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Monitoring changes in South Africa's surface water extent for reporting Sustainable Development Goal sub-indicator 6.6.1.a

For the first progress reporting on the Sustainable Development Goal sub-indicator 6.6.1a in 2020, the South African and global statistics related to wetlands were compared. Firstly, in terms of the total wetland extent, the South African National Wetland Map version 5 (NWM5) represented 87% more inland, surface aquatic ecosystems than the Global Surface Water (GSW) product. More than half of the lacustrine systems and none of the palustrine and arid systems in NWM5 are represented in the GSW layer. Secondly, in terms of changes in the extent of wetlands, both the global and South African statistics showed a decreasing trend in the spatial extent of surface aquatic ecosystems in South Africa. These trends should be further investigated against systematic assessments of decadal drought periods. The hydroperiod information (permanent, seasonal and ephemeral inundation periods) of the GSW products show that South African lacustrine wetlands do not have a single dominant class ($\geq 70\%$ of the extent of a polygon) of inundation, but consist of a mosaic of these classes.

Significance:

- The South African National Wetlands Map version 5 represents 87% more of the extent of lacustrine, palustrine and arid wetlands than the Global Surface Water products that are used for progress reporting on the Sustainable Development Goal sub-indicator 6.6.1.a.
- South African and global statistics suggest a decline in the extent of lacustrine wetlands, although a systematic comparison with decadal drought periods is required to confirm these trends.
- South African lacustrine wetlands consist of a mosaic of hydroperiod classes (permanent, seasonal and ephemeral inundation periods) with no individual class dominating ($\geq 70\%$ of the extent of) wetlands polygons.

Aquatic ecosystems play a pivotal role in water provision, but globally these systems are impacted and at the brink of collapse.¹ Monitoring ecosystem changes in surface aquatic systems using remote sensing is critical to facilitate urgent intervention strategies to safeguard these vulnerable and threatened ecosystems. Space-borne satellite images now enable monitoring at scales ranging from landscape to global.

Seventeen Sustainable Development Goals (SDGs) were adopted in 2015 by member states of the United Nations and 2020 was the first year of reporting progress on the targets identified. In terms of aquatic ecosystems, SDG target 6.6 states: 'By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes'. Global statistics derived from the Global Surface Water (GSW) products² were released to assist each country in reporting sub-indicator SDG 6.6.1a, which pertains to the spatial extent of surface aquatic ecosystems. In 2019, South Africa released the latest National Biodiversity Assessment of 2018, which included updates to the National Wetland Map version 5 (NWM5) and artificial wetlands spatial data layers.³ These data sets provide a new opportunity for comparing the spatial extent of surface aquatic ecosystems between the different data sets. In addition, other GSW products are also considered for characterising the hydroperiod of South African wetlands.

SDG target 6.6. has only one indicator (6.6.1): 'Change in the extent of water-related ecosystems over time'.⁴ Aquatic ecosystems included for this target are 'wetlands, lakes, estuaries, artificial ecosystems (dams), rivers and aquifers'. Indicator 6.6.1 aggregates three of the sub-indicators, namely change in (a) spatial extent, (b) water quality and (c) water quantity, while a fourth sub-indicator, related to the ecological condition of ecosystems, is reported separately. Two tiers of reporting are facilitated. Tier 1 uses globally available data from remote sensing derivatives and countries can validate these quantities against their own methods and/or data sets. Tier 2 allows for countries to report their own statistics for the sub-indicators of SDG 6.6.1.

To facilitate Tier 1 reporting for the spatial extent of aquatic ecosystems (sub-indicator 6.6.1.a), the United Nations extracted data from recent GSW products which quantify the total extent and changes in the spatial extent of surface aquatic ecosystems. The GSW products were derived from Landsat images since 16 March 1984, and more recently Sentinel-2 images after 10 October 2015.² The Freshwater Ecosystems Explorer application (www.sdg661.app) enables countries to view or download data for reporting.

The average extent of inundation between the years 2000 and 2004 was taken as the reference against which changes in the extent of surface water is measured for 6.6.1.a. These years were mainly drought free, i.e. they did not include a 60-month or 24-month decadal drought, with the exception of 2004, in which an intense summer drought affected 26% of the summer-rainfall region that covers about 90% of the areal extent of the country.⁵

The Freshwater Ecosystem Explorer statistics report 6144 km² of wetlands for South Africa (Table 1). The statistics show that, since the reference period, permanent water reduced by nearly 20% while seasonal water increased

by 32%. In addition, the minimum water extent of reservoirs (artificial) decreased by 25%, whereas the maximum water extent of reservoirs decreased by only 11%. These results suggest that South Africa may not yet have recovered from the 2015/2016 drought. However, no systematic assessment of the severity and geographic extent of this drought is yet available for the whole of South Africa, which would be necessary for comparing these to other decadal droughts described in Malherbe et al.⁵

The total spatial extent of surface aquatic ecosystems as reported for the SDG 6.6.1.a sub-indicator was compared to three data sets of South Africa (Table 1). Three research groups have mapped surface aquatic systems using various data sources, for different purposes, categories and intended uses.^{3,6,7} Using NWM5 and the artificial wetlands layer yielded the largest spatial extent of wetlands, with a total of nearly 44 000 km².³ These inland wetlands, and the extent of some of the rivers, include permanently and seasonally inundated (lacustrine), vegetated (palustrine), arid (with no dominant inundation or vegetation cover) and artificial systems/ water bodies. Van Deventer et al.³ report extensive omission errors in aquatic ecosystems, with 76% of the national extent mapped at a low confidence. The statistics used for reporting on the SDG 6.6.1.a sub-indicator therefore underreport the spatial extent of

inland wetlands by at least 87% of those mapped in NWM5 and the artificial wetland layers. Note that the GSW products do not include palustrine and arid systems at all, while these are included NWM5, in addition to the lacustrine systems.

The South African 2013/2014 land cover data⁶ have been used to track changes against a historical reference point of 1990 (Table 2)⁸. The year 1990 is a suitable reference, because it was just before the 1991–1995 decadal drought.⁵ In the comparative study, three categories of water are reported to have reduced between 1990 and 2014, including a loss of nearly 1% of artificial water bodies, 0.5% mining water and 24% natural water (Table 2). The report notes, however, that the data derived from remote sensing products may include some shadows erroneously classified as wetlands. Despite the errors noted for both the GSW and land cover products, both studies observed a decrease in the spatial extent of surface aquatic ecosystems over the past 20–30 years. These general trends should be further investigated through a systematic assessment of the decadal drought cycles⁵, and for specific regions to evaluate whether they relate to the natural variation in rainfall or to climate change trends associated with increasing temperatures and evapotranspiration.

Table 1: Descriptive statistics related to the spatial extent of surface wetland types available on the Freshwater Ecosystems Explorer for reporting on Sustainable Development Goal sub-indicator 6.6.1.a, in comparison to three South African data sets

Wetland type (down) / Source (across)	SDG 6.6.1.a statistics of 2020 (km ²) ²	Land cover (2013/2014) ⁶	DRDLR:NGI (2016) ⁷	SAIIAE and NWM5 ³
Total extent of wetlands	6 144.3 km ²	14 738.5 km ²	28 099.3 km ²	43 804.3 km ²
Permanently inundated (lakes and rivers)	-209 km ² (-19.7%)	Water permanent 3 919.6 km ² (includes natural and artificial systems)	2 309.3 km ² including perennial water bodies and the extent of some rivers	Lacustrine wetlands: 2 787.2 km ² (11% of inland wetlands in South Africa)
Seasonally inundated (lakes and rivers)	+190 km ² (+31.8%)	Water seasonal 631.5 km ² (includes natural and artificial systems)	3 765.4 km ² (including non-perennial water bodies and the extent of some rivers)	Palustrine wetlands: 14 479.3 km ² (55% of inland wetlands in South Africa)
Permanently or seasonally inundated systems	n/a	Wetlands 10 187.5 km ² (includes natural and artificial systems)	n/a	Rivers: 11 462.3 km ²
Arid (not predominantly inundated or vegetated)	n/a	Not distinguished from other classes	21 917.3 km ²	Arid: 9 091.6 km ² (34% of inland wetlands in South Africa)
Artificial	Minimum water extent: -379 km ² (-24.9%) Maximum water extent: -185 km ² (-11.5%)	Not distinguished from other classes.	107.3 km ² of dams, reservoirs and other structures mapped	5 983.9 km ²

DRDLR:NGI, Department of Rural Development and Land Reform: National GeoInformation; NWM5, National Wetland Map version 5; SAIIAE, South African Inventory of Inland Aquatic Ecosystems; SDG, Sustainable Development Goals

Table 2: Changes in the spatial extent of surface aquatic ecosystems between 1990 and 2014⁸

Category	Year 1990 (km ²)	Year 2014 (km ²)	Change (km ²)	Percentage change (%)
Artificial water bodies	3 062.3	3 006.2	-56.0	-0.9
Mining water	121.6	100.9	-20.8	-0.4
Natural water (including shadows)	2 837.9	1 390.6	-1 447.3	-24.0
Total	6 021.8	4 497.7	-1 524.1	-25.3

Table 3: Global Surface Water products² for two selected study areas in South Africa. The outlines of the National Wetland Map (NWM⁵) polygons are shown in grey. Legend files provided by the Global Surface Water Explorer were used as is for colours and categories displayed in the legends and maps.

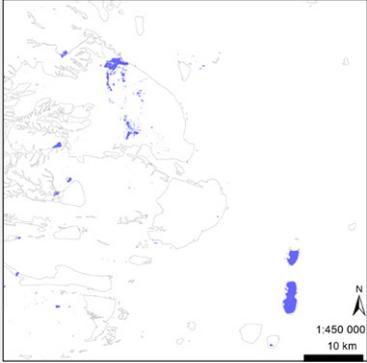
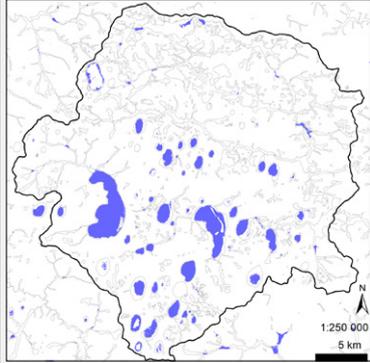
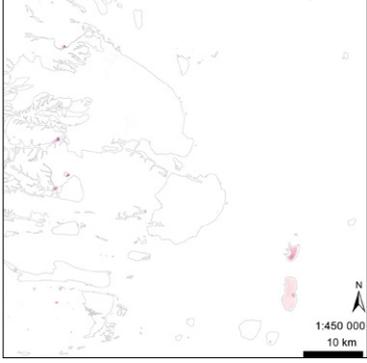
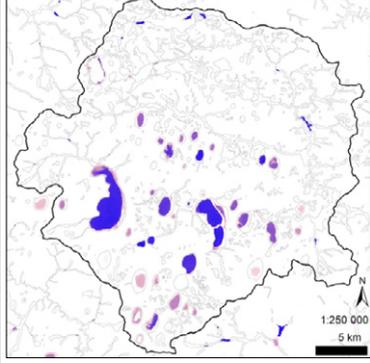
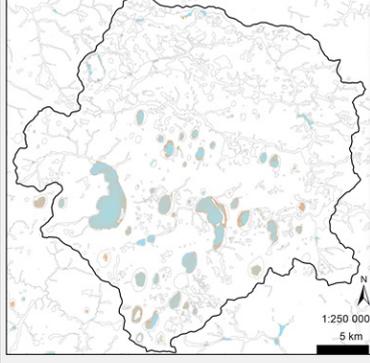
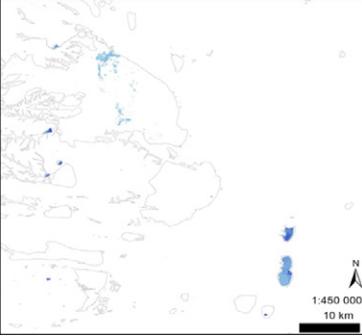
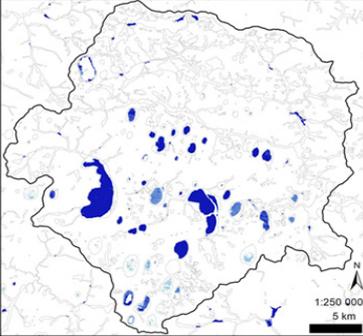
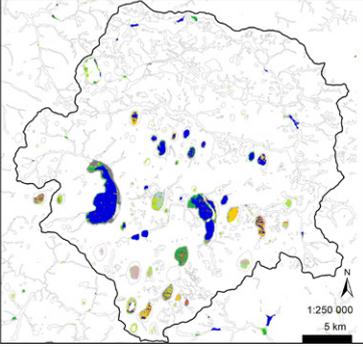
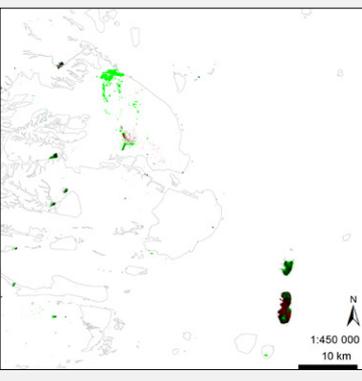
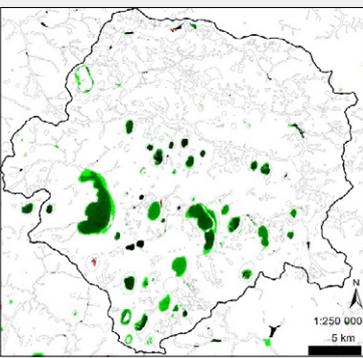
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<p>Occurrence: frequency with which water was present on the surface since March 1984</p>		<p>Occurrence:</p> <table border="1" style="font-size: small;"> <tr><td>25%</td><td>51%</td><td>77%</td></tr> <tr><td>26%</td><td>52%</td><td>78%</td></tr> <tr><td>27%</td><td>53%</td><td>79%</td></tr> <tr><td>28%</td><td>54%</td><td>80%</td></tr> <tr><td>29%</td><td>55%</td><td>81%</td></tr> <tr><td>30%</td><td>56%</td><td>82%</td></tr> <tr><td>31%</td><td>57%</td><td>83%</td></tr> <tr><td>32%</td><td>58%</td><td>84%</td></tr> <tr><td>33%</td><td>59%</td><td>85%</td></tr> <tr><td>34%</td><td>60%</td><td>86%</td></tr> <tr><td>35%</td><td>61%</td><td>87%</td></tr> <tr><td>36%</td><td>62%</td><td>88%</td></tr> <tr><td>37%</td><td>63%</td><td>89%</td></tr> <tr><td>38%</td><td>64%</td><td>90%</td></tr> <tr><td>39%</td><td>65%</td><td>91%</td></tr> <tr><td>40%</td><td>66%</td><td>92%</td></tr> <tr><td>41%</td><td>67%</td><td>93%</td></tr> <tr><td>42%</td><td>68%</td><td>94%</td></tr> <tr><td>43%</td><td>69%</td><td>95%</td></tr> <tr><td>44%</td><td>70%</td><td>96%</td></tr> <tr><td>45%</td><td>71%</td><td>97%</td></tr> <tr><td>46%</td><td>72%</td><td>98%</td></tr> <tr><td>47%</td><td>73%</td><td>99%</td></tr> <tr><td>48%</td><td>74%</td><td>100%</td></tr> <tr><td>49%</td><td>75%</td><td>No data</td></tr> <tr><td>50%</td><td>76%</td><td>No data</td></tr> </table>	25%	51%	77%	26%	52%	78%	27%	53%	79%	28%	54%	80%	29%	55%	81%	30%	56%	82%	31%	57%	83%	32%	58%	84%	33%	59%	85%	34%	60%	86%	35%	61%	87%	36%	62%	88%	37%	63%	89%	38%	64%	90%	39%	65%	91%	40%	66%	92%	41%	67%	93%	42%	68%	94%	43%	69%	95%	44%	70%	96%	45%	71%	97%	46%	72%	98%	47%	73%	99%	48%	74%	100%	49%	75%	No data	50%	76%	No data	
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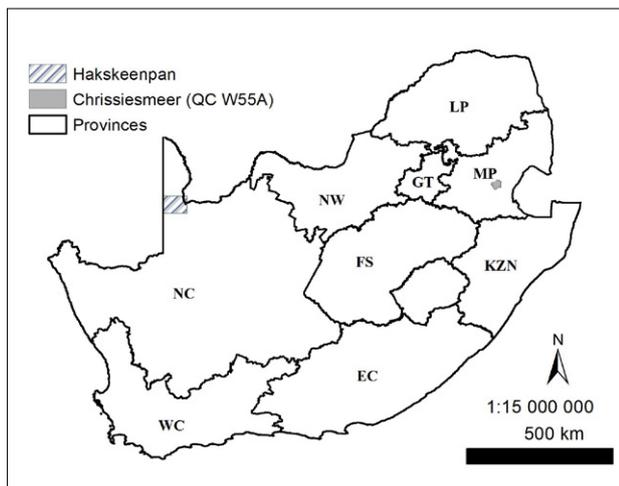
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<p>Transition between permanent water, seasonal water and land classes can be determined between any two years of observation; transitions between the first and last year of observation*</p>		<p>Transitions:</p> <ul style="list-style-type: none"> Not water Permanent New permanent Lost permanent Seasonal New seasonal Lost seasonal Seasonal to permanent Permanent to seasonal Ephemeral permanent Ephemeral seasonal No data 																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
<p>Change in water occurrence intensity between two epochs (16 March 1984 to 31 December 1999, and 1 January 2000 to 10 October 2015)*</p>		<p>Change:</p> <table border="1"> <tr> <td>75% decrease</td><td>42% decrease</td><td>19% decrease</td></tr> <tr> <td>100% decrease</td><td>71% decrease</td><td>41% decrease</td></tr> <tr> <td>99% decrease</td><td>70% decrease</td><td>40% decrease</td></tr> <tr> <td>98% decrease</td><td>69% decrease</td><td>39% decrease</td></tr> <tr> <td>97% decrease</td><td>68% decrease</td><td>38% decrease</td></tr> <tr> <td>96% decrease</td><td>67% decrease</td><td>37% decrease</td></tr> <tr> <td>95% decrease</td><td>66% decrease</td><td>36% decrease</td></tr> <tr> <td>94% decrease</td><td>65% decrease</td><td>35% decrease</td></tr> <tr> <td>93% decrease</td><td>64% decrease</td><td>34% decrease</td></tr> <tr> <td>92% decrease</td><td>63% decrease</td><td>33% decrease</td></tr> <tr> <td>91% decrease</td><td>62% decrease</td><td>32% decrease</td></tr> <tr> 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*1984 was part of a 60-month decadal drought cycle⁵.

Table 4: Number of polygons and percentage per type inundated, as derived from the Global Surface Water transition data layer² for inland wetlands and rivers mapped in National Wetland Map version 5 of South Africa³

Hydrogeomorphic unit (down)/ Inundation type (across)	Inundated		Not inundated		Total	
	No.	%	No.	%	No.	%
Channelled valley bottom	2 299	18.8	9 962	81.2	12 261	7.8
Depression	9 825	11.7	74 154	88.3	83 979	53.2
Flat	34	6.1	519	93.9	553	0.4
Floodplain	867	25.2	2 580	74.8	3 447	2.2
River	2 692	25.2	8 007	74.8	10 699	6.8
Seep	3 061	7.5	37 546	92.5	40 607	25.7
Unchannelled valley bottom	773	12.5	5 409	87.5	6 182	3.9
Total	19 551	12.4	138 177	87.6	157 728	100.0



EC, Eastern Cape; FS, Free State; GT, Gauteng; KZN, KwaZulu-Natal; LP, Limpopo; MP, Mpumalanga; NC, Northern Cape; NW, North West; WC, Western Cape

Figure 1: Location of the two study areas, Hakskeenpan and Chrissiesmeer, in the Northern Cape and Mpumalanga Provinces, respectively. See Table 3 for more information.

The Global Surface Water Explorer (GSWE, <https://global-surface-water.appspot.com/>) enables the viewing and download of several data layers (at 30 m spatial resolution) related to the spatial extent of inundation (Table 3, Figure 1). The transition data layer was used to investigate the three different hydroperiod classifications of permanently, seasonally and ephemerally inundated systems. The tiles were merged into a single raster using ArcGIS 10.6⁹, and statistics were calculated (Tabulate Area) for each polygon of the inland wetlands and rivers of NWM5. In total, 19 551 polygons (12%) of the 157 728 inland wetlands and rivers have signatures of inundation according to the GSW transition data layer (Table 4). This totals 1359.1 km² of inland wetlands, which is about half of the 2787.2 km² of the lacustrine systems identified using the 2013/2014 National Land Cover data⁷ for NWM5.³ On average, the

majority of inland wetlands and rivers showed that no more than 22% of their spatial extents are inundated, with the exception of depressions, which had an average of 29% of their extents inundated.

Fewer than 1% of the number of inland wetlands and river polygons in NWM5 had an extent of $\geq 70\%$ of polygon in any one of the three hydroperiod classes of the GSW transition product. Consequently, a new approach for assigning hydroperiod to a single wetland unit needs to be investigated.

The author provided information to the South African Department of Water and Sanitation concerning the reference period and the underrepresentation of wetlands in the global data sets relative to NWM5, as described in this article. The Department's SDG team incorporated this information in their Response to the United Nations Environment Programme 2020 data drive.¹⁰

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Competing interests

There are no competing interests to declare.

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