjun20	Average no. of days in June with 20mm or more
avgjul20	Average no. of days in July with 20mm or more
avgaug20	Average no. of days in August with 20mm or more
avgsep20	Average no. of days in September with 20mm or more
avgoct20	Average no. of days in October with 20mm or more
avgnov20	Average no. of days in November with 20mm or more
avgdec20	Average no. of days in December with 20mm or more
avgjan50	Average no. of days in January with 50mm or more
avgfeb50	Average no. of days in February with 50mm or more
avgmar50	Average no. of days in March with 50mm or more
avgapr50	Average no. of days in April with 50mm or more
avgmay50	Average no. of days in May with 50mm or more
avgjun50	Average no. of days in June with 50mm or more
avgjul50	Average no. of days in July with 50mm or more
avgaug50	Average no. of days in August with 50mm or more
avgsep50	Average no. of days in September with 50mm or more
avgoct50	Average no. of days in October with 50mm or more
avgnov50	Average no. of days in November with 50mm or more
avgdec50	Average no. of days in December with 50mm or more
avgyear1	Average no. of days in year with 1mm or more
avgyear5	Average no. of days in year with 5mm or more
avgyear10	Average no. of days in year with 10m or more
avgyear20	Average no. of days in year with 20mm or more
avgyear50	Average no. of days in year with 50mm or more

ANNEXURE D-12
DATA STRUCTURE FOR ANNUAL PERCENTILES FILE
"annual percentiles.xls"

Field Name	Explanation
main-code	Main code
Tot7th	7^{th} percentile
Tot10th	10^{th} percentile
Tot20th	20^{th} percentile
Tot25th	25^{th} percentile
Tot30th	30^{th} percentile
Tot33rd	33^{rd} percentile
Tot40th	40^{th} percentile
Tot50th	50^{th} percentile [median]
Tot60th	60^{th} percentile
Tot67th	67^{th} percentile
Tot70th	70^{th} percentile
Tot75th	75^{th} percentile
Tot80th	80^{th} percentile
Tot90th	90^{th} percentile

ANNEXURE D-13
DATA STRUCTURE FOR MOVING TOTALS FOR DROUGHT FILE
"moving totals for drought.xls"

Field Name	Explanation
main_code	Main code
name	Name of station
n_months	Number of months following 12 months with less than 75% of annual average
years	Number of years of data
percentage	Percentage of months following 12 months with less than 75% of annual average

ANNEXURE D-14
DATA STRUCTURE FOR PERCENTAGE OF DRY MONTHS FILE
"percentage of dry months.xls"

Field Name	Explanation
main_code	Main code
jan_per_dry	January: percentage of dry months
feb_per_dry	February: percentage of dry months
mar_per_dry	March: percentage of dry months
apr_per_dry	April: percentage of dry months
may_per_dry	May: percentage of dry months
jun_per_dry	June: percentage of dry months
jul_per_dry	July: percentage of dry months
aug_per_dry	August: percentage of dry months
sep_per_dry	September: percentage of dry months
oct_per_dry	October: percentage of dry months
nov_per_dry	November: percentage of dry months
dec_per_dry	December: percentage of dry months

ANNEXURE D-15
DATA STRUCTURE FOR FREQUENCIES OF DROUGHT MONTHS FILE
"drymthfreq.xls"

Field Name	Explanation
Main_code	Rainfall station code
Name	Rainfall station name
Years	Number of years of data
1	Frequency of single drought months
2	Frequency of two consecutive drought months
3	Frequency of three consecutive drought months
4	Frequency of four consecutive drought months
5	Frequency of five consecutive drought months
6	Frequency of six consecutive drought months
108	Frequency of 108 consecutive drought months