MAPPING THE MAJOR CATCHMENTS OF NAMIBIA

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ABSTRACT

Studies in landscape ecology which include hydrological and socio-economic aspects frequently use catchments as basic units. Similar studies are currently being undertaken in Namibia. Much information is available on many river system catchments in Namibia, but no detailed map of Namibian catchments exists.

SRTM-DEM (Shuttle Radar Topography Mission – Digital Elevation Model) data and available GIS data on the main rivers in Namibia was used to calculate a semi-detailed catchment map for Namibia using available standard routines. Fifty-seven catchments, in some cases forming sub-catchments to major catchments, were mapped, and their surface areas calculated. Brief descriptions of various interesting features of some of these catchments are given.

INTRODUCTION

Water, the prime ecosystem driver in arid environments, is the most important natural resource in Namibia. As a fluid, it flows through the landscape, forming channels through erosion upstream and depositing sediments (and often nutrients and/or pollutants) in downstream areas. The substrate (geology), the topography, local climate, vegetation cover, and human land use not only influence the characteristics of the streamflow, but are also interlinked through the flow of the water (Thornbury, 1985; Thomas, 1997; Rabeni & Sowa, 2002). Very practical examples of the effects of downstream erosion on upstream ecosystem functioning are provided in Pringle & Tinley (2003) and in Pringle, Watson & Tinley (2006).

Because of this strong interlinking, catchments (i.e. areas drained by rivers or bodies of water) are generally used as basic units in studies of landscape ecological processes (Hornung & Reynolds, 1995; Farina, 2000; Rabeni & Sowa, 2002). Studying a number of catchments as a complete ecosystem which includes socio-economic aspects is an approach that has been widely adopted in southern Africa, e.g. in the Okavango River project "Every River has its People" (Jones, Brown, Wamunyima, & Odendaal, 2003). Similar studies are being undertaken elsewhere in Namibia (Amakali & Shixwameni, 2003; Botes, Henderson, Nakale, Nantanga, Schachtschneider, & Seely, 2003; Manning & Seely, 2005).

Considerable information has been collected over the past decades on river catchments in Namibia. Pioneering work in this regard, describing the bigger ephemeral catchments in north-western Namibia, was done by Jacobsen, Jacobsen & Seely (1995). This was followed by more detailed studies on a number of catchment systems: The Kuiseb (O'Connor, 2001; Manning & Seely, 2005; Yoshida, 2005; Dahan, Tatarsky, Enzel, Kulls, Seely & Benito, 2008; Klaus, Külls & Dahan, 2008; Kok & Nel, 2008); the Swakop (Cowlishaw & Davies, 1997; Yoshida, 2005); the Omaruru and Ugab (Stengel, 1966; Yoshida, 2005); the rivers Koigab, Uniab, Hunkab and Hoarusib (Krapf, Stollhofen & Stanistreet, 2003); the Hoanib (Krapf *et al.*, 2003; Legget, Fennessy & Schneider, 2003 a & b, 2004, 2005; Yoshida, 2005); the Cuvelai Delta with its system of Oshanas (Marsh & Seely, 1992; Mendelsohn, El Obeid & Roberts, 2000); and the Okavango River (Ramberg, 1997; Jones *et al.*, 2003; Mendelsohn & El Obeid, 2003, 2004; Mbaiwa, 2004; Kgathi, Kniveton, Ringrose, Turton, Vanderpost, Lundqvist & Seely, 2006; Murray-Hudson, Wolski & Ringrose, 2006).

Although a large number of studies have been conducted on catchments, only Mendelsohn, Jarvis, Roberts & Robertson (2002) presented a catchment map for the entire Namibia. This map depicts 27 catchments, often combining (especially in the north and east) catchments of various larger rivers (e.g. the Daneib, Otjozondjou, Eiseb, Epukiro, Rietfontein and Chapman's) as one. Along the western escarpment, a number of smaller catchments (e.g. the Tumas, Orawab, Messum) have not been mapped. Further disadvantages are that the authors did not explain how the map had been derived, or comment on its accuracy.

With the Shuttle Radar Topography Mission (SRTM) dataset becoming available in 2003 at a resolution of 3 arc-seconds (90 m at the equator), and a vertical accuracy of 6 m (Jarvis, Rubiano, Nelson, Farrow & Mulligan, 2004), the mapping of topographical features such as watersheds has become fairly easy. The SRTM Digital Elevation Model (DEM) (often referred to as *Digital Terrain Model* or DTM) was produced using data from radar images gathered from NASA's shuttle. Whilst the data coverage was global, some regions are missing data because of a lack of contrast in the radar image, presence of water, or excessive atmospheric interference. These data gaps are especially concentrated along rivers, in lakes, and in steep regions (often on hillsides with a similar aspect due to shadowing). This non-random distribution of holes, ranging from 1 pixel to regions of 500 km^2, impedes the use of SRTM data, and requires the "filling-in" of these gaps through various spatial analysis techniques (Jarvis *et al.*, 2004). Reuter, Nelson & Jarvis

(2007) have further processed the SRTM dataset by filling in the no-data holes through the production of vector contours and points, and the re-interpolation of these derived contours back into a raster DEM. These interpolated DEM values were then used to fill in the original no-data gaps within the SRTM data. This refined dataset (version 4) is available for download from http://srtm.csi.cgiar.org/ as 5 x 5 degree tiles, in geographic coordinate system – WGS84 datum (Jarvis, Reuter, Nelson & Guevara, 2008).

METHODS

Ten 5 x 5 degree tiles of the version 4 SRTM data available from CIAT (http://srtm.csi.cgiar.org/), were used as base dataset for the catchment map. These ten tiles were merged to form one continuous DEM between 15° S and 30° S, and 10° E and 30° E (Figure 1). This continuous DEM is necessary to avoid edge effects in the determination of the catchments, especially within the boundaries of Namibia. (This is also the reason why SRTM_42_16, containing only the furthest tip of the Caprivi region and with it, the entire column 42, had to be used).

This image, at a resolution of 3 arc-seconds, contained 24 000 columns and 18 000 rows of data, or 432 000 000 pixels. This proved to be too large a dataset for the available computing hardware and software, necessitating the reduction of the dataset by aggregation. This was done with the CONTRACT routine in IDRISI, using a 5 x 5 pixel setting. The image contained 4 800 columns and 3 600 rows of data, or a total of 17 280 000 pixels. However, this reduction in the size of the dataset also meant a loss in resolution from 3 arc-seconds to 15 arc-seconds, or roughly from 90 m to 450 m.

A seeding image was prepared as follows: a shapefile with rivers from the NARIS dataset (2001) was used as source. Rivers mapped and named on the 1:1 000 000 scale farm map of Namibia were selected from this GIS dataset (e.g. the Swakop river, without smaller tributaries) and copied to a new shapefile in ArcView. The individual segments were merged, to give a continuous line of the main streambed (Figure 2).

This ArcView shapefile of the main rivers was converted to an IDRISI vector file. Some of the trans-boundary rivers, especially the Okavango, Kwando, Zambezi and Orange rivers, had to be lengthened by on-screen digitising along the clearly visible river bed. This vector file was converted to a raster image, using the same resolution as the input SRTM-DEM.

The contracted SRTM-DEM was used as input image for the WATERSHED routine in IDRISI (Eastman, 2006). This routine uses the algorithms of Jenson & Domingue (1988) to calculate the catchments based on derived flow directions of individual pixels in relation to their neighbours. It includes

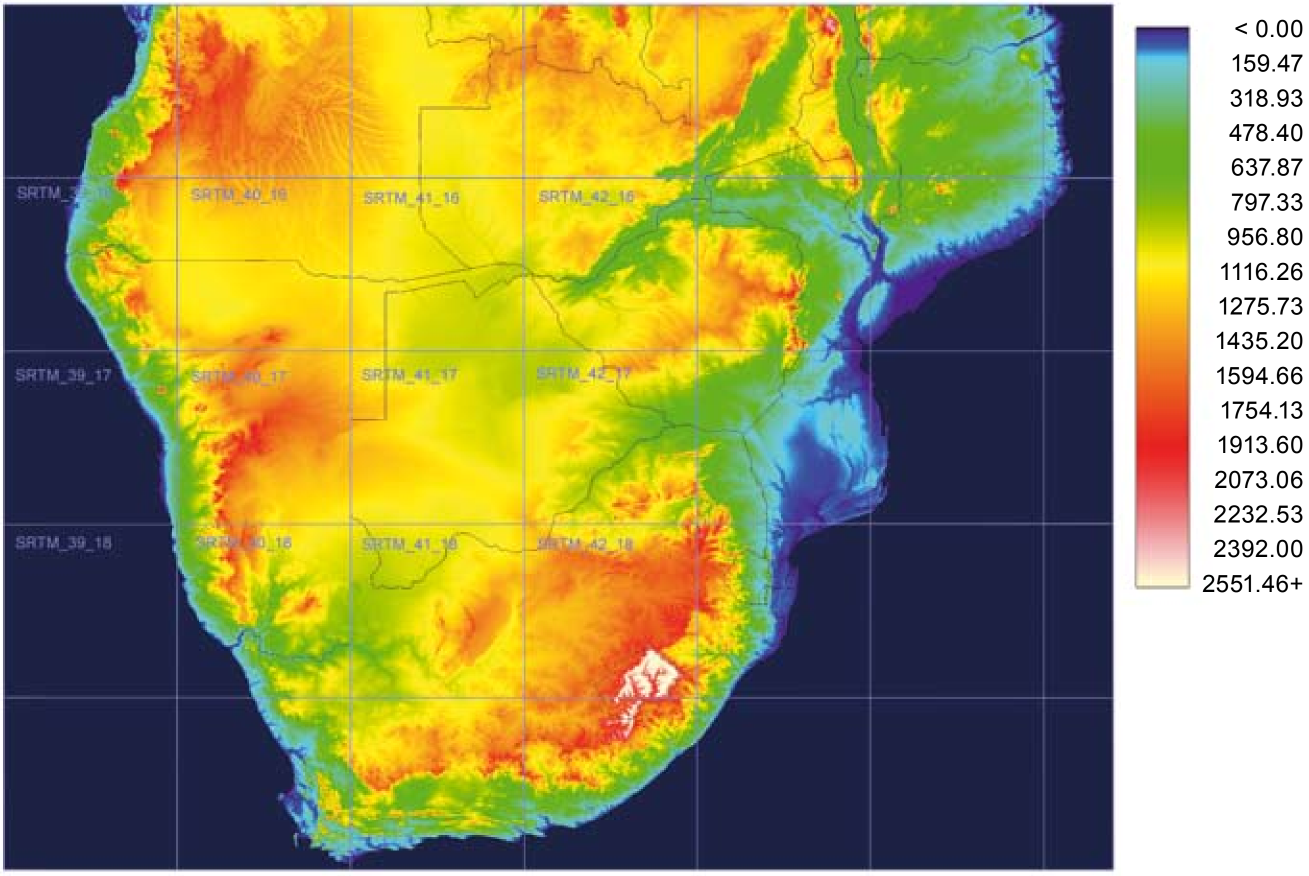


Figure 1. DEM of southern Africa, indicating the 5 X 5 degree SRTM data tiles used in the mapping of watersheds in Namibia (heights indicated in m).

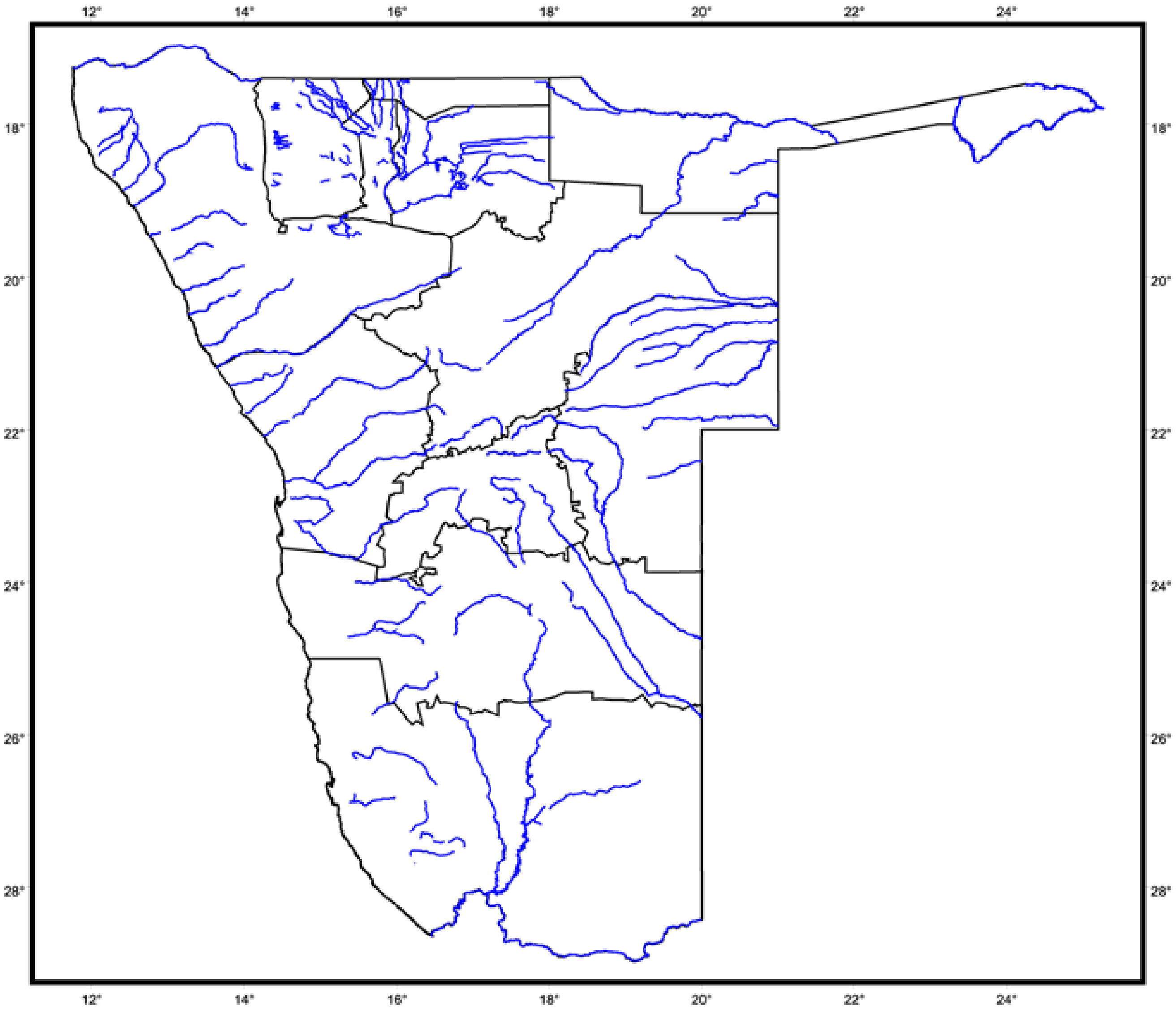


Figure 2. Map of the rivers used as seeding information for the WATERSHED procedure in IDRISI.

an automatic initial routine to exclude pits from the DEM. The WATERSHED routine was set to use the pre-prepared seeding image described above rather than an automatic calculation using a minimum area.

The process was repeated a number of times to refine the resultant watersheds map, mainly by selecting additional tributaries to the main streams in order to better define the catchments. This was especially necessary in the flat areas of the country, e.g. to distinguish between the main Cuvelai basin and the surrounding area feeding directly into the Etosha Pan or various pans to the west of Etosha.

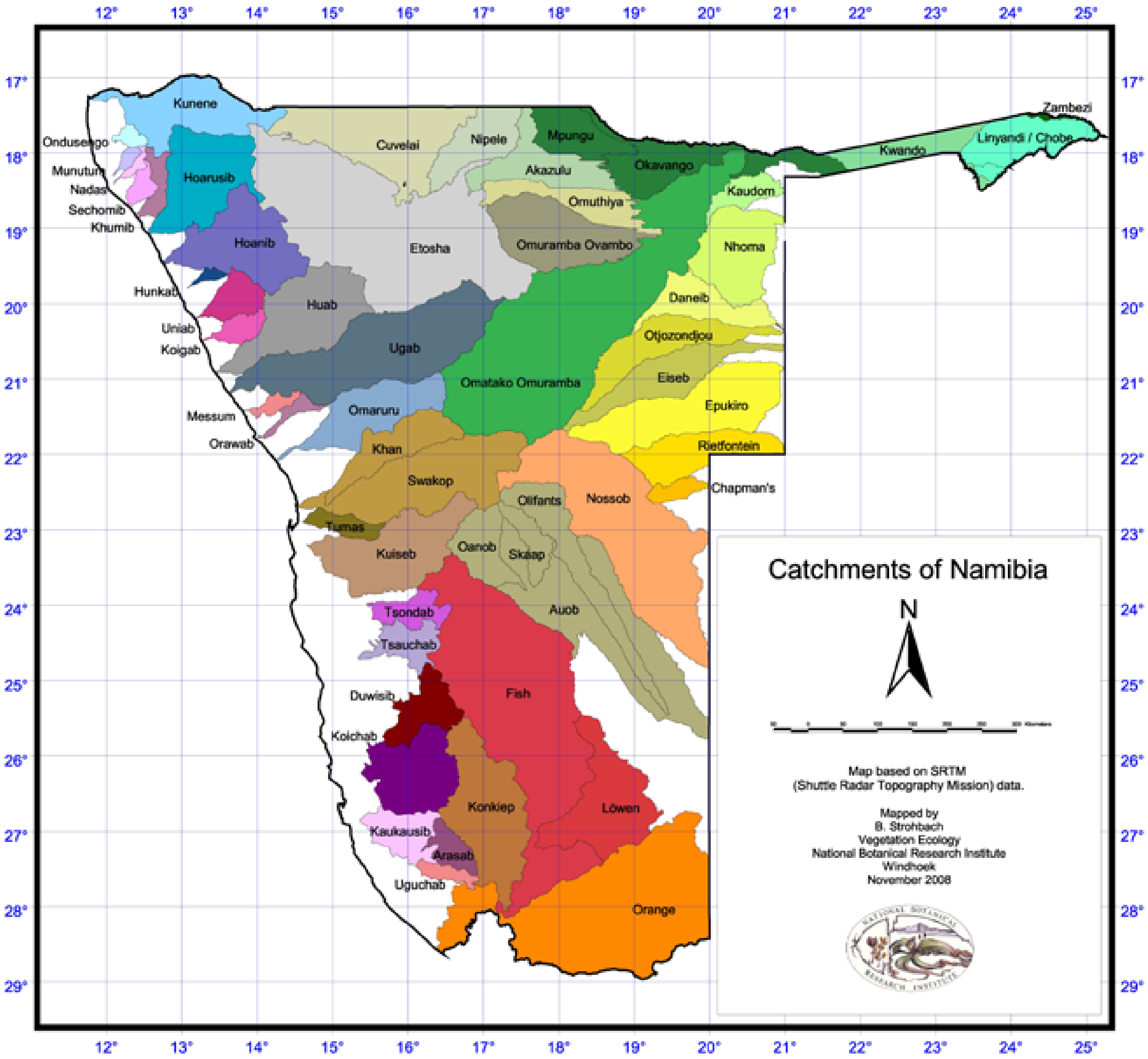
Once a reliable result was obtained, the image was masked with an image of the Namibian surface area. From this clipped image, the surface area of the catchments within Namibia was calculated using the AREA routine in IDRISI. The catchment image was converted to a vector file in IDRISI, which in turn was exported as a shapefile for general use in ArcView. Throughout the entire process, the original projection (geographical, with WSG84 as reference) was maintained.

As a final step, additional data about the end points of the rivers were identified from the topographical map series of Namibia.

RESULTS AND DISCUSSION

The catchments are mapped in Figure 3. An overview of these catchments, including their calculated surface areas, is given in Table 1.

As indicated by Mendelsohn *et al.* (2002), the central plateau forms a watershed between drainage to the west towards the coast, and into the Kalahari basin. Only the Zambezi river, of which the catchment covers 369 km^2 in the far north-eastern Caprivi Region, flows eastwards into the Indian Ocean.



Map based on SRTM
(Shuttle Radar Topography Mission) data.

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Figure 3. Map of the major catchments of Namibia.

Table 1. List of the most important catchments in Namibia, indicating their end points as well as their surface areas

Catchment name	River ending in / contributing to	Area in km²
Akazulu	Etosha Pan	9 845,183
Arasab	Arasab Pan	2 861,775
Auob	Molopo	24 540,698
Chapman's	Central Kalahari (Botswana)	1 856,759
Chobe	Okavango Delta	9 190,631
Cuvelai	Etosha Pan	20 730,677
Daneib	Okavango Delta	7 788,024
Duwisib	Pan in desert (unnamed)	6 053,052
Eiseb	Okavango Delta	10 671,777
Epukiro	Okavango Delta	19 425,793
Etosha	Etosha Pan	57 030,189
Fish	Orange	54 326,103

Hoanib	Atlantic Ocean	15 760,517
Hoarusib	Atlantic Ocean	15 237,459
Huab	Atlantic Ocean	16 465,695
Hunkab	Desert	592,636
Kaudom	Okavango Delta	3 528,597
Kaukausib	Desert	5 481,399
Khan	Swakop	8 399,274
Khumib	Atlantic Ocean	2 308,393
Koichab	Koichab Pan	11 746,600
Koigab	Atlantic Ocean	2 320,891
Konkiep	Fish	18 392,721
Kuiseb	Atlantic Ocean	16 692,588
Kunene	Atlantic Ocean	14 216,319
Kwando	Okavango Delta	6 846,593
Linyandi	Okavango Delta	811,809
Löwen	Fish	15 424,669
Messum	Atlantic Ocean	1 224,699
Mpungu	Okavango	7 249,993
Munutum	Okau Swamp off Cape Fria	672,356
Nadas	Desert	669,988
Nhoma	Okavango Delta	13 035,734
Nipele	Etosha Pan	8 224,640
Nossob	Molopo	37 904,985
Oanob	Auob	6 643,089
Okavango	Okavango Delta	13 644,787
Olifants	Auob	11 291,515
Omaruru	Atlantic Ocean	11 579,603
Omatako Omuramba	Okavango	61 057,419
Omuramba Owambo	Etosha Pan	15 783,756
Omuthiya	Etosha Pan	7 660,058
Ondusengo	Desert	1 010,425
Orange	Atlantic Ocean	44 068,812
Orawab	White Lady Salt Pans (Atlantic Ocean)	1 288,065
Otjozondjou	Okavango Delta	10 901,911
Rietfontein	Central Kalahari (Botswana)	9 424,755
Sechomib	Desert	1 534,229
Skaap	Auob	3 574,449
Swakop	Atlantic Ocean	21 010,149
Tsauchab	Sossus Vlei	4 431,358
Tsondab	Tsondab Vlei	3 844,167
Tumas	Desert	2 637,115
Ugab	Atlantic Ocean	29 355,496
Uguchab	Desert	1 606,149
Uniab	Atlantic Ocean	3 960,575
Zambezi	Indian Ocean	368,569

Catchments draining from the western escarpment

Krapf *et al.* (2003) described flow events of two desert river systems in the Kunene Region: the relatively short southern rivers Koigab, Uniab and Hunkab are effectively dammed by the coastal erg (sand sea) of the Skeleton Coast and very seldom break through to the coast. After such an event, the gap in the erg is closed relatively quickly by prevailing south-westerly winds. The two northern rivers, the Hoanib and Hoarusib, both with a larger catchment extending well into the higher-rainfall hinterland, regularly (on average every 9 years) break through to the coast, but are usually dammed by the ever-moving sand sea.

The pattern of damming by dunes is a widespread phenomenon, causing most of the ephemeral rivers along the western escarpment to end within the desert in a pan (internationally better known as playa), e.g., Sossus Vlei, Tsondab Vlei, Koichab Pan (Figure 4) or even a marsh, e.g., the Munutum ending in Okau Swamp off Cape Fria. The formation of pans is well described by Thomas (1997). This damming (or ponding – *sensu* Thomas, 1997) often results in the recharge of groundwater, as described by Klaus *et al.* (2008) for the Kuiseb. Only the deep-gorged rivers like the Fish, Konkiep, Swakop, Omaruru and Ugab reach their destinations relatively unhindered. This is also true

Figure 4. The Tsauchab catchment ends in Sossus Vlei. The river is well dammed by the huge expanse of the Namib Sand Sea.

Figure 5. Rooiboklaagte is a typical example of a deeply incised ruderal river (locally known as an omuramba) crossing the Kalahari sand plateau.

for the two rivers bordering the country, the Kunene (in the north) and the Orange (in the south), which are perennial rivers with headwaters in Angola and Lesotho respectively.

Catchments draining into the Kalahari

The catchments draining to the east traverse large expanses of the Kalahari Basin (Mendelsohn *et al*., 2002). Most of these deeply incised rivers are ruderal rivers (Figure 5) (King, 1963) carrying little or no water, especially in their downstream reaches (Nash, 1996). This is because the relatively flat sandy plateau of the Kalahari yields little run-off as most of the precipitation is absorbed into the deep sand. Anecdotal evidence has it that the Omatako Omuramba is dammed up by aeolian sand in the vicinity of Kanuvlei in the Otjozondjupa Region. The Omatako Omuramba, the Nossob and the Auob (with its tributaries the Oanob, Skaap, Olifants and Seeis) are known to be very active in the upstream reaches. As they enter the sandy Kalahari, however, their water seeps into the sand. For example, the entire Oanob and Skaap rivers vanish into a series of pans between Tsumis and Uhlenhorst, and are not directly linked to the main Auob riverbed. The Auob starts up again around 60 km further south, between Uhlenhorst and Stampriet; in the past it was fed by artesian springs at Stampriet. Due to a heavy infestation of prosopis trees in the riverbed (Smit, 2005), the flow of the Auob has dried up entirely (Figure 6).

Figure 6. The riverbed of the Auob north of Gochas is densely encroached with *Prosopis glandulosa*.

Between the Auob and the Orange catchments in south-eastern Namibia is a large area that does not form part of any catchment. This area, the Witrand and the Koës panveld (Figure 7), forms part of a larger panveld centred in the Northern Cape Province in the RSA (Shaw, 1988). The formation of these pans is attributed to the flat topography (i.e. no drainage), combined with various weathering and deflation processes (Shaw, 1988; Thomas, 1997). The Witrand plateau has a typical karstic character, with numerous small pans with very localised catchments.

The Etosha Pan, a fossil lake (Shaw, 1988), is mostly fed by the Cuvelai Delta with its well-known oshanas (Figure 8), which feed into the Omadhiya Lake complex. Lake Oponono is the best known of these lakes, draining into the Etosha Pan (Mendelsohn *et al*., 2002). Another major influx of water comes from the Omuramba Owambo which occasionally reaches Etosha Pan from the east through Fisher's Pan. It drains the northern Karstveld (*sensu* Giess, 1998) from the Otavi Mountain Range, with the headwater forming a series of vleis and pans along the interface between the relatively shallow-soiled Karstveld and the deep, highly absorptive sandy Kalahari between Maroelaboom and Tsintsabis – the so-called Parkiesveld (Figure 9). Other tributaries to Etosha are the ruderal rivers Nipele, Akazulu and Omuthyia from the north-east, as well as numerous smaller rivers and pans from the south and west. A large part of the south-western Omusati Region forms part of this catchment, but is essentially so flat that occasional rivers end in various pans, rather than reaching Etosha Pan.

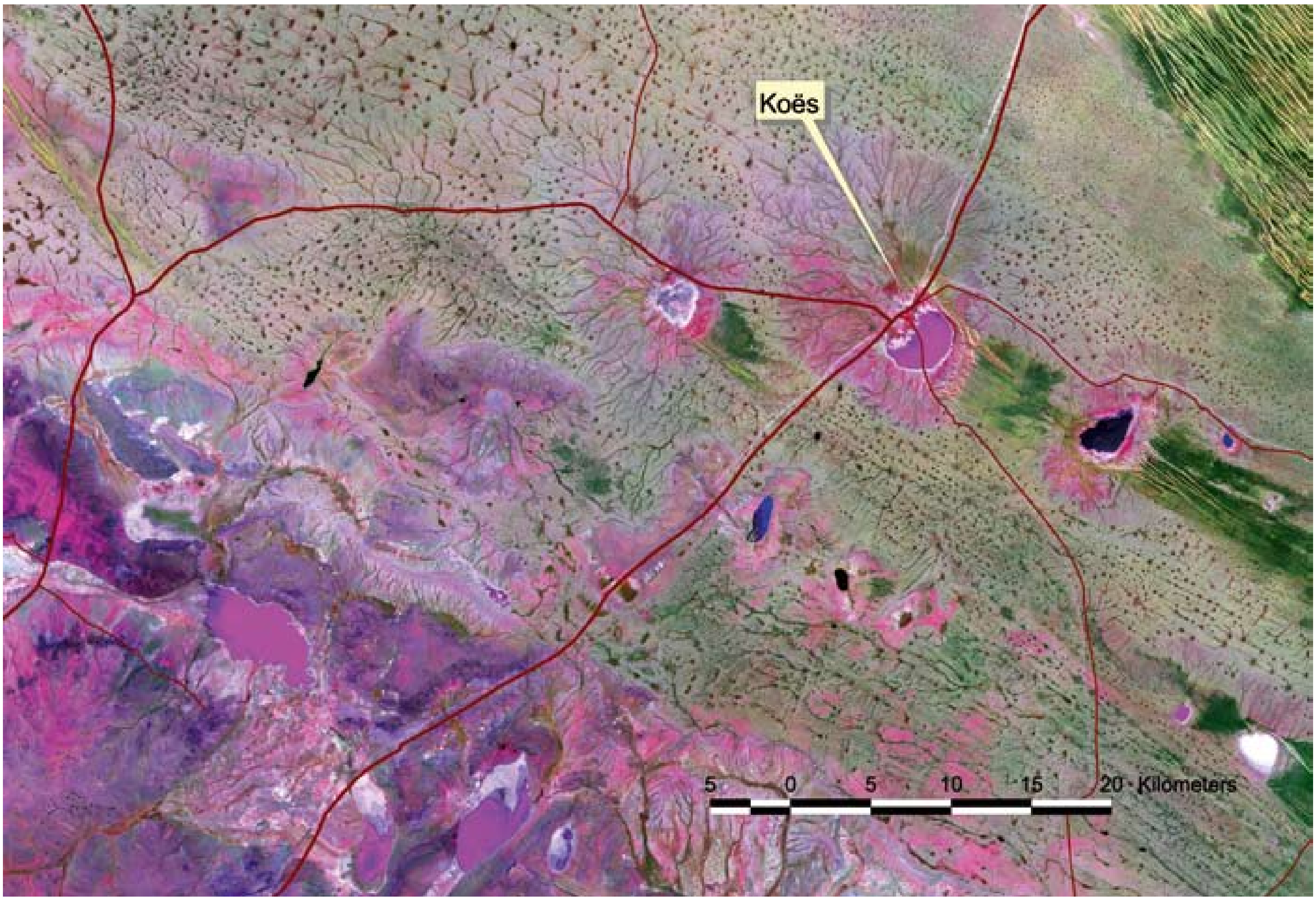

Figure 7. The Koës panveld in south-eastern Namibia (false colour composite of Landsat 7 ETM scene P176R078 dated 4 June 2000). Note the band of pans (in bright purple or dark blue) along the edge of the Prince Albert shale in the south-western corner of the image, and the Kalahari dune field in the north-eastern corner of the image. Numerous small pans form in the calcretes of the Witrand plateau (matrix in the central and northern part of the image).

Figure 8. A large part of the catchment of Etosha Pan is formed by the Cuvelai delta, characterised by its numerous oshanas.

Figure 9. Top: The Omuramba Owambo drains the Karstveld. Here water often flows over broad surfaces rather than in narrow channels.

Bottom: The "Parkiesveld" is formed by a series of pans, vleis, tree clusters and low grasslands, and forms the upstream part of the Omuramba Owambo before this forms a distinct channel from Tsintsabis westwards.

CONCLUSION

The availability of relatively high-quality SRTM-DEM data makes the mapping of catchments routine with the WATERSHED module of IDRISI. The produced map should be used as a general overview of the catchments of Namibia. The present resolution of about 450 m is acceptable for use up to a scale of 1:500 000, following the criteria of Westfall *et al.* (1996).

For studies of particular catchments at a smaller scale, it is recommended that this mapping procedure be repeated, using the original 3 arc-seconds SRTM data as source. Any catchment studies at a scale of 1:50 000 or smaller should either use other high-resolution DEM data, or the relevant fine-scale topographical map to delimit the catchments (Jarvis *et al.*, 2004).

The presented map can be downloaded as a pdf or an ArcView shapefile from www.nbri.org.na.

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