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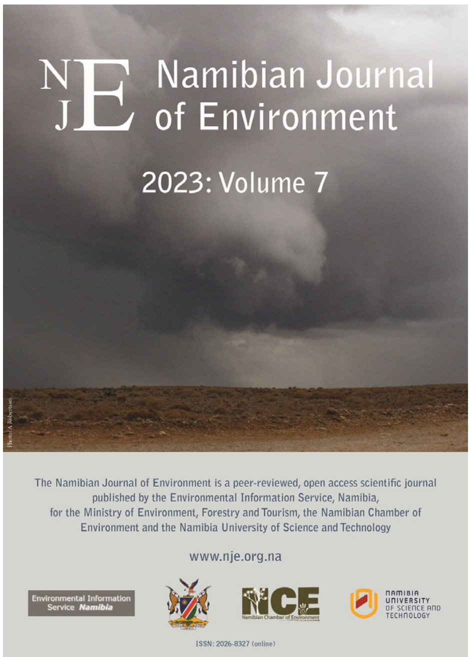

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How well do CHIRPS precipitation estimates relate to measured rainfall in Namibia?

A Robertson

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JARO Consultancy, PO Box 90692, Windhoek, Namibia

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Abstract

Measured rainfall data from 33 ground-based rainfall stations were compared with rainfall estimates from CHIRPS (Climate Hazards Infrared Precipitation with Stations) across a rainfall gradient in central Namibia. There was close agreement between the two datasets across the interior of the country from the escarpment eastwards. However west of the escarpment the two datasets diverged. In this zone all CHIRPS estimates were higher than measured values and the seasonal variability of CHIRPS estimates declined towards the coast whereas measured rainfall variability rose. Quality assessments of CHIRPS in the literature have suggested there is a tendency for the model to overestimate the frequency of rainfall events, and to record low rainfall rather than zero rainfall in low rainfall areas. These effects may be exacerbated in Namibia by the prevalence of coastal fog. Increasing the number of reliable ground-based stations across the coastal zone may go some way to addressing the discrepancy in Namibia between CHIRPS estimates and ground measurements.

Keywords: CHIRPS, Namibia, rainfall, satellite data, weather station data

Introduction

Over recent decades several satellite-based rainfall datasets such as RFE2 (Estimated daily precipitation), ARC2 (Africa Rainfall Climatology) and TAMSAT (Tropical Applications of Meteorology using Satellite data) have been developed and utilised as tools for estimating rainfall. The accuracy of predictive gridded datasets has recently been improved with the introduction of methods which blend weather station data and satellite data, known as gauge-satellite approaches. One such dataset, designed to fill existing gaps in vector datasets by offering low output lag, high resolution, low bias and reasonable record length, is the CHIRPS (Climate Hazards Infrared Precipitation with Stations) dataset (Funk *et al.* 2015) which was developed to assist the Famine Early Warning Systems Network (FEWS NET). In the initial production of the CHIRPS dataset several validation case studies were undertaken in Columbia, Peru and south-western North America. Various assessments comparing the performance of several satellite-based products including CHIRPS have been published, for example Dinku *et al.* (2018) in East Africa, Toté *et al.* (2015) in Mozambique and Masauso (2018) in Namibia. Across the various products CHIRPS outperformed others in many scenarios and currently appears to be favoured for general applications. However, these studies also identified a performance decline with CHIRPS in certain regimes, particularly in coastal and lower rainfall areas. For example, in Peru Aybar *et al.* (2019) determined that CHIRPS severely overestimated precipitation on the Pacific coast leading to the development of a bespoke gridded dataset which incorporated a modification to CHIRPS in combination with two other gauge-based datasets. Assessments of CHIRPS' validity in other areas where weather processes are strongly influenced by a cold ocean system are limited, however.

The cold Benguela current has a strong impact on the weather regime in coastal parts of Namibia where fog and low cloud is a common occurrence, particularly in the central coastal area, and may extend as far east as the base of the escarpment (Andersen *et al.* 2019). The country is dry with an aridity index ranging from hyper-arid in the west to semi-arid in the north-east and with a coastal desert along its entire Atlantic Ocean border (Atlas of Namibia Team 2022). In general, Namibia's relief is characterised by a hyper-arid desert coastal plain (extending approximately 100 km inland), a narrow rocky escarpment zone and central ridge, followed by the interior plateau to the east (Atlas of Namibia Team 2022; Figure 1).

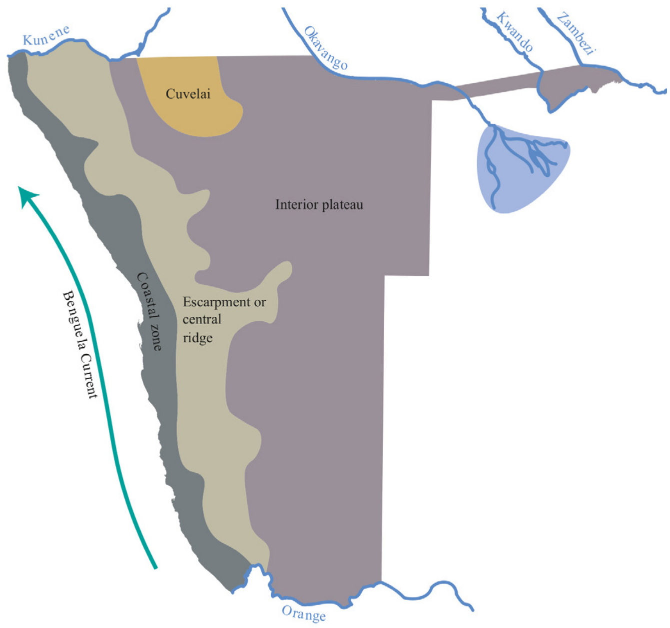

Figure 1: *Namibia's landform. Adapted from Atlas of Namibia Team (2022).*

Rainfall in Namibia is strongly seasonal with most rains falling between December and April. A complete rainfall season is commonly considered to extend from 1 July in one year to 30 June in the next. Average seasonal rainfall in Namibia is less than 100 mm in the western coastal parts increasing north-eastwards to over 600 mm in the Zambezi region (Mendelsohn *et al*. 2002; Figure 2).

This study focuses only on the performance of the CHIRPS dataset in an east-west continuum across the central rainfall gradient in Namibia, between the higher rainfall interior and the low rainfall coastal zone. I compare CHIRPS rainfall estimates with ground-based rainfall gauge measurements (hereafter referred to as stations) for 33 stations located between the west coast at Walvis Bay and around 475 kilometres inland to the east near the Botswana border. More specifically, I consider two questions: how do the measures and estimates of seasonal rainfall compare from east to west, and is variability within each dataset relatively constant along the gradient?

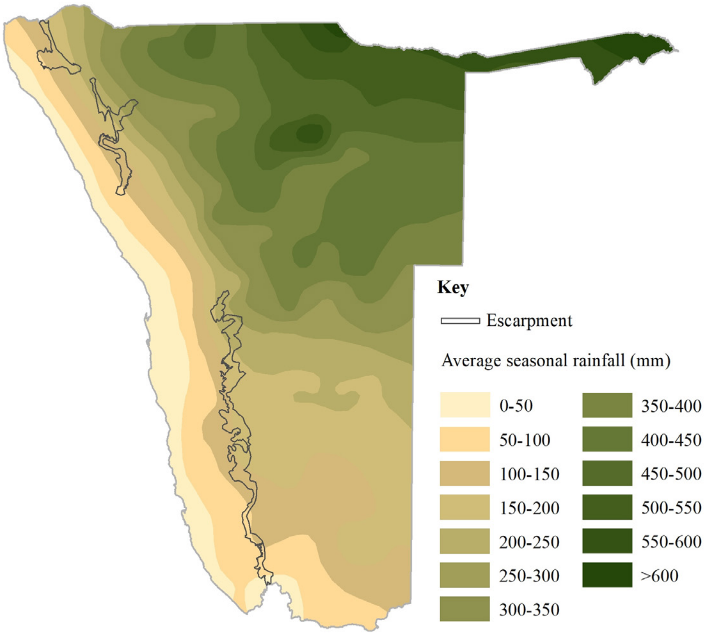

Figure 2: *Average seasonal rainfall (derived from kriging interpolation of station data) and the escarpment. Adapted from Mendelsohn* et al. *(2002).*

Methods

The CHIRPS dataset covers the period from 1981 to the present. This analysis covers the 40-year period from 1981-2020. Station data were available from the Namibia Meteorological Services (NMS) data and the SASSCAL (Southern Africa Science Service Centre for Climate Change and Adaptive Land Management) WeatherNet programme (http://www.sasscalweathernet.org). The number of complete annual rainfall seasons varied greatly across stations. The spatial distribution of stations is shown in Figure 3.

Most rainfall stations are located centrally and there are few within the coastal zone. Although stations introduced through the SASSCAL programme after 2010 fill some of the gaps in the central desert zone, data for most of these stations were limited to 8 seasons or fewer, and by several missing records for some months.

To assess the relationship between station records and CHIRPS estimates in an even spread across both the rainfall gradient and spatially across the country, a sample of representative stations was selected in a strip extending from the central coast around Swakopmund and Walvis Bay to 475 km inland. The shortest direct distance from each station to the nearest point of the coast was measured using a GIS.

Rainfall in Namibia is generally highly variable across seasons, both in terms of the amount of rain that falls and the timing of rainfall events, with approximately decadal cycles in seasonal rainfall peaks and troughs (Atlas of Namibia Team 2022). To capture the natural variation in seasonal rainfall only stations with more than 10 complete seasons were included in the selection. A season was considered complete if daily records were available for every day between July and

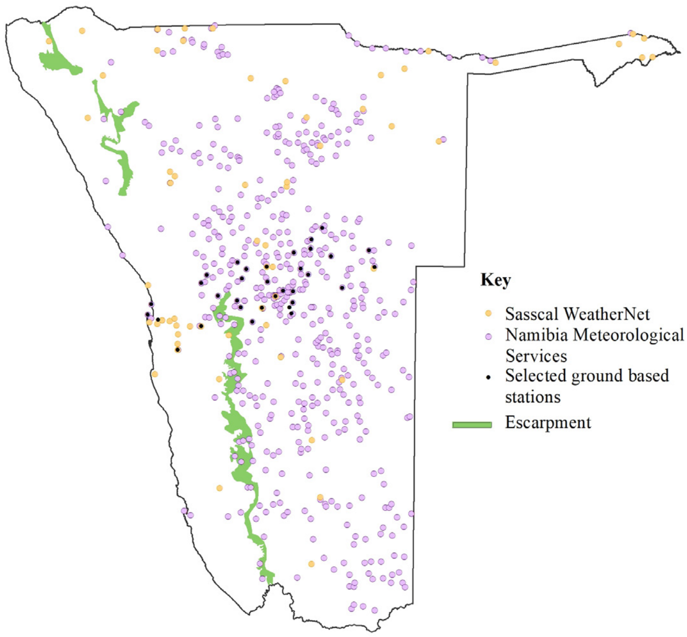

Figure 3: *Stations recording rainfall data in Namibia and rainfall stations selected for comparison of CHIRPS rainfall estimates and weather station rainfall data. From data supplied by Namibia Meteorological Services, Windhoek and http://www.sasscalweathernet.org.*

June. This provided a sample of 33 stations. Although over 80% of these stations had fewer than 30 seasons of complete data this was not considered a problem as the intention was not to compare *trends* between station data and CHIRPS but rather *value differences* for each season with complete data.

For each set of station seasons the corresponding CHIRPS estimates were extracted by grid cell using the zonal statistics tool in ARCGIS (ESRI 2013). The CHIRPS dataset provides estimates at 0.05° (approximately 5.5 km) grid resolution. The rainfall stations were ordered according to their distance from the coast and two simple analyses were performed:

1) Percentage difference between average station values and average CHIRPS values

$$\frac{\text{ABS (Average Station-Average CHIRPS)}}{\text{(Average Station+Average CHIRPS)/2}} \times 100$$

2) Coefficient of variation (COV) for both the rainfall station and CHIRPS values

$$\frac{\text{Standard Deviation Station}}{\text{Average Station}} \text{ x } 100 \quad \text{and} \quad \frac{\text{Standard Deviation CHIRPS}}{\text{Average CHIRPS}} \text{ x } 100$$

Results

A summary of statistical outputs is presented in Table 1. This includes the number of rainfall seasons, average seasonal rainfall (stations and CHIRPS), coefficient of variation (stations and CHIRPS) and the percentage difference between station and CHIRPS rainfall estimates.

CHIRPS estimates showed close agreement with measured station data between 140 and 475 km from the coast (Figure 4a). The most noteworthy contrast between the datasets however is evident between 140 km inland (the escarpment area) and the coast. Here CHIRPS estimates were consistently higher than measured rainfall, and between 50 km inland and the coast CHIRPS estimates steadily increased in contrast to the very low (and decreasing) rainfall station measurements. At the national scale, CHIRPS average rainfall patterns are very similar to station data east of the escarpment (compare Figure 2 with Figure 4b). However, west of the escarpment (excluding the Namib sand sea area) the 50-100 mm rainfall zone in the CHIRPS dataset extends further west than the same zone in the station data, and extends along the entire southern coastline. In parts of the Namib sand sea average rainfall estimates from CHIRPS are lower than those in the station dataset. The greatest contrast between the two datasets, however, is in the central coastal area and all along the northern coastline where CHIRPS average rainfall estimates increase near the coast and exceed 100 mm compared with rainfall averages of less than 50 mm in the dataset derived from station data.

The bias in CHIRPS rainfall estimates between the coast and the escarpment area is also illustrated in Figure 5 where a regression of CHIRPS estimates on station measurements, with a zero intercept, shows

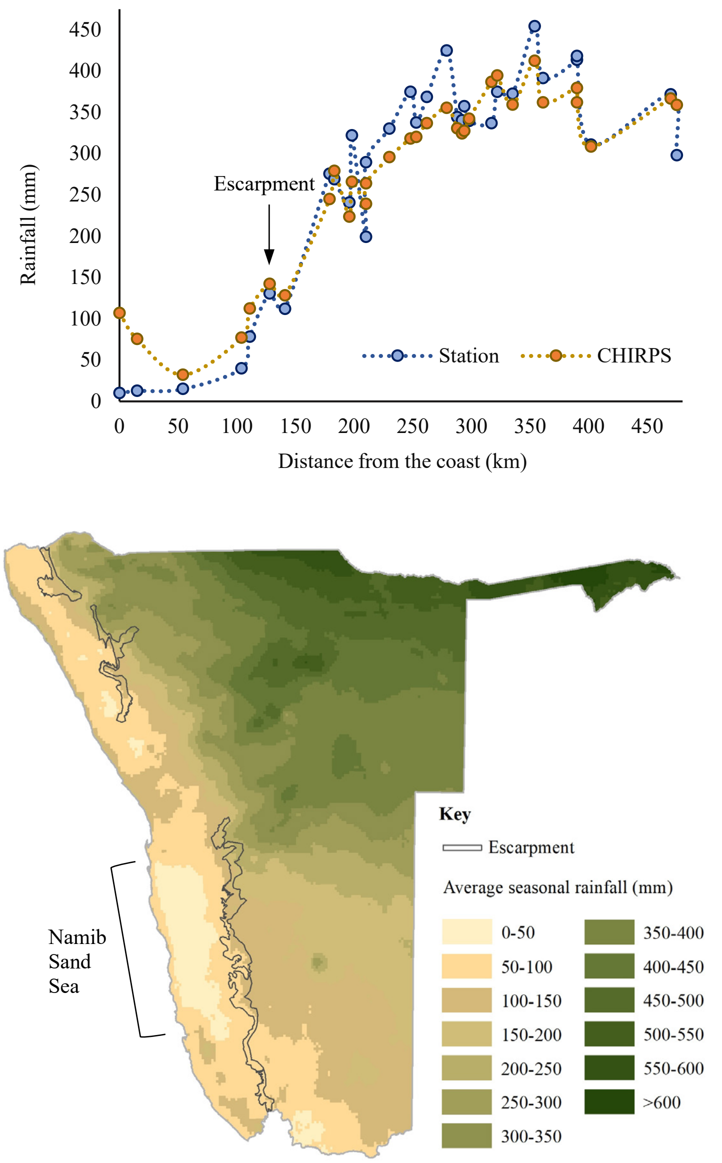

Figure 4: *a) Average seasonal rainfall with distance from the coast: measured rainfall versus CHIRPS estimates for 33 stations in Namibia (points) with smoothed trend lines (dotted lines); b) Average seasonal rainfall across Namibia from CHIRPS (1981-2020). Data downloaded from the FEWS NET data portal.*

Table 1: *Summary of average rainfall, coefficient of variation and percentage difference of average rainfall between measured rainfall and CHIRPS rainfall estimates for 33 stations in Namibia.*

Number	Rainfall station	Distance from coast (km)	Elevation (masl)	Rainfall seasons (n)*	Average rainfall recorded by rainfall station (mm)	Average rainfall recorded by CHIRPS (mm)	Percent difference of average rainfall	COV Station	COV CHIRPS	Latitude S	Longitude E
1	Pelican Point	0	< 10	17	6	67	166.3	160.6	7.0	-22.88	14.43
2	Swakopmund	0	< 10	19	14	147	164.4	115.9	11.6	-22.68	14.52
3	Walvis Bay Airport	15	93	15	13	75	142.7	145.6	20.5	-22.98	14.64
4	Gobabeb	54	407	28 (6)	15	32	73.8	104.9	21.2	-23.56	15.04
5	Ganab	104	1,000	13	40	77	63.6	48.9	13.3	-23.12	15.54
6	Dorstrivier	111	1,044	11	78	101	25.0	75.2	19.1	-22.30	15.57
7	Abbabis Ost	128	1,196	17	130	142	44.7	58.2	33.2	-22.65	16.45
8	Kaltenhausen	140	1,044	14	112	128	44.8	50.1	26.4	-22.55	15.90
9	Abochaibis	179	1,313	18	275	245	11.7	45.0	30.4	-22.65	16.30
10	Terra Rossa	183	1,677	27	269	279	3.7	39.9	28.9	-22.78	16.37
11	Westefallenhof	196	1,232	19	241	223	7.4	49.3	40.4	-22.23	16.40
12	Wilhelmstal	198	1,342	25	322	266	19.2	35.4	33.8	-21.92	16.32
13	Mahonda	210	1,824	14	199	239	18.3	37.8	19.9	-23.05	16.62
14	Erora Ost	210	1,331	18	289	264	9.2	43.6	25.2	-22.05	16.50
15	Claratal	230	1,933	35 (10)	330	295	11.1	36.6	32.2	-22.79	16.81
16	Otjiseva	248	1,401	35	375	318	8.6	45.3	33.9	-22.30	16.93
17	Okahandja	253	1,325	28	328	310	5.8	30.3	27.4	-22.01	16.92
18	Windhoek	262	1,735	39 (4)	368	337	9.0	49.8	34.3	-22.57	17.10
19	Bergvlug	279	2,017	30	425	355	17.8	38.2	33.0	-22.47	17.25
20	Binsenheim	288	1,751	31	344	330	4.1	46.5	34.3	-22.78	17.38
21	Rietfontein-Khomas	292	1,833	19	340	324	4.8	33.6	23.2	-22.90	17.42
22	Hohenau	294	1,789	18	357	327	8.7	37.8	25.6	-22.70	17.45
23	Hosea Kutako Airport	298	1,705	29	339	342	0.8	37.7	27.3	-22.48	17.47
24	Vooruitgang	317	1,609	12	337	387	13.8	33.2	17.4	-21.75	17.48
25	Otjikundua	322	1,765	21	375	395	5.2	28.8	30.8	-22.05	17.62
26	Okahua	335	1,652	29	372	359	3.6	37.5	28.6	-22.17	17.78
27	Ondunduwazarapi	354	1,654	31	454	412	9.6	39.4	28.8	-21.67	17.83
28	Hochveld	361	1,567	17	391	362	7.9	33.2	26.3	-21.48	17.87
29	Steinhausen	390	1,652	20	413	379	8.6	41.1	28.6	-21.82	18.25
30	Kalidona	390	1,522	27	364	331	9.4	31.8	20.5	-21.28	18.07
31	Witvlei	402	1,460	21	311	308	0.7	53.6	28.6	-22.42	18.48
32	Du Plessis	470	1,504	11	372	367	1.3	42.0	26.3	-21.70	19.03
33	Sandveld	475	1,521	16 (7)	298	359	18.6	47.4	29.7	-22.02	19.15

** Numbers in brackets indicate the number of rainfall seasons out of the total that were obtained from SASSCAL stations. All other season totals are from Namibia Meteorological Services.*

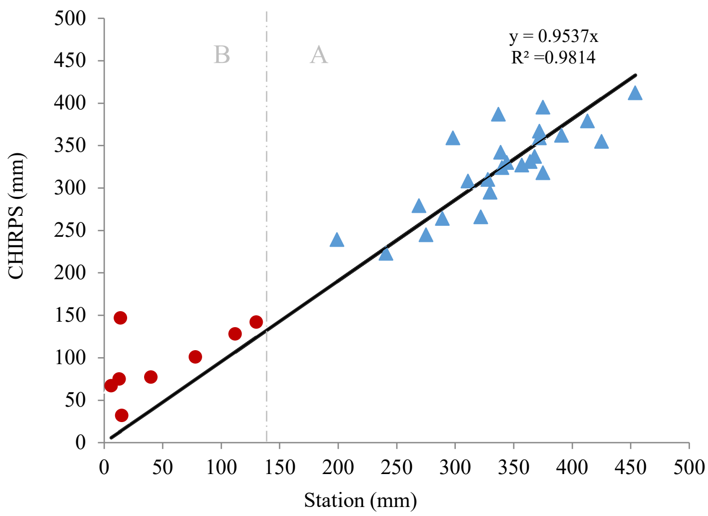

Figure 5: *Regression of average annual seasonal rainfall (CHIRPS) on measured rainfall for 33 stations in Namibia. Blue triangles indicate stations in zone A between 140 and 475 km from the coast. Red circles are stations in zone B between 0 and 140 km from the coast.*

that estimates from approximately 140 km inland to the furthest station east (475 km from the coast; hereafter referred to as zone A) are relatively evenly scattered above and below the line. By contrast, all 8 estimates west of 140 km inland (i.e. between 140 and 0 km from the coast, and referred to as zone B) were above the predicted line.

Expressing the difference between measured average seasonal rainfall and CHIRPS average estimates as a percentage may exaggerate the trend because regardless of which dataset is used average seasonal rainfall totals in the coastal zone are very low. However, what is apparent is the increasing divergence between the CHIRPS estimates and measured rainfall towards the coast (Figure 6a). In zone A, the difference between measured average seasonal rainfall and CHIRPS average estimates was less than 20%. However, in zone B, the percentage difference between the two values increased towards the coast to greater than 160%. At the national scale, the divergence of average rainfall estimates west of the escarpment between the two datasets results in a much higher percentage difference in this part of the country than elsewhere. The high values in the coastal zone in the southern part of the country arise from the fact that CHIRPS estimates in the eastern half of the sand sea are lower than station rainfall averages. Here (and in northern coastal parts of the country) both datasets are compromised by a lack of ground-based gauges (see Figure 3), referred to later in the Discussion.

Overall, there was a negative correlation between measured rainfall variability and distance from the coast ($r = -0.7$, $r^2 = 0.48$) but a weak positive correlation between rainfall variability and distance for CHIRPS rainfall estimates ($r = 0.51$, $r^2 = 0.26$).

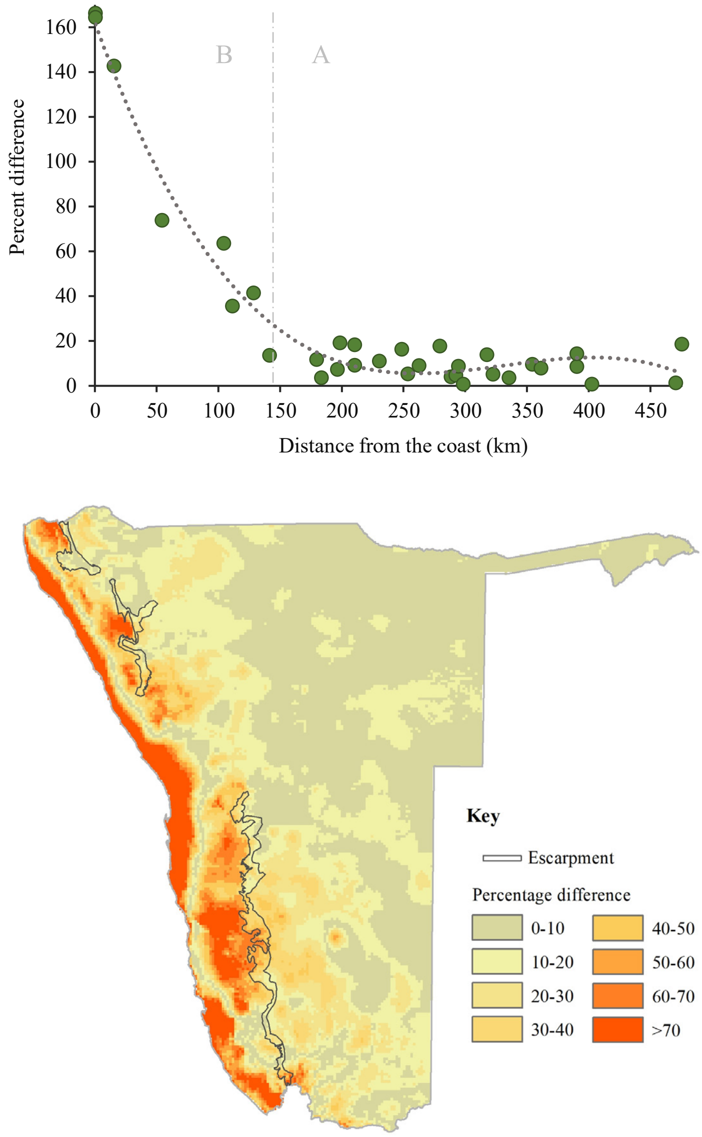

***Figure 6:** a) Percent difference between weather station average seasonal rainfall values and CHIRPS average seasonal rainfall estimates for 33 stations in Namibia (points) with a polynomial trend line (dotted line); b) . Percent difference between weather station average seasonal rainfall values (Figure 2) and CHIRPS average seasonal rainfall estimates (Figure 4b) across Namibia.*

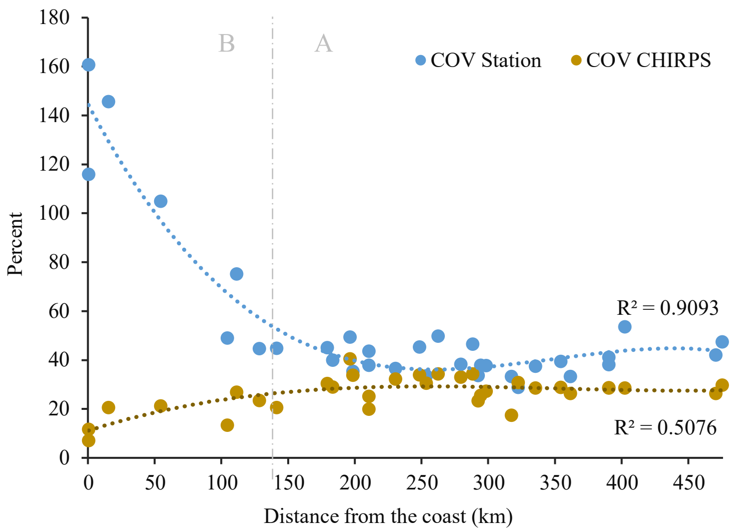

***Figure 7:** Coefficient of variation for station rainfall measurements (blue circles) versus CHIRPS rainfall estimates (gold circles) for 33 stations in Namibia with a polynomial trend line fitted to each.*

In zone A (Figure 7) rainfall variability was fairly moderate, with the COV for stations falling within a range of 29-54% while CHIRPS values were lower and within the range of 17-40%. In zone B (Figure 7) the percentage COV values diverged markedly between the two datasets. Variability of rainfall for station measurements showed a continual increase rising from 45% to 160%. In contrast, variability in CHIRPS estimates showed a gradual decrease from around 20% to 10% with increasing proximity to the coast.

Discussion

The results found here mirror those found elsewhere in an area adjacent to a cold ocean (Aybar *et al*. 2019) and in eastern Africa and Mozambique. Toté *et al*. (2015) in their multi-product comparison, found that the relationship between CHIRPS and measured values was best in the higher rainfall central areas of Mozambique, but performance declined with proximity to the coast due to an overestimation of the frequency of rainfall events. Masauso (2018) found similar performance patterns comparing CHIRPS with other products, from a three-rainfall year analysis in Namibia.

In eastern Africa Dinku *et al*. (2018) found that in low rainfall locations the overestimation of rainfall area resulted in low CHIRPS rainfall estimates where ground-based products recorded zero rainfall. This was identified as the 'drizzle' effect. In the derivation of CHIRPS estimates, merging of ground-based data with satellite-based estimates is done at the pentad (5-day) time scale. Monthly values are derived from the sum of pentads while daily values are derived from partitioning the pentad values according to cold cloud duration (which discriminates between rain and no-rain events) (Dinku *et al*. 2018). Consequently, CHIRPS daily estimates tend to be much better aligned with actual rainfall events. However, monthly (and annual) rainfall total estimates remain inflated in low rainfall areas. In a simple test I chose an arbitrary rainfall season for Gobabeb (situated about 50 kilometers from the coast) and compared CHIRPS pentad estimates with rain gauge records. Very low rainfall estimates were recorded in the vast majority of pentads when there were only a handful of actual rainfall events recorded at Gobabeb in that season. This has the effect of moderating differences between seasonal estimates, resulting in reduced variability.

Precipitation - by definition - excludes fog because this is moisture that remains in the air. No mention is made directly of the influence of fog in the CHIRPS analysis. However, Dinku *et al*. (2018) suggest that 'satellites could overestimate rainfall over desert areas owing to sub-cloud evaporation'. In other words, estimates close to the coast might also be inflated as a result of satellite measurements that include moisture in the air that does not reach the ground. Fog and low cloud occur frequently in Namibia's coastal zone extending as far east as the escarpment, the distance at which we start to see a divergence between the two datasets (Figure 8). Fog also occurs more frequently nearer the coast, and this might explain to some degree the decline in variability and the rise in CHIRPS rainfall estimates from 50 km inland to the coast. Compare average seasonal rainfall in the coastal zone from CHIRPS estimates (Figure 4b) with ground-based measurements in the same area (Figure 2).

How does the divergence between measured rainfall and CHIRPS rainfall estimates near the coast influence the integrity of CHIRPS data as a proxy for rainfall? The two maps of coefficient of variation presented in Figure 9 demonstrate the contrast in the way that rainfall patterns might be interpreted, depending on the dataset used. Seasonal variability from measured rainfall (derived from around 300 stations indicated in Figure 3) shows highest variability in the coastal zone and southern interior (Figure 9a) in contrast to CHIRPS which suggests the escarpment zone has the highest rainfall variability with the lowest variability along the coast and to the south (Figure 9b). It is important to note that both analyses are to some extent compromised by the paucity of coastal rainfall stations. As CHIRPS is a blended dataset, the dearth of coastal stations limits the extent to which measured records can moderate the satellite-based estimates in this part of the country.

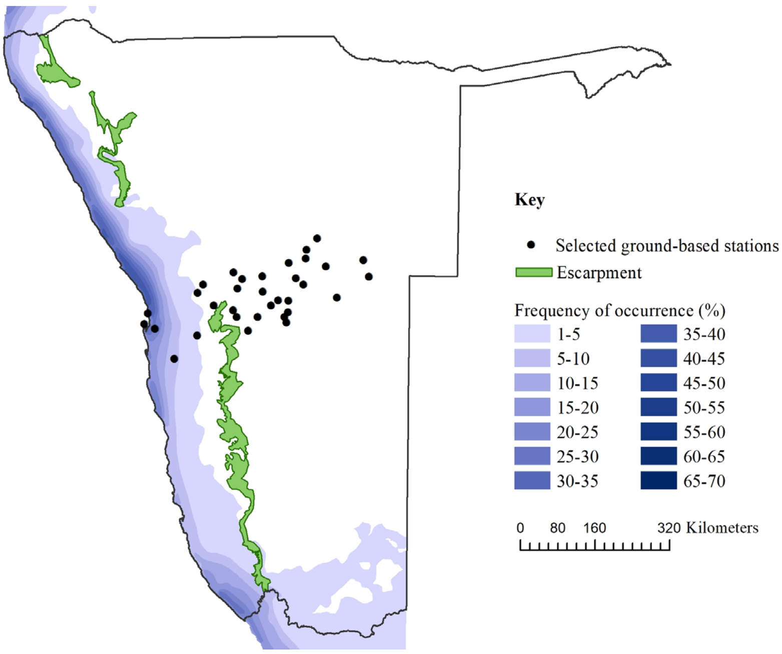

Figure 8: *The frequency of occurrence of fog and low cloud from 96 daily satellite scans in Namibia (between 2004 and 2017) in the context of the 33 selected ground-based weather stations used in this study. Data on fog from Andersen* et al. *(2019).*

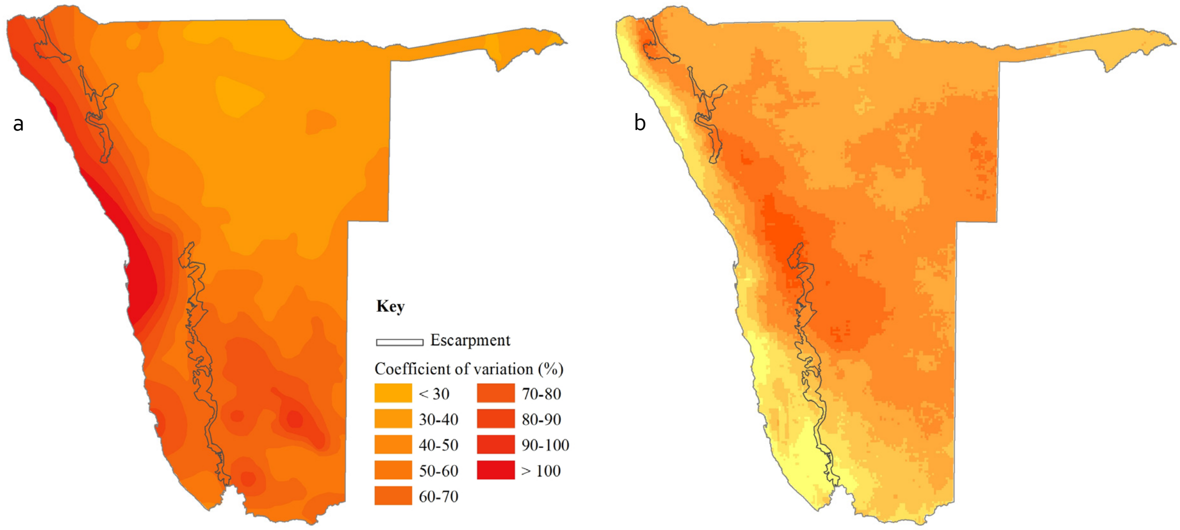

Figure 9. *Coefficient of variation interpolation from a) approximately 300 rainfall stations throughout Namibia, from Namibia Resource Consultants (1999) and b) CHIRPS rainfall estimates (1981-2020) downloaded from the FEWS NET data portal.*

Dinku et al. (2018) suggest that the future CHIRPS algorithm may incorporate a two-stage process at the blending stage, where initially, a rainfall probability factor is applied prior to any rainfall intensity adjustments. However, this would require the availability of an adequate selection of ground station records.

The consistent and increasing difference between the two datasets for all eight stations in zone B (Figures 5, 6 and 7) suggests that the divergence between the two datasets is not the consequence of a few aberrant ground stations. The results shown here, in combination with similar findings from other studies, point to the lack of suitability of the current CHIRPS dataset on its own for any rainfall-associated analyses west of the escarpment. Some effort should be put into addressing the paucity of ground-based station gauges in the coastal zone. This would allow for more accurate spatial analyses to be made of measured rainfall variability in the western parts of the country in addition to providing a means for future versions of the CHIRPS dataset and other blended satellite-based datasets to be more calibrated and aligned with measured rainfall.

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References

Atlas of Namibia Team (2022) *Atlas of Namibia: its land, water and life*. Namibia Nature Foundation, Windhoek.

Andersen H, Cermak J, Solodovnik I, Lelli L, Vogt R (2019) Spatiotemporal dynamics of fog and low clouds in the Namib unveiled with ground- and space-based observations. *Atmospheric chemistry and physics* 19: 4383–4392.

Aybar C, Fernández C, Huerta A, Lavado W, Vega F, Felipe-Obando O (2019) Construction of a high-resolution gridded rainfall dataset for Peru from 1981 to the present day. *Hydrological Sciences Journal* 65(5).

Dinku T, Funk C, Peterson P, Maidment R, Tadesse T, Gadain H, Ceccato P (2018) Validation of the CHIRPS satellite rainfall estimates over eastern Africa. *Quarterly Journal of the Royal Meteorological Society* 144(51).

ESRI (2013). *ArcGIS Desktop: Release 10*. Environmental Systems Research Institute, Redlands, CA.

Funk C, Peterson P, Landsfeld M, Pedreros D, Verdin J, Shukla S, Michaelsen J (2015) The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific Data* 2:150066.

Masauso S (2018). *Validation of satellite derived rainfall products over a Namibian rainfall gradient*. Master of Geoinformation Science and Earth Observation, Namibia University of Science and Technology, Windhoek.

Mendelsohn J, Jarvis A, Roberts C, Robertson T (2002) *Atlas of Namibia: a portrait of the land and its people*. David Philip Publisher, Cape Town.

Namibia Resource Consultants (1999). *Rainfall distribution in Namibia: Data analysis and mapping of spatial, temporal, and Southern Oscillation Index aspects*. Windhoek: Ministry of Agriculture, Water and Rural Development.

Toté C, Patricio D, Boogaard H, van der Wijngaart R, Tarnavsky E, Funk C (2015) Evaluation of Satellite Rainfall Estimates for Drought and Flood Monitoring in Mozambique. Remote Sensing 7(2): 1758–1776.