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Research paper

Can CHIRPS fill the gap left by the decline in the availability of rainfall stations in Southern Africa?

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Rainfall is the most important input to any hydrological or water resources study. The decline in the number of suitable rainfall stations since the 1970s is a cause for concern, plus there is an additional complication in that – for a number of catchments – mean annual precipitation (MAP), as derived from a recent study by Pegram, differs substantially from those adopted by the Water Resources of South Africa, 2012 study (WR2012) (mostly as derived by Dent). Rainfall data sourced by the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) satellite database was selected as a basis for comparison, both for catchment MAP and time series of monthly rainfall as used for input to the Pitman hydrological model (WRSM/Pitman, previously called WRSM2000). The analyses revealed that the WR2012 method of constructing the time series yielded the best results overall, but the difference was not marked, except in the winter rainfall region, where CHIRPS (and to a lesser extent, Pegram) performed poorly. It is concluded that CHIRPS will have a role to play in future water resources studies. It is recommended that the study be extended to cover a larger sample of catchments with up-to-date rainfall and that the possibility of CHIRPS data being recalibrated for the winter rainfall area be investigated.

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INTRODUCTION

Rainfall data is by far the most important input to any hydrological or water resources study. Particularly in the case of streamflow modelling, it is essential that the rainfall input should be as spatially and temporally representative as possible. Traditionally, reliance was based on the averaging of a selected number of rainfall records distributed over the area of interest (i.e. catchment). In South Africa, however, the number of rainfall stations in operation has seen a steady decline since about 1970 (Pitman, 2011). Figure 1 reveals how the number of gauges suitable for water resources analysis had declined up to 2009. Continuation of this graph up to the present could well show a further decline over the intervening 10 years. Furthermore, in most mountainous and remote areas the density of rain gauges has seldom been adequate to determine either mean catchment rainfall or time series of monthly (or daily) rainfall with any degree of reliability.

The first project to map digitally the variation in mean annual precipitation (MAP) over South Africa was by Dent et al. (1989). MAP was determined at a level of 1 minute of arc and this information was used in the Surface Water Resources of South Africa (WR90) study (Midgley et al., 1994) and subsequent studies – Water Resources of South Africa, 2005 Study (WR2005) (Middleton and Bailey, 2009) and WR2012 (Bailey and Pitman, 2016). In 2016 Pegram and Sinclair (2016) completed a similar study to that of Dent. For about 70% of the quaternary catchments the differences were less than 10% between the two studies, but there were marked differences in some areas – particularly in certain mountainous and remote areas. Both studies used MAPs of individual stations and interpolation among the stations using attributes such as altitude, aspect, etc.

It stands to reason that, the further apart the stations are, the less reliable will be the interpolations, especially in mountainous areas.

Recently, new resources of satellite observations like gridded satellite-based precipitation estimates from NASA and NOAA have been leveraged to build high resolution (0.05°) gridded precipitation (https://www.chc.ucsb.edu/data/chirps). When applied to satellite-based precipitation fields, these improved climatologies can remove systematic bias – a key technique in the production of the 1981 to near-present (CHIRPS) dataset. It is the purpose of this paper to investigate the suitability of CHIRPS rainfall data for hydrological applications in South Africa, bearing in mind the declining number of suitable rainfall records.

METHOD

This study took a three-pronged approach, namely:

1. Ascertain differences in MAP and time series of monthly rainfall between CHIRPS and station averages in areas where topographical influences are minimal and up to date observations of rainfall are readily available. (The Kruger National Park was selected for this study.)
2. Ascertain differences in MAP among CHIRPS, Dent (as generally used in WR2012) and Pegram in catchments where the largest discrepancies between Dent and Pegram occur.
3. Undertake calibrations of the WRSM/Pitman model for the above catchments using monthly rainfall time series derived from Pegram and CHIRPS data and compare them with the original

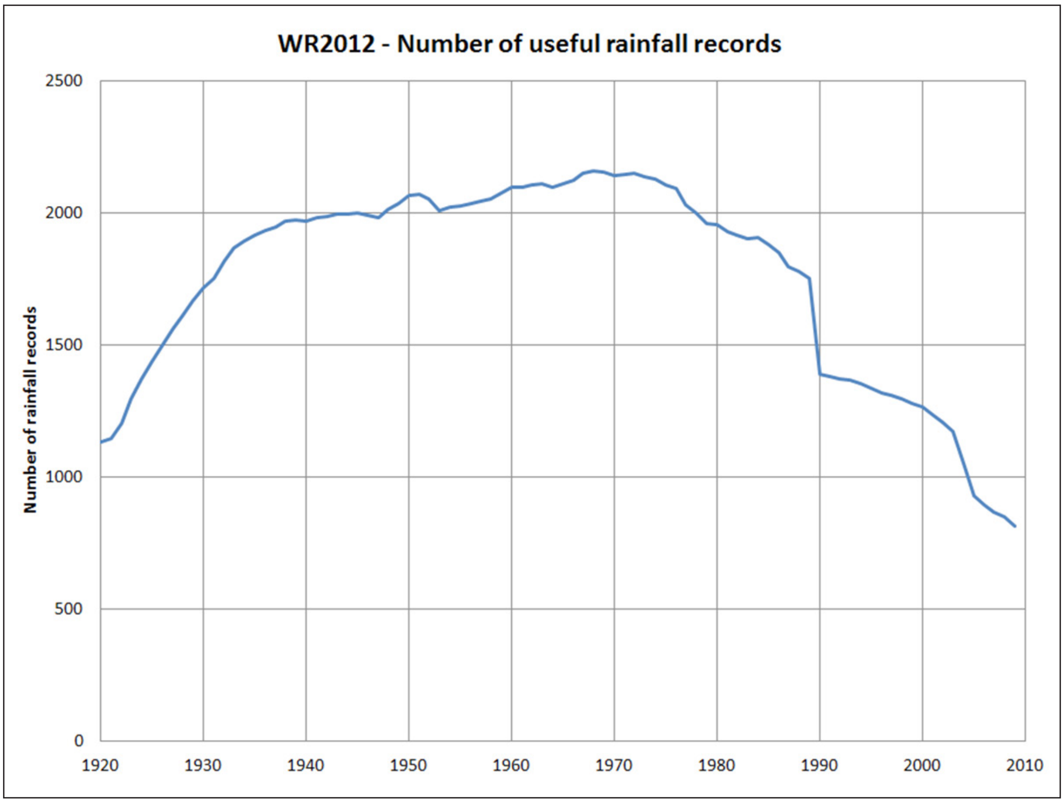

Figure 1. Decline in number of useful rainfall records in South Africa, Lesotho and Swaziland since the 1970s (Pitman, 2011)

calibrations undertaken in the WR2012 study. (Calibration involves a comparison between observed and simulated streamflow and subsequent adjustment of model parameters to achieve the closest fit.) Note that Pegram uses only a different MAP (i.e. the monthly time series expressed as %MAP was the same as for WR2012), whereas the CHIRPS data provided a completely different time series.

It should be stated at the outset that the focus of this study is on rainfall over a defined area – not on point rainfall. The 'pixel' size of CHIRPS (0.05 x 0.05 degrees) is approximately 5 x 5 km. Even within such a relatively small area the variation of point rainfall can be quite considerable.

The study culminates with recommendations for further research on the applicability of CHIRPS data for use in hydrological and water resources studies in South Africa, Lesotho and Swaziland.

BACKGROUND

As already mentioned, derivation of the spatial and temporal distribution of rainfall constitutes the most important input to any hydrological or water resources study.

Spatial distribution of rainfall

The first digital map of MAP of South Africa was produced by Dent et al. (1989), which was based on a spatial resolution of 1 minute of arc (slightly less than 2 km x 2 km). This study came at the right time for the Water Resources 1990 (WR90) study (Midgley et al., 1994), which adopted recently developed geographic information systems (GIS) for mapping purposes. By overlaying the coverage of the study's quaternary catchments with the digital map of MAP, it was possible to compute the average catchment MAP for each quaternary.

These quaternary MAPs were found to be eminently satisfactory for the stage where the model WRSM/Pitman (Bailey and Pitman, 2016), or WRSM90 as it was called then (Pitman and Kakebeeke, 1991), was used to simulate monthly streamflows. WRSM/Pitman is a modular water resources simulation program that runs under Windows on a monthly time step. The program features five different Module-types: Runoff, Channel, Irrigation, Reservoir and Mining. Each of these Modules contains one or more methodologies that simulate a particular hydrological aspect and are linked to one another by means of Routes. Multiple instances of the different Modules, together with the Routes, form a Network to represent virtually any real-world hydrological system. The WRSM/Pitman model has been used extensively throughout South Africa, Lesotho, Swaziland and other countries in Africa for over 4 decades.

The only major exception was in the Lesotho Highlands where the MAPs of Dent's map were found to be too low to generate realistic streamflows. Accordingly, the rainfall map lifted from the Lesotho Highlands Feasibility Study (Lahmeyer et al., 1986) was adopted for this area. There were also a couple of quaternary catchments in the Western Cape mountains where it was necessary to increase MAP to reconcile them with observed streamflows.

When the subsequent Water Resources 2005 (WR2005) study (Middleton and Bailey, 2008) was undertaken, the team undertaking the analyses in the Western Cape found it necessary to increase some additional quaternary catchment MAPs to reconcile them with observed streamflows.

In summary, it can be stated that MAPs from Dent's map were deemed to be satisfactory for all areas apart from the mountainous areas of Lesotho and the Western Cape.

In the most recent Water Resources 2012 (WR2012) study (Bailey and Pitman, 2016), the MAP values adopted for the WR2005 study were retained. About the time that WR2012 went to print, Pegram produced a new digital map of MAP (Pegram and Sinclair, 2016). It was based on the same premise as Dent's, of interpolation among all suitable rainfall station MAPs, using such attributes as altitude, aspect, etc., but applying different complex algorithms.

Pegram undertook an analysis to assess the differences between his and Dent's MAPs. It was found that, for about 70% of the quaternaries, the difference in MAP was less than 10%, but there were some marked differences in some catchments – particularly in certain mountainous and remote areas. Figure 2 shows the differences between the two studies on a quaternary catchment basis (Pegram and Sinclair, 2016). (Although the title on the diagram refers to WR2012, all the MAPs are as derived by Dent.)

Since 1999, USGS and CHC scientists – supported by funding from USAID, NASA, and NOAA – have developed techniques for producing rainfall maps, especially in areas where surface data is sparse. Early research focused on combining models of terrain-induced precipitation enhancement with interpolated station data (as per the Dent and Pegram studies). More recently, new resources of satellite observations like gridded satellite-based precipitation estimates from NASA and NOAA have been leveraged to build high-resolution (0.05°, or about 5 km x 5 km) gridded precipitation. When applied to satellite-based precipitation fields, these improved climatologies can remove systematic bias – a key technique in the production of the 1981 to near-present Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) data. This is a website (ClimateSERV, 2020) system of daily and monthly satellite-based gridded rainfall developed by Climate Hazards Group SC Santa Barbara in the USA (https://www.chc.ucsb.edu/data/chirps).

It was considered that this CHIRPS dataset may help to throw some light on the differences between Pegram and Dent data and provide a suitable alternative in areas where rainfall stations are sparsely distributed.

Temporal distribution of rainfall

Time series of monthly rainfall for the catchment being analysed constitute the primary input to the WRSM/Pitman model. The procedure used in the construction of a time series has remained the same for the WR90, WR2005 and WR2012 studies and can be summarized below.

- Divide the whole study area into a number of 'rainfall zones', each comprising a small group of quaternary catchments and covering an area where rainfall characteristics are assumed to be similar. (Ideally, it would have been preferable for each quaternary to be a zone, but the coverage of rain gauges is generally too sparse).
- For each zone select a number of rainfall stations, while attempting to maintain a reasonably even spread over the zone (i.e. not all clustered in one corner).
- Express monthly rainfalls as percentage of station MAP and determine the average percentage for each month of the time series.
- Dimensionalise the rainfall by applying catchment MAP. (This is done in the WRSM/Pitman model prior to simulation.)

One shortcoming of this method is that there may be a quaternary within the zone that does not have a single station within, but this is something one has to accept due to the lack of station coverage in some areas.

The method to determine a monthly time series via CHIRPS is quite different to that based on individual stations. On opening the webpage one can choose to draw a polygon describing the area of interest (e.g. catchment). After focusing on the area, one zooms in as far as possible and describes the area by drawing a polygon or importing a GeoJson file (Butler et al., 2016). Then one selects the time period to be analysed and, after some time, the graph of daily rainfall appears. The final step is to select a CSV Excel file which can be saved and manipulated to produce a monthly time series of rainfall (in addition to the MAP).

The advantage of using CHIRPS is that it is free and right up to date (April 2020 at the time of writing).

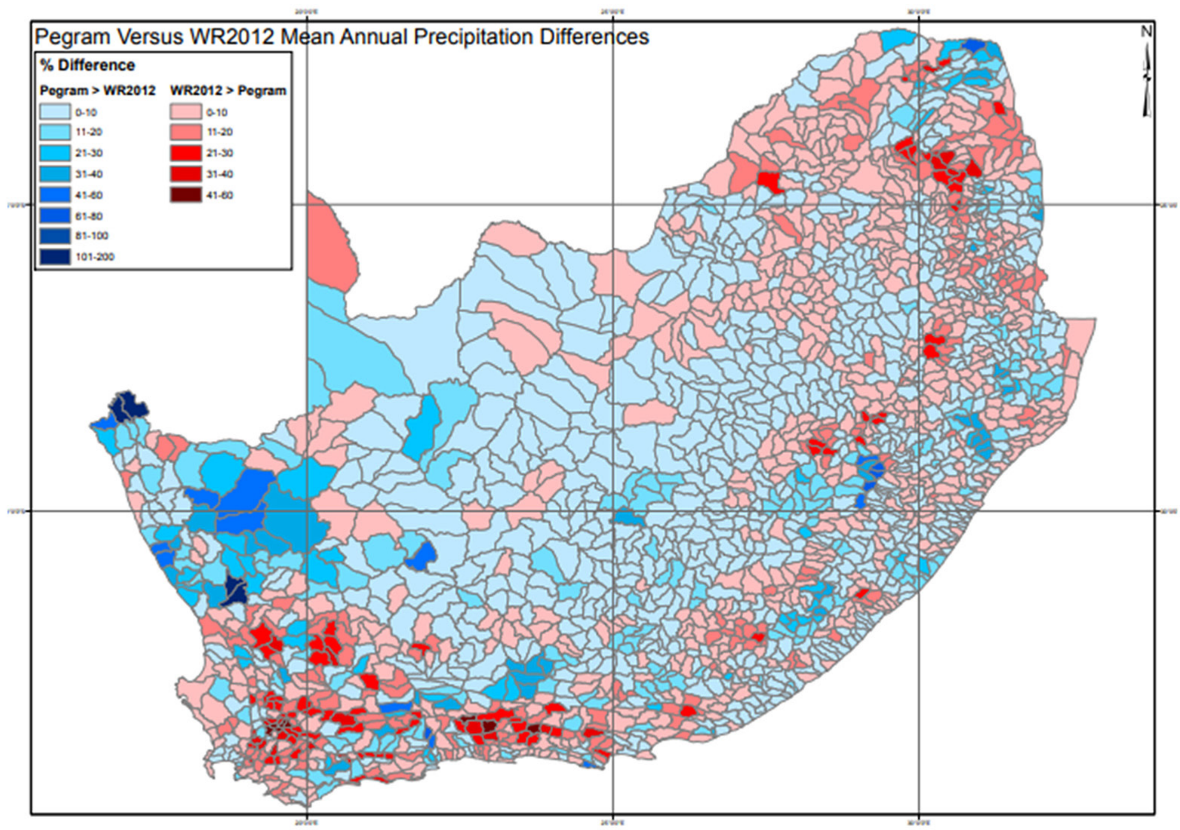

Figure 2. Differences between Pegram and Dent MAP by quaternary catchment

RESULTS

Comparison between CHIRPS and average station rainfall for the Kruger National Park

The Kruger National Park (KNP) was selected for this analysis because (i) it is a relatively flat area where orographic effects are likely to be minimal, and (ii) up-to-date information is readily available for the rainfall stations situated within the KNP in the form of monthly records.

For the purposes of this analysis, the KNP was sub-divided into three zones, namely North (i.e. north of the Letaba River), Central (i.e. between the Letaba and Sabie Rivers) and South (i.e. south of the Sabie River). Of the 23 rainfall stations in the KNP, 8 are situated in the North and Central zones and 7 are situated in the South zone, thus giving a fairly even spread of gauges across the KNP.

Comparison of MAP for each zone

The first step in the determination of MAP for the three zones using WR2012 and Pegram MAPs was to overlay each zone on the relevant quaternary catchment map provided by the WR2012 study. Each quaternary (or portion thereof) was noted and the area-weighted MAP for each zone was then calculated. (If a portion of a quaternary lay within a zone, only the area of that portion was used in the weighting process.)

The MAPs as derived by this procedure were then compared with zonal MAPs based on the CHIRPS data and a straight average of station MAPs for those stations situated in each zone. (Weighting via Thiessen Polygons was also tried but the differences between this method and straight averaging were found to be minimal.) It should be stressed that the CHIRPS MAPs are based on the period 1981 to 2018 (hydrological years), whereas the Dent and Pegram studies were based on records considered long enough to yield a reliable estimate of MAP. The KNP records were also of different length, varying from about 30 to 80 years in length, which should be adequate to determine reliable estimates of MAP.

The results of the analysis are summarized in Table 1.

For the KNP as a whole, the CHIRPS MAP is seen to be about 10% lower than the estimates from the other three sources, although the main discrepancy is to be found in the North zone. The greatest difference between Pegram MAP and the station average also occurs in this zone, but Pegram is somewhat higher, whereas the CHIRPS MAP is lower. The agreement among all sources for the Central and South zones is quite reasonable. There has been a great deal of checking and verification of rainfall and streamflow data in the various water resources studies leading up to WR2012. As can be seen by inspection of Table 2, it has been necessary to amend Dent's MAP values in some quaternary catchments. However, no such adjustments were found to be necessary for the catchments covered by the Kruger National Park.

Comparison between CHIRPS and station average for rainfall time series

As explained in the introduction, CHIRPS provides daily rainfall data from 1981 to date. These data were aggregated into monthly records for the purpose of comparison with the station records. However, a graph of (456) monthly values for the 38-year period (1981 to 2018 hydro years) would be difficult to interpret, hence annual values have been plotted for comparison. Figures 3, 4 and 5 respectively show the comparison of annual rainfall for the North, Central and South zones. Also shown is the range of values obtained from the individual records.

For all three zones the pattern of the CHIRPS rainfall follows that of the station average quite closely and falls within the range of observed rainfall, except for very few instances.

It may be concluded from this analysis that CHIRPS gives a fairly reliable estimate of rainfall over an area, when compared with data from a group of rainfall stations.

Analysis of selected quaternary catchments

For the last three water resources studies, South Africa, Lesotho and Swaziland have been sub-divided into 1 956 quaternary catchments. It is beyond the scope of this exploratory study to analyse all the catchments, hence a selection was made based on the following two criteria, namely:

- Where there was a significant difference between the Dent and Pegram MAPs.
- Where there was a streamflow gauge situated either within or at the outlet of the catchment (so that the calibration on observed streamflow could be checked).

In some instances a group of quaternaries was selected as dictated by the situation of a suitable streamflow gauge. In all, 29 quaternaries (or groups) were selected for the analysis.

Comparison of catchment MAP and rainfall time series

Table 2 was drawn up showing the catchment MAPs from 4 sources, namely Dent, WR2012 (i.e. Dent as modified for some catchments), Pegram and CHIRPS. It should be re-iterated that CHIRPS MAPs are for the period 1981 to 2019, whereas the other MAPs do not relate to any specific time period. A quick perusal of the table reveals a relatively large proportion of catchments are in the Breede Catchment (Drainage Region H). This is due to the disproportionate number of quaternaries that show a large difference between Dent and Pegram, and also have suitable streamflow gauges. However, an attempt was made to select catchments in other areas, even though the Dent–Pegram differences were not so great.

A quick perusal of the MAPs in Table 2 shows the WR2012 MAPs to be generally the highest, followed by Pegram, then CHIRPS.

Table 1. Comparison of MAP for KNP

KNP zone	MAP derived from the different sources (mm)			
	WR2012* (1920–2009)	Pegram (various to 2010)	CHIRPS (1981–2020)	Station average (from 30 to 80 years)
North	504	512	416	470
Central	526	508	494	487
South	594	625	595	624
Total KNP	529	530	480	523

*Note * for the whole area of the KNP, the WR2012 MAPs are identical to those of Dent*

Table 2. Comparison of catchment MAP

Catchment	Dent	WR2012	Pegram	CHIRPS
A80A,B,C	726	726	610	743
B72F	934	934	696	840
B90B	470	470	628	419
C81C	730	730	555	808
D16D-H	671	**895***	964	841
D17A,B	709	**1 000***	867	772
D17J,K	616	**796***	768	764
G10B	1 245	**1 306***	876	540
H10K	1 225	1 225	822	474
H20A	357	357	300	204
H20B	590	590	325	267
H20C	643	643	478	373
H20D	696	**967***	418	331
H20E	906	906	411	404
H20F	797	797	358	320
H20G	680	680	299	383
H20H	300	300	279	291
H30C	480	480	350	260
H40K	406	406	300	333
H60A	1 895	**2 141***	1 333	579
H80A	597	597	438	519
H90A	645	645	459	449
H90B	664	664	499	463
J33A	393	393	192	365
J33C,D	325	325	265	346
K10C,D	473	473	598	415
T40A,B,C	934	934	1 038	817
X14F	1 257	1 257	1 038	1 218
X23C,D	905	905	1 078	866

*Note * Highlighted values denote changes to Dent MAP by WR90 and WR2005 studies*

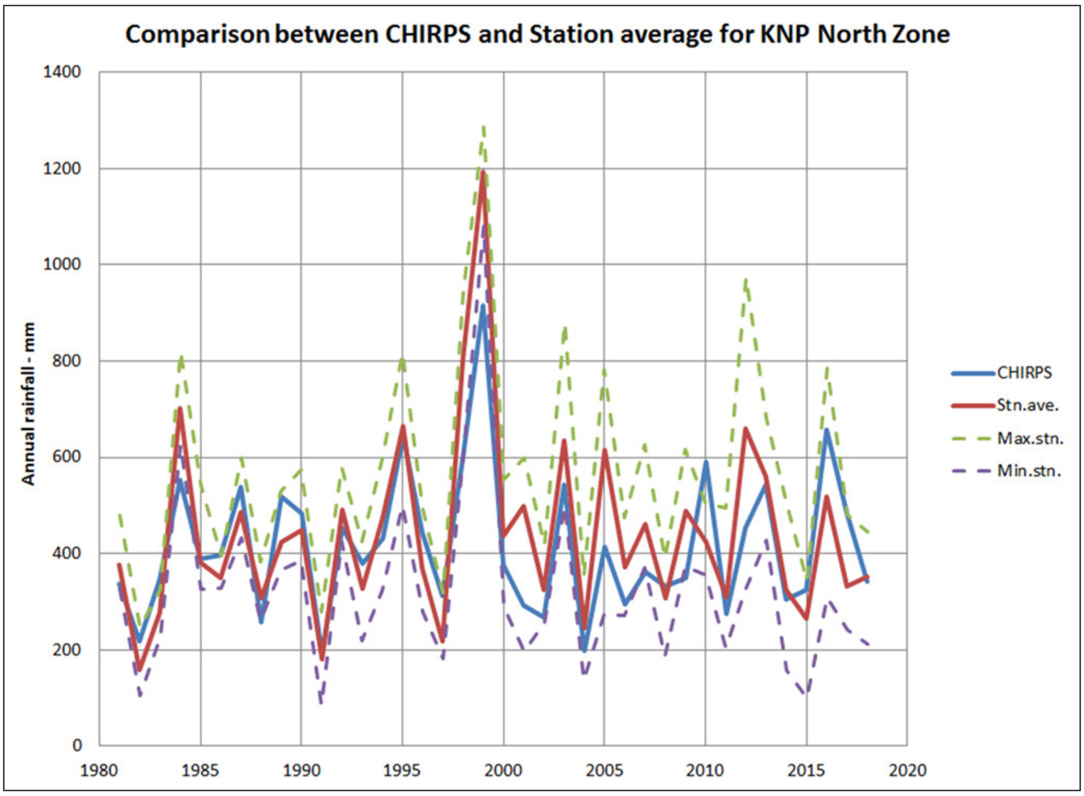

Figure 3. Comparison between CHIRPS and station average for KNP North zone

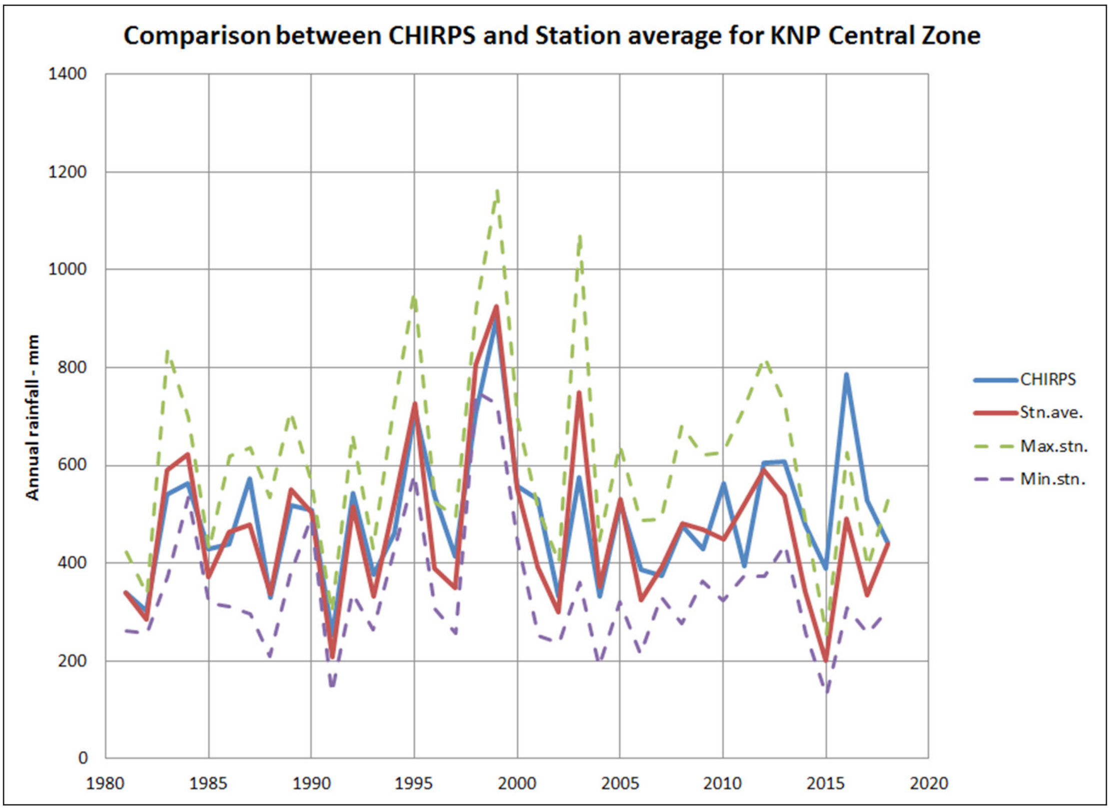

Figure 4. Comparison between CHIRPS and station average for KNP Central zone

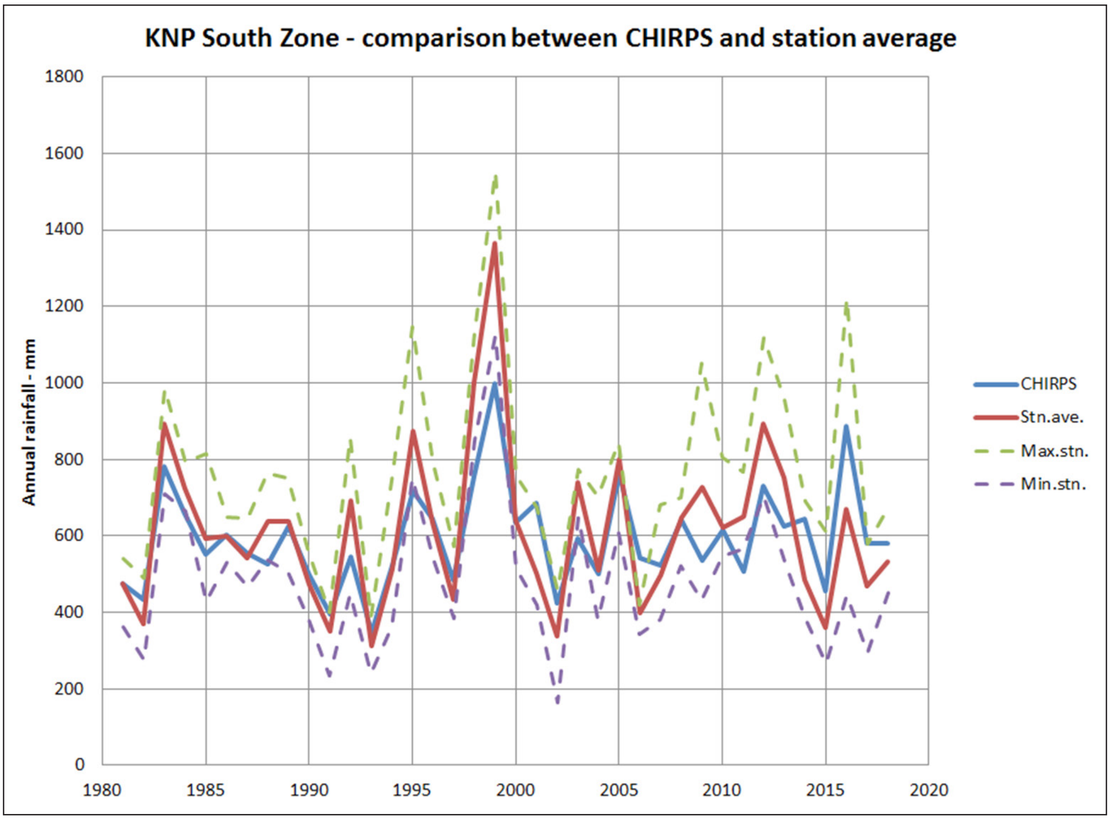

Figure 5. Comparison between CHIRPS and station average for KNP South zone

For all the catchments, the average ratio of Pegram/WR2012 is 0.77, while that for CHIRPS/WR2012 is 0.68. However, if one looks only at the winter rainfall zone (Drainage Regions G and H), the ratios are respectively 0.63 and 0.49. For the remainder of the catchments the ratios are respectively 0.95 and 0.94, i.e., quite close to unity.

One may conclude from this that, apart from the winter rainfall zone, there is a relatively good agreement among WR2012, Pegram and CHIRPS in the determination of catchment MAP. However, it remains to be seen which (if any) is likely to be the most reliable; it is for this purpose that the relevant streamflow gauges have been selected for calibration.

For each catchment the time series of annual rainfall were plotted, mainly to observe how the CHIRPS data compared with the other two sources. (The only difference between WR2012 and Pegram is due to different MAPs, as they both employ the same time series expressed as percentages of MAP). Figure 6 shows an example where there is close agreement between CHIRPS and WR2012, while Fig. 7 shows a typical catchment in Drainage Region H, where all three often differ considerably.

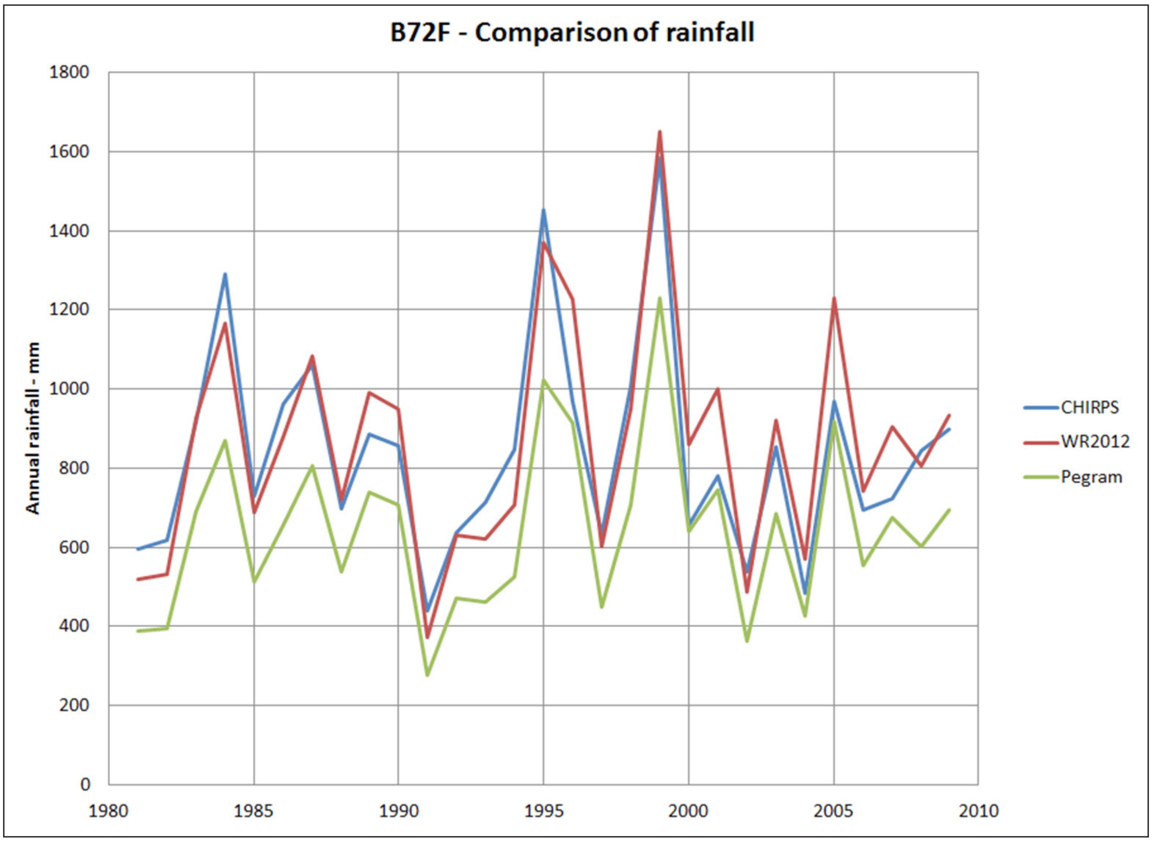

Figure 6. Comparison of annual rainfall on quaternary catchment B72F

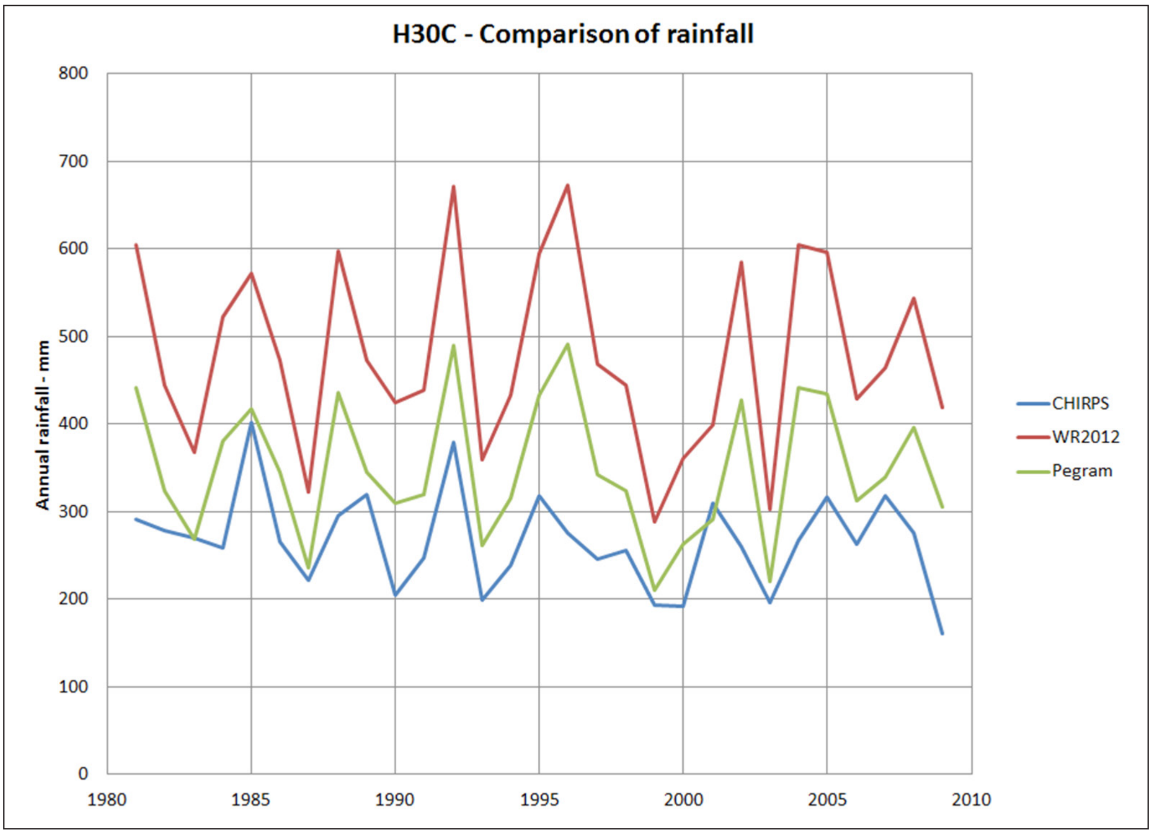

Figure 7. Comparison of rainfall on quaternary catchment H30C

Comparison of model calibrations on selected streamflow records

Table 3 lists the selected streamflow gauges, together with their associated quaternary catchments. For each gauge the calibration achieved in the WR2012 study was compared with calibrations of the WRSM/Pitman model using the monthly rainfall time series derived from the Pegram MAP and that derived from the CHIRPS data. This involved the change of certain model parameters in most cases in order to arrive at a satisfactory calibration with the different rainfall input. For each gauge, the calibrations were rated from 'best' (3 points) to 'worst' (1 point), with the intermediate one allotted a score of 2. However, in some cases it was not possible to achieve a satisfactory calibration; this occurred when the MAP was too low to generate sufficient runoff. In extreme cases the MAP was lower than the mean annual runoff (MAR) at a gauge when expressed as a unit runoff in mm. In such cases a score of zero was allocated. Scoring of the calibrations was somewhat subjective and was largely based on how well the statistics of the simulated time series matched those of the observed record and which annual time series matched the observed flows more closely. (It should be pointed out that, as the CHIRPS data starts in 1981, all calibrations were confined to the period 1981 to 2009.)

For the full set of streamflow gauges the average scores for WR2012, Pegram and CHIRPS were respectively 2.5, 1.8 and 1.3. This result is to be expected as some of the WR2012 MAPs were adjusted from the original Dent values on the basis of recorded runoff. If one omits the winter rainfall (G and H) catchments the ratios are respectively 2.3, 1.9 and 1.7. One may draw a number of conclusions from this analysis, namely:

- The rainfall time series used in the WR2012 study can be assumed to be the most representative for streamflow modelling purposes.
- The construction of time series based on the averaging of a suitable group of rainfall station records appears to be more reliable when compared with CHIRPS (at least for the period ending in 2009).
- CHIRPS, and to a lesser extent Pegram, underestimates rainfall in nearly all catchments in the winter rainfall region.

The first two comments refer to the period leading up to 2009; the situation could well change when looking at the situation as it stands today.

SUMMARY

Growing concern regarding both the decline in the number of suitable rainfall records and the (sometimes large) discrepancies between the WR2012 (derived from Dent but modified in some areas) and Pegram values for MAP, prompted the authors of this paper to investigate the possibility of using satellite data for estimating the spatial and temporal variation of rainfall across the country. To this end, the CHIRPS dataset was selected for the purposes of comparing the MAP and rainfall time series

Table 3. Selected streamflow gauges and the scoring of model calibrations

Gauge	Area (km^2)	MAR ($10^6 m^3$)	MAR (mm)	Calibration score		
				WR2012	Pegram	CHIRPS
A8R001	842	69.60	83	2	3	1
B7H014	83	8.38	101	1	2	3
B9H004	754	24.34	32	2	3	1
C8H010	250	20.91	84	3	1	2
G1R002	86	71.08	827	3	0	0
H2H001	697	93.11	134	3	2	1
H2H003	466	79.05	170	3	2	1
H2H004	175	39.46	225	3	2	1
H2H006	466	100.00	215	2	3	1
H2R001	139	17.62	127	3	2	1
H2R002	80	6.81	85	2	3	1
H3R002	116	0.86	7	1	3	2
H4H015	94	6.14	65	1	2	3
H4H016	117	5.87	50	2	3	1
H4R003	54	1.81	34	3	1	2
H6H008	38	27.95	1 618	3	0	0
H8R001	148	27.95	189	3	2	1
H9H004	50	14.41	288	3	0	0
H9R001	37	10.51	284	3	0	0
J3H012	688	15.24	22	3	1	2
J3H016	32	1.29	40	3	0	2
K1H004	215	13.49	63	2	2	1
LESG06	1 660	317.00	191	2	3	1
LESG07	797	149.00	187	2	2	2
LESG17	1 087	295.00	271	3	2	1
T4H001	715	162.00	227	3	2	1
X2H031	262	33.44	128	2	1	3

for a sample of quaternary catchments. As it was not feasible to examine all 1 956 quaternary catchments, 29 quaternaries (or groups of quaternaries) were selected that exhibited a marked discrepancy in MAP between Dent and Pegram. An additional criterion for selection was the existence of a streamflow gauge, either within or adjacent to the catchment.

The KNP was selected for a preliminary analysis as rainfall data were up to date (hydrological year 2018) and orographic effects over the KNP were considered to be minimal. This analysis revealed the CHIRPS data to compare reasonably well with that obtained by averaging of a number of suitable rainfall records. The one exception was the North zone of the KNP, where CHIRPS had a tendency to underestimate rainfall by about 10% when compared with average station rainfall.

In the main analysis, the first task was to compare catchment MAP as derived from the three different sources, namely WR2012, Pegram and CHIRPS. For the entire dataset, the WR2012 MAPs were found to be the highest, followed by Pegram, then CHIRPS; the average ratio of Pegram/WR2012 was 0.77, while that for CHIRPS/WR2012 was 0.68. However, if one looks only at the winter rainfall zone (Drainage Regions G and H), the ratios are respectively 0.63 and 0.49. For the remainder of the catchments the ratios are respectively 0.95 and 0.94, i.e., quite close to unity.

The second task was to compare the WRSM/Pitman model calibrations using the three different sources of monthly rainfall time series. The WR2012 calibrations came out on top with an average 'score' of 2.5, compared with 1.8 for Pegram and 1.3 for CHIRPS. If one omits the winter rainfall region, the scores are much closer, being respectively 2.3, 1.9 and 1.7.

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

One may conclude from this study that the winter rainfall zone remains a problem, with CHIRPS (and to a lesser extent, Pegram) underestimating MAP to a considerable degree. This finding was supported by model calibrations on the selected streamflow gauges, where the WR2012 calibrations comprehensively outscored those based on Pegram and CHIRPS rainfall. However, as was the case for catchment MAP, calibrations based on Pegram and CHIRPS rainfall fared much better in the rest of the country, although the WR2012 calibrations still came out on top.

For the relatively small sample of catchments selected for this analysis, it appears that the method of constructing a time series of monthly rainfall by averaging records from a number of stations is still the most reliable in nearly all cases. (CHIRPS resulted in the 'best' calibration in three catchments.) However, this situation could change if the coverage of rainfall stations continues the decline that started in the 1970s; it must be appreciated that, apart from the KNP study, rainfall data were available only up to the 2009 hydrological year. It is not known by how much the coverage has declined over the rest of the country in the intervening decade.

It is therefore concluded that this study be expanded, not only to include the most recent 10 years of rainfall, but also to include a much greater sample of quaternary catchments than was possible for this exploratory study. It is also suggested that feedback be given to the authors by practitioners who make use of CHIRPS in their studies.

As the primary output of CHIRPS is daily rainfall data, it is recommended that the WRSM/Pitman daily time-step model (Bailey and Pitman, 2016) be employed to ascertain the validity of such data.

The winter rainfall zone remains a problem with the wide disparity among the three methods to assess MAP. CHIRPS does use ground-truthing in the way of observations at certain stations, so it may be possible that CHIRPS can be re-calibrated to yield more reliable data in this region. It is the intention of the authors to contact the relevant organization with a view to exploring the possibility of such a re-calibration being undertaken.

Regarding the use of CHIRPS, there are a number of positives that have emerged from our comparative analyses. Firstly, it is obviously a very useful tool for obtaining daily and monthly time series of rainfall from 1981 to present, as well as MAP (which can be derived) in countries and/or catchments where there is very little or even no rainfall data at all. The fact that data are available right up to the present is extremely useful in studies where such recent data are a prerequisite. As a polygon describing the catchment is input, no averaging of a number of stations is required, which saves time as in most catchments one spends a good deal of time assessing different rainfall stations within and outside the catchment of interest. With rainfall records there is generally patching or infilling required and this can also be a time consuming and difficult task if rainfall stations have missing and/or unreliable values (which is often the case). By using a 'master' spreadsheet, it is a quick and easy process to convert CHIRPS data to the monthly format required by the WRSM/Pitman model. To use CHIRPS one has to ether draw the catchment boundary by outlining a polygon or provide a GeoJson (Butler et al., 2016) imported file. Towards the end of the study the procedure to create a GeoJson file was ascertained: it involves first saving a kmz file with Google Earth and then converting it to a GeoJson file using the software provided by the MyGeodata Converter website (MyGeodata Converter, 2020). (Freely available GIS software such as QGIS can also be converted to GeoJson format.) For example, any quaternary catchment can be converted, as a coverage of these catchments is available on Google Earth.

It may be concluded that CHIRPS could be a major benefit moving into the future, especially if rainfall station data continues on its unfortunate downward trend regarding the number of stations currently open.

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