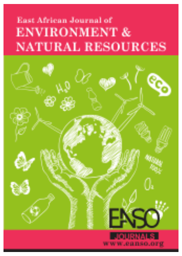

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*Original Article*

# Impact of Artisanal Gold Mining on Wetland Health in Buhweju District, Southwestern Uganda

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## ABSTRACT

Wetland degradation due to anthropogenic activities including artisanal gold mining is widely common in Uganda, and this affects vegetation health status if not controlled. However, the use of the Normalised Difference Vegetation Index (NDVI) to determine the health status of wetlands is rare. In this study, remote sensing techniques with the use of spatial-temporal Normalised Difference Vegetation Index (NDVI) were used for the wetlands in Bitsya Subcounty, Buhweju district (noted for artisanal gold mining with the use of mercury) to determine the wetland health status for the period between 2012-2021. This was for the purposes of identifying target areas for intervention and developing appropriate, location-specific intervention options. 7 images of 30 * 30 m and 3 images of 10 * 10 m respectively, ortho-rectified, cloud-free Landsat and Sentinel images obtained from the USGS archive were analysed. The results showed that the high NDVI value (0.775) was detected in the year 2019 and the low NDVI value (0.068) was detected in the year 2017. The NDVI maps showed low values mostly in the middle of the wetland where artisanal gold mining was mostly taking place, indicating a huge decline in the wetland health status as compared to other wetland edges noticed with high NDVI. The results from the study suggest that the wetland policies in the study area could not be effectively implemented and this reduces the vegetation health status, threatening the functionality of the wetland and as well as loss of the free natural goods and services derived from them. This necessitates the development of wetland restoration campaigns. However, failure to implement the wetland policies may have an ecosystem impact on the wetland micro and macro-organisms, soil nutrients, and water quality as well as a decline in vegetation health.

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## INTRODUCTION

Wetlands offer a variety of goods and services including provision (water and food), climate modification, regulatory (waste treatment and flood control), supporting (biological productivity, nutrient cycling, and soil formation), and cultural services (aesthetic, spiritual and religious functions) (Russi *et al*., 2013; Schuyt, 2005). They are key natural bioremediatory sites with various phytoremediators, reducing the pollutants load from the water before being accessed by the communities. However, the alarming degradation rates compromise their functionality, reducing the wetland biotic systems (Seelig & DeKeyser, 2006).

Despite all the functions, their degradation is primarily exacerbated by anthropogenic activities of the local communities such as agriculture, settlements, excessive harvesting of grass for mulching bananas, thatching houses, and making of crafts. Such community pressures in synergism with poorly planned development, pose a significant challenge to the wetland ecosystem in Sub-Saharan Africa (Kabii, 1996; Schuyt, 2005; Mugonola, *et.al.*, 2015; Thamaga, 2021). In Uganda, nearly 791 km$^2$ of wetland cover is lost on average every year following the statistics from the 2015 to 2017 land use/land cover change (NSOER, 2019). Not only agriculture but also mining contributes to wetland degradation as it sometimes involves excavations leading to the uprooting of the wetland vegetation. Artisanal mining in Uganda contributes approximately 90% of the minerals including gold and only 5% of artisanal mining is formally licensed in the whole country (Sebina-Zziwa & Kibombo, 2020). This implies that many mining activities including gold mining are not properly monitored and surveyed which might be of a great impact on the environment including the wetlands. Artisanal gold mining actions remain degrading aquatic resources in Uganda’s tropical watersheds (Barasa *et al*., 2016), affecting the wetland vegetation as is part of the watershed areas (Castendyk & Webster-Brown, 2007; Mpamba *et al*., 2008). Nevertheless, the intensity of degradation due to gold mining damages and distorts the earth’s surface hence destroying the landscape scenery due to abandonment of mined pits (McKernan *et al*., 2000; Gao *et al*., 2007; Barasa *et al*., 2016). Bitsya Sub-county in Buhweju district is one of the areas within wetlands, where artisanal small-scale gold mining is practiced.

Worst of it, during gold extraction from the wetland in Bitsya Subcounty, mercury is normally used to separate gold from sand (NSOER, 2019). According to Patra and Sharma, (2000), organic mercurial was noted to; cause abnormal germination and hypertrophy of the roots and coleoptile in cereals, affect both light and dark stages of photosynthesis by substituting the central atom of chlorophyll (Magnesium) with mercury atom in vivo thus stopping photosynthetic light harvesting in the affected chlorophyll molecules. This triggers the breakdown of photosynthesis, leading to reduced productivity and death of plants, and therefore reduction in the health status of the wetland ecosystem function. Besides, Mercury being a heavy metal, just its low concentrations harmfully degrade the capabilities of the soil micro-organisms (Patra and Sharma, 2000).

Attempts have been made to investigate the general impacts of human activities on wetlands e.g. (Kaggwa *et al*., 2009; Ssozi & Byaruhanga, 2012; Businge *et al*., 2017; Safari *et al*., 2017; Jim, 2018). However, there is a very limited number of studies that have focused attention on the use of the Normalised Difference Vegetation Index (NDVI) in assessing wetland health status. Even where attempts have been made, they are too generalised and provide scanty information about wetlands inundation north of Lake George in western Uganda (Owor *et al*., 2007). Effective planning, research and decision making for improved wetland health requires new and time-specific information. More so, such information is highly needed for lesson sharing across regional, national, and international levels to facilitate learning processes that can lead to global context support in wetland health monitoring.

Considerate use of the Normalised Difference Vegetation Index (NDVI) in assessing wetland spatial-temporal health status is a key component of wetlands across a scale (Wilson & Norman, 2018). In a similar way, vegetation monitoring with the help of Remote Sensing consists of an implicit association with the vegetation phenology (Manuilov, 1955). The Normalized Difference Vegetation Index (NDVI) uses multispectral scanner to measure the absorption and reflectance of solar radiation. NDVI is normally correlated with photosynthesis, because photosynthesis happens in the green areas of the plant and there often used to approximate the green vegetation (Lesschen *et al*., 2002). It is with such information that probable accelerated attention in wetlands for environmental management necessitates to thoughtful information about the location, spatial extent, and conformation of wetlands (Dong *et al*., 2014).

Besides, NDVI in southwestern Uganda has not been used to assess the wetland health, it has only been used in north eastern Uganda while looking at the savannah phenological characteristics in the Karamoja region (Magaya *et al*., 2018). Studies have been done globally and at a local scale on vegetation to monitor environmental changes through using remote sensing (Fawcett *et al*., 2021).

However, in this study, remote sensing technique with use of NDVI, through using the spatial-temporal dynamics was used to monitor a wetland's health status in Bitysa Subcounty (characterized by artisanal small-scale gold mining and agricultural practices) so as to identify target areas for intervention, and develop appropriate, location specific and intervention options.

## MATERIALS AND METHODS

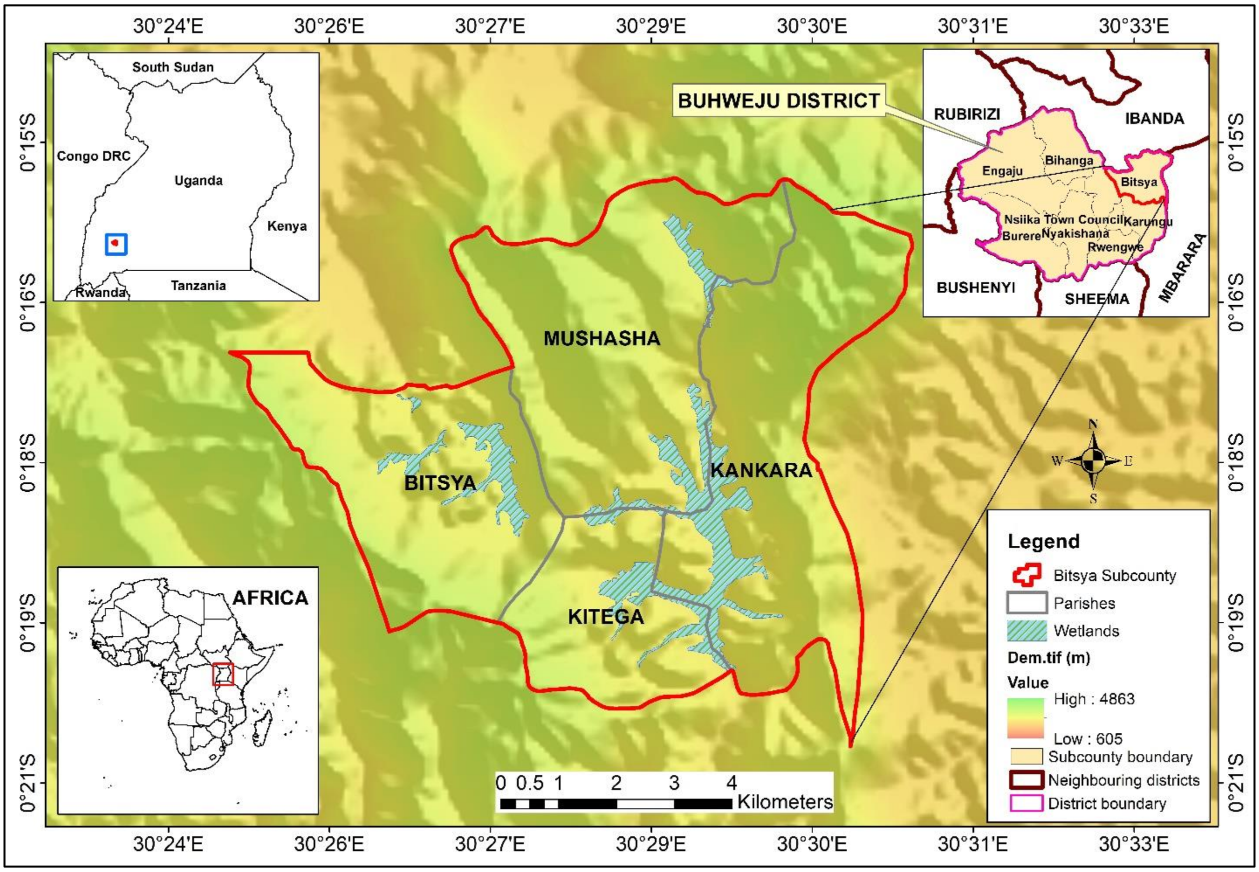
### Description of the Study Area

The study was conducted in Bitsya subcounty in Buhweju district in south western Uganda (*Figure 1*). The study area lies approximately between 0° 17.999'S and 30° 27.999'E. The district is bordered by Rubirizi district to the west and northwest, Ibanda district to the northeast, Mbarara district to the east, Sheema district to the southeast, and Bushenyi district to the southwest.

The district receives an annual rainfall of 1,112 mm with average temperature ranging from 20 $^{0}$C to 25 $^{0}$C and humidity of 75% (https://www.weather2visit.com/africa/uganda/buhweju.htm). The western part of Buhweju district is bounded and cut by the western arm of the rift valley while the central part is occupied by hilly to mountainous ranges and protected areas (e.g. Kasyoha-Kitomi and Kalinzu central forest reserves) (Bahiru & Woldai, 2016). The geology of Buhweju is categorised into five formations with: the Lukiri mudstone, Isingiro conglomerate, Lubare quartzite, Kasyoha shale and Munyoni quartzite in the order of succession from bottom to top (Reece, 1961). Based on field observations, the dominant vegetation in the study area are short grasses, bushlands, wetlands and numerous eucalyptus woodlots, and lies at an altitude of 1800 m.a.s.l.

Apparently, most of the population practices agriculture (banana for subsistence) to support their livelihood (Catherine *et al*., 2021). The youth also practice artisanal gold mining and sand mining to earn a living.

**Figure 1: Location of the study area**



## Data Source

### *Remote Sensing Satellite Data Acquisition and Fieldwork*

The data which was used during the analysis was acquired from four sensors (Landsat 7, Landsat 8 OLI, and Sentinel 2A), Landsat 5 and Landsat 8 were used because they cover the time series that the study was interested in (2012 and 2014) Sentinel 2A was selected to capture time series from (2015-2021) because of its better resolution (10 m), which gives better visualization. Further, all the satellite data was acquired using the Earth Explorer using the websites' link at (https://earthexplorer.usgs.gov/). Only the images that were considered and downloaded for the study were cloud free (less than 10%), and the scenes were taken from only the dry season to avoid incidences of cloud cover and haze that could affect the results.

Fieldwork was conducted to confirm the results of the analysis thereby capturing ground truth points with the help of Garmin GPS (GPSMAP 64s). This was to confirm whether the NDVI values from the spatial-temporal analysis are really accurate as compared to the NDVI maps produced using ArcGIS 10.8 Software.

**Table 1: Remote Sensing and NDVI data source.**

| Data source | Date of acquisition | Resolution(m) | Cloud cover (%) |
|---|---|---|---|
| Landsat 5 | 2012 | 30 | <10 |
| Landsat 8 OLI/TIRS | 2013 | 30 | <10 |
| Landsat 8 OLI/TIRS | 2014 | 30 | <10 |
| Landsat 8 OLI/TIRS | 2015 | 30 | <10 |
| Sentinel 2A | 2016 | 20 | <10 |
| Sentinel 2A | 2017 | 20 | <10 |
| Landsat 8 OLI/TIRS | 2018 | 30 | <10 |
| Sentinel 2A | 2019 | 20 | <10 |
| Landsat 8 OLI/TIRS | 2020 | 30 | <10 |
| Landsat 8 OLI/TIRS | 2021 | 30 | <10 |

### *Digitising the Wetland Stretches*

The wetland shape file in the Area of Interest (AOI) were obtained by digitizing with the help of Google Earth Pro. ArcGIS software 10.8 version was used to convert the digitized Kml file using the conversion tool in the Arc tool box (Kml to layer). The spatial extent of the wetland stretch was captured from Google Earth Pro to give a reader an impression of what the NDVI maps entailed, and also because the available wetland shape file for Uganda lacked the correct extent of the study area and hence the need to employ Google Pro in the digitization process.

### *Normalized Difference Vegetation Index*

Wetlands have been monitored and assessed with the use of Remote Sensing (Work & Gilmer, 1976; Jensen *et al*., 1991). NDVI was used to monitor vegetation health status and condition (Wang, 2017). In such instances, the Normalised Difference Vegetation Index (NDVI) makes use of band combination method of the Remote Sensing data to determine the site characteristics such as vegetation, land use or land cover types and water bodies (Choudhary *et al*., 2019). The vegetation indices calculated from recipes of the visible red and near-infrared spectral quantities, have been developed as a primary indicator for studying vegetation health (Manuilov, 1955). This study followed the use of the standard formula for determining NDVI by (Goward & Hope, 1989; Malingreau *et al*., 1989). See equation (1) below.

$$\text{NDVI} = \frac{\text{NIR}-\text{Red}}{\text{NIR}+\text{Red}} \qquad \text{equation (1).}$$

Where NIR = Near Infrared light and Red = Visible Red light of the electromagnetic spectrum.

The changes in the illumination conditions and terrain surface effects is partly replaced by the NDVI formula (Kidwell, 1995). However, Greenness and productivity levels in vegetation has concurrently been determined in various studies with the use of NDVI datasets (Manuilov, 1955). In the study, the NDVI spatial-temporal assessment about the vegetation health status considered time series data from 2012 to 2021 that was acquired from Landsat 5, Landsat 8 OLI & and Thermal Infrared Sensor (TIRS) and Sentinel 2A satellites, which helped in giving better results as they cover a long-time frame of the Area of Interest (AOI).

## Data Analysis

Three data analysis techniques were employed. Firstly, Google Earth Pro software was used to digitize the wetland stretches in the AOI to come up with the wetland shapefile. Secondary, ArcGIS software version 10.5 was used to compute the NDVI values of the 5 wetland stretches to determine the wetland health status. The NDVI values were determined using its foundation for RS phenology (https://www.usgs.gov/core-science-systems/eros/phenology/science/ndvi foundation-remote-sensing-phenology). The NDVI values of the wetland stretches were determined between -1 to 1. In case, of barren rock and sandy areas NDVI values are low (0.1 or < 0.1), areas with scarce or few vegetation e.g., shrubs and grasses show average NDVI values (between 0.2 to 0.5). Very high NDVI values (between 0.6 to 0.9) show dense vegetation, e.g., an intact wetland, a forest etc. Thirdly, Minitab software version 20.3.0 was also used to compute whether there was a significant variation in the wetland NDVI value over a decade. Further, descriptive statistics for example mean ± SD wetland NDVI was also computed using Special Package for Social Scientists version 25 (*Figure 4*).

## RESULTS

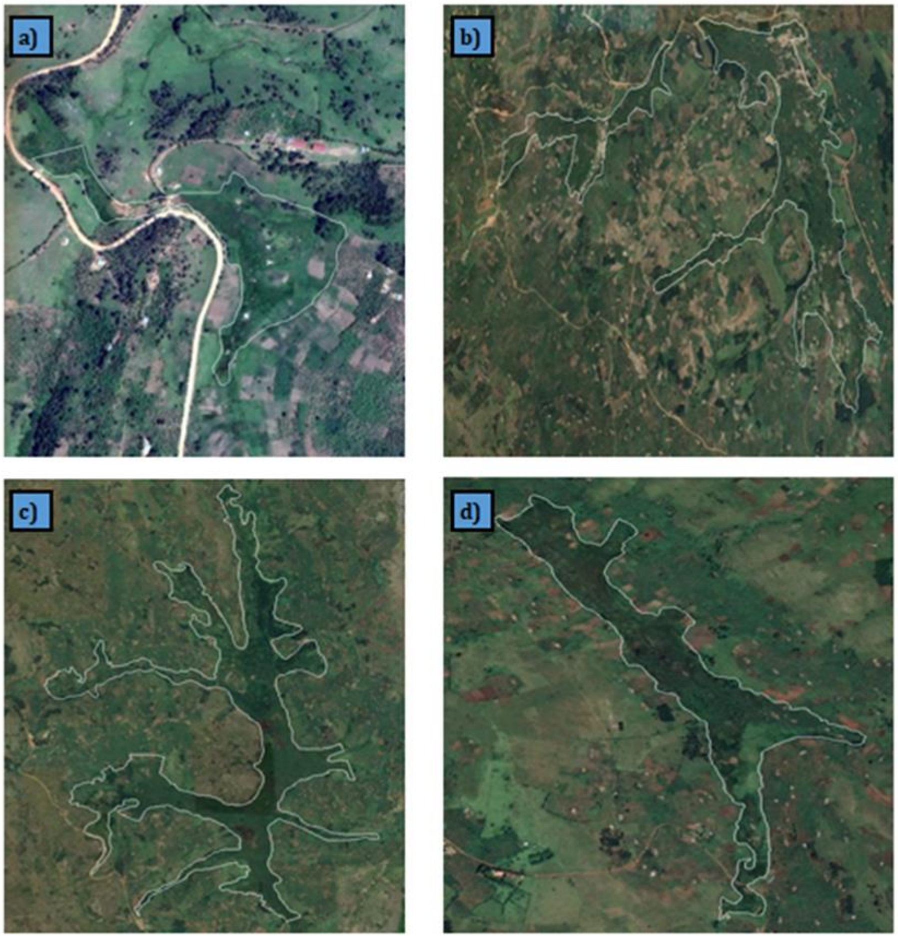
### Digitized Wetland Stretches

Figure 2 below shows the aerial view of the wetlands stretches where gold mining takes place in Bitsya subcounty in Buhweju district. In addition, the white lines show the wetland boundaries and beyond the wetland boundaries is the community that does small-scale farming (crop cultivation, and animal rearing). Furthermore, the gold miners reside in the communities near these wetlands. Finally, the analysis of the NDVI used the same wetland stretches as the Area Of Interest (AOI) for the analysis.

### NDVI for a Decade

In the study, NDVI values were determined in the 5 wetland stretches for a decade (*Figure 5*). NDVI values were recorded as follows; 2012 (high value = 0.614 and low value = 0.0065), 2013 (high value = 0.521 and low value = 0.106), 2014 (high value = 0.496 and low value = 0.160), 2015 (high value = 0.531 and low value = 0.182), 2016 (high value = 0.519 and low value = 0.111), 2017 (high value = 0.685 and low value = 0.0068), 2018 (high value = 0.526 and low value = 0.217), 2019 (high value = 0.775 and low value = 0.117), 2020 (high value = 0.485 and low value = 0.121), 2021 (high value = 0.565 and low value = 0.082). For instance, the highest NDVI value (0.775) was recorded in the year 2019 and the lowest NDVI value (0.068) was recorded in the year 2017 (*Figure 5*).

**Figure 2: Digitized wetland stretches**



*(**a and b**) eastern parts, (**c**) western part, and (**d**) northern part of Bitsya Subcounty. The white lines indicate the boundary of the wetland.*

**Figure 3: Wetland degradation as a result of artisanal gold mining and sand mining. These are photos that were captured during ground truthing on 11th August. 2021**

*(a) sand mining, (b) artisanal gold mining, (c) heaps of extracted sand from the artisanal gold mines, (d) part of the road damaged as a result of artisanal gold mining.*

**Figure 4: Decadal variations (Mean ± SD) in wetland NDVI values per year in Bitsya Sub County. Error bars represent standard deviation**

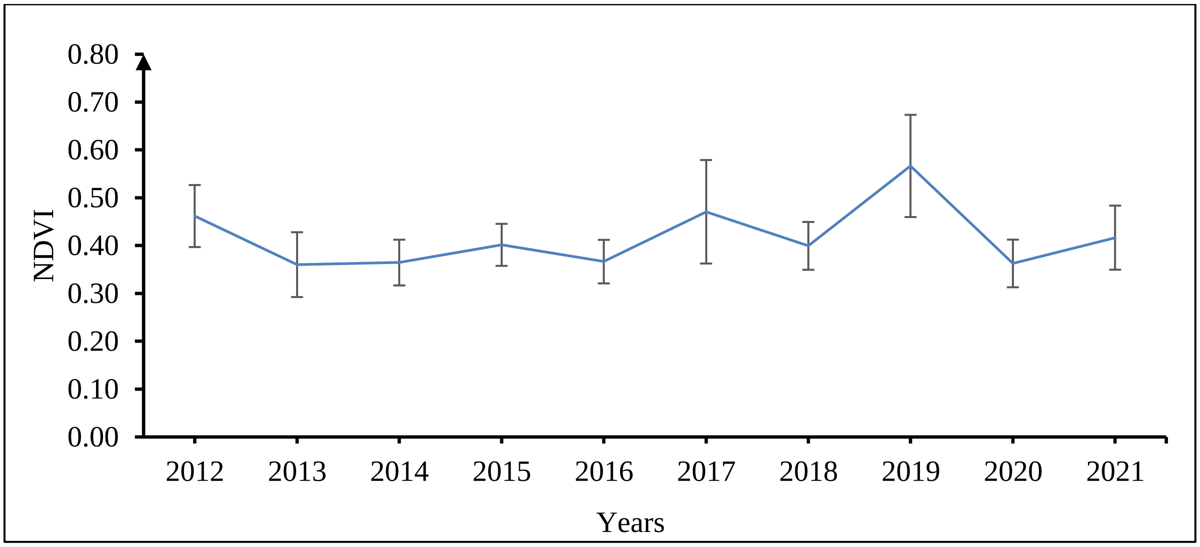
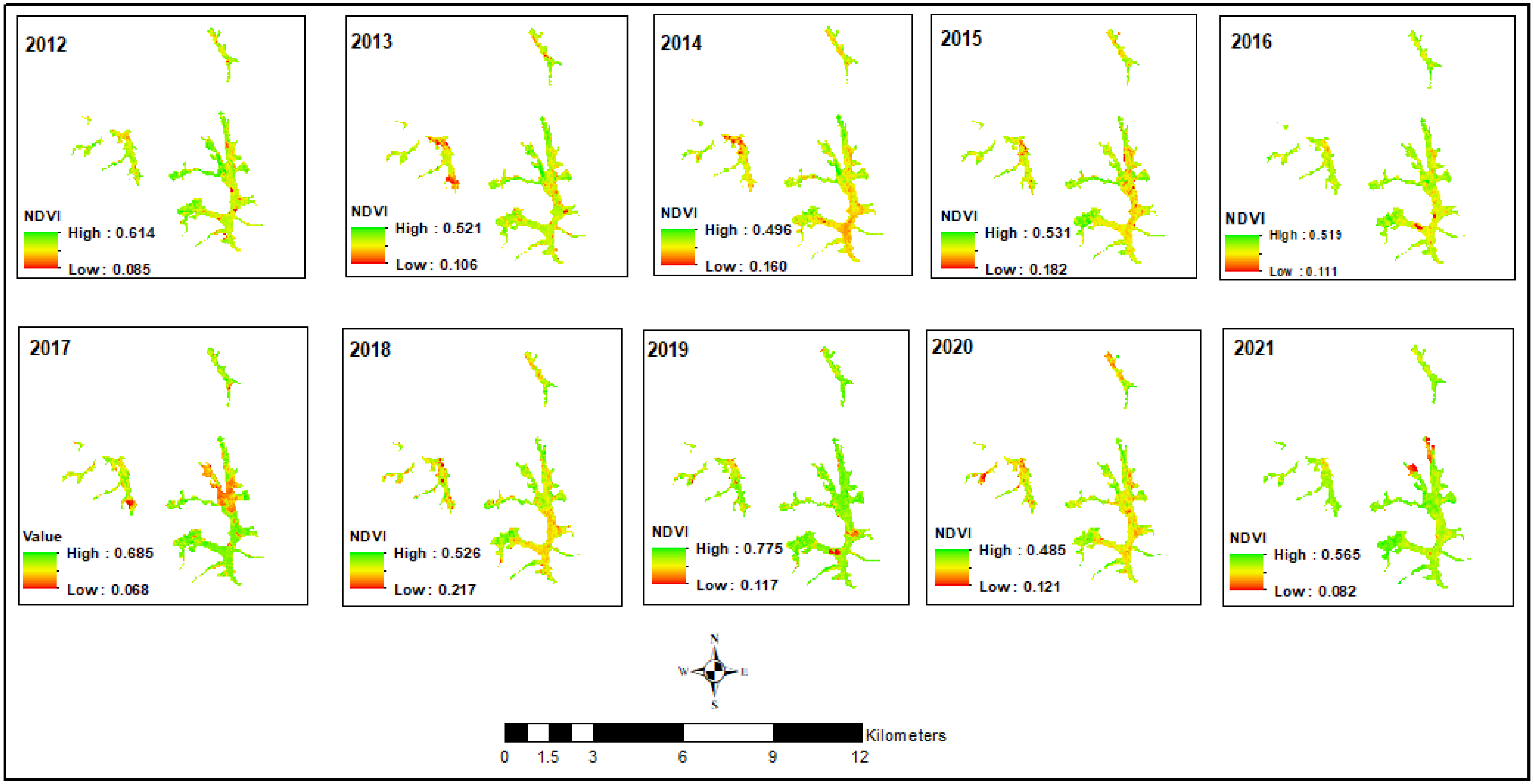


**Figure 5: NDVI maps showing the 5 wetland stretches health status in Bitsya Sub County in the past decade.**



## DISCUSSION

The study set out NDVI to monitor wetland health status using the spatial-temporal dynamics in order to identify target areas for intervention, and develop appropriate, location specific and intervention options. While the examination began at the wetland level, in the sequence of the analysis, it was obvious that other wetlands in the different landscapes can be also examined using NDVI to determine their health status.

### NDVI Decadal Analysis

Basing on the evidence obtained from remote sensing, the wetland health status seems to gradually change annually, a signal that gold mining activities had an influence on the wetland health status. Considering the spatial-temporal dynamics in the wetlands (*Figure 5*), most of the decline in the health status was evidenced within the middle of the wetland. The wetland boundaries showed less or no decline in the health status of vegetation throughout the study time. Areas where gold mining was taking place showed a gradual decline in vegetation health status as compared to areas where there were no gold mining activities This is in line with findings by Palacios-Torres *et al*. (2018) who reported that metals such as mercury have the potential to be toxic to biota, posing a serious threat to wetland ecosystem and human health. Furthermore, narrations from gold miners during field visits revealed how they resume mining from the wetland at intervals of 2 to 3 years. This is because they believe that that gold keeps on accumulating over time, and this explains the pattern in the observed NDVI maps (*Figure 5*). More so, this study's findings align with previous research highlighting the accumulation of gold after mining (Román-Dañobeytia *et al*., 2015).

During fieldwork, less mining was observed at the edge of the wetland which can also explain the pattern of the wetland health status from 2012 to 2021 at the edges. For example, no human activities like small-scale agriculture and grazing were evidenced at the edge of the wetland which explains the high NDVI values at the edges of the wetland. The decadal variations in the NDVI (mean ± SD) can also explain the trajectory of the wetland health status in the entire time series (*Figure 4*). Anthropogenic activities of artisanal gold mining can damage wetland vegetation (Bowell, 2003; Mpamba *et al.,* 2008), also results of the study can explain well the impact of artisanal gold mining activities on the wetland comparing the middle of the wetland with gold mining and the edges with no gold mining. There was also an exponential increase in the NDVI values between 2018 (0.526) and 2019 (0.775), indicating a reduction in the exploitation of the wetland between 2018 and 2019 as it could have been left to re-vegetate naturally. The increase in vegetation in 2019 could be due to the intervention which was done in 2017 to restore River Rwizi (https://www.nema.go.ug/media/nema-restores-buhweju-wetlands-protect-r-rwizi). High NDVI values are also indicative of intact perennial wetland vegetation (White *et al*., 2016), which indicates the better health status of the wetland at the edges whereas the low NDVI values in the middle are explained by the NDVI images, indicating the negative impact of artisanal gold mining in the middle of the wetland. Besides, other studies found that climate change coupled with anthropogenic activities such as mining, agriculture and cattle rearing have an impact on the vegetation health status and density (Sun *et al*., 2015; Shi *et al*., 2020; Deng *et al*., 2022; *Yang et al*., 2021). The fluctuations observed in the study's results could be attributed to changes in precipitation patterns, temperature variations, and potentially human interventions within the wetland stretches.

Mercury in Uganda most especially in the study area was used to separate gold that was normally extracted along with sand (NSOER, 2019). Therefore, the low NDVI values in the sites (middle) where artisanal gold mining was mostly done, confirms the negative effects of mercury on wetland vegetation as addressed by Patra and Sharma, (2000); Edmonds *et al*., (2010); Lázaro *et al*., 2018).

## CONCLUSIONS

Whereas most of the wetland part has experienced gradual changes in the decline of the wetland health, areas which are located at and close to the wetland edges experienced less decline in the vegetation health status as compared to the areas in the middle where gold mining was highly lucrative as evidenced from the NDVI images. Therefore, artisanal gold mining poses a huge negative influence on the wetland vegetation status. This implies that the increase in uncontrolled artisanal gold mining within the wetland, will uncompromisingly lead to the decline in the health status of wetland. This ultimately leads to the loss of the free natural wetland services and goods in the region. The increase in the health status of the wetland between 2018 and 2019 following NEMA's restoration strategies in 2017, is also evident that restoration campaigns are very yielding and effective if continually monitored and enforced. Hence the need for regulating the artisanal gold mining mostly in the middle as well other areas of the wetland, and as well design restoration strategies for the conservation of this wetland.

## RECOMMENDATIONS

We recommend that Buhweju district Natural resources and Environment departments should sensitize local people living near wetland and wetland dwellers about the ecological importance of wetlands to reduce pressure on the wetlands in the district.

In addition, artisanal gold miners should be encouraged to re-fill the gold mines with the soil after mining so as to encourage wetland regeneration.

National Environment Management Authority (NEMA) should make sure that the laws and policies governing wetlands utilisation are well enforced to reduce wetland degradation in the area.

NEMA should also put a ban on the use of Mercury especially in extracting gold within Buhweju district.

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