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Evaluation of Earth Observation Solutions for Namibia's SDG Monitoring System

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Abstract: In recent years, with more open data platforms and tools available to store and process satellite imagery, Earth Observation data have become widely accessible and usable especially for countries previously not in the possession of tasking rights to satellites and the needed processing capacity. Due to its ideal scanning and acquisition conditions for low cloud coverage imagery, Namibia aims to make use of this new development and integrate Earth Observation data into its national monitoring system of sustainable development goals (SDG). The purpose of this study is to assess the potential of open source tools and global datasets to estimate the national SDG indicators on *Change of water-related ecosystems* (6.6.1), *Rural population with access to roads* (9.1.1), *Forest coverage* (15.1.1) and *Land degradation* (15.3.1). The results are set into perspective of existing information in each particular sector. The study shows that, in the absence of in-situ measurements or data collected through surveys, the Earth Observation-based results represent a high potential to supplement the national statistics for Namibia or to serve as primary data sources once validated through ground-truthing. Furthermore, examples are given for the limitations of the assessed Earth Observation solutions in the context of Namibia. Hence, the study also serves as valuable input for discussions on a consensus on national definitions and standards by all stakeholders responsible for releasing official statistics.

Keywords: sustainable development goals (SDG) monitoring; Namibia; earth observation; land degradation; forest coverage; access to roads; water surfaces

1. Introduction

In a historic United Nations (UN) summit in September 2015, world leaders adopted Resolution 70/1 "Transforming our World: the 2030 Agenda for Sustainable Development" through the General Assembly [1]. In July 2017, a common Indicator Framework was adopted through Resolution 71/313 to monitor the progress of the 17 Sustainable Development Goals (SDGs) that represented this transformation [2]. For a variety of indicators, Earth Observation (EO) solutions play a significant role in providing cost effective, standardized, reliable, historic, and frequently updated information to assess the change in a country [3]. Considering the universal nature of the implementation of the 2030 Agenda, it appears consequential to develop and implement international EO solutions to support the national monitoring of the SDGs. This paper contributes to the assessment of some of these universal solutions by sharing results and experiences of the attempt to integrate them into the official national reporting structures of Namibia.

As a sparsely populated large country with low cloud coverage [4] for most of the year, Namibia appears to provide promising conditions where, in the absence of comprehensive monitoring capacity through ground data, EO solutions can serve to provide consistent information on a national scale with frequent updates. For instance, conditions with respect to the cloud free requirement (< 10%

respectively and < 20% average cloud cover across the scene) for effective observation frequencies for agricultural monitoring [5,6] through optical instruments are often met.

With recent economic struggles and limitations in federal budgets, cost-effective and resource-economical solutions to monitor the state of the country become more relevant if the commitment to report on the 2030 Agenda is to be upheld. Given the country's limitations in the storage and processing of raw satellite imagery, the aim is that new and cloud based EO applications, through the demonstration of quick gains, increase the conviction of practitioners and decision makers towards a more extensive utilization of remote sensing applications as is already implemented in other countries such as Colombia [7]. The potential of this paradigm shift for National Statistical Offices (NSOs) from traditional statistical methods toward pre-processed Analysis Ready Datasets (ARD) based on sensors, simulations, and modelling is highlighted in detail through use cases in the report on Earth Observation for Official Statistics by the United Nations Task Team on Satellite Imagery and Geospatial Data [8]. The report evenly highlights the limitation and risks of the application of EO technologies, emphasizing in particular the challenge to "generate a clear picture of the boundaries between complementarity and substitutability" [8] of EO solutions and gives guidelines and criteria for NSOs to decide whether or not to integrate EO solutions in the official statistical system. Furthermore, a global survey analyzed in the Report of the Global Working Group on Big Data for Official Statistics found that EO solutions can respond to the most prominent need of NSOs for "faster, more timely statistics" [9].

Having the advantage of being an administratively small country, Namibian institutions could respond to this need of more timely statistics and adopt more rapid procedural changes in their data production system than other countries once the feasibility of EO applications has been demonstrated and the uncertainties in the produced data have been acknowledged.

This study aims to contribute to that undertaking by evaluating the hypothesis that free data and open source applications can be used for the official SDG monitoring in Namibia. For that purpose, the study demonstrates the utilization and adaption of EO solutions and methods to monitor four SDG indicators:

- Indicator 6.6.1: Change in the extent of water-related ecosystems over time.
- Indicator 9.1.1: Proportion of the rural population who live within 2 km of an all-season road.
- Indicator 15.1.1: Forest area as a proportion of total land area.
- Indicator 15.3.1: Proportion of land that is degraded over total land area.

The selection of indicators is based on the readiness of data, tools, and methodologies, as well as socio-economic and environmental consequences for the country. In particular, water trends (6.6.1) as well as degraded land (15.3.1) and forest coverage (15.1.1) can be extracted from the ARD and are essential indicators to monitor land use potential and natural or man-made environmental changes in the country, such as bush encroachment [10] or the recent deforestation activities in the Kavango Regions [11]. Additionally, access of the rural population to roads (9.1.1) was chosen to investigate a potentially more cost effective workflow at the Namibia Statistics Agency (NSA) to substitute classical data collection done through survey questionnaires [12].

Trends and patterns of the above indicators are displayed to illustrate the monitoring potential relevant to decision makers. Furthermore, in the absence of national standards (for instance, for the categories to generate land cover maps), the used tools and methodologies aim to serve as valuable input to stimulate discussion to establish such standards, as foreseen in a national workshop on land cover classifications in the second half of 2019.

To take into account concerns about exaggerated or misleading data dependency through easy-to-generate maps and statistics not suitable for specific national contexts, the results are set into perspective to existing national datasets and assessments of other countries testing comparable tools and approaches. In particular, conclusions from the Namibian–German Project on Bush Control [13,14] indicate that, contrary to other countries, for the Namibian context, an increase of biomass through a specific type of vegetation could reduce the biodiversity and carrying capacity of the land and needs to be considered for the monitoring of land degradation. The "testing of the Global Surface Water Dataset for Canada" released by the Canadian Statistics Office [15,16], highlighted that many small rivers, wetlands, and ponds are not included in the dataset. For Namibia, having few water bodies, similar inaccuracies would influence the statistics on surface water coverage significantly. Findings from the Statistics Office of Colombia (DANE) for the monitoring of access to roads [17] emphasize that the numbers from global population grids and the categorization of urban and rural areas do not coincide with national projections. This is of special concern for Namibia, where the population density is low and the national definition of urban and rural areas is based on administrative functions potentially including small "urban" settlements with only a few thousand inhabitants.

The study found that the assessed solutions provide a high potential to detect trends and patterns in the country. Additionally, the solutions can serve as an independent data source thus avoiding coordination obstacles present in the institutional landscape experienced through the undertaking of establishing a national SDG monitoring system. Due to the fact that the production of open data and tools is expected to continue (e.g., through traditional space agencies programs such as the European Space Agency's Copernicus Program) and increase further through new commercial actors in the field known as "the New Space" [18], a utilization of the tested solutions for continuous monitoring appears justified. However, the remaining reservations in the results due to a lack of ground truth data and the lack of consensus for national standards raise concerns in using the results for quantitative analysis. It is rather recommended to use the results for Indicators 6.6.1 (assessment of water coverage through floods) and 9.1.1 (access to roads) to identify qualitative trends and motivate to adapt planning processes accordingly. Additionally, for Indicators 6.6.1 and 9.1.1, the information produced by EO solutions can be used as a supplement for existing Disaster Risk Management (DRM) systems such as the System for Flood Monitoring from the Ministry of Agriculture Water and Forestry (MAWF) [19] or infrastructural planning processes. For Indicators 15.1.1 (forest area as a proportion of total land area) and 15.3.1 (proportion of land that is degraded over total land area), which dealing with land classifications, no detailed assessment was conducted due to the absence of national standards guiding the monitoring.

2. Material and Methods

This article comprises two approaches to generate results for SDG Indicators 6.6.1, 9.1.1, 15.1.1, and 15.3.1. First, use cases are presented on the utilization and adaptation of internationally standardized methodologies and tools to identify land degradation [20,21], forest coverage [21–23], and surface water [16,24]. Second, a use case is described to develop and compare methods for the estimation of the rural population with access to roads. The results are set quantitatively into perspective to existing spatial datasets, in-situ data, and publications from the Namibian Ministry of Water, Agriculture and Forestry (MAWF), the Namibian Statistics Agency (NSA) and to international databases on SDG indicators such as the released data for Indicator 15.1.1 from the Food and Agriculture Organization (FAO).

The selection of open tools and methods used within the study is supported by those UN agencies being the custodians of the corresponding SDG indicators. Indeed, the use of the selected open data and tools allows for maximum re-use, sharing, and review of the approaches and results. Details on the material and methods for the assessment of each SDG indicator are presented in the subsequent chapters.

2.1. Change of Surface Water (Indicator 6.6.1)

As the United Nations Environment Program (UNEP) (as custodian agency for SDG indicator 6.6.1) promotes the Global Surface Water (GSW) Application [24] developed by the Joint Research Centre of the European Commission (JRC-EC) and the Google Earth Engine (GEE), the corresponding datasets were tested for Namibia.

To ease data handling and the comparison of results, a new GEE App [25] was developed in the scope of this study using the GSW dataset to calculate the change of permanent annual and monthly surface water (based on the GSW resolution of 30 m) over time on national and regional levels in Namibia. The GEE App can be described with the following algorithm for any defined area of interest (AOI):

1. Define the time frame for analysis based on the user's selection of a different trend type:
    a. For yearly trends, each year of the selected time frame is considered.
    b. For monthly trends, the time frame contains only the selected year.
2. Loop over the defined time range (monthly or yearly).
    a. Select the monthly water history dataset [26] for monthly trend or the yearly classification history dataset [26] for yearly trends.
    b. Retrieve the water layers from the selected dataset.
    c. Clip the dataset to the AOI.
    d. Calculate the area of permanent and seasonal inland water for yearly trend, or overall water area for monthly trends.
    e. Store the water area for the selected year or month.
3. If a yearly trend was requested:
    a. Calculate the 5-year average change β based on the calculated areas between 2001 and 2005.
    b. Calculate the 5-year average change γ based on the calculated areas for every available year (1984 to 2015).
    c. Calculate the percentage change $100 \times (\beta - \gamma)/\beta$
    d. Plot the permanent and seasonal water area and area change over time
4. Otherwise plot the water area over the month of the selected year.

Post-processing was done with an open GIS software: QGIS Version 2.18.18. All reference satellite imagery was produced by Sentinel-2A (10 m spatial resolution) taken from the EO Browser of the Sentinel-Hub [27].

To verify the information derived from the GEE App, the results were compared quantitatively to the data released on the official GSW platform for the 5-year average annual water coverage. Subsequently, the effect of different shapefiles for the boundaries of Namibia on the captured water surfaces was visualized and quantitatively compared. The extracted data for monthly water coverage was then set into perspective to water levels at different ground stations operated by the MAWF and the Normalized Difference Water Index (NDWI) according to Gao [28], for typical water bodies in September 2015 to showcase the potential and limitation of the GSW dataset. Finally, a use case is given for a well-known surface water related historic event in the country, the flooding of the Zambezi Region in 2009 [29], to demonstrate the potential of observations for specific and relevant events in the change of water eco-systems. Table 1 summarizes the tools and datasets used for the evaluation of SDG Indicator 6.6.1 in Namibia.

Table 1. Tools and Earth Observation (EO) data sources for the evaluation of Sustainable Development Goals (SDG) Indicator 6.6.1 (Water Surface Extent).

Tool	Dataset	Description
Google Earth Engine (GEE) App	Global Surface Water (GSW) [26]	Water detection using multi-temporal orthorectified Landsat 5, 7, and 8 archives [16]. **Information used:** Yearly History Layer: "Permanent Water" [26] Monthly History Layer: "Water detected" [26]
	GAUL [30], USDOS [31], NSA shapefile	GAUL by the FAO and USDOS LSIB by the U.S Government are administrative boundaries on a global level and are not validated by authoritative national sources. Coastlines are not completely validated by satellite imagery [32]. **Information used:** NSA shapefile with official national boundaries
Sentinel Hub	Sentinel 2 Imagery & Bands, NDWI	S2 provides high-resolution imagery in the visible and infrared part of the spectrum. L1C (orthorectified Top-Of-Atmosphere reflectance) and L2A (orthorectified Bottom-Of-Atmosphere reflectance). **Information used:** Level-1C: NDWI = according to Gao [28] NDWI values of water bodies are larger than 0.5 [33]

2.2. *Access to Roads (Indicator 9.1.1)*

The calculation of the Rural Access Index (RAI) for Indicator 9.1.1 is based on the methodology suggested by the World Bank Group [34], taking into account only population patterns and road networks. Here, the RAI is defined as the proportion of rural population living in a 2 km buffer zone around an all-season road. To explore the possibilities of calculating access to roads through global population grids for Namibia, different open datasets were considered: The WordPop Grid [35], the Gridded Population of the World v4 (GPW) dataset [36] from the Socioeconomic Data and Application Center (SEDAC) of the National Aeronautics and Space Administration (NASA) of the United States, the Global Human Settlement Layer (GHSL) [37] of the JRC-EC, and Facebook AI's High Resolution Population Density Map for Namibia (HRPD) [38]. Furthermore, global data sets such as OpenStreetMap [39] were visually compared against spatial datasets for road networks (trunk, main, and district roads) from NSA's National Spatial Data Infrastructure (NSDI) [40] to evaluate their applicability to Namibia. Following the approach of DANE in Colombia [17] to include terrain characteristics, a Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission (SRTM) [41] and the GSW dataset [24] from JRC-EC for water surfaces were used.

To determine the effect of different definitions on urban and rural areas on the RAI, the following three definitions were considered:

- The NSA's definition of administrative areas: For instance, the region of Omaheke, that was studied in detail, has only two towns declared as urban area [42], namely, Otjinene and Gobabis, meaning the rest of the population living outside these areas are considered to be rural.
- The GHSL urban/rural classification model (GHS-SMOD) [43] where
    - Urban Centre >1500 inhabitants/km^2.
    - Urban Cluster >300 inhabitants/km^2.
    - Rural <300 inhabitants/km^2.
- Segmentation using the Simple Non-Iterative Clustering (SNIC) algorithm [44].

The GHSL dataset includes a settlement layer with a resolution of 1 × 1 km that classifies the population clusters into the classes described above. Using this rural classification with a high precision dataset would negate the advantage of higher precision data. Therefore, to calculate the rural population distribution, the automatic population segmentation using SNIC with GEE with a seed space of 1000 m was applied on higher resolution grids.

A new GEE App was implemented to efficiently and consistently extract and combine information from the selected population datasets, the surface water dataset, the road network, and the digital elevation model. The GEE App's algorithm to calculate the RAI is as follows:

1. Retrieve the population distribution from the global datasets.
2. Calculate the rural population using a segmentation algorithm or urban boundaries masks.
3. Retrieve the road network.
4. Calculate the road network's buffer zone (± 2 km around the road lines) as a mask with 1 on the buffer zone, 0 elsewhere.
5. Optionally calculate the effect of terrain.
6. Retrieve the DEM.
7. Calculate the projected distance from the DEM slope information. The projected distance is equal to $\sqrt{1 + slope^2}$.
8. Multiply the projected distance by the road network's buffer zone layer.
9. Update the buffer zone mask by removing all the pixels with a value lower than 2, and set the remaining pixels value to 1.
10. Optionally calculate the effect of water:
11. Retrieve the permanent water distribution from the GSW dataset.
12. Remove any intersection between the water distribution and the road network from the buffer mask.
13. Calculate the intersection between the rural population and the buffer mask.
14. Sum the pixel values of the intersection to retrieve the total rural population within 2 km of a road.
15. Calculate the RAI by setting the population into perspective to the overall population.

To assess the plausibility of the results from the GEE App with respect to official statistics, the National Population and Housing Census 2011 (PHC) [45] as well as data from the Namibia Inter-Censal Demographic Survey 2016 (NIDS) [46] from the NSA were referenced for the overall and rural population count. Finally, the information from the GEE App was quantitatively compared against previously calculated RAI based on the Dwelling Unit set in 2011 for the Omaheke region and information from the Namibian Agriculture Census [12] from 2014 where access to roads was estimated on national scale through a survey. To show qualitative regional differences, Facebook's HRPD is used as input to calculate the RAI for all regions in 2018. Table 2 summarizes the tools and datasets used for the evaluation of SDG Indicator 9.1.1 in Namibia.

Table 2. Tools and EO data sources for the evaluation of SDG Indicator 9.9.1 (Road Access).

Tool	Dataset	Description
GEE App	WorldPop [35]	Gridded Population Density based on a semi-automated dissymmetric modeling approach that incorporates detailed census and ancillary data in a flexible, "Random Forest" estimation technique [47]. **Information used:** "Whole continent" datasets [35]
	GPW v4 [36]	Minimally modeled gridded population data collection that incorporates population estimates. Extrapolated from the raw census estimates and a set of estimates that have been nationally adjusted to data from the United Nation's World Population Prospects [48]. **Information used:** "Population-count": Estimated number of persons per 30 arc-second grid cell [36].
	GHSL [37]	The GHS framework uses heterogeneous data including global archives of fine-scale satellite imagery, census data, and volunteered geographic information [43]. **Information used:** GHS population grids (GHS-POP) [43], GHS urban/rural classification model (GHS -SMOD) [43]
	HRPD [38]	A mixture of machine learning techniques, high-resolution satellite imagery, and population data (census) from SEDAC/CIESIN [49] **Information used:** High Resolution Population Density Map Namibia – Population Layer [38]
	GSW [24]	See information under 6.6.1
	SRTM DEM v4 [41]	The SRTM data is available as 3 arc second (approx. 90m resolution) DEMs. A 1 arc second data product was also produced, but is not available for all countries [50]. **Information used:** "Elevation" [41]
	GAUL, USDOS, NSA shapefile	See information under 6.6.1
	Road Network [40]	Roads for Namibia from NSDI **Information used:** Trunk, main and district roads [40]
QGIS	DU Frame	DU collected during 2011 PHC at NSA. Urban/ Rural definition based on administration units. **Information used:** DU Omaheke. Urban areas: Otjinene and Gobabis [42]

2.3. *Forest Coverage (Indicator 15.1.1)*

Multiple open datasets and applications [21–23,51] exist to determine global and national forest/tree coverage as well as the loss and gain of the same through the solely biophysical constitution of the landscape. However, the question remains as to whether the applied methods are suitable for the specific vegetation in a country and if they are in line with national definitions. For instance, most existing EO forest analysis methods appear to be of limited use to detect processes in dry forest landscapes [52]. In Namibia, these dry woodlands are classified as forest, whereas this would not fall under the international definition of forest by the FAO (minimum 0.5 ha, minimum height of 5m, and crown cover of 15%) [53].

Furthermore, the FAO, the custodian agency for indicator 15.1.1, uses the Global Forest Resource Assessment (FRA) [54,55] to determine forest areas in a country relying not solely on the biophysical state described above but also taking into account land use criteria.

In this article, due to the lack of an adjusted national standard on forests, only a brief quantitative comparison of tree coverage trends between 2000 and 2015 is given for Namibia. Hereby, forest is defined as an area with a canopy density of 15% as by the QGIS plugin Trends.Earth [21] through the European Climate Change Initiative Land Cover (ESA CCI LC) [22] approach, by the Global Forest Watch application (GFW) [51] through the Hansen et al. dataset [23] and the FAO reporting [56]. Table 3 summarizes the tools and datasets used for the evaluation of SDG Indicator 15.1.1 in Namibia.

Table 3. Tools and EO data sources for the evaluation of SDG Indicator 15.1.1 (Forest Coverage).

Tool	Dataset	Description
GFW	Hansen et al. [23]	"Tree cover" is defined as all vegetation taller than 5 meters in height. "Tree cover" is the biophysical presence of trees in the form of natural forests or plantations [51]. **Information used:** Tree cover with >15% canopy density [51]
Trends.Earth	ESA CCI LC [22]	37 land cover classes based on United Nations Land Cover Classification System (UN-LCCS) [57] **Information used:** - Tree Cover, broadleaved, evergreen and deciduous; needle-leaved, evergreen and deciduous; mixed leaf type, closed to open (>15%) - Mosaic tree and shrub (>50%)/herbaceous cover (<50%) [22]
FAO database	FRA [54,56]	Biophysical and Land Use criteria combined: Forest cover is defined as land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in-situ. It does not include land that is predominantly under agricultural or urban land use [58]. **Information used:** Forest Coverage published through the FAO [56]

2.4. Land Degradation (Indicator 15.3.1)

The United Nations Convention to Combat Desertification (UNCCD), as the custodian for SDG Indicator 15.3.1, supports the development of the QGIS plugin Trends.Earth [21] under the supervision of Conservation International. The plugin directly calculates the extent of degraded land between 2000 and 2015 using land productivity, land cover, and soil carbon information as input parameters [20]. The tool was applied on a national and regional level and the results were visually compared to a contextualized approach along with a definition for degraded land in Namibia that considered bush encroachment as well, thereby adding a fourth factor to the definition of degraded land. Bush encroachment as a specific challenge for land use in Namibia is defined as "the invasion and/or thickening of aggressive undesired woody species resulting in an imbalance of the grass:bush ratio, a decrease in biodiversity, and a decrease in carrying capacity" [59]. Estimates for bush encroachment are taken from national assessments from 1999 [60], a recent update from a Strategic Environment Assessment [13] and from a land cover map of 2016 from the Bush Information System (BIS) currently under development for the region of Otjozondjupa [61]. Acknowledging the absence of an official national standard and the ongoing controversy on how to monitor degraded land in Namibia [62], the study does not present a quantitative analysis. Table 4 summarizes the tools and datasets used for the evaluation of SDG Indicator 15.1.1 in Namibia.

Table 4. Tools and EO data sources for the evaluation of SDG Indicator 15.3.1 (Land Degradation).

Tool	Dataset	Description
Trends.Earth	NDVI time series ESA CCI LC Soil Organic Carbon (SOC)	Uses 3 factors that determine Land Degradation: Land Cover, Land Productivity, Carbon Stock [20]. **Information used:** Direct computation of SDG 15.3.1 through 3 sub-indicators -NDVI time series (trajectory, performance, state) for Land Productivity - ESA CCI LC for Land Cover - Soil Organic Carbon [21]
Bush Information System	Landsat 8 satellite images, aerial photographs, and field data	7 land classes used for Otjozondjupa Region Namibia [61]. **Information used:** Degradation land based on class: Bushland

3. Results

3.1. Change of Surface Water (Indicator 6.6.1)

A GEE App [25] was applied to rapidly extract more customized results from the GSW dataset in GEE. This became necessary due to the limitations of the published data on the sdg661.app platform [63]. Figure 1 shows the change in the surface water area in Namibia from 2000 to 2015 for different shapefiles and processing tools. Further, it reveals that the main contribution to the overall area change in surface water originates solely from the increase in the Zambezi region from 2010 onwards, justifying a closer look at that region at a later stage. Additionally, the comparison shows that the data extracted through the GEE App matches the data accessible on the sdg666.app if the Global Administrative Unit Layers (GAUL) produced by FAO [30] or the Large Scale International Boundary (LSIB) Polygons of the United States Department of State (USDOS) [31] for the outline of Namibian administrative boundaries are used. However, when the official national administrative boundaries of the NSA were applied, an offset of the trend line became visible, explicable through the additional capturing of ocean water at the coast. For a dry country like Namibia with a coastline of 1500 km, the quality of coastal boundaries is highly relevant as a one pixel shift (with a width of 30 m) will already result in an additional permanent water surface of 45 km^2 or 15% to 20% of the overall permanent water surface.

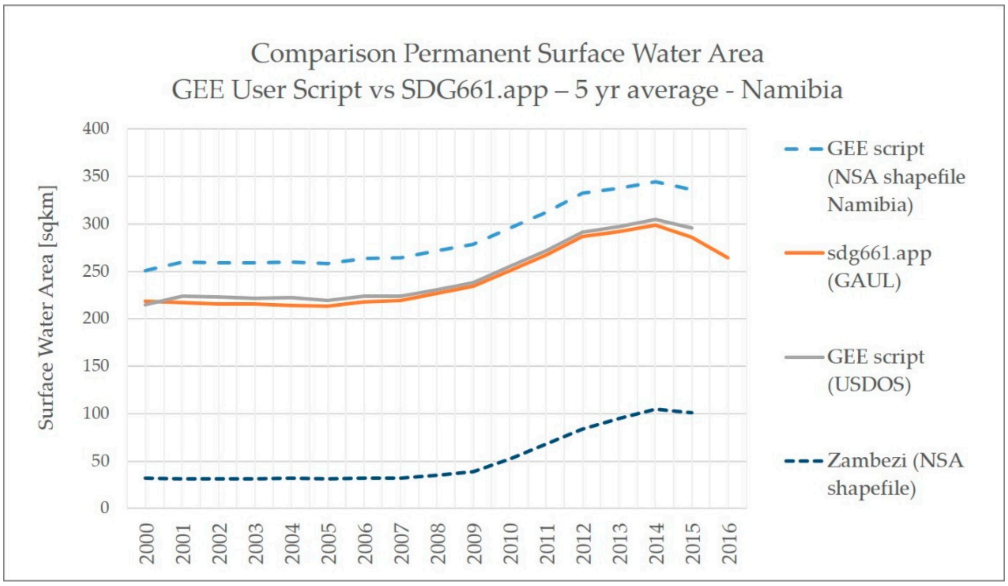


Figure 1. Comparison GSW 5-year average for Namibia with different shapefiles.

Figure 2 illustrates this volatility of detected water due to coastal boundaries discrepancies by plotting the differences (in red) of the USDOS LSIB against the NSA shapefile at Walvis Bay (Erongo Region) and the detected surface water (blue) from the GSW dataset. As the offset in the national trends was stable throughout the years, the official NSA shapefile for the national and regional boundaries was used in further trend analysis.

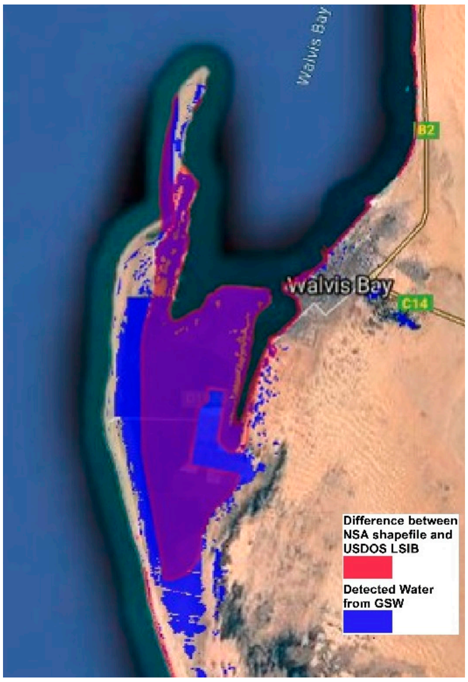


Figure 2. Comparison Boundaries of the United States Department of State Large Scale International Boundary (USDOS LSIB) vs. the Namibia Statistics Agency (NSA) shapefile at Walvis Bay (Erongo Region).

To assess the accuracy of the GSW dataset, it was compared to the NDWI [28], derived from Sentinel-Hub to evaluate if and how three typical small and large scale water bodies in Namibia are detected. Figure 3 shows the extent of water at Hardap Dam in September 2015. It can be seen that the GSW dataset does not detect all water at the edges of the dam as permanent water in the NDWI layer (NDWI > 0.5 [33]) from imagery from 22nd of September 2015 indicates.

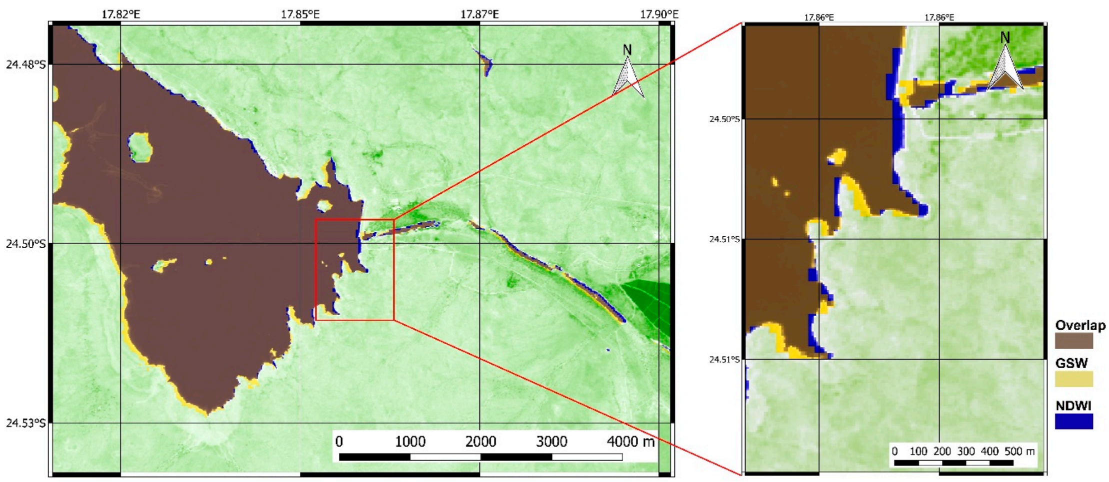


Figure 3. Comparison A: Hardap Dam GSW for September 2015 (orange) with Sentinel-2A Level 1C Normalized Difference Water Index (NDWI) (blue >0.5) from 22 September 2015 and overlap (grey).

Figure 4 shows the extent of water detection for typically small, temporarily filled Namibian waterbodies (known as Oshanas [64]) in September 2015 if the GSW dataset is compared to the NDWI derived from Sentinel-2 on 18 September 2015. Finally, Figure 5 compares detected water of the GSW dataset in September 2015 at the Okavango River close to Divundu and a corresponding NDWI data layer from the 18 September.

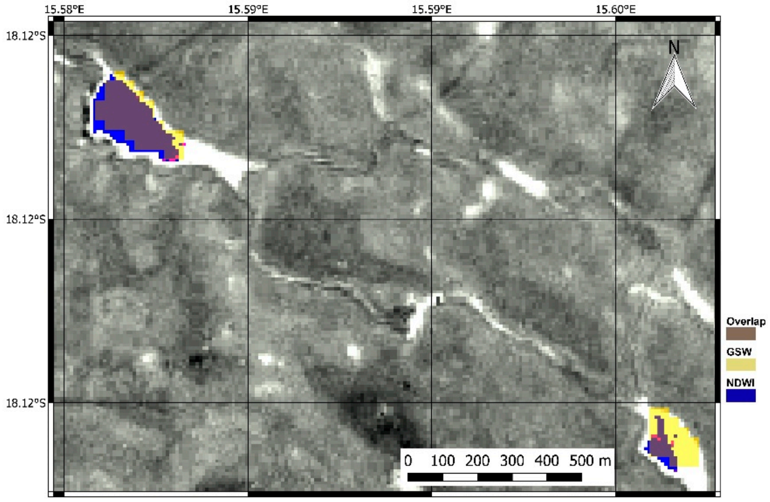


Figure 4. Comparison B: Oshana GSW for September 2015 (orange) with Sentinel-2A L1C NDWI (blue >0.5) from 18 September 2015.

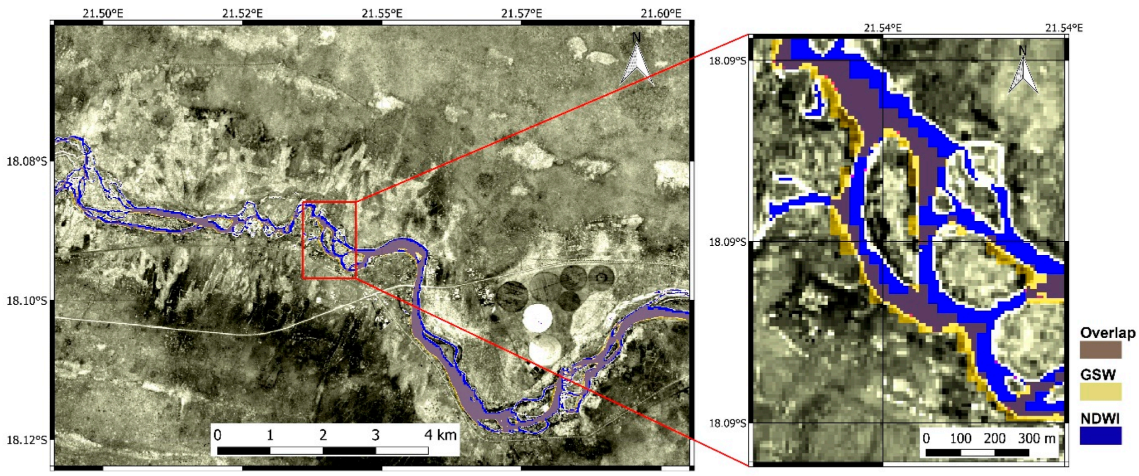


Figure 5. Comparison C: Okavango at Divundu GSW for September 2015 (orange) with Sentinel-2A L1C NDWI (blue >0.5) from 18 September 2015 and overlap (grey).

The three examples (Figures 3–5) illustrate that the procedure chosen for the GSW dataset, with a resolution of 30m, is able to detect narrow shallow water bodies such as Oshanas or flowing, ramified rivers such as the Okavango River on a monthly basis as well as stable larger water bodies such as dams. Against this background, Figure 6 and Table 5 displays the extent of permanent surface water in the different regions in the year 2015 and percentage changes to the area covered in 2000. As described earlier, the absolute figures need to be handled with care for the coastal regions of Karas, Hardap, Erongo and Kunene where ocean water is taken into account as well.

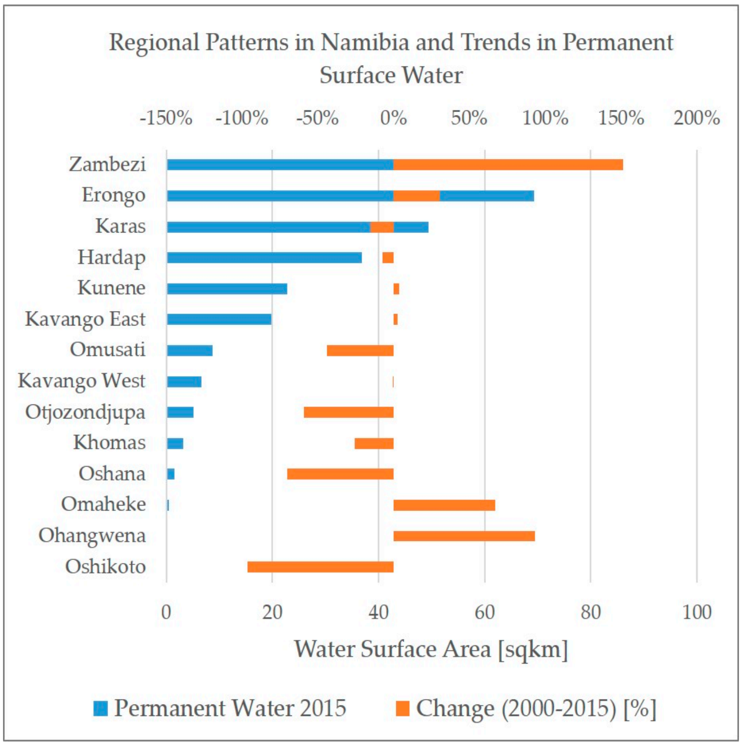


Figure 6. Regional Pattern and Trends in Permanent Surface Water.

Table 5. Permanent Surface Water Coverage per Region.

Region	Permanent Surface Water Coverage
Oshikoto	0.000%
Ohangwena	0.000%
Omaheke	0.001%
Oshana	0.018%
Khomas	0.009%
Otjozondjupa	0.005%
Kavango W	0.027%
Omusati	0.033%
Kavango E	0.083%
Kunene	0.020%
Hardap	0.033%
Karas	0.031%
Erongo	0.108%
Zambezi	0.555%

In order to further illustrate the potential of the GSW dataset, trends in surface water are plotted in more detail for the regular and extraordinary flooding of plains in the northern regions. It was already visible in Figure 1 that the increase in Namibian surface water was highly determined by the 2009 flood in the north east of the country and its aftermath on the surrounding flood plains, while in other affected areas such as Omusati, Ohangwena, Oshana, Kavango, and Kunene, no major trends were visible through the time series of GSW. Figure 7 shows that the Zambezi region with its vast flood plain shows a remarkable increase of water coverage that remained high even after 2009 and which only started to decrease from 2012.

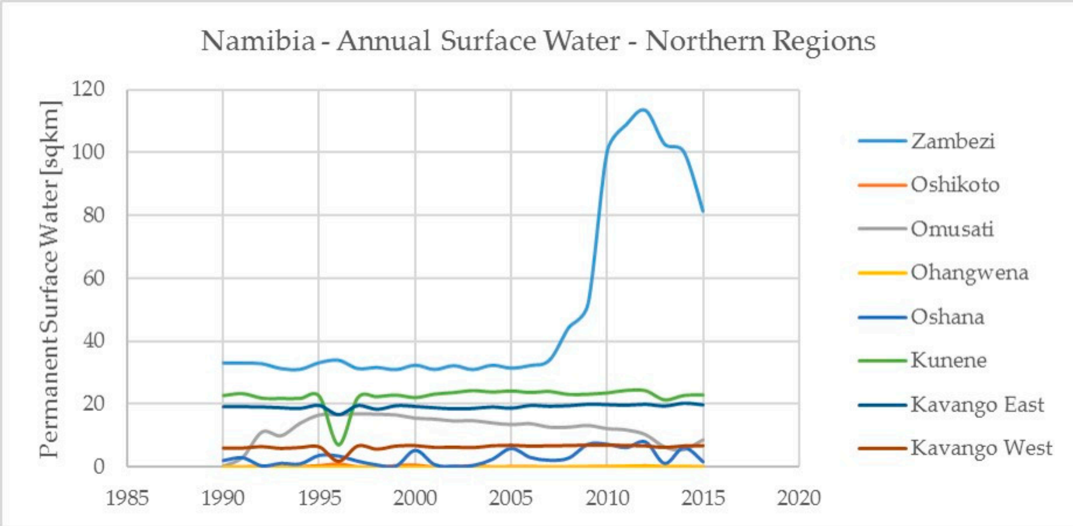


Figure 7. Annual Permanent Surface Water—Northern Regions.

In general, Namibian surface water is highly influenced by seasons. Surface water is mainly visible in the northern provinces and during the rainy season. Consequently, the state of the few perennial rivers in Namibia, the Orange, Kunene, Okavango, Zambezi, and Chobe, all shared with neighboring countries, highly determine the national change of water related eco-systems measured in Indicator 6.6.1.

To evaluate in more detail the GSW potential in this context, monthly data from the GSW dataset between 2008 and 2015 are compared to ground station measurements of the MAWF water levels and flows at the Zambezi River in Katima Mulilo. Figures 8 and 9 show that the monthly data from GSW captures the peaks of water presence in the Zambezi region throughout the year in comparison to water levels and flows of the Zambezi River. Within this data, the higher correlation is visible between the surface area and water flows.

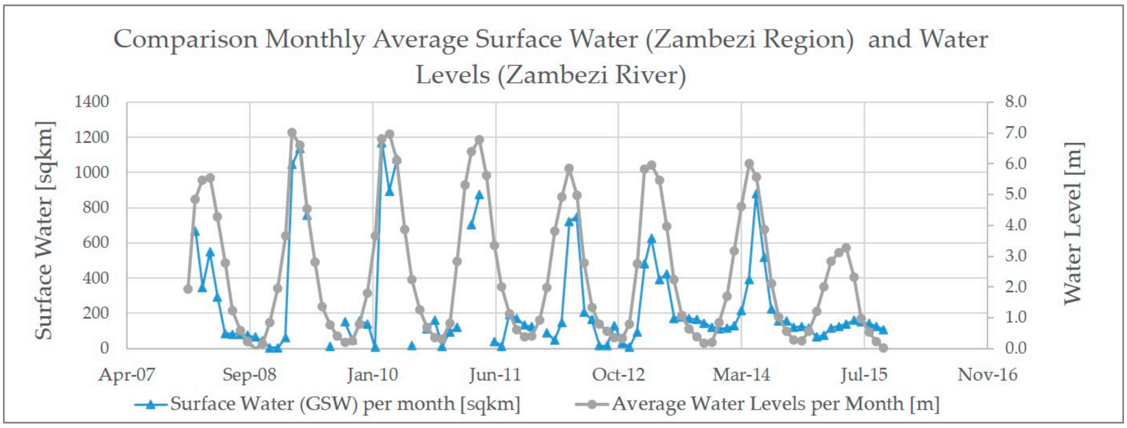


Figure 8. Monthly Average Surface Water and Water Level at Zambezi Region and River.

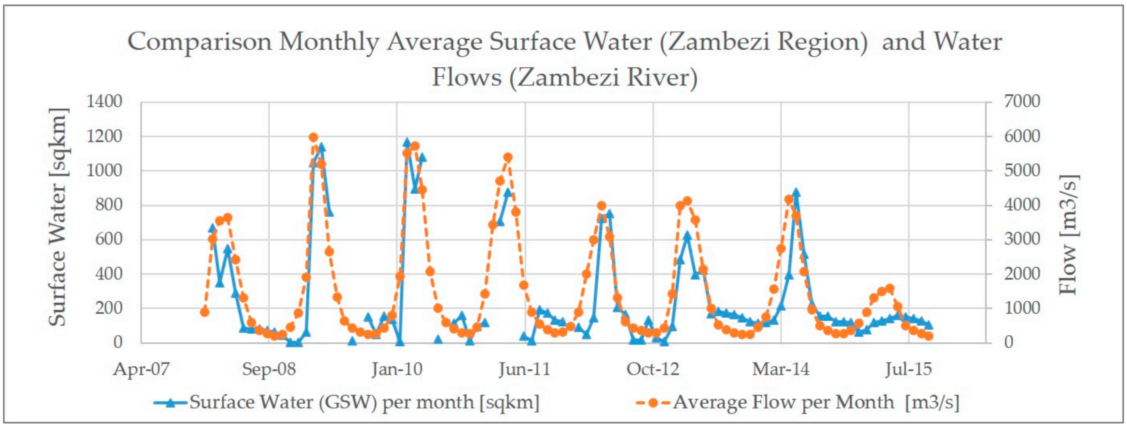


Figure 9. Average monthly surface water and flow at Zambezi Region and River.

Additionally, not only the link between surface water and water flows with respect to the occurrence of peaks is detectable but also the link between the magnitudes of those peaks. Figure 10 shows the correlation of the annual peak values over the years between the Zambezi region surface water and the Zambezi river water flows. For other rivers and regions such as the Kavango, these links are not as visible, indicating a weaker connection between surface coverage and water flows. Data from ground stations support this assumption, showing that the water flow increase in March 2009 of the Kavango (at Rundu) was around 3.2 times its average flow between 2008 and 2015 (Zambezi at Katima 3.9) while its water levels increased only by a factor of 1.6 (2.8 at the Zambezi).

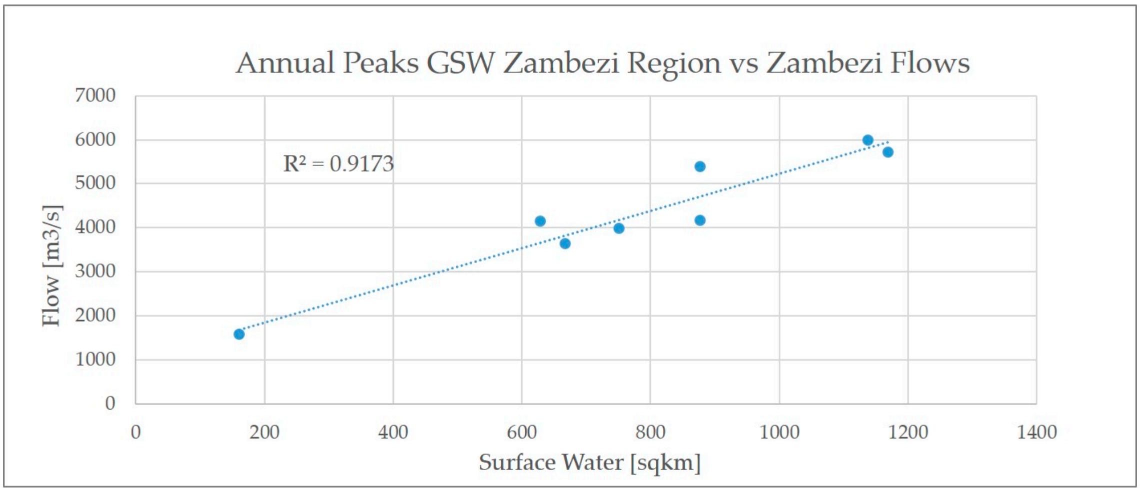


Figure 10. Comparison of surface water and water flows annual peaks between 2008 and 2015.

To understand better the link between the Namibian border rivers and their impact on the livelihood of the neighboring population, a closer look is taken at a historic event—the devastating flood of 2009 in northern Namibia [29]. Figure 11 is a comparison of the water coverage in April 2009 and April 2015 which shows the extent of flooding in the Zambezi Region with the rare filling of Lake Liambezi and its connection to the Zambezi River through the Bukalo Channel [65,66]. This use case demonstrates the potential of the GSW dataset as a basic disaster risk management tool as it clearly indicates affected areas in case of a similar event today.

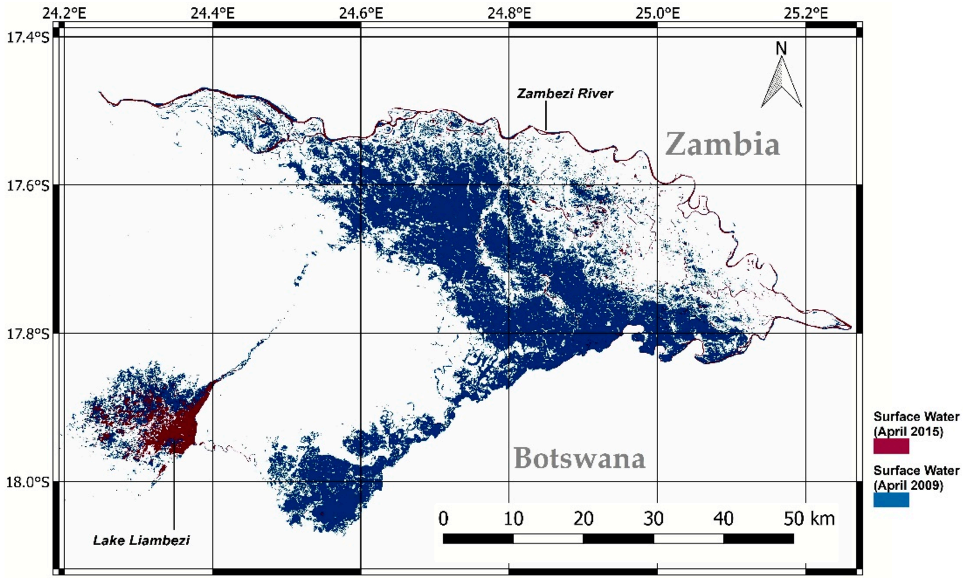
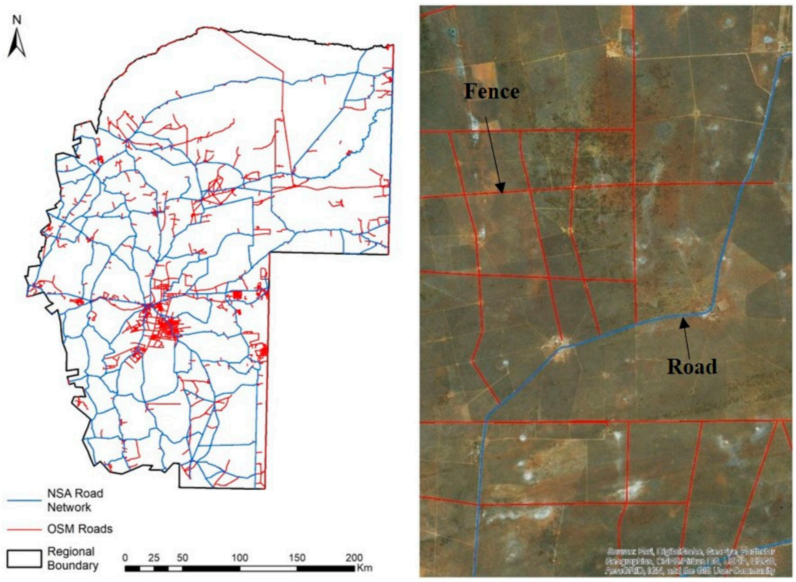


Figure 11. Comparison of surface water in April 2009 (blue) and April 2015 (purple) in the Zambezi Region.

3.2. Access to Roads (Indicator 9.9.1)

Figure 12 shows a visual comparison between OpenStreetMap (OSM) [39] and the NSA's official roadmap [40]. It can be seen that OSM detects more roads than the official roads dataset (Figure 12a) and that it shows unconfirmed roads and objects such as fences classified as roads (Figure 12b). Due to this lack of road quality information and in line with the World Bank approach [67], the OSM was not considered for the further assessment of access to roads for Namibia.



(a) (b)

Figure 12. (**a**) Comparison of OpenStreetMap to Namibia Official Roads, (**b**) zoom on one area showing OSM road as fence.

To evaluate if the access to all-season roads for the rural population could be determined precisely through open datasets, first the population dataset that best fits the official census data needs to be identified. Therefore, different population grids were compared to the population figures in the region of Omaheke originating from the PHC of Namibia of 2011 [45] and NIDS from 2016 [46]. This region was chosen as it is considered to have the most comprehensive DU spatial data set available. Table 6 shows that all extracted total population estimates from the global population grids differ significantly (>10%) from the population estimates from the PHC of 2011 or NIDS in 2016.

Table 6. Total Population estimates for Omaheke.

Year	World Pop 100 m Res	GPW 1000 m Res	GHSL 250 m Res	HRPD 30 m Res	PHC/NIDS NSA
2010	60,150	60,684	-	-	-
2011	60,699	-	-	-	71,233 (Population) 12,128 (Dwelling Units)
2015	62,973	63,095	80,170	-	-
2016	-	-	-	-	74,629
2018	-	-	-	85,437	75,734 (projected, medium variant) [68]

In addition to the overall population grid comparison, an overview is given on the rural population ratio based on the definitions described earlier. The results are listed in Table 7, where the ratio to the total population is written in parenthesis. Here, the estimates appear to be closer to the reference figures of PHC, NIDS, and the DU frame for Omaheke showing that the settlement patterns of the population between urban and rural areas fit better than the overall estimates.

Table 7. Rural population estimated with different datasets.

Year	Rural Definition	World Pop 100 m Res	GPW 1000 m Res	GHSL 250 m Res	HRPD 30 m Res	PHC/NIDS NSA
2010	NSA	47,352 (78.7%)	42,059 (69.3%)	-	-	-
	GHSL Rural mask	-	-	-	-	-
	SNIC Segmentation	52,799 (87.8%)	44,070 (72.6%)	-	-	-
2011	NSA	47,699 (78.6%)	-	-	-	50,030 (Pop) (70.2%) 8,135 (DU) (67.1%)
	SNIC Segmentation	53,204 (87.6%)	-	-	-	-
2015	NSA	49,112 (78.0%)	41,674 (66.0%)	54,307 (68.0%)	-	-
	GHSL Rural mask	55,438 (88.0%)	46,343 (73.5%)	58,390 (72.8%)	-	-
	SNIC Segmentation	53,799 (85.4%)	44,477 (70.5%)	44,145 (55.1%)	-	-
2016	NSA	-	-	-	-	43,284 (Pop) (58.0%)
2018	NSA	-	-	-	58,033 (67.9%)	-
	SNIC Segmentation	-	-	-	54,276 (63.5%)	-

In detail, the results show that:

- between 2010 and 2018, despite the variation in the results, the ratio of rural population with respect to the overall population was decreasing for all sources if the exact same approach is used, indicating a general trend of migration into the urban areas;

- the results from WorldPop and Facebook's HRPD appear overestimated when compared to the NSA census and NIDS data. GPW with a NSA rural definition for 2010 and the GHSL with SNIC segmentation for 2015 seem to have more accurate results compared to the NSA data if the rural/urban is considered.

In Table 8, the RAI is calculated for the different configurations (population grid, rural definition, terrain, and water consideration) and compared to the reference RAI for Omaheke calculated through the DU dataset visualized in Figure 13.

Table 8. 2 km RAI estimated with different datasets in Omaheke.

Year	Rural Mask	Terrain/Water Considered	World Pop (no UN adjustment) 100 m Res	GPW 1000 m Res	GHSL 250 m Res	HRPD 30 m Res	DU NSA (Ind. Unit)
2010	NSA	No/No	35,009 (73.9%)	15,793 (37.6%)	-	-	-
	GHSL Rural mask	No/No	-	-	-	-	-
	SNIC Segmentation	No/No	40,149 (76.0%)	17,675 (40.1%)	-	-	-
	NSA	Yes/Yes	35,009 (73.9%)	15,793 (37.6%)	-	-	-
2011	NSA	No/No	35,265 (73.9%)	-	-	-	DU = 4,816 (59.2%)
	SNIC Segmentation	No/No	40,462 (76.0%)	-	-	-	-
2015	NSA	No/No	36,310 (74.0%)	15,680 (37.6%)	34,512 (63.5%)	-	-
	GHSL	No/No	42,318 (76.3%)	20,197 (43.6%)	38,596 (66.1%)	-	-
	SNIC Segmentation	No/No	40,680 (75.6%)	18,331 (41.2%)	28,084 (63.6%)	-	-
2018	NSA	No/No	-	-	-	36,104 (62.2%)	-
	SNIC Segmentation	No/No	-	-	-	32,341 (59.6%)	-

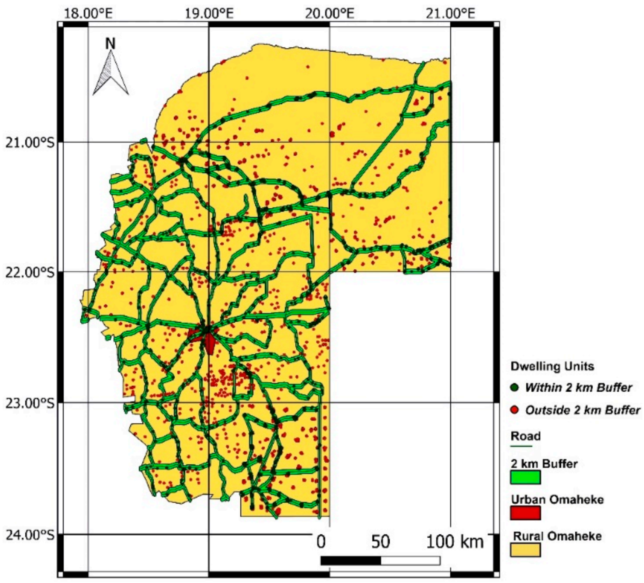


Figure 13. Rural Omaheke Dwelling Units 2011—within 2 km road buffer zone.

The results of Table 8 show that:

- The volatility caused by the urban/rural definition is relatively low with respect to the RAI for Omaheke but high for the rural/urban ratio of the population count.
- The estimates are highly dependent on the population grid, ranging from 37.6% (GPW, 2015) to over 75% for Worldpop. It appears that the low-resolution population grids (GPW and GHSL) are more inaccurate. This could be the result from the uniform distribution of the population within each grid cell. For a 2 km RAI, it can be assumed that the grid cell must be significantly lower than 1000 m. Unfortunately, for the RAI comparison, no DU frame update could be provided as reference after 2011. In general, the estimates for GHSL and HRPD with the NSA urban definitions of 2015 are respectively around 60%, which would be comparable to the 2011 NSA figures.
- For Omaheke, no effect of terrain and water is visible. Tests with regions with more water bodies such as Zambezi, and mountainous regions such as Kunene show evenly no difference, indicating that with the chosen approach to include terrain and water no changes in the results exist. Hence, in Namibia access to roads appears marginally affected by natural obstacles but mostly determined by road infrastructure. However, further investigations are needed to assess the weight of terrain and water for certain remote settlements in Namibia.

Figure 14 provides the rural estimates from the HRPD (with SNIC segmentation) for all Namibian regions for 2018. If compared to the rural figures for NIDS from 2016, the estimates appear representative even though they are based on population density and not administrative areas. On the national level, both datasets indicate 52% as rural population in Namibia.

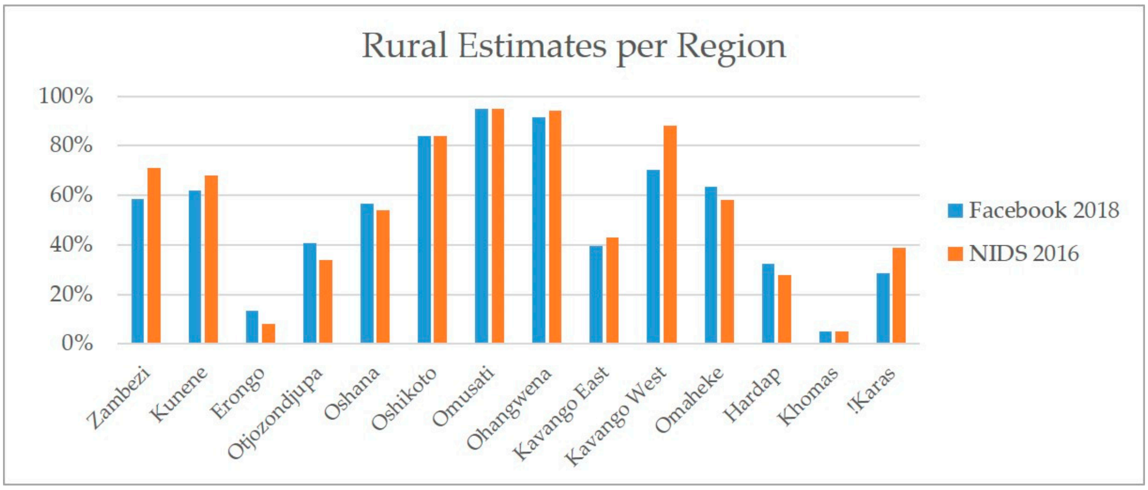


Figure 14. Rural population ratio estimates per region.

Based on the data above, the RAI originating from Facebook's HRPD population map and SNIC segmentation is shown for each region in the table below. Even though, these numbers are not considered to represent accurate figures, the corresponding RAI estimates do valuably highlight the differences in the regions (Table 9).

Table 9. 2 km RAI estimated per region with Facebook's High Density Population Map 2018 and SNIC segmentation.

Region	Population Overall	Rural Population	RAI
Zambezi	112,939	65961 (58.4%)	50,760 (76.9%)
Kunene	109,999	68,350 (62.1%)	43,387 (63.5%)
Erongo	203,437	27,602 (13.6%)	19,930 (72.2%)
Otjozondjupa	173,172	70,413 (40.7%)	49,364 (70.1%)
Oshana	213,232	120,939 (56.7%)	80,180 (66.3%)
Oshikoto	222,515	186,744 (83.9%)	82,211 (44.0%)
Omusati	289,450	274,491 (94.8%)	137,318 (50.0%)
Ohangwena	295,692	270,159 (91.4%)	144,945 (53.6%)
Kavango East	172,897	68,514 (39.6%)	58,179 (84.9%)
Kavango West	106,237	74,848 (70.5%)	53,861 (72.0%)
Omaheke	85,437	54,276 (63.5%)	32,341 (59.6%)
Hardap	98,125	31,835 (32.4%)	21,027 (66.1%)
Khomas	446,461	23,041 (5.2%)	13,974 (60.7%)
!Karas	93,814	26,965 (28.7%)	17,671 (65.5%)
National	2,623,407	1,364,138 (52.0%)	805,148 (59.0%)

3.3. Forest Coverage (Indicator 15.1.1)

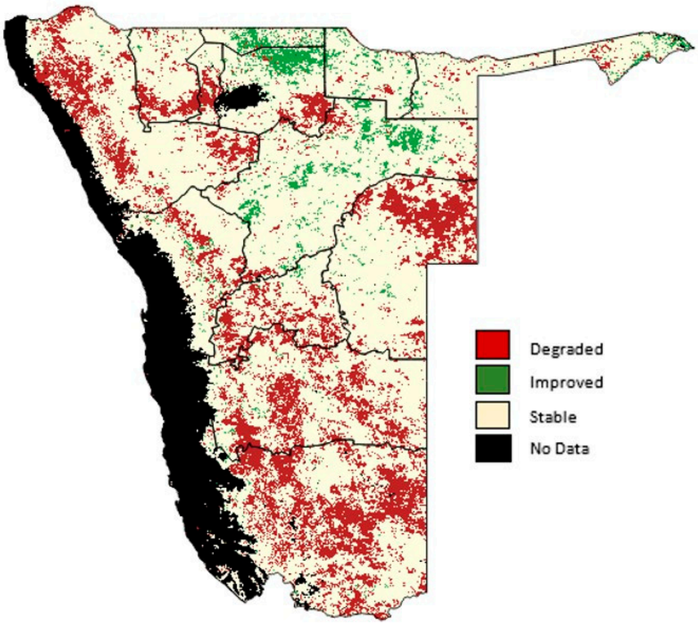
Table 10 shows that the derived figures from Trends.Earth for tree coverage and the official FAO reporting for forest coverage in Namibia are similar at around 9%, while the tree coverage published by GFW following the Hansen et al. dataset [23] displays significantly lower values. Furthermore, the trends from the FRA of FAO and the biophysical observation of tree coverage show opposing trends between 2000 and 2015. Due to the variation in the results, no further analysis was conducted with respect to tree coverage in Namibia as prior to this a national standard needs to be defined indicating which methodology to be used for the official SDG reporting.

Table 10. Forest/Tree Coverage Namibia 2010 and 2015.

Method	Source	Description of Forest/Tree Coverage	Tree Coverage
A	Trends.Earth (Own Calculation for Namibia)	- Tree cover, broadleaved, evergreen and deciduous, closed to open (>15%) - Tree cover, needle leaved, evergreen and deciduous, closed to open (>15%) - Tree cover, mixed leaf type, closed to open (>15%) - Mosaic tree and shrub (>50%)/herbaceous cover (<50%) over total land area (excluding water bodies)	2000: 9.08% 2010: 9.46% 2015: 9.54%
B	FAO (FRA) [54]	Forest cover is defined as land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in-situ. It does not include land that is predominantly under agricultural or urban land use.	2000: 9.8% 2010: 8.9% 2015: 8.4%
C	GFW	For the purpose of this study, "tree cover" was defined as all vegetation taller than 5 meters in height. "Tree cover" is the biophysical presence of trees and may take the form of natural forests or plantations existing over a range of canopy densities.	2000: 0.30% 2010: 0.32%

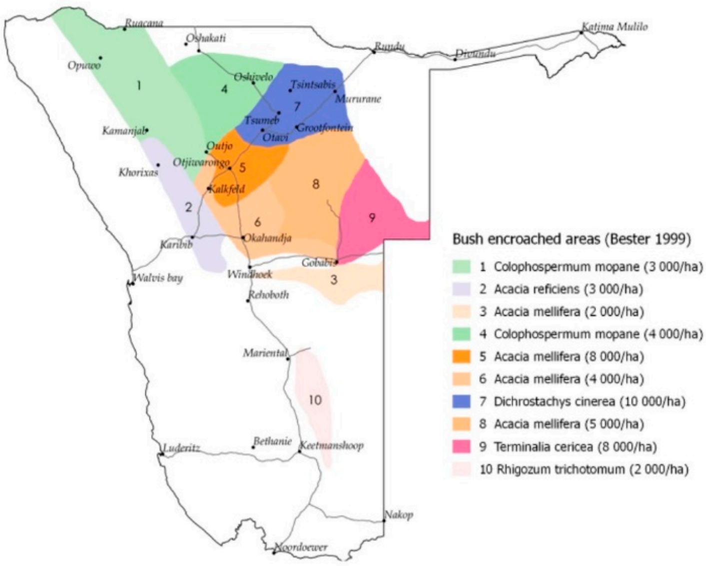
3.4. Land Degradation (Indicator 15.3.1)

Figure 15 shows the extent of degraded land between 2001 and 2015 according to the UNCCD definition used in Trends.Earth along with an assessment of bush encroachment types in the country from 1999 [60]. Figure 15b and a recent update from a Strategic Environmental Assessment in 2015 showing bush encroachment and the invasion of Prosopis trees [13] (Figure 15c). Furthermore, through Figure 16, a land cover map of 2016 for Otjozondjupa [61] is compared to the estimates of degraded land from Trends.Earth for the same region. The different maps indicate a large discrepancy between the evaluation of degraded land with international standards visible mainly in the south and the national evaluation of bush encroachment as a factor for land degradation mainly occurring in central Namibia. Consequently, prior to the application of EO solutions for the monitoring of SDG 15.3.1, a national consensus needs to be reached on a definition of "degraded land" in Namibia.



(**a**)

Figure 15. *Cont.*



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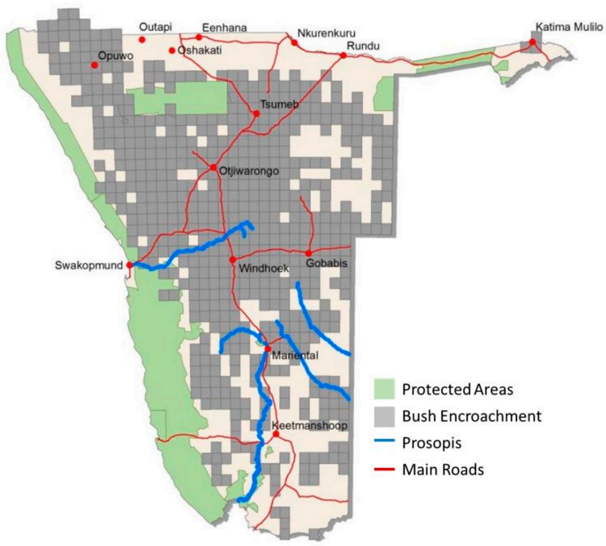
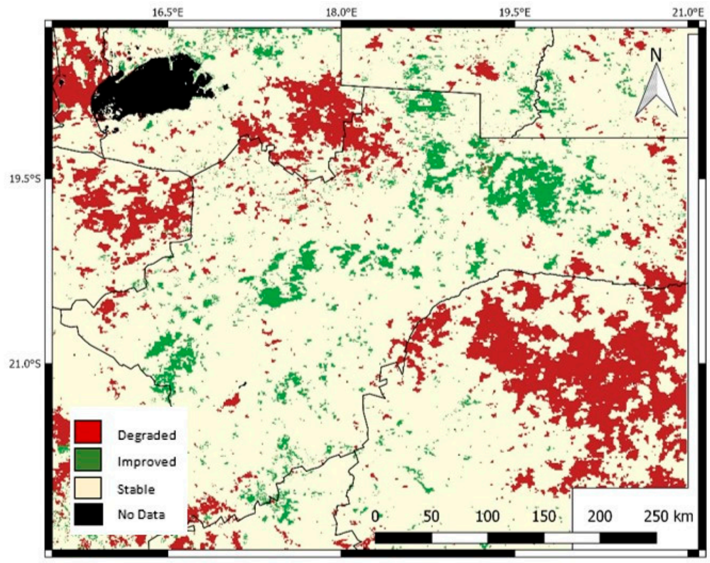


(**c**)

Figure 15. Comparison Land Degradation Map between 2001 and 2015. (**a**) Own calculation, (**b**) bush encroachment areas in 1999 [60], and (**c**) bush encroachment extent in 2015 [13].



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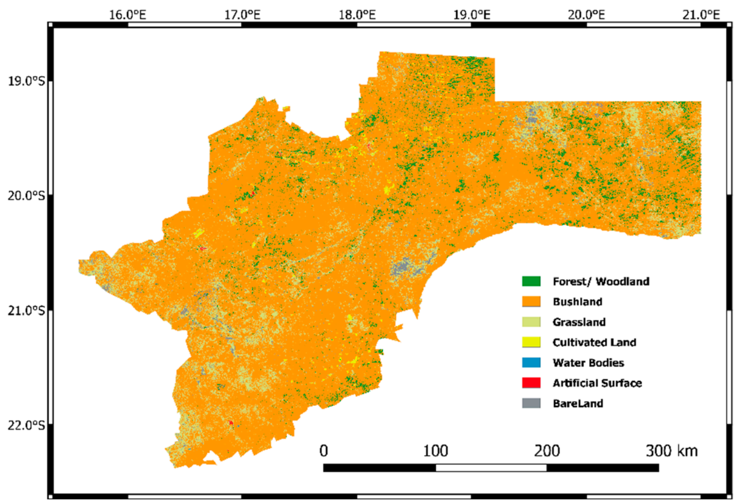

(**b**)

Figure 16. Comparison Land Degradation Map between 2001 and 2015 with (**a**) own calculation with Trends.Earth, and (**b**) bush encroachment areas in Otjozondjupa 2016 [61].

4. Discussion

The study is a first evaluation of EO solutions available to derive information on SDG indicators from open data sets and tools for Namibia and does not claim to provide a final picture on the matter. Taking into account the shortcomings in access to data and lack of clarity on methodologies of nationally published information, the study could not provide in-depth assessments for each indicator and was limited in making more use of ground-truth data and studies expected to be available in the country. Furthermore, references used were not always available on a suitable scale and for a relevant time period.

Still, the presented results support the assumption that open data and open EO solutions can be used to support the monitoring of a variety of SDG indicators in Namibia. The article shows that, thanks to the availability of analysis ready data (ARD), suitable information can be produced even without strong pre-processing expertise, storage, and processing capacity. The utilization of these tools provides a remarkable opportunity for Namibia and other countries to increase their monitoring capacity without major investments in time and resources in the existing data production system. Having the advantage of large spatial and temporal coverage, high standardization of data production, and frequent updates at a high reliability and low cost, open EO solutions are able to fill prevailing data gaps and can start to be incorporated into the Generic Statistical Business Process Model (GSBPM) [8].

On the other hand, if used without an initial validation and an in-depth assessment of the specific context, the solutions pose a risk of misleading reporting due to the fact that the barrier to retrieve maps and statistics is reduced. Furthermore, the solutions constitute a risk of ownership to NSOs in two ways. First, the tools can be used and results can be produced outside the institution that has the mandate to report on national statistics and second, NSOs "have little control or mandate with respect to big data held by private entities" [8].

To assess these risks in more detail, three levels of utilization of open EO solutions can be distinguished with different implications:

- First, using open data such as those originating from the Copernicus Program of ESA or Landsat from NASA in combination with innovative web applications (e.g., Sentinel-Hub) with integrated analysis functions (e.g., NDWI) reduces the limitations in storage and processing hardware fundamentally. In addition, these resources allow for the flexibility to use the information for specific investigations and post processing methods with the benefit of hosting updated information in a predictable manner. On the contrary, expertise is needed to process the data for specific analysis.
- Second, the utilization of platforms such as GEE allows us to source, in addition to raw satellite data, a variety and growing number of pre-processed datasets (e.g., GSW) and user-specific data layer combinations for a customized analysis (e.g., the different methods for Indicator 9.1.1). Moreover, stored pre-processed data layers rely on global expert knowledge and peer reviewed methodologies, which represents a remarkable support for non-experts. However, the user has no influence on the maintenance and updates of the datasets stored in GEE (e.g., GSW) and their applicability in the given context (e.g., Hansen et al. Forest Cover dataset for Indicator 15.1.1).
- Third, the utilization of fixed standalone tools or plugins such as Trends.Earth ensures a high level of comparability of data and reduces the risks of wrong processing. On the other hand, it limits the user's potential to decide on the methodology, apply customized approaches, and use updated or supplementary data layers. Still, these tools provide the biggest benefit for non-technicians and decision makers, enabling them to compare a state over time and space.

Besides the procedural opportunities and risks listed above, the UN Satellite Task Team indicates certain requirements for the use of EO solutions to decide whether or not to integrate them in the statistical system (Table 11).

Table 11. Requirement of the use of EO for official statistics [8].

Requirement	Questions
Justification	Do you need to use EO? Is there a better alternative source?
Suitability	Can EO provide the required data products?
Spatial resolution	What is the appropriate size of pixel?
Temporal frequency	What is the required frequency of these EO data acquisitions?
Record length	How far back in time does your data record need to go?
Reliability	Do you need guaranteed continuation of data supply into the future?
Accuracy	What degree of accuracy is needed in the information product?
Maturity	Do you want to use only information products that are well documented and are commonly used?
Complexity	What data management, processing and analysis capacity is available?

In general, it appears that the growing existence of universal EO solutions shifts the challenge from the production and storage of data more towards the validation of the data in the national context and the harmonization of standards to have a national consensus on which methodology to use. This might explain the fact that, despite having available multiple open tools and data layers that are relevant to the SDGs, the official reporting of countries has not yet adopted them in a systematic way. However, the clarity and consistency of the SDGs and the commitment of all countries to continuously monitor progress through the SDG indicator framework is a great opportunity to converge the variety of EO solutions and methodologies into best practices based on the experiences of all countries.

The assessment of the four SDG indicators tested in this study and the conclusions of further utilization in Namibia are presented in the section below and should be seen in the light of the discussed potential, the given requirements, and the prevailing limitations.

5. Conclusions

The conclusion over the usability of the tested EO solutions as suitable contributors to Namibia's official SDG monitoring system depends on the indicator in question. The following sections provide the recommendations regarding the suitability of the corresponding EO solution for each indicator studied in this article.

5.1. Change of Surface Water (Indicator 6.6.1)

The application of the GSW dataset is considered to be a powerful method for a cost effective, robust, qualitative measurement of seasonal, long term trends, regional patterns, and specific investigations of historic events of surface water in Namibia. As absolute values are highly dependent on the boundaries set and do consider ocean water for certain regions, it is not recommended to emphasize the actual surface area covered by water for national monitoring but rather to use the information to derive qualitative trends. For Namibia, the monthly data of GSW is more useful than annual or 5-year average values due to the high variation of surface water caused by regular flooding of the northern rivers. However, the datasets need to be used with care as they are not completely populated for each month (see Figure 8) and experience from Canada shows that important surface water might not be detected prior to 2000 [15]. Even though updates are expected to be added to the GSW dataset on a regular basis (e.g., for data until 2018 in May 2019) the continuation of monitoring capacity is dependent on external actors. Because of this, no national ownership and opportunities to broaden the data is given to Namibia. Still, in the absence of national data sets on surface water at MAWF and limited resources to produce maps from Landsat or Copernicus directly, the GSW dataset is considered to be a transparent, high quality EO solution to be used in the national SDG monitoring for Indicator 6.6.1 in the future. As an additional asset, the experience from natural disasters, such as the floods of 2009, and the detected water coverage can serve as an easy to use DRM tool to mitigate the impact of similar events in the future.

5.2. Access to Roads (Indicator 9.1.1)

Historically, the accessibility to roads was estimated through survey data. The availability of open source population grids makes it easier to estimate the RAI by spatial analysis and automate its calculation at minimal cost and effort using GEE at given points in time and at all levels. However, open data updated by external actors inherits the risk that they are not maintained in all areas consistently. Therefore, government data from census should be used whenever possible. Furthermore, many of the global population grids use national census datasets as input variables and therefore are still indirectly linked to national data. The identification of rural settlements can be performed conveniently with modern segmentation approaches such as SNIC. With ongoing production of both, higher precision satellite imagery as well as improved algorithms, the accuracy for the assessment is expected to further increase. Still, the results showed a high volatility with respect to the selected input datasets and a significant discrepancy to national census data. Hence, detailed investigation is necessary to find explanation for the discrepancies and search for ways to increase the accuracy. Therefore, for Namibia, it is not yet recommended to use global population grids for official reporting on the SDGs. However, trends and patterns, if the same methods are applied, could be regularly determined through the developed applications.

5.3. Forest Coverage (Indicator 15.1.1) and Land Degradation (Indicator 15.3.1)

The application of EO solutions to monitor forest coverage and land degradation gave similar experiences. Results can be easily extracted in a consistent, transparent, and customized manner with existing open source data and tools. The discussions with national stakeholders arising from the results showed that the challenge to use them as official SDG monitoring is not the technical feasibility to extract information but rather the absence of suitable national standards defining which methodology to use. A recent effort by the World Bank to introduce specific monitoring tools for dry forest in the framework of the Satellite Monitoring for Forest Management (SMFM) [52] in Namibia will provide further input on the necessary discussions. Hence, it is recommended to strengthen and harmonize current undertakings to produce land cover maps and establish national standards, ideally aligned with international definitions so that the tested tools can contribute to national statistics in the future. It is desired that the study gives valuable input for the discussions to come. Still, as of now, it is not recommended to use the results for Indicators 15.1.1 and 15.3.1 through EO solutions as official national statistics.

5.4. General

The presented study resulted from the overall undertaking of the Namibian–German project SDG-Initiative to support the establishment of a national SDG monitoring system. Extensive consultations with data providers showed that for a variety of information, even beyond the scope of the study, EO solutions and spatial datasets were already used in the country. However, most of the information was produced on case by case basis using the classical approach of downloading, archiving, and processing information of dedicated areas. Through this, information is only available for a specific period or a specific area. The next step, to produce national statistics on a regular basis, is not yet achieved. It is the authors' hope that the presented information will contribute to the paradigm change to use open data and tools more extensively in the future in Namibia and can serve to stimulate the same evaluation in other countries.

Author Contributions: V.M. and E.B. conceptualized the investigation on suitable EO solutions for the SDG Monitoring in Namibia. V.M. tested and assessed results for Indicator 6.6.1, 15.1.1 and 15.3.1; E.B. and V.M. assessed methods and definitions for indicator 9.1.1. K.R.O. developed the GEE applications to extract and visualize information from GSW for indicator 6.6.1 and developed different methodologies and a GEE application for indicator 9.1.1 tested by V.M. and E.B. against the national datasets. V.M. wrote the paper.

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