Use of Current Remote Sensing Methods for Biodiversity Monitoring and Conservation of Mount Kilimanjaro National Park Ecosystems

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Abstract: Climate and land use change have become serious challenges facing protected areas globally, more so those in the tropical forest ecosystems. Kilimanjaro-Mountain National Park was specifically designated to protect and safeguard the highest free-standing mountain in the tropics. The park attracts thousands of national and international tourists annually because of its snow capped-summit and the altitudinal gradients, representing the different eco-climatic zones of the world. Earnings from tourism boost the country's economy while ensuring the sustainability of this unique glacial-tropical mountainous forest ecosystem park. Conventional monitoring of key biodiversity and environmental parameters are carried out by park staff, following established guidelines by Tanzania National Parks. However, given the park's geo-morphological nature of mountainous terrain, efficient implementations of the labor intensive in-situ observations are hardly feasible. This research explored the use of Remote Sensing data from the European Satellite Agency–Sentinel- 2 Multi-Spectral Instrument, in developing a state-of-the-art monitoring protocol. The developed methodology ensures that essential biodiversity parameters, including Vegetation Indices, required in monitoring the vast areas of the park and its surroundings in the short-term and long-term, using up to date, high resolutions and frequently available Remote Sensing data from the Sentinel-2 Sensors are captured.

1 INTRODUCTION

It is well known that protected areas particularly those in the tropics face key challenges linked to loss of wildlife habitats, mainly due to land use changes in their surrounding ecosystems whilst exacerbated by the increasing impacts of global climate change (Peters, et al. 2016; Burgess, et al., 2017; Tabor, et al., 2018). Kilimanjaro Mountain National Park and its associated ecosystem represents such a world-wide unique and diverse habitat, with an altitudinal range of over 5,800 m and associated with climate and vegetation zones changing from the tropical savannas at the lowlands to the afro-alpine grasslands at the top (Hemp, 2009). Apart from the natural ecosystems within the national park, several land use types occur in the vicinity, including intensive annual monocultures (maize and other cereals), perennial coffee-plantations and diverse traditional agro-forestry systems of Chagga-Home-gardens which to some extent retain a semi-natural forestry structure (Hemp and Hemp, 2018).

This highest free-standing mountain in Africa acts as a water tower by feeding major river systems in the region. The tropical mountainous forest ecosystem plays a major role in the regional climate regulation, while providing many other important ecosystem services to the locals and beyond (Hemp and Hemp, 2018). Its melting "ice cap", which is an important tourism attraction by mountaineers and tourists visiting the park every year, though caused by decreasing precipitation (Hemp, 2005; Thompson, et al. 2002) rather than by increasing temperature, has become a global symbol for the accelerating trend of global warming. The KiLi-Project, funded by the German Research Foundation (DFG) studied the influence of climate and land-use change on biodiversity and multiple ecosystems processes on Mount Kilimanjaro from 65 established plots, across twelve different land covers and land uses along the elevation gradient (vertically from the lowlands of *Colline* savannas to the highest peak of vegetation layer dominated by the *Hellichrysum*) and across the land use gradient from the protected

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tropical montane forest of Kilimanjaro National Park to the disturbed lowlands of the savannas currently converted to intensive monoculture crops cultivation (Appelhans, et al., 2016).

This study, capitalizes on the recently concluded “KiLi1”-Project (2010-2018), with the main objective of a follow-up monitoring strategy for the Kilimanjaro National Park, being the custodian in ensuring the continuity of the ecosystem services provided by the park to the local, national and the international community at large. Apart from the direct ecosystem services provided by the park in its natural settings, it is particularly a key tourist destination in the country, contributing to the local and national economy from the foreign currency accrued through the tourism business and its tripling effects to the local communities surrounding the park. In doing so, Kilimanjaro National Park is vested with the responsibility of protecting this uniquely massif standing tropical montane cloud forest in the long run, at the face of its increasingly isolation from its surroundings, mainly through habitat conversions from the natural forest vegetation to croplands because of the adjacent intensifying land uses spearheaded by the increasing human population pressure (Hemp and Hemp, 2018).

The study explored the use of remote sensing by deploying the current state of the art from the Sentinel-2 Multi-Spectral Instrument (MSI) satellite of the European Satellite Agency (ESA), in developing a workflow protocol data-model tool. The implementation of the workflow protocol will enable “in-situ repeated observations up-scale”, which are hardly feasible in such a large protected area’s challenging ecosystem by park staff. The currently available data from the Sentinel-2 MSI provides multi-spectral bands with high spatial resolutions and quick revisit time of five days for both sentinel 2 A & B (ESA, 2017). The Sentinel- 2 MSI is comprised of 13 spectral bands ranging in resolutions from 10 m, (four bands) inclusive of the visible wavelengths; 20 m (six bands) inclusive of the new “Red-Edge”, near-infra red and short-wave infra-red wavelengths; important for vegetation monitoring and with high capabilities for use in ecosystem, biodiversity and conservation monitoring (Drusch, et al. 2012). The other three bands are of 60 m resolution including the aerosol, water vapor and cirrus bands (Table 1).

Table 1: Spectral bands available from the Sentinel- 2 A (since June 2015) and Sentinel- 2 B (since March 2017) NIR = near infra-red; SWIR = short wave infra-red; (Credit: ESA, 2017).

Sentinel -2 MSI Bands	**Central Wavelengths (µm)**	**Resolution (in m)**
Band 1 – Coastal Aerosol	0.443	60
Band 2 – Blue	0.490	10
Band 3 - Green	0.560	10
Band 4 – Red	0.665	10
Band 5-Red edge 1	0.705	20
Band 6-Red edge 2	0.740	20
Band 7-Red edge 3	0.783	20
Band 8- NIR	0.842	10
Band 8A – NIR	0.865	20
Band 9-Water vapor	0.945	60
Band 10 – SWIR-Cirrus	1.375	60
Band 11-SWIR- 1	1.610	20
Band 12-SWIR- 2	2.190	20

Spectral signatures and derived indices like the Normalized Difference Vegetation Index (NDVI) are used as a standardized way to measure the health of vegetation by quantifying the ratio of the difference between the NIR (strongly reflected by vegetation) and Red (strongly absorbed by vegetation). NDVI values ranges from -1 to + 1, with a distinct boundary for each type of land cover. Negatives likely represent water, while positives close to one indicate dense green leaves. However, values close to zeros represent no leaves (green vegetation) or degraded forest (Figure 1). In this research project, Sentinel – 2 MSI spectral bands and derived products, including the vegetation and biophysical indices such as NDVI and leaf area index (LAI), were explored and analyzed with the following objectives;

- Explore current RS data and methods in developing a biodiversity and conservation monitoring tool in the Kilimanjaro National Park and its surrounding ecosystems
- Link remote sensing derived information with in-situ data and predict/retrieve spatially explicit biodiversity measures
- Demonstrate the explanatory power in biodiversity analysis and its contribution to a deeper understanding of the biodiversity

and potential linkages to ecosystem functions along climatic and anthropogenic disturbance gradients at Mt. Kilimanjaro.

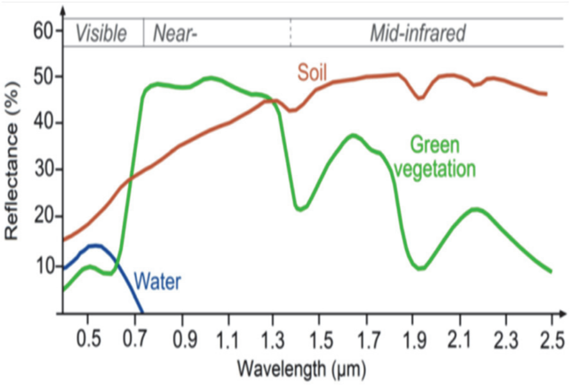

Figure 1: Spectral Bands Reflectance's Mapping Application of the Sentinel-2 MSI (*Credit: ESA, 2017*).

2 MATERIALS AND METHODS

2.1 Study Area

The Kilimanjaro Mountain National Park and its ecosystems, is located in the north-east of Tanzania (Figure 2) and spans an elevation gradient from the colline savanna plains (~ 700 m a.s.l.) to the glaciated areas encircling Kibo summit (5895 m a.s.l.). Its equatorial daytime climate is shaped by the passing of the inter-tropical convergence zone, with more than half of the annual rainfall occurring during the so called long-rainy season (March-May), (Appelhans, et al., 2016). While annual precipitation amounts to more than 2500 mm in the southern montane forest belt, the northern mountain side (lee ward) receives hardly more than 1000 mm (Hemp 2005; Detsch, et al., 2017).

The mountain's belt-like vegetation zonation (Figure 3) is characterized by major land-cover transitions at short horizontal distances resulting from changing climatic conditions and anthropogenic interferences (Hemp & Hemp 2018). This study covered the land-cover distributional zones which were marked by the 65 Kili-Research Project Plots (Detsch, et al., 2017; Appelhans, et al. 2016), which were distributed along the mountain elevation gradient; from the lowlands of savanna vegetation to the top elevation zone covered by the *Hellichrysum* spp. Plots were also selected to cover twelve land-cover uses, from the total protected forests in the park, dominated by *Ocotea*, *Podocarpus* and *Helichrysum* vegetation to the intensive monoculture crop cultivation dominated by Maize and the Coffee plantations.

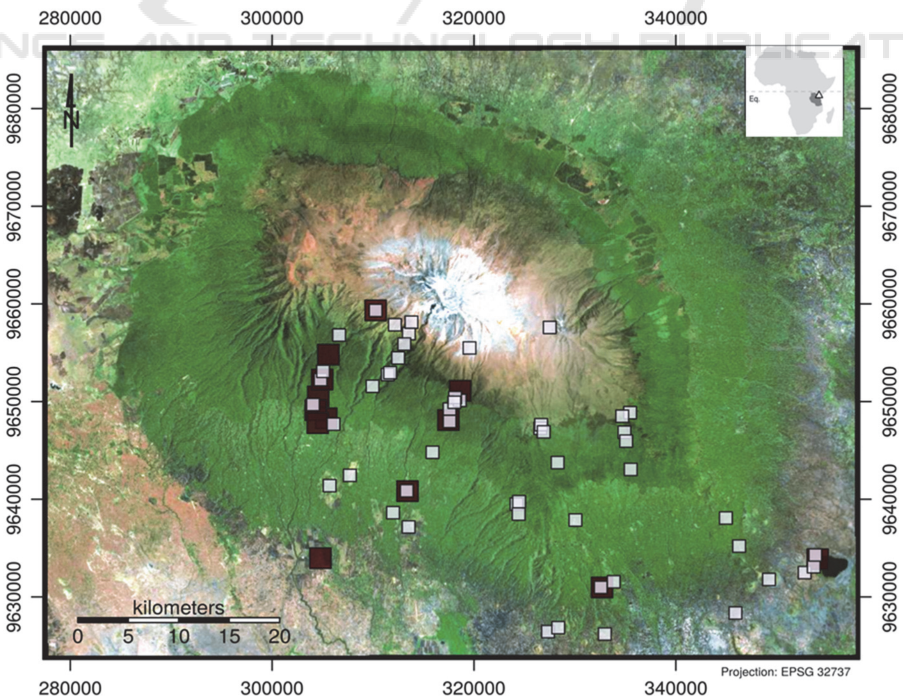

Figure 2: Study Area- the Kilimanjaro Mountain Ecosystems in Africa-Tanzania-(inset), showing the distribution of the sampled plots along the elevation and land-cover/use types gradient (Appelhans, et al., 2016).

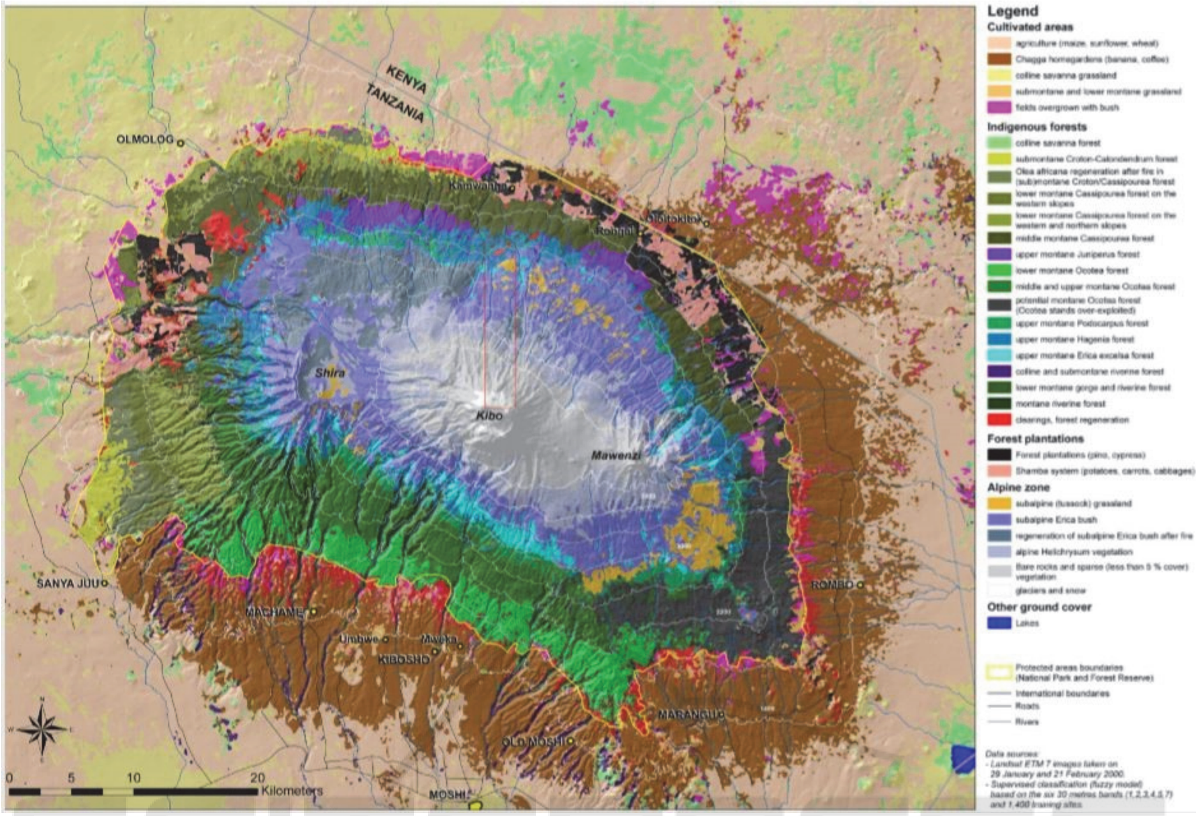

Figure 3: Map of Kilimanjaro Mountain Ecosystems showing land-cover/use vegetation types (Hemp and Hemp, 2018).

2.2 Sentinel 2 MSI Data Sets

Sentinel- 2 datasets used in this project were downloaded from the ESA-Copernicus website, https://sentinels.copernicus.eu/web/sentinel/sentinel-data-access/registration. The Kilimanjaro is covered with two-sentinel 2 tiles area wide; the T37MBS on the western side and the T37MCS on the eastern part according to the date of acquisition, in this case scenes taken between 2016 and 2019. Sentinel 2 A and B image data were searched and downloaded for the study area. The selected scenes were chosen based on cloud cover percentages in order to obtain good quality images. However, given the nature of the Kilimanjaro, being a tropical cloud montane forest, it is almost impossible to acquire cloud-free scenes at any time of the year. Images with less than 10 percent of cloud covers were downloaded from both sentinel 2 A and B, as Level 1 C Top of Atmosphere (TOA) products, through the Sentinel Application Platform (SNAP) Software. SNAP is also available for free through downloading at the ESA-Copernicus website, with its associated plug-ins, for the pre-processing of the Sentinel-2 data.

The downloaded images were further processed for atmospheric effects from the top of atmosphere Level 1C to bottom of atmosphere (BOA) Level 2A products, using the *Sen2Cor* Algorithm-plug-in from SNAP (Wilm, 2018). In order to automate the process, the image products (L1C) were exported from the SNAP- graphical processing tool (.gpt) into the R software, as .xml files for commands and functions creation using the R Studio processing environment. In R, image files were further corrected for atmospheric effects, to Level 2A products using the *Sen2Cor* algorithm. Image outputs were then used for the follow-up stages of extracting the various vegetation and biophysical indices from the sentinel-2 imagery data. In order to create a cloudless image, the T37-MBS and T37-MCS tiles had to be processed separately before mosaicking of the tiles using the *Cloud-Mask* layer, also produced as part of the level 2A processing output, performed in R as shown in Figure4below.

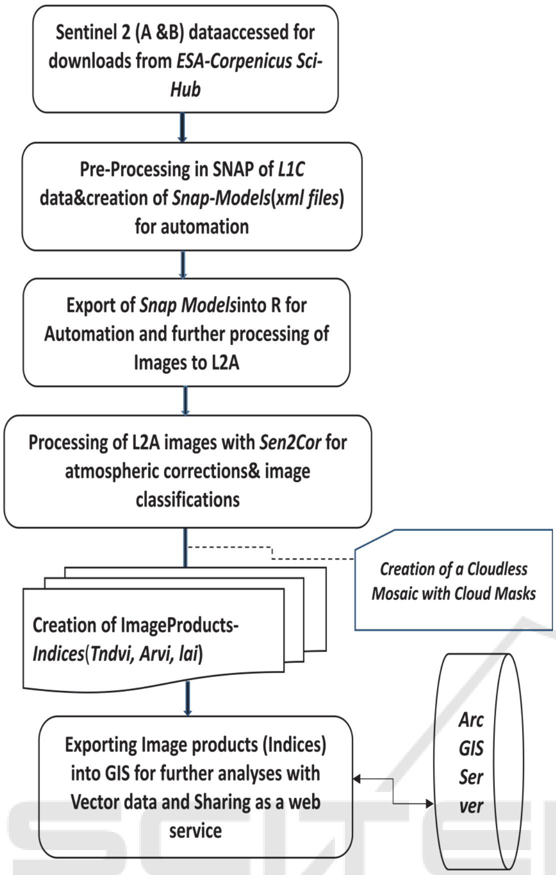

Figure 4: Workflows for access, pre- and processing, analyses and sharing Outputs of Image Data from Sentinel-2 through the TANAPA GIS Server.

2.3 Vegetation and Biophysical Indices Derived from Sentinel-2 Data

Creation of commands-data models for indices extraction automation was performed after the atmospheric corrections for each of the scenes, according to the date of acquisition, as year, month and day for the matching tiles. In order to ensure that the sampled indices from the Level 2A image products were not affected by clouds, further processing of the Level 2A image scenes using cloud masks application, as a byproduct of sentinel-2 data from the classification, was performed in R. Several vegetation and biophysical indices including the NDVI and its derivatives, and the leaf area index (LAI) were extracted using the created “Snap Models” function in R-Software environment. The output products (images), were exported as image files (Geotiff) into a GIS (QGIS/ArcGIS) software for visualizations and further analyses, including overlaying with the plots (sampled sites of the KiLi-project) for final products output and sharing with park staff as a web-service maps through the Tanzania National Parks (TANAPA) Server, located at the headquarters office in Arusha.

3 ANALYSES AND RESULTS

Sentinel-2 data used here, provides the ability to carry out consistent monitoring work at high spatial resolutions ranging from 10m, while providing a wide opportunity for the use of the Red-Edge bands (bands 5, 6 & 7) for a vast of biodiversity measurements for ecosystem monitoring (Rocchini, et al. 2015). This is because RS allows measurements of large regions in a short period of time thereby providing continuous information about vegetation status. The reflectance and emission of light from the Earth‘s surface can be directly related to physiological, morphological and structural composition of plants (Jetz et al., 2016).

Several studies have proven a significant correlation between species richness and spectral indices (Peters, et al. 2016). The most common used indices are NDVI, capturing the greenness and chlorophyll content. The green normalized difference vegetation index (GNDVI), a modified form of NDVI (Clevers, et al. 2002), which linearly correlates with LAI, the transformed soil adjusted index (TSAVI), which corrects the variations of soil background (Huete, 1988) and a simple ratio between Red and NIR, RVI; have also been used in various studies for assessing and monitoring biodiversity in tropical forest ecosystems (Rocchini, et al. 2015). All these indices were explored in the study and proved to be useful in monitoring the key biodiversity parameters at Kilimanjaro and its ecosystems, where frequent in-situ observations by field staff may be difficult given the nature of the terrain of this unique cloud montane forest.

Several vegetation and biophysical indices were derived from the final Sentinel- 2 images that were chosen based on the quality of their scenes output from the processes described in 2 above, with their descriptions in Table 2, and a few of the selected indices are presented in Figure 5.

3.1 Arvi Maps (2019, 2018 and 2017)

The Atmospherically Resistant vegetation index (Arvi), resistant to the atmospheric effects (in comparison to the NDVI) is accomplished by a self-correction process for the atmospheric effects on the red channel. Arvi takes advantages of the different scattering responses from the blue and red bands to

Table 2: Vegetation indices derived from Sentinel 2-MSI sensor products (images) used in this study between 2017 and 2019, for both tiles T37-MBS and T37-MCS of the Kilimanjaro Mountain ecosystems.

Index	Index Application	Derived formula from image bands
NDVI	Normalized Difference Vegetation Index (The most commonly used in RS studies) its values range between -1 and +1 (Rouse, et al. 1973)	NIR-RED / NIR+RED
RVI	Ratio Vegetation Index, also known as Simple Ratio has high reflectance for vegetation than soil, water and snow-preferred for mapping vegetation (Jordan, 1969)	NIR / RED
ARVI	Atmospherically Resistant Vegetation Index, accomplishes self-atmospheric corrections in the red channel (Kaufman & Tanre, 1992)	NIR-RED-y(RED-BLUE) / NIR+RED-y(RED-BLUE)
TNDVI	Transformed NDVI- preferred because it's the square root of NDVI and so its values are always positive (can be larger than 1) (Senseman, et al. 1996)	√ (NIR-RED / NIR+RED + 0.5)
IRECI	Inverted Red Edge Chlorophyll Index utilizes the Red-Edge bands (bands 5, 6 & 7) currently present in sentinel 2 data (Clevers, et al. 2002)	(NIR *NIR-RED1*RED1) / (RED2*RED2/RED3*RED3)
GNDVI	Green Normalized Difference Vegetation Index is strongly correlated to the leaf area index and hence chlorophyll content (Gitelson, et al. 1996)	NIR- GREEN / NIR+GREEN
NDI45	Normalized Difference Index is more linearly, less saturated at higher values than NDVI, (Delegido, et al. 2011b)	(NIR*NIR- RED*RED) / (NIR*NIR+RED*RED)
TSAVI	Transformed Soil Adjusted Vegetation Index is used to correct the effects of soil line arbitrary values due to slope/terrain of the area on vegetation (Baret & Guyot, 1991)	(NIR*NIR-s *RED*RED-a) / (a*NIR*NIR+RED*RED-a)

retrieve information regarding the atmospheric opacity (the blue sky). These properties therefore have determined that Arvi, has a similar dynamic range to the NDVI, but is on average four times less sensitive to the atmospheric effects than the NDVI (Jetz, et al., 2012). Areas of dense green vegetation (the montane forest belt) showed clearly high reflectance (more brightness) compared to non-vegetated areas of the Kilimanjaro, as shown in Figure 5.

3.2 Ireci Maps (2019, 2018 and 2017)

The Inverted Red Edge index (Ireci) algorithm incorporates the reflectance in four bands to estimate canopy chlorophyll content. The "red edge" is the name given to the abrupt reflectance change in the 680±740 nm region of vegetation spectra that is caused by the combined effects of strong chlorophyll absorption and leaf internal scattering. The position of the red edge has been used as an indication of stress and scene sense of vegetation, (Clevers, et al., 2002). The time series images show darker tones in areas void of vegetation compared with areas of the montane forest with brighter tones, for all the years; 2017 to 2019 (Figure 5).

3.3 Tndvi Maps (2019, 2018 and 2017)

The transformed normalized difference vegetation index (Tndvi) algorithm indicates a relation between the amount of green biomass that is found in a pixel and it's the square root of NDVI. It is superior to NDVI in that it has higher coefficient of determination for the same variable and always has positive values and the variances of the ratio are proportional to the mean values. Due to limitations from effects of clouds for obtaining more quality data, our results indicate that Tndvi could be better in determining changes of time series related to monitoring tropical cloud forests, but additional analyses are needed in the future (seeFigure5).

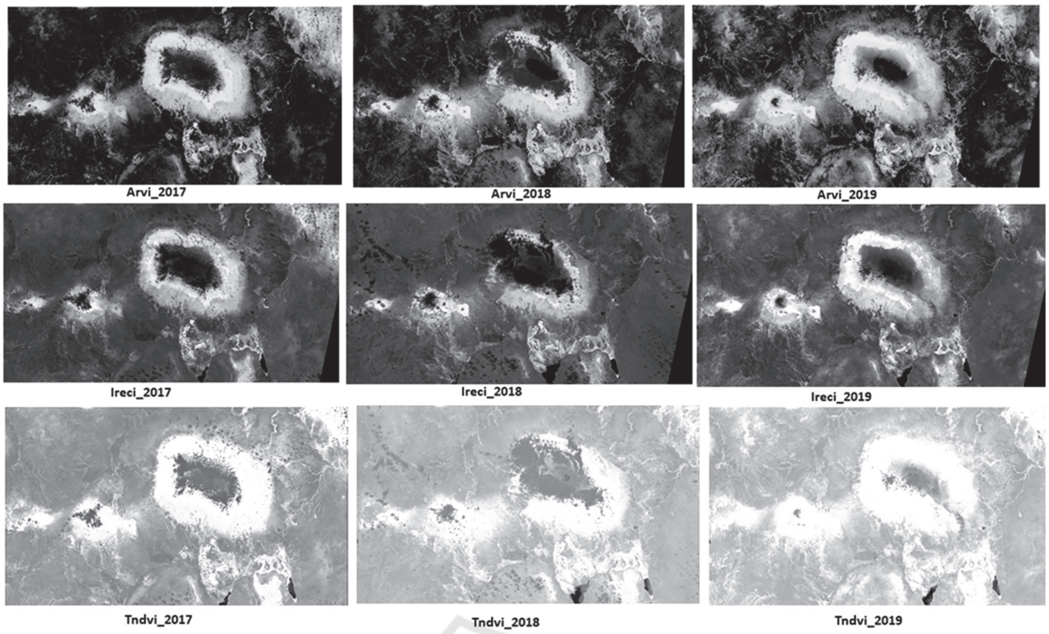

Figure 5: Derived vegetation indices from the sentinel-2 data for the Kilimanjaro between 2017 and 2019. Bright areas represent high values and dark areas low values of vegetation coverage. (Arvi= atmospherically resistant vegetation index; Ireci=Inverted red-edge chlorophyll index; Tndvi= Transformed normalize difference vegetation index).

4 DISCUSSION AND CONCLUSIONS

This study attempts to show the use of current remote sensing sensors capabilities, in particular the Sentinel- 2 MSI sensor of ESA, in providing data for ecological, biodiversity and conservation monitoring, much needed in managing vast protected areas such as Kilimanjaro Mountain and its ecosystems. Previous research work indicated that future climatic characteristics of the Kilimanjaro ecosystems are mainly determined by the local land-use and global climate change (Thompson, et al. 2002; Detsch, et al. 2017; Hemp & Hemp, 2018), and therefore it is imperative that Kilimanjaro Mountain National Park management is able to consistently carry out a monitoring program for the key biodiversity and environmental parameters in for both current and long-term plans. A workflow (protocol) developed here, (Figure 4) which is automated has been customized in such a way that it can be easily followed up, even with non-RS specialists, which is usually the case in many protected areas. Just with a minimum of a computer that is connected to the ArcGIS Server at TANAPA headquarters office in Arusha, through the internal network, the data model workflows output is uploaded, ran and results can be accessed for sharing using the available web-services in the ArcGIS Server network, through the publishing services (ESRI, ArcGIS Vers. 10.6) .

Results from the derived indices ascertain that it is possible to monitor key biodiversity changes using the workflows data-protocols developed here, given the fact that Sentinel-2 data are also available for free downloads through the ESA website, and expected to continue its operations for free data availability at least until 2028 (Skidmore, et al. 2015). The time-series images indicated that this technique can be used to show areas of change (increase or decrease in cover), either through anthropogenic disturbances such as land-cover conversions for cultivation and other illegal activities in the forest and/ or natural phenomenon associated with climate change, such as recurring wild fires in the montane forest in previous decades (Hemp, 2009; 2005). The outputs derived from the data workflows model will provide early warnings on the environmental conditions and lead in carrying out more detailed ground surveys, at focused areas. Such surveys will guide management decisions for quick interventions using the established protocols/methodologies while ensuring cost-effective park operation undertakings.

The use of the Sentinel-2 data products studied here will enable an integrated ecosystem measurement and monitoring, through the derived indices of vegetation like the NDVI- and its derivatives including TNDVI, ARVI, IRECI, TSAVI and more as well as the biophysical indices, such as LAI and the fraction of vegetation cover (FVC), (Wang, et al. 2018). These indices provide a bird's eye view snapshot urgently needed to monitor these vast areas, while contributing to the global biodiversity conservation and monitoring agenda, especially needed in achieving the Aichi Conservation Targets (2011-2020), in developing essential biodiversity variables (EBV) from RS data (Alleaume, et al., 2018; Skidmore, et al., 2015). Different spectral bands combination derived from Sentinel-2 sensors, ranging from the Visible, Red-Edge, Near and Short Infra-red spectra, important for biodiversity monitoring will provide data from consistent images of time series indices like NDVI and its derivatives for rigorous analyses in biodiversity monitoring of the park and its surrounding ecosystems.

In order to overcome limitations from accessing enough continuous image data from scenes that are cloud free, caused by the nature of the cloud forests, like in the Kilimanjaro Mountain ecosystems, the developed data-model protocols provide for automation of step by step in the selection of available scenes and enhancement techniques needed to obtain the final products for further analyses. Further work in this study would explore the variances in the ratios obtained for the different indices' derived here in relation to each of the research plots/sampled sites, along the elevation and across the different land cover/use types gradients in the study area.

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